Stony Brook Streamflow Restoration Plan: Addendum 1

Stony Brook Flow Restoration Project

2019 Water Management Act Grant Program

June 2019

Submitted by

Littleton Water Department
Westford Water Department
Geosyntec Consultants
Comprehensive Environmental, Inc.

With support from

Massachusetts Department of Ecological Restoration

Prepared for

Massachusetts Executive Office of Energy & Environmental Affairs
and Department of Environmental Protection

Contents

1. INTRODUCTION 1
1.1 Background 1
1.2 Project Overview 1
1.3 Stakeholder Coordination 3
2. PERMITTING 5
2.1 Low Flow Release Narratives 5
2.2 Owner and Regulatory Approval 6
3. STREAM GAGING 8
3.1 Stream Gaging Field Protocol 8
3.2 Stream Gaging 8
3.3 Rating Curve Validation 10
4. EMPIRICAL TESTING 15
4.1 Overview 15
4.2 Evaluation of Results 15
4.3 Recommended Operational Strategy Adjustments 17
5. SOURCE OPTIMIZATION EVALUATION 18
5.1 Data Collection 18
5.2 Model Software 18
5.3 Methodology 20
5.4 Results 23
5.5 Source Optimization Study Findings 27
6. FUTURE ACTIVITIES 28
7. REFERENCES 29

Appendices

Appendix A: Low Flow Release Narratives
Appendix B: Regulatory Approval Documentation
Appendix C: Stream Gaging Protocol
Appendix D: Stream Gaging Field Forms
Appendix E: Spectacle Pond Addendum to Stony Brook Flow Restoration Project
Appendix F: STRMDELP08 Data

List of Tables

Table 1: Permit Approval Summary
Table 2: Stream Gaging Event Information
Table 3: Stream Gaging Results Summary
Table 4: Littleton and Westford Well IDs
Table 5:Littleton Source Optimization Results
Table 6: Westford Source Optimization Results

List of Figures

Figure 1: Study Area Vicinity Map
Figure 2: Forge Pond Dam Rating Curve Validation Results
Figure 3: Mill Pond Dam Rating Curve Validation Results
Figure 4: Spectacle Pond Outlet Rating Curve Validation Results
Figure 5: Stony Brook Rating Curve Validation Results
Figure 6: DAM Dashboard Results During Empirical Testing
Figure 7: Study Area Public Water Supply Wells in Littleton and Westford
Figure 8: High-Response Well Example
Figure 9: Low-Response Well Example
Figure 10: Medium-Response Well Example
Figure 11: Littleton Stream Depletion Rate Results
Figure 12: Westford Stream Depletion Rate Results

Acknowledgements

This study involved collaboration and coordination amongst many project team members, stakeholders, and other collaborators. The Geosyntec / CEI project team thanks Westford Water Department and Littleton Water Department for their guidance, input, and enthusiasm throughout the duration of the project and for providing in-kind support to assist with stakeholder coordination, perform stream gaging, provide data for the source optimization evaluation, and many other tasks.

The project team also thanks all stakeholders and collaborators for providing invaluable input and guidance throughout the process, including attendance at stakeholder meetings and review of project deliverables. Project stakeholders and collaborators included: Littleton Clean Lakes Committee (LCLC), Friends of Forge Pond (FOFP), Mr. Chris Yule (owner and operator of the dam at Forge Pond/Abbot Mill), Westford Healthy Lakes and Ponds Collaborative, Spectacle Pond Association (SPA), and the Massachusetts Division of Ecological Restoration (MA DER). A special thanks to MA DER for their support during stream gaging activities and the generous use of their streamflow measurement equipment.

Finally, the project team would like to thank the Massachusetts Department of Environmental Protection for providing funding for this effort through the Water Management Act Grant Program. We are excited about the results of this unique study and hope to continue working with project stakeholders and collaborators to continue to implement recommendations from the Stony Brook Streamflow Restoration Plan.

1. Introduction

1.1 Background

The Massachusetts Department of Environmental Protection (MA DEP) has identified Westford Water Department (WWD) and Littleton Water Department (LWD) water supply source sub-basins in the Merrimack Basin as highly impacted by groundwater withdrawals; specifically, as groundwater withdrawal category 5, Biological Category 5, and August Net Groundwater Depletion greater than 25 percent. As such, WWD and LWD will need to minimize the impact of existing withdrawals to "the greatest extent feasible" to meet groundwater regulations through development of a minimization plan (MA DEP, 2014). These impacted sub-basins are primarily located in northern Littleton and Westford, within the Stony Brook watershed, which frequently experiences periods of low flow.

In fiscal year 2018 (FY2018), WWD, LWD, Geosyntec Consultants, and Comprehensive Environmental, Inc. (CEI) were awarded a grant under the Water Management Act (WMA) entitled the "Stony Brook Flow Restoration Project" to develop a Streamflow Restoration Plan (SRP) to assess opportunities for improvement of streamflow in Stony Brook. These efforts to restore streamflow in the Stony Brook watershed aim to mitigate impacts of groundwater withdrawals, consistent with goals of a minimization plan required as part of the MA DEP regulations. Specifically, the SRP evaluated if coordinated low flow releases from a series of impoundments along Stony Brook could be made to improve the timing, magnitude, and duration of streamflow to mimic natural conditions without compromising in-lake uses (e.g. recreation, ecology, and other uses). The SRP included the development of a regional surface water model and the installation of two continuous streamflow monitoring stations (in addition to four existing streamflow monitoring stations installed in 2017 as part of the DAM Dashboard Pilot Project[1]) to collect data in real-time and make the data accessible via online dashboards. Based on the modeling results, recommended operational strategies (e.g., open or close a sluice gate or remove or replace a stop-log) were developed for the flow control infrastructure (e.g., dams) at each impoundment and email alerts were setup from the online dashboard tool, DAM Dashboard, to inform stakeholders when to initiate such strategies.

WWD and LWD, in partnership with Geosyntec, then prepared another successful WMA grant application to secure funding needed to further refine and improve the recommended operational strategies and evaluate additional strategies to reduce groundwater withdrawals in the watershed. This addendum to the SRP was prepared to document the approach and results of these additional analyses included as part of the FY2019 Stony Brook Flow Restoration Project.

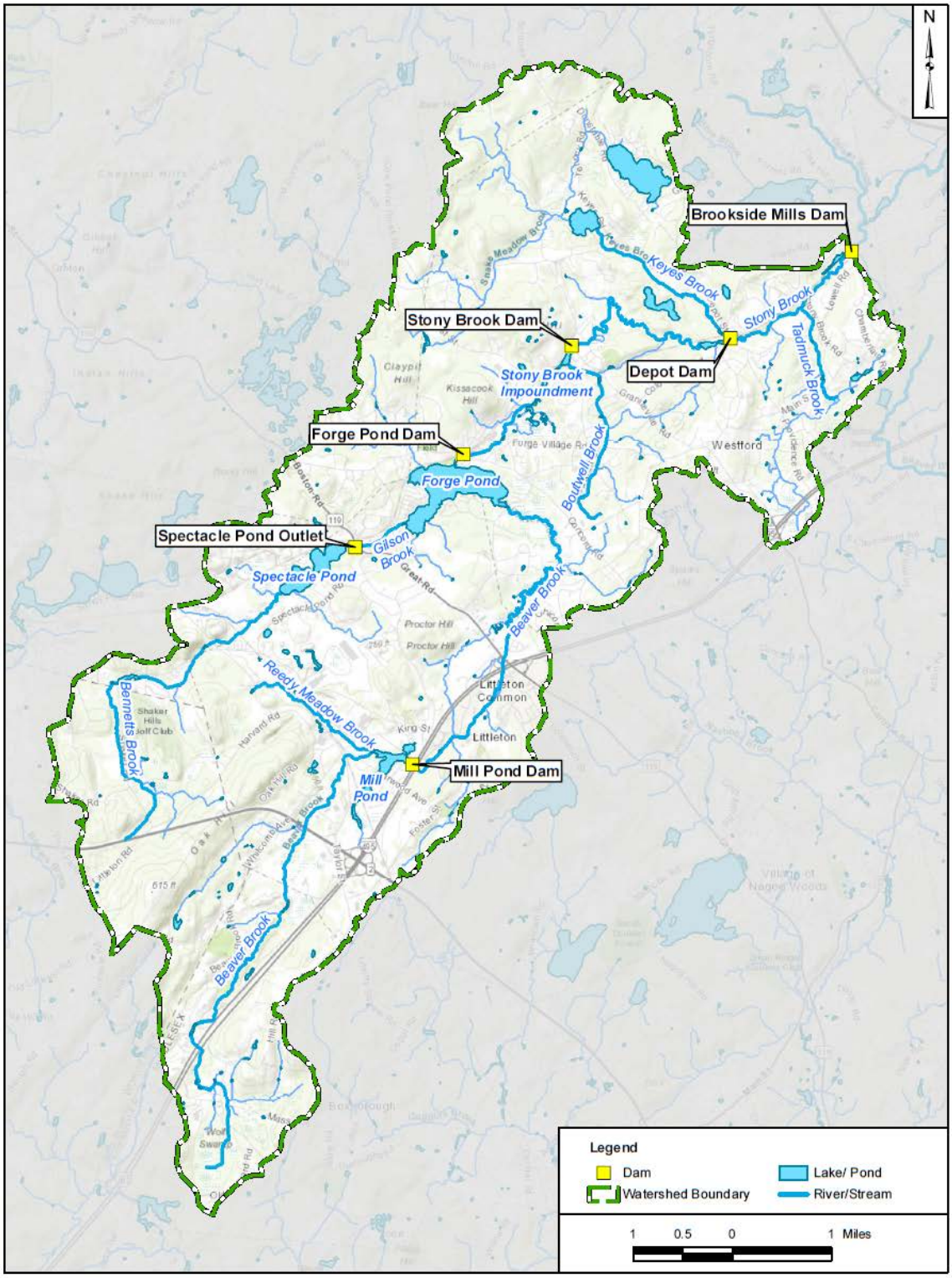
1.2 Project Overview

The purpose of the FY2019 Stony Brook Flow Restoration Project (Addendum 1) was to confirm previous assumptions and further assess opportunities for improvement of streamflow in Stony Brook through the coordinated operation of existing dams in the watershed using the DAM Dashboard decision support system, which is informed by actual streamflow data and model results. The existing study area impoundments are controlled by infrastructure at a series of four dams: the Mill Pond Dam, the Spectacle Pond Outlet, the Forge Pond Dam (or Abbot Mill Dam), and the Stony Brook Dam. These impoundments have public access points and are actively used by the public for recreation. The furthest downstream points of the study area are the Depot Dam and Brookside Mills Dam. The Depot Dam and the Brookside Mills Dam do not significantly impede streamflow because they pass flow continuously through low level culverts; these dams also do not have significant upstream impoundments. Streamflow from the Brookside Mills Dam

[1] The DAM Dashboard Pilot Project was a previous study conducted in 2017 by LWD and Geosyntec Consultants where continuous streamflow monitoring equipment was installed at Forge Pond and Spectacle Pond. Decision support dashboards were created for stakeholders to view data collected in real-time but the dashboards did not feature the email notifications developed in the FY2018 Stony Brook Flow Restoration Project. The data collected at the monitoring stations over the time between the DAM Dashboard Pilot Project and the FY2018 Stony Brook Flow Restoration Project was used to calibrate model results for the FY2018 Stony Brook Flow Restoration Project.

flows via Stony Brook to the Town of Chelmsford and then to the Merrimack River. See **Figure 1** for a map of the study area.

Figure 1: Study Area Vicinity Map



Existing infrastructure at the Depot Dam and Brookside Mills Dam is in poor condition and would require significant modifications or reconstruction to be actively controlled. Flow control infrastructure (i.e., sluice gates) at the Mill Pond Dam exists; however, it has not been operated in many years (last operation unknown) and the sluice gate is heavily impacted by sedimentation in the pond. Dredging to address sedimentation at Mill Pond would be required prior to initiating future activities focused on streamflow improvement (e.g., operation of the existing sluice gate or installation of a low flow orifice to conduct low flow releases). The Town of Littleton and the United States Army Corps of Engineers are currently in the process of completing a feasibility study to dredge Mill Pond as an Aquatic Ecosystem Restoration Project authorized under Section 206 of the Water Resources Development Act of 1996 (the draft report is expected in September 2019). A total of $395,000 has been invested in the project and it is expected that design and engineering efforts will begin within 6-9 months after the feasibility study has been completed and that construction will begin as soon as Spring 2021.

Due to the aforementioned operational constraints at three of the six dams in the Stony Brook watershed (Mill Pond Dam, Depot Dam, and Brookside Mills Dam), operational strategies for low flow releases in this study were focused on modifying existing infrastructure at Spectacle Pond Outlet, Forge Pond Dam, and the Stony Brook Dam to support improved streamflow in the watershed. Additional detail on the watershed and operational constraints at Mill Pond Dam, Depot Dam, and Brookside Mills Dam can be found in the Stony Brook Final SRP (Geosyntec Consultants, 2018).

The scope of the FY2019 study was based on recommendations from the FY2018 Stony Brook Flow Restoration Project. The primary activities and outcomes of this Stony Brook Flow Restoration Project Addendum 1 (the "Project") include:

- Re-engaging stakeholders to seek input throughout the project;
- Obtaining owner and regulatory approval to perform low flow releases at three impoundments;
- Performing stream gaging to validate decision support dashboard flow rating curves;
- Initiating empirical testing of low flow releases through implementation of DAM Dashboard informed operational strategies;
- Evaluating optimization of water supply wells to minimize impacts to streamflow from groundwater withdrawals; and
- Updating the Stony Brook SRP, with study findings.

The desired outcome of the Project was to further enable informed and coordinated management of shared water resources within the study area by many stakeholder groups to provide streamflow, water quality, and habitat benefits. Low flow releases (i.e., controlled dam releases during periods when downstream flows are low) were selected as the recommend operational strategy to supplement streamflow in the watershed. These releases enable operators to increase downstream streamflow to maintain preferred minimum flows (i.e., aquatic baseflow[2]) without quickly drawing down the water level of the upstream impoundment (i.e., maintaining uses such as recreation upstream). In addition, it is anticipated that the benefits to downstream resource areas of a slow, low flow release will far outweigh those of short, large releases from upstream impoundments.

1.3 Stakeholder Coordination

Two in-person stakeholder meetings served as the primary means to inform stakeholders of Project activities and to receive input throughout the Project's duration. The first meeting was held at the commencement of the project, on 10 April 2019, and resulted in the following feedback from stakeholders as recommendations for future study:

- Research the potential to use the DAM Dashboard system to manage high streamflows in the watershed (e.g., pre-hurricane streamflow relief efforts through forecast-based predictive management);

[2] Aquatic baseflow is a set of chemical, physical, and biological conditions that represent limiting conditions for aquatic life and wildlife in stream environments. In hydrological terms, it means median August streamflow (USFWS, 1999).

- Research the potential to use the DAM Dashboard system for climate resiliency (e.g., understand how changes in rainfall patterns have impacted impoundment water levels);
- Reach out to the Town of Ayer as a possible project partner to investigate potential impacts of an Ayer municipal water supply well impacting water levels and inflows into Spectacle Pond; and
- Expand public education of project to additional stakeholders outside the immediate project team (e.g., town boards, residents, etc.).

The second in-person stakeholder meeting was held near the conclusion of the project, on 20 June 2019, to summarize project activities and study results to stakeholders and receive feedback on potential future efforts. Stakeholders contributed the following recommendations:

- Establish a permitting framework for long-term empirical releases beyond the initial testing period;
- In addition to halting a release when the upstream impoundment's water level approaches the critical low level for recreational activities, also consider halting a release once aquatic baseflows are exceeded to conserve water discharged and maintain impoundment water depth upstream;
- Due to the impacts of beaver dams, investigate modeling Beaver Brook as an impoundment in the regional surface water model;
- Consider using the regional surface water model to predict how forecasted precipitation will impact the impoundments and streamflow (i.e., how much volume and/or flow may be increased based on anticipated storm events) and incorporate into the low-flow release logic;
- Evaluate options for using the DAM Dashboard platform to reduce flooding and mitigate impacts of climate change (e.g., conducting a release in anticipation of a large rainfall event); and
- Use annual stakeholder meetings and email distribution lists from the local lake associations to further inform residents about the project and low flow releases.

Additional stakeholder coordination throughout the project was conducted through phone, email, and mail communication. FOFP was engaged to inform residents on Forge Pond of upcoming low flow releases to alleviate concern for lowering water levels in the impoundment. In addition, the Littleton and Westford Water Departments issued letters to abutters of Forge Pond to inform them of project activities.

2. Permitting

In order to modify the infrastructure and/or to perform a low flow releases at Spectacle Pond Outlet, Forge Pond Dam and Stony Brook Dam, owner and regulatory approval (i.e., permitting) for these modifications was required. To communicate planned activities in the study with stakeholders and regulating agencies, "low flow release narratives" and conceptual design schematics of proposed infrastructure modifications were developed.

2.1 Low Flow Release Narratives

To illustrate the proposed changes to regulating authorities and stakeholders, brief narrative and conceptual design schematics were developed for each dam where future low flow releases are planned as part of this study: Spectacle Pond Outlet, Forge Pond Dam, and Stony Brook Dam. The low flow release narratives for each site include the following:

- Site location map;
- A narrative description of existing and proposed conditions, including any applicable sizing, configuration, installation, operation, and maintenance procedures;
- Photos of the site, as available, to illustrate existing conditions; and
- Conceptual design schematics showing the proposed modification to existing infrastructure, as applicable, with recommendations for equipment configuration.

A low flow release narrative for each location is included in **Appendix A.** A brief description is provided below.

Spectacle Pond Outlet

The dam at Spectacle Pond Outlet includes two weirs with adjustable concrete stop logs that can control water levels within the impoundment. The resulting streamflow from stop log removal was predicted to be higher than desired for a low flow release and would drain the upstream impoundment too quickly. Therefore, installation of a low-flow orifice was proposed to provide control of the streamflow rate released during future low flow release events. A conceptual schematic was developed for a newly fabricated concrete stop log that features a full-port knife gate valve to enable low flow releases. The newly fabricated concrete stop log would measure approximately 18 inches tall (twice the height of existing concrete stop logs) to accommodate a 12-inch diameter valve, but the stop log would otherwise mimic existing stop log dimensions so that it would fit into the existing infrastructure. For installation, the newly fabricated stop log would be placed into the east weir of the outlet structure by a backhoe from the top of the culvert headwall, after removing one or more existing stop logs.

Forge Pond Dam

Existing infrastructure at Forge Pond Dam is currently used each winter for drawdown and can be similarly used for low flow releases, so permanent modification of the Forge Pond Dam infrastructure was not proposed. Therefore, a release narrative was prepared to describe the activities required to perform a release, but a conceptual design was not prepared.

Stony Brook Dam

The Stony Brook Dam currently includes two low level sluice gates; however, the sluice gates have not been operated in recent years (last operation unknown) due to concerns that they may become stuck in the open position. It was anticipated that a siphon type system or alternative (e.g., pump) would be proposed to enable low flow releases at Stony Brook Dam. During development of the low flow release narrative, it became clear that a pump introduced greater risk to surrounding environments (i.e., risk of using gas-powered equipment within a wetland resource area) and would likely be difficult to obtain approval from the local Conservation Commission. In addition, it was found that installation of a siphon system would result in significant engineering design challenges (i.e., attaching pipes to an old bridge or excavating and trenching through the existing roadway) that would result in higher than anticipated costs

and additional permitting requirements. A conceptual schematic was developed for a basic siphon system as originally planned; however, regulatory approval was not pursued for this site as part of the Project since further feasibility evaluations are required to understand if modifications can be implemented at this location to perform low flow release in the future.

2.2 Owner and Regulatory Approval

The low flow release narratives were used to obtain both owner and regulatory approval of project activities at Spectacle Pond Outlet and Forge Pond Dam. LWD owns and operates the Spectacle Pond Outlet and, as a core stakeholder of the project, was willing to participate and act as applicants for necessary permit approvals. Forge Pond Dam is owned by Mr. Chris Yule (Yule Development Company), who coordinates with FOFP (another project stakeholder) to enable winter lake level drawdown and subsequent spring lake refill. Project activities with respect to Forge Pond Dam were discussed with Mr. Yule, who agreed to participate as a collaborator in the Project. Owners provided written approval in the form of signatures on applicable permit applications.

Multiple permit application approvals and regulatory notifications were required for the planned low flow releases. Requested regulatory approvals along with a summary of the response received or current status are summarized in **Table 1** and described in the following sections.

Table 1: Permit Approval Summary

Permit Type	Spectacle Pond Outlet	Forge Pond Dam
Massachusetts Wetland Protection Act	**Order of Conditions (OOC) issued 5/20/2019**	FOFP has an active OOC for winter drawdown therefore a new OOC was not required
Massachusetts Endangered Species Act	**Determination issued 5/3/2019**	**Determination issued 5/3/2019**
Chapter 91 Licensing	**Minor Modification Authorization issued 6/17/2019**	N/A – no proposed modifications to structure
Chapter 253 Jurisdictional Determination	N/A – outlet structure does not meet criteria of a dam	FOFP has coordinated with MA ODS since 2007; therefore, an additional determination was not required

Notes:
1. Permit approvals issued as a result of the Project are **bolded** in the table above.

Spectacle Pond Outlet

Regulatory approvals sought for the proposed Spectacle Pond Outlet modification and planned low flow releases included requests under the Massachusetts Wetland Protection Act (MA WPA), the Massachusetts Endangered Species Act, and the Chapter 91 licensing program as described in more detail below. Research into the Chapter 253 Jurisdictional Determination administered by the Massachusetts Office of Dam Safety (MA ODS) indicated that the Spectacle Pond Outlet was not subject to MA ODS jurisdiction because the structure is not greater than six feet in height.

Massachusetts Wetland Protection Act

It was anticipated that a Request for Determination of Applicability under the MA WPA would be an appropriate permitting approach for installation of a low flow orifice at Spectacle Pond Outlet; however, due to the short schedule for this Project, a Notice of Intent was submitted to the Littleton Conservation Commission to expedite the process (i.e., reduce the possible necessity of a second public hearing). A public hearing was held with the Littleton Conservation Commission on 20 May 2019, during which the Commission voted unanimously in favor of the project. The OOC was issued on 20 May 2019 and expires 21 May 2022. Conditions of the approval can be found in the OOC included in **Appendix B**.

Massachusetts Endangered Species Act

Spectacle Pond, including the area around the outlet structure, is designated as Priority Habitat Area 2029 and Estimated Habitat 1346 for Blanding's Turtle (*Emydoidea blandingii*). Therefore, a project review application was submitted (in a joint package with Forge Pond Dam) to the Natural Heritage & Endangered Species Program (NHESP) of the Massachusetts Division of Fisheries & Wildlife (MassWildlife). On 3 May 2019, NHESP issued a determination that one condition must be met to avoid a prohibited Take[3] of the state-listed species: "All empirical testing must occur during the Blanding's turtle active season (April 16th – October 14th). No work shall occur following October 14th." The letter of determination from NHESP is included in **Appendix B**.

Chapter 91 Licensing Program:

Based on information available at the time of the Project, the outlet structure at Spectacle Pond is currently not licensed under the Chapter 91 Waterways Program of MassDEP. Therefore, representatives from the Chapter 91 Waterways Program were consulted on the proper method to approve the proposed modifications to Spectacle Pond Outlet. After reviewing the low flow release narrative prepared for Spectacle Pond Outlet, representatives from the Chapter 91 Waterways Program advised that the project appeared to meet the requirements of 310 CMR 9.05(3)(c) and could be licensed in accordance with 310 CMR 9.22(3), a submittal of a notice for a Minor Project Modification. The representatives indicated that a letter submittal describing the proposed project would be acceptable and that if a response was not received within 30 days of the submittal, the proposed modifications could be considered approved. A Minor Project Modification notice was submitted to the Chapter 91 Waterways Program on 17 May 2019 and a Minor Project Modification Authorization letter was received from MassDEP's Waterways Program on 17 June 2019. The authorization letter is included in **Appendix B**.

Forge Pond Dam

To conduct low flow releases at Forge Pond Dam, modification of the existing infrastructure is not required; therefore, regulatory approval from the Chapter 91 Waterways Program was assumed to be not applicable and permitting efforts were focused on those regulatory approvals with jurisdiction over the low flow release activities. Low flow releases involve the same release activities as winter drawdown, which FOFP has been performing at Forge Pond for invasive species management over the last several years. Therefore, previous regulatory approvals that FOFP has coordinated and maintained with the Westford Conservation Commission and MA ODS with respect to the MA WPA and Chapter 253 Jurisdictional Determination, respectively, also apply to low flow releases conducted as part of this Project and therefore additional approvals are not required. The request under the Massachusetts Endangered Species Act is described in more detail below.

Massachusetts Endangered Species Act

While FOFP has received an OOC from the Westford Conservation Commission to conduct winter drawdown activities, the approval is seasonally dependent due to the presence of endangered species. Forge Pond is located west of Priority Habitat Area 1740 and Estimated Habitat 1196 for Blanding's Turtle (*Emydoidea blandingii*). Therefore, a project review application was submitted (in a joint package with Spectacle Pond Outlet) to the NHESP of MassWildlife. On 3 May 2019, NHESP issued a determination that one condition must be met to avoid a prohibited Take of the state-listed species: "All empirical testing must occur during the Blanding's turtle active season (April 16th – October 14th). No work shall occur following October 14th." The letter of determination from NHESP is included in **Appendix B**.

[3] A Take is defined as "in reference to animals … harm … kill … disrupt the nesting, breeding, feeding or migratory activity … and in reference to plants … collect, pick, kill, transplant, cut or process … Disruption of nesting, breeding, feeding, or migratory activity may result from, but is not limited to, the modification, degradation, or destruction of Habitat" (MassWildlife, 2019).

3. Stream Gaging

During the previous FY2018 Stony Brook Flow Restoration Project and DAM Dashboard Pilot Project, sensors were installed to measure water depths at Mill Pond Dam, Spectacle Pond Outlet, Forge Pond Dam, and Stony Brook Dam. Stage-discharge rating curves were developed to relate measured water levels upstream and/or downstream of each impoundment to estimate discharge (i.e., streamflow) downstream. A dashboard was created for each of these locations that displays forecasted precipitation estimates, real-time water level data collected from the sensors installed at the sites, and the resulting streamflow from the stage-discharge rating curves to determine when low flow releases should be initiated to maintain aquatic baseflows downstream. Under the current Project, stream gaging was performed to validate (or update) the previously developed stage-discharge rating curves.

3.1 Stream Gaging Field Protocol

A Stream Gaging Protocol was developed based on the following sources: *Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams* (US EPA 2014), *Measurement of stage and discharge* (Rantz 1982), *Discharge measurements at gaging stations* (Turnipseed and Sauer 2010), previous project experience, and guidance from MA DER. The protocol developed is included in **Appendix C** and describes the equipment used for stream gaging, stream gaging methodology (i.e., establishing cross sections, obtaining velocity measurements at set intervals, calculating streamflow), velocity meter technical manuals, field forms, and site accessibility figures. The protocol was reviewed and approved by MA DER and provided to LWD and WWD prior to the first stream gaging event.

3.2 Stream Gaging

Geosyntec, LWD, WWD, and MA DER coordinated to complete five stream gaging events. The field forms for these events are included in **Appendix D**.

The objective of each stream gaging event was to collect streamflow measurements downstream of each of the four continuous water level monitoring stations installed at Mill Pond Dam, Spectacle Pond Outlet, Forge Pond Dam, and Stony Brook Dam during a variety of streamflow conditions (i.e., low to high streamflow), as feasible. SonTek FlowTracker and FlowTracker2 instruments were used to measure in-stream velocities and calculate streamflow. When possible, two measurements were collected at each gaging location as part of the quality assurance/quality control procedures. If the two measurements varied by more than ten percent and conditions were favorable (i.e., there was sufficient time available for another measurement or safety concerns did not exist), additional measurements were collected.[4] If streamflow rates or weather resulted in unsafe conditions for entering a stream (e.g. heavy precipitation, water level too high, water moving too quickly), measurements were not collected at that location during that particular stream gaging event.

The streamflow measurements were compared to DAM Dashboard-estimated streamflow during the time of measurement to evaluate the accuracy of the stage-discharge rating curves used by DAM Dashboard as described in the following sections. A summary of stakeholders present and outcomes of each stream gaging event are included in **Table 2**.

[4] Discretion was used in some circumstances to allow a greater than 10 percent difference between the two measurements if greater error was expected (i.e., due to low flow conditions, which are typically more difficult to measure with the equipment used).

Table 2: Stream Gaging Event Information

Event Date	Stakeholders Present	Notes
4/23/2019	Geosyntec, LWD, WWD, MA DER	MA DER trained representatives from Geosyntec, LWD, and WWD on properly collecting velocity measurements. Measurements could not be collected at Stony Brook Dam during this event due to high water level and streamflow conditions.
5/15/2019	LWD, MA DER	Measurements could not be collected at Stony Brook Dam during this event due to high water level and streamflow conditions.
5/28/2019	LWD, WWD, MA DER	Measurements could not be collected at Forge Pond Dam due to heavy precipitation.
6/5/2018	Geosyntec, LWD, WWD	A second round of measurements to validate the first measurements could not be collected at Spectacle Pond Outlet due to time constraints.
6/12/2019	LWD, WWD, MA DER	Measurements were collected at each of the four sites.

A summary of the measured streamflow compared to the DAM Dashboard-estimated stream flow is presented in **Table 3**. The measured streamflow values represent the calculated streamflow values from stream gaging activities. Estimated streamflow and water depth values were obtained from DAM Dashboard for each location during the corresponding date and time when the stream gaging was performed. The water depths at Forge Pond Dam were measured at the monitoring station in the channel downstream of the impoundment; whereas, the water depths for Mill Pond Dam, Spectacle Pond Outlet, and Stony Brook Dam represent the upstream impoundment water levels.

Table 3: Stream Gaging Results Summary

Site	Date	Time	Data Collected During Stream Gaging Events			Data Downloaded from DAMDashbaord	
			Measured Streamflow (cfs)		Average Measured Streamflow (cfs)	Estimated Streamflow (cfs)	Water Level (ft, NAVD88)
Forge Pond Dam	4/23/2019	14:55	73.6	86.4	80.0	157.5	187.1
	5/15/2019	8:13	57.0	54.1	55.6	119.3	186.7
	5/28/2019	--	--	--	--	--	--
	6/5/2019	14:00	30.0	28.9	29.5	76.3	186.1
	6/12/2019	9:41	28.4	27.9	28.1	73.4	186.0
Mill Pond Dam	4/23/2019	13:00	55.9	55.7	55.8	17.0	215.5
	5/15/2019	12:46	23.9	22.9	23.4	10.5	215.34
	5/28/2019	10:29	11.7	9.1	10.4	7.9	215.28
	6/5/2019	16:40	6.5	6.9	6.7	6.9	215.26
	6/12/2019	9:09	14.5	15.6	15.0	8.1	215.29
Spectacle Pond Outlet	4/23/2019	10:25	29.6	--	29.6	26.4	209.7
	5/15/2019	10:00	19.4	18.4	18.9	19.7	209.4
	5/28/2019	12:05	9.8	10.6	10.2	12.0	209.1
	6/5/2019	15:15	9.0	7.7	8.37	10.0	209.0
	6/12/2019	10:15	7.9	8.1	8.0	9.4	209.0
Stony Brook Dam	4/23/2019	--	--	--	--	--	--
	5/15/2019	--	--	--	--	--	--
	5/28/2019	13:30	24.7	26.1	25.4	21.5	182.8
	6/5/2019	11:40	29.9	27.1	28.5	29.6	183.0
	6/12/2019	12:42	31.9	32.2	32.1	27.8	182.9

3.3 Rating Curve Validation

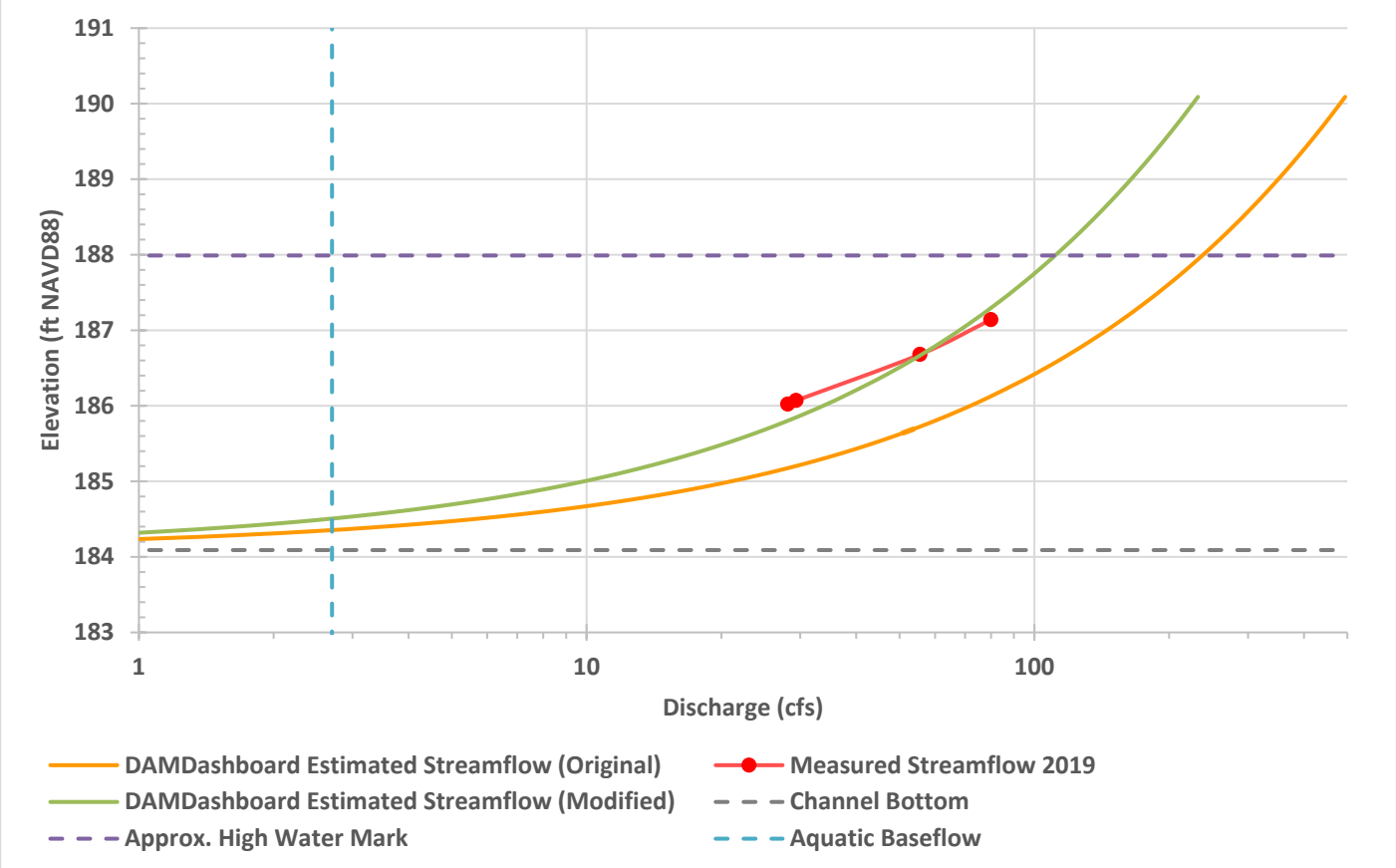
The DAM Dashboard stage-discharge rating curves were validated based on the stream gaging activities performed as described below.

Forge Pond

Streamflow downstream of Forge Pond was measured during four stream gaging events. The measurements are plotted in **Figure 2**. The results indicate that flow rates downstream of Forge Pond are overestimated by the DAM Dashboard stage-discharge rating curve. As a result, the longitudinal slope and Manning's roughness coefficients assumed when developing the original rating curve were modified to provide a revised stage-discharge rating curve with a better fit with the measured streamflow.

Additional stream gaging measurements should be collected to further validate this curve due to the limited range of flow conditions observed and measured during the Project. Low flow conditions were not observed during the study period and would likely contribute greatly to the validation of this rating curve.

Figure 2: Forge Pond Dam Rating Curve Validation Results



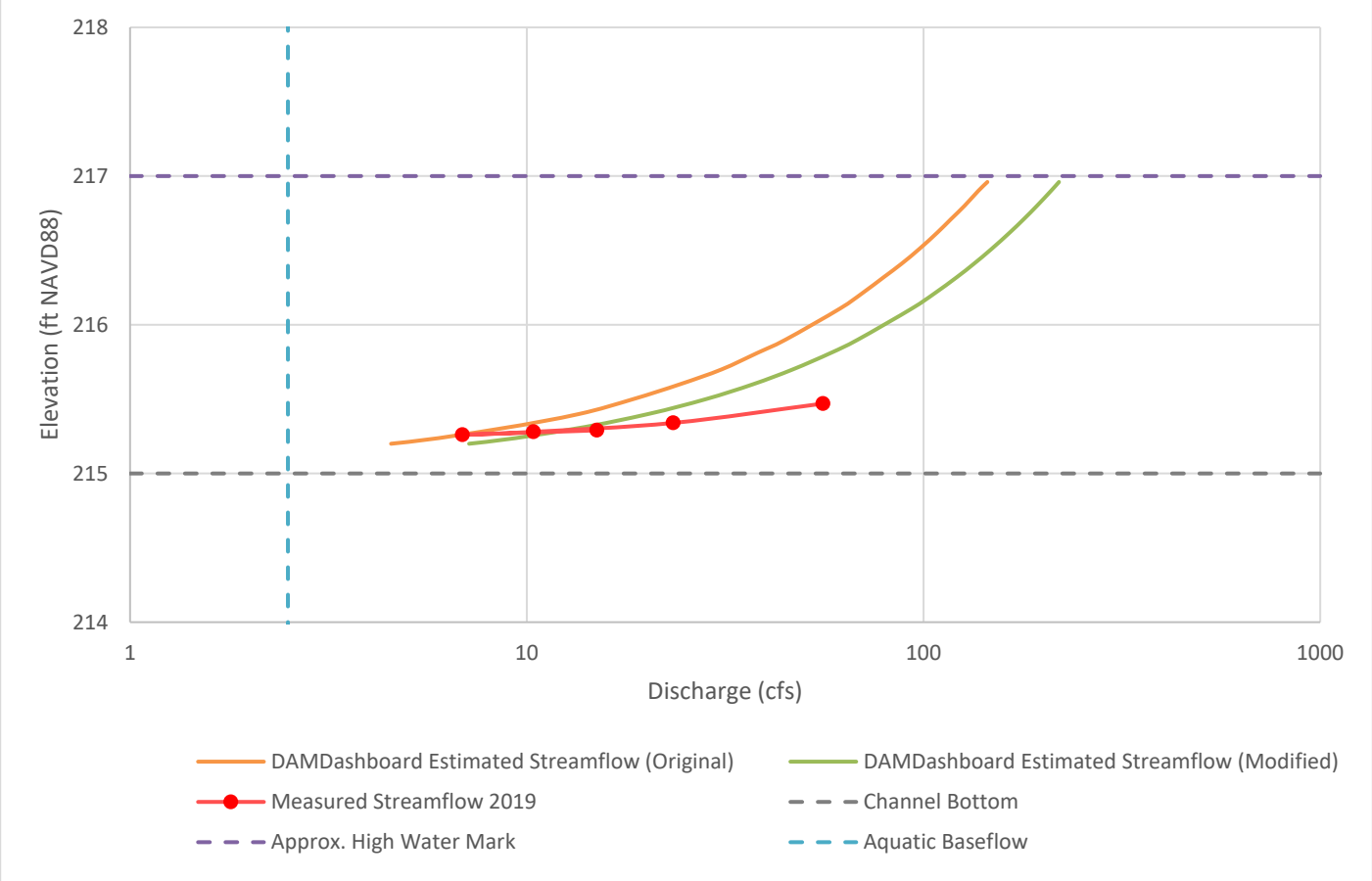
Mill Pond

Streamflow downstream of Mill Pond was measured during five stream gaging events. The measurements are plotted in **Figure 3**. The results indicate that flow rates downstream of Mill Pond are underestimated by the DAM Dashboard stage-discharge rating curve. However, it should be noted that the measured flows from the stream gaging events, particularly during the event on 5 June 2019 (when error alerts were received from the instruments), are low, and a higher amount of error is expected due to increased difficulty in measuring lower flow rates.

The effective width of the dam and the discharge coefficient assumed when developing the original rating curve were modified to provide a revised stage-discharge rating curve with a closer fit to the measured streamflow; however, due to the unique configuration of the horseshoe dam, it is difficult to estimate downstream flow from the upstream water level measurements at Mill Pond. An additional water level sensor was installed downstream of the Mill Pond Dam in May 2019 and may be used in future efforts to more accurately calibrate the rating curve to stream gaging data.

Additional stream gaging measurements should be collected to further validate this curve due to the limited range of flow conditions observed and measured during the Project.

Figure 3: Mill Pond Dam Rating Curve Validation Results



Spectacle Pond

Typically, the west weir in the Spectacle Pond Outlet is used to control water level by adding or removing stop logs. There are three primary stop log configurations at this dam: winter, summer, and maximum configurations. During typical operations two stop logs are removed at the end of Fall, modifying the dam into the winter configuration (one stop log in the west weir) and two stop logs are added at the beginning of Spring to return the dam to the summer configuration (three stop logs in the west weir). The dam has the capability to hold up to six stop logs (maximum configuration) but anecdotal information suggests that flooding of abutting properties would occur (see the Stony Brook SRP for further details on the Spectacle Pond Outlet). Visual observations during stream gaging events and follow-up with LWD indicated that the dam was not in one of the typical configurations (e.g., winter or summer) at the time of this study; two stop logs were installed in the west weir during the stream gaging events[5].

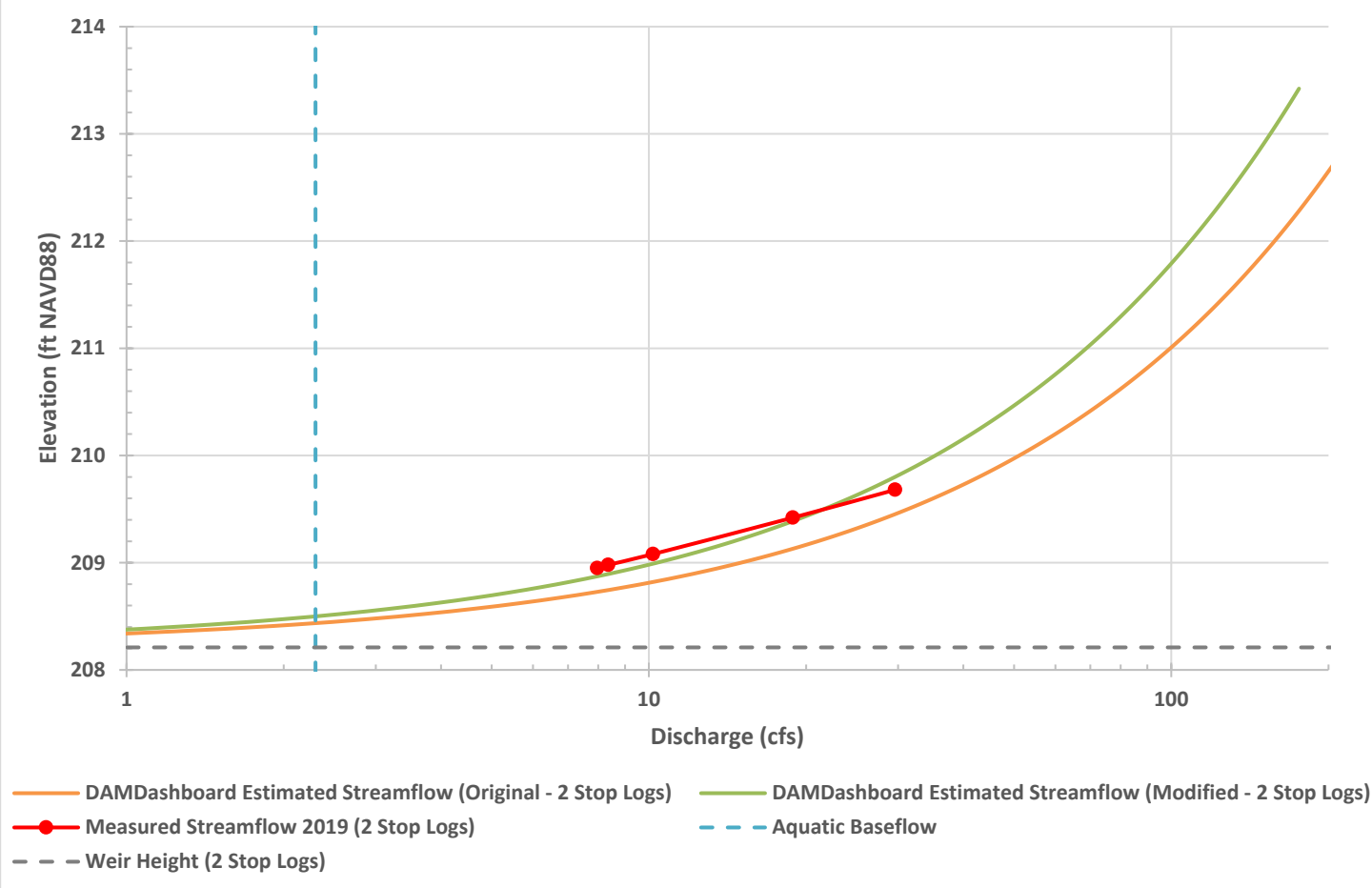
Streamflow downstream of Spectacle Pond was measured during five stream gaging events. The measurements are plotted in **Figure 4**. The results indicate that flow rates downstream of Spectacle Pond are overestimated by the DAM Dashboard stage-discharge rating curve. As a result, the weir discharge coefficient assumed when developing the original rating curve was modified to provide a revised stage-discharge rating curve with a better fit with the measured streamflow.

[5] DAM Dashboard assumes the outlet structure is in the summer configuration (3-stop log configuration) in May and June, so to estimate streamflow accurately for this study, the data presented in Figure 4 is not consistent with the data on DAM Dashboard. The data presented herein was corrected to use the lookup tables associated with a 2-stop log configuration to calculate the corresponding streamflow rather than using the data from DAM Dashboard directly (which shows streamflow associated with a 3-stop log configuration).

An additional water level sensor was installed downstream of the Spectacle Pond Outlet in May 2019 and may be used in future efforts to further calibrate the rating curve to stream gaging data.

Additional stream gaging measurements should be collected to further validate this curve due to the limited range of flow conditions observed and measured during the Project. In addition, stream gaging measurements should be conducted while the stop logs are in each typical configuration (winter and summer).

Figure 4: Spectacle Pond Outlet Rating Curve Validation Results

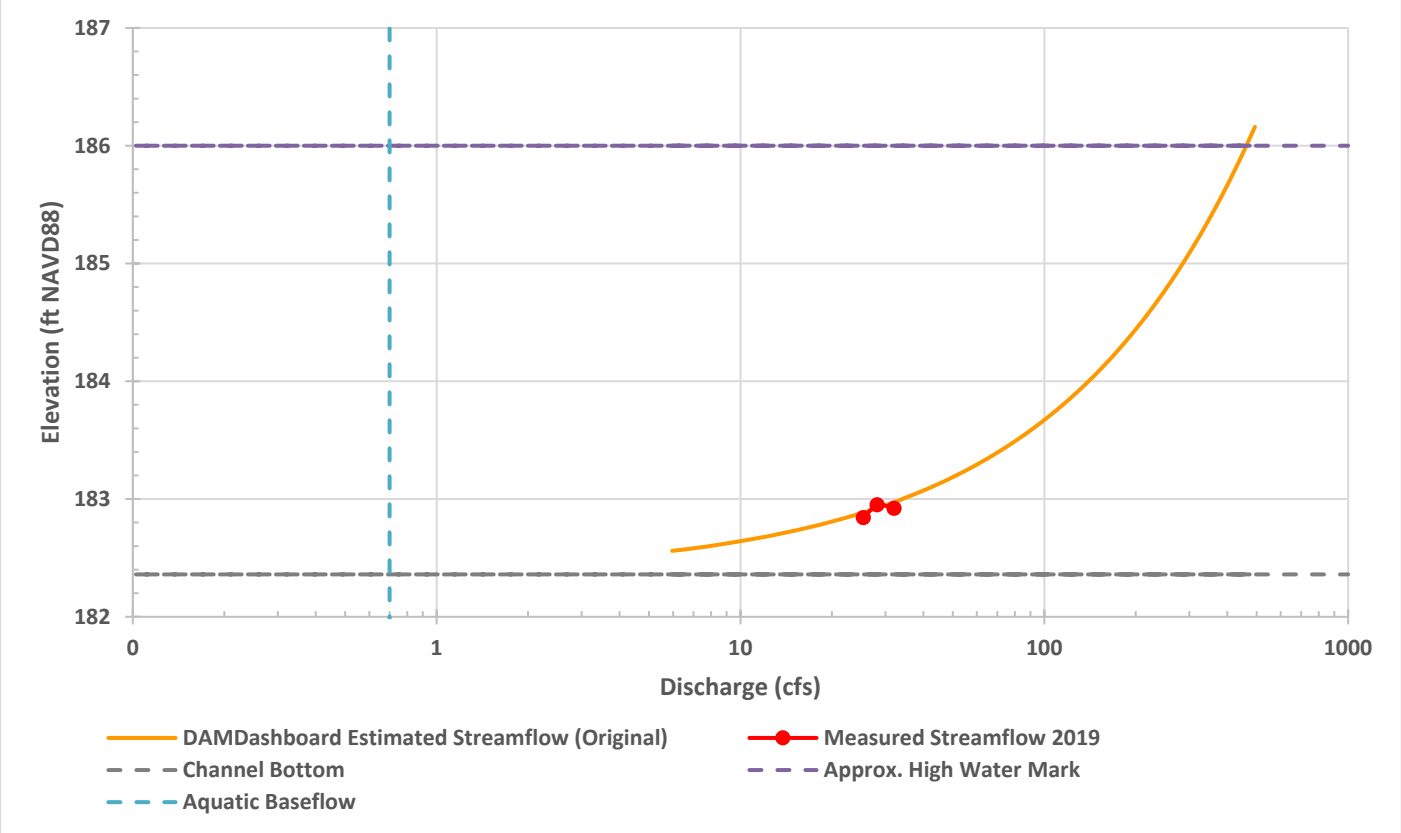


Note: Following completion of the original SRP in June 2018, stakeholders from SPA informed the project team that there is a partially buried stop log in the west weir that offsets the stop log elevations used in the SRP by 0.5 feet. To account for this offset, in July of 2018, an amendment to the SRP was drafted summarizing the adjusted stop log elevations used for development of the Spectacle Pond Outlet rating curves, referenced by the DAM Dashboard (see **Appendix E**). These lookup tables were used for comparison to stream gaging results collected in 2019 and presented herein.

Stony Brook Dam

Flow downstream of Stony Brook Dam was measured during three stream gaging events. The measurements are plotted in **Figure 5**. The results are not definitive, due to the limited number of stream gaging events, but the results appear to closely approximate the streamflow reported by DAM Dashboard. Therefore, the original DAM Dashboard stage-discharge curve was not modified. Additional stream gaging measurements should be collected to further validate this curve due to the limited range of flow conditions observed and measured during the Project.

Figure 5: Stony Brook Dam Rating Curve Validation Results



4. Empirical Testing

4.1 Overview

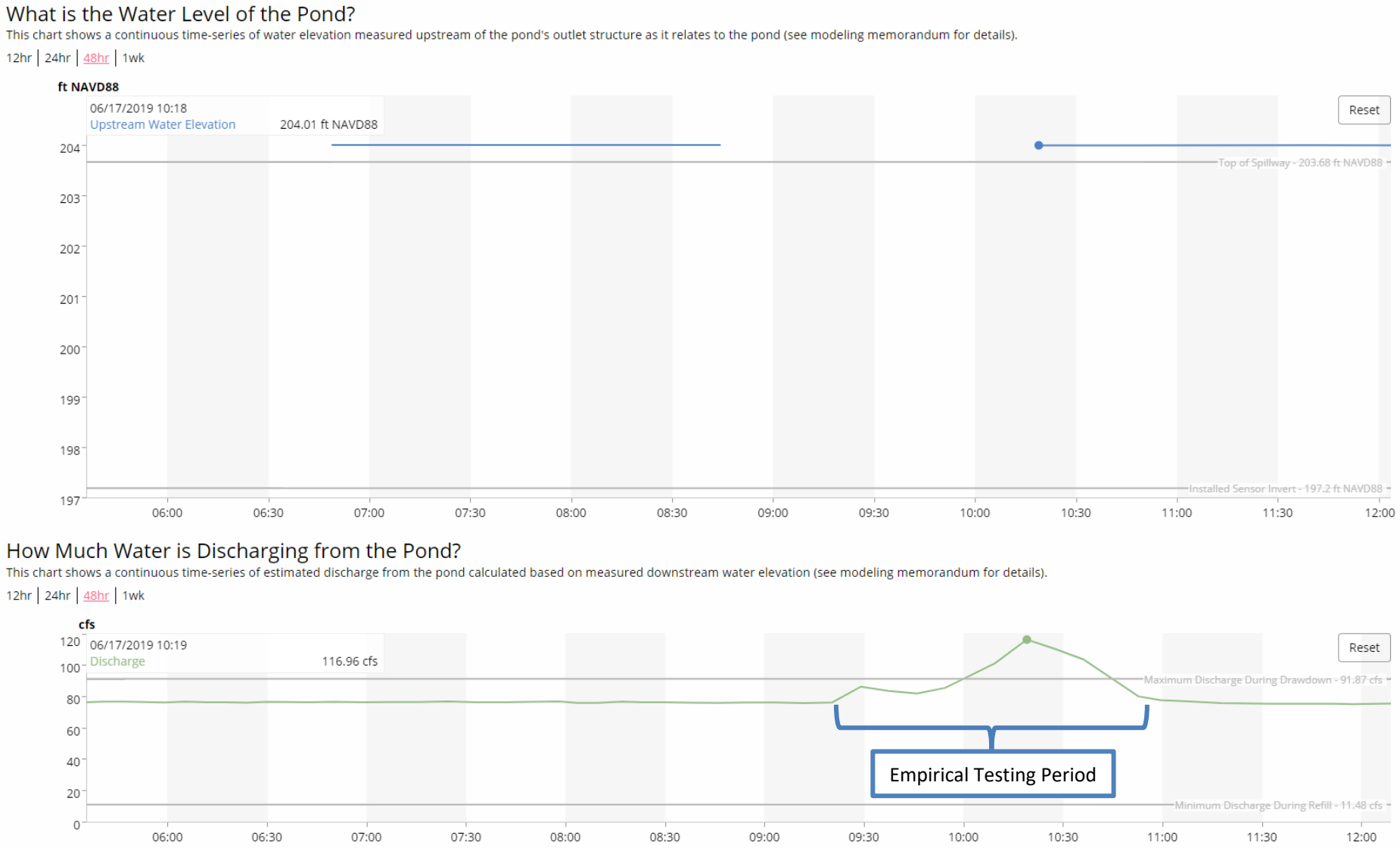
Low flow release empirical testing was planned in accordance with recommendations of the Stony Brook SRP. Forge Pond was selected as the first location to perform empirical testing because it was the only location that did not require infrastructure modification to initiate empirical testing. It was anticipated that alerts from DAM Dashboard would be used to trigger a recommended low flow release at Forge Pond Dam during the months of May and June (see the Stony Brook SRP for further details on decision support dashboard alerts and logic sequences). However, the downstream low flow condition was not achieved during the testing period. Despite flow conditions, the project team mobilized to perform one flow release on 17 June 2019 to better understand the operational procedures needed to perform the release and provide an overall assessment of the potential benefit.

4.2 Evaluation of Results

At approximately 9:15 AM on 17 June 2019, stop logs within the secondary outlet structure at Forge Pond Dam were removed iteratively as the water pressure slowly decreased between each stop log removal. In total, five of the eight stop logs were removed, with three remaining in place. The three upstream sluice gates were opened approximately 12 inches to match the optimized conditions modeled as part of the Stony Brook SRP. The result of the empirical test was documented on DAM Dashboard and showed an increase of approximately 40 cfs in an approximately one-hour period (see **Figure 6**); however, using the updated rating curve (see Section 3.3), this increase was likely closer to approximately 18 cfs.

Due to the upstream impoundment depth being higher than expected during a triggered low flow release, the flow entering the pen stock (the section of the secondary stream segment downstream of the sluice gates) was higher than the flow exiting through the secondary outlet structure, which resulted in a rapid increase of the pen stock depth (approximately one foot over 30 minutes). To stabilize this depth, two of the sluice gates were closed and the water depth subsequently dropped back to its original level. However, as shown in **Figure 6**, the upstream impoundment depth remained relatively unchanged during the test, suggesting that this release was successful in increasing downstream flow rates with minimal impact to the upstream depth during this short duration. The sluice gates were closed and the stop logs were re-inserted after only two hours due to the observed high flows during this period, which would not typically be expected during a triggered low flow release.

Figure 6: DAM Dashboard Results During Empirical Testing



4.3 Recommended Operational Strategy Adjustments

The following operational strategy adjustments and recommendations are based on observations during the empirical testing and discussions with Chris Yule, the owner of the Forge Pond Dam.

- Assess the future water demands of the Abbot Mill property and incorporate them into the operational strategy and decision support system so that low flow releases are optimized for streamflow restoration, to preserve recreational activities upstream, and to maintain the Abbot Mill water demands. At minimum, future releases should aim to balance sluice gate and stop log configurations to keep the water level in the pen stock from lowering during a release.
- Document the types and sizes of stop logs within the secondary outlet structure and order them in the structure to provide greater control of low flow releases (i.e., reordering stop logs so that smaller stop logs are at the top of the structure).
- Optimize the number and size of sluice gate openings based on upstream impoundment depth to avoid discharging greater flow through the sluice gates than can exit the secondary structure. Assessment may include SWMM model simulations and/or empirical testing under a variety of upstream conditions to iteratively determine the sluice gate opening recommendations during these conditions.
- Determine if sluice gate modifications are needed to maintain a stable depth in the pen stock. Assessment may include installing additional water level sensors in the pen stock to support this analysis.
- Prepare a stakeholder notification protocol for empirical testing locations. The notification protocol should establish and document:
  - Names and contact information for all stakeholders;
  - Instructions for notification (e.g., e-mail two weeks in advance);
  - A copy of any public notices required; and
  - A written description of roles and responsibilities for notification and performing the release.

5. Source Optimization Evaluation

LWD and WWD currently operate a combined total of 24 public water supply wells (six in Littleton and 18 in Westford) as shown in **Figure 7** and listed in **Table 4**. The purpose of this task was to evaluate the feasibility of implementing operational changes to minimize impacts to streamflow in Stony Brook from groundwater withdrawals without affecting the towns' ability to meet water supply demands. Separate scenarios for Littleton and Westford were analyzed as described in the following sections.

Table 4: Littleton and Westford Well IDs

Town	Well Name	Well IDs
Littleton	TWF Whitcomb Ave Well #3/4	2158000-01G
	GPW # 1 Whitcomb Avenue	2158000-02G
	GPW # 2 Beaver Brook RTE 119	2158000-05G, 2158000-06G, 2158000-07G
	GPW Spectacle Pond (Well #5)	2158000-04G
Westford	Forge Village Wellfield	3330000-01G, 3330000-09G, 3330000-10G, 3330000-11G, 3330000-12G
	Nutting Rd Well and Satellites	3330000-02G, 3330000-17G, 3330000-18G
	Depot Rd Well	3330000-03G
	Forge Village Rd GPW #2	3330000-05G
	Howard Rd Well	3330000-06G, 3330000-13G, 3330000-14G, 3330000-15G, 3330000-16G
Westford	Cote Well	3330000-07G
	Fletcher Well	3330000-08G
	Stepinski	3330000-20G
	Country Road Well No. 2	3330000-19G

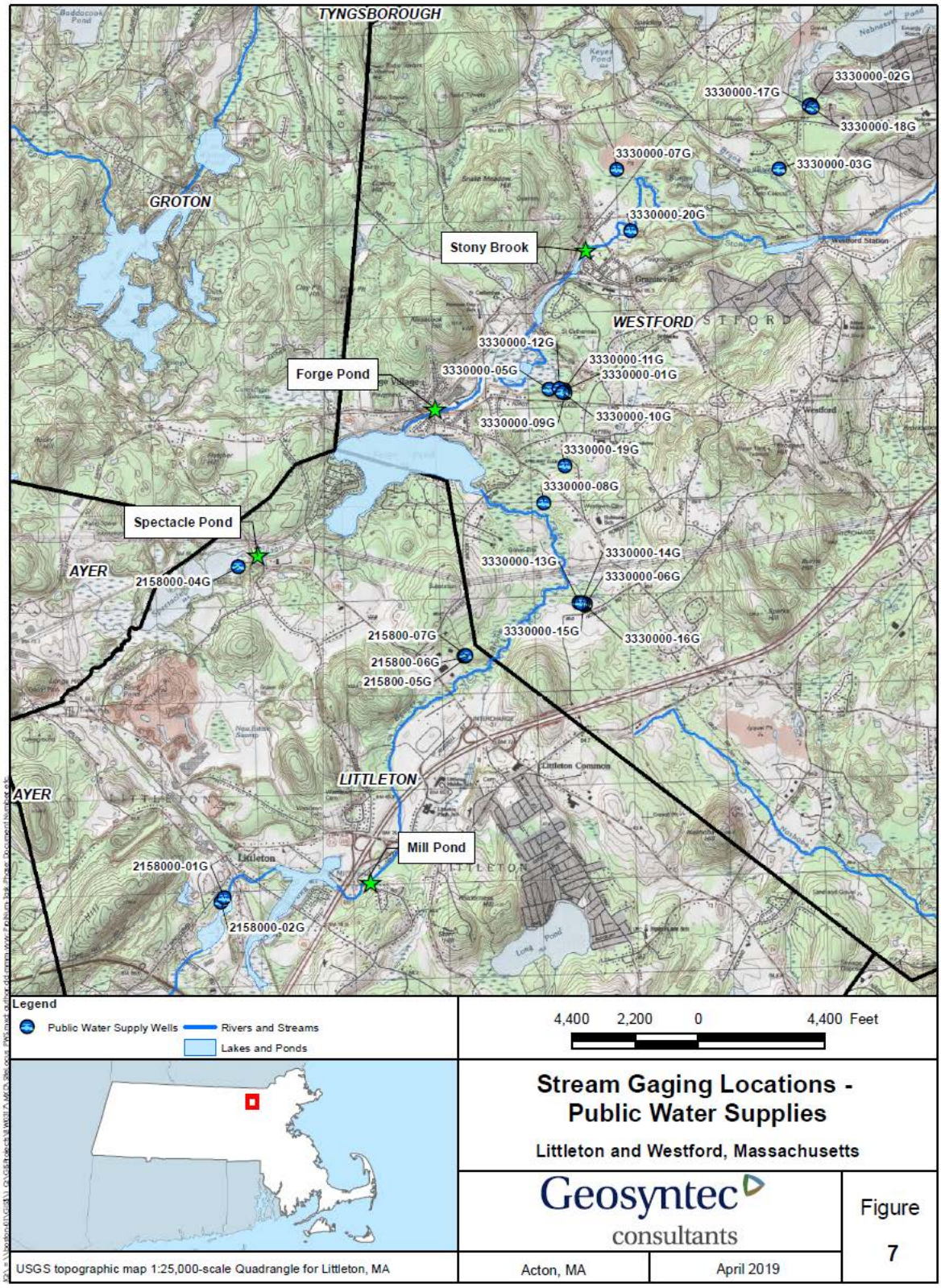
5.1 Data Collection

To complete the optimization analysis, data on pump rates, pump capacities, and physical characteristics (i.e., distance to surface water body, diffusivity, storage coefficient) were required for each well. These data were obtained from sources provided by LWD and WWD (Dufresne-Henry 1986, 2000, 2001, 2005, 2005, 2006; Earth Tech 1999, 2000; LWD 2018; WWD 2018; Whitman & Howard 1968). Input data and maximum pump rates used in the analysis are presented in **Appendix F**.

5.2 Model Software

STRMDEPL08 is an extended program of STRMDEPL, a computer program that calculates streamflow depletion by a nearby pumping well. The user inputs water supply well data, aquifer characteristics, and well pumping rates, and the program outputs the streamflow depletion over time (i.e., the rate of streamflow withdrawal compared to the pumping rate throughout the duration analyzed). It was anticipated that the web-interface of the STRMDEPL08 model would be used to perform the simplified desktop optimization analysis; however, after further research into this program, it was discovered that the web-interface could not account for pumping prior to the study time (i.e. the program assumes each well has not been pumped prior to the start date). In order to account for previous pumping at each well, the desktop-interface of the STRMDEPL08 model was used for this analysis.

Figure 7: Study Area Public Water Supply Wells in Littleton and Westford



5.3 Methodology

Baseline and Prioritization

For both the LWD and WWD wells, daily historical pumping data from 2018 for each well or wellfield was input to STRMDEPL08 to estimate the 2018 stream depletion volume and rates (established as the "baseline" scenario)[6] to understand how each well's characteristics and historical pumping data impact the nearest stream. Stream depletion ratios, the ratio of the well's pumping rate to the stream depletion rate or withdrawal rate, for each well vary due to aquifer characteristics and distance to nearby surface water bodies. Typically, wells that are closer to surface water bodies and/or have higher diffusivity values have higher depletion ratios during active pumping than those that are further from surface water bodies and/or have lower diffusivity values. This information and the results of the baseline analysis led to the well classifications described below.

After observation of the baseline results, it was clear that average or overall stream depletion was not the only indicator of each well's potential to impact to the stream. Temporal changes also needed to be considered since some wells had less of an impact on the stream during short durations of pumping, but their stream depletion ratio increased over the pumping duration. Similarly, the modeled stream depletion of some wells continued to slowly decrease after pumping had already ceased, resulting in periods where pumping was not occurring, but the stream was still being impacted. As a result of these nuanced observations, the following classifications were determined by visual inspection of the data to account for all of these variables:

- **High-Response** wells had a stream depletion rate approximately equal to the pumping rate of the well as soon as pumping was initiated. Therefore, when a well was pumped, the stream was depleted by an approximately equal amount, but when pumping ceased the stream depletion also ceased almost immediately (see **Figure 8**).
- **Low-Response** wells had a lower stream depletion ratio during active pumping compared to the high-response wells, with the stream depletion ratio slowly increasing over time (during active pumping). When low-response wells ceased pumping, the stream depletion rate did not immediately cease but instead slowly decreased, resulting in stream depletion ratios greater than 1 (i.e., the pump had ceased, but the stream was still being impacted) (see **Figure 9**).
- **Medium-Response** wells were those that fell in-between the high- and low-response wells. When the medium-response wells are pumped, the stream depletion rate did not immediately reach the pumping rate, though it did reach the pumping rate more quickly than the low-impacting wells. Similarly, when the medium-impacting wells ceased pumping, the stream depletion rate did not immediately cease, but it did decrease quicker than the low-response wells (see **Figure 10**).

This classification system helped prioritize wells and identify the wells to prioritize or minimize use to reduce overall stream depletion.

[6] To conservatively estimate the impacts of previous pumping, it was assumed that each of the wells had been pumping for ten years at the average 2018 pump rate.

Figure 8: High-Response Well Example

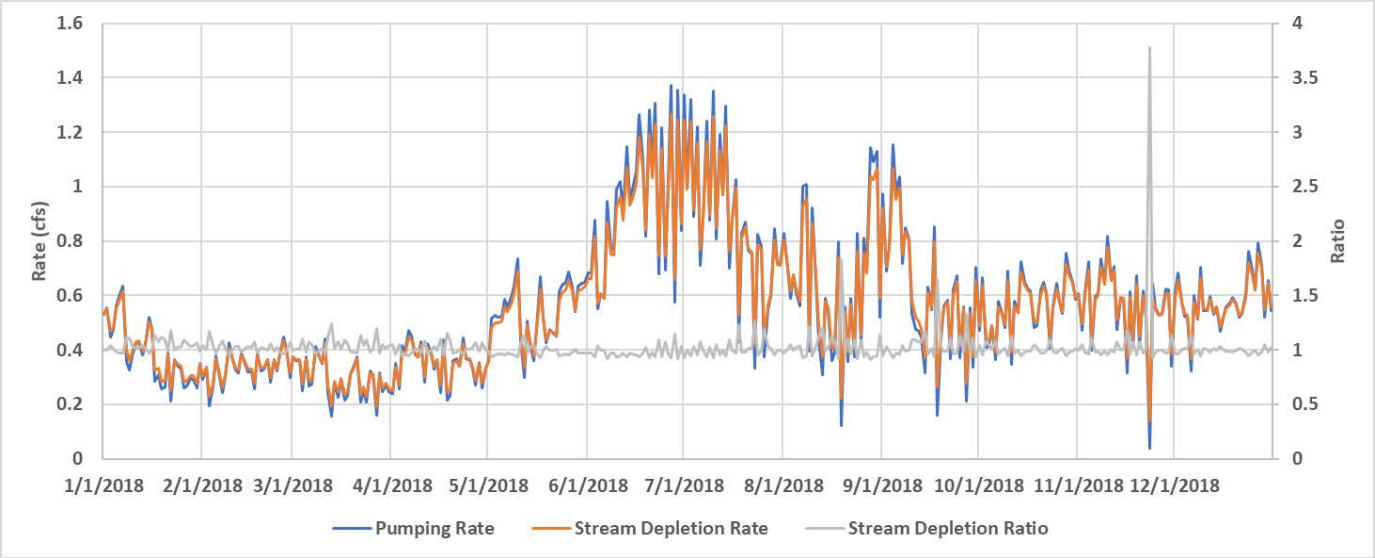


Figure 9: Low-Response Well Example

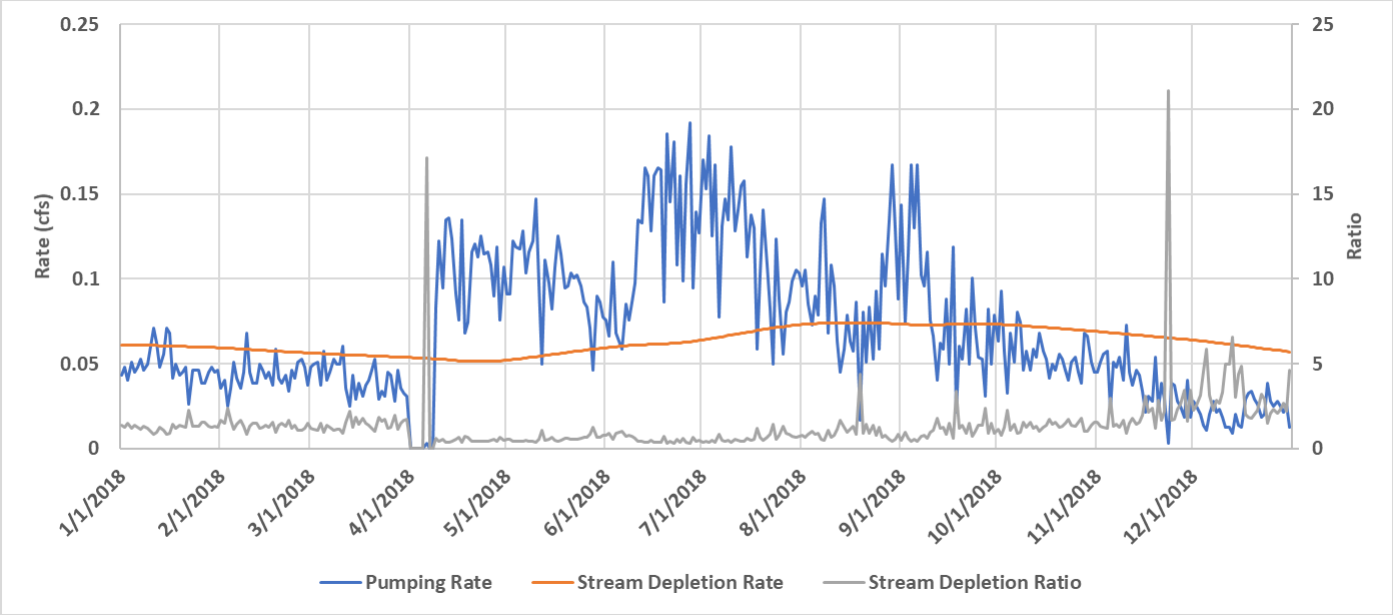
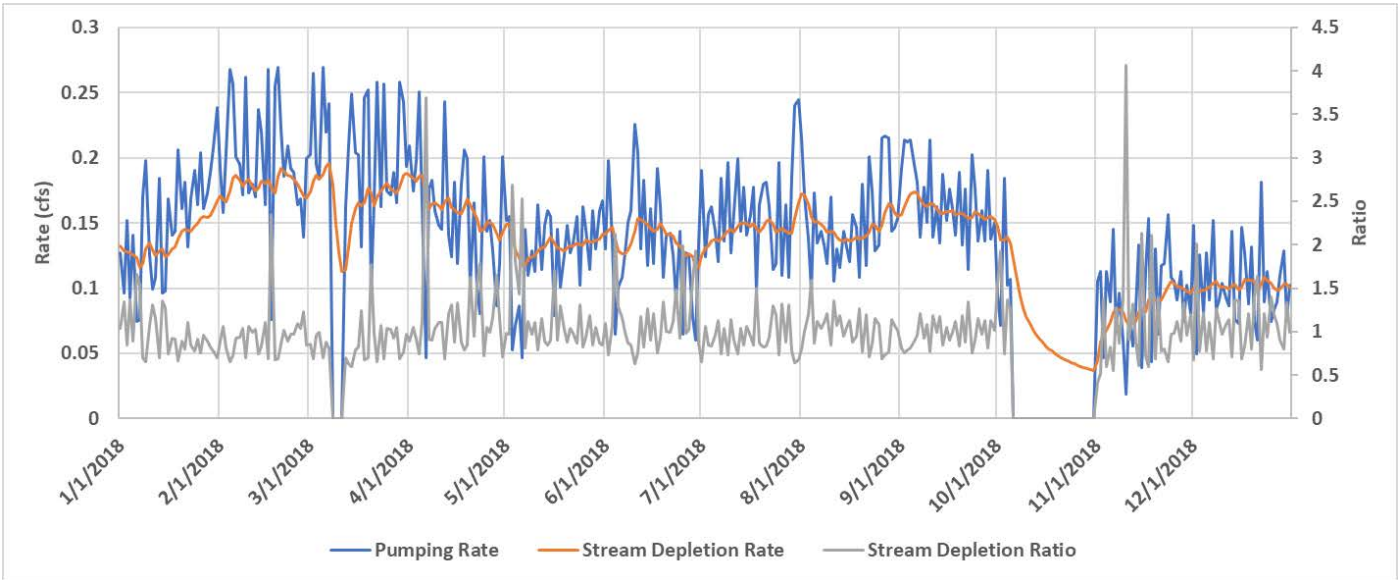


Figure 10: Medium-Response Well Example



Note: When pumping ceases, the stream depletion ratio is plotted as zero because dividing the stream depletion rate by the pumping rate during those periods would results in an undefined number.

Optimization Scenarios

The results of the baseline analysis and well prioritization were used to develop the following rules to be applied to the optimized scenarios:

- The pumping of low-response wells was maximized, as these wells had lower stream depletion ratios during active pumping when compared to the medium- and high-response wells.
- The pumping of high-response wells was minimized due to their high impact on stream depletion during active pumping. These wells were used as backup wells when the remaining wells could not meet the water supply demand. Due to the stream depletion rate decreasing quickly after pumping ceasing, these wells were cycled on and off as needed.
- The pumping of medium-response wells was analyzed on a case-by-case basis. Generally, these wells were pumped less than the low-response wells and more than the high-response wells. The medium-response wells were generally pumped in proportion to their stream depletion ratios.
- Ceasing pumping of the low-response wells does not immediately cease stream depletion, therefore these wells were initially set to pump continuously to minimize lag time with higher stream depletion ratios when feasible. However, when analyzed for a longer period, the stream depletion rate at the low-response wells slowly approached the well pumping rate suggesting that continuous pumping of these wells over time would result in a stream depletion ratio similar to the high-response wells. Therefore, some low-response wells were cycled on and off to maintain a lower stream depletion ratio in between pumping events.

The optimized scenarios manipulated the historical pumping data from 2018 for each well so that the daily well pumping volumes were unchanged, but the quantity pumped from each well was distributed according to the rules above. These optimized scenarios represent ideal conditions and, to simplify this analysis, do not take into consideration all of the necessary pump resting cycles, customer demand, water quality, or other maintenance needs. Future evaluations could apply the above rules, necessary pump resting cycles, and other logistical needs to refine these results. The intent is to use these results to understand how significantly well operational changes can reduce impacts to instream flows so that these rules can be applied to future scenarios and modified according to maintenance schedules and other limitations as needed (i.e., differing water quality between wells). Model results were analyzed

for one to three years to evaluate change in stream depletion ratios over time. While the results below describe an optimized scenario for Littleton and Westford, multiple scenarios with varying well pumping rules were also evaluated but showed limited improvement.

5.4 Results

Littleton – Baseline Scenario

The baseline analysis of LWD wells resulted in the following findings:

- **High-Response wells:** At the Spectacle Pond well, the stream depletion rate was approximately equal to the pumping rate, and when pumping ceased the stream depletion stopped.
- **Low-Response wells:** At the Beaver Brook wells, the stream depletion rate took a significant amount of time to reach the pumping rate, and when pumping ceased the stream depletion did not immediately stop.
- **Medium-Response wells:** At the Whitcomb Avenue wells, the stream depletion rate had an intermediate response compared to the Spectacle Pond and Beaver Brook wells; the stream depletion rate became equal to the pumping rate more quickly than the Beaver Brook wells but more slowly than at the Spectacle Pond well, and when pumping ceased the stream depletion decreased more quickly than the Beaver Brook Wells.

Littleton – Optimized Scenario

The optimized scenario for Littleton included the following pumping rules:

- prioritize pumping the Beaver Brook wells by diverting pumping from the Spectacle Pond well; and
- divide pumping evenly between the Whitcomb wells (rather than alternating pumping schedules).

Optimized scenario results applying the above rules to the historical pumping data from 2018 suggest that these operational changes would have reduced stream depletion by 3.9 million gallons (approximately 1% of the total volume pumped over the course of the year). Coincidentally, this optimized scenario aligns well with LWD's current planned changes to its operational strategy. LWD recently received a WMA permit amendment to increase the withdrawals from its Beaver Brook wells from 0.41 MGD to 0.65 MGD and is currently installing replacement wells at the Whitcomb wells, which will enable continuous operation of the wells at that site. These changes will allow LWD to rely primarily on the Beaver Brook and Whitcomb wells, except for during peak water demands times when the Spectacle Pond well will be used as needed.

Minimizing the stream depletion in August is often prioritized more than other months as this is likely the period when the stream is in low streamflow conditions. When the stream is naturally in low streamflow conditions, any amount of water depleted from the stream may have a larger impact than when the stream is in a higher streamflow condition. In the optimized scenario, there was a reduction in stream depletion in August of 0.2 million gallons (approximately 0.5% of the volume pumped in August). Therefore, if LWD were to update its pumping strategy to this optimized scenario, it would not be expected to significantly reduce stream depletion. This result may be primarily due to the large proportion of high and medium-response wells.

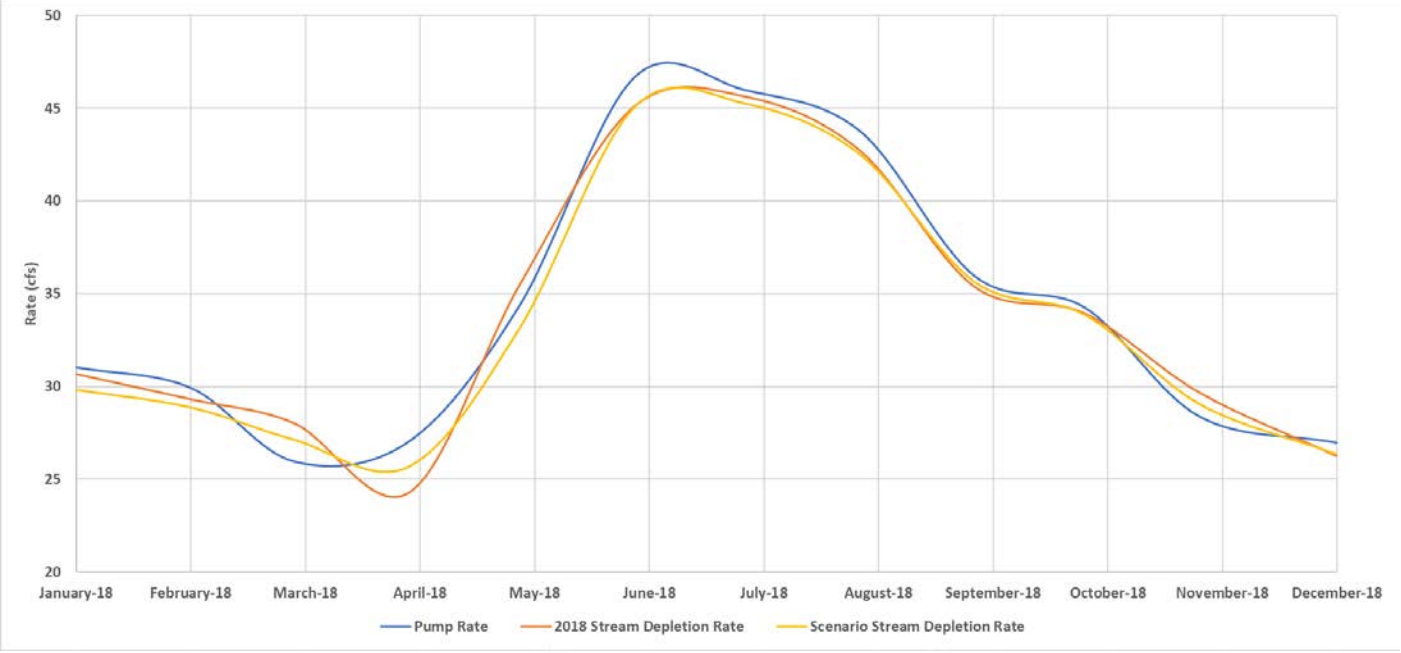
The results are included in **Table 5** and are shown on **Figure 11**. The "baseline ratio" represents the stream depletion ratio of the 2018 pumping data and the "optimized ratio" represents the stream depletion ratio of the optimization scenario.

Table 5: Littleton Source Optimization Results

Withdrawal Period	Volume Pumped (MG)	Baseline Depletion (MG)	Scenario Depletion (MG)	Depletion Reduction (MG)	Baseline Ratio	Optimized Ratio	Streamflow Improvement (cfs)	Percent Improvement (%)
January	31.0	30.7	29.8	0.8	1.0	1.0	0.04	2.7
February	29.9	29.3	28.9	0.4	1.0	1.0	0.02	1.4
March	26.0	28.0	27.1	0.9	1.1	1.0	0.04	3.3
April	27.0	24.3	25.7	-1.4	0.9	1.0	-0.07	-5.3
May	34.4	35.5	33.2	2.3	1.0	1.0	0.12	6.8
June	46.7	45.1	45.0	0.0	1.0	1.0	0.003	0.1
July	46.0	45.6	45.3	0.4	1.0	1.0	0.02	0.8
August	**43.8**	**42.7**	**42.5**	**0.2**	**1.0**	**1.0**	**0.01**	**0.5**
September	36.0	35.4	35.7	-0.3	1.0	1.0	-0.01	-0.8
October	34.3	33.9	33.9	0.1	1.0	1.0	0.003	0.2
November	28.4	29.7	29.1	0.6	1.0	1.0	0.03	2.1
December	27.0	26.3	26.4	-0.1	1.0	1.0	-0.006	-0.4
2018	410.5	406.4	402.5	3.9	1.0	1.0	0.02	1.0

Note: Depletion reductions may be negative if more water is depleted in the optimized scenario than in the baseline scenario. This may occur if certain wells were pumped more in the optimized scenario than in the baseline scenario, or if the wells were frequently turned off so that the stream depletion rate was greater than the pumping rate for a period of time.

Figure 11: Littleton Stream Depletion Rate Results



Westford – Baseline Scenario

The baseline analysis of WWD wells resulted in the following findings:

- **High-Response wells:** At the Fletcher and Stepinski wells, the stream depletion rate was approximately equal to the pumping rate, and when pumping ceased the stream depletion stopped.
- **Low-Response wells:** At the Depot Road, Howard, Nutting Satellites, and Country Road 2 wells, the stream depletion took a significant amount of time to reach the pumping rate, and when pumping ceased the stream depletion did not immediately stop.
- **Medium-Response wells:** At the Forge Village and Cote wells, the stream depletion rate had an intermediate response compared to the other wells; the stream depletion rate became equal to the pumping rate more quickly than the Depot Road, Howard, Nutting Satellites, and Country Road 2 wells but more slowly than the Fletcher and Stepinski wells, and when pumping ceased the stream depletion decreased more quickly than the Depot Road, Howard, Nutting Satellites, and Country Road 2 wells.

Westford – Optimized Scenario

The optimized scenario for Westford included the following pumping rules:

- prioritize pumping the Depot Road, Nutting Satellite, and Country Road 2 wells;
- alternate pumping each of the Nutting Satellite wells to reduce maximum depletion over time;
- after maximizing pumping from the above wells, prioritize Forge Village wells, Howard, and Cote wells; and
- pump the Fletcher and Stepinski wells only when necessary.

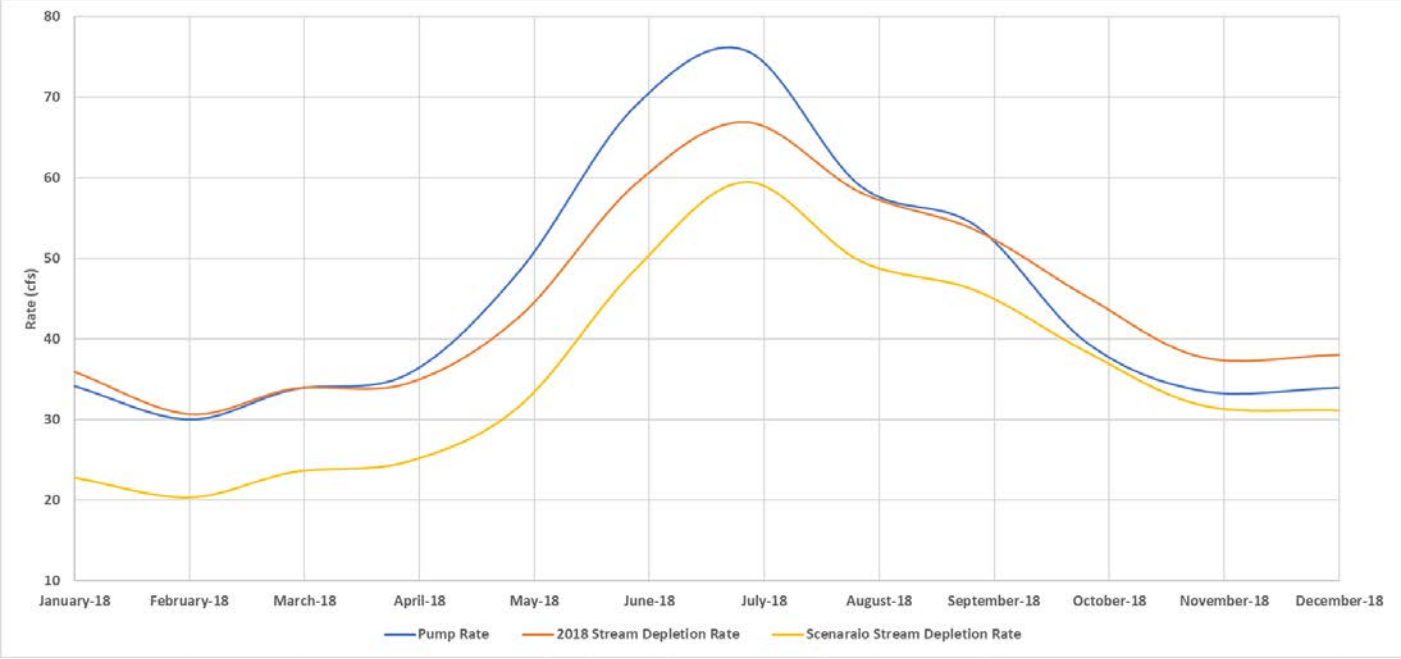
Optimized scenario results applying the above rules to the historical pumping data from 2018 suggest that these operational changes would have reduced stream depletion by 108.5 million gallons (approximately 20% of the total volume pumped). In this scenario, there was reduction in stream depletion in August of 8.5 million gallons (approximately 17% of the volume pumped in August).

The results are included in **Table 6** and are shown on **Figure 12**.

Table 6: Westford Source Optimization Results

Withdrawal Period	Volume Pumped (MG)	Baseline Depletion (MG)	Scenario Depletion (MG)	Depletion Reduction (MG)	Baseline Ratio	Optimized Ratio	Streamflow Improvement (cfs)	Percent Improvement (%)
January	34.2	35.9	22.8	13.1	1.1	0.7	0.7	38.5
February	30.0	30.7	20.3	10.4	1.0	0.7	0.6	34.5
March	33.7	33.8	23.5	10.4	1.0	0.7	0.5	30.7
April	35.7	34.5	24.8	9.7	1.0	0.7	0.5	27.3
May	48.4	42.7	31.6	11.1	0.9	0.7	0.6	22.9
June	68.7	59.1	48.5	10.6	0.9	0.7	0.5	15.4
July	75.8	66.9	59.4	7.4	0.9	0.8	0.4	9.8
August	**59.0**	**58.2**	**49.6**	**8.5**	**1.0**	**0.8**	**0.4**	**14.5**
September	54.1	53.5	46.0	7.5	1.0	0.9	0.4	13.9
October	39.6	45.2	38.4	6.9	1.1	1.0	0.3	17.4
November	33.6	37.7	31.8	6.0	1.1	0.9	0.3	17.8
December	34.0	38.0	31.1	6.9	1.1	0.9	0.3	20.4
2018	546.7	536.2	427.7	108.5	1.0	0.8	0.5	19.8

Figure 12: Westford Stream Depletion Rate Results



5.5 Source Optimization Study Findings

In evaluating the historical pumping data from 2018, it was observed that pumping certain wells resulted in higher stream withdrawals when compared to other wells. It was also observed that the duration of pumping had an impact on the stream withdrawal and impact of certain wells. The degree of stream withdrawal is largely based on distance from the wells to the stream, the diffusivity of the aquifer, and the pumping rate. To develop pumping strategies to minimize streamflow impact, the Littleton and Westford wells were categorized as either high-response, low-response, or medium-response, based on a visual inspection of how quickly stream depletion rates approached the pumping rate after pumping was initiated (and also how quickly the stream depletion rate decreased after pumping ceased).

Through this evaluation, it was determined that if the proposed well pumping rules had been initiated in 2018, Littleton and Westford could have reduced the volume of water depleted from Stony Brook by approximately 1% and 20%, respectively. It is suspected that the improved results observed in Westford are due to Westford having a higher number of low-response wells compared to Littleton.

6. Future Activities

Future activities for the Stony Brook Flow Restoration Project are primarily dependent on procurement of funds from additional funding sources. The project has been selected as a MA DER Priority Project which presents an opportunity for additional funding. Further funding through the MA DEP WMA Grant may also be sought in subsequent years. The project team will work closely with representatives from these organizations and project stakeholders to continue efforts to improve streamflow in the Stony Brook watershed. If funding is received, the following are recommended next steps to continue the progress of this study:

- Develop a comprehensive stakeholder engagement strategy that uses lake association (e.g., LCLC, SPA, and FOFP) annual meetings and email distribution lists, town websites, and other platforms (e.g., social media) to expand public education about the study and inform town residents and municipal officials when low flow releases are planned.
- Conduct additional stream gaging at all project locations for a variety of streamflow conditions (particularly low flow conditions) to further validate stage-discharge rating curves or refine downstream flow estimates.
- Update DAM Dashboard lookup tables with data from updated rating curves that have been validated through stream gaging.
- Fabricate and install the proposed concrete stop log and valve at the Spectacle Pond Outlet and initiate empirical testing of low flow releases.
- Continue empirical testing of low flow releases at Forge Pond Dam.
- Expand the SRP to include the Stony Brook Reservoir in Chelmsford, the final impoundment on the mainstem of Stony Brook prior to its discharge into the Merrimack River (recommendation from original SRP).
- Update the regional surface water model to incorporate new information collected as part of the study, including:
  - Using additional monitoring data collected at project monitoring stations in the watershed to recalibrate and refine the model;
  - Updating the model with finalized rating curves validated by stream gaging; and
  - Reevaluate operational strategies.
- Update the regional surface water model to address additional stakeholder concerns, including evaluating opportunities to include operational strategies to address flooding from extreme events and climate resiliency.
- Establish a permitting framework for long-term empirical releases beyond the initial testing period.
- Conduct additional source optimization evaluations that expand the study area (e.g., include Ayer wells) and take into account pump resting cycles, maintenance needs, changes in water supply demands, customer demand, and water quality.
- Update the Stony Brook SRP to incorporate findings from this and other continuations of the project.

Future activities may also include efforts to further refine conceptual designs for proposed modifications to the Stony Brook Dam to enable low flow releases. Additional recommendations for further model validation/calibration, baseline sampling, low flow release feasibility evaluation, empirical testing and implementation, and evaluation of automated controls, are listed in the Stony Brook SRP (Geosyntec Consultants, 2018). These recommendations include many additional potential options for further study within the watershed that were not investigated in this Addendum of the Stony Brook Flow Restoration Project due to schedule and budget constraints.

7. References

Dufresne-Henry. 1986. Report on Hydrogeological Study, Phase I, Westford, Massachusetts.

Dufresne-Henry. 2000. Stony Brook Center Water Supply and Aquifer Impact Study Draft, Westford, Massachusetts.

Dufresne-Henry. 2001. Report on Prolonged Pumping Test, Stepinski Site, Westford, Massachusetts.

Dufresne-Henry. 2005. Notice of Intent, Westford Water Department, Site 7 Pump Test, Westford, Massachusetts.

Dufresne-Henry. 2005. Notice of Intent, Westford Water Department, Nutting Road Well Replacement, Westford, Massachusetts.

Dufresne-Henry. 2006. Final Report on Prolonged Pumping Test, Country Road Well No. 2, Westford, Massachusetts.

Earth Tech, Inc. 1999. Source Water Assessment Program, Conceptual Zone II Delineation, Westford Water Department, Forge Village Road Wells and Country Road Well, Westford, Massachusetts.

Earth Tech, Inc. 2000. Conceptual Zone II Delineation, Westford Water Department, Howard Road Well Field, Westford, Massachusetts.

Littleton Electrical Light and Water Department (LWD). Raw Water Pumping Log, Groundwater_2018. Microsoft Excel file. Accessfrom: Corey Godfrey, 22 April 2019, Littleton, Massachusetts. MA DEP (2014). Water Management Act Permit Guidance Document, Published November 2014.

Rantz, S.E. et al. 1982. Measurement and computation of streamflow: Measurement of stage and discharge. U.S. Geological Survey Water-Supply Paper 2175, volume 1, 313pp. Available online: https://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_vol1.html

Turnipseed, D.P. and Sauer, V.B. 2010. Discharge measurements at gaging stations. U.S. Geological Survey Techniques and Methods book 3, chapter A8, 87pp. Available online: https://pubs.usgs.gov/tm/tm3-a8/

U.S. Environmental Protection Agency (EPA). 2014. Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R-13/170F.

USFWS (1999). Questions and Answers on the New England Flow Policy, Prepared by Vernon Lang, USFWS, May 11, 1999. <https://www.fws.gov/newengland/pdfs/Flowpolicy.pdf> Accessed May, 2018.

Westford Water Department (WWD). Raw Water Pumping Log, 2018 ASR. Microsoft Excel file. Access from: Mark Warren, 26 April 2019, Westford, Massachusetts.

Westford Water Department (WWD), Littleton Water Department (LWD), and Geosyntec Consultants. 2018. Stony Brook Flow Restoration Project. 2018 Water Management Act Grant Program. Final Streamflow Restoration Plan. June.

Whitman & Howard, Inc. 1968. Report of Test Well Investigation, Forge Village Road Near Pumping Station No. 1, Westford, Massachusetts.

Appendix A

Low Flow Release Narratives

LOW FLOW RELEASE NARRATIVE AND CONCEPTUAL DESIGN SCHEMATICS

ABBOT MILL DAM ADJACENT TO PLEASANT STREET
WESTFORD, MA



1. Imagery obtained from MassGIS OLIVER.

LIST OF DRAWINGS

DRAWING NO.	DRAWING TITLE
1	SITE LOCATION AND DRAWING INDEX
2	LOW FLOW RELEASE NARRATIVE
3	OUTLET STRUCTURE CONFIGURATION

PREPARED FOR:

LITTLETON LELWD ELECTRIC LIGHT & WATER DEPARTMENTS

TOWN OF WESTFORD INCORPORATED SEPT. 24, 1729

PREPARED BY:

Geosyntec consultants

SHEET TITLE: SITE LOCATION AND DRAWING INDEX

PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: ABBOT MILL DAM (FORGE POND) – WESTFORD, MA

Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

DESIGN BY:	DR	DATE:	4/12/2019
DRAWN BY:	DR	PROJECT NO.:	BW0317
CHECKED BY:	HLO	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	1 OF 3
APPROVED BY:	AMB		

Existing Conditions: Forge Pond is a 202-acre pond located in Littleton and Westford, Massachusetts with an approximate watershed area of 14,976-acres. Forge Pond's primary tributaries are Gilson Brook (from Spectacle Pond) and Beaver Brook (from Mill Pond). The pond is impounded to the north by a dam constructed of stone blocks, with a primary spillway weir constructed of wooden planks on its northern side and three timber sluice gates on its southern side. A secondary outlet control structure was constructed in the 1990's, downstream of the sluice gates, which consists of a concrete weir with adjustable aluminum stop logs.

The timber sluice gates and secondary outlet control structure are seasonally adjusted to allow for winter drawdown and spring refill in accordance with an approved Order of Conditions. Discharge from the dam flows into Stony Brook via a rectangular channel that passes through the Abbot Mill property. Stony Brook frequently experiences low flows during prolonged dry periods based on anecdotal evidence.

Proposed Conditions: Periodic low flow releases are proposed at this location to improve streamflow in Stony Brook. Low flow releases will be performed based on alerts from a decision support dashboard in accordance with recommendations from the streamflow restoration plan (SRP) developed by Geosyntec Consultants in June 2018. Once approved, low flow releases will be tested, evaluated for effectiveness, and adjusted based on system response findings.

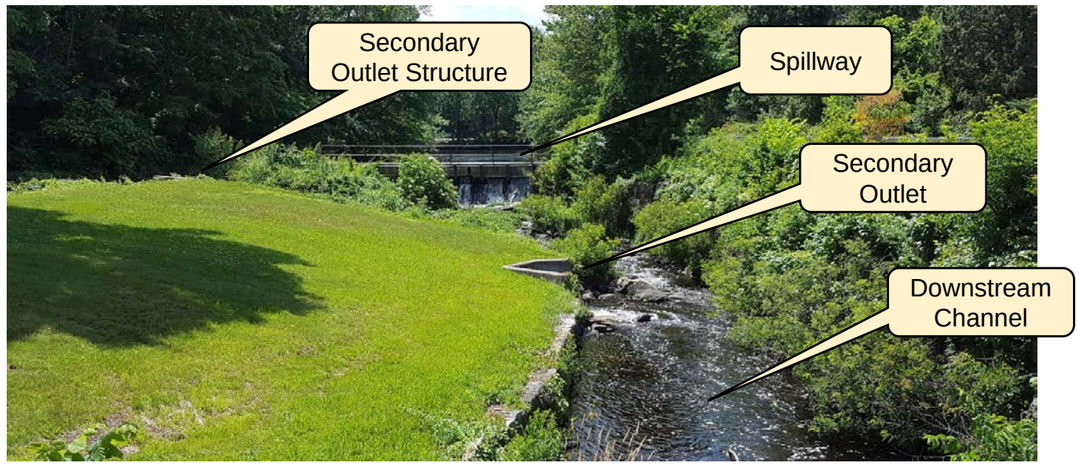
- **Sizing:** Low flow releases will be performed to maintain an Aquatic Baseflow (ABF) of at least 11.7 cubic feet per second. ABF is a simplified set of chemical, physical, and biological conditions that represent limiting conditions for aquatic life and wildlife in stream environments. Model simulations from the SRP indicate that adjustments to the existing timber sluice gates and secondary outlet control structure (i.e., aluminum stop logs) will allow passage of ABF without drawing down Forge Pond too rapidly.

- **Configuration**: Low flow releases will be accomplished by adjusting the existing timber sluice gates and aluminum stop logs at the secondary outlet control structure. The three existing sluice gates will each be opened by approximately 12-inches. Stop logs will be removed from the secondary outlet control structure to maintain ABF. Stop logs must be removed incrementally to minimize potential downstream impacts from releases. The outlet control structure includes eight stop logs. Five of the stop logs will be systematically removed up to an elevation of approximately 202.5 feet, NAVD88. Low flow releases are not anticipated to have an impact on the existing configuration of the outlet control structure. Elevated discharge from intense and/or large magnitude precipitation events will overflow over the primary and secondary spillways as currently configured. Low flow releases will be halted at an elevation of approximately 202.5 feet, NAVD88 to discourage potential recreation issues caused by lower upstream water levels in Forge Pond.

- **Operation:** Low flow releases will be initiated and halted by stakeholders based on alerts from a decision support dashboard available at www.opti.com from April-October. Alerts were developed from the 2018 SRP. Alerts will be based on continuous measurements of water level and discharge, and precipitation forecast data. For example, an alert will be issued if there is adequate water level in Forge Pond, but discharge is approaching or less than ABF at the outlet. All adjustments will be made by hand and will be made contingent upon approval of the Abbot Mill Dam Owner. Health and Safety Plan must be developed and implemented by all personnel performing low flow releases.



Abbot Mill Dam – Spillway and Sluice Gate (upstream view)



Abbot Mill Dam – Downstream Dam Components

SHEET TITLE: LOW FLOW RELEASE NARRATIVE

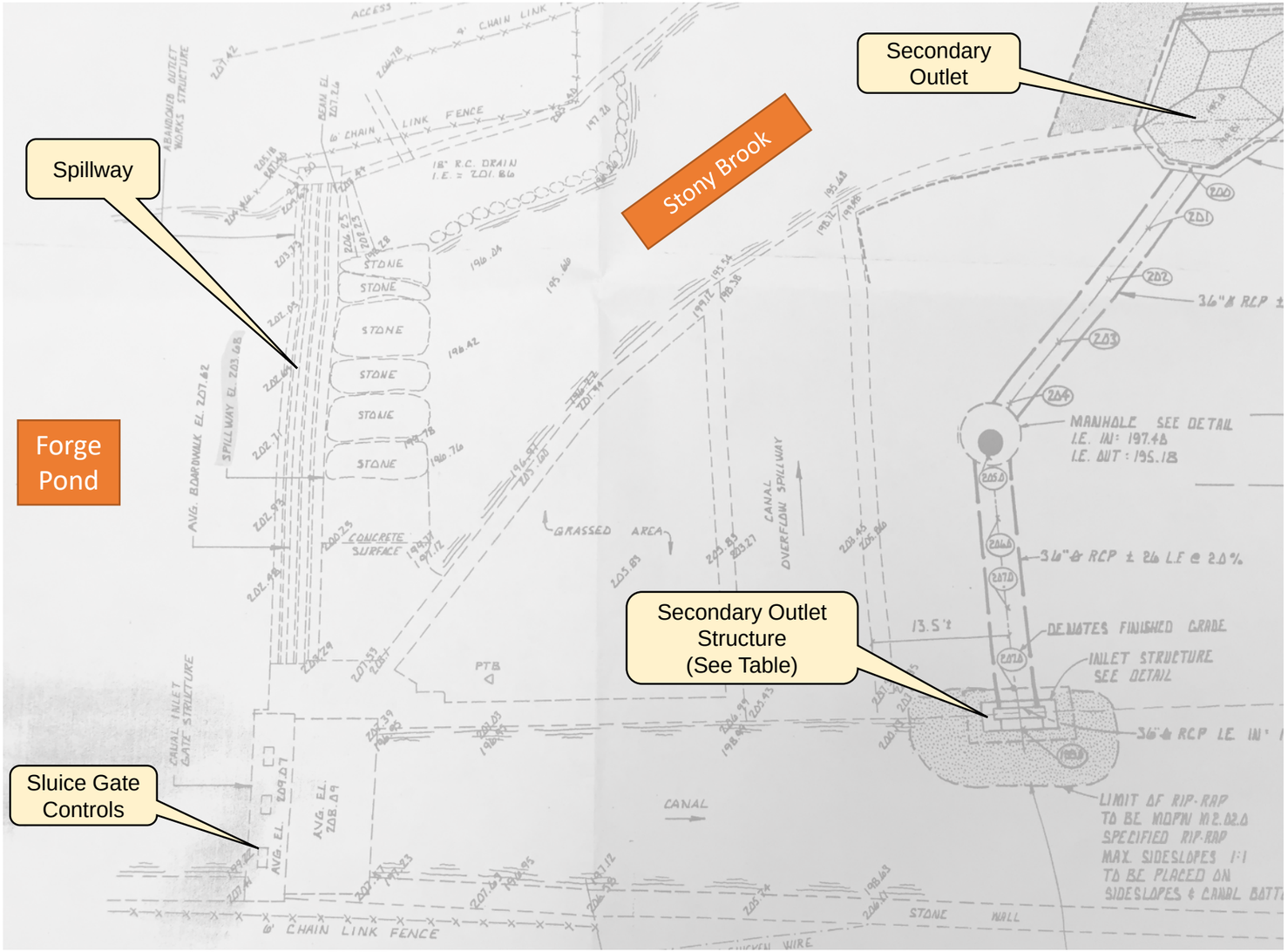
PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: ABBOT MILL DAM (FORGE POND) – WESTFORD, MA

Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

DESIGN BY:	DR	DATE:	4/12/2019
DRAWN BY:	DR	PROJECT NO.:	BW0317
CHECKED BY:	HLO	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	2 OF 3
APPROVED BY:	AMB		



Plan View of Abbot Mill Dam and Secondary Outlet Control Structure

Secondary Outlet Control Structure Configuration

Description	Value
Top Elevation	207.5 (ft, NAVD88)
Invert Elevation	199 (ft, NAVD88)
Overall Height of Stop Log Structure	8.5 (ft)
Stop Log Width	4 (ft)
Top El. of 1st (Bottom) Stop Log (12" Height, perforated with weep holes)	200 (ft, NAVD88)
Top El. of 2nd Stop Log (18" Height)	201.5 (ft, NAVD88)
Top El. of 3rd Stop Log (12" Height)	202.5 (ft, NAVD88)
Top El. of 4th Stop Log (12" Height)	203.5 (ft, NAVD88)
Top El. of 5th Stop Log (12" Height)	204.5 (ft, NAVD88)
Top El. of 6th Stop Log (12" Height)	205.5 (ft, NAVD88)
Top El. of 7th Stop Log (12" Height)	206.5 (ft, NAVD88)
Top El. of 8th Stop Log (12" Height)	207.5 (ft, NAVD88)

Notes:

1. Drawing is not to scale.
2. Plan view from plans entitled “Forge Pond Water Level Control Structure” prepared by Baystate Environmental Consultants, Inc. in August 1991 (1991 Plans).
3. Values from table obtained from 1991 Plans.
4. Low flow releases will be made by removing stop logs from secondary outlet control structure.

SHEET TITLE: OUTLET STRUCTURE CONFIGURATION

PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: ABBOT MILL DAM (FORGE POND) – WESTFORD, MA

Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

DESIGN BY:	DR	DATE:	4/12/2019
DRAWN BY:	DR	PROJECT NO.:	BW0317
CHECKED BY:	HLO	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	
APPROVED BY:	AMB		3 OF 3

LOW FLOW RELEASE NARRATIVE AND CONCEPTUAL DESIGN SCHEMATICS

GREAT ROAD OVER GILSON BROOK
LITTLETON, MA



1. Imagery obtained from MassGIS OLIVER.

LIST OF DRAWINGS

DRAWING NO.	DRAWING TITLE
1	SITE LOCATION AND DRAWING INDEX
2	LOW FLOW RELEASE NARRATIVE
3	PROPOSED EQUIPMENT CONFIGURATION

PREPARED FOR:

LITTLETON LELWD ELECTRIC LIGHT & WATER DEPARTMENTS

TOWN OF WESTFORD INCORPORATED SEPT. 23, 1729

PREPARED BY:

Geosyntec consultants

SHEET TITLE: SITE LOCATION AND DRAWING INDEX

PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: SPECTACLE POND OUTLET – LITTLETON, MA

Geosyntec consultants

NOT FOR CONSTRUCTION

DESIGN BY:	DCR	DATE:	4/2/2019
DRAWN BY:	DCR	PROJECT NO.:	BW0317
CHECKED BY:	HLO	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	1 OF 3
APPROVED BY:	AMB		

Existing Conditions: Spectacle Pond is a 79-acre pond located in Littleton, Massachusetts with an approximate watershed area of 4,416 acres. Spectacle Pond's primary tributary is Bennett's Brook. Spectacle Pond is impounded by a concrete outlet control structure that consists of two stop log-type weirs that discharge to a dual 48-inch culvert under Great Road. Each weir can accept up to five concrete stop logs. Discharge from Spectacle Pond flows via Gilson Brook to Forge Pond, approximately 0.5 miles to the northeast. Existing stop logs can be adjusted by lifting / lowering into place from above the headwall by a backhoe or excavator. Gilson Brook frequently experiences low flows during prolonged dry periods based on anecdotal evidence. For example, the outlet structure was completely dry for an unknown period during the drought of 2016.

Proposed Conditions: Periodic low flow releases are proposed at this location to improve streamflow. Low flow releases will be performed based on alerts from a decision support dashboard in accordance with recommendations from the streamflow restoration plan (SRP) developed by Geosyntec Consultants in June 2018. Once approved, low flow releases will be tested, evaluated for effectiveness, and adjusted based on system response findings.

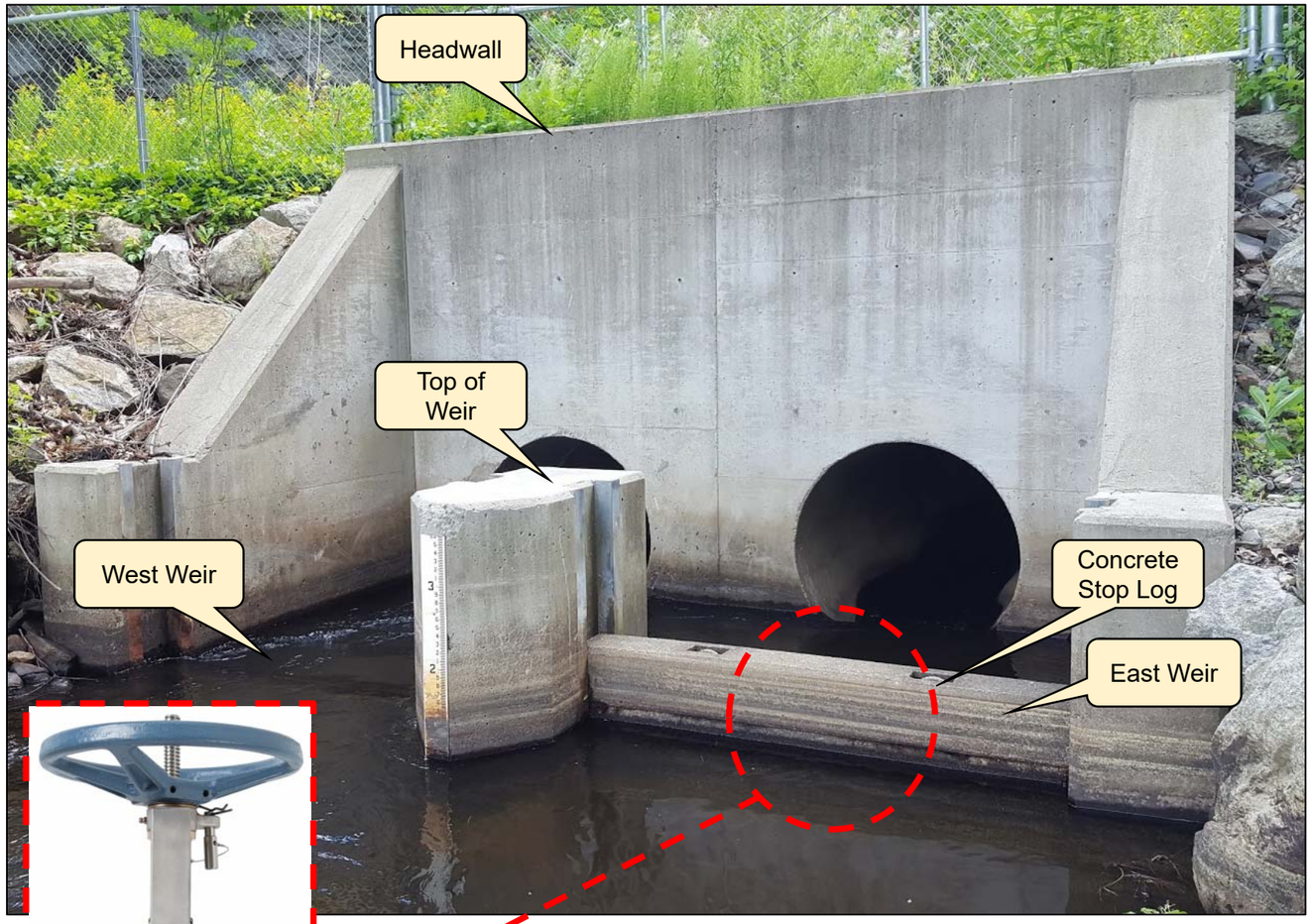
- **Sizing:** Low flow releases will be performed to maintain an Aquatic Baseflow (ABF) of at least 3.5 cubic feet per second. ABF is a simplified set of chemical, physical, and biological conditions that represent limiting conditions for aquatic life and wildlife in stream environments. Model simulations from the SRP indicate that a 12-inch diameter orifice installed at the invert of the existing outlet control weir structure will potentially provide an adequate opening to allow passage of ABF without drawing down Spectacle Pond too rapidly.

- **Configuration**: Low flow releases will be accomplished by fabricating a new stop log with an embedded 12-inch diameter pipe stub. A hand operated full-port lockable knife gate valve will then be attached to the pipe via flanged connection. Installation is not anticipated to have an impact on the existing configuration of the outlet control structure. Elevated discharge from intense and/or large magnitude precipitation events will overflow over the existing east and west weirs as currently configured.

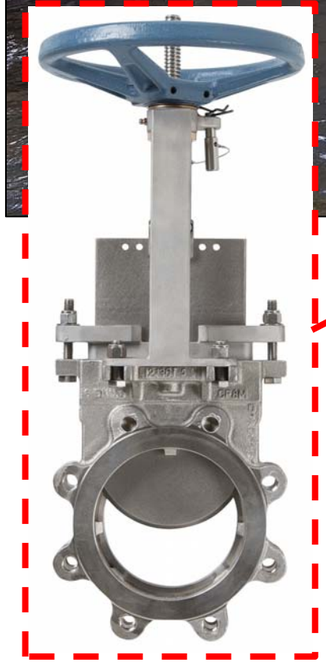
- **Installation Procedures:** The concrete stop log will be installed at the invert of the east weir by lowering it into place from a backhoe or excavator at the top of the headwall structure. Backhoe or excavator must have adequate lifting capacity. The knife gate valve will then be bolted into place via flanged connection by hand tools. No disturbance of the existing resource area is proposed.

- **Operation:** Low flow releases will be initiated and halted by stakeholders based on alerts from a decision support dashboard available at www.opti.com from April-October. Alerts were developed from the 2018 SRP. Alerts will be based on continuous measurements of water level and discharge, and precipitation forecast data. For example, an alert will be issued if there is adequate water level in Spectacle Pond, but discharge is approaching or less than ABF. Knife gate valve will be hand operable. Health and Safety Plan must be developed and implemented by all personnel performing low flow releases.

- **Maintenance:** A trash / debris rack is proposed to be installed at the upstream end of the knife gate valve. The knife gate valve will be configured with a lock to discourage vandalism. Periodic maintenance will be required to clear debris from the outlet control structure, particularly from beaver activity. Maintenance of the valve will be performed in accordance with manufacture instructions.



Existing Outlet Control Structure



Example Knife Gate Valve

SHEET TITLE: LOW FLOW RELEASE NARRATIVE

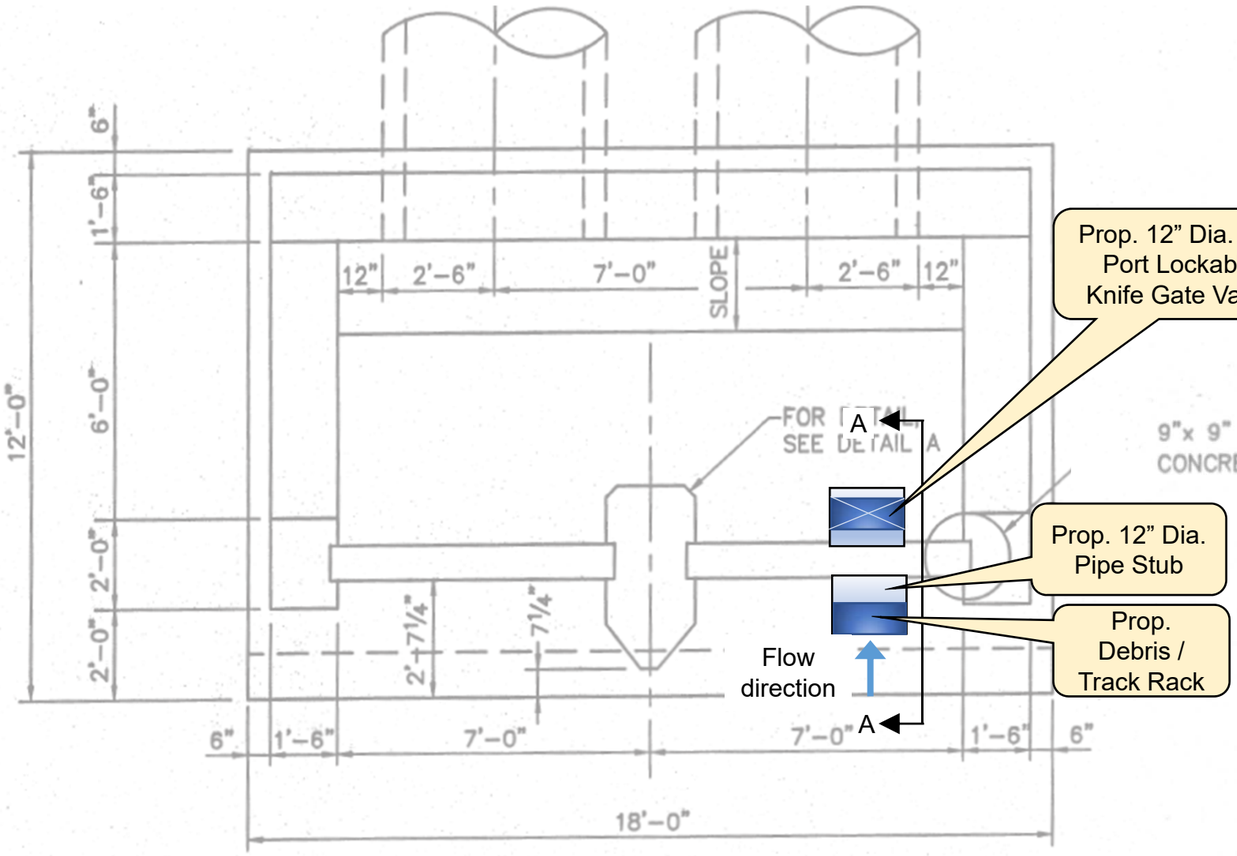
PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: SPECTACLE POND OUTLET – LITTLETON, MA

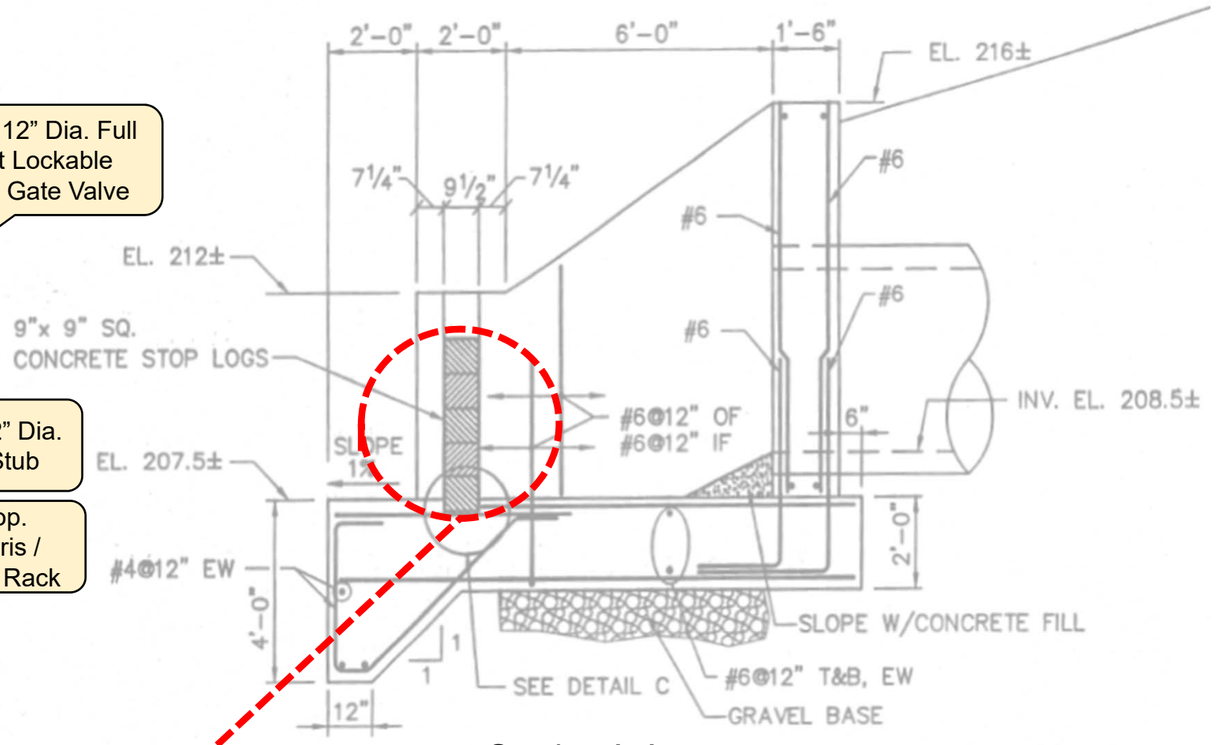
Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

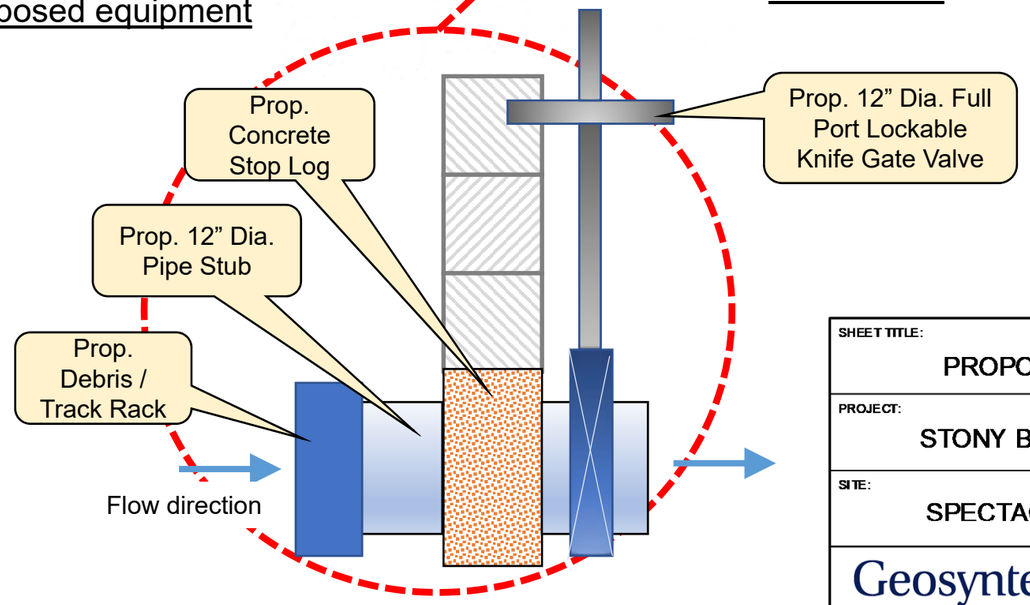
DESIGN BY:	DCR	DATE:	3/29/2019
DRAWN BY:	DCR	PROJECT NO.:	BW0317
CHECKED BY:	HLO	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	2 OF 3
APPROVED BY:	AMB		



Plan view of existing outlet structure with proposed equipment



Section A-A



Stop log and valve assembly close-up

Notes:

1. Drawing is not to scale.
2. Plan and Section details from Plans entitled "Proposed Culvert Rehabilitation" prepared by Fay Spofford and Thorndike for MassDOT in April 2010 (2010 Plans).
3. Precast concrete stop log dimensions shall fit into existing weir structure. Approximate dimensions are 9" wide by 18" tall by 77" long with a ¾" edge chamfer (detail is available from 2010 Plans; dimensions to be verified prior to construction).
4. Precast concrete stop log shall be reinforced with epoxy coated steel rebar and shall include two (2) 6" long by 4" wide by 3" deep pockets and steel rebar lifting device. Pockets and lifting device shall match existing concrete stop log configuration.
5. Pipe stub shall be installed into hole cored into precast concrete and set in place with non-shrink grout. Material of pipe stub shall match selected material of valve body (e.g., PVC vs. DIP)
6. Valve shall be securely affixed to downstream pipe stub via flanged connection. Valve body material must be corrosion resistant and rated for outdoor use.

SHEET TITLE:
PROPOSED EQUIPMENT CONFIGURATION

PROJECT:
STONY BROOK FLOW RESTORATION PROJECT

SITE:
SPECTACLE POND OUTLET – LITTLETON, MA

Geosyntec consultants

NOT FOR CONSTRUCTION

DESIGN BY:	DCR	DATE:	4/2/2019
DRAWN BY:	DCR	PROJECT NO.:	BW0317
CHECKED BY:	HLO	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	3 OF 3
APPROVED BY:	AMB		

LOW FLOW RELEASE NARRATIVE AND CONCEPTUAL DESIGN SCHEMATIC

BROADWAY STREET OVER STONY BROOK DAM
WESTFORD, MA



1. Imagery obtained from MassGIS OLIVER.

LIST OF DRAWINGS

DRAWING NO.	DRAWING TITLE
1	SITE LOCATION AND DRAWING INDEX
2	LOW FLOW RELEASE NARRATIVE
3	PROPOSED EQUIPMENT CONFIGURATION

PREPARED FOR:

LITTLETON LELWD ELECTRIC LIGHT & WATER DEPARTMENTS

TOWN OF WESTFORD INCORPORATED SEPT. 23, 1729

PREPARED BY:

Geosyntec consultants

SHEET TITLE: SITE LOCATION AND DRAWING INDEX

PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: STONY BROOK DAM – WESTFORD, MA

Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

DESIGN BY:	HLO	DATE:	6/13/2019
DRAWN BY:	HLO	PROJECT NO.:	BW0317
CHECKED BY:	AMB	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	1 OF 3
APPROVED BY:	AMB		

Existing Conditions: The Stony Brook Dam impounds an approximate 15-acre waterbody in Westford, Massachusetts with an approximate watershed area of 16,768 acres. The Stony Brook impoundment's primary tributaries are Stony Brook (from Forge Pond) and Boutwell Brook. The dam is comprised of an earthen dam with a stone masonry outlet structure with a primary spillway and low-level outlet with two (2) sluice gates. The sluice gates have not been operated in recent years and their condition is unknown. Discharge from the impoundment flows to Depot Street Dam, approximately two miles to the northeast. Stony Brook frequently experiences low flows downstream of the Stony Brook Dam during prolonged dry periods, based on anecdotal evidence.

Proposed Conditions: Periodic low flow releases are proposed at this location to improve streamflow. Low flow releases will be performed based on alerts from a decision support dashboard in accordance with recommendations from the Stony Brook Streamflow Restoration Plan (SRP) developed by Geosyntec Consultants in June 2018. Once approved, low flow releases will be tested, evaluated for effectiveness, and adjusted based on system response findings.

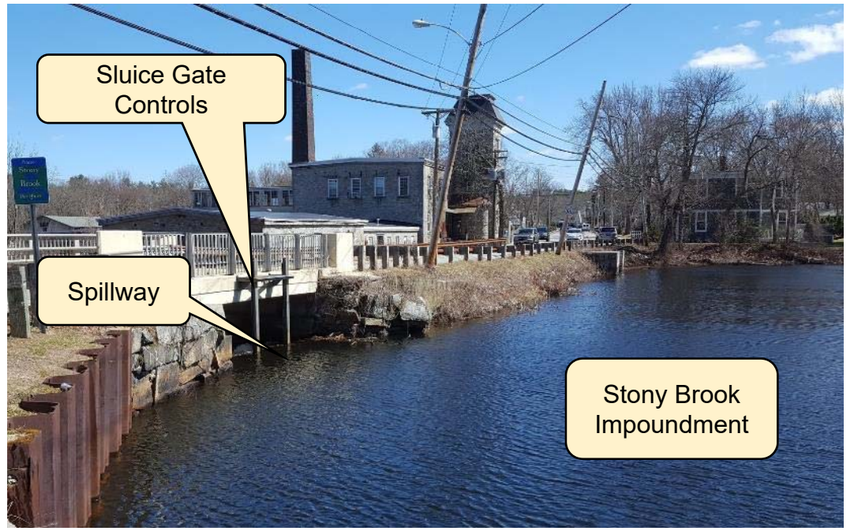
- **Sizing:** Aquatic Baseflow (ABF) is a simplified set of chemical, physical, and biological conditions that represent limiting conditions for aquatic life and wildlife in stream environments. Low flow releases will be performed to maintain an ABF of at least 13.1 cubic feet per second, if construction constraints allow. Sizing calculations (see Sheet 3) indicate that three (3) 8-inch diameter PVC siphons installed at the dam would potentially provide adequate flow to enable passage of ABF; however, it is unknown if the bridge and support structure for Broadway Street would be able to support the three (3) siphons. Sizing calculations indicate that one (1) 8-inch diameter PVC siphon would be adequate to potentially provide flow to maintain the 7-day, 2-year low flow (7Q2) of 4.0 cubic feet per second.

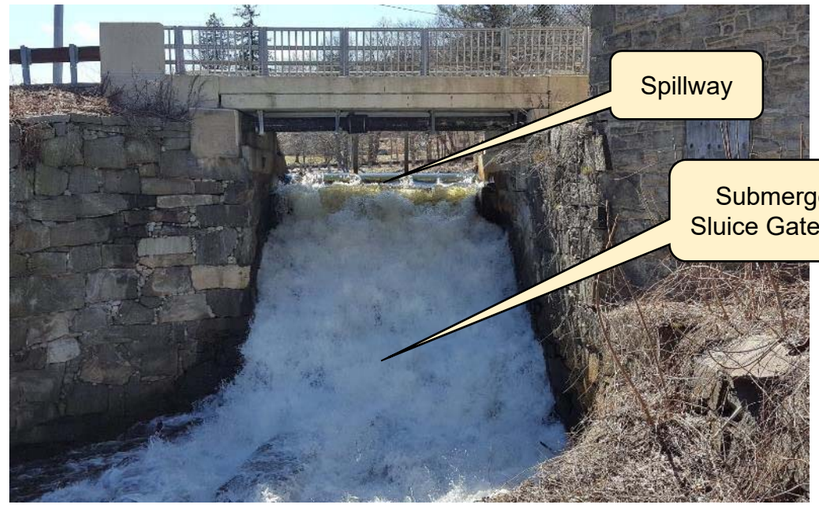
- **Configuration**: Low flow releases will be accomplished by fabricating one (1) to three (3) 8-inch schedule 80 PVC siphons. The perforated intake of each siphon will be configured with a spring-loaded ball check valve to allow water to flow into the siphon(s) but not out. The siphon(s) will feature a priming valve at the apex of the system that can be used to manually prime (i.e., fill with water) the system. A full-port lockable knife gate valve will be installed at the outlet of the siphon(s) to enable priming of the system (e.g., the valve will remain closed while the system is primed and then opened to begin the release). An emergency vent will be installed to stop suction when the system reaches the minimum allowable water level elevation in the impoundment (180.4 ft NAVD88). The intake of the siphon(s) will be installed approximately two (2) feet below the minimum allowable water level in the impoundment, to maintain sufficient pressure head to enable suction at the intake. To achieve the desired flowrate, the invert of the downstream outflow pipe(s) will be installed at least 10.5 feet below the invert elevation of the upstream intake of the siphon(s). Installation is not anticipated to have an impact on the existing dam but will potentially require alteration of the bridge and roadway over the dam. Elevated discharge from intense and/or large magnitude precipitation events will continue to overflow over the existing spillway as currently configured.

- **Installation Procedures:** It is anticipated that the proposed siphon(s) would be anchored to existing supports upstream and downstream of the dam. Installation of the siphon(s) will likely require anchoring to the existing bridge over the dam spillway (Broadway Street). It is anticipated that a bridge inspection will be needed to evaluate if the existing structure will be able to support the proposed siphon(s). Additional inspection of the downstream channel walls may also be required to evaluate support for the downstream outlet pipe. Broadway Street is an active roadway and will likely require a police detail to divert traffic for inspection and installation. Due to constraints and unknown condition of site features, further design and evaluation of installation procedures is recommended.

- **Operation:** Low flow releases will be initiated and halted by stakeholders based on alerts from a decision support dashboard available at www.opti.com. Alerts were developed from the 2018 SRP. Alerts will be based on continuous measurements of water level and discharge, and precipitation forecast data. For example, an alert will be issued if there is adequate water level in the Stony Brook impoundment, but discharge is approaching or less than ABF. The siphon(s) will require manual priming prior to initiating a release. Health and Safety Plan must be developed and implemented by all personnel performing low flow releases.

- **Maintenance:** A trash guard is proposed to be installed at the upstream end of the siphon. The priming valve will be configured with a lock to discourage vandalism. Periodic maintenance may be required to clear debris from the siphon intake. The pipes used for the siphon intake and outlet shall be removeable so that the siphon(s) may be partially disassembled to avoid damage from ice during winter conditions.





Existing Stony Brook Dam Components

SHEET TITLE: LOW FLOW RELEASE NARRATIVE

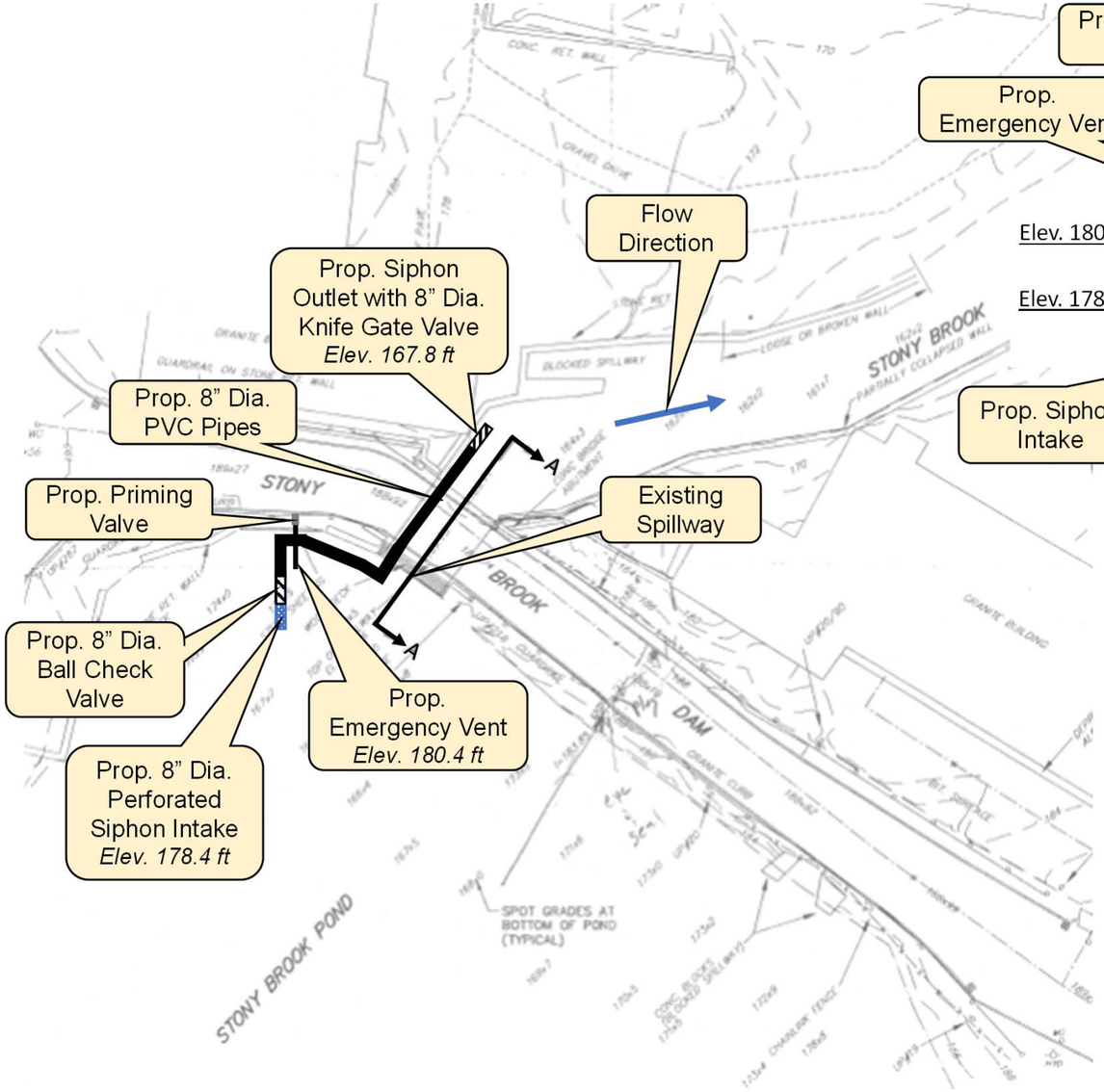
PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: STONY BROOK DAM – WESTFORD, MA

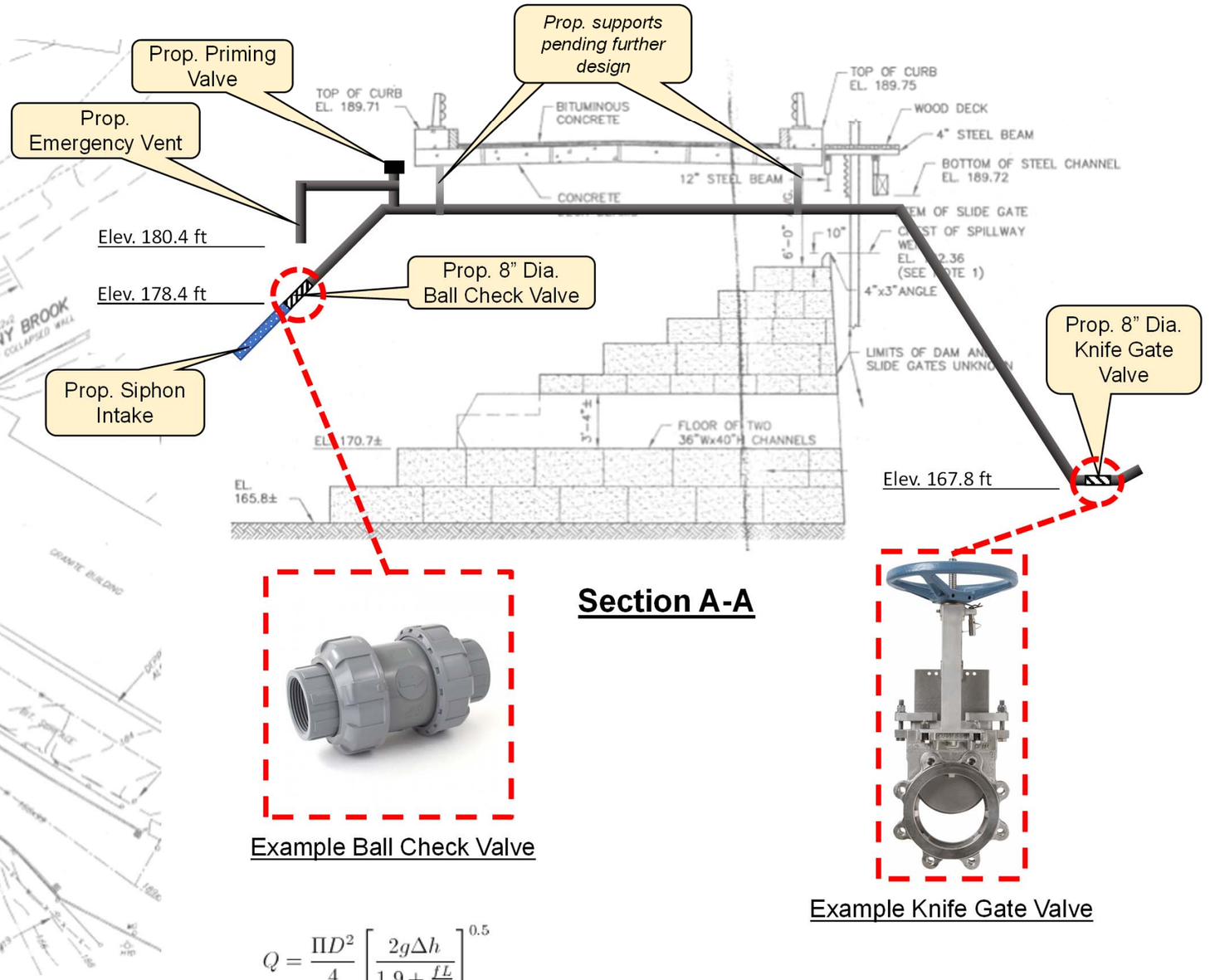
Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

DESIGN BY:	HLO	DATE:	6/13/2019
DRAWN BY:	HLO	PROJECT NO.:	BW0317
CHECKED BY:	AMB	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	2 OF 3
APPROVED BY:	AMB		



Plan View of Stony Brook Dam



Section A-A

Example Ball Check Valve

Example Knife Gate Valve

$$Q = \frac{\Pi D^2}{4}\left[\frac{2g\Delta h}{1.9 + \frac{fL}{D}}\right]^{0.5}$$

Where:
Q – flow rate
D – siphon diameter
g – acceleration due to gravity
Δh – operating head
f – friction loss coefficient
L – siphon length

Siphon Sizing Equation

Notes:
1. Drawings are not to scale.
2. Elevations are in feet NAVD88.
3. Plan and section details from Plans entitled "Stony Brook Dam Plan" prepared by Earth Tech in March 2001 (2001 Plans).
4. Details of conceptual design and installation are subject to change pending further evaluation of site conditions.

SHEET TITLE: PROPOSED EQUIPMENT CONFIGURATION

PROJECT: STONY BROOK FLOW RESTORATION PROJECT

SITE: STONY BROOK DAM – WESTFORD, MA

Geosyntec consultants
289 GREAT ROAD, SUITE 202
ACTON, MA 01720

NOT FOR CONSTRUCTION

DESIGN BY:	HLO	DATE:	6/13/2019
DRAWN BY:	HLO	PROJECT NO.:	BW0317
CHECKED BY:	AMB	FILE:	N/A
REVIEWED BY:	AMB	DRAWING NO.:	3 OF 3
APPROVED BY:	AMB		

Appendix B

Regulatory Approval Documentation

MA WPA Order of Conditions

Littleton Conservation Commission
P.O. Box 1305
37 Shattuck Street
Littleton, MA 01460
Phone: 978 540-2428 FAX: 978 952 2321
E-Mail: agreen@littletonma.org

May 20, 2019

Corey Godfrey
Littleton Water Department
PO Box 1305
Littleton, MA 01460

Re: Order of Conditions for 204-889 at 686 Great Road
Spectacle Pond Outlet

Dear Mr. Godfrey:

On May 20, 2019 the Littleton Conservation Commission voted to issue the attached Order of Conditions for the above referenced project. While you will be responsible for ALL the Conditions, please note especially the following:

The following must be done prior to the start of work:

1. General Conditions (GC) #8: There is a 10-day appeal period from the issuance of the Order of Conditions. If you start work during this time, you are working at your own risk
2. GC #9 and Special Condition Pre-Construction Condition (SC-PC) #1: This Order of Conditions must be registered in the Registry of Deeds, Middlesex South, prior to commencement of any work. As per SC-PC#1, recording information including date, book and page must be submitted to the Littleton Conservation Commission no later than 4 weeks from the date of this Order of Conditions.
3. GC#10: A sign with the MADEP File Number must be displayed prior to work commencing.
4. GC#14 and SC-PC#4: any changes to approved plans shall require the applicant to inquire of the Conservation Commission if the changes are significant enough to require the filing of a new Notice of Intent.
5. SC-C#1 and #10: Contact the Conservation Commission office to review the project before work, other than installation of erosion controls, commences.

You have three years to complete the approved work from the effective date of May 21, 2019, although you may apply for an extension before the Order of Conditions expires. Once work is completed and the site is stabilized, you shall submit a Request for Certificate of Compliance. The original signed version of this Order has been sent to Town Counsel for recording.

Best of luck moving forward. If you need to change your site plan, please call to discuss.

Sincerely,

Amy Green
Conservation Coordinator
Littleton Conservation Commission

Cc: MADEP
T. Harrington, Miyares-Harrington

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands

WPA Form 5 – Order of Conditions

Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP: 204-889
MassDEP File #

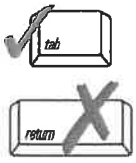
eDEP Transaction #

Littleton
City/Town

A. General Information

Please note: this form has been modified with added space to accommodate the Registry of Deeds Requirements

Important: When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.



1. From: Littleton
Conservation Commission

2. This issuance is for (check one): a. ☒ Order of Conditions b. ☐ Amended Order of Conditions

3. To: Applicant:

Corey — a. First Name
Godfrey — b. Last Name
Littleton Electric Light and Water Departments — c. Organization
39 Ayer Road — d. Mailing Address
Littleton — e. City/Town
MA — f. State
01460 — g. Zip Code

4. Property Owner (if different from applicant):

a. First Name
b. Last Name
Town of Littleton — c. Organization
37 Shattuck Street PO Box 1305 — d. Mailing Address
Littleton — e. City/Town
MA — f. State
01460 — g. Zip Code

5. Project Location:

686 Great Road (outlet to Spectacle Pond) — a. Street Address
Littleton — b. City/Town
R24 — c. Assessors Map/Plat Number
15 and 16 — d. Parcel/Lot Number

Latitude and Longitude, if known: d m s — d. Latitude; d m s — e. Longitude

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP: 204-889 MassDEP File #
eDEP Transaction #
Littleton City/Town

A. General Information (cont.)

6. Property recorded at the Registry of Deeds for (attach additional information if more than one parcel):
   Middlesex South — a. County
   b. Certificate Number (if registered land)
   R24-15 Bk 14615 Pg 0129 — c. Book
   R24-16 Bk 30707 Pg 366 — d. Page

7. Dates: April 30 , 2019 — a. Date Notice of Intent Filed; May 20, 2019 — b. Date Public Hearing Closed; May 21, 2019 — c. Date of Issuance

8. Final Approved Plans and Other Documents (attach additional plan or document references as needed):
   a. Plan Title
   b. Prepared By
   c. Signed and Stamped by
   d. Final Revision Date
   e. Scale
   NOI Package — f. Additional Plan or Document Title
   April 29, 2019 — g. Date

B. Findings

1. Findings pursuant to the Massachusetts Wetlands Protection Act:

   Following the review of the above-referenced Notice of Intent and based on the information provided in this application and presented at the public hearing, this Commission finds that the areas in which work is proposed is significant to the following interests of the Wetlands Protection Act (the Act). Check all that apply:

a. ☒ Public Water Supply
b. ☐ Land Containing Shellfish
c. ☒ Prevention of Pollution
d. ☐ Private Water Supply
e. ☒ Fisheries
f. ☒ Protection of Wildlife Habitat
g. ☒ Groundwater Supply
h. ☒ Storm Damage Prevention
i. ☒ Flood Control

2. This Commission hereby finds the project, as proposed, is: (check one of the following boxes)

Approved subject to:

a. ☒ the following conditions which are necessary in accordance with the performance standards set forth in the wetlands regulations. This Commission orders that all work shall be performed in accordance with the Notice of Intent referenced above, the following General Conditions, and any other special conditions attached to this Order. To the extent that the following conditions modify or differ from the plans, specifications, or other proposals submitted with the Notice of Intent, these conditions shall control.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP: 204-889 MassDEP File #

eDEP Transaction #

Littleton City/Town

B. Findings (cont.)

Denied because:

b. ☐ the proposed work cannot be conditioned to meet the performance standards set forth in the wetland regulations. Therefore, work on this project may not go forward unless and until a new Notice of Intent is submitted which provides measures which are adequate to protect the interests of the Act, and a final Order of Conditions is issued. **A description of the performance standards which the proposed work cannot meet is attached to this Order.**

c. ☐ the information submitted by the applicant is not sufficient to describe the site, the work, or the effect of the work on the interests identified in the Wetlands Protection Act. Therefore, work on this project may not go forward unless and until a revised Notice of Intent is submitted which provides sufficient information and includes measures which are adequate to protect the Act's interests, and a final Order of Conditions is issued. **A description of the specific information which is lacking and why it is necessary is attached to this Order as per 310 CMR 10.05(6)(c).**

3. ☒ Buffer Zone Impacts: Shortest distance between limit of project disturbance and the wetland resource area specified in 310 CMR 10.02(1)(a) — 0 a. linear feet

Inland Resource Area Impacts: Check all that apply below. (For Approvals Only)

Resource Area	Proposed Alteration	Permitted Alteration	Proposed Replacement	Permitted Replacement
4. ☐ Bank	a. linear feet	b. linear feet	c. linear feet	d. linear feet
5. ☐ Bordering Vegetated Wetland	a. square feet	b. square feet	c. square feet	d. square feet
6. ☒ Land Under Waterbodies and Waterways	5.2 (temp) a. square feet	5.2 (temp) b. square feet	na c. square feet	na d. square feet
	e. c/y dredged	f. c/y dredged		
7. ☐ Bordering Land Subject to Flooding	a. square feet	b. square feet	c. square feet	d. square feet
Cubic Feet Flood Storage	e. cubic feet	f. cubic feet	g. cubic feet	h. cubic feet
8. ☐ Isolated Land Subject to Flooding	a. square feet	b. square feet		
Cubic Feet Flood Storage	c. cubic feet	d. cubic feet	e. cubic feet	f. cubic feet
9. ☐ Riverfront Area	a. total sq. feet	b. total sq. feet		
Sq ft within 100 ft	c. square feet	d. square feet	e. square feet	f. square feet
Sq ft between 100-200 ft	g. square feet	h. square feet	i. square feet	j. square feet

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP: 204-889 MassDEP File #

eDEP Transaction #

Littleton City/Town

B. Findings (cont.)

Coastal Resource Area Impacts: Check all that apply below. (For Approvals Only)

	Proposed Alteration	Permitted Alteration	Proposed Replacement	Permitted Replacement
10. ☐ Designated Port Areas	Indicate size under Land Under the Ocean, below			
11. ☐ Land Under the Ocean	a. square feet	b. square feet		
	c. c/y dredged	d. c/y dredged		
12. ☐ Barrier Beaches	Indicate size under Coastal Beaches and/or Coastal Dunes below			
13. ☐ Coastal Beaches	a. square feet	b. square feet	c. nourishment cu yd	d. nourishment cu yd
14. ☐ Coastal Dunes	a. square feet	b. square feet	c. nourishment cu yd	d. nourishment cu yd
15. ☐ Coastal Banks	a. linear feet	b. linear feet		
16. ☐ Rocky Intertidal Shores	a. square feet	b. square feet		
17. ☐ Salt Marshes	a. square feet	b. square feet	c. square feet	d. square feet
18. ☐ Land Under Salt Ponds	a. square feet	b. square feet		
	c. c/y dredged	d. c/y dredged		
19. ☐ Land Containing Shellfish	a. square feet	b. square feet	c. square feet	d. square feet
20. ☐ Fish Runs	Indicate size under Coastal Banks, Inland Bank, Land Under the Ocean, and/or inland Land Under Waterbodies and Waterways, above			
	a. c/y dredged	b. c/y dredged		
21. ☐ Land Subject to Coastal Storm Flowage	a. square feet	b. square feet		
22. ☐ Riverfront Area	a. total sq. feet	b. total sq. feet		
Sq ft within 100 ft	c. square feet	d. square feet	e. square feet	f. square feet
Sq ft between 100-200 ft	g. square feet	h. square feet	i. square feet	j. square feet

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #
Littleton
City/Town

B. Findings (cont.)

* **#23.** If the project is for the purpose of restoring or enhancing a wetland resource area in addition to the square footage that has been entered in Section B.5.c (BVW) or B.17.c (Salt Marsh) above, please enter the additional amount here.

23. ☐ Restoration/Enhancement *:

a. square feet of BVW | b. square feet of salt marsh

24. ☐ Stream Crossing(s):

a. number of new stream crossings | b. number of replacement stream crossings

C. General Conditions Under Massachusetts Wetlands Protection Act

The following conditions are only applicable to Approved projects.

1. Failure to comply with all conditions stated herein, and with all related statutes and other regulatory measures, shall be deemed cause to revoke or modify this Order.
2. The Order does not grant any property rights or any exclusive privileges; it does not authorize any injury to private property or invasion of private rights.
3. This Order does not relieve the permittee or any other person of the necessity of complying with all other applicable federal, state, or local statutes, ordinances, bylaws, or regulations.
4. The work authorized hereunder shall be completed within three years from the date of this Order unless either of the following apply:
   a. The work is a maintenance dredging project as provided for in the Act; or
   b. The time for completion has been extended to a specified date more than three years, but less than five years, from the date of issuance. If this Order is intended to be valid for more than three years, the extension date and the special circumstances warranting the extended time period are set forth as a special condition in this Order.
   c. If the work is for a Test Project, this Order of Conditions shall be valid for no more than one year.
5. This Order may be extended by the issuing authority for one or more periods of up to three years each upon application to the issuing authority at least 30 days prior to the expiration date of the Order. An Order of Conditions for a Test Project may be extended for one additional year only upon written application by the applicant, subject to the provisions of 310 CMR 10.05(11)(f).
6. If this Order constitutes an Amended Order of Conditions, this Amended Order of Conditions does not extend the issuance date of the original Final Order of Conditions and the Order will expire on _____ unless extended in writing by the Department.
7. Any fill used in connection with this project shall be clean fill. Any fill shall contain no trash, refuse, rubbish, or debris, including but not limited to lumber, bricks, plaster, wire, lath, paper, cardboard, pipe, tires, ashes, refrigerators, motor vehicles, or parts of any of the foregoing.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #

Littleton
City/Town

C. General Conditions Under Massachusetts Wetlands Protection Act

8. This Order is not final until all administrative appeal periods from this Order have elapsed, or if such an appeal has been taken, until all proceedings before the Department have been completed.

9. No work shall be undertaken until the Order has become final and then has been recorded in the Registry of Deeds or the Land Court for the district in which the land is located, within the chain of title of the affected property. In the case of recorded land, the Final Order shall also be noted in the Registry's Grantor Index under the name of the owner of the land upon which the proposed work is to be done. In the case of the registered land, the Final Order shall also be noted on the Land Court Certificate of Title of the owner of the land upon which the proposed work is done. The recording information shall be submitted to the Conservation Commission on the form at the end of this Order, which form must be stamped by the Registry of Deeds, prior to the commencement of work.

10. A sign shall be displayed at the site not less then two square feet or more than three square feet in size bearing the words,

"Massachusetts Department of Environmental Protection" [or, "MassDEP"]

"File Number 204-889 "

11. Where the Department of Environmental Protection is requested to issue a Superseding Order, the Conservation Commission shall be a party to all agency proceedings and hearings before MassDEP.

12. Upon completion of the work described herein, the applicant shall submit a Request for Certificate of Compliance (WPA Form 8A) to the Conservation Commission.

13. The work shall conform to the plans and special conditions referenced in this order.

14. Any change to the plans identified in Condition #13 above shall require the applicant to inquire of the Conservation Commission in writing whether the change is significant enough to require the filing of a new Notice of Intent.

15. The Agent or members of the Conservation Commission and the Department of Environmental Protection shall have the right to enter and inspect the area subject to this Order at reasonable hours to evaluate compliance with the conditions stated in this Order, and may require the submittal of any data deemed necessary by the Conservation Commission or Department for that evaluation.

16. This Order of Conditions shall apply to any successor in interest or successor in control of the property subject to this Order and to any contractor or other person performing work conditioned by this Order.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #
Littleton
City/Town

C. General Conditions Under Massachusetts Wetlands Protection Act (cont.)

17. Prior to the start of work, and if the project involves work adjacent to a Bordering Vegetated Wetland, the boundary of the wetland in the vicinity of the proposed work area shall be marked by wooden stakes or flagging. Once in place, the wetland boundary markers shall be maintained until a Certificate of Compliance has been issued by the Conservation Commission.

18. All sedimentation barriers shall be maintained in good repair until all disturbed areas have been fully stabilized with vegetation or other means. At no time shall sediments be deposited in a wetland or water body. During construction, the applicant or his/her designee shall inspect the erosion controls on a daily basis and shall remove accumulated sediments as needed. The applicant shall immediately control any erosion problems that occur at the site and shall also immediately notify the Conservation Commission, which reserves the right to require additional erosion and/or damage prevention controls it may deem necessary. Sedimentation barriers shall serve as the limit of work unless another limit of work line has been approved by this Order.

19. The work associated with this Order (the "Project")
    (1) ☐ is subject to the Massachusetts Stormwater Standards
    (2) ☒ is NOT subject to the Massachusetts Stormwater Standards

    If the work is subject to the Stormwater Standards, then the project is subject to the following conditions:

    a) All work, including site preparation, land disturbance, construction and redevelopment, shall be implemented in accordance with the construction period pollution prevention and erosion and sedimentation control plan and, if applicable, the Stormwater Pollution Prevention Plan required by the National Pollution Discharge Elimination System Construction General Permit as required by Stormwater Condition 8. Construction period erosion, sedimentation and pollution control measures and best management practices (BMPs) shall remain in place until the site is fully stabilized.

    b) No stormwater runoff may be discharged to the post-construction stormwater BMPs unless and until a Registered Professional Engineer provides a Certification that:
    i. all construction period BMPs have been removed or will be removed by a date certain specified in the Certification. For any construction period BMPs intended to be converted to post construction operation for stormwater attenuation, recharge, and/or treatment, the conversion is allowed by the MassDEP Stormwater Handbook BMP specifications and that the BMP has been properly cleaned or prepared for post construction operation, including removal of all construction period sediment trapped in inlet and outlet control structures;
    ii. as-built final construction BMP plans are included, signed and stamped by a Registered Professional Engineer, certifying the site is fully stabilized;
    iii. any illicit discharges to the stormwater management system have been removed, as per the requirements of Stormwater Standard 10;

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #
Littleton
City/Town

C. General Conditions Under Massachusetts Wetlands Protection Act (cont.)

iv. all post-construction stormwater BMPs are installed in accordance with the plans (including all planting plans) approved by the issuing authority, and have been inspected to ensure that they are not damaged and that they are in proper working condition;

v. any vegetation associated with post-construction BMPs is suitably established to withstand erosion.

c) The landowner is responsible for BMP maintenance until the issuing authority is notified that another party has legally assumed responsibility for BMP maintenance. Prior to requesting a Certificate of Compliance, or Partial Certificate of Compliance, the responsible party (defined in General Condition 18(e)) shall execute and submit to the issuing authority an Operation and Maintenance Compliance Statement ("O&M Statement) for the Stormwater BMPs identifying the party responsible for implementing the stormwater BMP Operation and Maintenance Plan ("O&M Plan") and certifying the following:

i.) the O&M Plan is complete and will be implemented upon receipt of the Certificate of Compliance, and

ii.) the future responsible parties shall be notified in writing of their ongoing legal responsibility to operate and maintain the stormwater management BMPs and implement the Stormwater Pollution Prevention Plan.

d) Post-construction pollution prevention and source control shall be implemented in accordance with the long-term pollution prevention plan section of the approved Stormwater Report and, if applicable, the Stormwater Pollution Prevention Plan required by the National Pollution Discharge Elimination System Multi-Sector General Permit.

e) Unless and until another party accepts responsibility, the landowner, or owner of any drainage easement, assumes responsibility for maintaining each BMP. To overcome this presumption, the landowner of the property must submit to the issuing authority a legally binding agreement of record, acceptable to the issuing authority, evidencing that another entity has accepted responsibility for maintaining the BMP, and that the proposed responsible party shall be treated as a permittee for purposes of implementing the requirements of Conditions 18(f) through 18(k) with respect to that BMP. Any failure of the proposed responsible party to implement the requirements of Conditions 18(f) through 18(k) with respect to that BMP shall be a violation of the Order of Conditions or Certificate of Compliance. In the case of stormwater BMPs that are serving more than one lot, the legally binding agreement shall also identify the lots that will be serviced by the stormwater BMPs. A plan and easement deed that grants the responsible party access to perform the required operation and maintenance must be submitted along with the legally binding agreement.

f) The responsible party shall operate and maintain all stormwater BMPs in accordance with the design plans, the O&M Plan, and the requirements of the Massachusetts Stormwater Handbook.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #
Littleton
City/Town

C. General Conditions Under Massachusetts Wetlands Protection Act (cont.)

g) The responsible party shall:
1. Maintain an operation and maintenance log for the last three (3) consecutive calendar years of inspections, repairs, maintenance and/or replacement of the stormwater management system or any part thereof, and disposal (for disposal the log shall indicate the type of material and the disposal location);
2. Make the maintenance log available to MassDEP and the Conservation Commission ("Commission") upon request; and
3. Allow members and agents of the MassDEP and the Commission to enter and inspect the site to evaluate and ensure that the responsible party is in compliance with the requirements for each BMP established in the O&M Plan approved by the issuing authority.

h) All sediment or other contaminants removed from stormwater BMPs shall be disposed of in accordance with all applicable federal, state, and local laws and regulations.

i) Illicit discharges to the stormwater management system as defined in 310 CMR 10.04 are prohibited.

j) The stormwater management system approved in the Order of Conditions shall not be changed without the prior written approval of the issuing authority.

k) Areas designated as qualifying pervious areas for the purpose of the Low Impact Site Design Credit (as defined in the MassDEP Stormwater Handbook, Volume 3, Chapter 1, Low Impact Development Site Design Credits) shall not be altered without the prior written approval of the issuing authority.

l) Access for maintenance, repair, and/or replacement of BMPs shall not be withheld. Any fencing constructed around stormwater BMPs shall include access gates and shall be at least six inches above grade to allow for wildlife passage.

Special Conditions (if you need more space for additional conditions, please attach a text document):
SEE ATTACHED

20. For Test Projects subject to 310 CMR 10.05(11), the applicant shall also implement the monitoring plan and the restoration plan submitted with the Notice of Intent. If the conservation commission or Department determines that the Test Project threatens the public health, safety or the environment, the applicant shall implement the removal plan submitted with the Notice of Intent or modify the project as directed by the conservation commission or the Department.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP: 204-889
MassDEP File #

eDEP Transaction #

Littleton
City/Town

D. Findings Under Municipal Wetlands Bylaw or Ordinance

1. Is a municipal wetlands bylaw or ordinance applicable? ☒ Yes ☐ No

2. The Littleton Conservation Commission hereby finds (check one that applies):

   a. ☐ that the proposed work cannot be conditioned to meet the standards set forth in a municipal ordinance or bylaw, specifically:

   1. Municipal Ordinance or Bylaw | 2. Citation

   Therefore, work on this project may not go forward unless and until a revised Notice of Intent is submitted which provides measures which are adequate to meet these standards, and a final Order of Conditions is issued.

   b. ☒ that the following additional conditions are necessary to comply with a municipal ordinance or bylaw:

   Littleton Wetlands Protection Bylaw | Ch 171
   1. Municipal Ordinance or Bylaw | 2. Citation

3. The Commission orders that all work shall be performed in accordance with the following conditions and with the Notice of Intent referenced above. To the extent that the following conditions modify or differ from the plans, specifications, or other proposals submitted with the Notice of Intent, the conditions shall control.

   The special conditions relating to municipal ordinance or bylaw are as follows (if you need more space for additional conditions, attach a text document):

   SEE ATTACHED

Littleton Conservation Commission

MA Wetlands Protection Act and ByLaw Special Order of Conditions

DEP File #204-889
Owner/Applicant: Littleton Electric Light and Water Department
Project Title/Address: 686 Great Road (Spectacle Pond Outlet)

Findings: This Order of Conditions is for installation of new stop logs at the Spectacle Pond outlet and empirical flow testing in support of the Stony Brook Flow Restoration project. The MA Division of Fish and Wildlife found **on May 3, 2019** that the proposed project will not result in a prohibited Take of state-listed rare species if the required timing of the flow testing is adhered to.

Findings Under the Littleton Wetlands Protection Bylaw Regulations:

The Commission found, pursuant to Section 1.4 of its Wetlands Protection Regulations, that a waiver of the minimum 50-foot No Disturbance Area (NDA) was in the public interest, consistent with the intent and purpose of the Wetlands Protection Bylaw, and the least environmentally damaging practicable alternative (LEDPA). This is due to the significant public interest in restoring base flows along Stony Brook to enhance environmental conditions.

PRE-CONSTRUCTION CONDITIONS

PC-1. Pursuant to General Condition #9, the Order of Conditions must be registered in the Registry of Deeds, Middlesex South prior to commencement of work. The Littleton Conservation Commission (LCC) hereby orders that it be recorded in the registry and notice filed with the LCC no later than four (4) weeks from the date of this Order of Conditions. Failure to comply with this condition may be deemed cause to revoke this Order of Conditions.

PC-2. This Order of Conditions shall apply to any successor in interest or successor in control of the property. In the event that this property should change in ownership before or during construction or before a Certificate of Compliance is issued, any successor in interest or successor in control of this property shall meet with the LCC before construction shall begin or continue.

PC-3. In conjunction with the sale of the property or any subdivision of the property governed by this Order of Conditions before a Certificate of Compliance is issued the Applicant shall submit to the LCC a signed statement by the buyer that he/she is aware of an outstanding Order or Conditions on the development and has received a copy of this Order of Conditions.

PC-4. Any change or changes made or intended to be made, in the plans shall require the Applicant to file a new Notice of Intent, or to inquire of the LCC in writing whether the change or changes are substantial enough to require a new filing.

PC-5. Members and agents of the LCC shall have the right to enter and inspect the premises at any time and without notice to evaluate compliance with the Order of Conditions, and the LCC may require the submittal of any data necessary for the LCC to evaluate compliance.

PC-6. This document shall be included in all construction contracts and sub-contracts dealing with the work proposed and shall supersede any conflicting contract requirements.

PC-7. This document and approved plans shall be kept available on site at all times in a watertight enclosure.

PC-8. The Applicant/Owner is responsible for ensuring that all persons performing the permitted activities are fully aware of the terms and conditions of this Order.

PC-9. Prior to construction the general contractor shall designate a construction staging area, located outside all resource areas and buffer zones. All construction trailers, portable sanitary facilities, material storage and overnight parking of equipment shall be in the staging area. The perimeter of the staging area shall be protected as necessary with silt fence and the ground surface shall be protected with washed stone or another suitable non-erosive material.

PC-10. An area for cleanup and or maintenance of construction equipment shall be designated prior to construction. Any runoff resulting from the washing of trucks or construction equipment (include cement trucks) shall neither be directed to, nor dumped in, any on-site drainage system or in any area subject to protection under the Massachusetts Wetlands Protection Act. Any such washing shall occur in a designated area, protected by washed stone, outside of all resource areas and buffer zones. All construction vehicles exiting the property shall be cleaned of soil prior to traveling on public streets within the Town of Littleton.

PC-11. Prior to commencing any work the Applicant shall provide LCC with a list of all chemicals, pesticides, herbicides, fertilizers, fuels and other potentially hazardous materials anticipated to be used or stored on the premises. This list shall be updated prior to new subcontractors being allowed to store or use potentially hazardous materials on site. The method and location of storage shall be clearly described and shown on a site plan. The Applicant must immediately notify the LCC, Littleton Fire Department, and Mass DEP, when any spill of fuel, oil or hazardous waste occurs.

CONSTRUCTION CONDITIONS

C-1. The Commission will be notified one week prior to construction to allow for a pre-construction meeting. The following people shall, at a minimum, be present: Conservation Coordinator, the Applicant or their representative, the Contractor, and the individual responsible for erosion control monitoring. The purpose of the pre-construction meeting shall be to review the Order of Conditions, inspect erosion controls, discuss erosion control monitoring and collect the names and numbers of individuals responsible for the daily activities and erosion control at the site.

C-2. During construction, the owner shall identify a person who shall be available either in person or by phone (office, cell or home); this number is to be given to the LCC (or agent) who has the authority to direct the contractor to take measures of erosion and sedimentation control, to receive comments from the LCC or its agent, and cease work.

C-3. The LCC and/or its agent(s) have the authority to inform the owners or their representatives of violations of the erosion and sediment control measures of this Order. Upon such notification the owners shall take immediate action to correct the violation.

C-4. Used petroleum products from the maintenance of construction equipment and any construction debris shall be collected and disposed of off-site in a proper and prompt manner. The construction site shall be maintained in a clean condition.

C-5. No portable toilets, fuel, oil, trash, dumpsters or other possible pollutants/contaminants shall be stored in any resource area or buffer zone, unless specified on the plans for the Order of Conditions. Dumpsters shall be covered.

C-6. No overnight parking or storage of construction vehicles is allowed in resource areas or buffer zones unless specified on the plans for the Order of Conditions. No fueling of construction vehicles is allowed in resource areas or buffer zones.

C-7. During construction, dust control (if required) shall be limited to water; no salts or other wetting agents shall be used.

C-8. Any leakage or spillage of oil, hydraulic fluid, gasoline, or other pollutants must be cleaned up immediately and disposed of off the site. All fueling of equipment shall be performed outside of wetland resource areas and buffer zones. The LCC, Littleton Fire Department, Littleton Water Department and MA Department of Environmental Protection shall be notified immediately in the event of any spillage.

C-9. Appropriate erosion and sediment control measures shall be taken. These measures include but are not limited to:

a) Once begun, the grading and construction shall move uninterrupted to completion to avoid erosion and siltation of the wetlands. If it becomes necessary to delay completion of the project, temporary measures to stabilize sensitive areas are required.

b) As soon as possible during construction all disturbed areas shall be brought to final grade and stabilized with permanent vegetative cover.

c) Storm drainage systems and detention basins shall be constructed during the initial phase of the project so that they may be functional during construction.

d) The Applicant shall have on hand at the start of any soil disturbance removal or stockpiling a sufficient number of hay bales, wattles, silt fence and stakes for the control of emergency erosion problems. These emergency siltation and sediment control devices shall not be used for the normal control of erosion.

e) If at any time sediment accumulates more than halfway up any portion of the erosion/sedimentation controls, it shall be immediately removed. The erosion/sedimentation controls may not be removed until all sedimentation is removed and area stabilized.

f) Appropriate sedimentation and erosion controls shall be placed around any existing outlet which is to be removed before such removal may commence.

g) Erosion controls shall be installed before any work may begin.

C-10. After the erosion control measures are installed the Applicant or their contractor shall contact the LCC so that the LCC or its agent can inspect and approve the measures before any other activity takes place on the site within a resource area or the Buffer Zone.

C-11. Sedimentation barriers shall serve as the limit of work unless another limit of work line has been approved by this Order of Conditions. Construction equipment is prohibited beyond installed siltation barrier.

C-12. Erosion control methods shall consist of hay bales, 12-inch wattles and/or silt fencing, alone or in combination, as authorized by the LCC. After the erosion control measures are installed the Applicant or their contractor shall contact the LCC so that the LCC or its agent can inspect and approve the measures before any other activity takes place on the site within a resource area or the Buffer Zone. To minimize

wildlife entanglement and plastic debris pollution, choose temporary erosion and sediment control products that either do not contain netting, or that contain netting manufactured from 100% biodegradable non-plastic materials such as jute, sisal, or coir fiber. [Degradable, photodegradable, UV degradable, oxo-degradable, or oxo-biodegradable plastic netting (including polypropylene, nylon, polyethylene, and polyester) are not acceptable alternatives.] Netting used in these products should have a loose-weave wildlife-safe design with movable joints between the horizontal and vertical twines, allowing the twines to move independently and thus reducing the potential for wildlife entanglement. Avoid the use of silt fence reinforced with metal or plastic mesh. When no longer required, temporary erosion and sediment controls should be promptly removed.

C-13. If unforeseen problems occur during construction which may affect the statutory interests of the Wetlands Protection Act regulations or the Littleton Wetlands Protection Bylaw and regulations, the LCC shall immediately be notified and an immediate meeting held between the LCC, the Applicant and/or the representatives, and other concerned parties to determine the correct measures employed to resolve the issue. The Applicant shall then act to correct the problems using the measures agreed upon. Subsequent to resolution, the Applicant shall document the actions in writing to the LCC.

C-14. Any damage caused as a direct result of this project to any wetland resource areas, except as permitted by this Order of Conditions, shall be the responsibility of the Applicant to repair, restore and/or replace. Sedimentation or erosion into resource areas shall be considered an alteration of that resource area. If such damage occurs, the LCC shall be notified immediately and a plan for abatement and mitigation of the problem shall be submitted for approval and implementation.

C-15. Two (2) sets of 'as-built' plans for the project, drawn by a registered engineer or architect if the Notice of Intent plans were similarly prepared by a registered professional engineer, shall be submitted to the LCC at the same time as a written request for a Certificate of Compliance (WPA Form 8A) and shall specify in detail how the completed plan differs from that shown on the plans referred to in the Order of Conditions.

MASSWILDLIFE

DIVISION OF
FISHERIES & WILDLIFE

1 Rabbit Hill Road, Westborough, MA 01581
p: (508) 389-6300 | f: (508) 389-7890
MASS.GOV/MASSWILDLIFE

May 03, 2019

Cory Godfrey
Littleton Electric Light and Water Departments
39 Ayer Road
Littleton, MA 01460

Mark Warren
Westford Water Department
60 forge Village Road
Westford, MA 01886

RE:	Applicant:	Cory Godfrey, Littleton Electric Light and Water Departments Mark Warren, Westford Water Department
	Project Location:	Spectacle Pond, Littleton; Forge Pond, Westford
	Project Description:	Stony Brook Watershed Restoration Project: Empirical Testing
	NHESP File No.:	**19-38594**

Dear Applicants:

The Natural Heritage & Endangered Species Program of the Massachusetts Division of Fisheries & Wildlife (the "Division") received the MESA Project Review Checklists, Project Plans and other required materials for review pursuant to the Massachusetts Endangered Species Act (MESA) (MGL c.131A) and its implementing regulations (321 CMR 10.00).

The MESA is administered by the Division, and prohibits the Take of state-listed species. The Take of state-listed species is defined as "in reference to animals...harm...kill...disrupt the nesting, breeding, feeding or migratory activity...and in reference to plants...collect, pick, kill, transplant, cut or process...Disruption of nesting, breeding, feeding, or migratory activity may result from, but is not limited to, the modification, degradation, or destruction of Habitat" of state-listed species (321 CMR 10.02).

The Division has determined that this Project, as currently proposed, will occur **within** the actual habitat of the Blanding's Turtle (*Emydoidea blandingii*), a species state-listed as Threatened. This species and its habitats are protected in accordance with the MESA.

Based on the information provided and the information contained in our database, the Division finds that a portion of this project, as currently proposed, **must be conditioned** in order to avoid a prohibited Take of state-listed species (321 CMR 10.18(2)(a)). To avoid a prohibited Take of state-listed species, the following conditions must be met:

- All empirical testing must occur during the Blanding's turtle active season (April 16th – October 14th). No work shall occur following October 14th.

Provided the above-noted condition is fully implemented and there are no changes to the project plans, this project will not result in a Take of state-listed species. We note that all work is subject to the anti-segmentation provisions (321 CMR 10.16) of the MESA. This determination is a final decision of the Division of Fisheries and Wildlife pursuant to 321 CMR 10.18. Any changes to the proposed project or any additional work beyond that shown on the site plans may require an additional filing with the Division pursuant to the MESA. This project may be subject to further review if no physical work is commenced within five years from the date of issuance of this determination, or if there is a change to the project.

The Division notes that any future projects or activities proposed on the property which are (a) located outside of the approved limit of work shown on the site plan, (b) not exempt from review pursuant to 321 CMR 10.14, and (c) located within mapped Priority Habitat as indicated in the Massachusetts Natural Heritage Atlas, will require review by the Division pursuant to MESA. Furthermore, 321 CMR 10.16 provides that projects shall not be segmented or phased to evade or defer the review requirements under MESA. If the Division determines, based on the considerations provided for in 321 CMR 10.16, that a future project or activity proposed on the property is part of a larger common project or scheme, it may evaluate the cumulative impacts of the existing and proposed segments of the common project when reviewing the future proposed project or activity pursuant to MESA.

Please note that this determination addresses only the matter of state-listed species and their habitats. If you have any questions regarding this letter please contact David Paulson, Senior Endangered Species Review Biologist, at (508) 389-6366.

Sincerely,

Jonathan V. Regosin, Ph.D.
Deputy Director

cc: Hayley O'Grady, Geosyntec Consultants, Inc.
Chris Yule, Yule Development
Town of Littleton

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #
Littleton
City/Town

E. Signatures

This Order is valid for three years, unless otherwise specified as a special condition pursuant to General Conditions #4, from the date of issuance.

5-21-2019
1. Date of Issuance

Please indicate the number of members who will sign this form.
This Order must be signed by a majority of the Conservation Commission.

6
2. Number of Signers

The Order must be mailed by certified mail (return receipt requested) or hand delivered to the applicant. A copy also must be mailed or hand delivered at the same time to the appropriate Department of Environmental Protection Regional Office, if not filing electronically, and the property owner, if different from applicant.

Signatures:

James H Pickard
Sarah Seaward
[signature]

[signature]
[signature]

☒ by hand delivery on
5-21-2019
Date

☐ by certified mail, return receipt requested, on
Date

F. Appeals

The applicant, the owner, any person aggrieved by this Order, any owner of land abutting the land subject to this Order, or any ten residents of the city or town in which such land is located, are hereby notified of their right to request the appropriate MassDEP Regional Office to issue a Superseding Order of Conditions. The request must be made by certified mail or hand delivery to the Department, with the appropriate filing fee and a completed Request for Departmental Action Fee Transmittal Form, as provided in 310 CMR 10.03(7) within ten business days from the date of issuance of this Order. A copy of the request shall at the same time be sent by certified mail or hand delivery to the Conservation Commission and to the applicant, if he/she is not the appellant.

Any appellants seeking to appeal the Department's Superseding Order associated with this appeal will be required to demonstrate prior participation in the review of this project. Previous participation in the permit proceeding means the submission of written information to the Conservation Commission prior to the close of the public hearing, requesting a Superseding Order, or providing written information to the Department prior to issuance of a Superseding Order.

The request shall state clearly and concisely the objections to the Order which is being appealed and how the Order does not contribute to the protection of the interests identified in the Massachusetts Wetlands Protection Act (M.G.L. c. 131, § 40), and is inconsistent with the wetlands regulations (310 CMR 10.00). To the extent that the Order is based on a municipal ordinance or bylaw, and not on the Massachusetts Wetlands Protection Act or regulations, the Department has no appellate jurisdiction.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 5 – Order of Conditions
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40
Littleton Wetlands Protection Act

Provided by MassDEP:
204-889
MassDEP File #

eDEP Transaction #
Littleton
City/Town

G. Recording Information

Prior to commencement of work, this Order of Conditions must be recorded in the Registry of Deeds or the Land Court for the district in which the land is located, within the chain of title of the affected property. In the case of recorded land, the Final Order shall also be noted in the Registry's Grantor Index under the name of the owner of the land subject to the Order. In the case of registered land, this Order shall also be noted on the Land Court Certificate of Title of the owner of the land subject to the Order of Conditions. The recording information on this page shall be submitted to the Conservation Commission listed below.

Conservation Commission

Detach on dotted line, have stamped by the Registry of Deeds and submit to the Conservation Commission.

To:

Conservation Commission

Please be advised that the Order of Conditions for the Project at:

Project Location | MassDEP File Number

Has been recorded at the Registry of Deeds of:

County | Book | Page

for: Property Owner

and has been noted in the chain of title of the affected property in:

Book | Page

In accordance with the Order of Conditions issued on:

Date

If recorded land, the instrument number identifying this transaction is:

Instrument Number

If registered land, the document number identifying this transaction is:

Document Number

Signature of Applicant

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands

Request for Departmental Action Fee Transmittal Form

Massachusetts Wetlands Protection Act M.G.L. c. 131, §40

DEP File Number:

Provided by DEP

A. Request Information

1. Location of Project

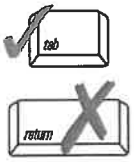
a. Street Address

b. City/Town, Zip

c. Check number

d. Fee amount

Important: When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.



2. Person or party making request (if appropriate, name the citizen group's representative):

Name

Mailing Address

City/Town

State

Zip Code

Phone Number

Fax Number (if applicable)

3. Applicant (as shown on Determination of Applicability (Form 2), Order of Resource Area Delineation (Form 4B), Order of Conditions (Form 5), Restoration Order of Conditions (Form 5A), or Notice of Non-Significance (Form 6)):

Name

Mailing Address

City/Town

State

Zip Code

Phone Number

Fax Number (if applicable)

4. DEP File Number:

B. Instructions

1. When the Departmental action request is for (check one):

☐ Superseding Order of Conditions – Fee: $120.00 (single family house projects) or $245 (all other projects)

☐ Superseding Determination of Applicability – Fee: $120

☐ Superseding Order of Resource Area Delineation – Fee: $120

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands

Request for Departmental Action Fee Transmittal Form

Massachusetts Wetlands Protection Act M.G.L. c. 131, §40

DEP File Number:

Provided by DEP

B. Instructions (cont.)

Send this form and check or money order, payable to the *Commonwealth of Massachusetts,* to:

Department of Environmental Protection
Box 4062
Boston, MA 02211

2. On a separate sheet attached to this form, state clearly and concisely the objections to the Determination or Order which is being appealed. To the extent that the Determination or Order is based on a municipal bylaw, and not on the Massachusetts Wetlands Protection Act or regulations, the Department has no appellate jurisdiction.

3. Send a **copy** of this form and a **copy** of the check or money order with the Request for a Superseding Determination or Order by certified mail or hand delivery to the appropriate DEP Regional Office (see http://www.mass.gov/eea/agencies/massdep/about/contacts/).

4. A copy of the request shall at the same time be sent by certified mail or hand delivery to the Conservation Commission and to the applicant, if he/she is not the appellant.

NHESP MESA Determination

MASSWILDLIFE

DIVISION OF
FISHERIES & WILDLIFE

1 Rabbit Hill Road, Westborough, MA 01581
p: (508) 389-6300 | f: (508) 389-7890
MASS.GOV/MASSWILDLIFE

May 03, 2019

Cory Godfrey
Littleton Electric Light and Water Departments
39 Ayer Road
Littleton, MA 01460

Mark Warren
Westford Water Department
60 forge Village Road
Westford, MA 01886

RE:	Applicant:	Cory Godfrey, Littleton Electric Light and Water Departments Mark Warren, Westford Water Department
	Project Location:	Spectacle Pond, Littleton; Forge Pond, Westford
	Project Description:	Stony Brook Watershed Restoration Project: Empirical Testing
	NHESP File No.:	**19-38594**

Dear Applicants:

The Natural Heritage & Endangered Species Program of the Massachusetts Division of Fisheries & Wildlife (the "Division") received the MESA Project Review Checklists, Project Plans and other required materials for review pursuant to the Massachusetts Endangered Species Act (MESA) (MGL c.131A) and its implementing regulations (321 CMR 10.00).

The MESA is administered by the Division, and prohibits the Take of state-listed species. The Take of state-listed species is defined as "in reference to animals…harm…kill…disrupt the nesting, breeding, feeding or migratory activity…and in reference to plants…collect, pick, kill, transplant, cut or process…Disruption of nesting, breeding, feeding, or migratory activity may result from, but is not limited to, the modification, degradation, or destruction of Habitat" of state-listed species (321 CMR 10.02).

The Division has determined that this Project, as currently proposed, will occur **within** the actual habitat of the Blanding's Turtle (*Emydoidea blandingii*), a species state-listed as Threatened. This species and its habitats are protected in accordance with the MESA.

Based on the information provided and the information contained in our database, the Division finds that a portion of this project, as currently proposed, **must be conditioned** in order to avoid a prohibited Take of state-listed species (321 CMR 10.18(2)(a)). To avoid a prohibited Take of state-listed species, the following conditions must be met:

- All empirical testing must occur during the Blanding's turtle active season (April 16th – October 14th). No work shall occur following October 14th.

Provided the above-noted condition is fully implemented and there are no changes to the project plans, this project will not result in a Take of state-listed species. We note that all work is subject to the anti-segmentation provisions (321 CMR 10.16) of the MESA. This determination is a final decision of the Division of Fisheries and Wildlife pursuant to 321 CMR 10.18. Any changes to the proposed project or any additional work beyond that shown on the site plans may require an additional filing with the Division pursuant to the MESA. This project may be subject to further review if no physical work is commenced within five years from the date of issuance of this determination, or if there is a change to the project.

The Division notes that any future projects or activities proposed on the property which are (a) located outside of the approved limit of work shown on the site plan, (b) not exempt from review pursuant to 321 CMR 10.14, and (c) located within mapped Priority Habitat as indicated in the Massachusetts Natural Heritage Atlas, will require review by the Division pursuant to MESA. Furthermore, 321 CMR 10.16 provides that projects shall not be segmented or phased to evade or defer the review requirements under MESA. If the Division determines, based on the considerations provided for in 321 CMR 10.16, that a future project or activity proposed on the property is part of a larger common project or scheme, it may evaluate the cumulative impacts of the existing and proposed segments of the common project when reviewing the future proposed project or activity pursuant to MESA.

Please note that this determination addresses only the matter of state-listed species and their habitats. If you have any questions regarding this letter please contact David Paulson, Senior Endangered Species Review Biologist, at (508) 389-6366.

Sincerely,

Jonathan V. Regosin, Ph.D.
Deputy Director

cc: Hayley O'Grady, Geosyntec Consultants, Inc.
Chris Yule, Yule Development
Town of Littleton

Chapter 91 Minor Project Modification Authorization

MassDEP
Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

One Winter Street Boston, MA 02108 • 617-292-5500

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Kathleen A. Theoharides
Secretary

Martin Suuberg
Commissioner

June 17, 2019

Littleton Electric Light and Water Departments
c/o Hayley O'Grady, Geosyntec Consultants
289 Great Road, Suite 202
Acton, Massachusetts 01720

Re: Request for a Minor Project Modification Pursuant to 310 CMR 9.05(3)(c)
Stony Brook Flow Restoration Project, Spectacle Pond, Littleton, Middlesex County

Dear Ms. O'Grady:

The Massachusetts Department of Environmental Protection Waterways Regulation Program (the "Department") received your letter on behalf of Littleton Electric Light and Water Departments dated May 16, 2019, received by the Department on on May 17, 2019, requesting authorization to conduct maintenance activities within Chapter 91 jurisdiction pursuant to the regulations at 310 CMR 9.05(3)(c) and 310 CMR 9.22. The submittal included:

- A letter in support of the request for a Minor Project Modification dated May 16, 2019;
- Figures 1-2;
- Low Flow Release Narrative and Conceptual Equipment Schematic Sheets 1-3;
- Stony Brook Final Streamflow Restoration Plan.

As described in your letter and depicted on the plan, the proposed scope of work will include the following activities:

- Remove existing stop logs as needed, install a new concrete stop log within the existing stop log structure, and secure the knife gate valve in place.

A review of the Department's Waterways records did not identify any licensing history for the subject outlet structure. Based on a review of the scope of work and use of the structures as specified above, the Department has determined that the project meets 310 CMR 9.05(3)(c), "continuation of any existing, unauthorized public service project, provided that no unauthorized structural alteration or change in use has occurred subsequent to January 1, 1984, unless the

Department determines, upon notice and opportunity for public comment, that licensing is essential to prevent significant harm to an overriding water-related public interest", and is therefore authorized in accordance with the regulations at 310 CMR 9.22(3).

The Department will retain this correspondence approving the proposed work along with the referenced submittal in our records. The work must conform to and be consistent with all submitted documentation. This Departmental action does not relieve or exempt you of the requirement to obtain all other applicable local, State and Federal authorizations necessary to perform said activities.

Should you have any further questions concerning this matter please contact Chrissy Hopps at Christine.Hopps@mass.gov or (617) 348-4084. Thank you.

Sincerely,

Ben Lynch
Section Chief
Waterways Regulation Program

cc: Corey Godfrey, Littleton Electric Light and Water Departments (via email)
Littleton Conservation Commission

Appendix C

Stream Gaging Protocol

Stony Brook Flow Restoration Project

Stream Gaging Field Protocol

Prepared for

Littleton Electric Light and Water Department
39 Ayer Road
Littleton, MA 01460

Westford Water Department
60 Forge Village Road
Westford, MA 01886

Massachusetts Department of Fish and Game, Division of Ecological Restoration
251 Causeway Street, Suite 400
Boston, MA 02114

Prepared by

Geosyntec Consultants, Inc.
1330 Beacon Street, Suite 317
Brookline, MA 02446

Project Number: BW0317

April 2019

TABLE OF CONTENTS

1. PURPOSE AND SCOPE....1

2. STREAMFLOW MEASUREMENT PROTOCOL....1
   2.1 Equipment....1
   2.2 Streamflow Discharge Measurement and Calculation Procedure....2

3. REFERENCES....7

LIST OF FIGURES

Figure 1: Stream Gaging Locations

Figure 2: Stream Gaging Site Location – Mill Pond

Figure 3: Stream Gaging Site Location – Spectacle Pond

Figure 4: Stream Gaging Site Location – Forge Pond

Figure 5: Stream Gaging Site Location – Stony Brook

Figure 6: Typical Stream Gaging Cross-Section

LIST OF ATTACHMENTS

Attachment A: Stream Gaging Field Form

Attachment B: FlowTracker Technical Manual

Attachment C: FlowTracker2 Technical Manual

Attachment D: HACH FH950 Technical Manual

Attachment E: Task Hazard Analysis (THA)

ACRONYMS AND ABBREVIATIONS

ADV	Acoustic Doppler Velocimeter
DEP	Department of Environmental Protection
DER	Division of Ecological Restoration
DFG	Department of Fish and Game
EPA	Environmental Protection Agency
LWD	Littleton Water Department
QA/QC	Quality Assurance/Quality Control
RMN	Regional Monitoring Network
THA	Task Hazard Analysis
USGS	United States Geological Survey
WWD	Westford Water Department

1. PURPOSE AND SCOPE

This Stream Gaging Field Protocol was prepared to document the project-specific protocols to be used by all parties conducting stream gaging in support of the Stony Brook Flow Restoration Project, funded through a Massachusetts Department of Environmental Protection (DEP) Water Management Act (WMA) grant. It is expected that as part of this project, staff from Geosyntec Consultants, Inc. (Geosyntec), Littleton Water Department (LWD), Westford Water Department (WWD), and the Massachusetts Department of Fish and Game, Division of Ecological Restoration (DER) [the Project Team] will all conduct stream gaging activities to support project tasks. Therefore, this document will support consistency across the Project Team's activities.

Four continuous water level monitoring stations, with In-Situ Inc. Level Troll 500 data loggers, were installed upstream or just downstream of the outlets of Mill Pond, Forge Pond, Spectacle Pond, and Stony Brook Dam during previous project phases (WWD et al., 2018). Stage-discharge rating curves were developed at these locations to estimate streamflow discharge based on measured depths but were not field-validated due to schedule constraints. Stream gaging will be performed downstream of all four monitoring locations using a handheld velocity meter at established cross-sections. The existing rating curves will be validated using the stream gaging measurements collected during at least ten (10)[1] flow measurement events conducted during a variety of flow conditions (i.e., low to high), as feasible.

This protocol is based on stream gaging guidance provided in the *US Environmental Protection Agency Best Practices for Continuous Monitoring of Temperature and Flow in Wadable Streams Guidance Document* (US EPA, 2014), *United States Geological Survey (USGS) Discharge measurements at gaging stations* (Turnipseed and Sauer, 2010), *USGS Measurement and computation of streamflow: Measurement of stage and discharge* (Rantz et al., 1982), and past project experience. See Figure 1 for all proposed stream gaging locations and Figures 2 through 5 for specific details on each site's parking areas, accessibility, and the proposed stream gaging cross-section locations.

2. STREAMFLOW MEASUREMENT PROTOCOL

Streamflow is calculated by summing discharge measurements at several segments within each cross-section of a stream. Streamflow will be measured during at least ten (10) flow events at each monitoring location to observe changes in discharge under varying conditions. This section describes the necessary equipment and procedure for measuring streamflow.

2.1 Equipment

The basic equipment for measuring streamflow includes:

[1] As part of this WMA grant funded project, the Project Team will only collect three to five stream gaging measurements. The Project Team will continue to collect measurements following project completion as part of ongoing project priorities and a subsequent DER Priority Project planned for the future.

- **Field form and writing utensil** to record field data (Attachment A);
- **Velocity meter** to measure point velocity and calculate discharge. An Acoustic Doppler Velocity meter, specifically a FlowTracker or FlowTracker2 manufactured by SonTek/YSI Inc., or a HACH FH950 handheld flow meter (or prior approved equivalent), will be used to measure discharge for this project;
- **Velocity meter technical manual** to review data collection procedures and to troubleshoot potential issues while in the field (Attachments B, C, and D);
- **Wading rod** to measure the wetted depth and to set the velocity meter at the appropriate depth;
- **Measuring tape and stakes** to define the cross-section and to determine the intervals along the cross-section where channel depth and velocity will be measured;
- **Camera** to record site conditions;
- **Spare batteries** for velocity meters (e.g., 8 AA for FlowTracker); and
- **Field clothing** such as waders, waterproof boots, and appropriate clothing to wear when working near or in streams.

These lists do not include Health and Safety equipment. A Task Hazard Analysis (THA) is included as Attachment E for Geosyntec staff, outlining equipment, procedures, and protocol to promote a safe environment during these field activities. It is expected that LWD, WWD, and DER will separately develop safety procedures and protocols for their personnel.

2.2 Streamflow Discharge Measurement and Calculation Procedure

The steps described below should be followed in order to measure and calculate streamflow discharge. Each of these steps will be completed at each of the four monitoring locations downstream of where existing water level sensors are currently installed. The locations have been selected according to accessibility and channel definition (see Figure 1). Figure 6 depicts the layout of a channel cross-section for obtaining discharge data, using the velocity-area procedure and collected velocity and depth measurements (Geosyntec, 2014).

1. **Prepare for field visit**
    - Notify (via email) applicable site owners(s) and Project Team of planned stream gaging event (Table 1);

Table 1: Site Owner and Project Team Contact Information

Name	Organization	E-Mail	Project Team	Site Contact (location)
Mark Warren	WWD	mwarren@westfordma.gov	Yes	Stony Brook
Corey Godfrey	LWD	cgodfrey@lelwd.com	Yes	Spectacle Pond, Mill Pond
Michelle Craddock	DER	michelle.craddock@mass.gov	Yes	-
Kate Bentsen	DER	kate.bentsen@mass.gov	Yes	-
Andrea Braga	Geosyntec	abraga@geosyntec.com	Yes	-
Adam Questad	Geosyntec	aquestad@geosyntec.com	Yes	-
Christopher Yule	Abbott Mill	chris@yuledevelopment.com	-	Forge Pond

- Order and gather required equipment (see Section 2.1):
  - Confirm Flowtracker or Flowtracker2 is available for use or rent replacement meter (Hach FH950 handheld flow meter) from US Environmental in Waltham, MA (781-899-1560); and
  - Load preliminary information into meter (e.g., operator, stream name).
- Review Health and Safety procedures and this protocol for site accessibility information.

2. **Select site for discharge measurement**

- At each site, use the Stream Gaging Site Location figures (Figures 2 through 5) to identify the proposed cross-section measurement location. During the first stream gaging event, the proposed locations will be reviewed with respect to their accessibility and/or whether modifying the location will meet more of the following ideal cross-section characteristics:
  - Be a relatively straight stream channel without undercut banks, with defined edges and with a fairly uniform shape;
  - Contain limited vegetation, large cobbles, and boulders;
  - Not have eddies, slack water, or turbulence;
  - Be greater than 0.5 feet deep and have velocities greater than 0.5 feet per second;
  - Have similar flow conditions to those at the gaging station; and
  - Not have tributaries, drain pipes, or other influent or effluent water streams between the cross-section and the gaging station.

- Minor alterations such as removing excessive vegetation or large rocks may improve cross-section quality. These changes must be made prior to starting measurement collection.

3. **Record gage height and/or depth of water adjacent to upstream monitoring location before start of discharge measurement**

4. **Establish the cross-section and reference bank**

   - Once a location is selected, extend a measuring tape across the stream perpendicular to the direction of flow. Anchor the tape at both banks with stakes. Leave tape in place for the duration of the discharge measurement Record the total length and GPS coordinates of each bank on the field form.

   - Anchor stakes sufficiently and leave them in-place between stream gaging measurement events so that the same location can be easily identified during subsequent events.

   - Establish one side of the bank as the reference bank so that all distance measurements will originate from this point. Record the reference bank on the field form.

5. **Divide cross-section into subsections**

   - Divide the total channel width so that a minimum of 20 increments are identified. Each incremental subsection should have no more than 5% of the total discharge.

     - If velocities are higher, depths are greater, or there are more channel irregularities in specific sections, the increments should be closer together.

     - If velocities are lower and depths are shallower, increments can be spaced farther apart.

6. **Collect distance, depth, and velocity measurements for each subsection**

   - Ensure no one is standing upstream during measurements, as this will affect flow readings.

   - Record distance on measuring tape to nearest 0.01 ft.

   - Record wetted depth to nearest 0.01 ft using wading rod.

- Adjust sensor on wading rod based on wetted depth. For water depths less than 1.5 ft, adjust sensor to measure velocity at 0.6-depth.[2] For water depths greater than 1.5 ft[3], velocities should be measured using the two-point method at 0.2-depth and 0.8-depth at each increment.[4]

- Position the tip of the sensor into direction of flow.

    - Measure velocity for 40 seconds. Ensure the ADV is level and held perpendicular to the measuring tape for the duration of the measurement.

- Review velocity measurements. If any subsections have more than 5% total discharge, insert additional velocity measurements before completing discharge profile.[5]

7. **Calculate discharge for the cross-section**

    - Once the distance, depth, and velocity measurements have been collected for each subsection along a cross-section, the ADV will compute the total discharge for the cross-section using the area-velocity discharge measurement method.[6]

    - The discharge may also be calculated manually as the product of the velocity measurement times the channel depth at the vertical times the sum of half the distances to adjacent verticals. This calculation should be completed in the office after field measurements are completed.

8. **Perform quality assurance/quality control (QA/QC)**

    - Collect repeat discharge measurements

        - Complete the methods outlined in Steps 6–7 above to collect and record an additional set of velocity measurements at the established cross-section.

        - If possible, the QA/QC measurement should be performed by different field personnel from the original measurement. The repeat measurement can be made concurrently with the original measurement if there are sufficient personnel and equipment.

---

[2] Fractional and actual measurement depths are shown on the FlowTracker display. Actual measurement depths reference from the bottom up (e.g., 0.23 feet above the channel bottom). Fractional measurement depths reference from the surface down (e.g., 0.6-depth from the surface).
[3] The two-point method applies to FlowTracker ADV and pygmy meters in depths greater than 1.5 ft; for other meters, the two-point method applies in depths greater than 2.5 ft.
[4] The two-point method averages the velocities measured at 0.2-depth and 0.8-depth.
[5] The FlowTracker and FlowTracker2 both compute the percent discharge within each section, such that additional velocity measurements may be added to maintain less than 5% total discharge within each section.
[6] This method calculates the discharge in each segment as the product of the segment area and the mean velocity in that segment; the total discharge in the stream is the summation of the discharge in each segment along a cross-section.

- Compare the original and QA/QC measurements
    - If the total discharge between the two measurements differs by more than 10%, collect an additional discharge measurement. The additional discharge measurement should be made at a different cross-section within the same gaging reach for comparison.

9. **Record gage height and/or depth of water adjacent to upstream monitoring location at end of discharge measurements**
    - If gage height differs by more than 0.1 ft between start and end of discharge measurements, collect an additional discharge measurement.

10. **Complete field form**
    - Record the following information on the field form:
        - Date and weather conditions (e.g., temperature, precipitation, cloud cover);
        - Velocity meter used;
        - Measurement start and end times;
        - Gage height and/or depth of water adjacent to upstream monitoring location at beginning and end of discharge measurements;
        - Description of the cross-section location and characteristics;
        - Notes on any observed changes (e.g., high water marks, debris) since last sampling event that may impact the rating curve or streamflow; and
        - Left and Right bank GPS coordinates.

3. REFERENCES

Geosyntec Consultants. 2014. Surface Water Monitoring Plan, *Ten Mile Creek Watershed: Pulte Homes Properties, Clarksburg, Maryland*.

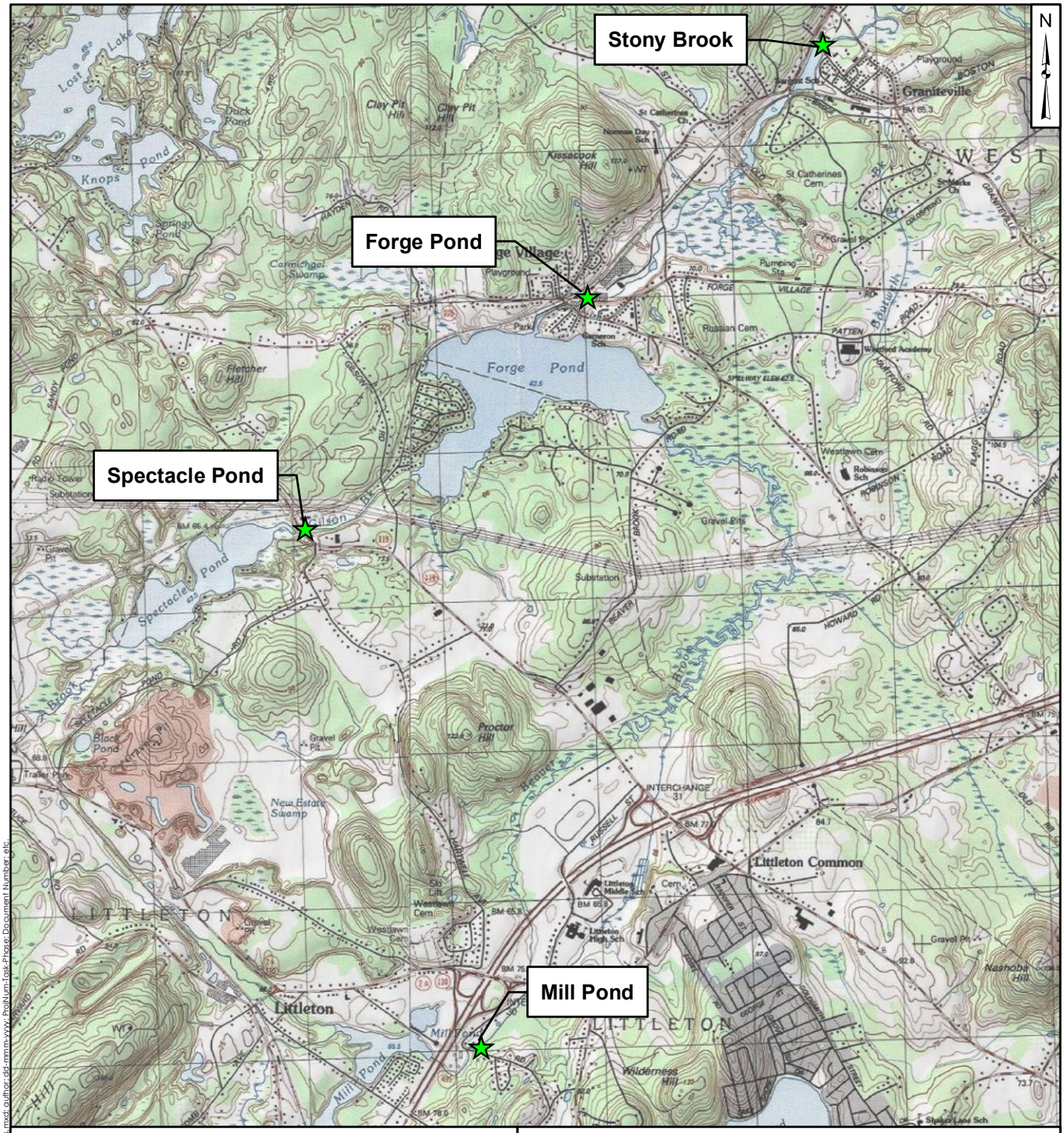
Rantz, S.E. et al. 1982. Measurement and computation of streamflow: Measurement of stage and discharge. U.S. Geological Survey Water-Supply Paper 2175, volume 1, 313pp. Available online: https://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_vol1.html

Turnipseed, D.P. and Sauer, V.B. 2010. Discharge measurements at gaging stations. U.S. Geological Survey Techniques and Methods book 3, chapter A8, 87pp. Available online: https://pubs.usgs.gov/tm/tm3-a8/

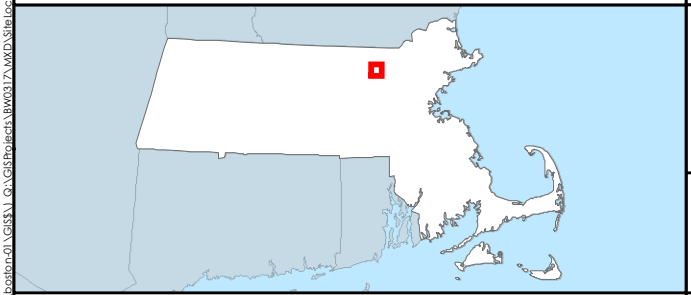
U.S. Environmental Protection Agency (EPA). 2014. Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R-13/170F.

Westford Water Department (WWD), Littleton Water Department (LWD), and Geosyntec Consultants. 2018. Stony Brook Flow Restoration Project. 2018 Water Management Act Grant Program. Final Streamflow Restoration Plan. June.

FIGURES



Legend



Stream Gaging Locations

Littleton and Westford, Massachusetts

Geosyntec consultants

Figure 1

USGS topographic map 1:25,000-scale Quadrangle for Littleton, MA

Acton, MA | April 2019

(Q:\ = \\boston01\GIS$\) Q:\GISProjects\MW0317.MXD\SiteLocus_CrossSections.mxd: author; dd-mmm-yyyy; ProjNum-Task-Phase; Document Number; etc.



Legend

- Approximate Location of Cross-Section
- Approximate Path from Parking to Cross-Section
- Parking Location

Notes:
Parking is located at 89-131 Mill Road Latitude 42.535207, Longitude -71.494060

N

0 60 Feet



Stream Gaging Site Location - Mill Pond

Mill Pond
Littleton, Massachusetts

Geosyntec consultants

Acton, MA | April 2019

Figure 2

Q:\GISProjects\BW0317\MXD\MillPond_SiteAccessibility.mxd 4/16/2019 4:23:36 PM



Legend

- Approximate Location of Cross-Section
- Approximate Path from Parking to Cross-Section
- Parking Location

N

Notes:
Parking is located at Latitude 42.566393, Longitude -71.508666

0 60 Feet

Stream Gaging Site Location - Spectacle Pond

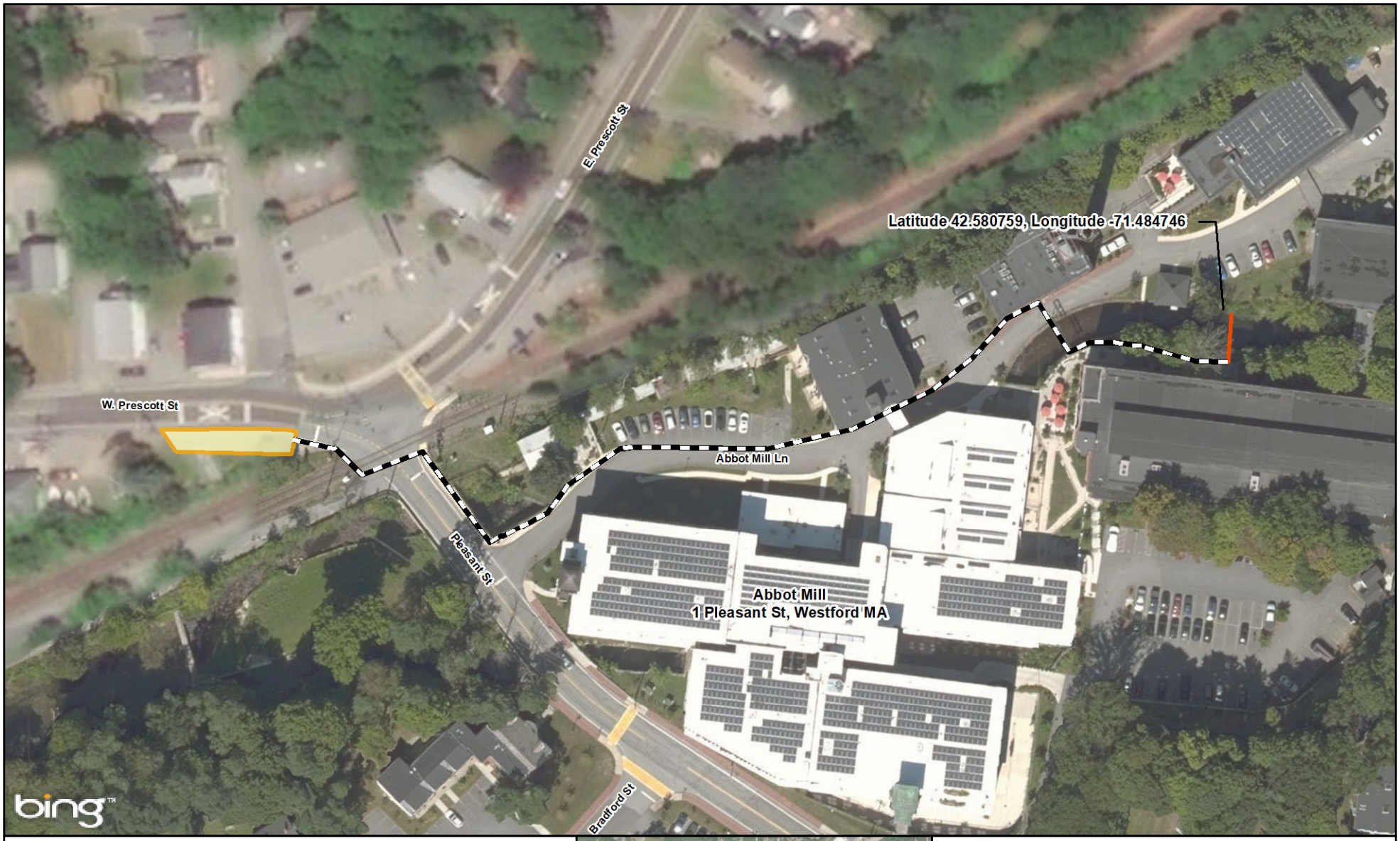
Spectacle Pond
Littleton, Massachusetts

Geosyntec consultants

Acton, MA | April 2019

Figure 3

Q:\GISProjects\BW0317\MXD\SpectaclePond_SiteAccessibility.mxd 4/19/2019 2:02:08 PM



Legend

- Approximate Location of Cross-Section
- Approximate Path from Parking to Cross-Section
- Parking Location

N

0 100 Feet

Notes:
Parking is located at Latitude 42.580465, Longitude -71.487484



Stream Gaging Site Location - Forge Pond

Forge Pond
Westford, Massachusetts

Geosyntec consultants

Acton, MA | April 2019

Figure 4

Q:\GISProjects\BW0317\MXD\ForgePond_SiteAccessibility.mxd 4/16/2019 4:16:28 PM



Legend

- Approximate Location of Cross-Section
- Approximate Path from Parking to Cross-Section
- Parking Location

Notes:
Parking is located at Latitude 42.596788, Longitude -71.465855

N

0 100 Feet



Stream Gaging Site Location - Stony Brook

Stony Brook
Westford, Massachusetts

Geosyntec consultants

Acton, MA | April 2019

Figure 5

Q:\GISProjects\BW0317\MXD\StonyBrook_SiteAccessibility.mxd 4/17/2019 10:03:06 AM

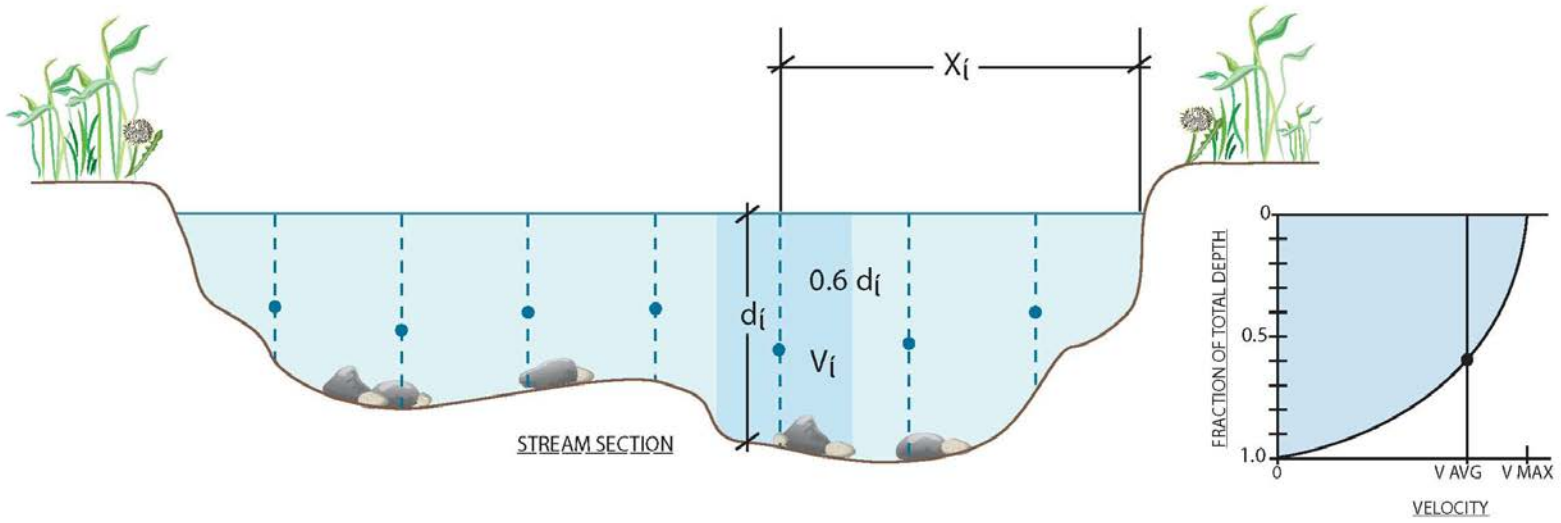


Figure 6. Typical Stream Gaging Cross-Section[7]

[7] Variables: x indicates distance from reference bank, d indicates depth of channel, v indicates velocity.

ATTACHMENT A
Stream Gaging Field Form

Stony Brook Streamflow Restoration Project

Stream Gaging Field Form

Site:		Date:		
Personnel:				
Weather:				
Start Time:		Finish Time:		
Left bank GPS Coordinates:		Right bank GPS Coordinates:		
Velocity meter used		Photos taken?		Y / N
Reference bank location:	Left / Right	Cross section length:		ft
Upstream gage measurement (beginning)	ft	Upstream gage measurement (end)		ft

Subsection	Distance from Reference Bank (ft)	Subsection Width (ft)	Channel Depth (ft)	Velocity Measurement Depth(s) (ft)	Velocity (ft/s)	Notes
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						
34						
35						
Total Flow (cfs):						

cfs = cubic feet per second
ft = feet
ft/s = feet per second

Stony Brook Streamflow Restoration Project

Stream Gaging Field Form

Site:		Date:		
Personnel:				
Weather:				
Start Time:		Finish Time:		
Left bank GPS Coordinates:		Right bank GPS Coordinates:		
Velocity meter used		Photos taken?		Y / N
Reference bank location:	Left / Right	Cross section length:		ft
Upstream gage measurement (beginning)	ft	Upstream gage measurement (end)		ft

Subsection	Distance from Reference Bank (ft)	Subsection Width (ft)	Channel Depth (ft)	Velocity Measurement Depth(s) (ft)	Velocity (ft/s)	Notes
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						
34						
35						
Total Flow (cfs):						

cfs = cubic feet per second
ft = feet
ft/s = feet per second

Cross Section Sketch	
Notes (cross section characteristics, potential impacts to rating curve or streamflow):	

ATTACHMENT B
FlowTracker Technical Manual

SonTek/YSI Inc.
9940 Summers Ridge Road, San Diego, CA 92121-3091 USA
Telephone (858) 546-8327 • Fax (858) 546-8150
E-mail: inquiry@sontek.com • Internet: http://www.sontek.com



YSI *incorporated*

FlowTracker®
Handheld ADV®
Technical Manual
Firmware Version 3.3
Software Version 2.20

featuring



Copyright 2007 by SonTek/YSI Inc. All rights reserved. This document may not, in whole or in part, be copied, photocopied, reproduced, translated, or reduced to any electronic medium or Machine-readable form without prior consent in writing from SonTek. Every effort has been made to ensure the accuracy of this manual. However, SonTek makes no warranties with respect to this documentation and disclaims any implied warranties of merchantability and fitness for a particular purpose. SonTek shall not be liable for any errors or for incidental or consequential damages in connection with the furnishing, performance, or use of this manual or the examples herein. The information in this document is subject to change without notice.

P/N 6054-60050--C

RECORD OF CHANGES

Effective	Description
31 AUG 2006	Initial release of Technical Manual after splitting old Operator's Manual into new Technical Manual and new Users Manual; CPU firmware version 3.0
15 NOV 2006	Support for CPU firmware version 3.1 and software version 2.10 added
05 JUL 2007	Support for CPU firmware version 3.3 and software version 2.20 added

Declaration of Conformity

Manufacturer's Name: SonTek/YSI Inc.
Manufacturer's Address: 9940 Summers Ridge Road
San Diego, CA 92121 U.S.A.

Sontek/YSI declares that the product(s):

Equipment Type: Water Velocity Measurement Device

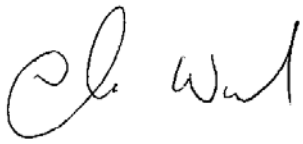
Model: ADV Series

Product Name: Standard ADV 10MHz, Triton ADV 10MHz, Arg ADV 10MHz, ADV 6600 10MHz, FlowTracker 10MHz, ADV Ocean 5MHz, ADV Field 16MHz.

Conforms to the following European Union Council Directives and Standards as of 7/21/04:

EMC DIRECTIVE 89/336/EEC:
-EN 61326 (1997), A1 (1998), A2 (2001), Class "A"
-EN 61000-3-2 (2000)
-EN 61000-3-3 (1995)
-IEC 61000-4-2 (1995), A1 (1998), A2 (2000)
-IEC 61000-4-3 (2002), A1 (2002)
-IEC 61000-4-4 (1995), A1 (2000), A2 (2001)
-IEC 61000-4-5 (1995), A1 (2001)
-IEC 61000-4-6 (1996), A1 (2000)
-IEC 61000-4-11 (2001)

Director of Sales and Marketing,



Chris Ward

Release Notice

This is the July 2007 release of the *FlowTracker Handheld ADV Technical Manual*. During the creation of this manual, the following were the latest available versions of firmware/software. As such, if you are using different firmware/software versions, not all aspects of this manual may apply.

- FlowTracker firmware version 3.3
- *FlowTracker* software version 2.20

Trademarks

The terms SonTek, ADP, ADV, Argonaut, FlowTracker, RiverSurveyor, and SmartQC are registered trademarks of SonTek/YSI, Inc. All rights are reserved. All other brand names are trademarks of their respective holders.

Warranty, Terms, and Conditions

The system you have purchased is covered under a one year limited warranty that extends to all parts and labor for any malfunction due to workmanship or errors in the manufacturing process. The warranty does not cover shortcomings that are due to the design, nor does it cover any form of incidental damage as a result of errors in the measurements.

If your system is not functioning properly, first try to identify the source of the problem. If additional support is required, we encourage you to contact us immediately, and we will work to resolve the problem as quickly as possible.

If the system needs to be returned to the factory, please contact SonTek/YSI to obtain a Return Merchandise Authorization (RMA) number. We reserve the right to refuse receipt of shipments without RMAs. We require the system to be shipped back in the original shipping container using the original packing material with all delivery costs covered by the customer (including all taxes and duties). If the system is returned without appropriate packing, the customer will be required to cover the cost of a new packaging crate and material.

Contact Information

Any questions, concerns, or suggestions can be directed to SonTek by telephone, fax, or email. Business hours are 8:00 a.m. to 5:00 p.m., Pacific Standard Time, Monday through Friday.

Phone : (858) 546-8327

Fax : (858) 546-8150

Email : inquiry@sontek.com (General information)

sales@sontek.com (Sales information)

support@sontek.com (Support information)

Web : http://www.sontek.com

See our web site for information concerning new products and software/firmware upgrades.

INTRODUCTION

The FlowTracker® Handheld ADV® (Acoustic Doppler Velocimeter) featuring SmartQC™ provides the proven velocity performance of the SonTek ADV from a simple handheld interface. The FlowTracker is designed for a variety of current monitoring applications.

- River discharge measurements (using established USGS/ISO methods)
- Open-channel flow measurements
- Current measurements in large pipes
- Rapid, multi-point current surveys
- Current monitoring in water treatment facilities

Basic operation of the FlowTracker is described below.

- The FlowTracker is operated from a simple keypad interface, with instructions and real-time data displayed on an LCD screen. No PC is required for data collection.
- The system collects data for a fixed length of time at each location.
- For each location, you enter a few parameters to document the data set (e.g., location, water depth, measurement depth).
- For river discharge applications, these parameters are used with velocity data to compute discharge in real-time.
- All data are stored on an internal recorder. Later, you can download the data to a PC for additional processing, display, and archiving.

This operation manual is divided into the following sections.

- **Section 1 – Components, Terminology, Sampling, and Quality Control:** Definitions of terms used in this manual, and a description of all quality control parameters
- **Section 2 – Using the Keypad Interface:** Menus, setup parameters, and system functions accessed using the keypad interface
- **Section 3 – Getting Started: Operational Overview:** Basic instructions for collecting data with the FlowTracker
- **Section 4 – General Purpose Measurements:** How to use the FlowTracker to measure velocity at several locations
- **Section 5 – River Discharge Measurements:** How to make a river discharge measurement with the FlowTracker using USGS/ISO methods
- **Section 6 – PC Software:** Software used to download data files, extract data to readily usable ASCII format, and perform system diagnostics
- **Section 7 – Hardware:** Detailed descriptions of cables, connectors, and FlowTracker hardware and electronics
- **Section 8 – Operational Considerations:** Sensor mounting, velocity coordinate system, maintenance, and troubleshooting
- **Appendix A – FlowTracker Principles of Operation**
- **Appendix B – FlowTracker Direct Command Interface**
- **Appendix C – Discharge Uncertainty Calculation**
- **Appendix D – Multiple Language Keypads**

TABLE OF CONTENTS

INTRODUCTION ..... **v**

Section 1. Components, Terminology, Sampling, and Quality Control **1**

1.1. System Components 1
1.2. Definitions and Terminology 3
1.3. Sampling Strategy 4
1.4. Quality Control Data 5
1.4.1. Adjusting Quality Control Criteria 5
1.4.2. Signal-to-Noise Ratio (SNR) 7
1.4.3. Standard Error of Velocity (σV) 8
1.4.4. Boundary Adjustment (Boundary QC) 9
1.4.5. Spike Filtering 9
1.4.6. Velocity Angle 10
1.4.7. Maximum Section Discharge 11
1.4.8. Maximum Depth Change 11
1.4.9. Maximum Location Change 12

Section 2. Using the Keypad Interface, Menus, and Display **13**

2.1. On/Off Switch 13
2.2. Keypad 14
2.3. Main Menu 18
2.4. Setup Parameters Menu (Main Menu <1>) 19
2.4.1. Units System (Setup Parameters <1>) 19
2.4.2. Averaging Time (Setup Parameters <2>) 19
2.4.3. Data Collection Mode (Setup Parameters <3>) 19
2.4.4. QC Settings (Setup Parameters <4>) 20
2.4.5. Discharge Settings (Setup Parameters <5>) 20
2.4.6. Salinity (Setup Parameters <6>) 21
2.4.7. Language (Setup Parameters <7>) 21
2.5. System Functions Menu (Main Menu <2>) 22
2.5.1. View Data File (System Functions <1>) 22
2.5.2. Check Recorder Status (System Functions <2>) 23
2.5.3. Format Recorder (System Functions <3>) 23
2.5.4. Temperature Data (System Functions <4>) 23
2.5.5. Battery Data (System Functions <5>) 24
2.5.6. Raw Velocity Data (System Functions <6>) 24
2.5.7. Automatic QC Test (System Functions <7>) 24
2.5.8. Show System Configuration (System Functions <8>) 25
2.5.9. Set System Clock (System Functions <9>) 25
2.6. QC Menu 26
2.7. Start Data Run (Main Menu <3>) 26

Section 3. Getting Started: Operational Overview **27**

3.1. Power 27

3.2. Pre-Deployment Diagnostics 27
3.2.1. Office Diagnostic Procedures 27
3.2.2. Field Diagnostic Procedures 27
3.3. Data Collection Modes 28
3.4. Other Deployment Considerations 28

Section 4. General Purpose Measurements 29

4.1. Overview 29
4.2. General Data Collection Procedure 29
4.2.1. Preparing the System for General Data Collection in the Field 29
4.2.2. Data Collection in General Mode 30

Section 5. River Discharge Measurements 33

5.1. Overview 33
5.2. Discharge Calculation Equation 33
5.2.1. Mid Section Discharge Equation 34
5.2.2. Mean Section Discharge Equation 35
5.2.3. Japanese Discharge Equation 36
5.2.4. Determining Mean Station Velocity (Discharge Measurement Method) 38
5.2.5. Discharge Uncertainty Calculation 41
5.3. Discharge Data Collection Procedure 42
5.3.1. Preparing the System for Discharge Data Collection in the Field 42
5.3.2. Data Collection in Discharge Mode 43

Section 6. PC Software for the FlowTracker 49

6.1. Installing Software 49
6.2. FlowTracker Windows Software 50
6.3. Data Display and Export 51
6.4. Download Data Files (Recorder) 55
6.4.1. Recorder Downloading Steps 55
6.4.2. Recorder Formatting Steps 56
6.5. Diagnostic Software (BeamCheck) 57
6.5.1. BeamCheck Overview 58
6.5.2. BeamCheck Menu and Control Items 59
6.5.3. BeamCheck Display Features 61
6.5.4. BeamCheck Operation 62
6.5.5. Sample Program Output 63
6.5.6. Diagnosing Hardware Programs with BeamCheck 65

Section 7. Hardware 71

7.1. Cables and Connectors 71
7.1.1. Probe Cable 71
7.1.2. External Power/Communication Cable 71
7.2. Power Supply 72
7.2.1. Input Power 72
7.2.2. Batteries 73
7.2.3. Changing the Batteries 73
7.3. Internal Electronics and Wiring Overview 74

7.4. FlowTracker Processor 75
7.5. Accessing Electronics 77
7.6. Upgrading the CPU EPROM 78

Section 8. Operational Considerations 79

8.1. Mounting and Installation 79
8.1.1. Handheld Controller Mounting 79
8.1.2. Probe Cable 79
8.1.3. Probe Mounting 80
8.1.4. Flow Interference 81
8.2. Velocity Data Coordinate System 82
8.3. Temperature Sensor 83
8.4. Real-time Clock Backup Battery 83
8.5. Routine Maintenance 84
8.5.1. Regular Diagnostic Procedures 84
8.5.2. Cleaning the Transducers 84
8.5.3. Cable Maintenance 84
8.5.4. O-rings 84
8.5.5. Condensation in FlowTracker Housing 85
8.5.6. Zinc Anodes for Corrosion Protection 85
8.6. Seeding 86
8.7. Troubleshooting 87
8.7.1. Cannot Turn System On 87
8.7.2. Cannot Communicate with the FlowTracker 87
8.7.3. Cannot Retrieve Data from Internal Recorder 87
8.7.4. Velocity Data Appears Noisy or Unreasonable 88
8.7.5. Keypad Does Not Operate Reliably 88

Appendix A. FlowTracker Principles of Operation 89

Appendix B. FlowTracker Direct Command Interface 99

Appendix C. Discharge Uncertainty Calculation 101

Appendix D. Multiple Language Keypads 109

INDEX 113

Section 1. Components, Terminology, Sampling, and Quality Control

1.1. System Components

Figure 1 shows the FlowTracker with all major components labeled.

- **Probe** – The probe (Figure 2) contains the acoustic elements used to measure velocity. See the *FlowTracker Principles of Operation* for more information.
- **Probe cable** – The probe is mounted from a 200-cm (80-in) flexible cable. The probe cable is custom built and highly noise-sensitive; it must never be modified.
  - A 300-cm (120-in) cable length is also available for specialized applications.
- **Handheld controller** – The handheld controller contains the processing electronics, batteries, keypad, and LCD screen. The controller is designed to withstand temporary submersion, but is not intended for underwater operation.
- **Keypad** – The FlowTracker keypad is designed for quick, efficient entry of data collection parameters and commands.
- **LCD screen** – The LCD screen displays instructions and real-time data.
- **External power/communication connector** – A waterproof connector on the bottom of the handheld controller connects to an external power/communication cable. This is used to download data from the FlowTracker to a PC. During data collection, the connector is sealed with a dummy cap.

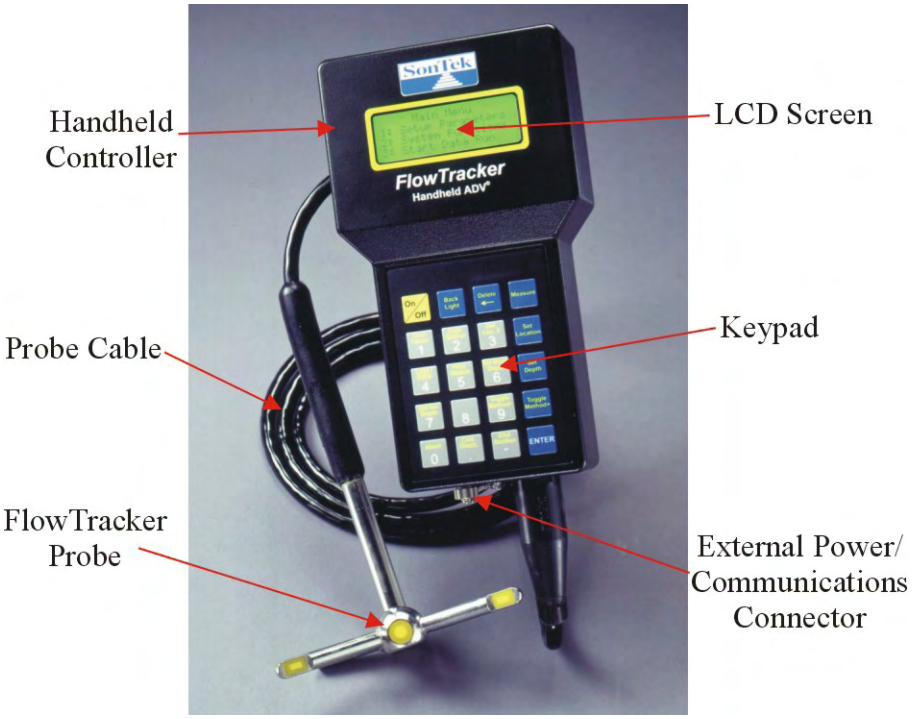


Figure 1 – FlowTracker with 2D Probe

The following terms are commonly used with the FlowTracker probe (Figure 2).

- **Transmitter** – The acoustic transmitter generates a short pulse of sound with the majority of energy concentrated in a narrow beam (6 mm in diameter).
- **Receivers** – The acoustic receivers are mounted on arms from the central probe head. The receivers are sensitive to a narrow beam and are focused on a common volume located a fixed distance (10 cm; 4 in) from the probe. The FlowTracker uses two or three acoustic receivers for 2D or 3D probes (see §8.2).
- **Sampling volume** – The sampling volume is the physical location of the water velocity measurement. See the *FlowTracker Principles of Operation* for details.
- **Temperature sensor** – The temperature sensor is mounted inside the probe. Temperature data is used to compensate for changes in sound speed. Sound speed is used to convert the Doppler shift to water velocity. See §8.3 for details on the temperature sensor; see the *FlowTracker Principles of Operation* for details about the effect of sound speed on velocity data.

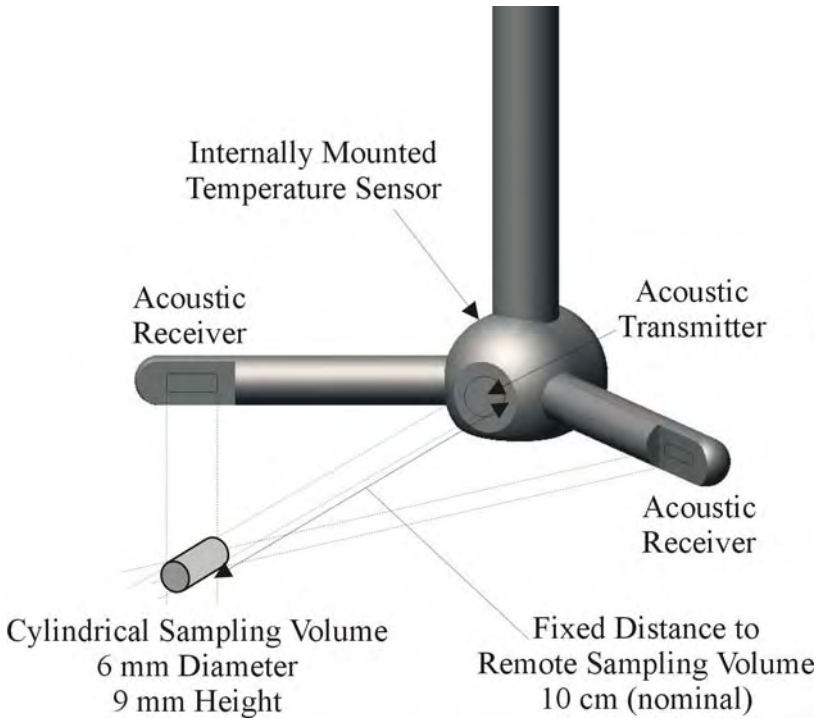


Figure 2 – 2D Side Looking FlowTracker Probe and Sampling Volume

1.2. Definitions and Terminology

This section defines terms commonly used when working with the FlowTracker.

- **Keypad interface** – The FlowTracker is controlled from the keypad on the handheld controller. The LCD screen is used to display command options and real-time data.
- **External control** – The FlowTracker can be controlled by an external computer using the RS232 serial interface. This is accessed from the external power/communication connector. External control is used to download data from the internal recorder to a PC for further analysis, display, and archiving.
- **Quality control data** – In addition to velocity, the FlowTracker records several quality control parameters. These include signal-to-noise ratio (SNR), standard error of velocity, boundary adjustment, the number of spikes filtered from data, and velocity angle. For details about quality control data, see §1.4.
- **Signal strength** – This refers to the strength of the reflected acoustic signal. It is a function of the acoustic conditions of the water – primarily the amount and type of suspended material (scatterers) present. This is most commonly accessed as a signal-to-noise ratio (SNR).
- **Signal-to-noise ratio (SNR)** – SNR is the ratio of the received acoustic signal strength to the ambient noise level. It is expressed in logarithmic units (dB), and is the most important quality control data for the FlowTracker (§1.4).
- **Temperature** – Water temperature (in °C) is measured by the internal temperature sensor. Temperature is used for sound speed calculations.
- **Salinity** – Water salinity (in ppt) is a user-supplied value that is used for sound speed calculations. Note: If using the system in salt water, a zinc anode should be installed on the probe for corrosion protection (see §8.5.6).
- **Sound speed** – Speed of sound in water (in m/s) is used to convert the Doppler shift to velocity. See the *FlowTracker Principles of Operation* regarding the effect of sound speed on velocity data.

SmartQC™

The FlowTracker has several QA/QC features designed to increase data integrity. Some of these features have bounds that can be set by the user, while others automatically adapt to the given situation. **SmartQC™** refers to the collective ability of all these features towards helping you make a better measurement. Specific QA/QC features are identified in this manual with the **SmartQC** symbol.

1.3. Sampling Strategy

There are several terms specific to the FlowTracker sampling strategy.

- **Ping** – A single estimate of the 2D or 3D water velocity.
- **Ping rate** – The number of pings per second (Hz). The FlowTracker ping rate is 10 Hz.
- **Sample** – A sample refers to the mean of 10 pings to produce a measurement of the 2D or 3D water velocity. A sample includes velocity and signal strength data. The FlowTracker records one sample per second.
- **Averaging time** – The time (in seconds) in which the FlowTracker records data at each measurement location. This is a user-specified value from 10 to 1000 seconds.
- **Measurement location** – At each measurement location, the FlowTracker records one-second velocity data for the specified averaging time, location, and water depth parameters (to document the data set), and a variety of statistical and quality control data.

The basic FlowTracker data collection process, using the keypad interface, is described below.

- At the start of data collection, you are prompted for a file name.
- For **Discharge** measurements, you enter edge location data prior to data collection.
- At each measurement location, you specify location, water depth, and measurement depth data to document the data set. For **Discharge** measurements, these are used to calculate discharge in real-time.
- A fixed-length burst of velocity data is recorded at each measurement location. Velocity data is recorded once per second during the burst; mean velocity and quality control data are recorded at the end of each burst.
- Summary velocity and quality control data are displayed at the end of each measurement.
  - Quality control data is automatically reviewed. Values outside expected boundary limits generate a warning to the user.
  - You are allowed to repeat individual measurements if desired.
- The user proceeds through a series of measurement locations (up to 100 stations can be recorded with each file).
- You can scroll through previous stations to view data and edit station information.
- When done, you press **End Section** to close the file. For **Discharge** measurements, you enter ending-edge information and are then shown the final discharge data.

1.4. Quality Control Data SmartQC

The FlowTracker records quality control (QC) data with each measurement (Table 1-1). QC parameters are automatically reviewed with each measurement and at the completion of a discharge cross section (when the **End Section** key is pressed). If any value exceeds expected criteria, a warning is given. Table 1-2 lists different QC warning messages and gives guidelines for interpreting these messages. All QC review criteria can be adjusted or disabled.

1.4.1. Adjusting Quality Control Criteria SmartQC

All quality control criteria can be modified or disabled. To access quality control settings:

- From the **Main Menu**, press **1** for **Setup Parameters**.
- From **Setup Parameters**, select **4** for **QC Settings**.
  - Select **1** to specify **SNR Threshold** (§1.4.2).
  - Select **2** to specify **σV Threshold** (§1.4.3).
  - Select **3** to specify **Spike Threshold** (§1.4.5).
  - Select **4** to specify **Max Velocity Angle** (§1.4.6).
- From **Setup Parameters**, select **5** for **Discharge Settings**.
  - Select **4** to specify **Max Section Discharge** (§1.4.7).
  - Select **5** to specify **Max Depth Change** (§1.4.8).
  - Select **6** to specify **Max Location Change** (§1.4.9).
- To disable any QC criteria, set that parameter to a value of **0**.

Table 1-1. Quality Control (QC) Parameters

Parameter	Description	Expected Values
SNR (§1.4.2)	**SNR** is the most important QC parameter. • It measures the strength of the acoustic reflection from particles in the water. • Without sufficient SNR, the FlowTracker cannot measure velocity.	Ideally > 10 dB Minimum ≥ 4 dB
σV (§1.4.3)	**σV** (standard error of velocity) is a direct measure of the accuracy of velocity data. • It includes the effects of turbulence in the river and instrument uncertainty.	Typically < 0.01m/s (0.03 ft/s). Higher in turbulent environment.
Boundary QC (§1.4.4)	**Boundary QC** evaluates the measurement environment for interference from underwater obstacles. • **FAIR** or **POOR** results may indicate significant interference from an underwater obstacle.	**BEST** or **GOOD**
Spikes (§1.4.5)	**Spikes** in FlowTracker velocity data are removed using a spike filter. • Some spikes are common and no cause for concern. • Too many spikes indicate a problem in the measurement environment (e.g., interference from underwater obstacles or highly aerated water).	Typically < 5% of total samples. Should be < 10% of total samples.
Angle (§1.4.6)	**Angle** is the direction of the measured velocity relative to the FlowTracker X-axis. • Used for discharge measurements only. • A good site should have small velocity angles. • Large angles may be unavoidable at some sites.	Ideally < 20º
%Q (§1.4.7)	**%Q** is the percentage of the total discharge in a single measurement station. • Most agencies have criteria for the maximum **%Q**.	Typical criteria: Ideally < 5% Maximum < 10%

Table 1-2. QC Warning Messages

Warning	QC Criteria	Description	Suggested Action
Low SNR (§1.4.2)	**None**	SNR < 4 dB	• Improve SNR (§8.6)
Beam SNR (§1.4.2)	**SNR Threshold**	Difference in SNR for any 2 beams is > **SNR Threshold**.	• Look for underwater obstacles; repeat measurement. • Check probe operation (§6.5).
SNR Variation (§1.4.2)	**None**	One-second SNR data varies more than expected during a measurement. May indicate underwater interference or a highly aerated environment.	• Look for underwater obstacles; repeat measurement. • Look for environmental sources (e.g., aerated water).
SNR Change (§1.4.2)	**SNR Threshold**	SNR more than **SNR Threshold** different previous measurements; major change in measurement conditions.	• Look for underwater obstacles or other changes in river condition. • Repeat measurement
High σV (§1.4.3)	**σV Threshold**	**σV** > **σV Threshold**; adjusted based on previous data and measured velocity. May indicate interference or a highly turbulent environment.	• Look for underwater obstacles or a change in conditions. • Consider real turbulence levels in river. • Repeat measurement.
Bad Boundary QC (§1.4.4)	**None**	**Boundary QC** is **FAIR** or **POOR**. Indicates possible interference from underwater obstacles.	• Consider re-locating probe and repeating test. • Measurement can proceed if results are consistent.
High Spikes (§1.4.5)	**Spike Threshold**	**Spikes** > **Spike Threshold** percent of samples. May indicate poor measurement conditions.	• Look for underwater obstacles or unusual conditions (e.g., aerated water). • Repeat measurement.
High Angle (§1.4.6)	**Max Velocity Angle**	**Angle** > **Max Velocity Angle**. May only indicate non-ideal measurement environment.	• Consider if measured angle is realistic. • Repeat measurement if needed.
High %Q (§1.4.7)	**Max Section Discharge**	**%Q** > **Max Section Discharge**. Station contains a large portion of the total discharge.	• Consider adding more stations.
Suspect Depth Value (§1.4.8)	**Max Depth Change**	Station depth differs from adjacent stations by more than **Max Depth Change** %. This may indicate a data entry problem.	• Verify station depth value. • Re-enter if needed.
Suspect Location Value (§1.4.9)	**Max Location Change**	Spacing between stations has changed by more than **Max Location Change** %. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.
Location Out of Order / Location Outside Edge (§1.4.9)	**None**	Station location out of sequence or outside river edge. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.

1.4.2. Signal-to-Noise Ratio (SNR) SmartQC

Signal-to-noise ratio (**SNR**) is a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the FlowTracker. SNR is the most important quality control data provided by the FlowTracker.

- SNR is reported in logarithmic units (dB). It is recorded with each one-second velocity sample. Mean values are recorded for each measurement location.
- For the best operating conditions, SNR should be greater than 10 dB.
- The FlowTracker can operate reliably with SNR as low as 4 dB, although the noise in individual measurements will increase.
- The FlowTracker displays an alert at the end of a measurement if SNR of any beam is <4.0 dB. SNR data are displayed during the measurement and with the measurement summary.
  - For 2D systems, if the SNR of either beam is low, this will affect all velocity data even if the other beam shows higher SNR values.
  - For 2D/3D systems, if only the SNR of Beam 3 is low, vertical velocity data (Vz) are affected; the horizontal velocity data (Vx and Vy) may still be valid. This can occur if Beam 3 is out of the water in very shallow water.
- Low SNR indicates a lack of suspended material in the water. For clear water, seeding material can be introduced to increase SNR. Seeding is typically only required in large laboratory tanks. Most field applications have sufficient natural scattering material.
- The SNR data shown during data collection is the mean of the primary receivers (depending on the operating mode of the FlowTracker – either General or Discharge). Individual receiver data can be accessed after downloading the data file to a PC (see §6.3).
  - General Mode: SNR is the mean of all receivers (2 or 3 depending on probe type).
  - Discharge Mode: SNR is the mean of Receivers 1 and 2. Receiver 3, if installed, is not used in the mean calculation because we assume the probe is side-looking (either a 2D or 2D/3D probe), and only Vx and Vy are of interest. Receiver 3, which is only used for Vz, is irrelevant. Additionally, Receiver 3 can potentially be out of the water while Receivers 1 and 2 are submerged (and still collecting good data).

SNR data are evaluated as follows.

- SNR from all beams must be greater than 4 dB for reliable data collection.
  - If any beam is below this threshold, an alert is given.
  - These criteria cannot be disabled.
- The **SNR Threshold** (default 10 dB) is used for several additional tests.
  - When the difference between any two beams is greater than **SNR Threshold**:
    - This may indicate interference from an underwater obstacle or a potential problem with the probe.
    - At the first alert, repeat the measurement (perhaps after moving probe location).
    - If the problem persists, run *BeamCheck* from a PC to evaluate FlowTracker operation in more detail (§6.5).
  - When the variation of SNR during a measurement (as measured by the standard deviation SNR data) is greater than a fixed threshold of 5 dB:
    - This may indicate interference from an underwater obstacle, a highly turbulent environment, or highly aerated water.
    - At the first alert, repeat the measurement (perhaps after moving probe location).
    - If the problem persists, evaluate the measurement environment. In some cases, large variations may be unavoidable and may not impact the quality of velocity data.

  - When SNR for a new measurement differs from the mean of all previous measurements in this file by more than **SNR Threshold**:
    - This may indicate interference from an underwater obstacle or some other dramatic change in stream conditions.
    - At the first alert, repeat the measurement (perhaps after moving probe location).
    - If the problem persists, evaluate the measurement environment to look for any potential cause for the change in SNR.
  - This criterion can be adjusted or disabled (by setting **SNR Threshold** to 0; §2.4.4).
- **SNR Threshold** is checked with each measurement and when the **End Section** key is pressed in **Discharge** mode.
  - You are notified of any stations that exceed the above criteria.
  - If desired, you can go back and delete suspect stations and repeat the measurements.

SNR is primarily a function of the amount and type of particulate matter in the water.

- While SNR cannot be immediately converted to sediment concentration, it provides an excellent qualitative picture of sediment fluctuations and, with proper calibration, SNR can be used to estimate sediment concentration. Contact SonTek for details.

1.4.3. Standard Error of Velocity (σV) SmartQC

Standard error of velocity (**σV**) is a direct measure of the accuracy of the mean velocity data.

- **σV** can be directly interpreted as the accuracy of the mean velocity.
- **σV** is calculated by dividing the standard deviation of one-second samples by the square root of the number of samples.
- **σV** is normally dominated by real variations in the flow and will vary depending on the measurement environment (see *FlowTracker Principles of Operation*).
- **σV** shown during data collection is the standard error of Vx (**σVx**).

σVx is evaluated as follows.

- The standard error threshold for each measurement is the greater of the following:
  - **σV Threshold** (default 0.01 m/s / 0.033 ft/s).
  - If the mean **σVx** for all previous measurements is greater than **σV Threshold**, we use (**Mean σVx + σV Threshold**).
  - A fixed percentage (5%) of the X-velocity (high velocity has higher **σVx**).
- When **σVx** is greater than the standard error threshold for that measurement:
  - This may indicate interference from an underwater obstacle, a highly turbulent environment, or highly aerated water.
  - At the first alert, repeat the measurement (perhaps after moving probe location).
  - If the problem persists, evaluate the measurement environment. In some cases, large variations may be unavoidable (e.g., in highly turbulent waters).
- This criterion can be adjusted or disabled (by setting **σV Threshold** to 0; §2.4.4).
- **σV Threshold** is checked with each measurement and when the **End Section** key is pressed in **Discharge** mode.
  - You are notified of any stations that exceed the above criteria.
  - If desired, you can go back and delete suspect stations and repeat the measurements.

1.4.4. Boundary Adjustment (Boundary QC) SmartQC

The FlowTracker has a potential for acoustic interference from underwater objects. The system tries to avoid this interference, but you must be aware of system limitations.

- Reflections can occur from the bottom, the water surface, or submerged objects (e.g., rocks).
- The FlowTracker measures velocity in a sampling volume 10 cm (4 in) from the probe tip.
- If the sampling volume is on top of or beyond an underwater object, velocity data will be meaningless.

When working in very shallow water or near underwater obstacles (with the sampling volume within 15 cm (6 in) of the obstacle), acoustic reflections can potentially affect velocity data.

- At each measurement location, the FlowTracker looks for these conditions, and if necessary, adapts its operation to avoid interference.
- For most locations, any required changes do not affect system performance.
- In some environments, changes may result in a lower maximum velocity.

The FlowTracker records any changes required to avoid acoustic interference. It reports this as **Boundary QC**. This value describes the effect (if any) of boundary adjustments on performance. The **Boundary QC** variable (**Bnd**) can have the following values (0 and 1 are the most common).

- **0 (BEST)**: No boundary adjustments were necessary, or if necessary, they have minimal impact on system performance. Maximum velocity is at least 3.5 m/s (11 ft/s).
- **1 (GOOD)**: Minor boundary adjustments were necessary, with moderate impact on system performance. Maximum velocity is at least 2.5 m/s (8 ft/s).
- **2 (FAIR)**: Larger boundary adjustments were necessary, with notable impact on system performance. Maximum velocity is at least 1.2 m/s (4 ft/s).
- **3 (POOR)**: Major boundary adjustments were necessary, with significant impact on system performance. Maximum velocity is less than 1.2 m/s (4 ft/s). The FlowTracker will still provide good performance for lower flows.

The **Boundary QC** test looks for interference with underwater objects that are in or close to the FlowTracker sampling volume.

- If the **Boundary QC** results are **FAIR** or **POOR**, this indicates possible interference, and the FlowTracker will issue an alert before the measurement is made.
  - You are prompted to consider moving the probe to avoid this interference.
  - If the probe is moved, repeat the boundary test prior to data collection.
  - If repeated **Boundary QC** tests do not give improved results, you can proceed with the measurement, but should carefully evaluate velocity data.

1.4.5. Spike Filtering SmartQC

Spikes in velocity data occur with any acoustic Doppler velocity sensor such as the FlowTracker. Spikes may have a variety of causes – large particles, air bubbles, or acoustic anomalies.

- Velocity data from each FlowTracker measurement are evaluated to look for spikes.
- The FlowTracker spike filter is a variation on a method called “Tukey’s Outlier”.
  - A histogram of each velocity component is calculated.
  - The FlowTracker determines the lower quartile (**Q1**; 25% of samples are less than this value), the upper quartile (**Q3**; 75% of samples are less than this value), and the inter quartile range (**IQR = Q3-Q1**).

  - If the **IQR** is less than 0.015 m/s, **IQR** is set to 0.015 m/s.
  - Any value less than (**Q1–2*IQR**) or greater than (**Q3+2*IQR**) is considered a spike and is not used for mean velocity calculations.
- Spikes are filtered based on all velocity components (Vx, Vy, and Vz). If any component falls outside the above limits, that sample is not used for the mean velocity calculation.
- The FlowTracker spike filter was updated with firmware version 3.0.
  - The new filter commonly results in a greater number of spikes being identified.
  - The greater number of spikes does not indicate a problem with FlowTracker operation, but just the effect of the new spike filter.
- The number of spikes is displayed and recorded at the end of each measurement.
- Raw, one-second velocity data are recorded with each measurement station. This allows you to evaluate unedited velocity data for each station.
- No other filtering or editing is done to FlowTracker velocity data.

The number of velocity spikes present in data is evaluated as follows.

- The **Spike Threshold** (default 10%) is used as follows.
  - If the number of spikes is a greater percentage of the total number of points than specified by the **Spike Threshold**, a warning is given.
    - This may indicate interference from an underwater obstacle, a highly turbulent environment, or highly aerated water.
    - At the first alert, repeat the measurement (perhaps after moving probe location).
    - If the problem persists, evaluate the measurement environment – a large number of spikes may be unavoidable, but may not overly impact the quality of velocity data.
  - This criterion can be adjusted or disabled (by setting **Spike Threshold** to 0; §2.4.4).
- **Spike Threshold** is checked with each measurement and when the **End Section** key is pressed in **Discharge** mode.
  - You are notified of any stations that exceed the above criteria.
  - If desired, you can go back and delete suspect stations and repeat the measurements.

1.4.6. Velocity Angle SmartQC

In **Discharge** mode, an additional quality control parameter is provided – *velocity angle*.

- Velocity angle is defined as the direction of flow relative to the X direction, and is calculated as **`atan(Vy/Vx)`**.
- For an ideal discharge measurement site, flow should be perpendicular to the tag line used to define the cross section.
- The FlowTracker's X-axis is always held perpendicular to the tag line.
- Only the X component of velocity (Vx) is used for discharge calculations. This ensures proper discharge measurements regardless of the flow direction.
- The ability of the FlowTracker to measure the 2D flow eliminates the need to estimate the flow direction with each measurement, as is required for most 1D current meters. This reduces a potential source for error in velocity measurements.
- An angle of 0° means flow direction is perpendicular to the tag line (as desired for an ideal measurement location).
- A good measurement site will typically show some flow variations, but with all angles less than about 20-30°.

The measured velocity angle is evaluated to ensure reliable data collection.

- The **Max Angle** criterion (default 20º) is used as follows.
  - Velocity angle is checked only if velocity is greater than a fixed threshold (0.02 m/s; 0.07 ft/s).
  - When measured angle is greater than **Max Angle**, a warning is given.
    - Evaluate the measurement site to verify the measured angle is reasonable.
    - Consider repeating the measurement if the angle does not appear reasonable (perhaps after moving probe location).
    - For large velocity angles, consider moving the measurement site.
  - This criterion can be adjusted or disabled (by setting **Max Angle** to 0; §2.4.4).
- **Max Angle** is active only in **Discharge** data collection mode.
- **Max Angle** is checked with each measurement and when the **End Section** key is pressed.
  - You are notified of any stations that exceed the above criterion.
  - If desired, you can go back and delete suspect stations and repeat the measurements.

1.4.7. Maximum Section Discharge SmartQC

Most agencies monitoring discharge expect that no individual station should contain more than a certain percentage of the total discharge. The **Max Sect. Q** criterion (default 10%) alerts you if this standard is exceeded.

- **Max Sect. Q** is active only in **Discharge** data collection mode.
- If you have entered rated flow, the discharge from each station is checked against this rated value when the station is completed.
  - If the station discharge exceeds **Max Sect. Q** percent of the rated flow, a warning is issued; you are prompted to consider adding another station.
- **Max Sect. Q** is also checked when the **End Section** key is pressed.
  - You are warned if any station exceeds **Max Sect. Q** percent of total measured discharge.
  - If desired, you can go back and add more stations.
- This criterion can be adjusted or disabled (by setting **Max Sect. Q** to 0; §2.4.5).

1.4.8. Maximum Depth Change SmartQC

The **Max Depth Change** criterion (default 50%) is intended to avoid data entry errors.

- **Max Depth Change** is active only in **Discharge** data collection mode.
- It is assumed that depth changes between stations will be gradual.
- If the entered depth is different from a reference by more than **Max Depth Change** (and at least 0.20 m; 0.66 ft) an alert is issued to be sure the depth was not incorrectly entered.
  - If only the previous station is available, the newly entered depth is compared to the depth from the previous station.
  - If depth data are available on both sides of this station, the newly entered depth is compared to an interpolated depth between the two adjacent stations.
  - You are prompted to verify the depth value or re-enter the depth.
  - This criterion can be adjusted or disabled (by setting **Max Depth Change** to 0; §2.4.5).
- **Max Depth Change** is also checked when the **End Section** key is pressed.
  - You are notified of any stations that exceed the **Max Depth Change** criterion, and are given the option to review all stations and modify any incorrectly entered data.

1.4.9. Maximum Location Change SmartQC

The **Max Location Change** criterion (default 100%) is intended to avoid data entry errors.

- **Max Location Change** is active only in **Discharge** data collection mode.
- It is assumed that the spacing of adjacent stations will be nearly constant across the river.
- If spacing between stations has changed by more than **Max Location Change**, an alert is issued to be sure the location was not incorrectly entered.
  - A 100% **Max Location Change** means the new station spacing is more than two times the previous station spacing.
  - This criterion can be adjusted or disabled (by setting **Max Location Change** to 0; §2.4.5).
- Any time a station location is changed, the location is compared to adjacent value(s) to see if the station is out of order.
  - If the station is out of order, an alert is issued to ensure the location has been correctly entered.
  - Collecting an out-of-order station is allowed. However, when an out-of-order station is entered we verify the location value since the station is sorted into the correct place within the stream.
- Any time a station location is changed, the location is compared to the starting edge location. If the new location is outside the starting edge, a warning is given.

Section 2. Using the Keypad Interface, Menus, and Display

This section describes FlowTracker's keypad interface, its menus, and the LCD display.

2.1. On/Off Switch

The **On/Off** power button  is in the upper left hand corner of the keypad.

- To turn the system on, hold the button for one second until the LCD screen turns on.
- To turn the system off, hold the button for four seconds until the LCD screen resets.
- The FlowTracker draws a small amount of current when off (< 1 mA).
  - If the system is to be left idle for a long period (more than 1 month), remove the batteries to prevent unnecessary draining and potential battery leakage.

IMPORTANT

Always return to the Main Menu <u>before</u> turning the system off to ensure all data has been properly saved (see last step in §4.2.2 and §5.3.2).

2.2. Keypad



Figure 3 – FlowTracker Keypad

Figure 3 shows the FlowTracker keypad.

- The function of each key is described below. Many keys have multiple functions.
- Keys are described starting at the top left, moving right and down by rows.
- Keypad overlays are available in languages supported by the FlowTracker (Appendix D).

Note: In June 2006, there were significant changes to the keypad with firmware version 3.0. A customized overlay for the keypad is available for older systems.

Numbers (0-9) | . | –

- These keys are used to enter information when prompted by the FlowTracker for:
  - Menu selections
  - Filename and extension
  - Station location, depth, and other information

Letters (A-Z)

- These keys are used to enter text for the filename and for comments in the file.
- Text entry is done in the same manner as for mobile phones. For file names, the text entry assumes numbers first (i.e., for "C" press **2** button four times **2** – **A** – **B** – **C**); for all other text, it assumes letters first (i.e. for "C" press **2** button three times **A** – **B** – **C**)

On/Off 

- To turn the system on, press and hold the key for one second until the LCD screen turns on.
- To turn the system off, press and hold the key for four seconds until the LCD screen resets.

IMPORTANT

Always return to the Main Menu before turning the system off to ensure all data has been properly saved (see last step in §4.2.2 and §5.3.2).

Back Light 

- This key turns the LCD backlight on/off.
  - If the backlight is already on, it turns the backlight off.
  - The backlight will turn off automatically after 1 minute.
- Minimize backlight use to increase battery life (the backlight doubles power consumption).

Delete ←

- This key deletes the last character when entering parameters, and is used for deleting stations from a file.

Measure

- This key starts a measurement.
  - It works identically in both **Discharge** and **General** data collection modes.
  - It is only active if the FlowTracker is displaying the current station information screen. It is not active when displaying data from a previous measurement.

Corr. Factor

- This key is used to enter special correction factors.
  - The correction factor is used only in the **Discharge** mode.
  - The correction factor is only used for certain situations, described in §5.2.4.

Next Station

- This key is used to view the next station when scrolling through completed stations.
  - It works identically in both **Discharge** and **General** data collection modes.
  - It is not active during a measurement, nor from the time **Measure** is used to start a station until the time the last measurement for that station is completed.
  - In **Discharge** mode, stations are sorted/displayed by location (regardless of the order in which they were collected).
  - In **General** mode, stations are displayed in the order they were collected.

Set Velocity

- This key is used to enter a user-estimated velocity.
  - It is active only in **Discharge** mode for stations using the **Input V** method (§5.2.4).

Set Location

- This key is used to set the measurement location.
  - It sets the location value (**Loc**) in **Discharge** mode.
  - It sets both the location 1 and location 2 values (**L1 / L2**) in **General** mode.
  - It can be used either for the current station (before the measurement) or to edit data from a previous station.

LEW / REW

- This key is used to specify the starting or ending edge of water.
  - It is used only in the **Discharge** mode.
  - **LEW** means "Left Edge of Water"; **REW** means "Right Edge of Water".
  - This is only used to document the data set and has no impact on calculations.

Prev. Station

- This key is used to view the previous station when scrolling through completed stations.
  - It works identically in both **Discharge** and **General** data collection modes.
  - It is not active during a measurement, nor from the time **Measure** is used to start a station until the time the last measurement for that station is complete.
  - In **Discharge** mode, stations are sorted/displayed by location (regardless of the order in which they were collected).
  - In **Discharge** data collection mode, it will scroll past station 1 to the starting edge and starting gauge information.
  - In **General** mode, stations are displayed in the order they were collected.

Set Meas Depth

- This key is used to set the measurement depth.
  - It is active in **General** mode and in **Discharge** mode only when using the **Multi Point** method (§5.2.4).
  - It sets the measurement depth value (**MDep**).
  - It can be used either for the current station (before the measurement) or to edit data from a previous measurement.

Set Depth

- This key is used to set the water depth (**Dep**).
  - It works identically in both **Discharge** and **General** data collection modes.
  - It can be used either for the current station (before the measurement) or to edit data from a previous station.

Set Ice Depth

- This key is used to set the ice depth.
  - It is active only in **Discharge** mode.
  - It sets the ice depth value (**Idep**) as measured from the water surface to the bottom of the ice.
  - It can be used either for the current station (before the measurement) or to edit data from a previous station.

QC Menu SmartQC

- This key is used access the **QC Menu** during data collection (§2.6).
  - It works identically in both **Discharge** and **General** data collection modes.
  - The **QC Menu** includes the following functions.
    - Input supplemental data (gauge height, rated flow, and comments).
    - Accessing **QC Settings** and **Discharge Settings** (§2.4.4 and §2.4.5).
    - Changing the averaging time for each measurement.
    - Display raw velocity data (§2.5.6).
    - Run the automatic QC test (§2.5.7).

Method –

- This key sets the method used for calculating the mean velocity in discharge measurements.
  - It is active only in **Discharge** mode.
  - See a description of all methods in §5.2.
  - This key changes the method to the previous method in the list.

Method +

- This key sets the method used for calculating the mean velocity in discharge measurements.
  - It is active only in **Discharge** mode.
  - See a description of all methods in §5.2.
  - This key changes the method to the next method in the list.

Abort

- This key is used to stop data collection during a measurement.
  - It works identically in both **Discharge** and **General** data collection modes.
  - It is active only when the system is collecting velocity data.
  - After pressing **Abort**, it can take 1-2 seconds to stop data collection.
  - The FlowTracker will display a message saying that data collection was aborted and how much data were collected.
  - You can accept the aborted measurement (using the mean values of the data that were collected) or repeat the measurement.

Calculate Disch.

- This key tells the FlowTracker to perform the final discharge calculation.
  - It is active only in **Discharge** mode.
  - It is active only when all stations have been completed, and the **End Section** key has been pressed to enter the ending edge information.
  - It is active only when the ending edge screen is displayed.
  - The system will display a series of discharge screens showing final discharge data.

End Section

- This key is used to end a series of measurements.
- In **General** mode, it ends the series of measurements and displays the summary of all data collected.
  - It is active only when the current station (not yet measured) is displayed.
  - It takes a few seconds for the file to be closed before displaying the summary.
- In **Discharge** mode, this indicates that all stations have been collected.
  - It ends the section and displays the ending edge screen. After this data has been entered, the final discharge calculation can be done.
  - It is active only when the current station (not yet measured) is displayed.

ENTER

- This key serves several functions and works identically in both **Discharge** and **General** data collection modes.
  - It is used to complete the entry of any user parameter.
  - It is used to toggle between multiple display screens when available.
  - It is used to acknowledge a FlowTracker system message.

2.3. Main Menu

When turned on, the FlowTracker displays a wake up screen showing the firmware version and the date/time from the system clock (continually updating).

```
  FlowTracker 3.0
2006/06/01  08:10:25
    Press Enter
   For Main Menu
```

Pressing **Enter** displays the **Main Menu**.

```
     Main Menu
1:Setup Parameters
2:System Functions
3:Start Data Run
```

From the **Main Menu**, press the appropriate key to access the desired function.

- Press **1** for the **Setup Parameters Menu** (§2.4).
- Press **2** for the **System Functions Menu** (§2.5).
- Press **3** to start a data run (§2.7).

IMPORTANT

Always return to the Main Menu before turning the system off to ensure all data has been properly saved (see last step in §4.2.2 and §5.3.2).

2.4. Setup Parameters Menu (Main Menu <1>)

Setup parameters determine how the FlowTracker collects data. This section describes each item in the **Setup Parameters Menu**.

```
1:Units English
2:Avg Time (40)
3:Mode Discharge
0=Exit or Enter=More
```

```
4:QC Settings
5:Discharge Settings
6:Salinity (0.00)
0=Exit or Enter=More
```

```
7:Language English


0=Exit or Enter=More
```

- The **Setup Parameters Menu** is shown above (three screens are needed to show all options).
- Press **Enter** to cycle through the screens.
- To change a setting, press the appropriate menu number.

2.4.1. Units System (Setup Parameters <1>)

The **Units** option defines the units system used for display and output data (**English** or **Metric**).

- The units system does not affect internal calculations or storage (internal units are metric).
- To change the units system, press **1** from the **Setup Parameters Menu**, and then:
  - Press **1** for **English** units.
  - Press **2** for **Metric** units.
- Table 2-1 lists the units that are used for display.

Table 2-1. FlowTracker Display Units

Parameter	English Units	Metric Units
Location	feet	meters
Depth	feet	meters
Velocity	ft/s	m/s
Standard error of velocity (**σV**)	ft/s	m/s
Staff/gauge height	feet	meters
Discharge	ft^3/s	m^3/s
SNR	dB	dB

2.4.2. Averaging Time (Setup Parameters <2>)

The **Avg Time** (averaging time) option specifies the amount of data (in seconds) to be collected at each measurement site.

- Averaging time is specified in 1-second intervals from 10 to 1000 seconds.
  - To change the averaging time, press **2** from the **Setup Parameters Menu**.

2.4.3. Data Collection Mode (Setup Parameters <3>)

The **Mode** option determines the procedure when collecting a series of measurement stations.

- To change the data collection mode, press **3** from the **Setup Parameters Menu**, and then:
  - Press **1** for **Discharge** mode.
  - Press **2** for **General** mode.
- **Discharge Mode**
  - In **Discharge** mode, a sequence of measurements is used to calculate river discharge.
  - See Section 5 for a complete description of discharge measurements.

- **General Mode**
  - In **General** mode, no additional calculations are made by the FlowTracker.
  - Location and depth information are recorded to document the data set.
  - See Section 3 for a complete description of general measurements.

2.4.4. QC Settings (Setup Parameters <4>) SmartQC

The **QC Settings** menu sets universal quality control criteria (**Discharge** or **General** mode).

- To access the **QC Settings** menu, press **4** from the **Setup Parameters Menu**, and then:
  - Press **1** to set the **SNR Threshold** (§1.4.2).
  - Press **2** to set the **σV Threshold** (§1.4.3).
  - Press **3** to set the **Spike Threshold** (§1.4.5).
  - Press **4** to set **Max Velocity Angle** (§1.4.6).

2.4.5. Discharge Settings (Setup Parameters <5>)

The **Discharge Settings** menu specifies settings for the discharge calculations and the quality control criteria used for **Discharge** measurements.

- To access the **Discharge Settings** menu, press **5** from the **Setup Parameters Menu**. You can also access **Discharge Settings** by pressing **3** from the **QC Menu**. (Although options **1**, **2**, and **3** are not available when a data file is open.)
  - Press **1** to set the discharge **Equation** (§5.2).
    - Press **1** to select **Mid Section**.
      - Selecting this option sets **Repeat Depth** and **Repeat Velocity** to **NO**.
    - Press **2** to select **Mean Section**.
      - Selecting this option sets **Repeat Depth** and **Repeat Velocity** to **NO**.
    - Press **3** to select **Japanese**.
      - The **Japanese** equation normally involves repeating each depth and velocity measurement. This option sets **Repeat Depth** and **Repeat Velocity** to **YES**.
  - Press **2** to toggle **Repeat Depth** (§5.2) between **YES/NO**.
    - This option is normally used with the Japanese method, and involves recording each depth value two times – once when going across the river and a second time when returning. The mean of these two readings is used.
  - Press **3** to toggle **Repeat Velocity** (§5.2) between **YES/NO**.
    - This option is normally used with the Japanese method, and involves measuring each velocity value two times in a row. The mean of these two readings is used.
  - Press **4** to set **Max Section Discharge** (§1.4.7).
  - Press **5** to set **Max Depth Change** (§1.4.8).
  - Press **6** to set **Max Location Change** (§1.4.9).
  - Press **7** to set the discharge **Reference** value.
    - The section discharge (**%Q**) displayed for each station can be calculated based either on the user-supplied **Rated** discharge or the total **Measured** discharge.
    - Select the desired reference, **Rated** or **Measured**.
    - The default is **Rated**. If no **Rated** value is specified, the **Measured** value is used.
  - Press **8** to select the **Methods Displayed**.
    - The FlowTracker supports several methods to determine mean velocity (§5.2.4). The method determines the number and location of velocity measurements.
    - You scroll through available methods using the **Method+** and **Method–** keys.

- If some methods will never be used, you can remove those methods from display (reducing the number of methods to scroll through).
  - Press **1** to toggle **2-6-8 Methods** (**0.6**, **0.2/0.8**, **0.8/0.2**, **.2/.6/.8**, **.8/.6/.2**) on/off.
  - Press **2** to toggle **Ice Methods** (**Ice 0.6**, **Ice 0.5**, **Ice 2/8**, **Ice 8/2**) on/off.
  - Press **3** to toggle **Kreps Methods** (**Kreps 2-**, **Kreps 2+**) on/off.
  - Press **4** to toggle **2-6-8 Methods** (**5 Point-**, **5 Point+**) on/off.
  - Press **5** to toggle **Multi Methods** (**Multi Pt**) on/off.

o Press **9** to select the **Uncertainty** calculation.

- The FlowTracker supports 2 uncertainty calculations: Statistical and ISO. Each provides an estimate of the uncertainty of each discharge calculation.
- Refer to §5.2.5 and Appendix C for details about each calculation type.

2.4.6. Salinity (Setup Parameters <6>)

The **Salinity** option specifies the salinity value (in ppt) used to compute sound speed.

- To change salinity, press **6** from the **Setup Parameters Menu**, and then:
  - Enter the desired salinity value in ppt.
- Sound speed is used in Doppler velocity calculations (see *FlowTracker Principles of Operation* for details).
- Salinity is specified in parts per thousand (ppt). Fresh water has a salinity of 0; seawater typically has a salinity of about 35 ppt.
- As a rule of thumb, a 12-ppt error in the value of salinity will result in a 1% error in sound speed, which results in a 2% error in velocity data.
- Salinity should be specified as accurately as possible for each location.

IMPORTANT: When using the FlowTracker in salt water, a sacrificial zinc anode should be installed on the probe for corrosion protection (see §8.5.6).

2.4.7. Language (Setup Parameters <7>)

The FlowTracker firmware can operate in five different languages. Keypad labels are changed for compatibility with each language; keypad overlays are available on request for each language (and are included with each system shipped outside the United States and Canada).

- To change the language, press **7** from the **Setup Parameters Menu**:
  - Press **1** for **English**.
  - Press **2** for **Spanish**.
  - Press **3** for **French**.
  - Press **4** for **German**.
  - Press **5** for **Italian**.

2.5. System Functions Menu (Main Menu <2>)

The **System Functions Menu** provides access to items that should be checked periodically, but do not directly effect how data is collected. This section describes those items.

1:View Data File 2:Recorder Status 3:Format Recorder 0=Exit or Enter=More	4:Temperature Data 5:Battery Data 6:Raw Velocity Data 0=Exit or Enter=More	7:Auto QC Test 8:Show Config 9:Set System Clock 0=Exit or Enter=More

- Three screens (above) are needed to show all items.
- Press **Enter** to switch between screens.
- To change a setting, press the number shown.

2.5.1. View Data File (System Functions <1>)

The **View Data File** option allows you to view data files stored on the internal recorder.

- To view a data file stored on the internal recorder, press **1** in the **System Functions Menu**.
- The FlowTracker will display a menu of the files on the internal recorder. At most, three files are displayed on each screen.

```
31532.111    Press 1
12342.05     Press 2
872663.310   Press 3
0=Exit or Enter=More
```

  - Use **Enter** to scroll through the entire recorder directory (three files at a time).
  - Press **1**, **2**, or **3** to select the desired file.
  - Press **0** to exit the **View Data File** option without loading a file.
- After loading the file, the FlowTracker displays a summary of the data file.
  - The summary is the same one used at the end of data collection for **General Mode** (§4.2.2) or **Discharge Mode** data collection (§5.3.2).
  - Press **Enter** to move between the different summary display screens.
  - Press **Previous Station** from any file summary screen to view station data.
  - Use **Next Station** and **Previous Station** to scroll through station data (no new measurements can be added). The same station display screens are available as those used during data collection. Press **Enter** to scroll through the station data screens.
  - Pressing **Next Station** from the last station returns you to the file summary screens.
  - When done, press **0** to exit and return to the main menu. The **0** key is only active when the display is showing the summary data. If you have scrolled back to a previous station to view data, you will not be able to exit until you scroll forward to the summary data screen.

2.5.2. Check Recorder Status (System Functions <2>)

The **Recorder Status** option displays the number of files stored on the internal recorder, and the number of files remaining.

- To view the status of the recorder, press **2** from the **System Functions Menu**. Press any key to return to the main menu.
- The FlowTracker will have either a 2-MB or 4-MB recorder.
  - Systems produced before about February 2002 have a 2-MB recorder. The 2-MB recorder stores at most 32 data files.
  - Systems produced after about February 2002 have a 4-MB recorder. The 4-MB recorder stores at most 64 data files.
- The recorder is divided into blocks of 64 KB per block. No more than one file can be stored per block, but one file can occupy more than one block.
- Most data files will fit within one block. Larger data files will occupy multiple blocks (and reduce the total number of files that will fit on the recorder).
- The system will not allow you to collect data if the recorder is full.
- If recorder space is low (three or less blocks remaining), the system will prompt you at the start of a data run to see if you wish to format the recorder before data collection.

2.5.3. Format Recorder (System Functions <3>)

The **Format Recorder** option erases all data on the internal recorder.

- To format the recorder, press **3** from the **System Functions Menu**.
- The system will prompt you to enter **123** to confirm your decision to format (erase) the recorder. Entering any other value will abort the formatting process.
- Be certain that all data has been downloaded before formatting the recorder; data cannot be recovered after the recorder is formatted.
- Recorder formatting takes 20-60 seconds to complete.

2.5.4. Temperature Data (System Functions <4>)

The **Temperature Data** option displays the current temperature sensor data.

- To view temperature data, press **4** from the **System Functions Menu**. Press any key to return to the main menu.
- The temperature sensor is in the probe head and is accurate to ±0.1°C.

2.5.5. Battery Data (System Functions <5>)

The **Battery Data** option shows the current battery voltage and an estimate of remaining capacity.

```
   Battery 9.7 V
    Alkaline 75%
NiMH 80%  NiCad 90%
    Press Enter
```

- To view battery data, press **5** from the **System Functions Menu**. Press any key to return to the main menu.
- An estimate of remaining capacity (as a percent of total) is given for three battery types. The FlowTracker does not know what type of batteries are installed. Typical capacities:
  - Alkaline: ≈25 hours
  - NiMH: ≈15 hours
  - NiCad: ≈7 hours
- **Battery capacity estimates are based on voltage and are only approximate.**
- **Cold weather can greatly affect battery voltage and capacity; always check battery voltage after the system has acclimated to outside temperatures.**
- See §7.2 for more information about battery types and expected battery life.

2.5.6. Raw Velocity Data (System Functions <6>)

The **Raw Velocity Data** option shows a continuous display of raw velocity and SNR data.

- To display raw data, press **6** from the **System Functions Menu**.
  - This can also be accessed by pressing **5** from the **QC Menu**.
- Press any key to exit the raw velocity display.
- This can be done as a quick test before data collection or to check stream conditions during data collection.
  - Data displayed during this function are not recorded.
- Velocity and SNR data are updated once per second.
- Velocity data can be expected to show notable variations (most of which are real), and should be indicative of the general conditions in the water.
- SNR is primarily a function of the amount of particulate matter in the water. For good conditions, SNR should be at least 10 dB. The system can operate effectively with SNR as low as 2-3 dB, although the noise in individual velocity measurements will increase.

2.5.7. Automatic QC Test (System Functions <7>) SmartQC

The Auto QC Test is an automated version of the *BeamCheck* software described in §6.5.

- This test can be run in three ways:
  - When you are prompted to run this test at the start of each data file.
  - When you press **7** from the **System Functions** menu.
  - When you press **6** from the **QC Menu**.
- Follow the instructions on the LCD.
- When the test is done while a data file is open, results are recorded with the file.
- Place the probe in moving water well away from any underwater obstacles.
  - The FlowTracker collects data for about 30 seconds.
  - The data are analyzed based on several criteria:

- Noise level
  - Measured electronics noise level is compared to reference data. Any significant deviation causes a warning.
  - A large change in noise level may indicate damage to the probe.
- SNR
  - The SNR is checked as sufficient for reliable data collection.
  - Each beam SNR is compared to be sure all beams perform equally.
  - A warning is issued for low SNR or if beam SNR values differ.
- Peak shape
  - The shape of the sampling volume curve is compared to the expected shape. Any significant deviation causes a warning.
  - This criterion can only be checked with sufficient SNR (> 7 dB).
- Peak location
  - The physical location of the sampling volume is compared to the expected location. Any significant deviation causes a warning.
  - This criterion can only be checked for sufficient SNR (> 7 dB).

o If any warnings are issued, you are given the option to repeat the test.
- We recommend repeating the test at least once, after you verify that the probe and sampling volume are well away from any underwater obstacles.
- If multiple warnings are received, run *BeamCheck* from a PC (§6.5) to evaluate FlowTracker performance in more detail.

2.5.8. Show System Configuration (System Functions <8>)

The **Show Config** option displays basic system configuration information.

- To display system configuration information, press **8** from the **System Functions Menu**. Press any key to return to the main menu. Displayed items include:
  - Firmware version number
  - Serial number
  - Probe type
    - **Side XY 10cm** indicates a side-looking 2D probe.
    - **Side XYZ 10cm** indicates a side-looking 2D/3D probe.
    - **Down XYZ 10cm** indicates a down-looking 3D probe.

2.5.9. Set System Clock (System Functions <9>)

The **Set System Clock** option displays the date and time (continually updated) from the FlowTracker's internal clock.

- To change the date/time, press **9** from the **System Functions Menu**, and then:
  - Follow the menu options to change the date or time.

2.6. QC Menu SmartQC

The **QC Menu** is accessed only during data collection by pressing the **QC Menu** key (in either **Discharge** or **General** mode). It provides access to several functions.

- Input supplemental data
  - Supplemental data is provided to allow you to further document that data set.
  - Up to 20 different supplemental data records can be included with each file.
  - Each record can include gauge height, rated flow, user comments, a time stamp and a location stamp.
    - The time stamp and location stamp are automatically generated with any gauge height, rated flow, or comment entries, but can be edited.
  - Data in all records can be viewed and modified following the on-screen instructions in the **QC Menu**.
- Modify **QC Settings** (§2.4.4).
- Modify **Discharge Settings** (§2.4.5) (**Discharge** mode only).
- Change the averaging time (**Avg Time**) used for each measurement.
- Display **Raw Velocity Data** (§2.5.6) from the FlowTracker without recording to a file.
  - One possible use for this function is to use the FlowTracker to locate the bottom of a slush layer under ice.
- Run and record an additional **Auto QC Test** (§2.5.7).

2.7. Start Data Run (Main Menu <3>)

Pressing **3** from the main menu starts a data collection run. The procedure for data collection will vary depending on the data collection mode setting (**Discharge** or **General**).

- For a detailed description of the **General** data collection procedures, see Section 4.
- For a detailed description of **Discharge** measurement procedures, see Section 5.

IMPORTANT

Always return to the Main Menu before turning the system off to ensure all data has been properly saved (see last step in §4.2.2 and §5.3.2).

Section 3. Getting Started: Operational Overview

For both the first-time user and the seasoned veteran, this section provides an operational overview of how to get your FlowTracker up and running.

3.1. Power

- The FlowTracker operates on 6 to 15 VDC input power typically supplied by internal batteries. **CAUTION:** Voltages greater than 15 VDC will seriously damage the electronics.
- Ensure adequate power is available before starting a data collection run (see §2.5.5).
- See §7.2 for details about installing and checking batteries.
- An external power supply can be used; see §7.1.2.

3.2. Pre-Deployment Diagnostics

Simple diagnostic procedures are provided to verify system operation.

- One procedure requires an external PC and should be performed before every extended field trip (or about once per week) – see §3.2.1.
- Other procedures, requiring only a few minutes, can be performed in the field from the keypad interface. These should be performed before each data run – see §3.2.2.

3.2.1. Office Diagnostic Procedures

The system software includes a program named *BeamCheck*.

- *BeamCheck* lets you evaluate all aspects of system performance and should be run before an extended field trip (about once per week).
- Using *BeamCheck* for the first time will require about 30 minutes; experienced users should need about 5 minutes.
- The system must be connected to an external PC. *BeamCheck* details are described in §6.5.

3.2.2. Field Diagnostic Procedures

Several diagnostic functions are available from the **System Functions Menu** (press **2** from the **Main Menu**). Field diagnostics should be run before every data collection run.

Recorder Status (**2** in **System Functions Menu**)

- The FlowTracker internal recorder can store up to 32 files (2-MB recorder) or 64 files (4-MB recorder).
- Check recorder status before each data collection run. Download data and format the recorder as needed (§2.5.2).

Temperature Data (**4** in **System Functions Menu**)

- Temperature data is used for sound speed calculations and can affect velocity data.
- Check temperature data to be sure it is reasonable for the environment.

Battery Data (**5** in **System Functions Menu**)

- An estimate of remaining capacity (as a percent of total) is given for three battery types. The FlowTracker does not know what type of batteries are installed.
- Typical expected life from fully-charged batteries:
  - Alkaline: ≈25 hours
  - NiMH: ≈15 hours
  - NiCad: ≈7 hours

- These battery life estimates are at ~20° C (70° F). Cold weather will have a significant effect on voltage and capacity.
- See §7.2 for more information about battery types and expected battery life.

Display Raw Data (**6** in **System Functions Menu**)

- Place the probe in the area to be measured.
- This displays raw velocity and SNR data, updated once per second.
  - SNR data should ideally be above 10 (units are dB), but measurements can be made as low as 3-4 dB.
  - Velocity data should appear reasonable for the environment (short term variations are expected and are most likely real).
- See §2.5.6 for more information about the raw data display.

Auto QC Test (**7** in **System Functions Menu**) SmartQC

- You will be prompted to run this test at the start of each data file. When done collecting data, test results are recorded with the data file. The test can also be run directly from the **System Functions Menu**, although test results are not recorded.
- Place the probe in moving water well away from any underwater obstacles; follow the on screen instructions for the test.
- See §2.5.7 for more information about the automatic QC test.

System Clock (**9** in **System Functions Menu**)

- The FlowTracker uses an internal clock to record time information for all measurements.
- Verify the clock is correctly set before each data collection run. Change date/time as needed from this menu.

3.3. Data Collection Modes

The FlowTracker has two data collection modes that affect how the system collects data.

- **Discharge Mode** assumes you are measuring discharge in a river/stream. This mode follows established discharge measurement procedures. Details about this mode are in Section 5.
- **General Mode** is intended for a general series of measurements; the FlowTracker makes no calculations based on the data. Details about this mode are in Section 4.

You can switch between data collection modes using the **Setup Parameters Menu** (§2.4.3).

3.4. Other Deployment Considerations

In addition to the diagnostic routines mentioned above (§3.2), you should review the following operational considerations.

- Probe mounting, installation, and interference (§8.1)
- Routine maintenance (§8.5)
- Seeding requirements (§8.6)

IMPORTANT

Always return to the Main Menu before turning the system off to ensure all data has been properly saved (see last step in §4.2.2 and §5.3.2).

Section 4. General Purpose Measurements

4.1. Overview

The **General Mode** of data collection is for applications that need a series of current measurements at different locations, but that do not require a standard discharge calculation.

- The FlowTracker records the velocity data with parameters to document the data set.
- The following parameters are recorded with each measurement location.
  - Station number
  - Two location variables
  - Water depth
  - Measurement depth
- No parameters are required (station number is automatically generated). They are provided only to document the data set as desired for a particular application.

4.2. General Data Collection Procedure

This section outlines a typical procedure when collecting data in the **General Mode**. Though typical, the sequence of steps you use may vary based on your application.

4.2.1. Preparing the System for General Data Collection in the Field

Preliminary

- Run pre-deployment diagnostics before taking the instrument to the field (§3.2 and §6.5).

Mount the Probe

- Use a proper probe mounting to avoid flow interference (§8.1).

Turn the FlowTracker On

- Hold the **On/Off** key for 1 second until you see the LCD screen turn on.
- From the opening (i.e.; wakeup) screen, press the **Enter** key to view the **Main Menu**.

Field Diagnostics

- Perform field diagnostics (§3.2.2).
  - Check recorder status (**2** in **System Functions Menu**)
  - Check temperature data (**4** in **System Functions Menu**)
  - Check battery capacity (**5** in **System Functions Menu**)
  - Check raw velocity and SNR data (**6** in **System Functions Menu**)
  - Check system clock (**8** in **System Functions Menu**)

Set System Parameters

- Check the **Setup Parameters Menu** (**1** in **Main Menu**; §2.4).
  - Units system [Metric/English] (**1** in **Setup Parameters Menu**)
  - Averaging time (**2** in **Setup Parameters Menu**)
  - Data collection mode (set to **General**) (**3** in **Setup Parameters Menu**)
  - QC Settings (**4** in **Setup Parameters Menu**; §2.4.4) SmartQC
  - Salinity (**6** in **Setup Parameters Menu**)
    - In salt water, a zinc anode should be installed (§8.5.6).

4.2.2. Data Collection in General Mode

Table 4-1 lists the items shown on the display screens during data collection.

Table 4-1. Items Displayed During Data Collection (General Mode)

Label	Description	English	Metric
Stn	Station number		
L1	Location value 1	ft	m
L2	Location value 2	ft	m
Dep	Water depth	ft	m
MDep	Measurement depth	ft	m
Vx	X velocity component	ft/s	m/s
Vy	Y velocity component	ft/s	m/s
Vz	Z velocity component	ft/s	m/s
SNR	Signal-to-noise ratio (mean of all receivers); §1.4.2	dB	dB
Time	Time remaining in sampling average		
σV	Standard error of velocity; §1.4.3	ft/s	m/s
Spikes	Number of spikes edited from mean; §1.4.5		
Bnd	Boundary QC value; §1.4.4		
NPts	Number of points collected (may differ from averaging time if **Abort** key used)		

The following steps describe the data collection sequence when in **General Mode**.

1. From the **Main Menu**, press **3** to **Start Data Run**.
2. The file name menu will be displayed (right).

```
   Data File Name
1:Name (none)
2:Extension (none)
9:Accept name
```

   a. Press **1** to specify file name (required).
      - A maximum of 8 characters (letters or numbers) are allowed.
      - To enter an alpha-numeric filename:
        - To enter a number, simply type the number.
        - Letters use the mobile phone method (e.g., for **C** press **2** four times: **2 – A – B – C**).
        - Press **Enter** to complete the filename.
        - Use the **Delete** key to correct mistakes.
      - After entry, the file name is shown in parentheses.
   b. Press **2** to specify file extension (optional).
      - A maximum of 3 characters (letters or numbers) is allowed
      - After entry, the extension is shown in parentheses.
   c. Press **9** when ready to start data collection. The system checks that the filename does not already exist on the recorder, and then displays station information.
   d. **Or**, press **Abort** or **End Section** to return to the **Main Menu**.
3. Input site and operator name (right). These are optional values used only to document the data set.

```
1:Site
Poudre River FC
2:Operator Billy Bob
9:Start
```

   a. Press **1** to enter site name.
   b. Press **2** to enter operator name(s).
   c. Up to 20 characters is allowed for each.
   d. Press **9** to start data collection.
4. You will be prompted (right) to conduct an automatic QC test (§2.5.7). SmartQC

```
 Automatic QC Test

1:Run Test
2:Skip Test
```

   a. Press **1** to run the automatic QC test, and follow on screen instructions.
   b. Press **2** to skip the test and begin data collection.

5. Station information will be displayed (right).
   a. Data are in meters or feet based on the units selection.
   b. Press **Set Location** to set location 1 (**L1**) and location 2 (**L2**) values.
   c. Press **Set Depth** to set water depth (**Dep**).
   d. Press **Set Meas Depth** to set measurement depth (**MDep**).

```
Station 1
L1 0.00    Dep 0.00
L2 0.00   MDep 0.00
Press Meas to Start
```

6. When the probe is located at the desired station, press **Measure** to start data collection. The display (right) shows a running mean of velocity and SNR data. The displayed values represent the running mean of data collected at the selected station.

```
Stn 1     MDep 0.00
Vx 0.00   Vy 0.00
Vz 0.00   SNR 0.0
Time (sec) 19
```

7. When the station is complete, a summary of velocity and quality control data are shown (right).
   a. The data represent the mean over the entire averaging period after removing any spikes.
   b. Press **1** to accept the measurement and move on to the next station.
   c. Press **2** to repeat the measurement (using the same station number).
   Note: When a measurement is repeated, data are not lost. However, you can longer view the *old* data using the keypad interface. The *old* data are still recorded. Later, you can extract the data from the raw data file (**`*.dat`**) and the measurement summary file (**`*.sum`**).

```
Vx 2.25   σV 0.02
Vy 0.42   SNR 15.1
Spikes 0  Bnd BEST
1:Accept   2:Repeat
```

8. When a measurement is accepted, the FlowTracker displays the next station.
   a. Location and depth data for new stations are predicted based on previous stations.
   b. At this point, you would repeat Steps 3 through 8 to add additional stations; otherwise, continue with Step 9 below.
   Note: In **General Mode**, the maximum number of stations for a data file is 100. Measurements that are repeated (Step 7.c.), do not count towards the maximum number of stations.
9. Use the **Previous Station** and **Next Station** keys to scroll through completed stations.
   a. Three screens (below) are available for each completed station; press **Enter** to scroll through the screens for each station.
   b. You can edit station information using **Set Location**, **Set Loc. 2**, **Set Depth**, and **Set Meas Depth**.

```
Station 3
L1 4.00    Dep 2.25
L2 6.50   MDep 1.50
Press Enter For More
```

```
Stn 3     MDep 1.50
Vx 2.25   Vy 0.42
Vz 0.05   Npts 40
Press Enter For More
```

```
Stn 3     MDep 1.50
SNR 14.5   Bnd BEST
σV 0.02    Spikes 0
Press Enter For More
```

10. At any point, press **QC Menu** to access a variety of special functions (§2.6). SmartQC
    a. Enter supplemental data (gauge height, rated flow, user comments).
    b. Modify **QC Settings** (§2.4.4).
    c. Change averaging time (**Avg Time**) used for each measurement.
    d. Display **Raw Velocity Data** (§2.5.6).
    e. Run and record an additional **Auto QC Test** (§2.5.7).
11. When all stations are done, press **End Section** to close the file and view summary data (this process may take a few seconds). Note: The **End Section** key is only active when the display is showing the last station in the file. If you have scrolled back to a previous station to view data, you will not be able to end the section until you scroll forward to the ending station.

12. After the file has been closed, seven screens of file summary data are available (below). Table 4-2 lists the items shown on the summary screens.
    a. Press **Enter** to move between the different file summary screens.
    b. Press **Previous Station** from any file summary screen to view the station data. You can then scroll through all station data using the **Next Station** and **Previous Station** keys. Press **Next Station** from the last station screen to return to the file summary screens.
    c. When done, press **9** to exit and return to the main menu. The **9** key is only active when the display is showing the file summary data. If you have scrolled back to a previous station to view data, you cannot exit until you scroll forward to the summary data.
    d. **IMPORTANT: Always return to the Main Menu before turning the system off to ensure all data has been saved.**

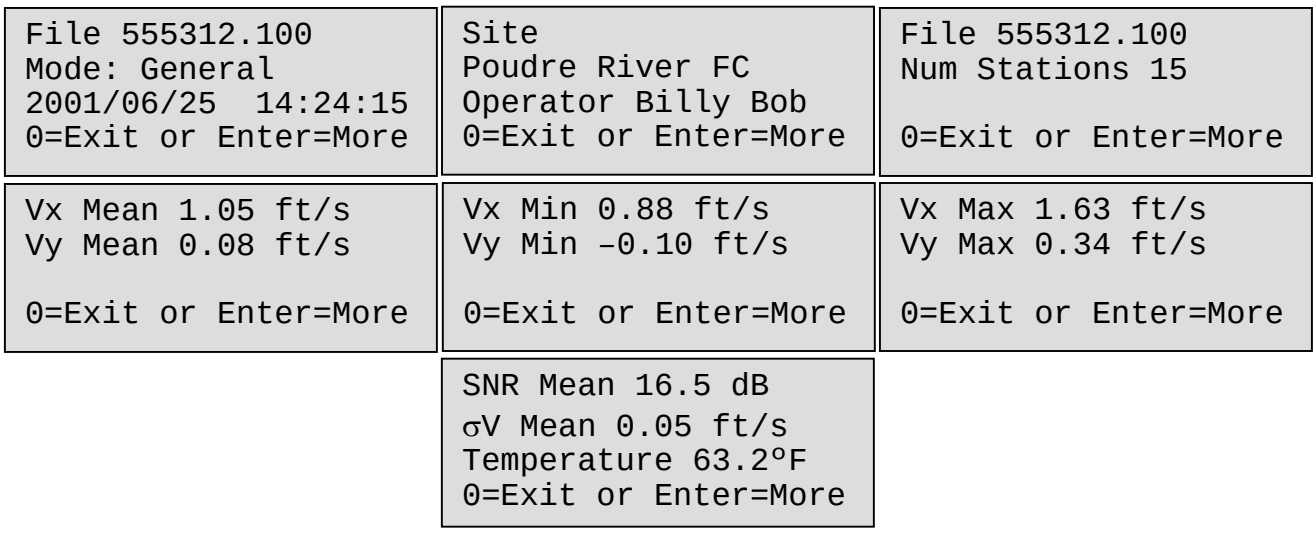


Table 4-2. Items Displayed on Summary Screens (General Mode)

Label	Description	English Units	Metric Units
Stations	Total number of stations (including edges)	-	-
Site	Site name	-	-
Operator	Operator name	-	-
Vx Mean	Mean X velocity	ft/s	m/s
Vy Mean	Mean Y velocity	ft/s	m/s
Vz Mean	Mean Z velocity (if present)	ft/s	m/s
Vx Min	Minimum X velocity	ft/s	m/s
Vy Min	Minimum Y velocity	ft/s	m/s
Vz Min	Minimum Z velocity (if present)	ft/s	m/s
Vx Max	Maximum X velocity	ft/s	m/s
Vy Max	Maximum Y velocity	ft/s	m/s
Vz Max	Maximum Z velocity (if present)	ft/s	m/s
SNR Mean	Mean signal to noise ratio; §1.4.2	dB	dB
σV Mean	Mean standard error of velocity; §1.4.3	ft/s	m/s
Temperature	Mean water temperature	°F	ºC

Section 5. River Discharge Measurements

5.1. Overview

Discharge Mode is for applications where the primary goal is to measure river/stream discharge. The technique involves taking a series of velocity measurements at different locations throughout the cross section. These measurements are combined with location and water depth information to compute the total discharge.

- Section 5.2 describes the measurement methodology and discharge calculations in detail.
- Section 5.3 describes how to make discharge measurements with the FlowTracker.

5.2. Discharge Calculation Equation

The basic procedure for making a discharge measurement is as follows.

- A site is selected. Site selection is a crucial part of collecting discharge measurement data.
  - In an ideal measurement site, the flow should be perpendicular to the tag line at all points with no flow reversals or obstructions.
  - Look for sites with reasonably smooth, consistent bottom conditions.
  - Flow conditions at the site are the most important factor in determining overall accuracy of measurements at that site (§5.2.5).
- A graduated tag line is strung across the river.
- The operator starts at one edge, recording the starting-edge location and water depth.
- The river cross section is split into several stations. At each station, the operator records the station location and water depth, and then takes velocity measurements at one or more depths to determine the mean velocity at that station.
- During velocity measurements, the probe's X-axis is maintained perpendicular to the tag line (Figure 4); the red band (receiver arm #1) should face downstream. Only the X-component of velocity (**Vx**) is used to ensure proper discharge calculation, regardless of the flow direction (flow direction is also measured and recorded).
- When complete, the operator records the ending-edge location and water depth.
- The total discharge is the sum of all station discharge values.

The FlowTracker supports several equations for calculating discharge following the basic procedure outlined above.

- **Mid Section** equation (§5.2.1)
- **Mean Section** equation (§5.2.2)
- The **Japanese** equation (§5.2.3)

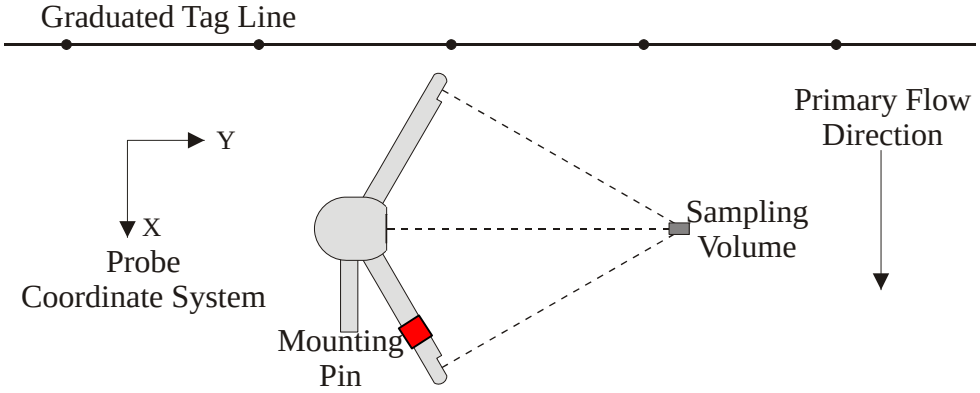


Figure 4 – FlowTracker Probe Orientation Relative to Stream Flow

5.2.1. Mid Section Discharge Equation

The **Mid Section** discharge equation is the default used by the FlowTracker.

- This method is used by the U.S. Geological Survey (USGS), the primary U.S. government agency responsible for river discharge monitoring.
- The same methodology is described in ISO standards 748 (1997) and 9196 (1992).
- Figure 5 shows the **Mid Section** equation. In this figure:
  - **Loc** $_i$ represents the location of measurement station **i**.
  - **Dep**$_i$ represents the measured water depth at station **i**.
  - **Vel** $_i$ represents the mean velocity at station **i** (§5.2.4).

There are a few special cases to consider.

Edges

- Velocity from the adjacent station is used, scaled by a user-supplied correction factor.

Multiple channels (internal islands)

- If a river is split into multiple channels, any internal island(s) must be accounted for in the discharge calculation.
- The stations at each edge of the internal island(s) are treated like the river edges.
- Enter station location and water depth, and then select the velocity measurement method **None** to indicate an internal island. For an internal island, there should be two method **None** stations in a row (one for each edge).

Ice covered water

- For under ice measurements, calculations must take into account the thickness of the ice.
- Holes are cut through the ice at each measurement station.
- The operator enters station location and water depth as normal.
- The operator enters an ice depth parameter (**Ice**), which is the distance from the water surface to the bottom of the ice or bottom of the slush (if present).

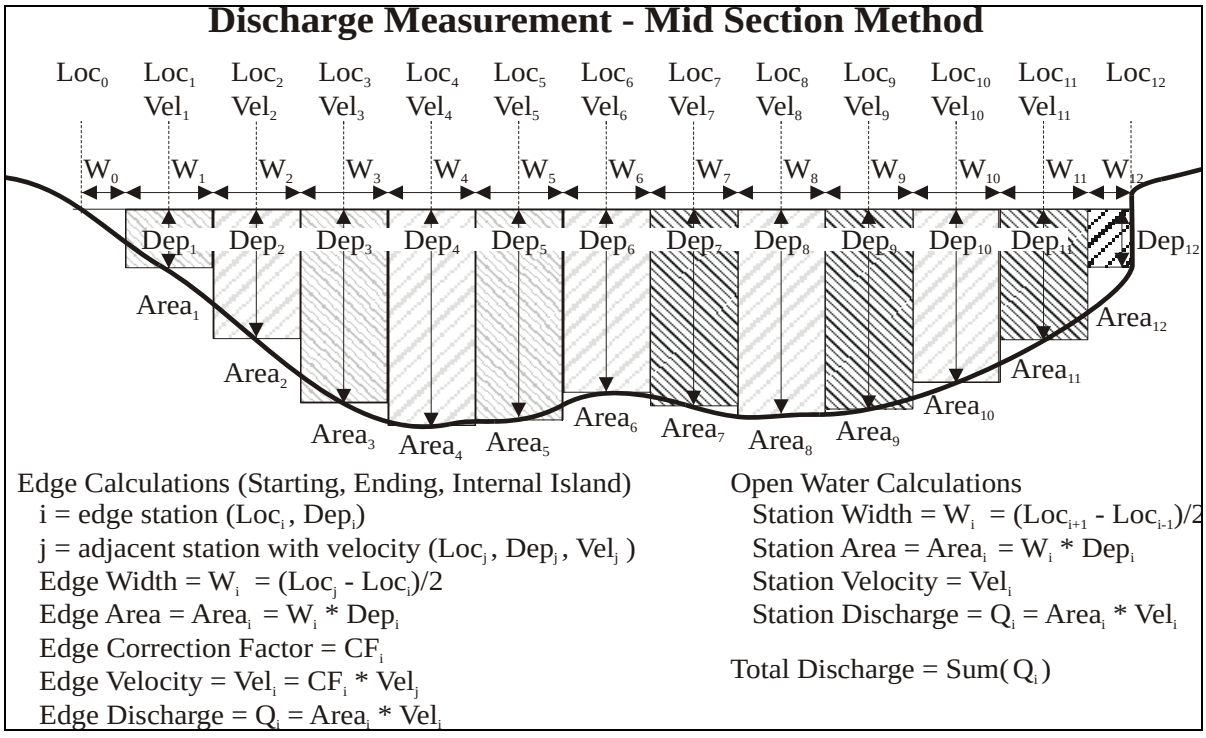


Figure 5 – Mid Section Discharge Equation

- Station width is calculated as normal.
- Effective depth is calculated as **$EffD_i = Dep_i - Ice_i$**.
- Station area is the effective depth times station width **$Area_i = W_i * EDep_i$**.

5.2.2. Mean Section Discharge Equation

The **Mean Section** discharge equation uses the same data collection procedure as the **Mid Section** equation, but differs in the details of how discharge is calculated.

- The **Mean Section** methodology is described in ISO standards 748 (1997) and 9196 (1992).
- Figure 6 shows the **Mean Section** equation. In this figure:
  - **Loc_i** represents the location of measurement station **i**.
  - **Dep_i** represents the measured water depth at station **i**.
  - **Vel_i** represents the mean velocity at station **i** (§5.2.4).

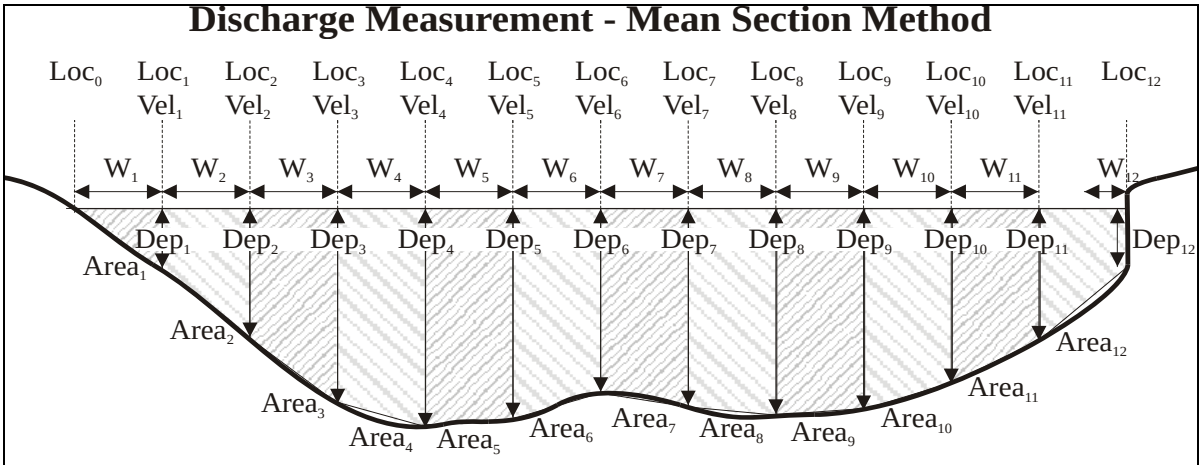
There are a few special cases to consider.

Edges

- Velocity from the adjacent station is used, scaled by a user-supplied correction factor.

Multiple channels (internal islands)

- If a river is split into multiple channels, any internal island(s) must be accounted for in the discharge calculation.
- The stations at each edge of the internal island(s) are treated like the river edges.
- Enter station location and water depth, and then select the velocity measurement method **None** to indicate an internal island. For an internal island, there should be two method **None** stations in a row (one for each edge of the internal island).



Edge Calculations
- Starting edge, second edge of internal island
  - $Q_0 = W_0 = Area_0 = 0.0$
- Ending edge, first edge of internal island
  - i = edge station (Loc_i, Dep_i)
  - Edge Width = $W_i = Loc_i - Loc_{i-1}$
  - Edge Area = $Area_i = W_i * (Dep_i + Dep_{i-1}) / 2$
  - Edge Correction Factor = CF_i
  - Edge Velocity = $Vel_i = CF_i * Vel_{i-1}$
  - Mean Edge Velocity = $MeanV_i = (Vel_i + Vel_{i-1}) / 2$
  - Edge Discharge = $Q_i = Area_i * Vel_i$

Open Water Calculations
- Station Width = $W_i = Loc_i - Loc_{i-1}$
- Station Area = $Area_i = W_i * (Dep_i + Dep_{i-1}) / 2$
- Mean Station Velocity = $MeanV_i = (Vel_i + Vel_{i-1}) / 2$
- Station Discharge = $Q_i = Area_i * MeanV_i$

Total Discharge = $Sum(Q_i)$

Figure 6 – Mean Section Discharge Equation

Ice covered water

- For under ice measurements, calculations must take into account the thickness of the ice.
- Holes are cut through the ice at each measurement station.
- The operator enters station location and water depth as normal.
- The operator enters an ice depth parameter (**Ice**), which is the distance from the water surface to the bottom of the ice or bottom of the slush (if present).
- Station width is calculated as normal.
- Effective depth is calculated as $\mathbf{EffD_i = Dep_i - Ice_i}$.
- Station area is the effective depth times station width $\mathbf{Area_i = W_i * EDep_i}$.

5.2.3. Japanese Discharge Equation

The **Japanese** discharge equation includes several modifications to the two other data collection procedures described above.

- Location and water depth are recorded for every station; however, velocity is only measured at every second station.
  - Stations without a velocity measurement use velocity method **None** (§5.2.4).
- Depth for each station is recorded twice, once when going across the river and a second time on the return trip. The mean of the two values is used for discharge calculations.
  - When the **Japanese** equation is selected, the FlowTracker automatically supports two depth values using the **Set Depth** key; the mean value is displayed.
- Each velocity measurement is repeated twice. The mean of the two values is used for discharge calculations.
- Figure 7 shows the **Japanese** equation. In this figure:
  - $\mathbf{Loc_i}$ represents the location of measurement station **i**.
  - $\mathbf{Dep_i}$ represents the measured water depth at station **i**.
  - $\mathbf{Vel_i}$ represents the mean velocity at station **i** (§5.2.4).

There are a few special cases to consider.

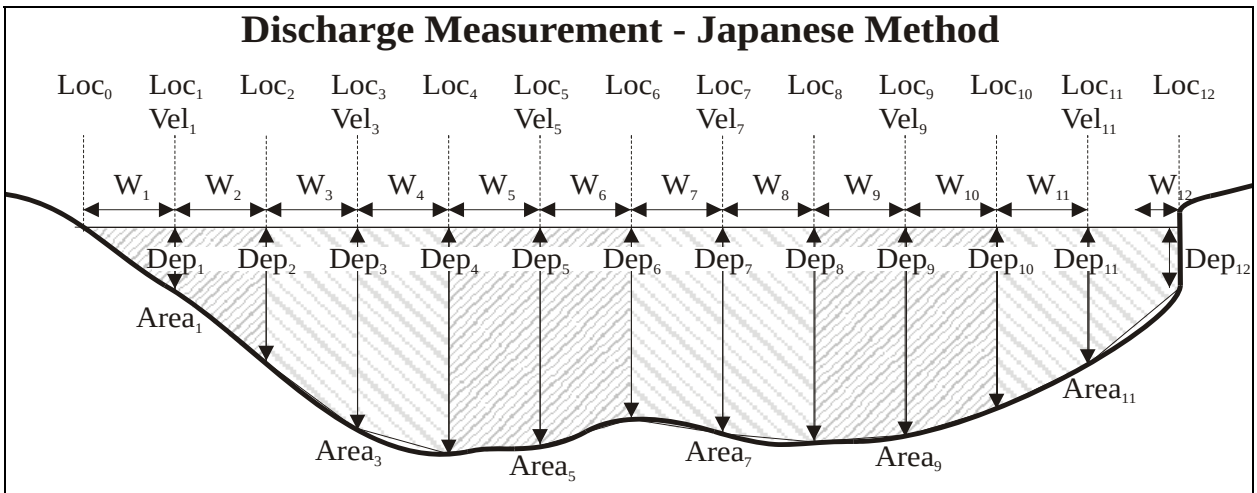


Figure 7 – Japanese Method Discharge Equation

Multiple channels (internal islands)

- If a river is split into multiple channels, any internal island(s) must be accounted for in the discharge calculation.
- The stations at each edge of the internal island(s) are treated like the river edges.
- Enter station location and water depth, and then select the velocity measurement method **None** to indicate an internal island. For an internal island, there should be two method **None** stations in a row (one for each edge of the internal island).

Ice covered water

- For under ice measurements, calculations must take into account the thickness of the ice.
- Holes are cut through the ice at each measurement station.
- The operator enters station location and water depth as normal.
- The operator enters an ice depth parameter (**Ice**), which is the distance from the water surface to the bottom of the ice or bottom of the slush (if present).
- Station width is calculated as normal.
- Effective depth is calculated as $\mathbf{EffD_i = Dep_i - Ice_i}$.
- Station area is the effective depth times station width $\mathbf{Area_i = W_i * EffD_i}$.

5.2.4. Determining Mean Station Velocity (Discharge Measurement Method)

The discharge measurement **Method** specifies how the FlowTracker determines mean velocity at each station.

- The **Method** involves variations in the number of velocity measurements, measurement depths, and how data are combined.
- Table 5-1 lists all **Methods** supported by the FlowTracker.
- **Methods** involving more than one measurement can be done in either direction (from surface to the bottom, or from the bottom towards the surface).
  - The FlowTracker automatically alternates between directions at adjacent stations to make setting the probe location easier.
- Select the method using the **Method +** and **Method –** keys.
- If some **Methods** will never be used, you can specify which methods to display (§2.4.5)
  - From the **Main Menu**, press **1** for **Setup Parameters**.
  - Select **5** for **Discharge Settings**.
  - Select **9** to specify **Methods Displayed**.
- Both fractional and actual measurement depths are shown on the FlowTracker display.
  - Fractional measurement depth is referenced from the surface down (e.g., 0.6*depth down from the surface).
  - Actual measurement depth is referenced from the bottom up (e.g., 0.23 ft above bottom).

There are a few special cases to consider.

Method **None**

- Method **None** is used in two different situations:
  - When no measurement is possible (perhaps due to weed growth) and velocity will be estimated based on velocity from the adjacent station(s).
  - To specify the banks of an internal island (for a multiple channel river).
- If *one* method **None** station is recorded, it is assumed that no measurement was possible.
  - Velocity for this station is based on the mean station velocity from the adjacent station(s) with velocity measurements multiplied by the user-specified correction (**CF**) factor for this station. The default **CF** is 1.00.
- If *two* method **None** stations are recorded together, they are assumed to represent an internal island and discharge is calculated accordingly (§5.2.1, §5.2.2, §5.2.3).

Method **Multi Pt**

- This is a general-purpose method that lets you make any number of velocity measurements at any location in the water column.
  - For each measurement, you must manually enter the measurement depth (using the **Set Meas Depth** key).
  - When all measurements for a station have been made, press the **End Section** or **Abort** key to complete the station.
- The mean velocity is calculated by integrating all velocity measurements considering their location as illustrated in Figure 8.
  - If multiple measurements are made at the same measurement depth, these measurements are averaged prior to calculating the velocity integration.

Table 5-1. FlowTracker Discharge Measurement Methods

Method	Measurement Locations	Mean Velocity Equation
0.6	0.6 * depth	$V_{mean} = V_{0.6}$
0.2/0.8 **0.8/0.2**	0.2 * depth 0.8 * depth	$V_{mean} = (V_{0.2} + V_{0.8}) / 2$
.2/.6/.8 **.8/.6/.2**	0.2 * depth 0.6 * depth 0.8 * depth	$V_{mean} = (V_{0.2} + 2*V_{0.6} + V_{0.8}) / 4$
Ice 0.6	0.6 * effective depth	$V_{mean} = 0.92*V_{0.6}$ (Correction Factor 0.92 can be changed by user)
Ice 0.5	0.5 * effective depth	$V_{mean} = 0.89*V_{0.5}$ (Correction Factor 0.89 can be changed by user)
Ice 2/8 **Ice 8/2**	0.2 * effective depth 0.8 * effective depth	$V_{mean} = (V_{0.2} + V_{0.8}) / 2$
Kreps 2- **Kreps 2+**	0.0 (near surface) 0.62 * depth	$V_{mean} = 0.31*V_{0.0} + 0.634*V_{0.62}$
5 Point+ **5 Point-**	0.0 (near surface) 0.2 * depth 0.6 * depth 0.8 * depth 1.0 (near bottom)	$V_{mean} = (V_{0.0} + 3*V_{0.2} + 3*V_{0.6} + 2*V_{0.8} + V_{1.0}) / 10$
Multi Pt	Any number of points at user-specified depths	Integrated velocity average (Figure 8) Measurements can be made in any order; they are sorted by depth to calculate the integrated mean velocity. Repeat measurements at the same depth are averaged prior to calculating the integrated velocity.
None	No velocity measurement	$V_{mean} = CF * V_{adjacent}$ Mean velocity is based on the velocity from the adjacent station(s), multiplied by a user-specified correction factor. This method is used when velocity measurements cannot be made, and to specify the edges of an internal island in a multiple channel river.
Input V	User input velocity	$V_{mean} = V_{input}$ User enters an estimated velocity value. This method is used when velocity measurement is not possible, most commonly due to weed growth along a riverbank.

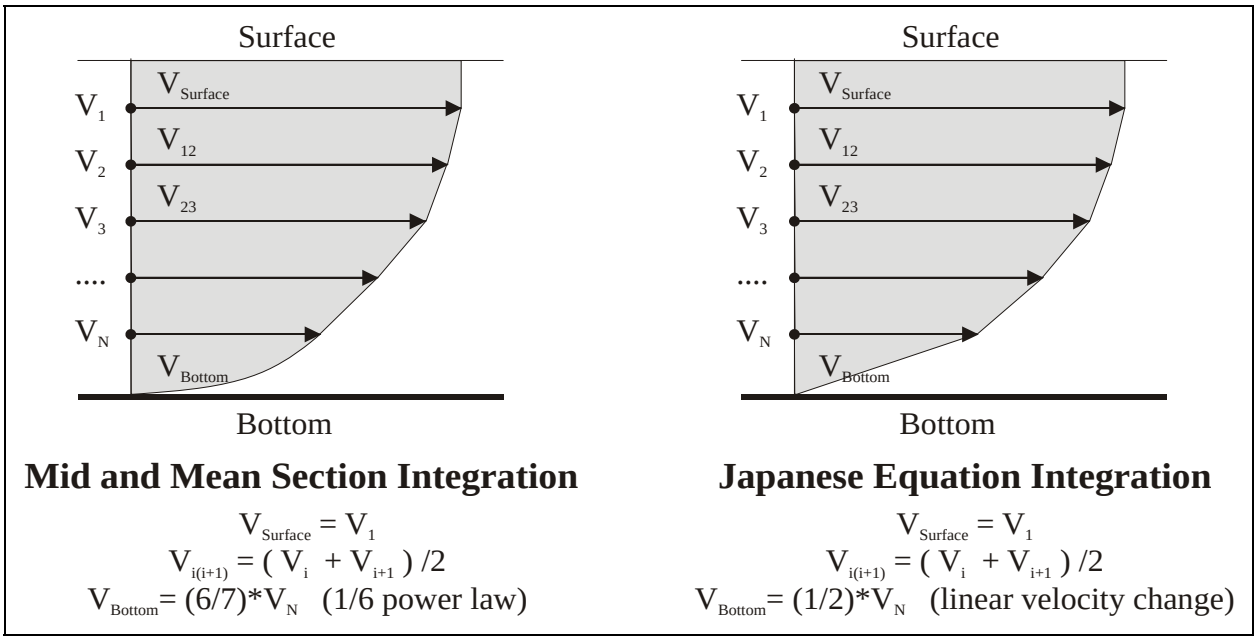


Figure 8 – Multiple Point Mean Velocity Integration

*Correction Factor (***CF***)*

- The correction factor (**CF**) is a user-supplied parameter used to scale the mean station velocity; it is entered using the **Corr. Factor** key.
- The **CF** is most commonly used at edges, internal islands, and other method **None** stations to scale the velocity from the adjacent station(s).
  - The default **CF** value is 1.00.
  - Any value from -1.00 to 1.00, except 0.0, is allowed.
- The **CF** can be entered for any station and mean velocity will be multiplied by the **CF**.
  - One possible use is near the edges in very narrow streams.
  - In these cases, the orientation of the FlowTracker probe can be reversed 180° to allow measurement closer to the edge.
  - A **CF** of -1.00 should be entered to correct the FlowTracker X-velocity.
- Be careful when entering the **CF**, as mean velocity is always scaled by this value. Incorrect use of this parameter will affect the final discharge measurement.

5.2.5. Discharge Uncertainty Calculation SmartQC

The FlowTracker estimates the uncertainty of every discharge measurement. This calculation can be done using two different ways: **Statistical** or **ISO**.

- The **Statistical** (abbreviations **Stats**) uncertainty calculation uses a method developed by researchers at the U.S. Geological Survey; this is the default calculation as it provides the most reliable indicator of measurement quality.
- The **ISO** method is based on the international standard. It provides users with the results of a published, standard technique; however, in some cases this calculation may not provide a reliable indicator of data quality.

The uncertainty calculations are based on several different parameters. In addition to overall uncertainty, the FlowTracker also looks at the contribution of each parameter.

- **Accuracy**: the accuracy of the FlowTracker calibration (this is generally negligible).
- **Depth**
  - In the **Statistical** calculation, this term includes both uncertainty in the depth measurement and the effect of changes in depth between stations.
  - In the **ISO** calculation, this term includes only the uncertainty in depth measurements.
- **Velocity**
  - In the **Statistical** calculation, this term includes both uncertainty in the velocity measurement and the effect of changes in velocity between stations.
  - In the **ISO** calculation, this term includes only the uncertainty in velocity measurements.
- **Width**
  - Estimated uncertainty in width measurements.
- **Method**: Discharge measurement method (§5.2.4)
  - Use for the **ISO** method only.
- **Number of stations**
  - Use for the **ISO** method only.

In the FlowTracker real time display, uncertainty is shown with the calculated discharge; the largest individual source of uncertainty is also shown. The *FlowTracker* software program shows both uncertainty calculations and the contribution of each parameter to the overall uncertainty. A complete description of the discharge uncertainty calculations can be found in Appendix C – Discharge Uncertainty Calculation.

5.3. Discharge Data Collection Procedure

This section outlines a typical procedure when collecting data in the **Discharge Mode**. Though typical, the sequence of steps may vary based on your application.

5.3.1. Preparing the System for Discharge Data Collection in the Field

Preliminary

- Use §5.2 to determine the discharge procedure and equation you will use.
- Run pre-deployment diagnostics before taking the instrument to the field (§3.2 and §6.5).

Mount the Probe

- Mount the probe properly to avoid flow interference (§8.1).
- Be sure to keep the X direction perpendicular to the tag line being used to define the cross section at all times (see §5.2 and 8.1).

Turn the FlowTracker On

- Hold the **On/Off** key for one second until you see the LCD screen turn on.
- From the opening (i.e.; wakeup) screen, press the **Enter** key to view the **Main Menu**.

Field Diagnostics

- Perform field diagnostics (§3.2.2).
  - Check recorder status (**2** in **System Functions Menu**)
  - Check temperature data (**4** in **System Functions Menu**)
  - Check battery capacity (**5** in **System Functions Menu**)
  - Check raw velocity and SNR data (**6** in **System Functions Menu**)
  - Check system clock (**9** in **System Functions Menu**)

Set System Parameters

- Check the **Setup Parameters Menu** (**1** in **Main Menu**; §2.4).
  - Units system [Metric/English] (**1** in **Setup Parameters Menu**)
  - Averaging time (**2** in **Setup Parameters Menu**)
  - Data collection mode (set to **Discharge**) (**3** in **Setup Parameters Menu**)
  - QC Settings (**4** in **Setup Parameters Menu**) (§2.4.4)
  - Discharge Settings (**5** in **Setup Parameters Menu**) (§2.4.5)
  - Salinity (**6** in **Setup Parameters Menu**)
    - In salt water, a zinc anode should be installed (§8.5.6).

5.3.2. Data Collection in Discharge Mode

Table 5-2 lists the items shown on the display screen during data collection.

Table 5-2. Items Displayed During Data Collection (Discharge Mode)

Label	Description	English	Metric
RatedQ	Rated discharge (as input by the user)	ft^3/s	m^3/s
TotalQ	Computed discharge (based on FlowTracker measurements)	ft^3/s	m^3/s
Loc	Location	ft	m
Dep	Water depth	ft	m
0.6 0.2/0.8, *etc.*	Velocity method used; §5.2.4, Table 5-1	-	-
0.6(0.32)	Measurement depth • First is the fractional depth (e.g., **0.6** indicates 0.6 * depth), referenced from the surface down. • Second (in parenthesis) is the actual depth, referenced from the bottom up. This calculated depth includes the effect of ice, if present.	ft	m
Vel	X velocity component	ft/s	m/s
SNR	Signal-to-noise ratio; §1.4.2	dB	dB
Time	Time remaining in sampling average		
σV	Standard error of velocity; §1.4.3	ft/s	m/s
Spikes	Number of spikes removed from mean; §1.4.5	-	-
Bnd	Boundary QC value; §1.4.4	-	-
NPts	Number of points collected (may differ from averaging time if **Abort** key used)	-	-
Ang	Flow angle relative to X direction; §1.4.6	°	°
StnQ	Station discharge	ft^3/s	m^3/s
StnV	Mean station velocity; §5.2.4	ft/s	m/s
%Q	Station discharge as percent of either rated or measured discharge, based on the discharge **Reference** value (§2.4.5).	%	%

The following steps describe the data collection sequence when in **Discharge Mode**.

1. From the **Main Menu**, press **3** to **Start Data Run**.
2. The file name menu will be displayed (right).

```
   Data File Name
1: Name (none)
2: Extension (none)
9: Accept name
```

   a. Press **1** to specify file name (required).
      - A maximum of eight characters (letters or numbers) are allowed.
      - To enter an alpha-numeric filename:
        - To enter a number, simply type the number.
        - Letters use the mobile phone method (e.g., for **C** press **2** four times: **2–A–B–C**).
        - Press **Enter** to complete the filename.
        - Use the **Delete** key to correct mistakes.
      - After entry, the file name is shown in parentheses.
   b. Press **2** to specify file extension (optional).
      - A maximum of 3 characters (letters or numbers) is allowed
      - After entry, the extension is shown in parentheses.
   c. Press **9** when ready to start data collection.
      - The system checks that the filename does not already exist on the recorder, and then displays starting gauge information.
   d. **Or**, press **Abort** or **End Section** to return to the **Main Menu**.

3. Enter site and operator name (right). These are optional values used only to document the data set.
   a. Press **1** to enter site name.
   b. Press **2** to enter operator name(s).
   c. Up to 20 characters are allowed for each entry.
   d. Press **9** to start data collection.

```
1:Site
Poudre River FC
2:Operator Billy Bob
9:Start
```

4. At any point, press **QC Menu** to access a variety of special functions (§2.6). SmartQC
   a. The operator is prompted to do so at the start and end of each data file; this is typically to enter starting and ending gauge height values.
   b. Enter supplemental data (gauge height, rated flow, user comments).
   c. Modify **QC Settings** (§2.4.4) or **Discharge Settings** (§2.4.5).
   d. Change averaging time (**Avg Time**) for each measurement.
   e. Display **Raw Velocity Data** (§2.5.6).
   f. Run and record an additional **Auto QC Test** (§2.5.7).

```
Press QC Menu
At Any Time
For Gauge Data
ENTER = Continue
```

5. You will be prompted (right) to conduct an automatic QC test (§2.5.7). SmartQC
   a. Press **1** to run the automatic QC test; follow the on-screen instructions.
   b. Press **2** to skip the test and begin data collection.

```
Automatic QC Test

1:Run Test
2:Skip Test
```

6. Starting-edge information will be displayed (right).
   a. Press **Set Location** to set starting-edge location (**Loc**).
   b. Press **Set Depth** to set starting-edge water depth (**Dep**).
   c. If needed, press **Set Ice Depth** (**Ice**); this is displayed only if non-zero.
   d. Press **Corr. Factor** to set any required correction factor (**CF**); see §5.2.4.
   e. Press **LEW/REW** to toggle the starting edge of water – left or right (this is used to document the data set and is not required).
   f. When complete, press **Next Station** to continue.

```
   Starting Edge
Loc 1.00   Dep 0.50
LEW        CF 1.00
 Press Next Station
```

7. Station information will be displayed (right).
   a. Press **Set Location** to set station location (**Loc**).
   b. Press **Set Depth** to set water depth (**Dep**).
   c. If needed press **Set Ice Depth** (**Ice**); this is displayed only if non-zero.
   d. Use **Method+** and **Method–** to select the method used for velocity at that station (§5.2.4). Note that the measurement depth will change at the same time.
   e. If needed press **Corr. Factor** to set the correction factor (**CF**), this is displayed only if the value is something other than **1.00**.

```
Stn 1      Loc 2.00
0.6        0.6(0.54)
           Dep 1.35
          Enter=More
```

8. When all values are correctly set, and the probe is located as desired, press **Measure** to start data collection. Make sure you keep the probe's X direction perpendicular to the tag line being used to define the stream cross section (see Figure 4, §5.2, and §8.1).
   Note: You can recover if you mistakenly press **Measure** with an incorrect parameter or **Method**. Press **Abort** to terminate the measurement (or let the measurement finish), and press **2** to repeat the measurement. Until one measurement is accepted at a station, you have the ability to change all parameters. After one measurement has been accepted, **Method** can no longer be changed (although other parameters can still be changed).

9. An updating display (right) shows velocity and SNR data. Displayed values represent the running mean of data at that station.

```
Loc 2.00  MDep .6D
Vel    2.23
SNR    14.3
Time   19
```

10. When the station is complete, a summary of velocity and quality control data is shown (right).
    a. Prior to the summary screen, the data are reviewed using a variety of quality control criteria (§1.4). If any data are outside expected values, a warning is issued.
    b. The values represent the mean over the entire averaging period after removing any spikes.

```
Vel 2.25   σV 0.04
Ang 5°     SNR 15.1
Spikes 0   Bnd BEST
1:Accept   2:Repeat
```

    c. Press **1** to accept the measurement and move on to the next measurement (or to the next station if this is the last measurement for this station).
    d. Press **2** to repeat the measurement (using the same station number).
    Note: When a measurement is repeated, data are not lost. However, you will no longer be able to view the *old* data from the keypad interface. The *old* data are still recorded. Later, the data can be extracted in the raw data file (**`*.dat`**) and the measurement summary file (**`*.sum`**), but not in the discharge summary file (**`*.dis`**).
11. If there is more than one measurement at a station (e.g., 0.2 and 0.8 times the water depth), the system will proceed to the next measurement in the series.
    - When using method **Multi Pt**, any number of measurements for each station is allowed. When the last measurement is complete, press **End Section** or **Abort** to end that station.
12. When a station is completed, the FlowTracker displays the next station.
    a. Location, depth, and method data for new stations are predicted using previous stations.
    b. If a multiple measurement method was used (e.g., 0.2 and 0.8 times water depth), the next station will use the same method in the opposite order (i.e.; 0.8 then 0.2 times depth).
    c. To add more stations, repeat Steps 7 through 12; otherwise, continue with Step 13.
    Note: In **Discharge Mode**, the maximum number of stations for any data file is 100, and the maximum number of measurements is 300. The starting and ending edges are considered stations. Station measurements that are repeated (Step 10.d.), do not count towards the maximum number of stations.
13. Use **Previous Station** and **Next Station** to scroll through the completed station(s).
    a. Stations are sorted based on location and displayed in that order.
    b. Four screens are available for each completed station; use **Enter** to scroll through screens.

```
Stn 1      Loc 2.00
0.6        0.6(0.54)
           Dep 1.35
          Enter=More
```

```
Stn 1      Loc 2.00
Npts 40    0.6(0.54)
Vel 2.25
Ang 5°    Enter=More
```

```
Stn 1      Loc 2.00
SNR 14.5   0.6(0.54)
σV 0.04    Bnd BEST
Spikes 0  Enter=More
```

```
Stn 1      Loc 2.00
StnQ 2.523 cfs
StnV 2.25 ft/s
%Q 4.5%   Enter=More
```

    c. You can edit station information using **Set Location**, **Set Depth**, **Corr.Factor**, **Set Ice Depth**.
    d. **Next Station** and **Previous Station** are not active from the time the **Measure** key is used to start a station until the time the last measurement for that station is complete.
    e. **Measure** is active only on the current (uncompleted) station.

f. Use **Calculate Disch.** to view (right) the total discharge for all completed stations. This is a temporary calculation and does not affect ongoing data collection.

```
TotalQ 44.234 cfs
RatedQ 45.000 cfs
Difference -1.7%
    Press Enter
```

14. It is possible to delete or repeat a station if desired.
    a. To delete an existing (completed) station:
       - All measurements at that station will be deleted. You cannot delete only one measurement at a station.
       - Use **Next Station** and **Previous Station** to scroll to the desired station.
       - Press **Delete**.
       - When prompted, enter **123** to confirm; any other entry keeps the station intact.
       - The station is deleted, and the display returns to the current station.
    b. To repeat a station:
       - **Delete** the desired station.
       - At the current station, enter the location, depth, and measurement method of the station to be repeated. Follow standard measurement procedures for that station.
       - The new station data will automatically be sorted into the correct position so that discharge calculations are accurate.
    c. Data from a deleted station is not lost. However, you will no longer be able to view the *old* data from the keypad interface. The *old* data are still recorded. Later, the data can be extracted in the raw data file (**`*.dat`**) and the measurement summary file (**`*.sum`**), but not in the discharge summary file (**`*.dis`**).
15. When all stations are completed, press **End Section**.
    a. The FlowTracker reviews all data using several quality control criteria (§1.4). SmartQC
       - If any stations / measurements are outside expected values, a warning is issued and these measurements are displayed.
       - You can review data and repeat or add measurements to ensure optimal data quality.
    b. When the review is complete, the ending-edge screen is shown. At this point, enter the ending-edge information. This screen works just like the starting-edge screen (Step 6).
    c. **Next Station** and **Previous Station** can be used to view/edit other stations.
       - To add new measurements, press the **Measure** key and confirm when prompted that you wish to re-open the file and add measurements.
    d. When all values are correctly set, press **Calc. Disch.** to complete discharge calculations and close the file.
16. After final discharge calculations are complete, nine data screens are available (next page and Table 5-3).
    a. Press **Enter** to move between the different display screens.
    b. Press **Previous Station** from any file summary screen to view the station data. You can then scroll through all station data using the **Next Station** and **Previous Station** keys. Press **Next Station** from the ending edge screen to return to the file summary screens.
17. Press **0** to return to the main menu. Note: The **0** key is only active when the display is showing the discharge summary. If you have scrolled back to a previous station to view data, you will not be able to exit until you scroll forward to the discharge summary.

IMPORTANT:
Always return to the Main Menu before turning the system off to ensure all data has been saved.

TotalQ 44.234 cfs RatedQ 45.000 cfs Difference -1.7% 0=Exit or Enter=More	Q Uncertainty 3.5% Largest Source Num Stations 0=Exit or Enter=More	Num Stations 27 V Mean 1.43 ft/s V Max 2.21 ft/s 0=Exit or Enter=More
Width 23.000 ft Area 47.350 ft^2 0=Exit or Enter=More	Depth Mean 2.77 ft Depth Max 3.15 ft 0=Exit or Enter=More	SNR Mean 16.5 dB σV Mean 0.05 ft/s Temperature 61.2°F 0=Exit or Enter=More
Start Height 4.900 End Height 5.000 Change 0.100 ft 0=Exit or Enter=More	File 555312.100 Mode: Discharge 2001/06/25 14:24:15 0=Exit or Enter=More	Site Poudre River FC Operator Billy Bob 0=Exit or Enter=More

Table 5-3. Items Displayed on Summary Screens (Discharge Mode)

Label	Description	English Units	Metric Units
RatedQ	Rated discharge	ft^3/s	m^3/s
TotalQ	Calculated discharge	ft^3/s	m^3/s
Q Uncertainty	Uncertainty in discharge measurement (§5.2.5)	%	%
Stations	Total number of stations (including edges)	-	-
MeanV	Mean velocity (equals discharge / area)	ft/s	m/s
Max V	Maximum station velocity	ft/s	m/s
Width	Total width	ft	m
Area	Total area	ft^2	m^2
Mean Depth	Mean river depth (area / width)	ft	m
Max Depth	Maximum station depth	ft	m
MeanSNR	Mean signal to noise ratio; §1.4.2	dB	dB
MeanσV	Mean standard error of velocity; §1.4.3	ft/s	cm/s
Temperature	Mean water temperature.	ºF	°C
Start / End Height, Change	First and last gauge height values, and the difference between the two; §2.6	ft	m
Site	Site name	-	-
Operator	Operator name		

Section 6. PC Software for the FlowTracker

The *FlowTracker* software (Figure 9) is intended to be largely self-explanatory; this section is provided for reference purposes. The software can be found on the CD included with the system or downloaded from the SonTek/YSI website at www.sontek.com.

6.1. Installing Software

To install the PC-based FlowTracker software on your computer:

- *FlowTracker* software is compatible with Windows 2000 and XP.
- Insert the distribution CD in your computer.
- An installation menu should automatically appear after the CD has been inserted.
  - If the installation window does not appear in a few seconds, click **Start | Run** and type `d:\install.exe` where `d:\` is the letter of your CD-ROM drive.
- Click the **FlowTracker Software Installation** button from the software installation menu.
- Follow the on-screen installation instructions.
- We also recommend installing *SonUtils*.
- Click the **SonUtils Software Installation** button from the software installation menu.
- Follow the on-screen installation instructions.

Links to the FlowTracker User's and Technical manuals are provided in the software.

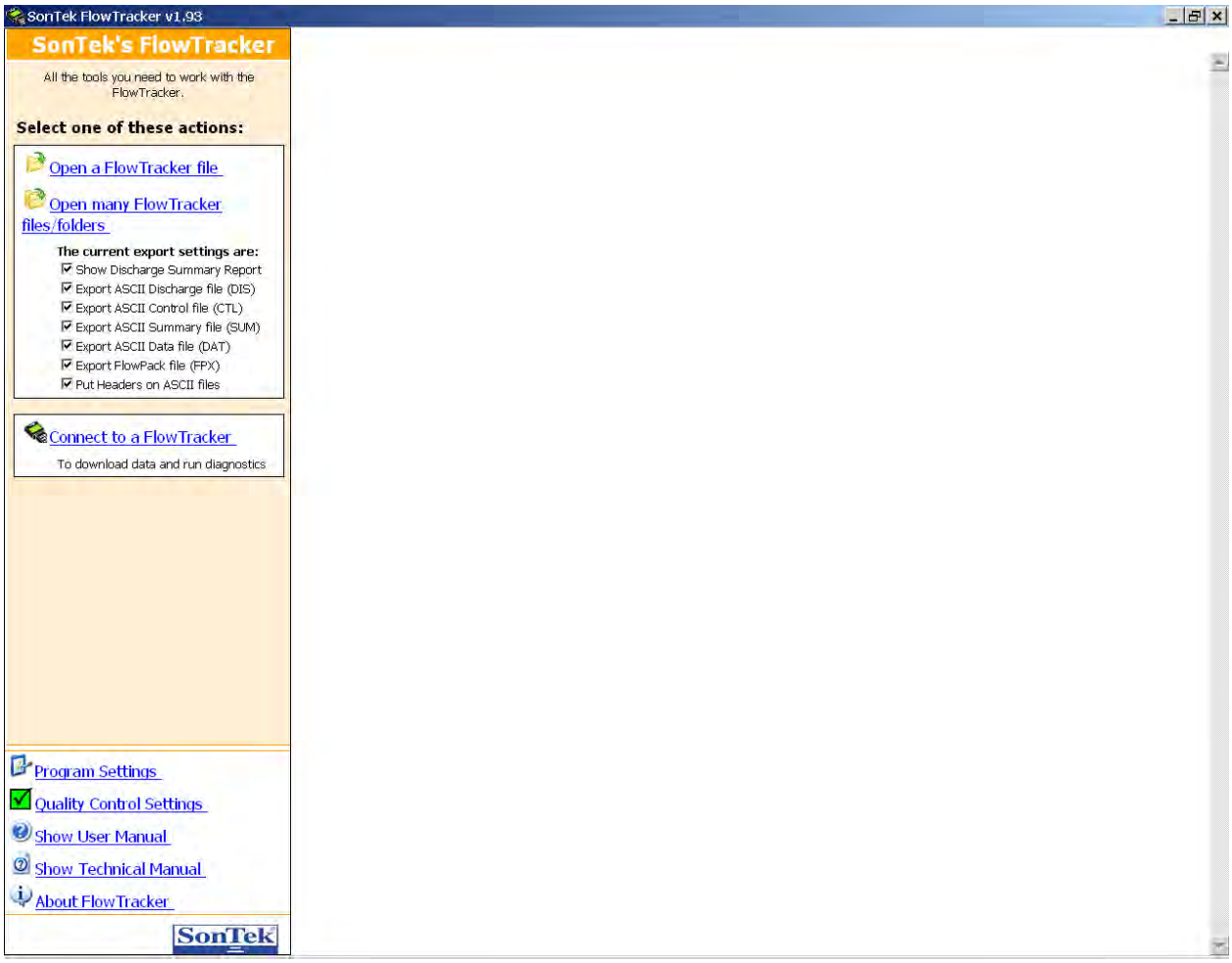


Figure 9 – FlowTracker Launch Window

6.2. FlowTracker Windows Software

The *FlowTracker* Windows software package is used for all major FlowTracker functions.

- To run *FlowTracker*, click **Start | Programs | SonTek Software | FlowTracker**.

Figure 9 shows the *FlowTracker* software launch window. From the launch window:

- Click **Open a FlowTracker File** to display and export data from a single data file, see §6.3.
  - Select data export options using **Program Settings**.
  - Select the desired output data and file formats; several are available.
    - **Discharge Summary Report**: A graphical report for easy viewing and printing.
    - **ASCII Discharge File** (**DIS**): Final data results in a self-explanatory form that is easy to integrate with database utilities.
    - **ASCII Summary File** (**SUM**): Velocity and quality control data from all measurements.
    - **ASCII Raw Data File** (**DAT**): Raw, one-second velocity and SNR data.
    - **ASCII Control File** (**CTL**): System configuration data.
  - Output formats should be self-explanatory and can include optional column headers.
- Click **Open many FlowTracker files/folders** to display and export data from multiple FlowTracker files or folders. This operation is referred to as Batch Export. When this item is selected, the **Batch Export** window is displayed (Figure 10). Use the **Add File** and **Add Folder** buttons to add files/folders for processing. When a folder is added, all FlowTracker files in that folder are processed. Items may be removed from the list by selecting them and clicking **Remove**. When **Export** is clicked, all the listed files/folders are processed using the options selected from the main menu. If **Show Discharge Summary Report** is selected, all files will be added as tabs to the main window.
- Click **Connect to a FlowTracker** to establish communications with a FlowTracker connected to a COM port on your computer. After clicking **Connect**, you have the following options.
  - **Recorder** – Download data files from the FlowTracker to your computer; see §6.4.
  - **BeamCheck** – Perform detailed system diagnostics; see §6.5.

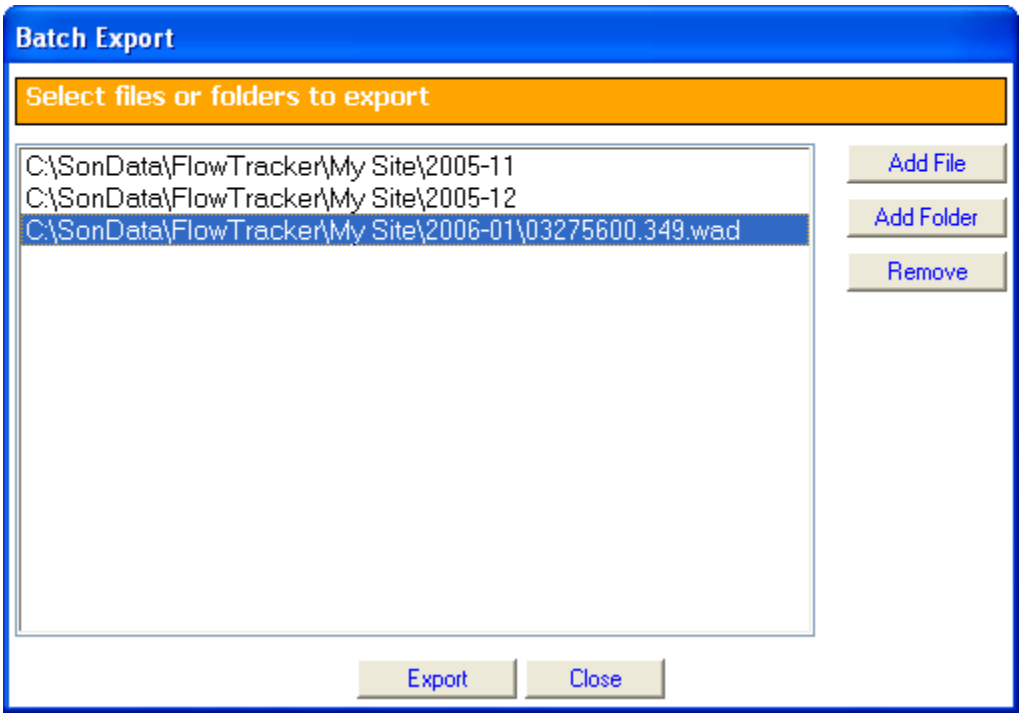


Figure 10 – Batch Export Window

6.3. Data Display and Export

FlowTracker data files are recorded in a compact binary format. The *FlowTracker* software is used to access these files, generating a graphical data report and various ASCII output files, each containing a particular type of data. To access the binary data files, use the following steps.

- Run the *FlowTracker* software (click **Start | Programs | SonTek Software | FlowTracker**).
- Download data from the FlowTracker to your computer as described in §6.4.
- Click **Program Settings** to specify the output units system, language settings, and (if desired) a fixed output directory for all ASCII output files (Figure 11). Click **OK** when done.
  - Language settings affect the software display, data report, and all ASCII output files.
  - Specify a different output directory for the ASCII files (if desired) using the **Browse** button in the **Export Settings** section (Figure 11).
  - You can include a logo to be added to all FlowTracker data reports if desired. Click **Browse** in the **Report Logo** section.
- Select the desired output file types (Figure 12).
  - **Show Discharge Summary Report**: Figure 13 and Figure 14 show the final discharge calculation and measurement summary report in tabular and graphic form. This includes automatic quality control analysis to flag measurements that may include suspect data.
  - **Export ASCII Discharge file (DIS)**: Final discharge calculation data and overall measurement summary. The most widely used output file, especially for database integration.
  - **Export ASCII Control file (CTL)**: System configuration data.
  - **Export ASCII Summary file (SUM)**: All mean data recorded with each measurement.
  - **Export ASCII Data file (DAT)**: Raw one-second velocity and SNR data.
  - **Export FlowPack file (FPX)**: Binary file for use with SonTek's *FlowPack* software.
  - **Put Headers on ASCII files**: Adds/removes column headers from above ASCII files.
- Click the **Open a FlowTracker file** or **Open many FlowTracker files/folders** button; use the browse window to select FlowTracker binary files/folders (file extension **`*.wad`**).
- *FlowTracker* looks for data files with the **`*.wad`** file extension and generates the selected reports and output files selected (Figure 12). All output files use the same base file name with different extensions based on the content of the files. **Important: *FlowTracker* does NOT prompt before overwriting the ASCII output files. Be sure any modified files, or files using the same file name, have been moved to a different folder before extracting the ASCII data.**

Table 6-1 describes the parameters reported in FlowTracker output files.

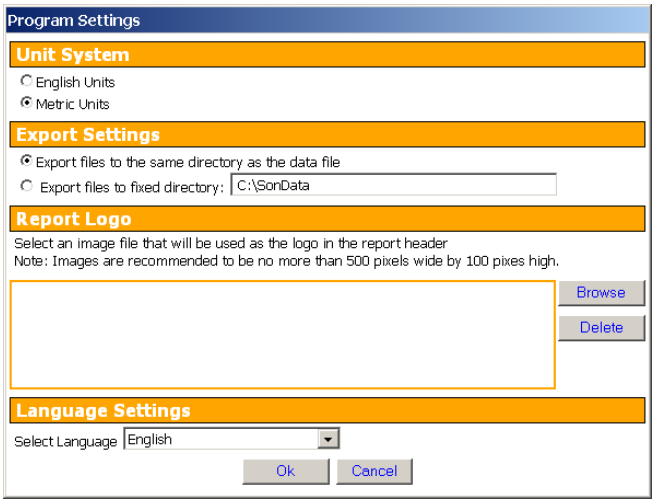
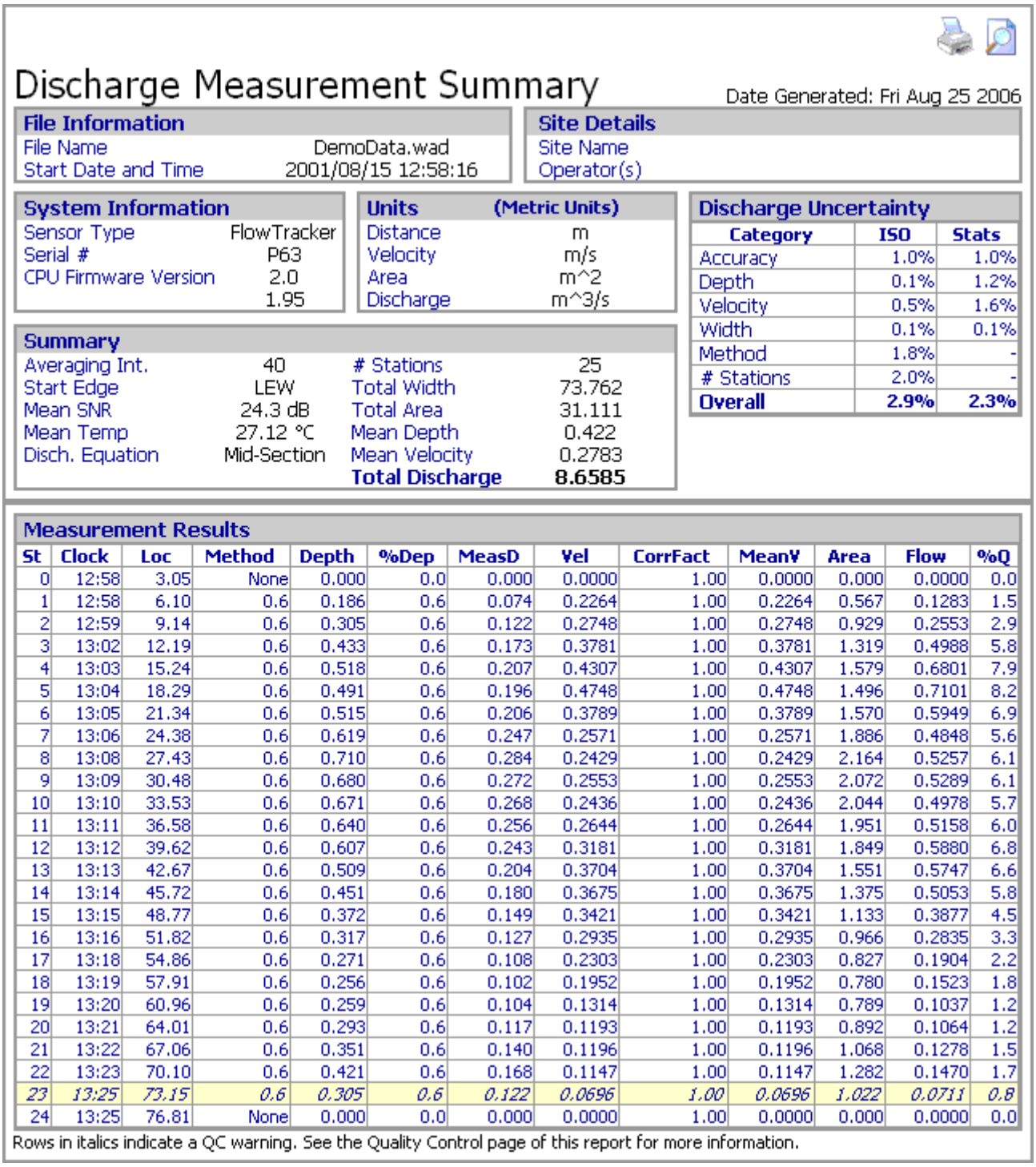


Figure 11 – FlowExporter Options Window



Figure 12 – Output File Options



Discharge Measurement Summary

Date Generated: Fri Aug 25 2006

File Information

File Name	DemoData.wad
Start Date and Time	2001/08/15 12:58:16

Site Details

Site Name	
Operator(s)	

System Information

Sensor Type	FlowTracker
Serial #	P63
CPU Firmware Version	2.0
	1.95

Units (Metric Units)

Distance	m
Velocity	m/s
Area	m^2
Discharge	m^3/s

Discharge Uncertainty

Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.1%	1.2%
Velocity	0.5%	1.6%
Width	0.1%	0.1%
Method	1.8%	-
# Stations	2.0%	-
Overall	**2.9%**	**2.3%**

Summary

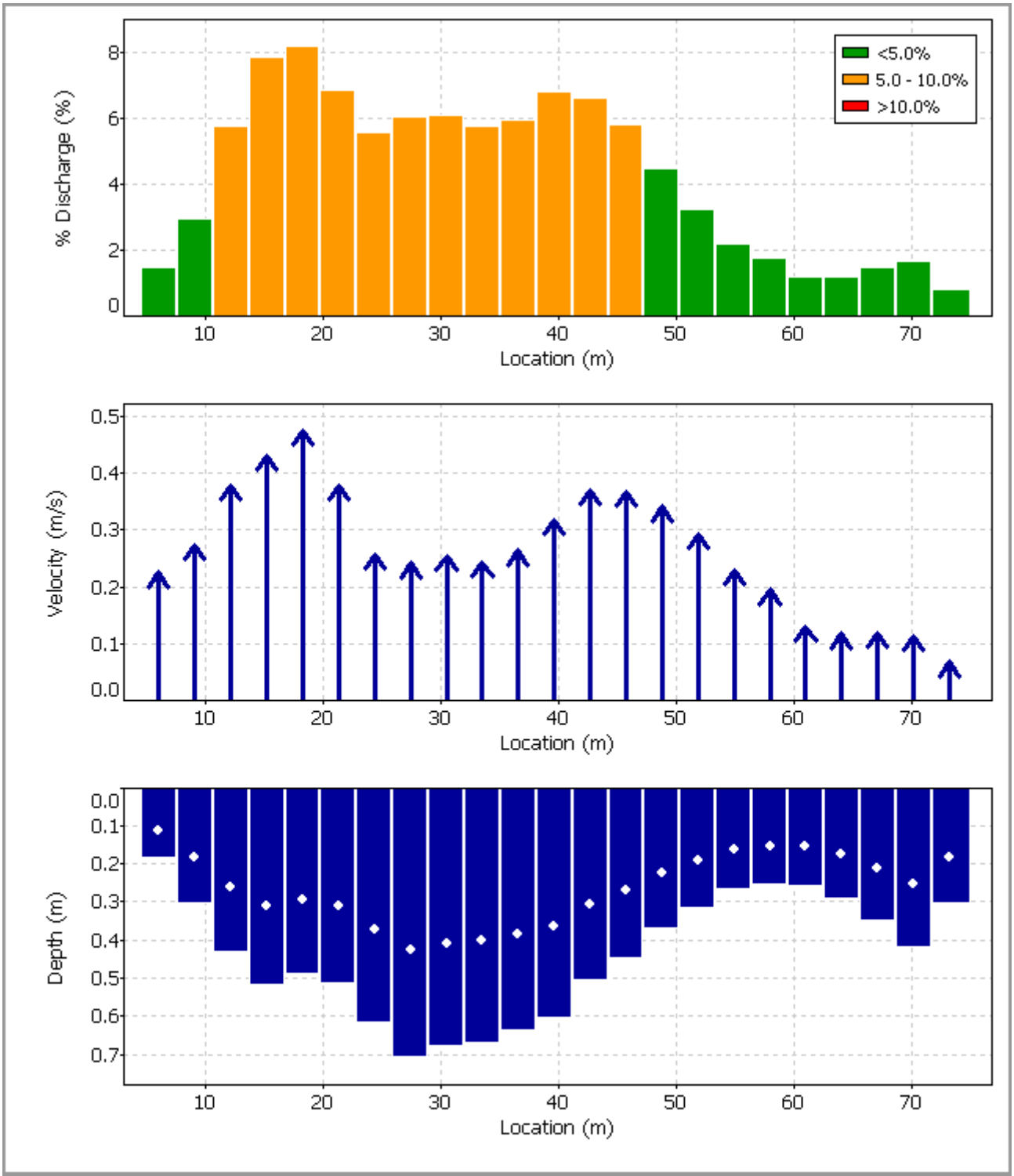
Averaging Int.	40	# Stations	25
Start Edge	LEW	Total Width	73.762
Mean SNR	24.3 dB	Total Area	31.111
Mean Temp	27.12 °C	Mean Depth	0.422
Disch. Equation	Mid-Section	Mean Velocity	0.2783
		Total Discharge	**8.6585**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	12:58	3.05	None	0.000	0.0	0.000	0.0000	1.00	0.0000	0.000	0.0000	0.0
1	12:58	6.10	0.6	0.186	0.6	0.074	0.2264	1.00	0.2264	0.567	0.1283	1.5
2	12:59	9.14	0.6	0.305	0.6	0.122	0.2748	1.00	0.2748	0.929	0.2553	2.9
3	13:02	12.19	0.6	0.433	0.6	0.173	0.3781	1.00	0.3781	1.319	0.4988	5.8
4	13:03	15.24	0.6	0.518	0.6	0.207	0.4307	1.00	0.4307	1.579	0.6801	7.9
5	13:04	18.29	0.6	0.491	0.6	0.196	0.4748	1.00	0.4748	1.496	0.7101	8.2
6	13:05	21.34	0.6	0.515	0.6	0.206	0.3789	1.00	0.3789	1.570	0.5949	6.9
7	13:06	24.38	0.6	0.619	0.6	0.247	0.2571	1.00	0.2571	1.886	0.4848	5.6
8	13:08	27.43	0.6	0.710	0.6	0.284	0.2429	1.00	0.2429	2.164	0.5257	6.1
9	13:09	30.48	0.6	0.680	0.6	0.272	0.2553	1.00	0.2553	2.072	0.5289	6.1
10	13:10	33.53	0.6	0.671	0.6	0.268	0.2436	1.00	0.2436	2.044	0.4978	5.7
11	13:11	36.58	0.6	0.640	0.6	0.256	0.2644	1.00	0.2644	1.951	0.5158	6.0
12	13:12	39.62	0.6	0.607	0.6	0.243	0.3181	1.00	0.3181	1.849	0.5880	6.8
13	13:13	42.67	0.6	0.509	0.6	0.204	0.3704	1.00	0.3704	1.551	0.5747	6.6
14	13:14	45.72	0.6	0.451	0.6	0.180	0.3675	1.00	0.3675	1.375	0.5053	5.8
15	13:15	48.77	0.6	0.372	0.6	0.149	0.3421	1.00	0.3421	1.133	0.3877	4.5
16	13:16	51.82	0.6	0.317	0.6	0.127	0.2935	1.00	0.2935	0.966	0.2835	3.3
17	13:18	54.86	0.6	0.271	0.6	0.108	0.2303	1.00	0.2303	0.827	0.1904	2.2
18	13:19	57.91	0.6	0.256	0.6	0.102	0.1952	1.00	0.1952	0.780	0.1523	1.8
19	13:20	60.96	0.6	0.259	0.6	0.104	0.1314	1.00	0.1314	0.789	0.1037	1.2
20	13:21	64.01	0.6	0.293	0.6	0.117	0.1193	1.00	0.1193	0.892	0.1064	1.2
21	13:22	67.06	0.6	0.351	0.6	0.140	0.1196	1.00	0.1196	1.068	0.1278	1.5
22	13:23	70.10	0.6	0.421	0.6	0.168	0.1147	1.00	0.1147	1.282	0.1470	1.7
23	*13:25*	*73.15*	*0.6*	*0.305*	*0.6*	*0.122*	*0.0696*	*1.00*	*0.0696*	*1.022*	*0.0711*	*0.8*
24	13:25	76.81	None	0.000	0.0	0.000	0.0000	1.00	0.0000	0.000	0.0000	0.0

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

Figure 13 – FlowTracker Discharge Measurement Summary Report (Top Half)



Quality Control

St	Loc	%Dep	Message
23	73.15	0.6	High angle: 27

Figure 14 – FlowTracker Discharge Measurement Summary Report (Bottom Half)

Table 6-1. Description of Output Parameters

Label	Description	English	Metric
St	Station number. Note: Stations may include more than one measurement.		
#	Burst or measurements number. Even measurements not used for final calculations are recorded and output in the .sum and .dat files.		
Clock	Measurement time from FlowTracker clock		
Loc	Station location	ft	m
Loc1	Station location value 1 (general mode only)	ft	m
Loc2	Station location value 2 (general mode only)	ft	m
Method	Discharge measurement method (§5.2.4)		
Depth	Water depth	ft	m
Depth1	Water depth 1 (when RepeatDepth enabled, normally with Japanese discharge equation)	ft	m
Depth2	Water depth 2 (when RepeatDepth enabled, normally with Japanese discharge equation)	ft	m
MeanD	Mean water depth (when RepeatDepth enabled, normally with Japanese discharge equation)	ft	m
IceD	Ice depth, water surface to bottom of ice or slush	ft	m
%D	Measurement depth location, as fraction of the effective depth. Effective depth is water depth minus ice depth. This value is referenced from the surface down (e.g., 0.6 indicates 0.6*depth down from the surface).		
MeasD	Measurement depth location, in depth units. This value is referenced from the bottom (e.g., 0.40 m up from the bottom).	ft	m
Vel	Mean X velocity	ft/s	m/s
MeanV	Mean station velocity	ft/s	m/s
Vx	Mean X velocity	ft/s	m/s
Vy	Mean Y velocity	ft/s	m/s
Vz	Mean Z velocity	ft/s	m/s
VelX	Raw 1 second X velocity	ft/s	m/s
VelY	Raw 1 second Y velocity	ft/s	m/s
VelZ	Raw 1 second Z velocity	ft/s	m/s
CorrFact	Correction factor used to scale measured velocity		
Area	Station area	ft^2	m^2
Flow	Station discharge	ft^3/s	m^3/s
%Q	Percent of total discharge	%	%
Npts	Number of samples in measurement; one sample collected per second		
Spike	Number of spikes removed before calculating mean values		
SNR	Mean Signal-to-Noise Ratio	dB	dB
SNR1	Signal-to-Noise Ratio beam 1	dB	dB
SNR2	Signal-to-Noise Ratio beam 2	dB	dB
SNR3	Signal-to-Noise Ratio beam 3	dB	dB
Angle	Velocity angle calculated as atan(Vy/Vx)	°	°
Verr	Standard error of X velocity (§1.4.3)	ft/s	m/s
VxErr	Standard error of X velocity (§1.4.3)	ft/s	m/s
VyErr	Standard error of Y velocity (§1.4.3)	ft/s	m/s
VzErr	Standard error of Z velocity (§1.4.3)	ft/s	m/s
Bnd	Boundary QC measurement (§1.4.4); 0=Best, 1=Good, 2=Fair, 3=Poor		
Temp	Water temperature	°F	°C
ASD1	Standard deviation of SNR data, beam 1	dB	dB
ASD2	Standard deviation of SNR data, beam 2	dB	dB
ASD3	Standard deviation of SNR data, beam 3	dB	dB
Batt	Battery voltage	V	V

6.4. Download Data Files (Recorder)

When you have connected to a FlowTracker system, the *Recorder* module (Figure 15) becomes available. *Recorder* is used to download binary data files from the internal recorder (§6.4.1), and to format (erase) data files from the internal recorder (§6.4.2).

- It establishes communication with the FlowTracker.
- It downloads a directory of files on the internal recorder.
- The user specifies which files to download and a destination directory.
- The software enters a special download mode at a higher baud rate (usually 57600) and downloads the specified files at this rate.
- It allows you to format (erase) the recorder.

6.4.1. Recorder Downloading Steps

The following steps describe how to download data files from the FlowTracker's internal recorder to your computer. Note: Files are downloaded with the **`*.wad`** file extension.

- Click **Recorder** to open the dialog box (Figure 15). This action will establish communication and display the recorder's directory. Note: The **Recorder** option is only available after you have successfully connected to a FlowTracker system.
- Select one or more files from the display list. You can:
  - Click one file to select it.
  - Hold **Control** or **Shift** and click a series of files.
  - Click **Select All** to select all files on the recorder.
- Set the download **Baud rate**.
  - **Recorder** uses a higher rate to download files (compared to the standard system communication rate). The default download baud rate is 57600.
  - If you have trouble downloading data, try using a slower download baud rate.
- Specify a **Destination folder** (or use the **Browse** control).
- Click **Download** to copy all the selected files to the specified folder. Note: A **Cancel** control will appear to let you abort the download process.
- Watch the status area at the bottom of the dialog box to view the download progress.
- Select more files to download, or **Close** the **Recorder** dialog box.

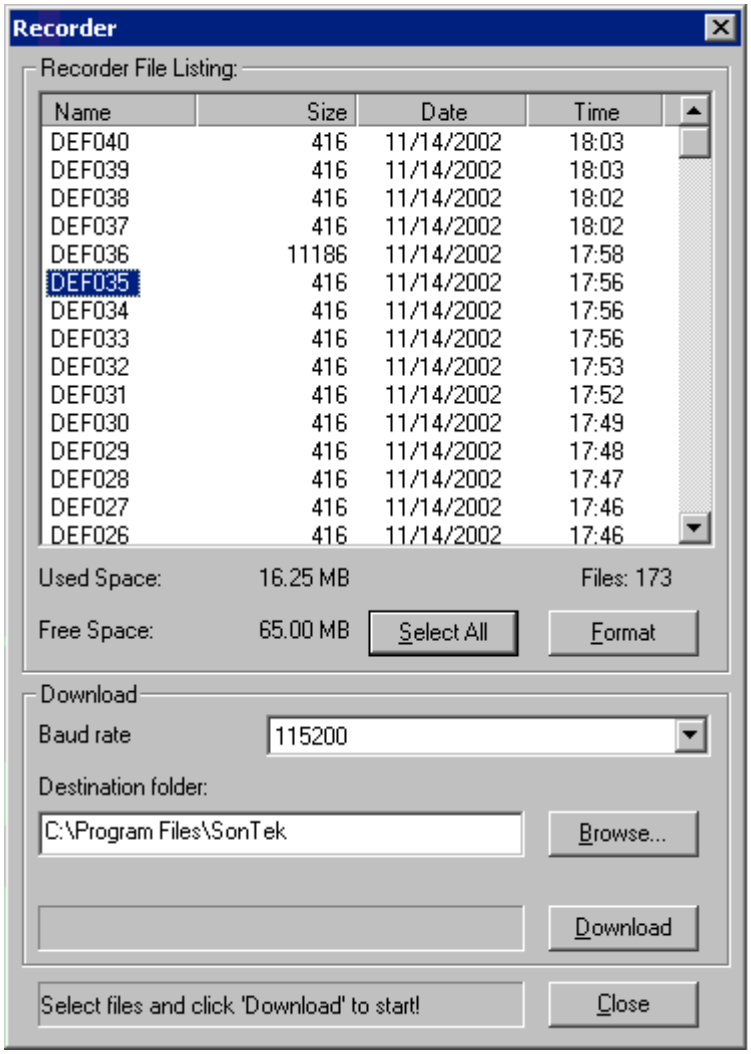


Figure 15 – Recorder Dialog Box

6.4.2. Recorder Formatting Steps

The following steps describe how to format (erase) the FlowTracker's internal recorder.

- Click **Recorder** to open the dialog box. This action will establish communication and display the recorder's directory. Note: The **Recorder** option is only available after you have successfully connected to a FlowTracker system.
- Caution: Ensure that all desired data files have been downloaded to your computer (§6.4.1) before executing the **Format** command. Note that all files will be erased from the recorder; that is, there is no option to erase individual files from the recorder. Files cannot be recovered from the recorder after it has been formatted.
- Click **Format**, and then **OK** (or **Cancel**) to verify your decision to format/erase the recorder.
- **Close** the **Recorder** dialog box.
- The recorder can also be formatted from the keypad interface (see §2.5.3).

6.5. Diagnostic Software (BeamCheck)

BeamCheck (Figure 16) is a diagnostic program used to verify FlowTracker performance.

- This is the same diagnostic program used at SonTek. It provides you with a powerful tool for understanding and verifying system performance.
- We recommend you become familiar with this software and use it on a regular basis.

Typically, *BeamCheck* operates by sending a pulse of sound into the water, and then plots the signal strength of the return signal versus range for each of the FlowTracker's receivers. This information can be evaluated to determine the effective measurement range, to look for interference from boundaries/structures, to survey a deployment site, or to observe the quality of the returned signal. General program information is provided in §6.5.1 through §6.5.4. Example *BeamCheck* outputs are provided in §6.5.5 and §6.5.6.

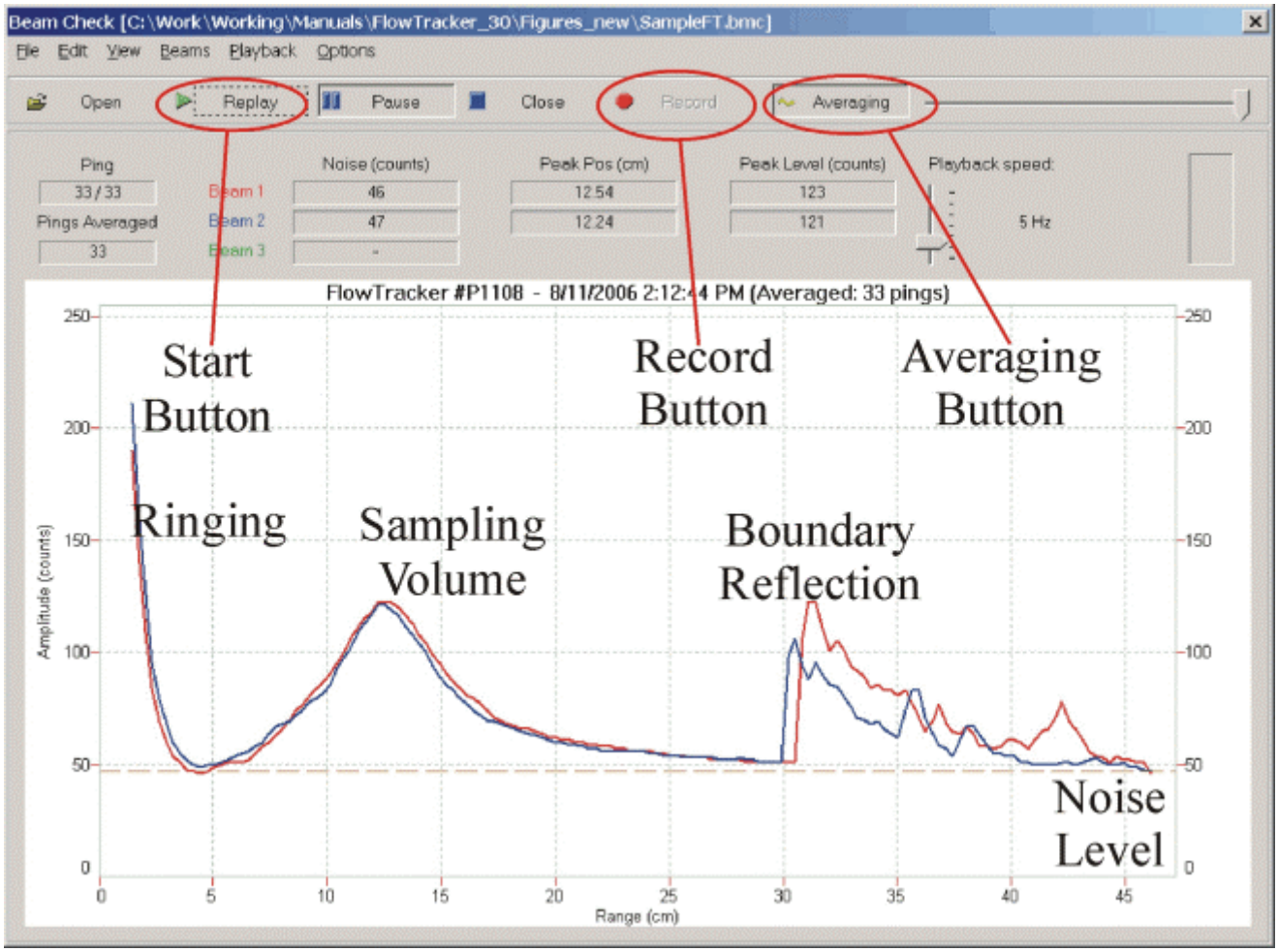


Figure 16 – BeamCheck Main Window with Sample Output

6.5.1. BeamCheck Overview

In *BeamCheck*, the FlowTracker sends a pulse of sound and outputs the return signal strength for each receiver as a function of time. Features in the signal strength profile verify different aspects of system performance (Figure 16).

- The horizontal axis indicates the range from the FlowTracker probe (in cm).
- The vertical axis is in internal signal strength units called counts (1 count = 0.43 dB).
- *Ringing* from the transmit pulse appears on the left side of the graph.
- The location of the *sampling volume* is indicated by increased signal strength in a bell-shaped curve.
  - The sampling volume curve corresponds to the transmit pulse passing through the focal point of the receivers.
  - The peak of this curve corresponds to the center of the sampling volume.
  - The location of the sampling volume varies, but is typically 10-12 cm.
  - All receivers (2 or 3) should see the peak in the same location, although there will be variation in the height and shape of the curve.
- A sharp spike indicates a *boundary reflection* (if a boundary is within range).
  - If the probe is close to a boundary, a sharp reflection should be seen.
  - The size and shape of this reflection will vary depending on the nature of the boundary and its distance from the FlowTracker.
- Signal strength decreases to the electronic *noise level* past the boundary.

When using *BeamCheck*, it is important to understand that the output plot will vary considerably because of the nature of acoustic scattering.

- Each of the items described above should be visible (Figure 16).
- If no sampling volume peak can be seen, try adding some fine dirt or other seeding material and stirring the water to increase the signal strength (§8.6).
- If the *BeamCheck* output differs significantly from the sample shown here, refer to §6.5.5 and §6.5.6 for more details about interpreting this data.

6.5.2. BeamCheck Menu and Control Items

This section describes *BeamCheck* menu and control items.

- File Menu
  - **Open** – Opens a previously recorded beam check file (**.bmc**) for playback and review.
  - **Record** – Starts the data recording process if you wish to store the real-time information being displayed to a data file. You will be prompted for a file name and location.
  - **Print** – Sends the currently displayed graph to a selected printer.
  - **Close** – Closes the currently selected beam check file (**.bmc**), but not the main window.
  - **Exit** – Stops the beam check process and closes the **Beam Check** window.
- Edit Menu
  - **Copy** – Sends the currently displayed graph to the Windows clipboard. You can then "paste" the graph in another program such as Microsoft Word.
- View Menu
  - **Amplitude** – Sets the graph to display a representation of signal strength versus time.
  - **Sine/Cosine** – Not used.
  - **Show range as X-Axis** – Sets the X-axis of the graph to display signal strength data in meters rather than number of samples.
  - **Show decay curve** – Not used.
- Beams Menu
  - **Beam 1/2/3** – Lets you select which combination of beams to display. **Beam 3** is disabled on 2-beam systems.
  - **All beams** – Displays data for all the beams.
- Playback Menu
  - **Start/Replay** – Begins the process of displaying either real-time (**Start**) or previously recorded (**Replay**) data to the graph and tabular displays.
  - **Pause** – Toggles between either pausing or continuing the display of data.
  - **Stop/Close** – Ends the process of displaying real-time data or closes a file being replayed.
- Options Menu
  - **Averaging** – Smoothes the display of data by continually averaging successive pings. The number of pings that have been averaged is shown in the **Pings Averaged** box. By averaging the pings, a more representative display of the data is shown.
  - **Force high-speed connection** – Sets the computer-to-instrument interface to a higher baud rate so that data updates occur more quickly. The default for this feature is ON. You should only turn this feature OFF if you experience communication problems.
- Controls (e.g., buttons, slide switches)
  - **Open** – Opens a previously recorded beam check file (**.bmc**) for playback and review.
  - **Start** / **Replay** – Begins the process of displaying either real-time (**Start**) or previously recorded data (**Replay**) to the graph and tabular displays. If no previously recorded data file has been opened, the button says **Start**; if a file has been opened, the button says **Replay**.
  - **Pause** – Toggles between either pausing or continuing the display of data.
  - **Stop** / **Close** – Ends the process of displaying data. If no previously recorded data file has been opened, the button says **Stop**. If a file has been opened, the button says **Close**, and will now function to both stop the display of data and to close the data file.
  - **Record** – Starts the data recording process if you wish to store the real-time information being displayed to a data file. You will be prompted for a file name and location. From that point on, the data that is being displayed will be recorded until you click **Stop**.

- **Averaging** – Smoothes the display of data by continually averaging successive pings. The number of pings that have been averaged is shown in the **Pings Averaged** box. By averaging the pings, a more representative display of the data is shown.
- **Ping Selector** (slide control next to **Averaging** button) – Lets you select an individual "ping" to display. Click and drag the slider to select the desired ping number (shown in the **Ping** box). When used, the **Averaging** feature is disabled.
- **Playback Speed** (slide control) – Lets you change the rate at which playback data is displayed. Click and drag the slider to the desired playback speed. Values in Hz display data faster than values in seconds. For example: a setting of **50 Hz** will replay data at a rate of 50 pings per second, while a setting of **10 s** will display a ping every 10 seconds. The default for this setting is **5 Hz** (i.e., data replayed at a speed of 5 pings per second).
- **Zoom In/Out** (mouse control) – To zoom-in on a particular area of the graphic display, use your mouse to click-and-drag a box around the desired area (see Figure 17). You can also zoom-in just by clicking on a particular feature within the graph. To zoom-out, right-click your mouse anywhere on the graph to step through the zoom-out levels. The click point will coincide with the center of the zoom.

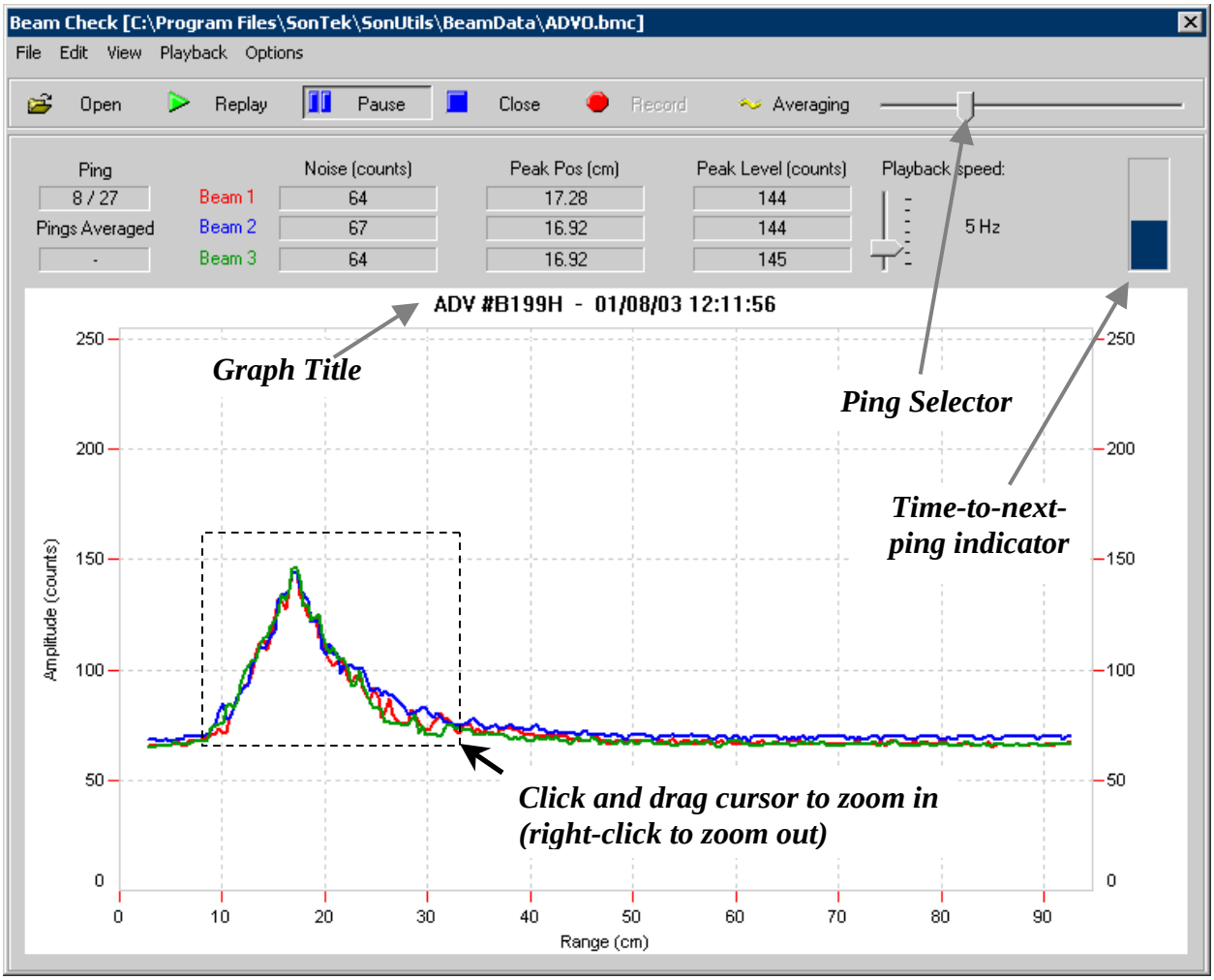


Figure 17 – BeamCheck Playback Example

6.5.3. BeamCheck Display Features

This section describes *BeamCheck* display features (Figure 17).

- **Ping** – Indicates the number of the transmitted pulse (i.e., "ping") that is currently being displayed on the graph and in the tabular data boxes. If real-time data is being displayed, only the current ping number is displayed. If previously recorded data is being displayed, both the current ping and the total number of recorded pings are displayed. For example, **3 / 27** means ping number 3 from a data set containing 27 pings is being displayed.
- **Pings Averaged** – When **Averaging** has been selected, this box indicates the number of pings that have been averaged together for the currently displayed graph and tabular data.
- **Noise** – Shows the electronics noise level for the receiver of each beam. This value is determined by the signal strength when the instrument is not receiving any return reflections from the water. This value should match the signal strength for the flat portion of the graph. The noise value is displayed in "counts".
- **Peak Pos** – This is the location of the center of the peak for the sampling volume for each of the receivers. The displayed value can be in either centimeters (cm) or counts, depending on the setting of the **Show range as X-Axis** option. The position of the peak should be about the same for each receiver.
- **Peak Level** – This is the height of the peak for the sampling volume for each of the receivers. This will vary depending on the amount of scattering material in the water.
- **Graph Title** – A title bar appears within the graph itself (Figure 17). This title bar shows the type of instrument (e.g., ADV, FlowTracker), its serial number, and the date/time that data collection began. Time is displayed in the format set within the Windows Control Panel (**Start|Settings|Control Panel|Regional Options|Time**).
- **Graph Range/Samples** (X-axis) – The graph itself shows a plot of the return signal strength for each beam as a function of time following the transmit pulse. The "time" portion is shown along the graph's X-axis. This value can be shown as a function of range (in meters) or as a function of samples depending on the setting of the **Show range as X-Axis** option.
- **Graph Amplitude** (Y-axis) – The graph itself shows a plot of the return signal strength for each beam as a function of time following the transmit pulse. The "signal strength" portion is shown along the graph's Y-axis. This value is shown in "counts".

6.5.4. BeamCheck Operation

To run *BeamCheck*:

- Hold the FlowTracker in a small tank or bucket of water (or in a natural environment) such that the probe is submerged and there is a boundary (surface, side, or bottom) within view.
  - Ideally, the boundary should be placed 20-30 cm (8-12 in) from the probe.
  - You may need to add a small amount of fine dirt or other seeding material and stir the bucket well for good test conditions. Regular tap water usually does not have enough scatterers (seeding) for a valid test.
- Connect the FlowTracker to the computer and turn the system on.
- Run the *FlowTracker* software (click **Start | Programs | SonTek Software | FlowTracker**).
- Click **Connect to a FlowTracker**. Select the correct COM port and click **Connect**.
- Click **BeamCheck**.
- To view real-time beam check data:
  - Click **Start**. This establishes communication with the instrument and starts data display.
  - Use the menu and control items (§6.5.2) to alter the display of data as desired.
  - See §6.5.5 and §6.5.6 for examples of how to interpret the data.
  - Click **Stop** to end the display of data.
  - Use **File|Exit** to close the **Beam Check** window.
- To record real-time beam check data for later playback:
  - Start the display of real-time data as described above.
  - Click **Record** to save all data to a file. You will be prompted for a file name and storage location. Typically, a minimum of 20 pings is required for proper data analysis.
  - Use the menu and control items (§6.5.2) to alter the display of data as desired. The recorded data is not affected; only the display of data is affected.
  - Click **Pause** or **Stop** to interrupt or end data collection.
- To play back previously recorded beam check data (using a .bmc data file):
  - Click **Open** to select a previously recorded beam check file (**.bmc**).
  - Click **Replay** (or **Pause**) to start the playback of data.
  - Use the menu and control items (§6.5.2) to alter the display of data as desired. The recorded data is not affected; only the display of data is affected.

6.5.5. Sample Program Output

BeamCheck operates in the following manner.

- The FlowTracker transmits a pulse of sound. It then receives the return signal strength for each of the 2 (or 3) receivers as a function of time following the transmit pulse.
- Features in the return signal strength profile are used to verify different aspects of system performance.
- The software also plots sine and cosine channel versus time for each receiver. These are used for internal diagnostics at SonTek and are not needed for user diagnostics. The sine and cosine outputs are not discussed in this manual.

The plot of signal strength versus time shows several features (Figure 18):

- Ringing from the transmit pulse.
- Increased signal strength in a bell-shaped curve corresponding to the sampling volume.
- A sharp spike from the boundary reflection, if within range.
- Signal strength leveling to the electronic noise level past the boundary.
- The display is updated every ≈5 seconds (each plot is the average of a number of samples).
- The horizontal axis is in FlowTracker timing units; time corresponds to the distance from the transmitter. One count axis equals 0.06 cm (0.15 in).
- The vertical axis is in internal signal strength units called counts (1 count = 0.43 dB).

Each feature of the *BeamCheck* signal strength plot is described in detail below.

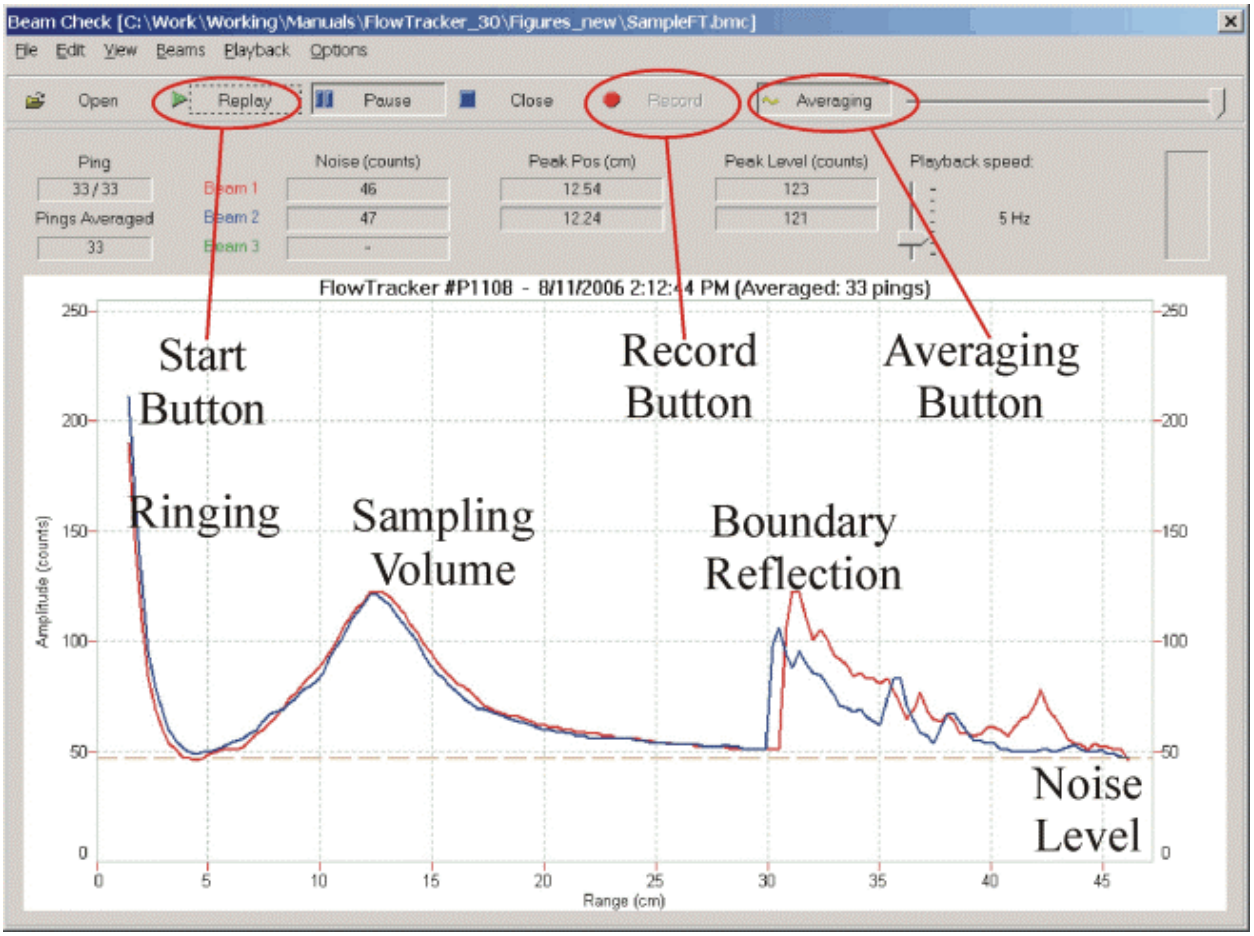


Figure 18 – BeamCheck Sample Output Screen

- The first ≈5 cm of the horizontal axis is electronic "ringing" following the transmit pulse. The transmit pulse is generated by a strong electrical signal, and requires some time for the electronics and transducers to recover.
- If there is sufficient scattering material in the water, there will be an increase in signal strength in a bell-shaped curve that corresponds to the transmit pulse passing through the focal point of the receivers. The peak of this curve corresponds to the center of the sampling volume. The location of the center of the sampling volume varies from probe to probe but typically is in the range of 10-12 cm. All receivers (2 or 3) should see the peak in the same location, although there will be variation in the height and shape of the curve.
- If the probe is close to a boundary (bottom, surface, or side), a sharp reflection should be seen. The size and shape of this reflection will vary depending on the nature of the boundary, its distance from the FlowTracker, and the acoustic conditions of the water. We can estimate the distance from the probe to the boundary by the location of the boundary reflection. In Figure 18, this occurs at about 30 cm from the probe.
- After the boundary reflection, the signal strength flattens out in the region where there is no reflected signal from the water. The value at which it flattens out is the electronics noise level. This noise level is typically about 30-70 counts; it is also shown in the tabular display at the top of the screen. An easy way to measure the instrument noise level is to run *BeamCheck* when the probe is not in the water. In this case, the entire plot should show a constant return at the instrument's noise level.
- When using *BeamCheck*, it is important to understand that the output plot will vary considerably because of the nature of acoustic scattering. The shape and height of the return signal, particularly the bell curve for the sampling volume, will show considerable variation between updates. When using the program for diagnostics, look at the general shape of the curve and for features that are consistently present.

6.5.6. Diagnosing Hardware Programs with BeamCheck

BeamCheck can be used to detect most problems that can occur with a FlowTracker. This section describes the program output for some possible situations.

Low Scattering Strength (Figure 19)

If there is insufficient scattering material (e.g., very clear water), the sampling volume peak will be small or non-existent. This situation can be confused with a malfunctioning transmitter (see Figure 20) unless the boundary is in view. Note that in Figure 19 we clearly see the boundary reflection at ≈23 cm, but do not see a sampling volume peak around 10 cm. In this situation, place a small amount of seeding material in the water to act as scattering material (fine dirt or clay will work quite well; see §8.6).

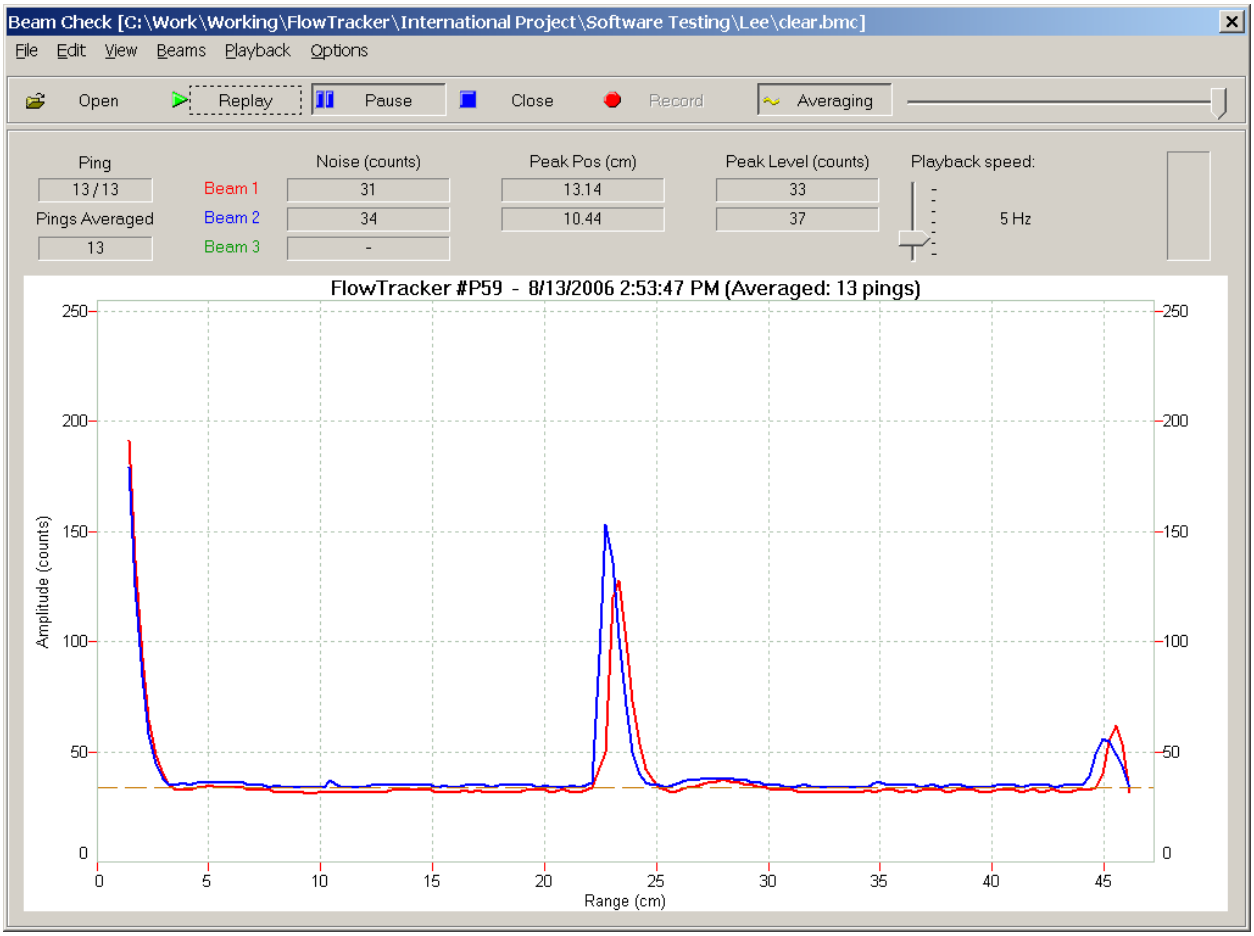


Figure 19 – BeamCheck Output with Low Scattering Strength

Malfunctioning transmitter (Figure 20)

This appears as a flat response with signal strength at the normal noise level. This can be confused with a disconnected probe or low scattering levels (see Figure 19). Note the absence of a boundary reflection to distinguish this from low scattering levels.

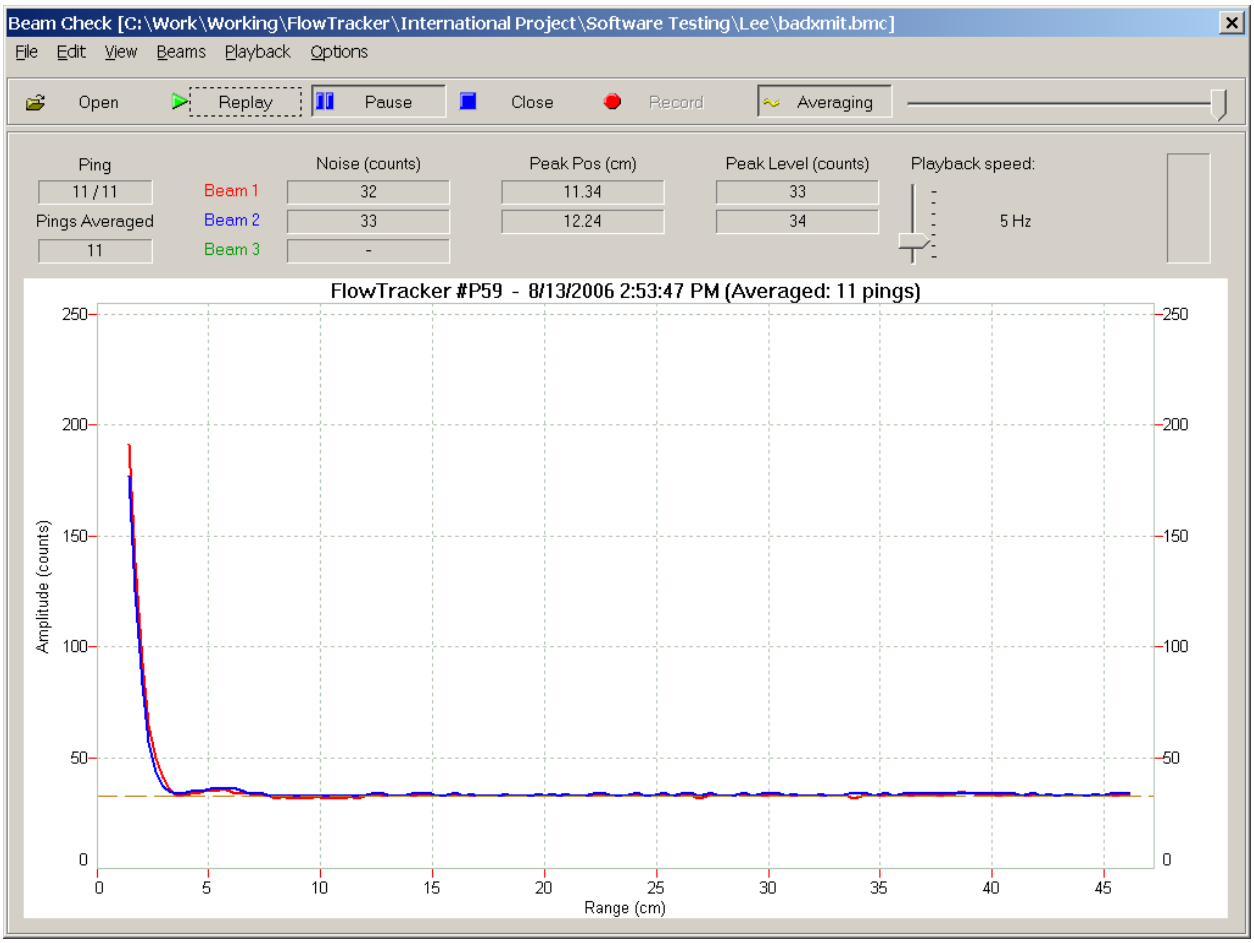


Figure 20 – BeamCheck Output with Malfunctioning Transmitter

Malfunctioning receiver(s) (Figure 21)

The signal from each receiver should have approximately the same strength as the sampling volume. If the differences exceed 10-20 counts, clean off the each transducer and make sure the beams are not physically blocked before calling SonTek.

Damaged receiver arm (no Figure provided)

If the sampling volume in one receiver is offset along the horizontal axis, it means the receiver arm has been physically bent. A bent arm will change the FlowTracker calibration and will affect the accuracy of velocity data. Contact SonTek if you have a damaged probe for details about repair options.

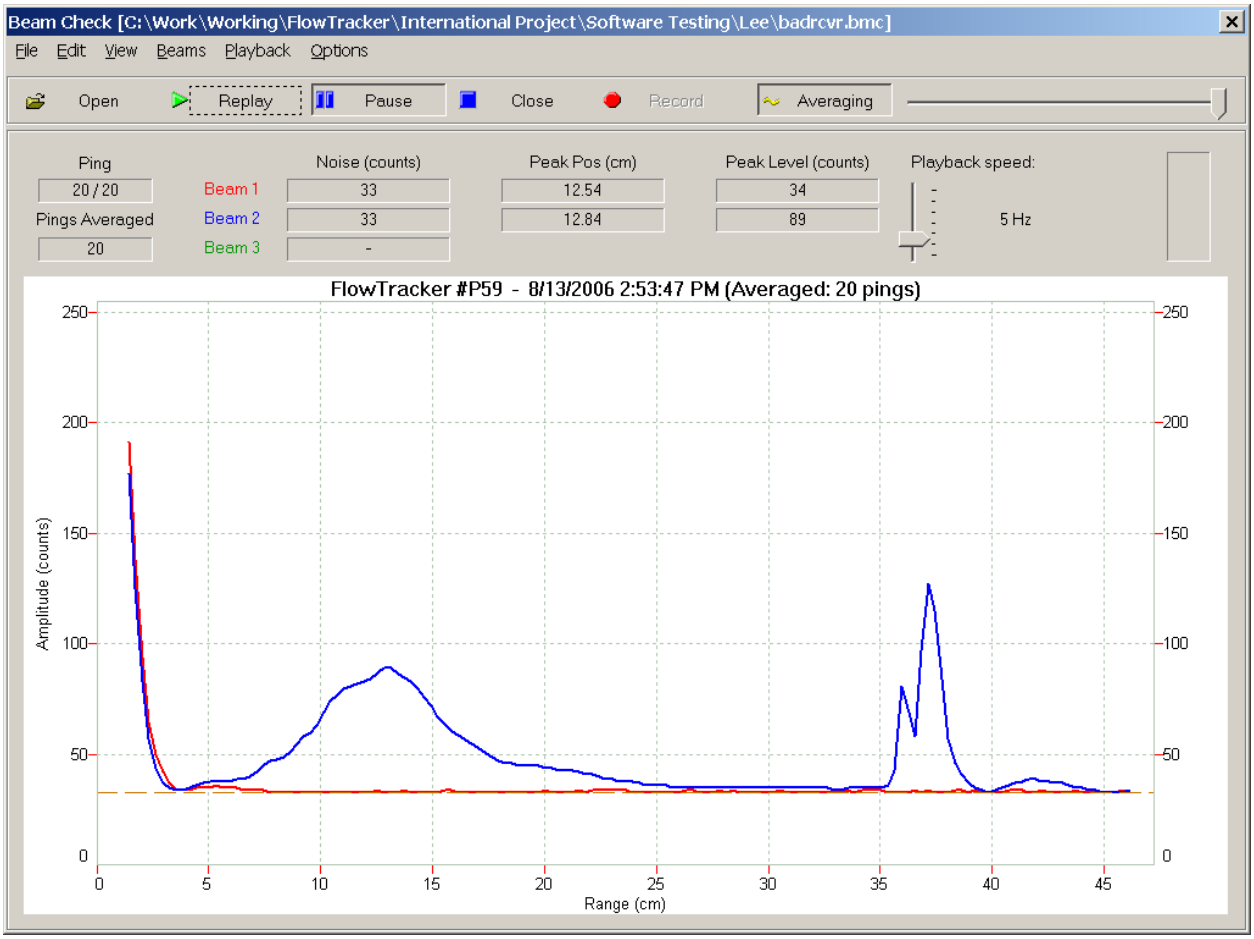


Figure 21 – BeamCheck Output with Malfunctioning Receiver

Excessive noise (Figure 22)

If the electronics noise level is more than 10 counts above its normal level, it may be a sign that something is wrong. Likewise, if the noise level between beams is significantly different (as in Figure 22), this may indicate a system problem. The noise level may also be higher than normal because of external electromagnetic interference, or because water has condensed on the receiver electronics.

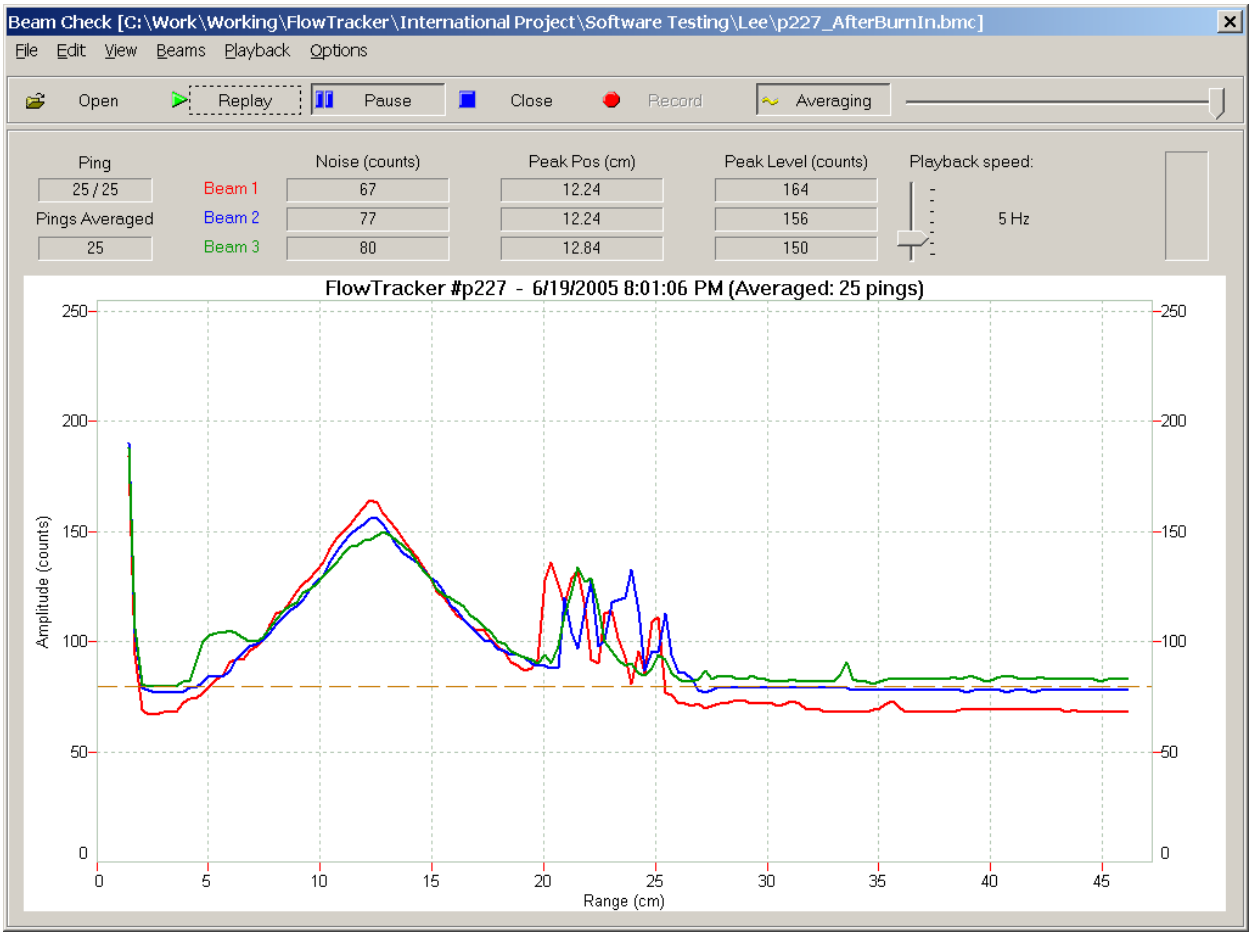


Figure 22 – BeamCheck Output with Excessive Noise

High signal strength past the boundary (Figure 23)

If the signal strength does not fall off rapidly past the boundary, the additional acoustic noise can potentially increase the noise in velocity measurements. This additional acoustic noise is most commonly seen in small tanks, particularly when built from acrylic or glass. While it may occur during testing in the office or laboratory, it is rarely a factor during field operations with the FlowTracker.

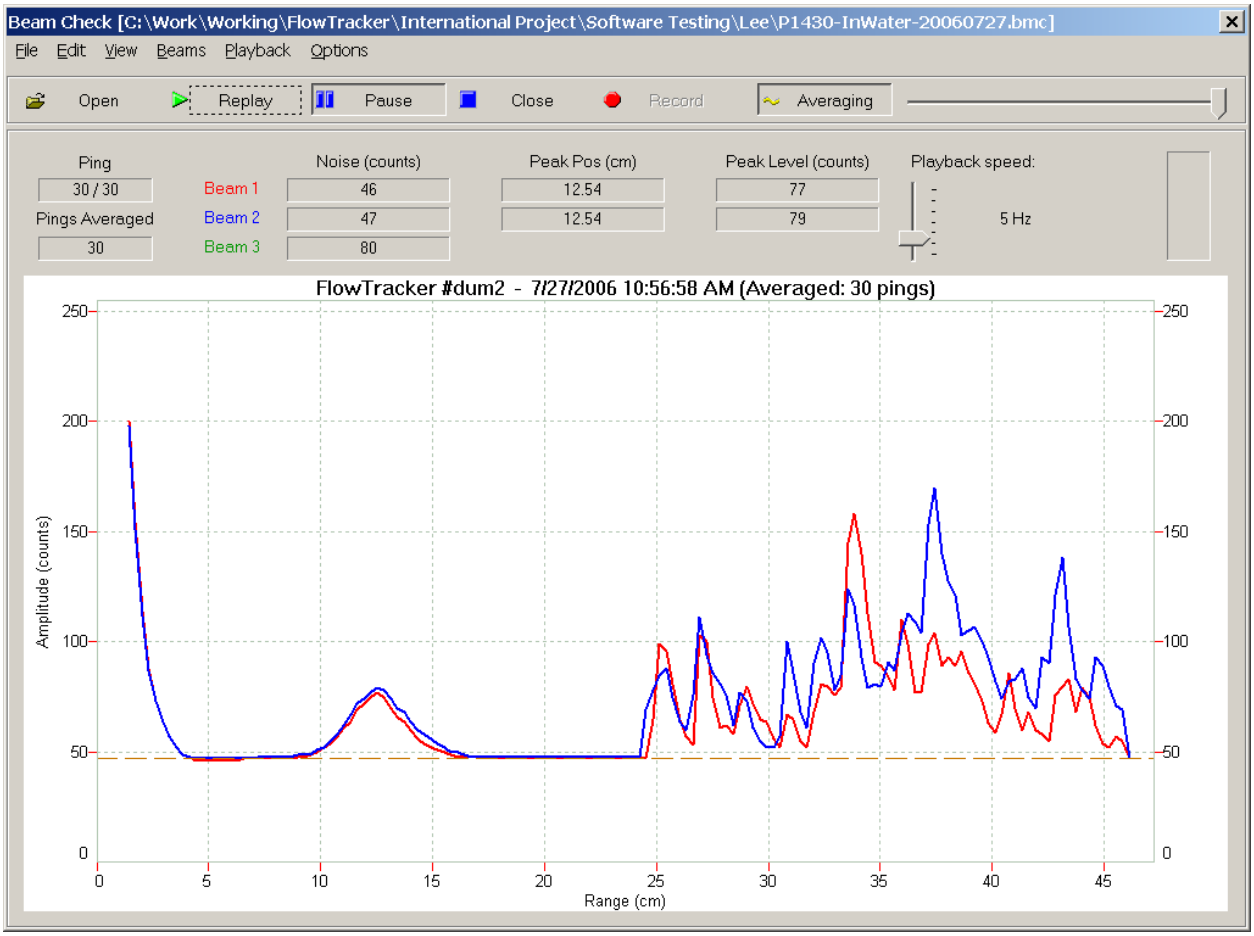


Figure 23 – BeamCheck Output with Noise Past Boundary

Section 7. Hardware

7.1. Cables and Connectors

7.1.1. Probe Cable

The ADV probe is connected to the handheld controller by a 200-cm (80-in) cable.

- This is a custom built, highly noise-sensitive cable.
- It is permanently attached to the handheld controller.
- Avoid damage to the cable, especially cuts to the jacket or sharp bends that could damage internal conductors. Damage to the cable can severely affect FlowTracker operation.
- A longer cable (300 cm; 120 in) is available for special applications. It is not possible to up-grade an existing system to a different cable length.

7.1.2. External Power/Communication Cable

A cable is supplied that lets you interface the handheld controller to an external PC and power supply. This cable has three connectors.

- A 5-pin waterproof connector matches the connector on the handheld controller.
- A female DB9 connector matches the serial port on a standard PC.
- A 2-pin connector matches the FlowTracker external power supply (optional). You can use the external supply to conserve battery power when downloading data or when testing the system.

Table 7-1 shows the wiring of the power/communication connector.

Table 7-1. Power/Communication Cable Connector Wiring

5-Pin Connector	Function	DB9 Female	2-Pin Connector
Pin A	Power (6-15 VDC)	Not connected	Pin 1
Pin B	RS232 Data Out	Pin 2	Not connected
Pin C	RS232 Data In	Pin 3	Not connected
Pin D	RS232 Ground	Pin 5	Not connected
Pin E	Power Ground	Not connected	Pin 2

7.2. Power Supply

7.2.1. Input Power

The FlowTracker operates on 6-15 VDC input power.

- An input voltage greater than 15 V will seriously damage the electronics.
- The FlowTracker draws about 1.0 W during data collection (with the LCD backlight off).
  - The LCD backlight increases total power consumption to about 2.0 W.
- When off, the FlowTracker draws a small residual current (≈0.5 mA).

The FlowTracker will not start data collection unless the input voltage is at least 7.0 V.

- Voltage less than 7.0 V indicates the batteries are drained.
- If voltage is below 7.0 V when the FlowTracker is turned on, it will display a low battery warning and force the system to power down.
- If voltage is less than 7.0 V when a data collection run is started, the FlowTracker will display a low battery warning and force the system to power down.
- If voltage is less than 8.0 V when a data collection run is started, the FlowTracker will display a warning but allows you to continue data collection if desired.
- If voltage drops below 8.0 V during data collection, the FlowTracker will display a warning message. Data collection should be stopped and batteries replaced to prevent loss of data.

To Avoid Draining of Batteries When System is Not in Use

- Always turn the system off before storing the system.
- When off, the FlowTracker draws a small amount of current from the batteries (≈0.5 mA).
- The current would drain a new set of alkaline batteries is 6-8 months.
- If the system will be left unused for a long period (more than 1 month), remove the batteries to prevent them from being drained unnecessarily.

7.2.2. Batteries

The FlowTracker uses eight AA batteries: alkaline, NiMH, or NiCad. Table 7-2 compares the three types of batteries.

Table 7-2. Comparison of Battery Types

	Alkaline	NiMH	NiCad
General description	Single use	Rechargeable	Rechargeable
Nominal battery capacity (typical)	2.85 Ah	1.60 Ah	0.70 Ah
New battery voltage	12.0 V	10.5 V	10.0 V
Drained battery voltage	7.0 V	8.0 V	8.5 V
Approximate operating life	25 hours	15 hours	7 hours

To access FlowTracker battery data:

- Press **2** from the main menu to access the **System Functions Menu**, and then press **5** for battery data.
- The FlowTracker will display battery voltage and estimated remaining capacity (percent of total) based on voltage for all three battery types.
- The FlowTracker has no way to determine what types of batteries are installed.
- **Predicting capacity based on voltage is only approximate, particularly for rechargeable batteries where voltage characteristics can change significantly over the life of the batteries.**
- These battery life estimates are at ≈20° C (70° F); cold weather will have a significant effect on voltage and capacity. Always check battery capacity with the system acclimated to the outside temperature.

To Avoid Draining of Batteries When System is Not in Use

- Always turn the system off before storing the system.
- When off, the FlowTracker draws a small amount of current from the batteries (≈0.5 mA).
- The current would drain a new set of alkaline batteries in 6-8 months.
- If the system will be left unused for a long period (more than 1 month), remove the batteries to prevent them from being drained unnecessarily.

7.2.3. Changing the Batteries

The batteries are accessed from the back of the FlowTracker handheld controller.

- Turn the system off.
- Remove the six screws holding the battery compartment lid to the main housing.
- Remove the old batteries from the battery holder.
- Install the new batteries, matching the orientation shown on the battery holder.
- Secure the battery compartment lid using the six screws.
- Turn the system on and check the battery voltage level to ensure proper installation. From the main menu, press **2** for the **System Functions Menu**, and then **5** for battery data.
  - New alkaline batteries should show about 12.0 VDC.
  - Fully charged NiMH batteries should show about 10.5 VDC.
  - Fully charged NiCad batteries should show about 10.0 VDC.

7.3. Internal Electronics and Wiring Overview

Under normal conditions, you should never need to open the FlowTracker (except for battery replacement). The information provided here is for reference only.

This section provides information about the internal layout of the FlowTracker. The handheld controller is described from the view of being opened and looking at the inside of the housing and lid.

- The LCD screen is mounted to the inside of the lid.
- The keypad is mounted to the outside of the lid, and is connected to the LCD.
- The o-ring seal is exposed on the top of the housing. When opening the system, take care to avoid damage to o-rings and surfaces. Clean and inspect the o-ring and surfaces before closing the system.
- The receiver board is mounted at the narrow end of the housing. The probe is permanently wired to the receiver board.
- The FlowTracker Processor (Analog and CPU boards) is mounted in the wide end of the housing. The two boards are connected using an edge connector at one end. See §7.4 for a detailed description of the FlowTracker Processor.
- The batteries are installed below the Receiver board and are accessed from the back of the housing.

Cables used to connect the different portions of the FlowTracker are described below.

- A 16-pin ribbon cable connects the Receiver board to the Analog board. The cable uses the same connectors at each end with pin-to-pin wiring. The ribbon cable can be installed at either end. However, the connectors are keyed and can be installed in only one direction.
- A 2-wire cable from the temperature sensor (in the probe) connects to a red, 2-pin, keyed connector on the Analog board (labeled **Temperature**).
- The batteries and external power supply (via the external power/communication connector) are connected to a red, 3-pin, keyed connector on the Analog board (labeled **Power**).
- RS232 serial communication is wired from the external power/communication connector to a red, 5-pin, keyed connector on the CPU board (labeled **User**).
- The 5-pin connector attached to the LCD is wired to two connectors: a red, 3-pin, keyed connector on the CPU board (labeled **CTD**), and a red, 5-pin, keyed connector on the CPU board (labeled **Compass**).

7.4. FlowTracker Processor

The FlowTracker processor consists of two printed circuit boards – the Analog board (Figure 24) and the CPU board (Figure 25).

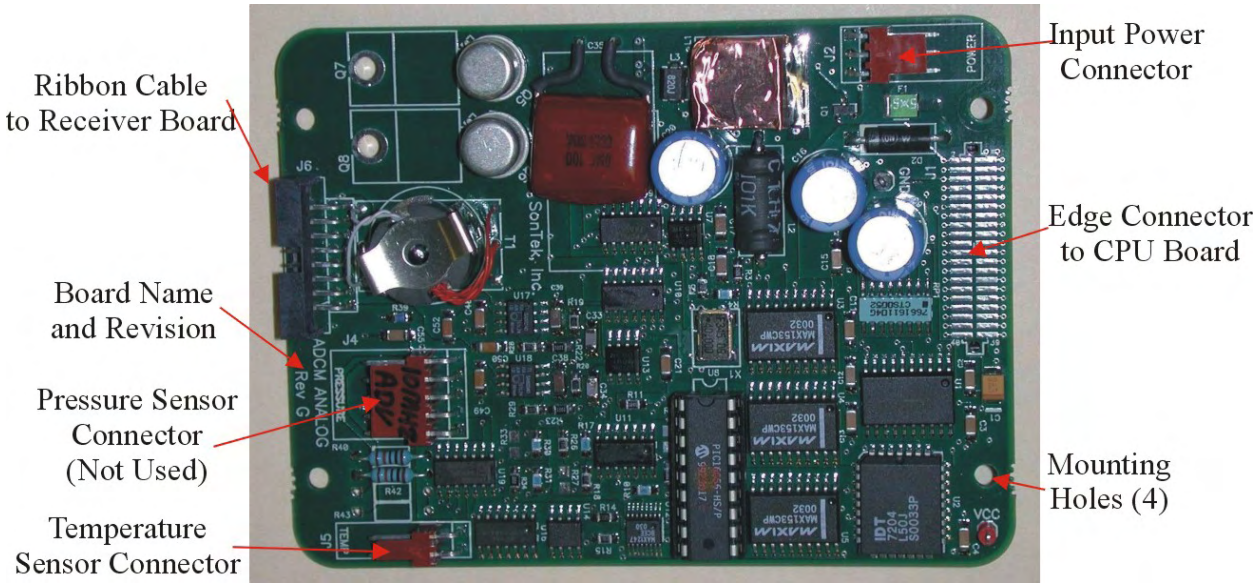


Figure 24 – FlowTracker Analog Board

Figure 24 shows the layout of the Analog board.

- A 16-pin, keyed connector (not labeled) connects to a ribbon cable to the Receiver board.
- The board name and revision is printed next to the pressure sensor connector.
- A red, 5-pin connector (labeled **Pressure**) is not used in the FlowTracker.
- A red, 2-pin, keyed connector (labeled **Temp**) connects to the temperature sensor in the probe.
- A red, 3-pin, keyed connector (labeled **Power**) is connected to the input power wiring. See §7.2 for input power specifications.
- A 40-pin edge connector mates below to the CPU board (Figure 25).
- The Analog board includes four holes for mounting, which match the mounting holes on the CPU board and are used with a set of #4-40 screws and standoffs.

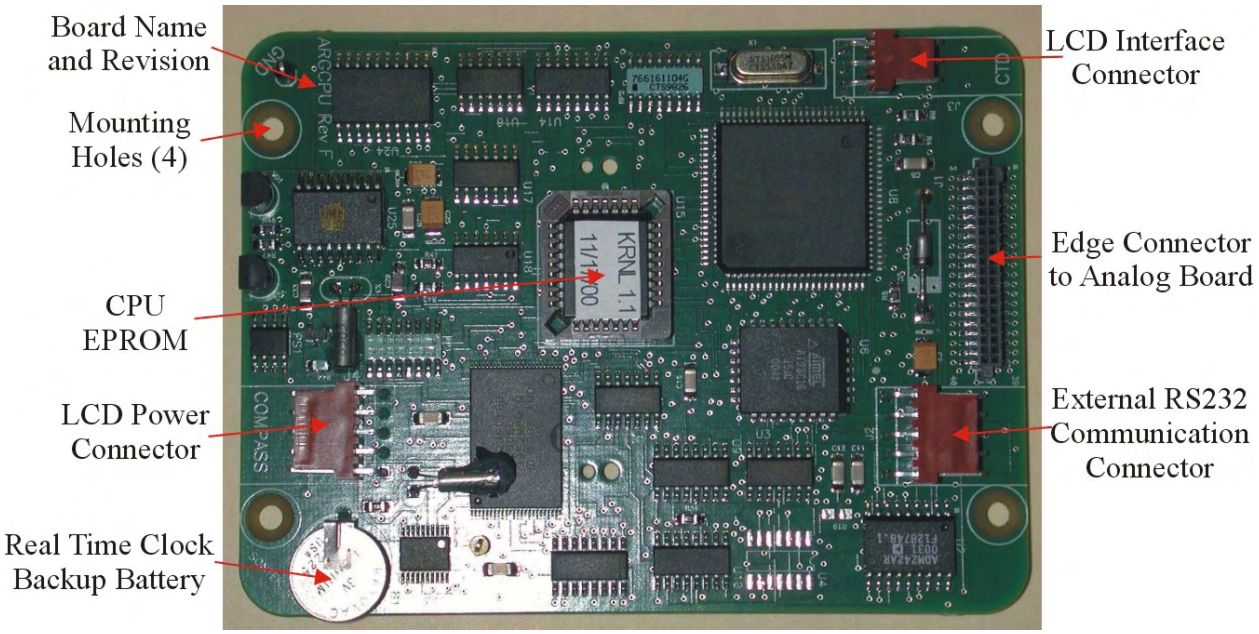


Figure 25 – FlowTracker CPU Board

Figure 25 shows the layout of the CPU board.

- The board name and revision are printed in the upper left corner.
- The EPROM containing the software to control FlowTracker operation is installed in a socket at the center of the board. Upgrades for the EPROM may be periodically available; see §7.6 for details.
- A 5-pin connector (labeled **Compass**) provides power to the LCD screen.
- The backup battery is installed in the corner of the board. This battery is used to supply the real-time clock when main power is not available. See §8.4 for details.
- A red, 3-pin connector (labeled **CTD**) connects to the interface of the LCD screen.
- A 40-pin edge connector mates above to the Analog board (Figure 24).
- A red, 5-pin connector (labeled **User**) connects to the external power/communication connector for external serial communications (RS232).

7.5. Accessing Electronics

Under normal conditions, you should never need to open the FlowTracker (except for battery replacement). The instructions here are provided for reference only. The system should only be opened after receiving instructions from SonTek/YSI personnel.

To open the FlowTracker handheld controller, use the following steps.

1. Perform all maintenance in a static-safe environment.
2. See §7.3 for a description of the internal layout of the FlowTracker. See §7.4 for a description of the FlowTracker Processor.
3. Open the battery compartment and remove all batteries (§7.2.3).
4. Loosen the dummy cap on the external power/communication connector to allow the inside of the housing to equalize to atmospheric pressure.
5. From the back of the handheld controller, remove the six screws holding the housing to the lid (these screws are accessed from recessed holes on the edge of the housing).
6. Carefully lift the lid from the housing.
7. Take care to avoid any damage to the o-ring and o-ring surfaces.

To close the FlowTracker handheld controller, use the following steps.

1. Clean and inspect all o-rings and o-ring surfaces for damage; replace o-rings if necessary.
2. Reconnect all internal wiring (if removed).
3. Inspect the desiccant pack installed inside the handheld controller. Replace if necessary.
4. If the o-ring was removed, lay it back into the o-ring groove on the housing.
5. Lay the lid on top of the housing.
6. From the back of the controller, secure the lid to the housing using the six screws.
7. Reinstall the batteries (§7.2.3).

7.6. Upgrading the CPU EPROM

Downloadable CPU firmware

- All FlowTracker systems have downloadable firmware.
- Firmware upgrades may be periodically available; check the SonTek web site for details (http://www.sontek.com).
- For firmware upgrades, all software and instructions will be provided with the upgrade. Contact SonTek for details.

Verifying system operation after a change

- Following any EPROM change, you should verify basic system operation.
- Turn the system off and on.
- From the keypad interface, use the raw data display (see §2.5.6) in a small tank of water to verify basic velocity and SNR data.
- Perform full system diagnostics as described in §3.2.

Section 8. Operational Considerations

8.1. Mounting and Installation

The FlowTracker is commonly mounted on a top-setting wading rod. The probe and controller mounting have been designed with wading rod use in mind, but the design is flexible enough to allow a variety of mounting arrangements. Top-setting wading rods are available from SonTek.

8.1.1. Handheld Controller Mounting

Mounting the handheld controller to the top of a wading rod can simplify data collection.

- A mounting bracket compatible with the mounting pin on a top-setting wading rod is available from SonTek (Figure 26).
- The handheld controller includes two threaded inserts on the back, which can be used to secure a user-supplied mounting bracket.
- User-supplied mounting brackets can also be constructed using Velcro® adhered to the back of the controller, or a strap around the controller.
- User-supplied mounting brackets should avoid direct contact with the keypad and LCD.

8.1.2. Probe Cable

The cable from the probe to the handheld controller is highly noise-sensitive and should be treated with care.

- The cable should be protected from cuts, abrasions, and other damage.
- In any mounting arrangement, secure the cable to prevent excessive motion or damage.
- Avoid sharp bends in the cable, particularly near the probe.



Figure 26 – Handheld Controller Mounting

8.1.3. Probe Mounting

2D and 2D/3D Side-Looking Probes

- An adaptor bracket (Figure 27) is available for mounting the probe from a top-setting wading rod. Both the bracket and complete wading rods are available from SonTek.
- The adaptor replaces the standard wading rod current meter mount.
- The bracket offsets the probe to one side of the wading rod, placing the sampling volume closer to the wading rod, approximately 5 cm (2 in) to one side.
- The bracket allows the wading rod to be used in its standard "forward" orientation.
- Installation and mounting instructions are included with the mounting bracket.



Figure 27 – Probe Mount Adaptor Bracket

Probe Orientation

- Figure 28 shows the proper orientation of the probe for discharge measurements.
- The tag line is installed perpendicular to the primary flow direction, although the flow direction may vary at different points across the stream.
- At each station, the X-axis should be perpendicular to the tag line. It should **not** be kept in line with the true flow direction. The red band (which marks receiver arm #1) should face downstream.
- The FlowTracker uses the X component of velocity (Vx) for discharge measurements, and calculates flow direction for each measurement as a quality parameter (see §1.4.6).

3D Down-Looking Probes

- 3D down-looking probes are not normally used from a wading rod.
- Mounting arrangements are user-constructed to meet the requirements of the application.
- Probe mounting should be done to avoid flow interference in the sampling volume (§8.1.4).

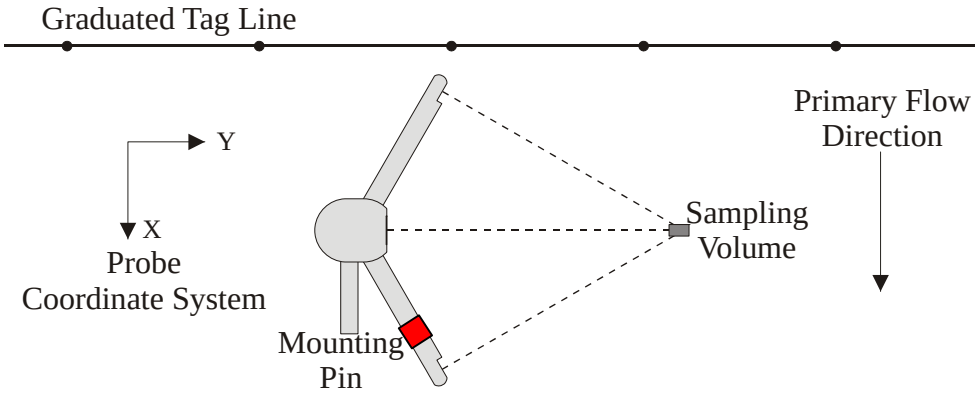


Figure 28 – FlowTracker Probe Orientation Relative to Stream Flow

8.1.4. Flow Interference

The FlowTracker measures velocity in a small sampling volume nominally located 10 cm (4 in) from the tip of the probe (see *FlowTracker Principles of Operation*). The placement of the sampling volume relative to other structures in the water must be considered when measuring velocity to avoid flow interference.

Structures

- The FlowTracker probe should be located away from any underwater structures or obstacles, particularly those upstream.
- Consider the size and location of nearby structures and obstacles, and the probable magnitude and direction of flow, when choosing a measurement location.

Probe orientation relative to flow

- The FlowTracker should be oriented so the axis of the transmit transducer is roughly perpendicular to the expected direction of flow (Figure 29).
- For side-looking probes (2D and 2D/3D), the probe should be oriented looking across the expected direction of flow (so the X-axis aligns with the expected flow).
- For 3D down-looking probes, this is usually simple since the probe is most commonly looking vertically down in a region of horizontal flow.
- FlowTracker probes have been tested and have shown negligible flow interference with the probe as much as 40-50° away from the preferred alignment. At higher angles, the FlowTracker may see flow interference in the sampling volume.

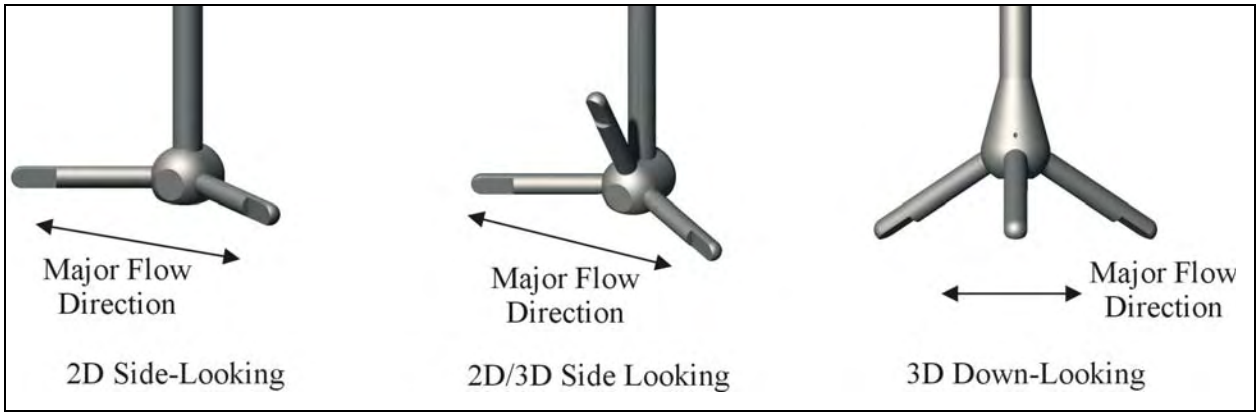


Figure 29 – Preferred Flow Direction to Avoid Flow Interference

8.2. Velocity Data Coordinate System

FlowTracker velocity measurements are reported using a right-hand Cartesian coordinate system relative to the probe. The XYZ coordinate systems for each probe type are shown below.

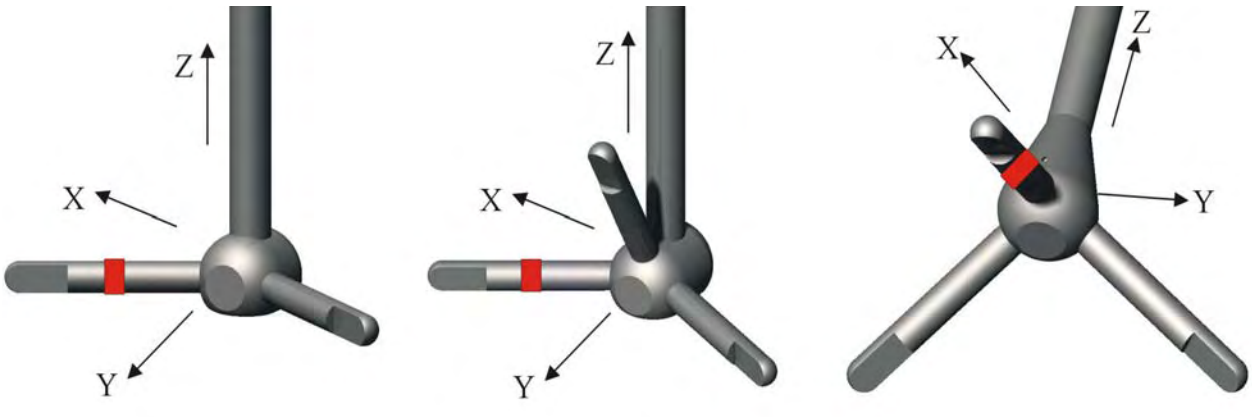


Figure 30 – FlowTracker Looking Probe XYZ Coordinate Systems

2D Side-Looking Probe (Figure 30a)

- The positive Z-axis is defined as vertically up in the direction of the probe's stem.
- The positive X-axis is defined perpendicular to both the probe's stem and the axis of the transmit transducer in the direction of receiver arm #1 (marked with a red band).
- The positive Y-axis is defined along the axis of the transmit transducer from the transmitter towards the sampling volume (making a right-handed coordinate system).

2D/3D Side-Looking Probe (Figure 30b)

- The positive Z-axis is defined as vertically up in the direction of the probe's stem.
- The positive X-axis is defined perpendicular to both the probe's stem and the axis of the transmit transducer in the direction of receiver arm #1 (marked with a red band).
- The positive Y-axis is defined along the axis of the transmit transducer from the transmitter towards the sampling volume (making a right-handed coordinate system).

3D Down-Looking Probe (Figure 30c)

- The positive Z-axis is defined as vertically up in the direction of the probe's stem, which for this probe is the same as the axis of the transmit transducer.
- The positive X-axis is defined perpendicular to probe's stem in the direction of receiver arm #1 (marked with a red band).
- The positive Y-axis is defined based on the X and Z-axes to make a right-handed coordinate system.

8.3. Temperature Sensor

The FlowTracker uses a thermistor mounted inside the probe head to measure temperature.

- The coupling of the thermistor to the metal probe head gives good response to changes in temperature and ensures the temperature data accurately reflect the water temperature at the location velocity measurements are being made.
- The temperature sensor has a specified accuracy of ±0.1°C (±0.2°F).
- Temperature data are sampled once per second (with each velocity sample) during each measurement burst. Mean temperature is recorded with each measurement burst.

8.4. Real-time Clock Backup Battery

The FlowTracker has a backup battery to run the system clock when main power is not available.

- The battery is installed on the processor CPU board (see §7.4).
- The battery can be expected to last for many years with no maintenance.
- If the backup battery dies, the system clock will reset when power is disconnected.
- Contact SonTek before attempting to replace the battery.

8.5. Routine Maintenance

The FlowTracker requires little maintenance for years of reliable performance.

- Normal use does not change instrument performance.
- The FlowTracker never requires recalibration for velocity data (unless the probe is physically damaged).
- This section describes the suggested maintenance procedures.

8.5.1. Regular Diagnostic Procedures

In addition to the diagnostic procedures available from the handheld interface, the FlowTracker software includes a diagnostic program named *BeamCheck*.

- This is the same program used at SonTek for system testing and diagnostics.
- The program lets you verify all major aspects of system performance and probe condition.
- Use of the program is described in §6.5.
- We recommend running this program on a regular basis (e.g., once per week).

8.5.2. Cleaning the Transducers

Biological growth on the transducers does not affect velocity measurements, but can decrease acoustic signal strength and potentially increase noise in velocity data in clear water.

- Periodic cleaning of the FlowTracker transducers may be needed to maintain optimal performance in areas of high biological activity.
- FlowTracker transducers are encapsulated in an epoxy that is impervious to damage from barnacles or other types of growth.
- To remove growth, simply clean with a cloth or stiff (non-metallic) brush. The transducer epoxy is very durable and cannot be easily damaged except by direct impact.

8.5.3. Cable Maintenance

The FlowTracker probe cable is often the most vulnerable part of the system.

- The cable uses a durable polyurethane jacket that provides excellent long-term wear and abrasion resistance.
- Any cable is susceptible to damage and reasonable precautions should be taken.
- Inspect the cable and all connectors on a regular basis.
- This cable is highly noise-sensitive and should not be modified by the user.

8.5.4. O-rings

The FlowTracker handheld controller uses an o-ring seal.

- The controller is designed to withstand temporary submersion, but is not intended for underwater operation.
- We do not recommend opening the system without specific instructions from SonTek/YSI.

8.5.5. Condensation in FlowTracker Housing

Moisture in the air can potentially damage FlowTracker electronics if allowed to condense inside the controller housing.

- The housing is shipped with a desiccant pack inside to absorb moisture.
- We do not recommend opening the system without specific instructions from SonTek/YSI personnel. If the housing has not been opened, the desiccant should not need to be replaced.

8.5.6. Zinc Anodes for Corrosion Protection

When using the FlowTracker in salt water, additional precautions must be taken to prevent corrosion.

- A sacrificial zinc anode should be installed on the probe (attached to the metal portion of the probe stem).
- Anode condition should be inspected regularly, and the anode should be replaced when necessary. Zinc anodes are available from SonTek.
- To check anode condition, try to chip away part of the anode with a screwdriver. If large portions of the anode easily fall away, the anode should be replaced.
- The probe and cable should be thoroughly rinsed with fresh water after each use.

8.6. Seeding

If FlowTracker velocity data appears “noisy”, the most common cause is a lack of scattering material in the water.

- See the *FlowTracker Principles of Operation* (§A-7.3) for details about how/why the FlowTracker uses scattering material for velocity measurements.
- A lack of scattering material can increase noise in velocity data. If insufficient scattering material is present, the FlowTracker will not be able to accurately measure velocity.
- In most field applications, there is sufficient scattering material naturally present.
- Large, quiet laboratory tanks often have insufficient natural scattering material.
- To evaluate seeding requirements, use the raw data display from the handheld interface (see §2.5.6).
  - For ideal operating conditions, the SNR should be above 10 dB.
  - The FlowTracker can operate reliably with SNR as low as 3-4 dB.
- A lack of scattering material can be remedied by adding seeding.

For field applications, seeding can be introduced by stirring the bottom (e.g., walking across the river upstream of the measurement location). In some situations, seeding material will need to be introduced. An ideal seeding material should have the following qualities.

- Neutrally buoyant (to remain in suspension for a long period)
- Mean particle diameter of 10-20 µm (for peak sensitivity of the acoustic signal)
- Inexpensive, readily available, with no adverse effects on the operating environment

The best seeding material we have found (from an acoustics point of view) are hollow glass spheres with a mean diameter about 10 µm and a mean density close to that of water.

- Small quantities of this material are available from SonTek.
- Larger quantities can be purchased from the manufacturer at the address below.

  Potters Industries
  Valley Forge PA USA
  Phone: +1-610-651-4700
  Internet: www.pottersbeads.com
  Part name: Potters Sphericel

For most applications, a more practical seeding material is lime or pulverized limestone (the chalk commonly used on athletic fields).

- Large bags are inexpensive and readily available from most hardware stores.
- While not perfect, the acoustic performance is sufficient for most applications.
- A variety of distribution arrangements can be arranged to seed even very large tanks.
- A note of caution: repeated addition will gradually increase the pH in a tank (in addition to creating a layer of lime/limestone on the bottom of the tank).

8.7. Troubleshooting

This section provides suggestions for diagnosing problems with the FlowTracker. If you have trouble finding the source of a problem, please contact SonTek.

8.7.1. Cannot Turn System On

FlowTracker power-up problems are usually related to the batteries or power supply.

- Check/replace the existing batteries (§7.2.3).
- Verify that all batteries are correctly oriented as shown on the battery holder.
- Try operating the system with the SonTek external power supply, if available.

If the system still will not turn on, try the following.

- Hold the **On/Off** key down for at least four seconds.
- Release the **On/Off** key, and then hold down the key again for at least one second.
- Try to establish direct serial communication (see Appendix B).

8.7.2. Cannot Communicate with the FlowTracker

If you are unable to establish external communications with the FlowTracker (typically using the data download software), the following may be helpful in identifying the cause.

- Verify all cables to the FlowTracker are securely connected.
- Verify the batteries are correctly installed (or the external supply is connected) and that you can turn on the system.
- Try to establish direct communications with the FlowTracker using *SonUtils* (Appendix B).
- Verify the computer serial port is functioning correctly. Try using another computer.
- Inspect the external power/communications cable. Verify all cable connections match the wiring diagram listed in §7.1.2.

8.7.3. Cannot Retrieve Data from Internal Recorder

The following are common causes of communication errors when retrieving data from the Flow-Tracker's internal recorder (using the *Recorder* software described in §6.4).

- Verify you can establish direct communication with the FlowTracker using *SonUtils* (Appendix B).
- The data-extraction baud rate may be too high (default is 57600). The maximum baud rate is a function of the length and quality of cables, the computer, and the operating environment. Run *Recorder* using a lower extraction rate (§6.4).
- Some computers have poor quality serial ports and cannot retrieve large amounts of data at high baud rates. Try using another computer or lower the extraction baud rate.

8.7.4. Velocity Data Appears Noisy or Unreasonable

If the velocity data from the FlowTracker does not seem reasonable, the following list may help establish the cause.

- Lack of scattering material in the water is the most common problem (particularly in large laboratory tanks). See §8.6 and the *FlowTracker Principles of Operation* for details about seeding requirements.
- Run *BeamCheck* as described in §6.5. This can address all aspects of FlowTracker operation, in particular, signal strength (scattering/seeding issues) and probe operation.
- Inspect the FlowTracker to be sure debris is not fouling the probe.
- Verify the FlowTracker mounting is stable and that instrument motion is not causing noise in the velocity data.
- Consider any possible environmental influences, particularly flow interference from underwater structures or obstacles.
- Consider the measurement environment. Highly turbulent or highly aerated water will greatly affect FlowTracker operation. In highly aerated water, the FlowTracker may not be able to operate reliably.
- Consider the orientation of the probe with respect to the flow direction to be sure the probe is not causing flow interference in the sampling volume (see §8.1.4).

8.7.5. Keypad Does Not Operate Reliably

The handheld controller is fully sealed; this can potentially affect operation of the keypad.

- Changes in temperature or atmospheric pressure may affect the keypad because of a difference in internal and external pressure.

Significant changes in pressure can affect system operation. To avoid problems, the controller must be vented to equalize pressure.

- To vent the keypad, simply loosen the dummy cap on the external communication connector a few turns (it is not necessary to completely remove the cap).
- Pressure will equalize within a few seconds.
- When pressure has equalized, tighten the dummy cap.
- When storing or shipping the system, leave the dummy cap loose to allow the system to adapt to changes in pressure.

Appendix A. FlowTracker Principles of Operation

A-1. Introduction

The FlowTracker Handheld ADV is a single-point Doppler current meter designed for field velocity measurements. The FlowTracker uses the proven Doppler technology of the SonTek/YSI Acoustic Doppler Velocimeter (ADV), the leading high-resolution velocity sensor. ADV technology provides several advantages.

- Accurate velocity measurements in a remote sampling volume
- 2D or 3D velocity measurements (depending on probe configuration)
- Invariant factory calibration – no periodic recalibration required
- Rapid response time
- Simple operation
- Excellent performance for low and high flows – accuracy 1% of measured velocity
- Built-in temperature sensor

The FlowTracker offers ADV performance from a simple handheld interface, allowing rapid data collection without the use of a computer. Some common applications include:

- River discharge measurements (using established methodology, including USGS/ISO)
- Open-channel flow measurements
- Current measurements in large pipes
- Rapid, multi-point current surveys
- Current monitoring in water treatment facilities

This appendix presents the operating principles of the FlowTracker. It does not attempt to provide a detailed discussion of all technical issues, nor a detailed description of FlowTracker operation. To learn more about specific applications, please contact SonTek/YSI.

A-2. The Doppler Shift

The FlowTracker uses an adaptation of the Doppler principle to measure water velocity.

- Velocity can be determined by measuring the change in pitch of sound coming from (or reflected from) a moving target.
- A common example is the pitch of a whistle from a moving train. The pitch is higher when the train is approaching, and lower when it is going away.
- Some common implementations of the Doppler principle include police radar sets for tracking automobile speeds and Doppler weather radar that tracks the speed of water particles suspended in the air (clouds).
- The FlowTracker uses a highly sophisticated form of this technique, which processes underwater sound (sonar) reflected from particulate matter suspended in the water.

The Doppler principle says that if a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmit frequency.

$$F_{doppler} = -F_{source} (V / C)$$

where

$F_{doppler}$ = change in received frequency (Doppler shift)
F_{source} = frequency of transmitted sound
V = velocity of source relative to receiver
C = speed of sound

The velocity, V, represents the relative speed between source and receiver (motion that changes the distance between the two).

- If the distance between the two objects is decreasing, frequency increases.
- If the distance is increasing, frequency decreases.
- Motion perpendicular to the line connecting source and receiver does not introduce a Doppler shift.

A-2.1. Bistatic Doppler Current Meters

Figure 31 shows the FlowTracker probe. The FlowTracker is a *bistatic* Doppler current meter.

- Bistatic means separate acoustic transducers are used for transmitter and receiver.
- The transmitter generates sound concentrated in a narrow beam.
- The receivers are sensitive to sound coming from a narrow beam.
- The receivers are mounted such that the beams intersect at a volume of water located a fixed distance (10 cm; 4 in) from the tip of the probe.
- The beam intersection determines the location of the *sampling volume* (the volume of water in which measurements are made).

The FlowTracker measures velocity as follows.

- The transmitter generates a short pulse of sound at a known frequency.
- The sound travels through the water along the transmitter beam axis.
- As the pulse passes through the sampling volume, sound is reflected in all directions by particulate matter (sediment, small organisms, bubbles).
- Some portion of the reflected energy travels back along the receiver beam axes.
- The reflected signal is sampled by the acoustic receivers.
- The FlowTracker measures the change in frequency (Doppler shift) for each receiver.
- The Doppler shift is proportional to the velocity of the particles along the bistatic axis of the receiver and transmitter. The bistatic axis is located halfway between the transmit and receive axes.
- Knowing the relative orientation of the bistatic axes allows the FlowTracker to calculate 2D or 3D water velocity.

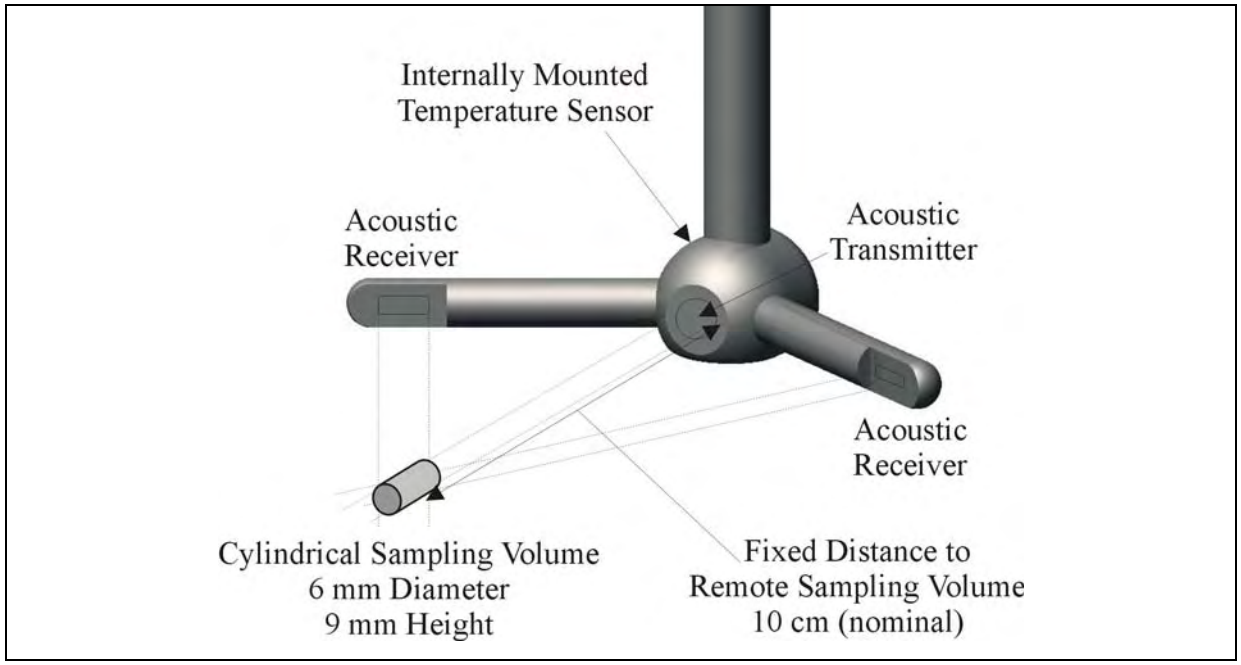


Figure 31 – FlowTracker 2D Side Looking Probe and Sampling Volume

Figure 32 shows a profile of signal strength versus time for the FlowTracker.

- The horizontal axis shows time after the transmit pulse
- The vertical axis shows the return signal strength measured by one receiver.
- As the transmit pulse travels through the water, sound is reflected in all directions.
- Immediately following the transmit pulse, reflections come from outside the receiver beam. The receiver measures only the ambient noise level.
- As the pulse propagates along the transmit axis, it moves closer to the receiver beam. The receiver sees an increase in signal strength.
- Signal strength reaches a maximum at the intersection of the transmit and receive beams.
- By sampling the return signal at its peak, the FlowTracker makes measurements in the sampling volume defined by the intersection of the transmit and receive beams.

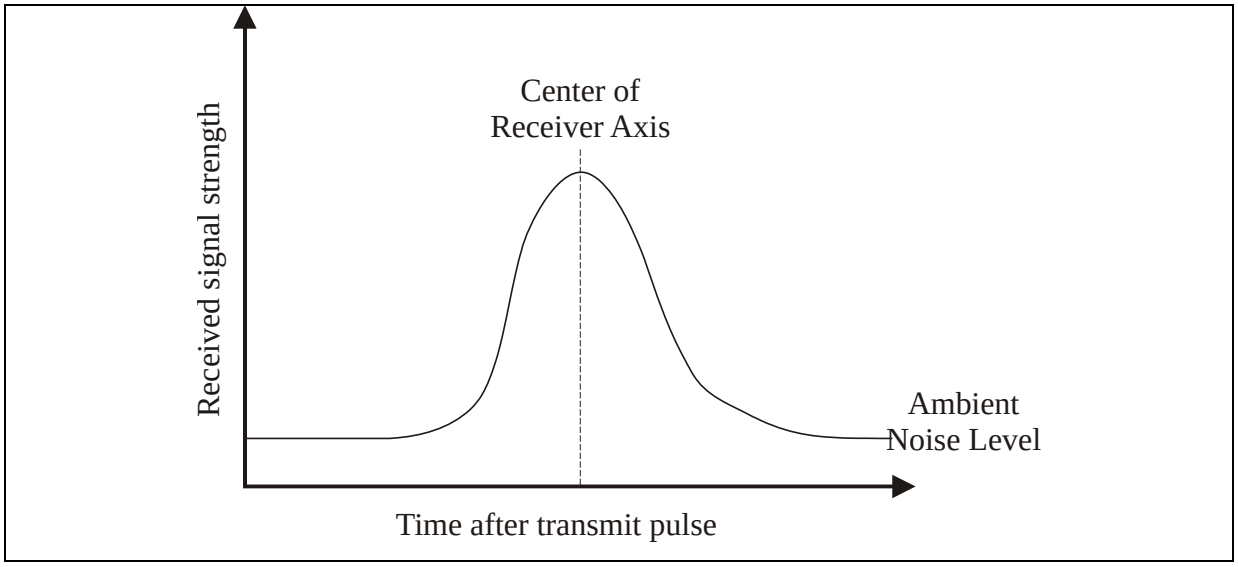


Figure 32 – FlowTracker Signal Strength Profile

A-3. Beam Geometry and 3D Velocity Measurements

A single transmit/receive pair measures the projection of the 3D water velocity onto the bistatic axis.

- The bistatic axis is halfway between the transmit and receive beam axes (see Figure 33).
- The velocity measured by each receiver is called the bistatic velocity.
- The FlowTracker uses one transmitter and two or three receivers (for 2D or 3D probes).
- See §A-7 for other FlowTracker probe configurations.
- Receivers intersect with the transmit beam pattern at a common sampling volume.
- Bistatic velocities are converted to Cartesian (XYZ) velocities using the probe geometry (the relative angles of transmit and receive beams). Cartesian velocities give the 2D or 3D velocity relative of the FlowTracker probe.
- During the manufacturing process, probe geometry is precisely determined by a calibration procedure.
- This calibration only needs to be performed once.
- No periodic re-calibration is required.

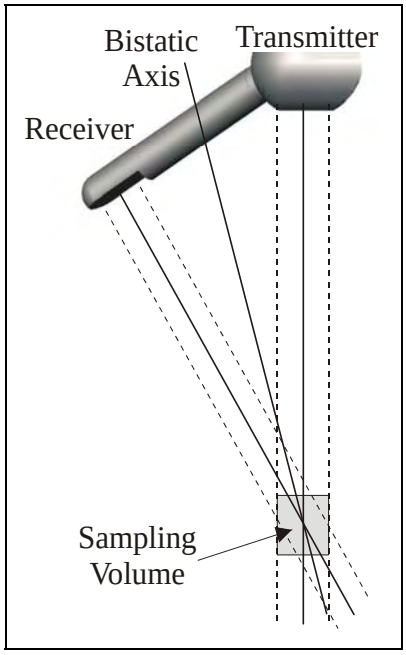


Figure 33 – Bistatic Axis

A-4. Sampling Volume Definition

The FlowTracker sampling volume is specified as follows.

- The sampling volume is nominally 10 cm (4 in) from the tip of the probe.
- The exact location varies ±1.0 cm (±0.4 in) from probe to probe.
- Precise sampling volume location is fixed for any given probe.
- The physical size of the sampling volume is a cylinder 6 mm (0.24 in) in diameter by 9 mm (0.35 in) in length (see Figure 31).

A-5. Pulse-Coherent Processing

This section does not attempt to provide a detailed description of pulse-coherent processing. It presents a simple overview with a focus on how this affects FlowTracker operation. SonTek can provide additional information on request.

The description of FlowTracker operation given in §A-2 is an oversimplification.

- §A-2 describes incoherent Doppler processing in which the transducer sends a single pulse of sound and measures the frequency change of the return signal.
- The FlowTracker uses a technique called *pulse-coherent processing*.

Pulse-coherent processing provides the best possible performance of any Doppler processing technique. In the simplest terms, pulse-coherent processing works as follows.

- The FlowTracker sends two pulses of sound separated by a time lag (τ).
- Each receiver measures the phase (ϕ) of the return signal from each pulse.
- The change in phase ($\phi 2 - \phi 1$) divided by the time lag (τ) is proportional to velocity.
- Because of the nature of the phase measurement (which can only be determined from -180° to +180°), the system has an inherent maximum velocity limitation.
- The FlowTracker velocity algorithms have been optimized to give the best possible performance over a wide velocity range of ±4.5 m/s (±15 ft/s).
- FlowTracker processing provides unmatched results for low flows (<1 cm/s; <0.03 ft/s).

FlowTracker processing has been designed to give the best possible performance in all environments. However, there is a situation where system performance may be affected by operating conditions.

- When working near boundaries or underwater obstacles, the system may need to adapt its operation to avoid acoustic interference.
- This is called *boundary adjustment* and is performed automatically by the system at each measurement location.
- The system reports a quality parameter with each measurement location that tells you if the environment has any effect on FlowTracker performance. This quality parameter is described in §1.4.4.

A-6. FlowTracker Data

A-6.1. Basic Sampling Strategy

The FlowTracker collects a burst of velocity data at each measurement location.

- All data are recorded to the FlowTracker internal recorder.
- You are prompted to enter location, depth, and other data at each measurement location to document the data set.
- For river discharge applications, measurements follow a prescribed sequence. This allows the FlowTracker to calculated river discharge in real-time.
- The system collects a fixed-length time-series of velocity at each measurement location.
- The *averaging time* at each location is user-specified (10 to 1000 seconds).
- Velocity data are recorded once per second during the averaging time.

When each measurement location is complete, you are presented with a summary of the velocity and quality control data. All data are stored to the internal recorder for later downloading to a computer for display, archiving, and further analysis.

A-6.2. Velocity Data

The FlowTracker provides several important performance advantages.

- It can measure 2D or 3D water velocities from 0.0001 to 4.5 m/s (0.0003 to 15 ft/s).
- Velocity data are accurate to 1% of the measured velocity in a one-second sample.
- Velocity data can be used immediately without any postprocessing corrections.
- True 2D or 3D velocity data are output in Cartesian coordinates (XYZ) relative to probe orientation.
- The FlowTracker calibration will not change unless the probe is physically damaged. No periodic calibration is required.
- Diagnostic software is included to evaluate system performance periodically.

The following describes the basic FlowTracker sampling strategy.

- An individual measurement of the 2D or 3D velocity is referred to as a *ping*.
- The FlowTracker pings 10 times per second, averaging these pings for a single velocity *sample*.
- One velocity sample is recorded each second.
- Velocity data are collected at each measurement location over the user-specified time. Raw one-second velocity, mean velocity, and quality control data are recorded with each station.
- For river discharge measurements, the FlowTracker combines velocity data with station location, water depth, and other data to determine total discharge in real-time.

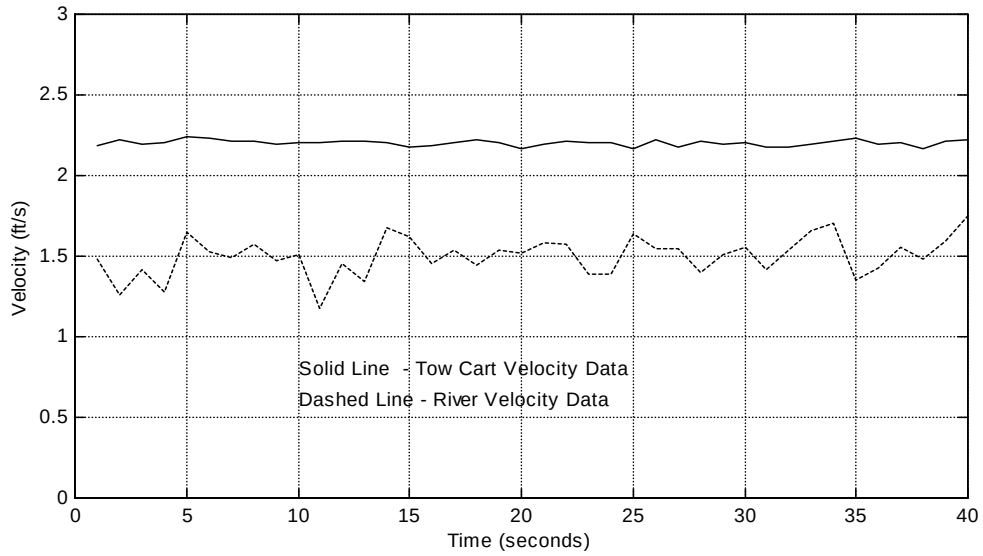


Figure 34 – FlowTracker Velocity Comparison

Accuracy of Velocity Data

The FlowTracker has been optimized to provide the best possible velocity data.

- Velocity data are accurate to 1% of measured velocity for each one-second sample.
- Variations in velocity data are dominated by true variations in water velocity.
- Instrument noise does not normally have an impact on velocity data.
- The averaging time required to determine the true mean velocity at a given location is a function of the real variations in velocity at that site.

FlowTracker velocity performance is shown in Figure 34.

- The solid line is data from a tow carriage test (the FlowTracker was towed at a known speed). Variations represent instrument noise and are less than 1% of the true velocity.
- The dashed line is data collected in a small stream. Variations represent real changes in the flow field (at this site they are about 8% of the mean velocity).

Two factors influence accuracy of FlowTracker velocity data – sound speed and probe geometry.

- The effect of sound speed is discussed in §A-7.2. With properly specified salinity data, sound speed errors are negligible (less than 0.25%).
- Probe geometry is calibrated at the factory for each FlowTracker; no recalibration is required unless the probe has been physically damaged.
- The FlowTracker calibration procedure is specified to ±1.0% of the measured velocity.
- There is no potential for zero offset or zero drift in velocity measurements. There is no inherent minimum measurable velocity.
- The FlowTracker is very well suited to low-flow applications to less than 1 cm/s (0.03 ft/s).

A-6.3. Quality Control Data

In addition to velocity, the FlowTracker records quality control data with each measurement station to quickly evaluate velocity data quality. Parameter details are in the FlowTracker manual.

- Standard Error of Velocity – §1.4.3
- Signal-to-Noise Ratio (SNR) – § 1.4.2
- Boundary Adjustment – §1.4.4
- Spike Filtering – §1.4.5
- Flow Angle – §1.4.6

A-7. Special Considerations

A-7.1. Probe Configurations

Several FlowTracker probe configurations (Figure 35) are available for different applications.

Probe mounting

- The probe is mounted from a 200 cm (80 in) flexible cable.
  - A 300 cm (120 in) cable is available for special applications. However, it is not possible to upgrade an existing system to a different cable length.
- The cable is custom built to reduce electronic noise. It should not be modified by the user.
- Cable length is limited to a maximum of 200 cm (80 in).
- Take care to avoid damage to the cable, as this can affect system operation.

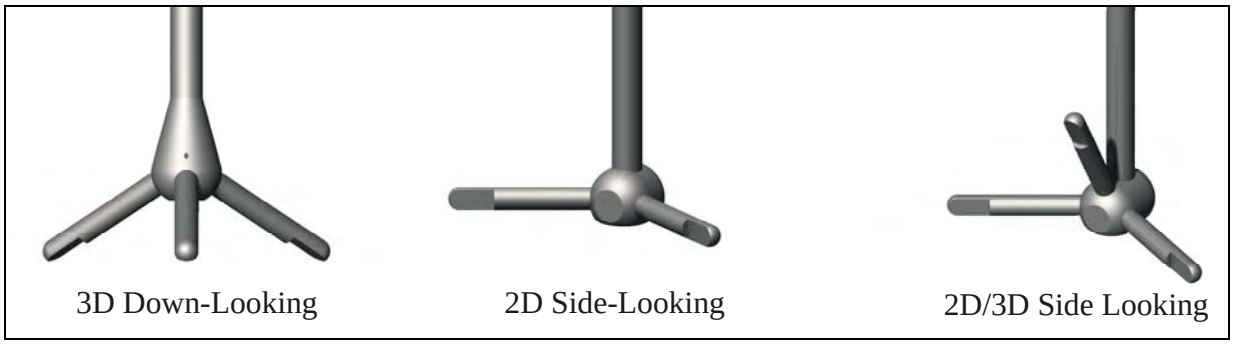


Figure 35 – FlowTracker Probe Configurations

Probe type

- Three probe types are available (Figure 35).
- The standard FlowTracker uses a 2D side-looking probe. The sampling volume is located 10 cm (4 in) to the side of the probe, and can operate in as little as 2 cm (1 in) of water.
- To work in both shallow and deeper water, a combination 2D/3D side-looking probe is available. This has a sampling volume located 10 cm (4 in) to the side of the probe, and can operate in as little as 2 cm (1 in) of water. It measures 2D velocity in shallow water (with only two arms submerged), and 3D velocity in deeper water (with all three arms submerged).
- For some applications, the 3D down-looking probe is preferred based on the location of the sampling volume, which is 10 cm (4 in) below the probe. It has a minimum operating depth of about 12 cm (5 in).

A-7.2. Sound Speed

The FlowTracker uses sound speed to compute velocity from the measured Doppler shift, and to precisely determine the location of the sampling volume. The speed of sound in water is primarily a function of temperature and salinity.

- A temperature change of 5°C (9°F) results in a sound speed change of ≈1%.
- A salinity change of 12 ppt results in a change in sound speed of ≈1%.
- A 1% error in sound speed results in a ≈2% error in velocity data.

To compensate for changing sound speed, the FlowTracker does the following.

- The FlowTracker includes a temperature sensor for automatic sound speed corrections. Resolution is ±0.1°C (±0.2°F).
- A user-input value of salinity is used for sound speed calculations.
- If accurate salinity data has been specified by the user (±2 ppt), sound speed changes can be assumed to have no impact on velocity data.

A-7.3. Environmental Conditions

Doppler current meters, such as the FlowTracker, do not measure movement of water, but actually the movement of particles **in** the water. We must assume that the movement of the particles in the water is representative of the movement of the water itself. This actually turns out to be a very safe assumption. As such, if you have a body of water where no particles (other than the water molecules themselves) are present, Doppler current meters will not work. Thankfully, natural streams almost always have something else other than just "water" (even if just tiny air bubbles), and the technology is such that even a small amount of particles in the water is usually enough for good measurements.

Two questions quickly come to mind: (1) how many particles does it take for the instrument to work, and (2) how small can these particles be? The short answers to these questions are: (1) just a few and (2) very small.

Visual inspection is **not** an acceptable method for determining the amount of particles in the water and no simple relationship exists with turbidity. We cannot say that for a given turbidity level your water is too clear for a Doppler-based measurement. The amount of particles in the water is not the only factor affecting signal amplitudes. Particle size, shape, distribution, and type also control these values, and these conditions vary from site to site. Therefore, one stream may meet these conditions, but another with the same turbidity may not.

Our best recommendation is that if you are unsure as to whether a stream will be "too clear" for a FlowTracker, simply take one and place it in the water to check the SNR values (signal-to-noise ratio; §1.4.2). The FlowTracker can return reliable measurements down to about 3 dB (in SNR), although we recommend 10 dB and above for best operating conditions.

Appendix B. FlowTracker Direct Command Interface

It is possible to establish direct communication with the FlowTracker using its RS232 serial interface.

- The serial interface is accessed through the external power/communication connector on the handheld controller.
- The serial interface is most commonly used to download data files from the internal recorder (see §6.4).
- A terminal emulator program (*SonUtils*) is included with the system to allow direct serial communication with the system.
- Direct communications are not commonly required, but can be a good diagnostic tool for verifying external communication with the FlowTracker.

Use the following steps to establish direct serial communications.

- Run *SonUtils*. Select COM1 and set the baud rate to 9600.
- Connect the external power/communication cable from the FlowTracker to COM1 of the computer.
- Turn on the FlowTracker.
- Send a **BREAK** to wake up the FlowTracker.
  - A **BREAK** is sent either by clicking the **BREAK** icon or by pressing **Alt+B**.
  - The **BREAK** is a serial communications signal that consists of holding the transmit line high for a period of at least 300 ms.
  - The **BREAK** causes a hardware reset in the FlowTracker, and should cause it to output a wake up message (e.g., “SonTek FlowTracker Handheld ADV …”).
  - After the wake-up message, you should see the command prompt “>”.
- You have now established direct communications and can send and receive commands.

A variety of commands are available from the direct command interface. They are not documented here as they are not required for FlowTracker operation.

- Type **`show <CR>`** to see a list of functions used to display all major system settings.

Appendix C. Discharge Uncertainty Calculation

C-1. Overview

The FlowTracker estimates the uncertainty of every discharge measurement. This calculation can be done using two different methods – **Statistical** or **ISO**.

- The **ISO** uncertainty calculation (§C-2) is based on the international standard[1]. It provides users with the results of a published, standard technique. However, in some cases, this calculation does not provide a reliable indicator of data quality.
- The **Statistical** uncertainty calculation (§C-3) uses a method developed by researchers at the U.S. Geological Survey[3]. This is the default calculation as it provides the most reliable indicator of measurement quality.
- The FlowTracker software displays the results of both uncertainty calculations.
- In the FlowTracker firmware, you can select the discharge uncertainty calculation from the Discharge Settings menu (§2.4.5).
- A comparison of the uncertainty results from the two calculations is shown in §C-4.

C-2. ISO Uncertainty Calculation

The ISO uncertainty calculation is based on a working version of ISO Standard 748[1]. While it is normally not appropriate to use a working version, an exception was made since the working version provides a more thorough calculation than the released ISO standard (1997). Equation 1 shows the ISO method to calculate uncertainty applied to a FlowTracker discharge measurement.

$$u_Q^{\,2} = u_m^{\,2} + u_s^{\,2} + \frac{\sum_{i=1}^{m}\left((b_i d_i v_i)^2\left(u_{bi}^{\,2} + u_{di}^{\,2} + u_{pi}^{\,2} + \left(\frac{u_{ci}^{\,2} + u_{ei}^{\,2}}{n_i}\right)\right)\right)}{\left(\sum_{i=1}^{m}(b_i d_i v_i)\right)^2} \qquad \text{(Eq. 1)}$$

Where:

u_Q = relative (percentage) uncertainty in discharge calculation

u_m = relative uncertainty due to the number of verticals (stations); §C-2.1

u_s = relative uncertainty due to calibration errors in measurements of width, depth and velocity. This is assumed to be accuracy of the FlowTracker calibration (1%).

m = number of verticals across the width of the stream

b_i = width at vertical i

d_i = depth at vertical i

v_i = mean velocity at vertical i

u_{bi} = relative uncertainty in the width measurement at vertical i. From the ISO standard, this is assumed to be 0.5%.

u_{di} = relative uncertainty in the depth measurement at vertical i. From the ISO standard, this is assumed to be 0.5% for depth > 0.30 m (1 ft), and 1.5% for depth < 0.30 m (1 ft).

u_{pi} = relative uncertainty due to limited number of velocity measurements at vertical i; §C-2.2

$u_{ci}+u_{ei}$ = relative uncertainty in velocity measurements at vertical i, with contributions from instrument uncertainty (u_{ci}) and real fluctuations in the river (u_{ei}). The combination of these two terms is directly measured by the FlowTracker as the standard error of velocity (v_{i_err}), and is calculated as ($u_{ci} + u_{ei} = v_{i\_err} / v_i$)

n_i = number of velocity measurements at vertical i

In Equation 1, the ISO calculation breaks the sources of uncertainty into two groups. The first group contains uncertainty sources that are applied for each vertical – width (u_{wi}), depth (u_{di}), method (u_{pi}, for the number of velocity measurements at each vertical), and velocity ($u_{ci} + u_{ei}$). These uncertainty sources are assumed to be independent, and are being weighted based on the discharge of each vertical.

The second group contains those values applied to the measurement as a whole – the accuracy of instrument calibration (u_s), and the number of verticals (u_m) (see §C-2.1).

In addition to overall uncertainty, the FlowTracker looks at the contribution of each parameter. To calculate the contribution of each parameter, the calculation is repeated while setting all other parameters to zero. At the end of each discharge measurement, the FlowTracker displays the overall uncertainty and the largest individual source of uncertainty. The FlowTracker software shows the contribution of each parameter.

- **Accuracy** (u_s): uncertainty due to the accuracy of the FlowTracker calibration
- **Depth** (u_{di}): uncertainty due to depth measurements
- **Velocity** ($u_{ci} + u_{ei}$): uncertainty due to velocity measurements (instrument uncertainty and real fluctuations in the flow)
- **Method** (u_{pi}): uncertainty due to number and location of velocity measurements at each vertical
- **Number of verticals** (u_m): uncertainty due to a limited number of verticals
- **Width** (u_{wi}): uncertainty due to width measurements

C-2.1. Number of Verticals

Velocity and depth are measured at a limited number of verticals across the stream, and are assumed to vary linearly between them. To estimate the uncertainty of this assumption, the ISO provides a guideline based on the number of verticals in Table C-1.

Table C-1. Number of Verticals vs. Uncertainty

Number of Verticals	Uncertainty % (u_m)
5	7.5
10	4.5
15	3.0
20	2.5
25	2.0
30	1.5
35	1.0
40	1.0
45	1.0

Sauer and Meyer[2] provide the same data and Equation 2 below to calculate this uncertainty for any number of verticals. In this equation, u_m is given in percent and m is the number of verticals. This is the equation used by the FlowTracker when calculating the ISO uncertainty estimate.

$$u_m = 32 * m^{-0.88} \quad \text{(Eq. 2)}$$

This estimate is based on a statistical analysis of many streams. It does not take into account the data available with an individual stream that could strongly influence the overall uncertainty. For example, it might be possible with five verticals to accurately measure the flow in a broad concrete lined channel of constant depth, as the velocity distribution across the width of the channel will likely be very consistent. In comparison, a natural stream can show large velocity and depth changes, so the accuracy of a discharge measurement with five verticals would be much lower. The ISO calculation would not account for this difference. This is perhaps the most significant shortcoming of the ISO calculation.

C-2.2. Limited Velocity Measurements at Each Vertical (Discharge Method)

A limited number of velocity measurements are made at each vertical; the mean velocity is calculated using assumptions about the velocity distribution. The ISO standard provides an estimate of the uncertainty associated with these assumptions in Table C-2.

Table C-2. Measurement Method vs. Uncertainty

Measurement Method	Uncertainty (u_{pi}) %
1 point (0.6 * depth)	7.5
2 points (0.2 and 0.8 * depth)	3.5
5 points (near surface, near bottom, and 0.2 / 0.6 / 0.8 * depth)	2.5
Velocity distribution method (multiple points with the change between points not to exceed 20% of the higher value)	0.5

For the FlowTracker calculations, we have simplified Table C-2 above to estimate the uncertainty based only on the number of measurements in the vertical as shown in Table C-3 below.

Table C-3. Number of Measurements vs. Uncertainty

Number of Measurements	Uncertainty (u_{pi}) %
1	7.5
2	3.5
3	3.0
4	2.7
5 or more	2.5

C-3. Statistical Uncertainty Calculation

The technique we refer to as the **Statistical** uncertainty calculation was developed by researchers at the U.S. Geological Survey (USGS): Tim Cohn, Julie Kiang, and Robert Mason [3]. It has also been called the interpolated difference technique, though no final name has been selected. As of August 2006, they have not published the technique, but have plans to do so in the future. The calculation described here should be considered preliminary, and may be subject to change.

The **Statistical** technique takes a very different approach from the ISO method. The ISO looks at the physical characteristics of the measurement and discharge calculation to estimate uncertainty. The **Statistical** technique is a strictly statistical approach, using adjacent values of each measured variable to estimate the uncertainty in these measurements. This appendix presents a brief overview of the **Statistical** technique, deferring a full description to future publications of Cohn, Kiang, and Mason. The basic form of the **Statistical** calculation is similar to the ISO calculation.

$$u_Q^{\,2} = u_s^{\,2} + \frac{\sum_{i=1}^{m}\left((b_i d_i v_i)^2\left(u_{bi}^{\,2} + u_{di}^{\,2} + u_{vi}^{\,2}\right)\right)}{\left(\sum_{i=1}^{m}(b_i d_i v_i)\right)^2} \qquad \text{(Eq. 3)}$$

Where:

- u_Q = relative (percentage) uncertainty in overall discharge calculation
- u_s = relative uncertainty due to calibration errors in measurements of width, depth and velocity. This is assumed to be accuracy of the FlowTracker calibration (1%).
- m = number of verticals across the width of the stream
- b_i = width at vertical i
- d_i = depth at vertical i
- v_i = mean velocity at vertical i
- u_{bi} = relative uncertainty in the width measurement at vertical i. This is not specifically calculated by the Statistical technique; it uses the same 0.5% value as the ISO calculation.
- u_{di} = relative uncertainty in the depth measurement at vertical i.
- u_{vi} = relative uncertainty in the velocity measurement at vertical i.

As with the ISO, this calculation breaks the sources of uncertainty into two groups. The first are uncertainty sources that are applied for each vertical: width (u_{wi}), depth (u_{di}), and velocity (u_{vi}). These uncertainty sources are weighted based on the discharge of each vertical. The other source is applied to the measurement as a whole: the accuracy of instrument calibration (u_s). All uncertainty sources are assumed to be independent.

To estimate the uncertainty in depth and velocity, the **Statistical** technique uses adjacent measurements. The calculation is the same for depth or velocity (only depth is shown here).

A basic assumption of a discharge measurement is that velocity and depth change linearly between verticals. Following this assumption, we can estimate the depth at vertical i (d_i) by using depth values from the adjacent vertical (d_{i-1} and d_{i+1}). For simplicity, the calculation here assumes equal spacing of verticals. The FlowTracker implementation does a linear interpolation based on the location of each vertical.

$$d_{i\_est} = (d_{i-1} + d_{i+1}) / 2 \qquad \text{(Eq. 4)}$$

An estimate of the uncertainty in depth for vertical i can be calculated as the difference between the estimated and measured depth.

$$\Delta_i = d_{i\_est} - d_i \qquad \text{(Eq. 5)}$$

Any individual uncertainty estimate (Δ_i) is subject to considerable variability; combining all estimates from a given measurement gives a better overall estimate of uncertainty. Equation 6 calculates an overall estimate of the uncertainty in depth measurements (σ_d), a statistical average of the individual uncertainty estimates (Δ_i). This value (σ_d) is in depth units (m or ft). (The derivation of Equation 6 is deferred to future publications of Cohn, Kiang, and Mason.)

$$\sigma_d^{\,2} = \left(\frac{2}{3}\right)\left(\frac{1}{(m-2)}\right)\sum_{2}^{m-1}\left(\Delta_i^{\,2}\right) \qquad \text{(Eq. 6)}$$

The relative depth uncertainty for each vertical is calculated below in Equation 7. This relative depth uncertainty (u_{di}) is used directly in Equation 3. A similar term can be calculated for velocity (u_{vi}; not shown here).

$$u_{di} = \sigma_d / d_i \qquad \text{(Eq. 7)}$$

Perhaps the primary advantage of the **Statistical** technique is that the estimated uncertainty takes into account variability in depth/velocity across the stream, and as such, includes measurement uncertainty, natural stream conditions (e.g., different bottom types), and the assumption that depth and velocity change linearly between stations.

In addition to overall uncertainty, the FlowTracker looks at the contribution of each parameter. To calculate the contribution of each parameter, the calculation is repeated while setting all other parameters to zero. At the end of each discharge measurement, the FlowTracker displays the overall uncertainty and the largest individual source of uncertainty. The *FlowTracker* software shows the contribution of each parameter.

- **Accuracy** (u_s) – uncertainty due to the accuracy of FlowTracker calibration
- **Depth** (u_{di}) – this term includes both uncertainty in the depth measurement and the effect of changes in depth between verticals.
- **Velocity** (u_{vi}) – this term includes both uncertainty in the velocity measurement and the effect of changes in velocity between verticals.
- **Width** (u_{wi}) – uncertainty due to width measurements

C-4. Uncertainty Comparison: ISO and Statistical

Why offer two different uncertainty calculations – should not one be sufficient? To answer this, we need to look at the results of each method.

The ISO calculation seems a natural choice – it is well documented and from an internationally recognized agency. However, analysis shows the ISO does not always provide a meaningful indication of the measurement quality. In comparison, the **Statistical** technique appears to provide a good indicator of measurement quality, particularly at sites with variable flow conditions. However, it is currently (August 2006) an unpublished technique and may be subject to change. Since there are drawbacks to each calculation, we decided to present results from both calculations.

To compare the two uncertainty calculations, we used a set of 24 real discharge measurements made with a FlowTracker. These represent a range of conditions – discharge values from 0.004 to 8.6 m^3/s (0.13 to 300 ft^3/s) and mean velocity from 0.01 to 0.50 m/s (0.03 to 1.6 ft/s). All measurements are in natural rivers in North America.

Figure 36 compares the **Statistical** and ISO calculations from all 24 files.

- The **Statistical** calculation shows uncertainty values from 2.1 to 19%; the ISO calculation shows values from 2.4 to 8.4%.
- If you remove one outlier (with very low velocity and high uncertainty), the **Statistical** calculation varies from 2.1 to 15% while the ISO varies only from 2.4 to 4.3%.
- Since uncertainty under 5% is considered a "Good" measurement by many agencies, the ISO equation would rate all of these measurements as Good, which is clearly not the case on closer analysis of some files.
- To understand this better, we will also look at two individual files in detail.

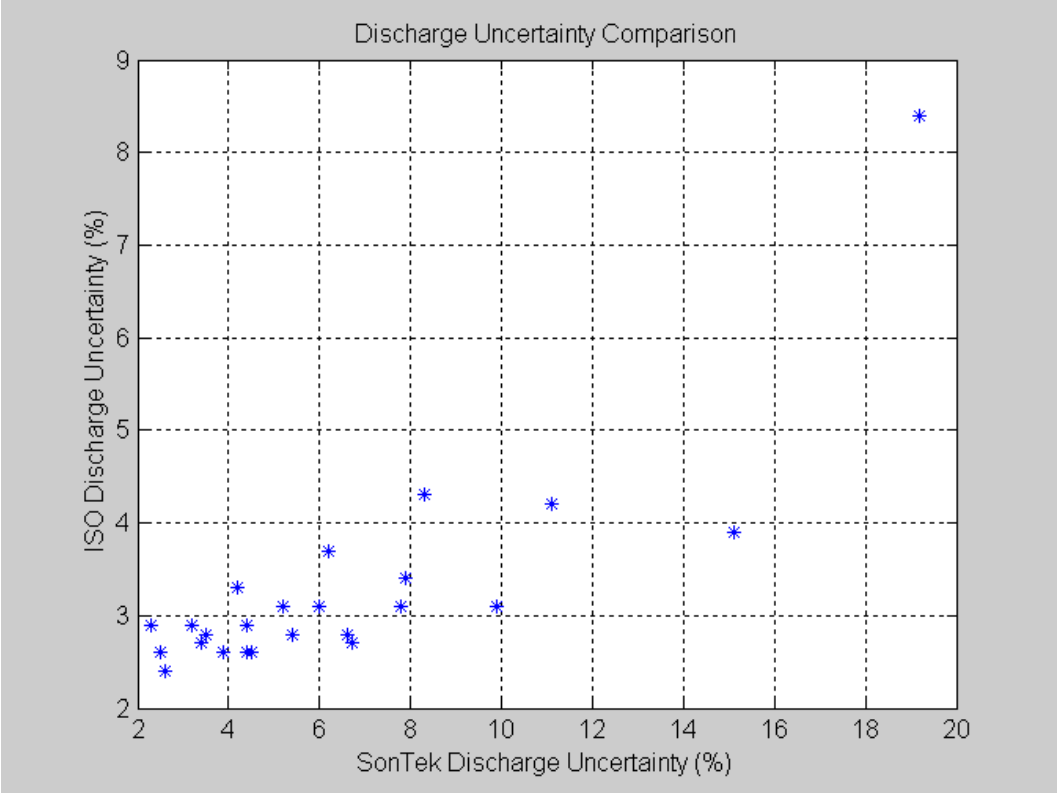


Figure 36 – Statistical and ISO Calculation Comparison

Figure 37 shows depth and velocity profiles from a file where **Statistical** shows 2.5% uncertainty, while ISO shows 2.6%. As both calculations indicate, this is a good measurement with smooth, linear variations in depth and velocity with few large inconsistencies. Both calculations correctly represent this.

Figure 38 shows depth and velocity profiles from a file where the **Statistical** calculation shows 15.1% uncertainty, while the ISO calculation shows 3.9%. Looking closely at the measurement, there are several large and dramatic changes in both depth and velocity (particularly velocity; for example, look at the verticals at location 5.5 and 8.1 m). This indicates either unusual flow conditions (which would require more verticals to resolve) or measurement problems. The ISO calculation still reports an uncertainty (3.9%) that would be considered good by most users. The **Statistical** calculations report a much higher uncertainty (15.2%), correctly indicating there are areas that are cause for concern in the quality of this measurement.

Because of the ability of the **Statistical** calculation to distinguish data quality issues as shown here, we recommend using the **Statistical** uncertainty calculation. It is hoped that additional publications and data analysis will help further the development of uncertainty calculations, leading to a single accepted method in the future.

It is also interesting to look at the contribution of each parameter to the estimated uncertainty. For the ISO calculation, six different parameters contribute to the overall uncertainty – width, depth, velocity, method, number of stations, and accuracy (FlowTracker calibration). For the **Statistical** calculation, there are four parameters – width, depth, velocity, and accuracy (FlowTracker calibration again).

For the ISO calculation, the number of stations is the largest single component of uncertainty for 22 of 24 files; method and velocity are each the largest source in one file. Since the number of stations parameter is essentially based on a statistical analysis of many rivers, rather than data from the specific measurement site, this raises significant concerns if it is the largest source of uncertainty. The contribution of velocity is generally small, except in cases where the mean velocity is very low (velocity is the largest component of uncertainty in a file where the mean velocity is 0.01 m/s (0.04 ft/s)). The measurement method is generally a modest contributor to overall uncertainty, but can be significant in files with low overall uncertainty (<3%). The contribution of width, depth, and accuracy to the overall ISO uncertainty is small to negligible.

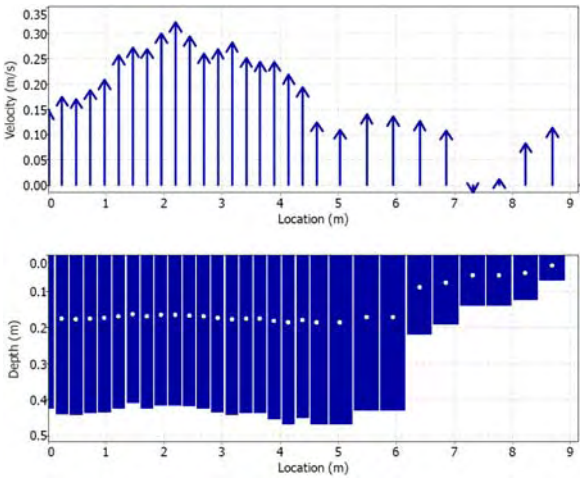


Figure 37 – Uncertainty Comparison: Good Discharge Measurement

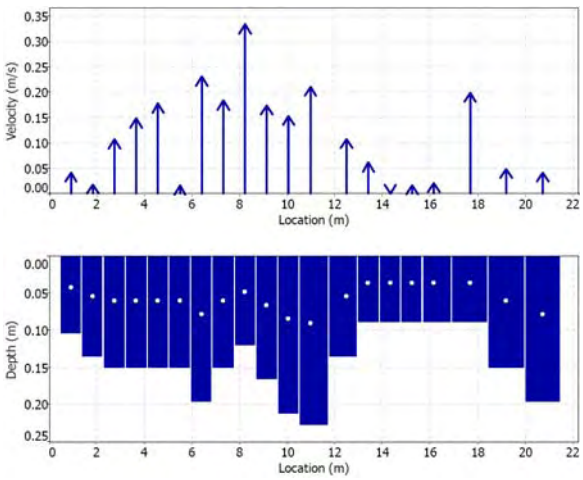


Figure 38 – Uncertainty Comparison: Poor Good Discharge Measurement

For the Statistical calculation, the velocity term is the largest individual source of uncertainty in all 24 files. Keep in mind that this term includes not only uncertainty in the velocity measurement, but also variation in velocity between stations (which is typically the dominating factor). Depth adds a small but notable amount to the Statistical uncertainty calculation; again, this is dominated by the variation in depth between stations. The contributions of width and accuracy are small to negligible. Analysis of this data tends to indicate that variation between stations, both of depth and velocity, are the most important factor in overall measurement uncertainty.

C-5. References

[1] ISO 748, Hydrometry - Measurement of liquid flow in open channels using current meters or floats. Working version 2003.

[2] V.B. Sauer, and R.W. Meyer, Determination of Error in Individual Discharge Measurements. U.S. Geological Survey, Open File Report 92-144. 1992.

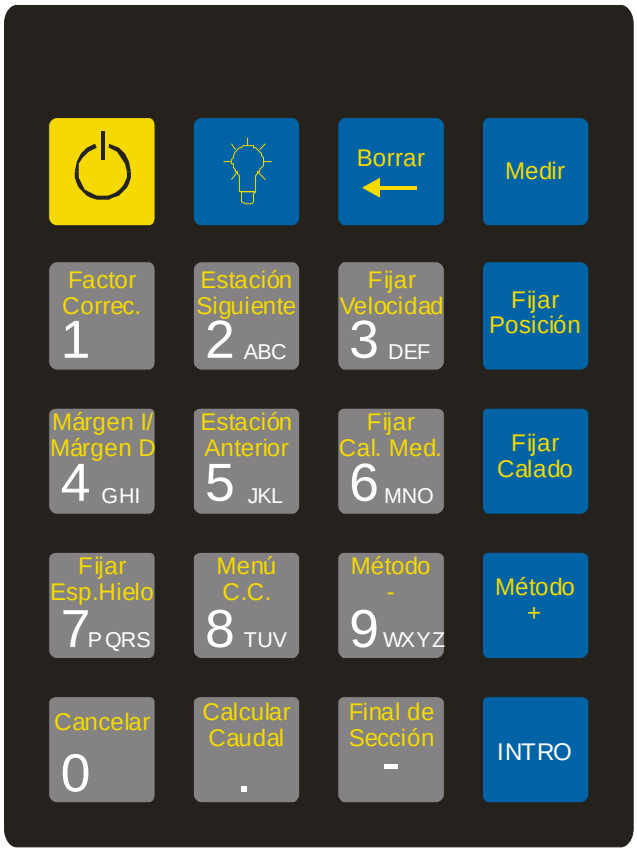
[3] Tim Cohn, Julie Kiang, and Robert Mason, U.S. Geological Survey. Personal communication, June-August 2006.

Appendix D. Multiple Language Keypads

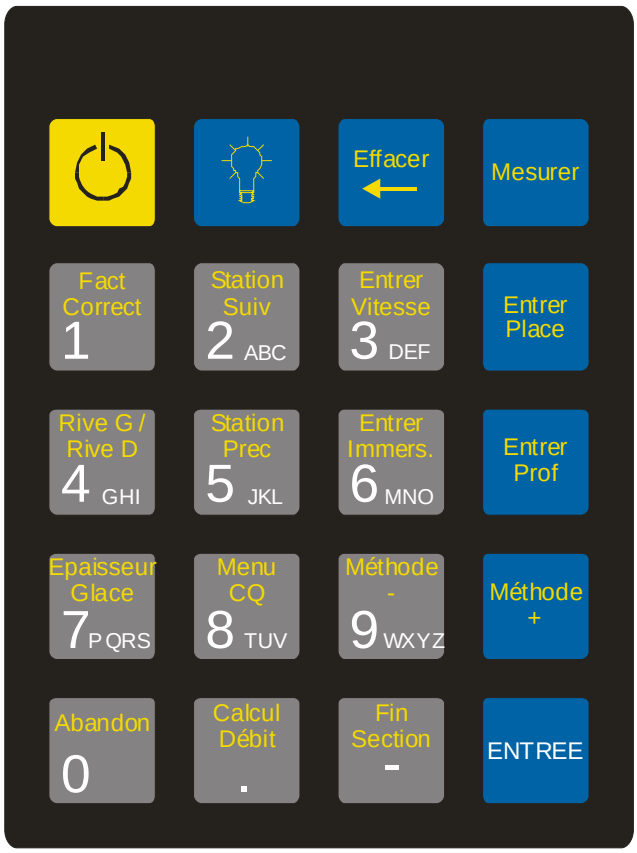
The FlowTracker supports operation in five languages using translated keypad overlays for each language. The keypads are shown in actual size within the document, so they can be printed and temporarily taped over the keypad for testing purposes. High quality, embossed decals to overlay onto existing keypads are available as a permanent way to show the different key labels.



English Keypad



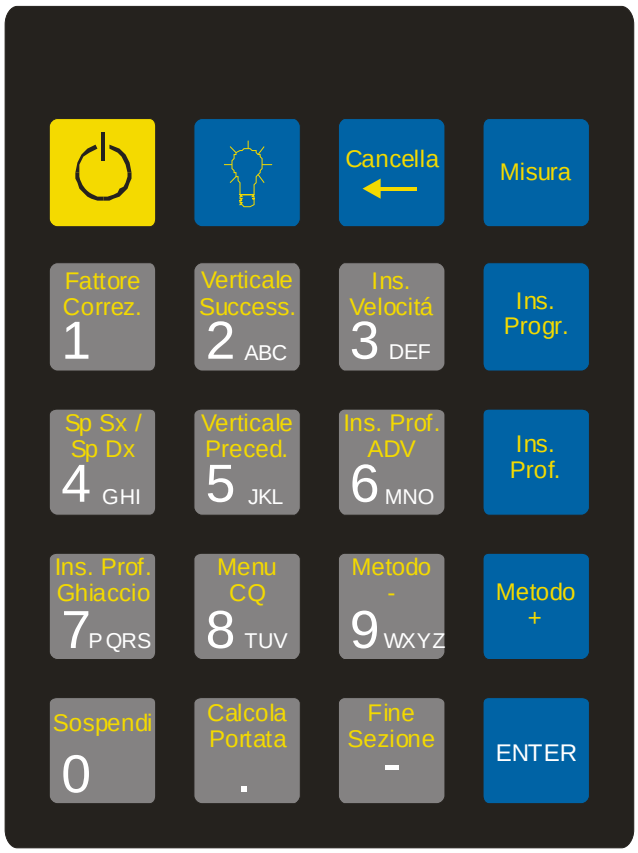
Spanish Keypad



French Keypad



German Keypad



Italian Keypad

INDEX

.

.bmc extension, 59

0

0-9 (keypad), 14

A

Abort key, 17
accuracy, 96
all beams (beam check), 59
amplitude (beam check), 59, 61
analog board, 75
anodes, 85
averaging (beam check), 59, 60
averaging time, 4, 19
A-Z (keypad), 14

B

Back Light key, 15
battery data display, 24
battery power, 73
battery, backup clock, 83
baud rate (recorder), 55
beam 1/2/3 (beam check), 59
beam geometry, 93
BeamCheck, 57
bistatic, 91, 93
boundary adjustment, 9, 94
boundary QC, 9

C

cables
  and connectors, 1, 71
  power/comm., 1, 71
  probe, 1, 71, 79
Calculate Disch key, 17
calibration, 89
cartesian (xyz), 93
check recorder status, 23
clear water conditions, 98
clock battery, 83
close (beam check), 59
command interface, direct, 99
components, system, 1
condensation, 85
considerations, 97
considerations, operational, 28, 79
contact information, iv
control, external, 3
controller, handheld, 1
coordinate system, 82
copy (beam check), 59
Corr. Factor key, 15
corrosion protection, 85
cosine (beam check), 59
cpu board, 76
cpu, upgrading, 78

D

data collection
  discharge mode, 42
  general mode, 29
  modes, 19, 28
data export, 51
definitions, 3
Delete key, 15
deployment considerations, 28, 79
destination folder (recorder), 55
diagnostics, 27
direct command interface, 99
discharge
  calculation method, 33
  data collection, 42
  measurements, 33
  mode, 19, 33
display raw data, 24
Doppler principle, 90

E

edges, 34, 35
electronics overview, 74
electronics, accessing, 77
End Section key, 17
Enter key, 17
environmental conditions, 98
exit (beam check), 59
extraction software, 51

F

filtering, spike, 9
flow angle, 10
flow interference, 81
FlowExporter, 51
flowtracker software, 50
force high-speed connection (beam check), 59
format recorder, 23

G

general mode, 20, 29
general purpose measurements, 29
getting started, 27
graph title (beam check), 61

H

hardware, 71

I

ice covered water, 34, 36, 37
interface, keypad, 3
interference, flow, 81
islands, internal, 34, 35, 37

K

keypad, 1, 13, 14

L

LCD screen, 1
letters (keypad), 14
LEW/REW key, 16

M

main menu, 18
maintenance, 84
mean station velocity, determining, 38
Measure key, 15
measurement
  discharge, 33
  general purpose, 29
  location, 4
mounting, 79
mounting, probe, 97
multiple channels, 34, 35, 37

N

Next Station key, 15
noise (beam check), 61
numbers (keypad), 14

O

On/Off key, 13, 15
open (beam check), 59
operational considerations, 79
operational overview, 27
o-rings, 84

P

particles, 98
pause (beam check), 59
peak level (beam check), 61
peak pos (beam check), 61
ping, 4
ping (beam check), 61
ping rate, 4
ping selector (beam check), 60
pings averaged (beam check), 61
playback speed (beam check), 60
power, 27, 72
power/comm. cable, 71
Prev. Station key, 16
print (beam check), 59
probe, 1
probe cable, 1, 71, 79
probe configurations, 97
processor board, 75
pulse-coherent, 94

Q

quality control, 96
quality control data, 3, 5

R

receiver, 2
receivers, 91
record (beam check), 59
Recorder program, 55
recorder, format, 23
release notice, iv
replay (beam check), 59
river/stream measurements, 33

S

salinity, 3, 21, 98
sample, 4
samples (beam check), 61
sampling strategy, 4, 95
sampling volume, 2, 91, 93
scatterers, 98
seeding, 86
select all (recorder), 55
sensor, temperature, 2, 83
Set Depth key, 16
Set Ice Depth key, 16
Set Location key, 15
Set Meas Depth key, 16
set system clock, 25
Set Velocity key, 15
setup parameters menu, 19
show decay curve (beam check), 59
show range as x-axis (beam check), 59
show system configuration, 25
signal strength, 3, 4, 92
signal-to-noise ratio, 3, 7
sine/cosine (beam check), 59
SNR, 3, 7, 98
software, 49
sound speed, 3, 98
spike filtering, 9
standard deviation, 4
standard error of velocity, 8
start (beam check), 59
start data run, 26
station velocity, determining mean, 38
stop (beam check), 59
stream/river measurements, 33
support, iv
system functions menu, 22

T

temperature, 3, 98
temperature data, 23
temperature sensor, 2, 83
terminology, 3
Toggle Method key, 17
trademarks, iv
transmitter, 2, 91
troubleshooting, 87

U

units system, 19

V

velocity data, 95
velocity data coordinate system, 82
view data file, 22

W

warranty, iv
wiring overview, 74

Z

zinc anodes, 85

zoom in/out (beam check), 60

ATTACHMENT C
Flowtracker2 Technical Manual



FlowTracker®2

USER'S MANUAL 1.1
SOFTWARE VERSION 1.1
FIRMWARE VERSION 1.17



For Sales & Service Contact

geotech

2650 E. 40th Ave. • Denver, CO 80205
Phone 303-320-4764 • Fax 303-322-7242
1-800-833-7958
www.geotechenv.com

Copyright 2016 by Xylem Inc. All rights reserved. This document may not, in whole or in part, be copied, photocopied, reproduced, translated, or reduced to any electronic medium or Machine-readable form without prior consent in writing from Xylem. Every effort has been made to ensure the accuracy of this manual. However, Xylem makes no warranties with respect to this documentation and disclaims any implied warranties of merchantability and fitness for a particular purpose. Xylem shall not be liable for any errors or for incidental or consequential damages in connection with the furnishing, performance, or use of this manual or the examples herein. The information in this document is subject to change without notice.

SonTek
a xylem brand

9940 Summers Ridge Rd
San Diego, CA 92121
+1.858.546.8327
inquiry@sontek.com
sontek.com

Release Notice **45-0120 Rev B**

This is the February 2016 release of the FlowTracker2 User's Manual. During the creation of this manual, the following were the latest versions of firmware/software. As such, if you are using different firmware/software versions, not all aspects of this manual may apply.

- FlowTracker2 firmware version 1.17
- FlowTracker2 software version 1.1

Trademarks

The terms FlowTracker2 are registered trademarks of Xylem Inc. All rights are reserved. All other brand names are trademarks of their respective holders.

Warranty, Terms, and Conditions

Thank you for purchasing the FlowTracker2. The instrument was thoroughly tested at the factory and found to be in excellent working condition. If the shipping crate appears damaged, or if the system is not operating properly, please contact us immediately.

The system you have purchased is covered under a two year limited warranty that extends to all parts and labor for any malfunction due to workmanship or errors in the manufacturing process. The warranty does not cover shortcomings that are due to the design, nor does it cover any form of incidental damage as a result of errors in the measurements.

If your system is not functioning properly, first try to identify the source of the problem. If additional support is required, we encourage you to contact us immediately, and we will work to resolve the problem as quickly as possible.

If the system needs to be returned to the factory, please contact technical support to obtain a Service Request (SR) number. We reserve the right to refuse shipments without SR numbers. We require the system to be shipped back in the original shipping container using the original packing material with all delivery costs covered by the customer (including all taxes and duties). If the system is returned without appropriate packing, the customer will be required to cover the cost of a new packaging crate and material.

Contact Information

Any questions, concerns, or suggestions can be directed to SonTek by telephone, fax, or email. Business hours are 8:00 a.m. to 5:00 p.m., Pacific Standard Time, Monday through Friday.

Phone :	+1 (858) 546-8327
Fax :	+1 (858) 546-8150
Email :	inquiry@sontek.com (General information)
	sales@sontek.com (Sales information)
	support@sontek.com (Support information)
Web :	http://www.sontek.com

See our web site for information concerning new products and software/firmware upgrades.

FCC INFORMATION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

The FlowTracker2 FCC license number can be found in two locations: (1) on the shipping box label and (2) engraved on the back of the FlowTracker2. Examples of the shipping box label and engraving are shown below.

Table of Contents

List of Tables ***13***

List of Equations ***15***

Section 1. Quick Overview ***16***

1.1. System Components 16

1.2. Definitions and Terminology 18

Section 2. System Operation ***20***

2.1. On/Off Switch 20

2.2. Keypad 20

2.3. Screen Layout 22

2.4. Main Menu 22

2.4.1 Device Configuration Menu (Main Menu) 23
2.4.2 Utilities (Main Menu) 23
2.4.3 Communication (Main Menu) 24
2.4.4 System Information (Main Menu) 24
2.4.5 Measurement (Main Menu) 25
2.4.6 Data Files (Main Menu) 26

Section 3. Device Configuration ***28***

3.1. User Interface 28

3.1.1 Language 28
3.1.2 Use Beeper 29
3.1.3 Color Scheme 29
3.1.4 Font Size 29
3.1.5 Font Smoothing 30

3.2. Application Settings 30

3.2.1 Units 30
3.2.2 Wading Rod 31
3.2.3 File Naming 32
3.2.4 Folder Naming 33
3.2.5 GPS Station Tagging 33

3.3. Configuration Templates 35

3.3.1 Template Options 35
3.3.2 Managing Templates 36
3.3.2.1 Accessing Templates 36
3.3.2.2 New Template 37
3.3.2.3 Selecting Template 37

3.4. Template Functions 37

3.4.1 File Properties 38

3.4.2 Data Collection Settings 39
3.4.2.1 Averaging Time 40
3.4.2.2 Salinity 40
3.4.2.3 Temperature 41
3.4.2.4 Sound Speed 41
3.4.2.5 Mounting Correction 42
3.4.3 Quality Control Settings 42
3.4.3.1 SNR Threshold 43
3.4.3.2 Std Error Threshold 43
3.4.3.3 Spike Threshold 43
3.4.3.4 Velocity Angle for Warning 44
3.4.3.5 Tilt Angle Warning 44
3.4.4 Discharge Settings 44
3.4.4.1 Discharge Equation 45
3.4.4.2 Discharge Uncertainty 46
3.4.4.3 Discharge Reference 46
3.4.4.4 Max Station Q for Warning (%) 47
3.4.4.5 Max Depth Change for Warning (%) 47
3.4.4.6 Max Spacing Change for Warning (%) 47
3.4.4.7 0.6 Method Depth 47
3.4.5 Displayed Velocity Methods 48

Section 4. Utilities 50

4.1. System Clock 50
4.1.1 Manual Change 50
4.1.2 Sync with GPS Time 51

4.2. Recorder 52
4.2.1 Manage Recorder 52
4.2.2 Erase Recorder 53

4.3. Battery Data 54
4.3.1 Battery Type 54
4.3.2 Battery Voltage 55
4.3.3 Percentage Full 55

4.4. Raw Data Display 55
4.4.1 Velocity Raw Data 56
4.4.2 SNR Raw Data 57
4.4.3 Temperature Raw Data 58
4.4.4 Tilt Raw Data 58
4.4.5 Battery Indicator 58

4.5. Automated Beam Check 59

4.6. Beam Check 61

4.7. GPS Data 61

4.8. System Maintenance 63
4.8.1 Force Probe Upgrade 63

Section 5. Data Collection Modes 64

5.1. Discharge Mode 64
5.1.1 Measurement Technique 64
5.1.2 Discharge Calculation Methods 65
5.1.2.1 Mid-Section Equation 65
5.1.2.2 Mean-Section Equation 67
5.1.2.3 Japanese Equation 68
5.1.3 Determining Mean Station Velocity 70
5.1.3.1 Method None 71
5.1.3.2 Vertical Velocity Curve 72
5.1.3.3 Correction Factor 73
5.1.4 Discharge Uncertainty Calculation 73
5.1.5 Under Ice Measurements 74
5.1.6 Weighted Gauge Height 75
5.2. General Mode 76
5.2.1 Measurement Technique 76
5.2.2 Determining Mean Velocity 76
Section 6. Quality Control 77
6.1. Quality Control Parameters 77
6.1.1 Signal to Noise Ratio (SNR) 78
6.1.2 Velocity Standard Error 81
6.1.3 Boundary Interference 82
6.1.4 Velocity Spike Filter 84
6.1.5 Velocity Angle 85
6.1.6 Tilt Angle 86
6.1.7 Station Percent Discharge 87
6.1.8 Station Water Depth 88
6.1.9 Station Location 88
6.1.10 Velocity Profile 0.2 \ 0.8 89
6.2. Quality Control Warning Messages 89
6.2.1 Types of Warning Messages 89
6.2.2 Timing of Warning Messages 91
6.3. Beam Check 92
6.3.1 Beam Check Overview 92
6.3.2 Beam Check Features 93
6.3.3 Beam Check Operation 94
6.3.4 Diagnosing Measurements with Beam Check 94
6.3.4.1 Low Scattering Strength 94
6.3.4.2 Strong Scattering Strength 95
6.3.4.3 Boundary Detected within Beam Check 95
6.3.4.4 Boundary in Sampling Volume 96
Section 7. Measurement Process 98
7.1. Office Procedures 98
7.1.1 Equipment List 98
7.1.2 Hardware Inspection 99
7.1.3 Office Diagnostic 99

7.2. Measurement Site Information 101
7.3. Pre Measurement Diagnostics 101
7.4. Measurement Procedure 102
7.5. Post Measurement Requirements 104
7.5.1 Review of Measurement Site Information 104
7.5.2 Review Measurement Summary 105
7.5.3 Data Management 105
7.5.4 Storage 106
Section 8. Discharge Measurement 107
8.1. Create Measurement 107
8.1.1 Measurement 107
8.1.2 New File Type 107
8.1.3 New File Template 108
8.1.4 New Data File 108
8.2. Automated Beam Check 109
8.2.1 Start Automated Beam Check 109
8.2.2 Evaluate Beam Check Results 110
8.3. Data Collection 111
8.3.1 Data Collection Window 112
8.3.1.1 Add Station 112
8.3.1.2 Delete Station 113
8.3.1.3 Edit Station 114
8.3.2 Station Types 115
8.3.2.1 Bank (left or right) 116
8.3.2.2 Island Edge 117
8.3.2.3 Open Water 118
8.3.2.4 Ice 119
8.3.3 Station Measurement 120
8.3.3.1 Station Parameters 120
8.3.3.2 Point Velocity Measurement 121
8.3.3.3 Review Point Measurement 123
8.3.3.4 Review Station Measurement 124
8.3.4 Data Collection Menu 126
8.3.4.1 Settings 127
8.3.4.2 Supplemental Data 127
8.3.4.3 Discharge Summary 128
8.3.4.4 Station Summary 129
8.3.4.5 Automated Beam Check 130
8.3.4.6 Complete Measurement 130
8.3.4.7 Discard Measurement 131
8.3.4.8 Go to Home Screen 132
8.4. Measurement Summary 132
Section 9. General Measurement 134
9.1. Create Measurement 134

9.1.1 Measurement 134
9.1.2 New File Type 134
9.1.3 New File Template 135
9.1.4 New Data File 135
9.2. Automated Beam Check 136
9.2.1 Start Automated Beam Check 136
9.2.2 Evaluate Beam Check Results 137
9.3. Data Collection 138
9.3.1 Data Collection Window 138
9.3.1.1 Add Station 139
9.3.1.2 Delete Station 140
9.3.2 Station Measurement 141
9.3.2.1 Point Velocity Measurement 141
9.3.2.2 Review Point Measurement 143
9.3.2.3 Review Station Measurement 144
9.3.3 Data Collection Menu 145
9.3.3.1 Settings 146
9.3.3.2 Velocity Summary 146
9.3.3.3 Automated Beam Check 147
9.3.3.4 Complete Measurement 148
9.3.3.5 Discard Measurement 149
9.3.3.6 Go to Home Screen 149
9.4. Measurement Summary 149
Section 10. FlowTracker2 Hardware 152
10.1. ADV Probe 152
10.2. Handheld 152
10.3. Cables and Connectors 154
10.4. Certifications 154
10.5. PC System Requirements 154
Section 11. Operational Considerations 156
11.1. Software Upgrade 156
11.1.1 Upgrading Handheld Software 156
11.1.2 Upgrading ADV Firmware 158
11.2. Mounting and Installation 158
11.2.1 FlowTracker2 Handheld 158
11.2.2 Handheld Mounting Bracket 158
11.2.3 Probe Mounting Bracket 159
11.3. Routine Maintenance 160
11.3.1 Battery Power Supply 160
11.3.2 Cleaning Instrument 160
11.3.2.1 Handheld 160
11.3.2.2 Transducers 161

11.3.3 Cable Maintenance 161
11.3.4 O-rings 162
11.3.4.1 Housing 162
11.3.4.2 Battery Cap 162
11.3.5 Condensation in FlowTracker2 Housing 162
11.3.6 Zinc Anodes for Corrosion Protection 162
11.4. Seeding 163
11.4.1 Scattering Material 163
11.4.2 Field Applications 163
11.5. Troubleshooting 164
11.5.1 Cannot Turn System On 164
11.5.2 Cannot Communicate with the FlowTracker2 164
11.5.2.1 Handheld 164
11.5.2.2 Communication 164
11.5.3 Cannot Retrieve Data from Internal Recorder 165
11.5.4 Velocity Data Appears Noisy or Unreasonable 165
11.5.5 Recovery Mode 165
11.6. Health and Safety 166
11.6.1 Planning Field Work 166
11.6.2 Communication 166
11.6.3 Measurement Site Conditions 167
Section 12. FlowTracker2 File Format 168
12.1. FlowTracker2 JSON File 168
12.1.1 Measurement File Framework 169
12.1.2 Measurement File Structure 170
12.2. FlowTracker2 CSV Output 178
12.2.1 CSV File Structure 178
12.2.2 CSV Variables 179
12.3. Original FlowTracker ASCII vs JSON 186
Section 13. Principle of Operations 194
13.1. FlowTracker2 Overview 194
13.2. The Doppler Shift 194
13.3. Bistatic Doppler Current Meters 195
13.3.1 Bistatic Doppler Operation 195
13.3.2 The FlowTracker2 Measurement Principle 195
13.3.3 Signal to Noise Ratio Profile 196
13.4. Pulse-Coherent Processing 197
13.5. Beam Geometry and 3D Velocity Measurements 198
13.6. Sampling Volume Definition 198
13.7. Velocity Data Coordinate System 199

13.7.1 2D Side-Looking Probe (Figure 30a) 199
13.7.2 2D/3D Side-Looking Probe (Figure 30b) 199
13.8. FlowTracker2 Data 199
13.8.1 Basic Sampling Strategy 199
13.8.2 Velocity Data 200
13.8.3 Accuracy of Velocity Data 200
13.8.3.1 Optimizing of FlowTracker2 200
13.8.3.2 Factors Influencing Accuracy 201
13.8.4 Quality Control Data 201
13.9. Special Considerations 201
13.9.1 Probe Configurations 201
13.9.1.1 Probe mounting 201
13.9.1.2 Probe type 201
13.10. Sound Speed 202
13.10.1 Sound Speed Function 202
13.10.2 Compensate for Changes 202
13.10.3 Environmental Conditions 202
13.11. Flow Interference 203
13.11.1 Structures 203
13.11.2 Probe orientation relative to flow 203
13.11.3 Mounting Correction 204
13.11.3.1 No Correction 204
13.11.3.2 Custom Correction 204
Section 14. FlowTracker2 Desktop Software 206
14.1. Overview of Software Features and Functions 206
14.2. Installing Software 207
14.3. Changing Settings 208
14.3.1 User Interface Tab 208
14.3.1.1 Changing Language (Settings > User Interface > Language) 208
14.3.1.2 Changing Scale and Font Size (Settings > User Interface > Scale) 209
14.3.2 General Tab 209
14.3.2.1 Show paired device connection options (Settings > General > Show paired device connection options) 209
14.3.2.2 Show Download Options Dialog (Settings > General > Show download options dialog) 210
14.3.2.3 Check for Crash Reports and Send to SonTek Support (Settings > General > Check for crash reports) 210
14.3.3 Units Tab 211
14.3.3.1 Changing Software Units (Settings > Units) 211
14.3.3.2 Changing Software Display Decimals (Settings > Units) 212
14.4. Utilities 213
14.4.1 FlowTracker1 Import (Utilities > FlowTracker1 Import) 213
14.4.2 Run Translator (Utilities > Run Translator) 214
14.4.3 Import Language File (Utilities > Import Language File) 214
14.4.4 New Discharge Template (Utilities > New Discharge Template) 214

14.4.5 New General Template (Utilities > New General Template) 215
14.5. Connecting to the FlowTracker2 Handheld ADV 215
14.5.1 USB Connection (Device > USB) 216
14.5.2 Bluetooth Connection 216
14.6. Device Menu and Functions 217
14.6.1 Download Data Files (Device > [Choose your connection] > Download) 218
14.6.2 Delete Data files (Device > [Choose your connection] > Delete) 220
14.6.3 Upgrading FlowTracker2 Firmware (Device > [Choose your connection] > Upgrade) 220
14.6.4 Uploading and Downloading Templates (Device > [Choose your connection] > Templates) 221
14.6.5 Custom Localization 222
14.6.6 Disconnecting the FlowTracker2 222
14.7. Opening a Data File 222
14.7.1 Opening FlowTracker2 Handheld ADV Data Files (.ft files) 223
14.7.2 Opening FlowTracker2 BeamCheck Files (.ft_beamcheck) 223
14.7.3 Opening FlowTracker2 Template Files (.ft_template) 224
14.7.4 Opening Original FlowTracker Handheld ADV Data Files (.WAD files) 225
14.8. Overview of View Data Options 227
14.8.1 Measurement Summary Pane 227
14.8.2 Main Viewing Pane 228
14.8.2.1 Section 228
14.8.2.2 Stations 229
14.8.2.3 Area 232
14.8.2.4 Sensors 233
14.8.2.5 Supplemental Data 234
14.8.2.6 Diagnostics 235
14.8.2.7 Summary 236
14.8.3 Settings Pane 236
14.9. Post-Processing FlowTracker Measurements 237
14.9.1 Enable Editing 238
14.9.1.1 FlowTracker2 .ft File Editing 238
14.9.1.2 Original FlowTracker .wad File Editing 239
14.9.2 Editing through the Settings Pane 239
14.9.3 Editing by Station 240
14.9.4 Editing Supplemental Data 243
14.10. Data Export and File Formats 243
14.10.1 Export Discharge Summary to PDF 243
14.10.2 Export Files to ASCII 244
14.10.3 Matlab Tools for JSON files 244
Appendix A. Software Flow Diagram 245
Appendix B. Site Selection Requirements 247
Appendix C. Japanese Method Example 248
Appendix D. Measurement Equipment List 249

Appendix E. CE Declaration of Conformity ***250***

INDEX ***252***

List of Tables

Table 3:1 – FlowTracker2 Display Units 31
Table 3:2 - Wading Rod Graphics 32
Table 3:3 - File Naming Conventions 32
Table 3:4 - GPS Status Icons 35
Table 3:5 - File Properties - Properties 39
Table 3:6 - Data Collection Settings - Properties 39
Table 3:7 - Quality Control Settings - Properties 42
Table 3:8 - Discharge Settings - Properties 45
Table 3:9 - Displayed Velocity Methods - Properties 48
Table 4:1 - Date and Time - Properties 51
Table 4:2 - File Types - Properties 52
Table 4:3 - Raw Velocity Display 56
Table 4:4 - Beam SNR Display 58
Table 4:5 – Battery Specification 59
Table 4:6 - Automated Beam Check Quality Control Criteria 59
Table 4:7 - Automated Beam Check Display 60
Table 4:8 - GPS Data - Properties 62
Table 5:1 - Predetermination of Measuring Intervals 68
Table 5:2 - Determining Mean Station Velocity 70
Table 6:1 - Quality Control Parameters 77
Table 6:2 – SNR Data Types 78
Table 6:3 – σV Data Types 81
Table 6:4 - Quality Control Warning Messages 90
Table 6:5 - Timing of Quality Control Warning Messages 91
Table 7:1 - Hardware Inspection 99
Table 7:2 - Office Diagnostics 100
Table 7:3 – Measure Site Information 101
Table 7:4 - Pre Measurement Diagnostics 102
Table 8:1 - Automated Beam Check Quality Control Criteria 110
Table 8:2 - Automated Beam Check Display 111
Table 8:3 - Incompatible Velocity Methods and Station Types 115
Table 8:4 - Bank Station Type - Properties 116
Table 8:5 - Island Edge Station Type - Properties 117
Table 8:6 - Open Water Station Type - Properties 118
Table 8:7 - Ice Station Type - Properties 119
Table 8:8 - Review Point Measurement 124
Table 8:9 - Review Station 125
Table 8:10 - Discharge Summary 128
Table 8:11 - Station Summary 129

Table 8:12 - Measurement Summary *133*
Table 9:1 - Automated Beam Check Quality Control Criteria *137*
Table 9:2 - Automated Beam Check Display *138*
Table 9:3 - Station - Properties *140*
Table 9:4 - Review Point Measurement *143*
Table 9:5 - Review Station *144*
Table 9:6 - Velocity Summary *147*
Table 9:7 - Measurement Summary *150*
Table 10:1- ADV Probe Specifications *152*
Table 10:2- Handheld Specifications *152*
Table 10:3- Cable and Connector Specifications *154*
Table 12:1 - CSV File Types *178*
Table 12:2 - CSV Row and Column *178*
Table 12:3 - Control File Variables *179*
Table 12:4 - Raw Data File Variables *180*
Table 12:5 - Discharge File Variables *180*
Table 12:6 - Summary File Variables *184*
Table 14:1- Units Available for Software Parameters *211*
Table 14:2. Measurement Summary Pane *227*
Table 14:3: Station Information Values Available *230*
Table 14:4. Summary of Settings Pane Values *236*

List of Equations

Equation 5:1 - Mid-Section Method 66
Equation 5:2 - Mean-Section Method 67
Equation 5:3 - Japanese Method > 10m 69
Equation 5:4 - Japanese Method < 10m 69
Equation 5:5 - Discharge Weighted 75
Equation 5:6 - Time Weighted 75
Equation 5:3 - Japanese Method > 10m 248

Section 1. Quick Overview

1.1. System Components

Layout of FlowTracker2 and all major components are labeled in Figure 1:1.

- **Probe** – The FlowTracker2 probe (Figure 1:2) contains the acoustic elements to measure velocity. See Principle of Operations for more information.
- **Keypad** – The FlowTracker2 keypad is designed for quick and efficient software operation, configuration and data entry.
- **Handheld** - The handheld contains the processing electronics, batteries, keypad, and LCD screen. The handheld is designed to withstand temporary submersion, but is not intended for underwater operation.
- **Battery Compartment** – Battery Compartment consist of a water tight battery cap and an AA battery cartridge for quick access and battery replacement.
- **LCD Screen** – The LCD screen display the FlowTracker2 handheld software and real-time graphical display of raw data.
- **Probe cable** – The probe is factory mounted to a 1500mm (59-in) flexible cable. The handheld connects to the probe cable with rugged underwater flexible connector. The standard cable (1500mm) supplied with the FlowTracker2 can be extended with either an 1500mm (59-in) or 3500mm (137-in) cable extension up to maximum length of 10m (32.8-ft).
- **Communication Connector** – A waterproof (IP67) micro USB connector on the bottom of the handheld connect to external communication cable



Figure 1:1 - FlowTracker2 with 2D Probe

Layout of FlowTracker2 Probe and all major components are labeled in Figure 1:2

- **Transmitter** – The acoustic transmitter generates a short pulse of sound with the majority of energy concentrated in a narrow beam (6 mm in diameter).
- **Receivers** – The acoustic receivers are mounted on arms from the central probe head. The receivers are sensitive to a narrow beam and are focused on a common volume located a fixed distance (10 cm; 4 in) from the probe. The FlowTracker2 uses two or three acoustic receivers for 2D or 3D probes. See Beam Geometry and 3D Velocity Measurements for details.
- **Sampling volume** – The sampling volume is the physical location of the water velocity measurement. See Principle of Operations for details.
- **Temperature sensor** – The temperature sensor is mounted inside the probe. Temperature data is used to compensate for changes in sound speed. Sound speed is used to convert the Doppler shift to water velocity. See Hardware Specification for details on the temperature sensor; see Principle of Operations for details about the effect of sound speed on velocity data.

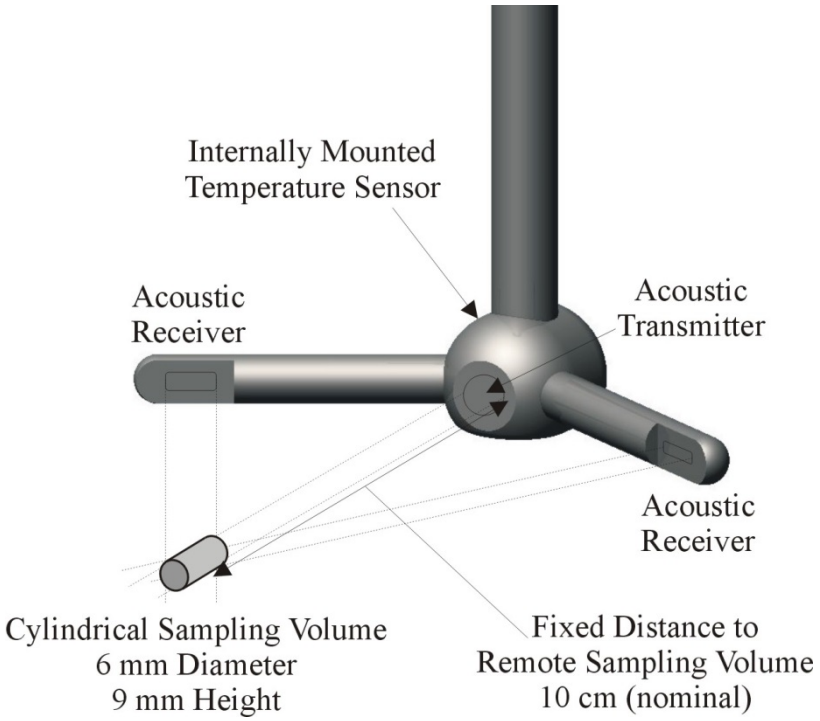


Figure 1:2 - 2D Side Looking FlowTracker2 Probe and Sampling Volume

1.2. Definitions and Terminology

This section defines terms commonly used when working with FlowTracker2

- **Averaging Time** – The time (in seconds) in which the FlowTracker2 records data at each measurement location. This is a user-specified value from 10 to 1000 seconds.
- **Handheld** – The FlowTracker2 is controlled from the keypad on the handheld. The LCD screen is used to display FlowTracker2 handheld software and real-time graphical display of raw data.
- **Measurement Location** – At each measurement location, the FlowTracker2 records one-second velocity data for the specified averaging time, location, water depth parameters and a variety of statistical and quality control data.
- **Ping Rate** – The number of pings per second (Hz). The FlowTracker2 ping rate is 40 Hz.
- **Ping** – A single estimate of the 2D or 3D water velocity.
- **Quality Control Data** – In addition to velocity, the FlowTracker2 records several quality control parameters. These include signal-to-noise ratio (SNR), standard error of velocity, boundary adjustment, the number of spikes filtered from data, and velocity angle. For details about quality control data, see Quality Control for details.
- **Salinity** – Water salinity is a user-supplied value that is used for sound speed calculations. Note: If using the system in salt water, a zinc anode should be installed on the probe for corrosion protection described in Zinc Anodes for Corrosion Protection.
- **Sample** – A sample refers to the mean of 10 pings to produce a measurement of the 2D or 3D water velocity. A sample includes velocity and signal to noise ratio data. The FlowTracker2 records one sample per second.
- **Signal Strength** – This refers to the strength of the reflected acoustic signal. It is a function of the acoustic conditions of the water – primarily the amount and type of suspended material (scatterers) present. This is most commonly accessed as a signal-to-noise ratio (SNR).
- **Signal-to-Noise Ratio (SNR)** – SNR is the ratio of the received acoustic signal strength to the ambient noise level. It is expressed in logarithmic units (dB), and is the most important quality control data for the FlowTracker2, see Quality Control for details.
- **Sound Speed** – Speed of sound in water (in m/s) is used to convert the Doppler shift to velocity. See Principle of Operations regarding the effect of sound speed on velocity data.

- **Temperature** – Water temperature (in °C) is measured by the internal temperature sensor. Temperature is used for sound speed calculations.
- **UTC** - Coordinated Universal Time, abbreviated as **UTC**, is the primary time standard by which the world regulates clocks and time



WARNING! The WARNING symbol and notice highlight instructions that must be followed to avoid personal injury. Do not proceed until all stated conditions are clearly understood and met.



CAUTION! The CAUTION notice highlights instructions that must be followed to avoid damage to the product or other equipment. Do not proceed until all stated conditions are met and clearly understood.

Section 2. System Operation

The **System Operation** section describes the keypad interface, handheld software menus and the LCD display.

2.1. On/Off Switch

The On/Off power button  for the FlowTracker2 can be accessed on the right side of the keypad, 3rd row from the top.

a) Start system, hold the power button until the LCD screen turns on.
b) Shutdown system, hold the power button until a message is displayed to shut down the handheld.
c) Activate sleep mode, press the power button once shutdown.
d) Wakeup system, press any button on keypad.



It's good practice to remove the battery cartridge at the end of each workday for inspection and or charging \ replacement.



If the system is not used or stored for long periods, remove the batteries to prevent unnecessary draining and potential battery leakage.

2.2. Keypad

a) **Navigation Keys** – The handheld has a number of keys that are assigned to operate handheld software. The following keys are available for the user to either navigate or select options in the software,

i). **Left Soft Key** – The text directly above the soft key is associated with the key operations and allows the user to perform the following actions,

- return to previous menu,
- select action based on text displayed,
- restart or cancel current operation.

ii). **Right Soft Key** - The text directly above the soft key is associated with the key operations and allows the user to perform the following actions,

- start a new measurement,
- accept data entry or operation,
- create new template,
- access the quality control menu.

iii). **Left & Right arrow** – The key allows the user to perform the following actions,

- select different options under each parameter in



Figure 2:1 - Keypad Layout

configuration,
- select station type or velocity method in measurement,
- select station in data collection.

iv). **Top & Bottom arrow** – The key allows the user to perform the following actions,
- scroll through the menu options,
- select files or templates,
- display graphics during data collection,
- scroll through the measurement, station and discharge summary reports.

b) **Enter Key** – The enter key (square) is situated between the four arrow keys and allow the user to perform the following actions,

i). Select the menu item in the menus
ii). Activate or deactivate running average during the beam-check data collection. This information is only displayed graphically and will not be stored in the data files.

c) **Numbers (0-9)** – The keys allows the user to perform the following actions. Numbers will default to the first option on the key if only numerical values are required in the entry field.

i). Menu shortcut (number next to text) associated with each menu item.
ii). Configuration of instrument such, data collection settings, quality control parameters and discharge settings
iii). Enter measurement data such, station location, depth and other information.



Figure 2:2 - Keypad Layout

d) **Letters (A-Z)** – The keys allows the user to perform the following actions. Letters will default to the first option on the key if letters are required in the entry field.

i). Create file and template names,
ii). Enter comments at a station, supplement data or overall measurement.

e) **Backspace** – The key allows the user to perform the following delete actions,

i). Text or values in user entry fields,
ii). Data file folder with all content or individual data files,
iii). Selected station in Discharge and General mode.

Text entry is done in the same manner as for mobile devices.

- numerical fields, the text entry assumes numbers first (i.e. for "2" press **2** key one time, **2** – **A** – **B** – **C**);
- text fields, it assumes letters first (i.e. for "B" press **2** key two times, **A** – **B** – **C**)

2.3. Screen Layout

The Screen Layout of the FlowTracker2 consists of the following main features. The options or information displayed may vary from one screen to the next based on the software features that are used.

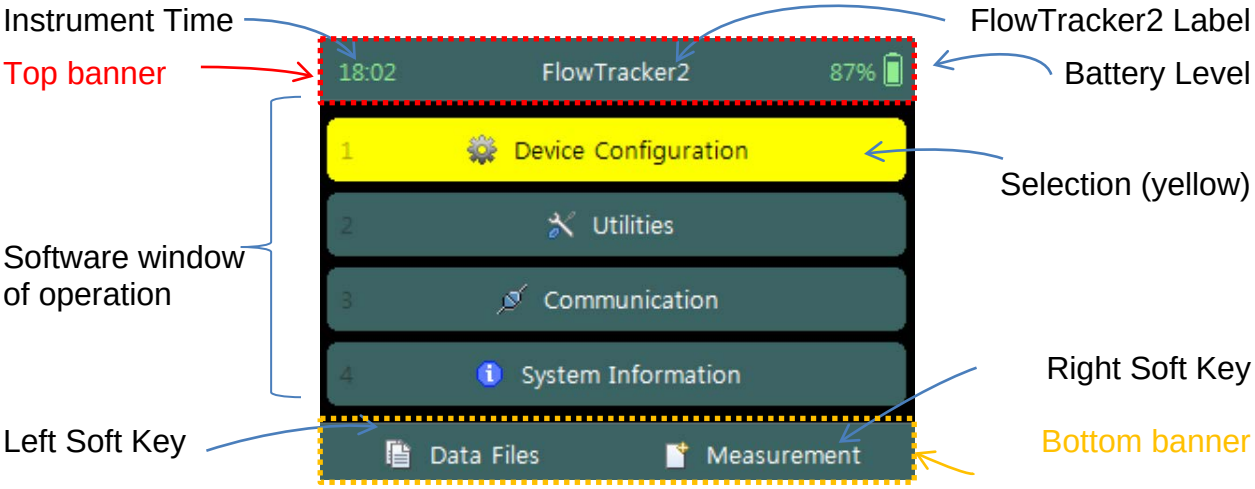


Figure 2:3 - Screen Layout

2.4. Main Menu

When the FlowTracker2 handheld is switched on the FlowTracker2 image is displayed during the startup process. Flow diagram of the handheld software is supplied in Software Flow Diagram for both the Discharge and General modes.

FlowTracker2 software layout of the handheld is similar to the "Original FlowTracker" consisting of the same three main groups, although the wording has changed.

The **Main Menu** of the handheld software is displayed after the startup process of the FlowTracker2 is completed.

Main menu consists of four menu options,

a) Device Configuration,
b) Utilities,
c) Communication,
d) System Information

*e) To **select** a menu option,*

i). Use up or down scroll arrows keys to select menu option,

ii). The menu option selected will be highlighted in

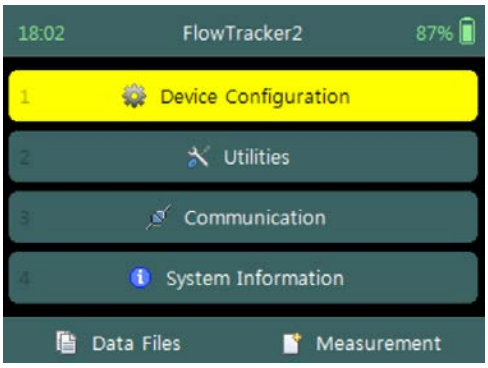


Figure 2:4 - Main Menu

yellow,
iii). Press the enter key to access the menu option.

There are also two additional menu options “Data Files” and “Measurement” available to the user that is situated in the bottom banner of the screen.

*f) To **select** Data Files or Measurement functions,*
i). Data Files – Press the Left Soft Key,
ii). Measurement – Press the Right Soft Key.

The number opposite each menu option is a shortcut key (i.e. pressing “2” key will access the Utilities menu).

2.4.1 Device Configuration Menu (Main Menu)

The **Device Configuration Menu** configures how the FlowTracker2 collects data, performs internal discharge calculations, evaluate data against data quality parameters and finally determine uncertainty of the measurements based on the method selected.

Device Configuration menu consists of four menu options,

a) User Interface,
b) Application Settings,
c) Discharge Templates,
d) General Templates.

*e) To **select** a menu option,*
i). Use up or down scroll arrows keys to select menu option,
ii). The menu option selected will be highlighted in yellow,
iii). Press the enter key to access the menu option.

*f) To **navigate** to Main Menu,*
i). Press the Left Soft Key.

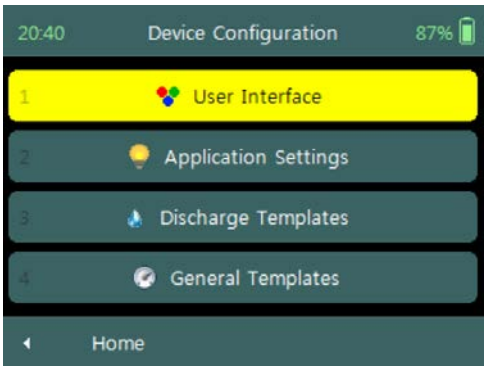


Figure 2:5 - Device Configuration Menu

2.4.2 Utilities (Main Menu)

The **Utilities Menu** accesses internal system functions of the FlowTracker2. The available functions assists with setting the internal clock and power source, management of recorder, displaying raw velocity and GPS data and performing tests on measurement and boundary conditions.

Utilities menu consists of the following menu options,

a) System Clock,
b) Recorder,
c) Battery Data,
d) Raw Data,
e) Automated Beam Check,
f) Beam Check,
g) GPS Data.

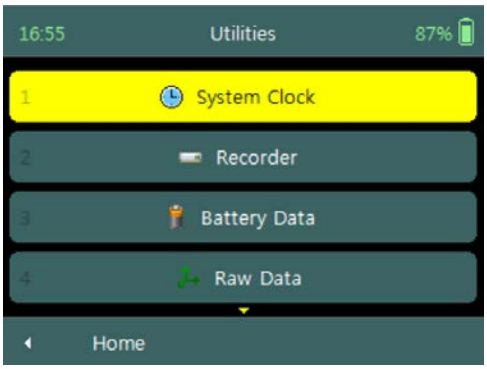


Figure 2:6 - Utilities Menu

*h) To **select** a menu option,*
i). Use up or down scroll arrows keys to select menu option,
ii). The menu option selected will be highlighted in yellow,
iii). Press the enter key to access the menu option.

*i) To **navigate** to Main Menu,*
i). Press the Left Soft Key.

The Utilities Menu provides access to functions that should be checked periodically, but do not directly affect how data is collected.

2.4.3 Communication (Main Menu)

The **Communication** function permits communication between an external device equipped with the FlowTracker2 Desktop Software and the handheld. Communication between the desktop software and handheld can be established by using either a Micro USB cable or Bluetooth. See Connecting to the FlowTracker2 Handheld ADV for details of hardware and configuration requirements to enable communication.

The Communication function on the handheld software must be activated first before the connection feature is selected on the FlowTracker2 desktop software.

2.4.4 System Information (Main Menu)

The **System Information** screen displays the system information of the FlowTracker2 for both the Handheld and Probe, with the serial number and firmware versions as the key data sets.

Handheld System Information of the FlowTracker2 includes the following system information,

a) Device (FlowTracker2 Handheld),

b) Serial Number (123456),

c) Upgraded Firmware (V0.14.7).

*d) To **navigate** to Main Menu or Probe Information,*
i). Main Menu – Press the Left Soft Key,
ii). Probe Information – Press the Right Soft Key.



Figure 2:7 - Handheld System Information

Probe System Information of the FlowTracker2 includes the following system information,

a) Device (FlowTracker2 Probe),
b) Serial Number (123456),
c) Probe Firmware (V0.14.7),
d) Number of Beams (2 or 3).

*e) To **navigate** to Main Menu,*
i). Press the Left Soft Key two times.

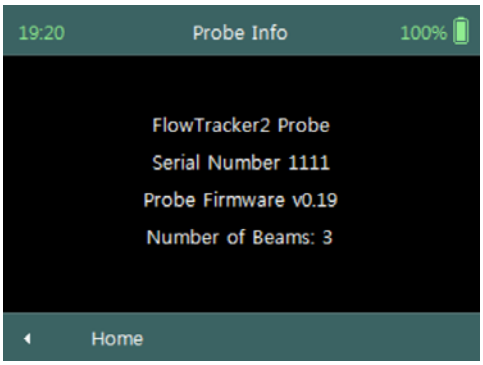


Figure 2:8 - Probe System Information

2.4.5 Measurement (Main Menu)

The **Measurement** function is the main component of the FlowTracker2 handheld software and includes two measurement modes. The Discharge mode is for applications where the primary goal is to measure river/stream discharge. The technique involves taking a series of velocity measurements at different locations throughout the cross section. These measurements are combined with location and water depth information to compute the total discharge. The General mode is designed to perform a series of velocity measurements at different locations, but does not provide discharge as an output.

The methods and techniques implemented for determining the mean station velocity, calculation of discharge and uncertainty analysis of a measurement are based on the following literature,

- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- WMO-No. 1044, Volume I – Fieldwork, 2010.
- IVE, Quantifying Uncertainty in Discharge Measurements: A New Approach

Measurement function consists of two measurement modes in the menu,

a) Discharge,
b) General.

*c) To **select** a menu option,*
i). Use up or down scroll arrows keys to select menu option,
ii). The menu option selected will be highlighted in yellow,
iii). Press the enter key to access the menu option.

*d) To **navigate** to Main Menu,*
i). Press the Left Soft Key.

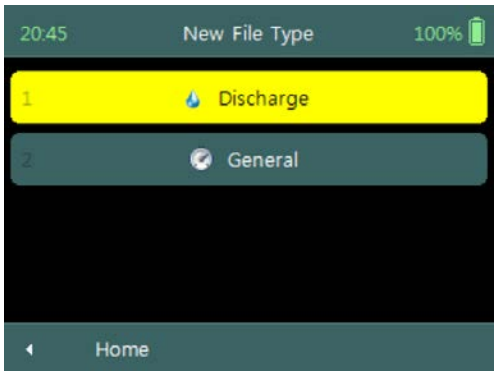


Figure 2:9 - Measurement

2.4.6 Data Files (Main Menu)

The **Data Files** function displays the recorder contents and gives the user access to FlowTracker2 measurements files.

The FlowTracker2 measurement files can be organized in the recorder based on the following user defined folder naming conventions,

- Site Name,
- Site Number,
- Month.

Data Files screen displays a list of folders based on the naming convention. Each folder can consist of either a single or multiple measurement files.

*a) To **select** a measurement folder,*
i). Use up or down scroll arrows keys to select folder,
ii). The folder will be highlighted in yellow,
iii). Press the enter key to access the folder content,
iv). Selecting a measurement file in the folder, follow steps i to iii.

*b) To **DELETE** a measurement file or folder*
i). Use up or down scroll arrows keys to select folder or file,
ii). The folder or file will be highlighted in yellow,
iii). Press backspace to delete the folder or file.
iv). The operator will be requested to confirm deletion of the files or folders.

*c) To **navigate** to Main Menu,*
i). Press the Left Soft Key.

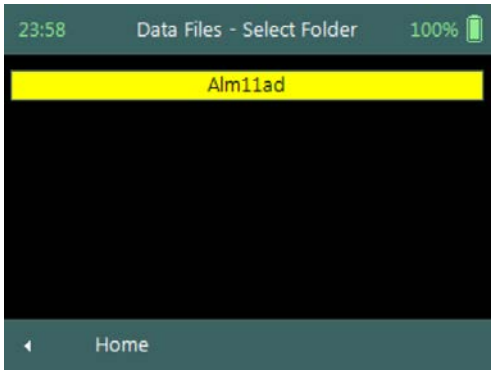


Figure 2:10 - Data Files



Before any measurement files and or folders are deleted please ensure that the following steps are performed,

- Download all measurement files using the FlowTracker2 desktop software,
- Ensure that measurement files are stored in a secure location on PC or Tablet,
- Create a secondary backup of the measurement files by copying to external USB or network drive.

The delete process is irreversible and the user will not able to retrieve the measurement files once this action is performed.

Section 3. Device Configuration

3.1. User Interface

User Interface defines the settings related to interaction (view and audio) between the operator and the device.

User Interface screen includes the following parameters,

a) Language,
b) Use Beeper,
c) Color Scheme,
d) Font Size,
e) Font Smoothing.

*f) To **select** a parameter,*
i). Use up or down scroll arrows keys to select a parameter,
ii). The parameter selected will be highlighted in yellow.

*g) To **navigate** to Configuration Menu,*
i). Press the Left Soft Key.

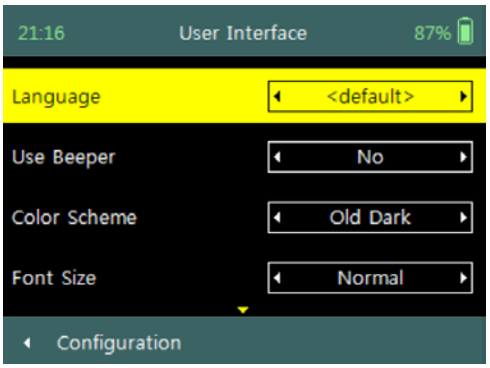


Figure 3:1 - User Interface

3.1.1 Language

The list of **Predefined Languages** supported in FlowTracker2 handheld software is grouped under the following.

a) Default language – English (US),
b) Other – Chinese-Simplified, Chinese Traditional, French, German, Italian, Japanese, Korean, Portuguese, Russian, Spanish and Catalan.
c) More languages will be added to FlowTracker2 in subsequent revisions as SonTek receives translation files. Please contact SonTek if you use the FlowTracker2 desktop software translator tool to create translation files you wish to share.

d) *To **change** the Language,*

i). Use the left or right arrow key to scroll through the list of available languages.
ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

Additional languages can be uploaded on the FlowTracker2 handheld using the **FlowTracker2 Translator** function available in the FlowTracker2 desktop software. The process involved in creating translation files and uploading to the handheld is described in FlowTracker2 Desktop Software.



If you selected a wrong language the menu functions can be a bit hazy! The following steps will get you out of the gate.

i) *the main menu must be displayed,* ***ii)*** *top menu option must be highlighted,* ***iii)*** *press the enter key two times,* ***iv)*** *use left or right arrow key to select different language,* ***v)*** *press left soft key two times,* ***vi)*** *handheld software will restart with new selected language.*

3.1.2 Use Beeper

An internal speaker is available in the handheld for creating a "**Beep**" after major functions is completed in the handheld software.

a) Functions that will create a beep sound are the following,
   i). Setting the LCD brightness will result in a beep when the maximum level is reached,
   ii). Sampling completed during point velocity measurement,
   iii). Sampling completed during Automated Beam Check.

b) *To **change** the Beeper option*,
   i). Use the left or right arrow key to select either Yes or No,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.1.3 Color Scheme

Color Schemes give the operator the ability to improve visibility of the LCD display under different light conditions that may be experienced during field work.

a) Color schemes implemented in FlowTracker2 are categorized under the following schemes,
   i). Light,
   ii). Medium,
   iii). Dark.

b) *To **change** the Color Scheme option*,
   i). Use the left or right arrow key to scroll through the list of available color schemes,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.1.4 Font Size

Font Sizes give the operator the ability to improve visibility of text on the LCD display under different light conditions that may be experienced during field work.

a) Font sizes implemented in FlowTracker2 are categorized under the following schemes,
   i). Normal,
   ii). Large,
   iii). Extra Large.

b) *To **change** the Font Size,*
   i). Use the left or right arrow key to scroll through the list of available font sizes,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.1.5 Font Smoothing

The option for **Font Smoothing** was implemented to improve the overall font appearance that is affected by low resolution normally associated with small LCD displays.

a) Font smoothing options that were implemented are categorized under the following options,
   i). Enabled,
   ii). Disabled.

b) *To **change** the font Smoothing Option,*
   i). Use the left or right arrow key to scroll through the list of options,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.2. Application Settings

Application Settings define the operator requirements with respect to the units system used, management of measurement files and overall GPS operation during data collection.

Application Settings screen includes following parameters,

a) Units,
b) Wading Rod,
c) File Naming,
d) Folder Naming,
e) GPS Station Tagging.

*f) To **select** a parameter,*
   i). Use up or down scroll arrows keys to select a parameter,
   ii). The parameter selected will be highlighted in yellow.

*g) To **navigate** to Configuration Menu,*
   i). Press the Left Soft Key.

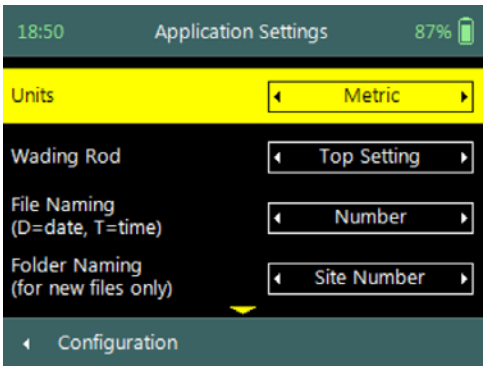


Figure 3:2 - Application Settings

3.2.1 Units

The **Units** function defines the **Units System** used for displaying and outputting measurement data.

a) The Units Systems supported in FlowTracker2 is grouped under the following,

   i). Metric,
   ii). English,

b) The internal unit system used is Metric and this does not affect internal calculations or data storage,

c) Table 3:1 list the units that are used for display.

Table 3:1 – FlowTracker2 Display Units

Parameter	English Units	Metric Units
Location	feet	meters
Depth	feet	meters
Pressure	dbar	dbar
Velocity	ft/s	m/s
Standard error of velocity	ft/s	m/s
Staff / Gauge height	feet	meters
Discharge	ft^3/s	m^3/s
SNR	dB	dB

d) *To **change** the Unit option*,

   i). Use the left or right arrow key to scroll through the list of options,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.2.2 Wading Rod

Wading Rod function gives the operator the choice of what type of wading rod is used during the measurement. The selection of the type of wading rod will impact what graphics are displayed during the data collection process and what reference (water surface or bottom) is used in determining instrument depth.

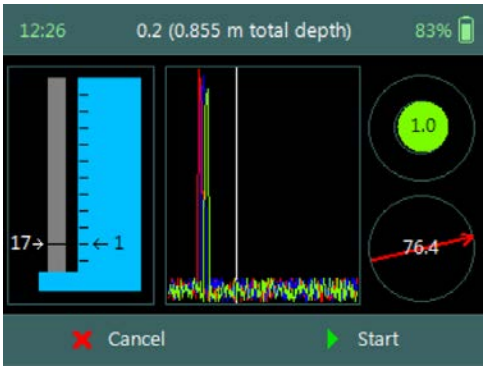


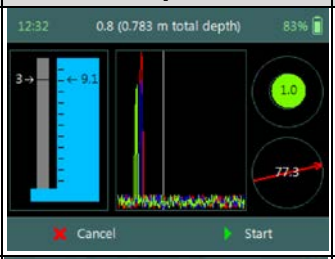
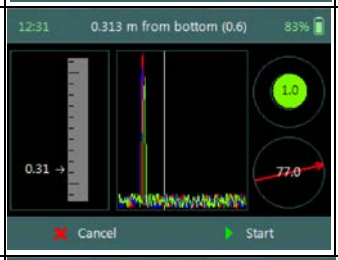
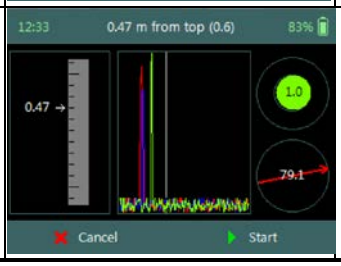
Figure 3:3 - Top Setting Wading Rod Graphic

a) The Wading Rods supported in FlowTracker2 are grouped under the following,

   i). Top-Setting (Instrument referenced to water surface)
   ii). Universal (Instrument referenced to bottom)
   iii). Ice (Instrument referenced to water surface)
   iv). Unknown

b) The graphic representation of the Wading Rods supported and the fractional depth indicators are defined in Table 3:2,

Table 3:2 - Wading Rod Graphics

Wading Rod	Graphic	Wading Rod Setting	Example	Reference
Top Setting		$= \left[\frac{(1 - f_{depth}) \times w_{depth}}{0.4}\right]$ f_{depth} – Fractional Depth w_{depth} – Water Depth	w_{depth} = 0.783m f_{depth} = 0.8 Rod = 0.391	Water Surface
Universal		$= w_{depth} - \left(f_{depth} \times w_{depth}\right)$ f_{depth} – Fractional Depth w_{depth} – Water Depth	w_{depth} = 0.783m f_{depth} = 0.6 Rod = 0.313	Channel Bed
Ice		$= \left(f_{depth} \times w_{depth}\right)$ f_{depth} – Fractional Depth w_{depth} – Water Depth	w_{depth} = 0.783m f_{depth} = 0.6 Rod = 0.469	Water Surface

c) *To **change** the Wading Rod type*,

i). Use the left or right arrow key to scroll through the list of options,

ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.2.3 File Naming

The **File Naming** function enables the operator to assign a unique name for each measurement file. The file naming process in FlowTracker2 ensures that existing measurement files are not overwritten.

a) The file naming conventions that are supported in FlowTracker2 software are listed in Table 3:3,

Table 3:3 - File Naming Conventions

Naming Convention	Description	Example
Number	Site Number	09429500
Number_Date	Site Number_yyyymmdd	09429500_20151013
Number_DT	Site Number_yyyymmdd-hhmmss	09429500_20151013-170220
Date_Number	yyyymmdd_Site Number	20151013_09429500
DT_Number	yyyymmdd-hhmmss_Site Number	20151013-170220_09429500

Naming Convention	Description	Example
Name	Site Name	Colorado
Name_Date	Site Name_yyyymmdd	Colorado_20151013
Name_DT	Site Name_yyyymmdd-hhmmss	Colorado_20151013-170220
Date_Name	yyyymmdd_Site Name	20151013_Colorado
DT_Name	yyyymmdd-hhmmss_Site Name	20151013-170220_Colorado

b) A **Follow Number** is incorporated at the end of the new file name, if there are files in the recorder with the same file name. The follow number will increase incrementally for every new file created with the same file name (e.g. 09429500_20151013_3)

d) *To **change** the File Naming convention,*
   i). Use the left or right arrow key to scroll through the list of options,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.



It's recommended that file the naming convention used contains both the date and time. This will ensure that an unique file name is created for each measurement and can easily be sorted in Windows explorer when downloaded from FlowTracker2 handheld,

- yyyymmdd-hhmmss_Site Number,
- yyyymmdd-hhmmss_Site Name.

3.2.4 Folder Naming

The **Folder Naming** function enables the operator to organize measurement files in the recorder by grouping by site or month.

a) The folder naming conventions that are supported in FlowTracker2 software are grouped under the following,
   i). Site Number,
   ii). Site Name,
   iii). yyyy-mm.

b) A folder is created automatically in the recorder when a measurement file is created based on the folder naming convention. If all the measurement files are deleted, the folder will be removed from the recorder.

c) *To **change** the Folder Naming convention,*
   i). Use the left or right arrow key to scroll through the list of options,
   ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.2.5 GPS Station Tagging

The **GPS Station Tagging** function allows the operator control over the GPS operation during measurements.

a) The GPS options that are supported in FlowTracker2 software are grouped under the following,

i). **Automatic**. The automatic option for the GPS allows the FlowTracker2 to perform GPS measurements at each station without any additional interaction with the software.

- The GPS receiver is *Continuously Operating* and receiving data from satellites when the FlowTracker2 handheld is activated.
- If a GPS lock is not obtained before the station measurement is completed, the software will not record positional information for the station. The GPS status Icons are listed in Table 3:4.
- The positional information is averaged over the time a station is created to improve the overall measurement accuracy. The software starts averaging the positional information when the *Add Station* function is selected and stops when the station is completed, from where the averaged position is recorded against the station. The averaging process is performed for both Discharge and General modes.
- When editing an existing station and Automatic GPS mode is selected, the logic reverts to "Manual GPS" mode to ensure that a position is not assigned while editing away from the actual station location.



The operator needs to ensure that the wading rod is placed in the correct position and vertical before the "Add Station" function is selected. This will improve the overall accuracy of the GPS measurement.

ii). **Manual**. The manual option provides the operator control over GPS measurements and requires the operator to select "Record GPS Location" function before velocity measurements are made at a station for both Discharge and General modes.

- The GPS receiver is on *Cold Start and is NOT* receiving data from satellites.
- The manual GPS measurement option forms part of the "Add Station" configuration screen and is located at the bottom of the screen. The "Record GPS Location" function can be accessed by using the Bottom Arrow.
- If a GPS lock is not obtained before the station measurement is completed, the software will not record positional information for the station. The GPS status Icons are listed in Table 3:4.
- The positional information is averaged when the "Record GPS Location" function is selected. The period of averaging the positional information is dependent on the user and a counter will display the number of measurements averaged.
- The "Record GPS location" at the bottom of the configuration screen will state "Record GPS location" if no location is assigned yet and "Update GPS location" if a location is already assigned.

iii). **Disabled**. The GPS is disabled and the operator will not be able to perform any GPS measurements.

b) The status of GPS lock is indicated by GPS icon displayed on the left corner of the top banner of the LCD screen. The icon's describing the GPS status in the handheld is defined in Table 3:4,

Table 3:4 - GPS Status Icons

Icon	Description	Conditions
	Attempting to acquire satellite signal.	GPS has not acquired any satellite signal or GPS lock and is unable to determine positional information
	Acquiring satellite signal in progress.	GPS is acquiring additional satellite signals, low quality positional information available, number of satellites < 4 and or HDOP > 2.5.
	Satellite signal acquired from available satellites.	GPS lock is obtained, high quality positional information available.

c) The averaging of positional information from the internal GPS is based on the following criteria,

i). Averaging is limited to 1000 records. If more than 1000 records are reported – the oldest records are dropped.

ii). Averaging is performed only when 5 or more records are recorded, otherwise the record with the lowest HDOP/max satellites is used.

iii). If 10 or more "high quality records" are recorded – only high quality records are used for the averaging. Otherwise both high/low quality records are used for the averaging.

d) *To **change** the GPS station tagging option*,

i). Use the left or right arrow key to scroll through the list of options,

ii). Press the Left Soft Key to return to Configuration for the software to accept the change.

3.3. Configuration Templates

3.3.1 Template Options

The **Templates** implemented in FlowTracker2 consists of the following template options. The templates consist of number of configuration parameters required for performing measurements in either **Discharge** or **General** mode under the Measurement function.

- **Discharge** Template
- **General** Template

Templates are similar to configuration files where the operator defines the configuration of the instrument, based on,

- site details,
- data collection requirements
- quality control parameters,
- measurement methods *(only for discharge mode)*.

The operator has the ability to create a unique configuration template for a single monitoring site, region or organization.



It's recommended that a unique template is created for each monitoring site. The advantage of this is twofold, operator does not have to enter in the site number and name for every measurement, and ensure that site number and name is consistent.

3.3.2 Managing Templates

3.3.2.1 Accessing Templates

Templates are stored separately from the measurement files on the internal memory of the FlowTracker2 handheld and are managed from the Discharge or General Template functions under the Device Configuration Menu. The following process describes how to create, remove or select an existing template.

Templates for Discharge and General Modes can be accessed from the Device Configuration menu,

*a) To **select** a Template type,*
   i). Use up or down scroll arrows keys to select the template,
   ii). The template option selected will be highlighted in yellow,
   iii). Press the enter key to access the template operating screen.

*b) To **navigate** to Main Menu,*
   i). Press the Left Soft Key.

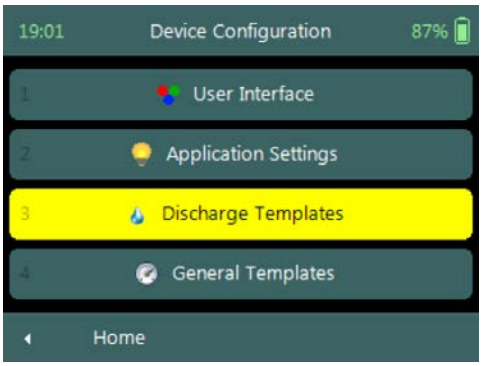


Figure 3:4 - Device Configuration Menu

Template Operating Screen will list all available templates on the handheld or if there are no templates available, indicate "Currently there are no user templates defined – please use the 'New Template' button to create the first template".

*a) To **create** a new Template,*
   i). Press the Right Soft Key,
   ii). The software will redirect to "New Template" screen.

*b) To **navigate** to Configuration Menu,*
   i). Press the Left Soft Key.

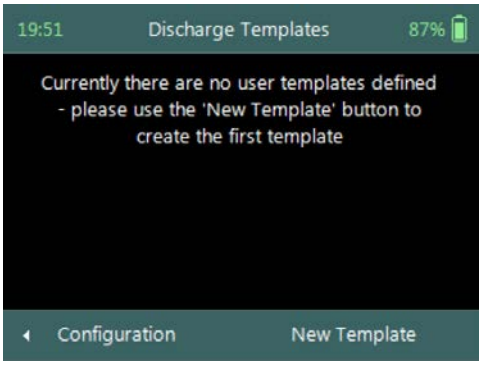


Figure 3:5 - Template Operating Screen

3.3.2.2 New Template

New Template screen displays two parameters that need to be completed to create a new template,

a) **Template Name** is user defined. The template name can be up to 50 characters long.

b) **Base Template** defines the default configuration used for new template. The user has the option to select the default SonTek configuration or from existing user configurations.

*c) To **accept** new Template,*
i). Press the Right Soft Key,
ii). The software will return to template screen.

*d) To **CANCEL** new Template,*
i). Press the Left Soft Key.

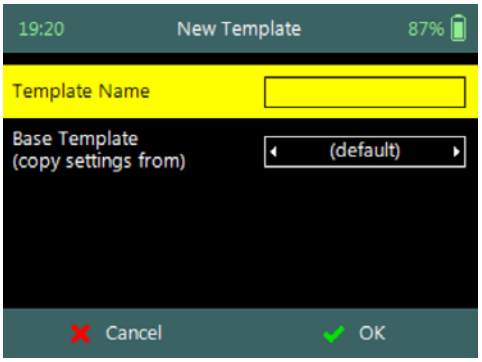


Figure 3:6 - New Template

3.3.2.3 Selecting Template

Selecting Template is performed from the template main screen.

*a) To **select** a Template,*
i). Use up or down scroll arrows keys to select the template,
ii). The template name selected will be highlighted in yellow,
iii). Press the enter key to access the template screen.

*b) To **navigate** to Configuration or New Template,*
i). Configuration - Press the Left Soft Key
ii). New Template - Press the Right Soft Key

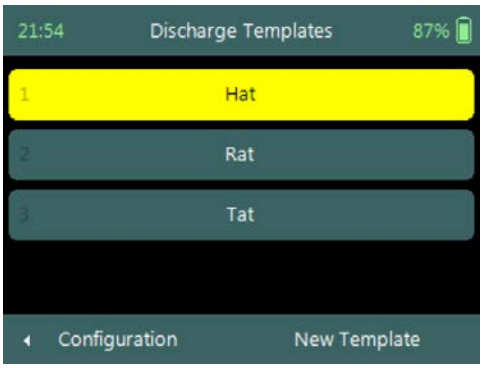


Figure 3:7 - Selecting Template

3.4. Template Functions

The **Template** functions for Discharge and General Modes contain all the configuration parameters required for performing velocity measurements, discharge calculation and uncertainty analysis. The functions defined under each template contain site information, data collection criteria, quality control parameters and measurement methods *(only for discharge mode)*.

Template menu consists of the following menu options,

a) File Properties,
b) Data Collection Settings,
c) Quality Control Settings,
d) Discharge Settings *(only for discharge mode)*,
e) Displayed Velocity Methods *(only for discharge mode)*.

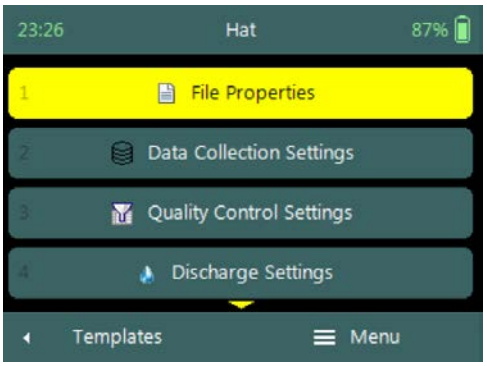


Figure 3:8 - Template Menu

*f) To **select** a menu option,*
i). Use up or down scroll arrows keys to select menu option,
ii). The menu option selected will be highlighted in yellow,
iii). Press the enter key to access the menu option.

*g) To **navigate** to Template Screen,*
i). Press the Left Soft Key.

*h) To **Rename** or **DELETE** a Template in Menu,*
i). Press the Right Soft Key.
ii). To select menu option, use up or down scroll arrows keys,
iii). The menu option selected will be highlighted in yellow,
iv). Press the enter key to access the menu option.

3.4.1 File Properties

The **File Properties** function contains site information applicable to the measurement site and operator details. The file properties ensure that the required Metadata are associated with both measurement site and data collected.

File Properties screen includes the following parameters,

a) Site Number,
b) Site Name,
c) Operator.

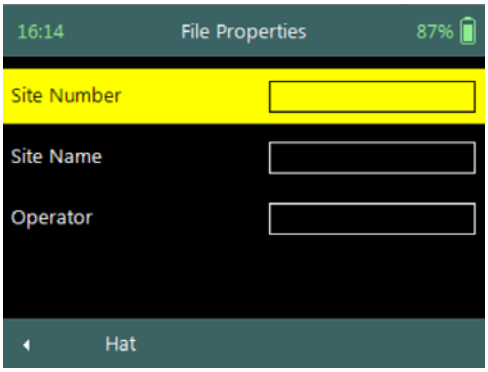


Figure 3:9 - File Properties

*d) To **select** a parameter,*
i). Use up or down scroll arrows keys to select a parameter,
ii). The parameter selected will be highlighted in yellow.

*e) To **enter** text,*
i). Use the backspace key to clear current entry,
ii). Enter numerical or alphabetical characters using

the keypad.

*f) To **navigate** to Template Menu,*

i). Press the Left Soft Key.

Properties associated with the parameters in file properties are defined in Table 3:5,

Table 3:5 - File Properties - Properties

Parameter	Description	Field Size	Default	Required
Site Number	Enter unique site number (e.g. Hydrometric Station Number)	50	Number keypad	No
Site Name	Enter unique site name (e.g. Hydrometric Station Name)	50	Alphabet keypad	No
Operator	Operator name can be entered in this field (e.g. Bees Blaas)	50	Alphabet keypad	No

3.4.2 Data Collection Settings

The **Data Collection Settings** function contains parameters required for sound speed calculation and averaging time of velocity measurements,

Data Collection Settings screen includes the following parameters,

a) Averaging Time,
b) Salinity,
c) Temperature,
d) Sound Speed,
e) Mounting Correction.

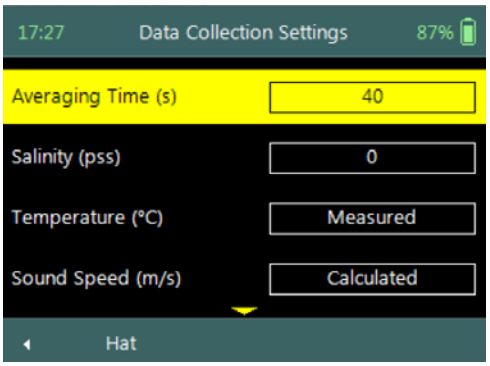


Figure 3:10 - Data Collection Settings

*f) To **select** a parameter,*

i). Use up or down scroll arrows keys to select a parameter,

ii). The parameter selected will be highlighted in yellow.

*g) To **navigate** to Template Menu,*

i). Press the Left Soft Key.

Properties associated with the parameters in data collection settings are defined in Table 3:6,

Table 3:6 - Data Collection Settings - Properties

Parameter	Min	Max	Default	Units	Required
Averaging Time	10	1000	40	seconds	Yes
Salinity	0	42	0	PSU	Yes
Temperature	-5	50	Internal Measured	°C or °F	Yes
Sound Speed	1400	1580	Internal Calculated	m/s or ft/s	Yes
Mounting Correction	-5	5	0	%	Yes

3.4.2.1 Averaging Time

The **Averaging Time** parameter specifies the time duration (in seconds) of data collection during each point velocity measurement.

a) Averaging time is specified in 1-second intervals from 10 to 1000 seconds.
b) The default Averaging Time applied in FlowTracker2 is 40s.

*c) To **change** the Averaging Time,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

The averaging time required for single point velocity measurement is usually from 40 to 60 seconds. This however is site dependent and longer averaging times are required when measuring in turbulent flow conditions.

3.4.2.2 Salinity

The **Salinity** parameter specifies the salinity value in **Practical Salinity Scale** (dimensionless) used to compute sound speed.

a) Salinity is specified in Practical Salinity Scale (PSS-78). Fresh water has a salinity of 0; seawater salinity generally ranges from 31 to 39 (PSS). The PSS-78 range is 2 to 42 for a temperature range of -2°C to +35°C and hydrostatic pressure 0 – 10000dBar.
b) The default Salinity applied in FlowTracker2 is 0 (PSS).

Where a measurement location exceeds the PSS-78 range, Salinity cannot be used for calculation of Sound Speed. **Sound Velocimeters** must be used to measure the actual sound speed of the water directly at the measurement location.

c) As a rule of thumb, a 12 (PSS) error in the value of salinity will result in a 1% error in sound speed, which results in a 2% error in velocity data.

d) Salinity should be specified or determined using a CTD instrument as accurately as possible for each measurement location. The **CastAway-CTD** is a lightweight, easy to use instrument designed for quick and accurate conductivity, temperature, and depth profiles. Starting with a unique six-electrode conductivity cell and fast response thermistor the CastAway makes use of modern technology to provide state of the art CTD measurements.



Figure 3:11 - CastAway - CTD

e) Sound speed is used in Doppler velocity calculations. See the Principle of Operations for details about the effect of sound speed on velocity data.

*f) To **change** the Salinity,*
i). Use the backspace key to clear current entry,

ii). Type in the new value using the keypad.

3.4.2.3 Temperature

The **Temperature** parameter specifies the temperature value used to compute sound speed.

a) The temperature value used to compute sound speed is based on internal temperature sensor by default. The temperature field will be populated with the value "**Measured**" to indicate it is based on internal temperature sensor.
b) Water temperature measured by external devices can be entered in the temperature field. The temperature value from the external sensor will then be used for sound speed calculations.

The temperature field cannot be used to store reference temperature readings as this will be used in the sound speed calculations. It is recommended that reference temperature readings be documented in the comments fields.

c) Sound speed is used in Doppler velocity calculations. See the Principle of Operations for details about the effect of sound speed on velocity data.

d) ***Enter*** *external temperature reading,*
i). If the default value "Measured" is displayed, start typing using keypad, otherwise,
ii). Use the backspace key to clear current entry,
iii). Type in the new value using the keypad.

3.4.2.4 Sound Speed

The **Sound Speed** parameter specifies the sound speed value used in Doppler velocity calculations.

a) The sound speed value used in Doppler velocity calculations is based on internal calculations by default. The sound speed field will be populated with the value "**Calculated**" to indicate it is based internal calculations.
b) Sound Speed measured by external devices can be entered in the sound speed field. The sound speed value from the external sensor will then be used in Doppler velocity calculations.

Where a measurement location exceeds the PSS-78 range, Salinity cannot be used for calculation of Sound Speed. **Sound Velocimeters** must be used to measure the actual sound speed of the water directly at the measurement location.

The sound speed field cannot be used to store reference sound speed readings as this will be used in the Doppler velocity calculations. It is recommended that reference sound speed readings be documented in the comments fields.

c) Sound speed is used in Doppler velocity calculations. See Principle of Operations for details about the effect of sound speed on velocity data.

d) ***Enter*** *external Sound Speed reading,*

i). If the default value "Calculated" is displayed, start typing using keypad, otherwise,
ii). Use the backspace key to clear current entry,
iii). Type in the new value using the keypad.

3.4.2.5 Mounting Correction

The **Mounting Correction** parameter specifies how to account for the device used to hold the FlowTracker2 in the water. The type of mount may have a small impact on velocity measurements.

a) The mounting correction allows the FlowTracker2 to account for the effect of flow disturbances caused by the mount.
b) The default mounting correction applied in FlowTracker2 is 0%.
c) The application of a mounting correction to account for the effects of flow disturbance on velocity measurements was researched by several independent agencies. At present, no consensus has been reached between different agencies in the requirement of the mounting correction. See Mounting Correction for details about the effect of flow disturbance on velocity measurements.

*d) To **change** the Mounting Correction,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

3.4.3 Quality Control Settings

The **Quality Control Settings** function contains parameters required for the Quality Control process.

Quality Control Settings screen includes the following parameters,

a) SNR Threshold,
b) Std Error Threshold,
c) Spike Threshold,
d) Velocity Angle for Warning,
e) Tilt Angle Warning.

*f) To **select** a parameter,*
i). Use up or down scroll arrows keys to select a parameter,
ii). The parameter selected will be highlighted in yellow.

*g) To **navigate** to Template Menu,*
i). Press the Left Soft Key.

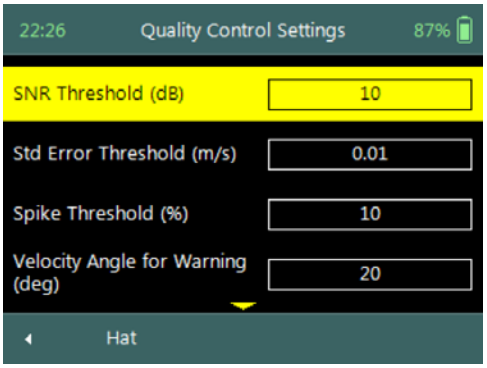


Figure 3:12 - Quality Control Settings

Properties associated with the parameters in quality control settings are defined in Table 3:7,

Table 3:7 - Quality Control Settings - Properties

Parameter	Min	Max	Default	Units	Required
SNR Threshold	0	50	10	dB	Yes
Std Error Threshold	0.001	0.25	0.01	m/s or ft/s	Yes
Spike Threshold	0.01	50	10	%	Yes
Velocity Angle for Warning	0.1	90	20	degrees	Yes
Tilt Angle Warning	0.1	5	5	degrees	Yes

3.4.3.1 SNR Threshold

The **SNR Threshold** parameter is a minimum threshold placed on the SNR variable during real-time data collection.

a) SNR is primarily a function of the amount of particulate matter in the water. For good conditions, SNR should be at least 10 dB.
b) The system can operate effectively with SNR as low as 2-3 dB, although the noise in individual velocity measurements will increase.
c) The default SNR Threshold applied in FlowTracker2 is 10dB.

*d) To **change** the SNR Threshold,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*e) To **DISABLE** the SNR Threshold,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.3.2 Std Error Threshold

The **Standard Error Threshold** parameter is a maximum threshold placed on the Standard Error of velocity measurements.

a) Standard error of velocity (**σV**) is a direct measure of the accuracy of the mean velocity data.
b) The default Standard Error Threshold applied in FlowTracker2 is 0.01m/s.

*c) To **change** the Standard Error Threshold,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Standard Error Threshold,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.3.3 Spike Threshold

The **Spike Threshold** parameter is the maximum threshold placed on the percentage of spikes within a measurement.

a) Spikes in velocity data occur with any acoustic Doppler velocity sensor such as the FlowTracker. Spikes may have a variety of causes – large particles, air bubbles, or acoustic anomalies.
b) The default Spike Threshold applied in FlowTracker2 is 10%.

*c) To **change** the Spikes Threshold,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Spikes Threshold,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.3.4 Velocity Angle for Warning

The **Velocity Angle for Warning** parameter is the maximum threshold placed on the velocity angle towards the probe.

a) An angle of 0° means flow direction is perpendicular to the tag line (as desired for an ideal measurement location).
b) The default Velocity Angle for Warning applied in FlowTracker2 is 20 degrees.

*c) To **change** the Velocity Angle for Warning,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Velocity Angle for Warning,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.3.5 Tilt Angle Warning

The **Tilt Angle Warning** parameter is the maximum threshold placed on the tilt angle of the wading rod.

a) An angle of 0° means the wading rod is vertical (as desired for an ideal mounting position).
b) The default Tilt Angle Warning applied in FlowTracker2 is 5 degrees.

*c) To **change** the Tilt Angle Warning,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Tilt Angle Warning,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.4 Discharge Settings

The **Discharge Settings** function contains parameters required for discharge calculations, discharge uncertainty analysis and quality control process.



Discharge settings function is only applicable to the Discharge Mode. The General Mode does not contain any discharge calculation or uncertainty analysis.

Discharge Settings screen includes the following parameters,

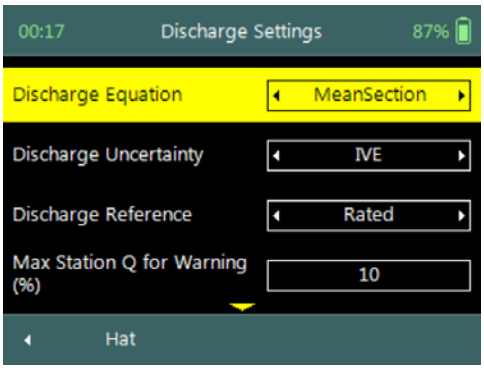


Figure 3:13 - Discharge Settings

a) Discharge Equation,
b) Discharge Uncertainty,
c) Discharge Reference,
d) Max Station Q for Warning,
e) Max Depth Change for Warning,
f) Max Spacing Change for Warning.
g) 0.6 Method Depth

*h) To **select** a parameter,*
   i). Use up or down scroll arrows keys to select a parameter,
   ii). The parameter selected will be highlighted in yellow.

*i) To **navigate** to Template Menu,*
   i). Press the Left Soft Key.

Properties associated with the parameters in discharge settings are defined in Table 3:8,

Table 3:8 - Discharge Settings - Properties

Parameter	Min	Max	Default	Units	Required
Max Station Q for Warning	0.01	100	10	%	Yes
Max Depth Change for Warning	0.01	200	50	%	Yes
Max Spacing Change for Warning	0.01	200	100	%	Yes
0.6 Method Depth	0	100	0.5	m or ft	Yes

3.4.4.1 Discharge Equation

The **Discharge Equation** parameter allows the user to specify what type of discharge calculation method must be applied in the discharge calculation process.

a) The discharge equation calculation methods supported in FlowTracker2 software is grouped under the following,
   i). Mid-Section Method,
   ii). Mean-Section Method,
   iii). Japanese Method.
b) The default Discharge Equation applied in FlowTracker2 is Mid-Section.

The Arithmetic methods implemented for calculation of discharge are based on the following literature,

- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using

current meters or floats,

- WMO-No. 1044, Volume I – Fieldwork, 2010.
- Japanese Literature

c) *To **change** the Discharge Equation method,*
   i). Use the left or right arrow key to scroll through the list of options,

3.4.4.2 Discharge Uncertainty

The **Discharge Uncertainty** parameter allows the user to specify what type of uncertainty analysis must be applied in the discharge calculation process.

a) The discharge uncertainty analysis supported in FlowTracker2 software is grouped under the following,
   i). ISO 748 - 2007
   ii). Interpolated Variance Estimator (IVE)
b) The default Discharge Uncertainty method applied in FlowTracker2 is IVE.
c) The discharge uncertainty analysis was not implemented for the Japanese discharge equation method.

The uncertainty analysis implemented for determining the overall discharge uncertainty are based on the following literature,



- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- Cohn, T., Kiang, J., and Mason, R., Jr. (2013). ”Estimating Discharge Measurement Uncertainty Using the Interpolated Variance.

d) *To **change** the Discharge Uncertainty method,*
   i). Use the left or right arrow key to scroll through the list of options,

3.4.4.3 Discharge Reference

The Discharge Reference parameter allows the user to specify what discharge should be used to determine the percentage discharge displayed at each station.

a) The discharge reference types supported for determine the percentage station discharge are the following,
   i). Rated Discharge
   ii). Measured Discharge
b) The default Discharge Reference applied in FlowTracker2 is Rated Discharge.
c) *To **change** the Discharge Reference,*
   i). Use the left or right arrow key to scroll through the list of options,

3.4.4.4 Max Station Q for Warning (%)

The **Max Station Q for Warning** parameter is the maximum threshold placed on station discharge.

a) Station discharge less than 5% of the total discharge is ideal; between 5 – 10% indicates that an additional station is required in the specific location, larger than 10% is not recommended.
b) The default Max Station Q for Warning applied in FlowTracker2 is 10%.

*c) To **change** the Max Station Q for Warning,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Max Station Q for Warning,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.4.5 Max Depth Change for Warning (%)

The **Max Depth Change for Warning** parameter is the maximum threshold placed on depth change.

a) The change in depth between stations is evaluated to determine if depth may have been entered incorrectly.
b) The default Max Depth Change for Warning applied in FlowTracker2 is 50%.

*c) To **change** the Max Depth Change for Warning,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Max Depth Change for Warning,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.4.6 Max Spacing Change for Warning (%)

The **Max Spacing Change for Warning** parameter is the maximum threshold placed on spacing change.

a) The change in spacing between stations is evaluated to determine if depth was not entered incorrectly.
b) The default Max Spacing Change for Warning applied in FlowTracker2 is 100%.

*c) To **change** the Max Spacing Change for Warning,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*d) To **DISABLE** the Max Spacing Change for Warning,*
i). Use the backspace key to clear current entry until "Disabled" is displayed.

3.4.4.7 0.6 Method Depth

The 0.6 Method Depth parameter is the threshold placed on the application of the six tenths velocity method.

a) The six tenths velocity method is set as default method in the software when the measured depth is below the threshold specified.
b) Different velocity method can be selected if the flow conditions are not suited for six tenths method.

*c) To **change** the 0.6 Method Depth,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

3.4.5 Displayed Velocity Methods

The **Displayed Velocity Methods** function allows the user to specify which Discharge Velocity Methods must be displayed in the function.



Displayed Velocity Methods function is only applicable to the Discharge Mode. The General Mode does not contain any discharge calculation or uncertainty analysis.

Displayed Velocity Methods screen includes the following parameters,

a) 0.2/0.8/0.6 Methods
b) Kreps Methods
c) 5-Point Methods
d) 6-Point Methods
e) Vertical Velocity Curve

*f) To **select** a velocity method,*
i). Use up or down scroll arrows keys to select a parameter,
ii). The parameter selected will be highlighted in yellow.

*g) To **display** a velocity method,*
i). Use the left or right arrow key to select either "Yes" or "No"

*h) To **navigate** to Template Menu,*
i). Press the Left Soft Key.

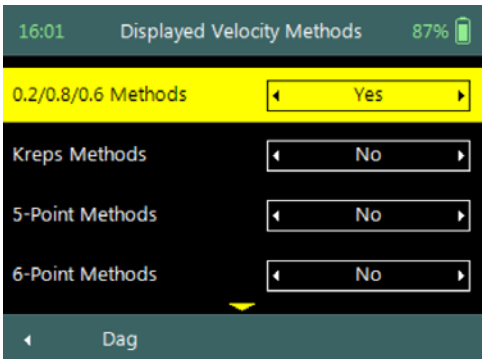


Figure 3:14 - Displayed Velocity Methods

Discharge Velocity Methods specifies how the FlowTracker2 determines mean station velocity at each station. See Determining Mean Station Velocity for details on the Discharge Velocity Methods. **Properties** associated with the parameters in displayed velocity methods are defined in Table 3:9,

Table 3:9 - Displayed Velocity Methods - Properties

Discharge Velocity Method	Default Display	Required
0.2/0.8/0.6 Methods	Yes	At least one method is required for
Kreps Methods	No	
5-Point Methods	No	

Discharge Velocity Method	Default Display	Required
6-Point Methods	No	Discharge Mode
Vertical Velocity Curve	No	

Methods implemented for determining mean velocity in a vertical are based on the following literature,



- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- WMO-No. 1044, Volume I – Fieldwork, 2010.

Section 4. Utilities

4.1. System Clock

System Clock function enables the setting of the internal date and time used in the FlowTracker2 handheld software. The main data collection processes are associated with internal date and time stamps and it is important that the instrument date and time are configured correctly.

System Clock screen includes the following parameters,

a) Date,
b) Time,
c) UTC Time.

*d) To **change** internal date and time,*
i). Press the Right Soft Key to select Menu,
ii). Use up or down scroll arrows keys to select an option,
iii). Press enter key to select the parameter highlighted in yellow.

*e) To **navigate** to Utilities menu,*
i). Press the Left Soft Key.

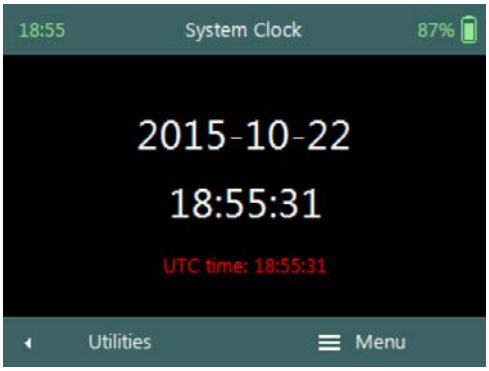


Figure 4:1 - System Clock

The System Clock options implemented to set the internal data and time of the FlowTracker2 handheld are the following,

- Manual Change
- Sync with GPS Time

Setting the correct date and time in the FlowTracker2 handheld is important to ensure that the correct metadata are associated with all measurements.

4.1.1 Manual Change

Manual Change option requires the user to enter the correct date and time based on external references.

Change System Clock screen includes the following parameters,

a) Offset From UTC,
b) Date,
c) Time.

*d) To **select** a parameter,*
i). Use up or down scroll arrows keys to select a parameter,
ii). The parameter selected will be highlighted in yellow.

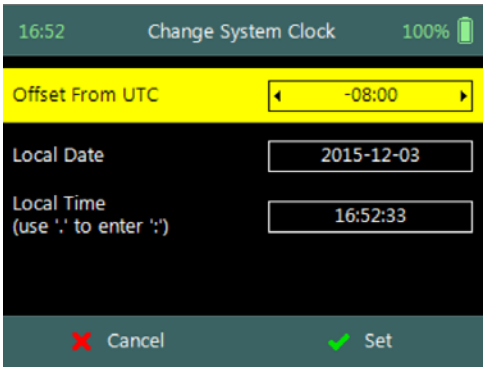


Figure 4:2 - Change System Clock

*e) To **change** the Offset From UTC,*
i). Use the left or right arrow key to scroll through the list of available offsets,
ii). Type in the new value using the keypad.

*f) To **change** the Date or Time,*
i). Use the backspace key to clear current entry,
ii). Type in the new value using the keypad.

*g) To **accept** the new Date and Time settings,*
i). Press the Right Soft Key,
ii). The software will return to System Clock screen.

*h) To **CANCEL** change of System Clock settings,*
i). Press the Left Soft Key.

The System Clock time is displayed on the left corner of the top banner of the LCD screen in hh:mm. The time displayed can be referenced against an external reference to determine if the instrument internal clock is correct.

The **Properties** associated with the date and time parameters for manual Change option are defined in Table 4:1,

Table 4:1 - Date and Time - Properties

Parameter	Format	Separator	Example
Date	yyyy-mm-dd	-	2015-10-22
Time	hh:mm:ss	:	19:11:22
Offset From UTC	hh:mm	:	00:15

4.1.2 Sync with GPS Time

Sync with GPS Time option synchronizes the internal date and time of the FlowTracker2 handheld to GPS date and time.

When synchronizing the System Clock with GPS the internal time will be based on UTC time. Make sure the offset from UTC is set based on your region and select “Sync with GPS Time” again. The GPS time will now be correct with the offset from UTC time.

a) The information displayed on **Sync with GPS Time** screen includes the following,
   i). Waiting for GPS time.

b) The date and time will be updated when there are sufficient satellites in view of the handheld to establish a GPS lock.

c) The software will Navigate to the System Clock screen when the synchronization is complete.

*d) To **CANCEL** Sync with GPS Time,*
i). Press the Left Soft Key.

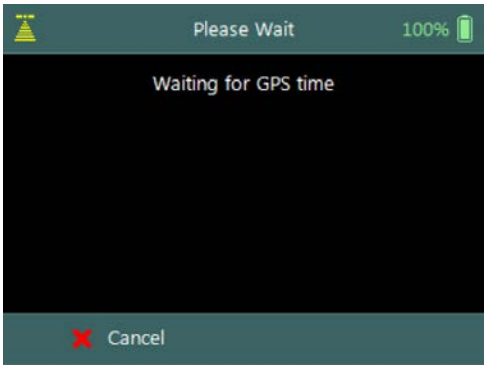


Figure 4:3 - Sync with GPS Time

GPS On: If the internal clock is detected to be more than one minute off – the clock text will be displayed in red and blinking. If the time difference with internal clock is less than 1 minute – the clock will be green.
GPS off: If the time difference with internal clock is less than 1 minute – the clock will be green.

The **system clock** has an internal battery that will keep time for approximately 3 months without the handheld AA battery cartridge installed. If the system is stored for a similar or longer period of time, it will be necessary to check or change the time.

4.2. Recorder

Recorder function enables the user to manage the memory usage of the internal recorder in the FlowTracker2 handheld. The available memory of the internal recorder is dependent on the type, number and size of the files stored.

a) The following information is displayed on the **Recorder** screen,
   i). Pie chart showing percentage of free and used recorder space,
   ii). Free Space in Megabytes (MB),
   iii). Used Space in Megabytes (MB).

b) The size of the internal recorder is 2000MB.

*c) To **ERASE** internal recorder,*
   i). Press the Right Soft Key to select Erase All.

*d) To **navigate** to Utilities menu,*
   i). Press the Left Soft Key.

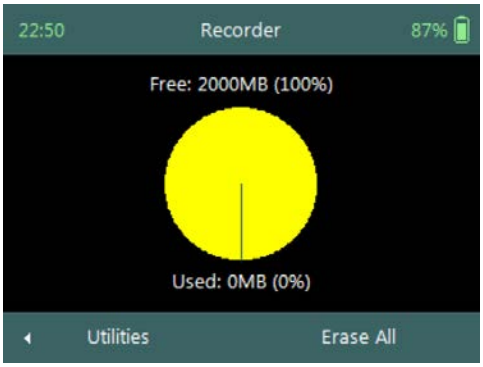


Figure 4:4 - Recorder

4.2.1 Manage Recorder

The FlowTracker2 stores different file types in the internal recorder based on the measurement method selected, templates created, configuration, firmware upgrade or language translation. The **Properties** associated with the FlowTracker2 file types stored on the internal recorder are defined in Table 4:2,

Table 4:2 - File Types - Properties

File	Type	Extension	Visible	Erase
Measurement File	Flow Tracker 2 Measurement File	.ft	Yes	Yes
Templates	Flow Tracker 2 Configuration Template File	.ft_template	Yes	Yes
Manual Beam Check	Flow Tracker 2 Beam Check File	.ft_beamcheck	Yes	Yes
Configuration	not relevant/not	**.dat**	No	No

File	Type	Extension	Visible	Erase
	user exposed			
Firmware	Flow Tracker 2 Firmware File	.ft_firmware	1) Uploaded from PC. 2) Not visible or accessible in HH by user.	No
Language	Flow Tracker 2 Localization File	.lang	1) Created and uploaded from PC. 2) Can be deleted in HH by pressing the Delete button while the language is selected.	No

The management of the internal recorder is important requirement to ensure that good data management practices are followed with regard to the following aspects,

- safe keeping of measurement files,
- discarding unwanted measurement files,
- available recorder space,
- removing hidden or corrupt files.

The internal recorder should not be used as the main storage device for safe keeping of measurement files. It is recommended that measurements are downloaded by the end of each day and a copy of the measurement files are stored on either a computer or USB flash drive.

4.2.2 Erase Recorder

The **Erase** function allows the user to erase all Measurement, Template and Manual Beam Check files that were stored on the internal recorder. See Table 4.2 for file types that are impacted by the erase function.

a) **Erase Recorder** require the user to input confirmation code "**123**".

*b) To **ERASE** internal recorder,*
i). Enter the confirmation code using the keypad,
ii). Press the Right Soft Key to confirm.

*c) To **CANCEL** Erase Recorder,*
i). Press the Left Soft Key.

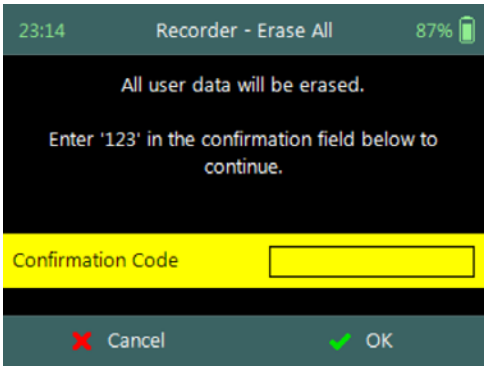


Figure 4:5 - Erase Recorder

Be certain that all data has been downloaded before erasing the recorder. Data cannot be recovered after the recorder is erased.

Regularly erasing the recorder ensures that good data management practices are followed. This will process will reduce the impact of unwanted or corrupt files on the available memory.

4.3. Battery Data

Battery Data function displays the battery voltage and estimated capacity of the battery used within the FlowTracker2 handheld.

The available battery capacity is displayed on the right corner of the top banner of the LCD screen as a percentage of the full capacity. The percentage available will guide the user in determining if batteries need to be replaced before a new measurement is started.

The **Battery Data** screen includes the following parameters,

a) Battery Type,
b) Battery Voltage,
c) Percentage Full.

*d) To **change** the Battery Type,*
i). Use the left or right arrow key to scroll through the list of available offsets.

*e) To **navigate** to Utilities menu,*
i). Press the Left Soft Key.

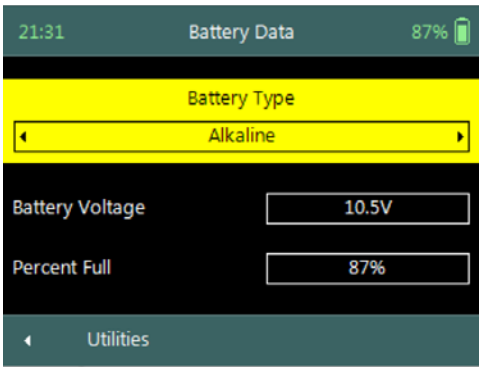


Figure 4:6 - Battery Data

4.3.1 Battery Type

The **Battery Type** parameter specifies the type of battery used within the FlowTracker2 handheld.

a) The Battery Types supported in FlowTracker2 is grouped under the following,
   i). Alkaline: 8 x size AA/LR6 Alkaline batteries,
   ii). NiMH : 8 x size AA, Type BK200AAB, 1.2Vdc, 1900mAh

Only this type of NiMH rechargeable batteries with IEC 62133 approval can be used, or else safety protection will be void.

The use of NiMH Rechargeable Batteries is only CE certified per IEC 62133 for FlowTracker2 part number FT2-HH-2 and above.

b) Battery specifications vary depending on brand. FlowTracker2 specifications are based on,
   i). Alkaline: Energizer Industrial EN91,
   ii). NiMH: Panasonic Rechargeable BK200AAB,
   iii). See also Table 4:5 – Battery Specification.

c) The typical capacity for battery types operating FlowTracker2 are the following. This is dependent on the brand of battery used and the environmental conditions that it is exposed to. **Battery capacity estimates are based on voltage and are only approximate, particularly for rechargeable batteries where voltage characteristics can change significantly over the life of the batteries.**

i). 8 x size AA: ≈ 15 hours continuous use with typical settings.

The typical settings used for determining the battery capacity indicated above are based on the following,

- Operating screen at 100% brightness,
- ADV sensor pinging at 50% of the measurement time,
- No sleep periods,
- GPS off.

Cold weather can greatly affect battery voltage and capacity; always check battery voltage after the system has acclimated to outside temperatures**.**

Battery manufacturer guidelines must be followed during normal use, long term storage and charging requirements. The disposal of batteries must be done with care and it is recommended that local authority guidelines be used.

4.3.2 Battery Voltage

The **Battery Voltage** displayed is the current battery voltage level available from the batteries installed in the FlowTracker2 handheld.

4.3.3 Percentage Full

The **Percentage Full** is an estimate of the remaining capacity of the battery as a percentage of the full capacity.

When the remaining capacity of the battery reaches **0%**, the FlowTracker2 handheld will supply the following message, "*Battery level critically low – shutting down*". The user will be required to replace the batteries before continuing with operations.

4.4. Raw Data Display

Raw Data function allows the graphical display of raw time series data measured by the FlowTracker2. The raw time series data displayed are velocity and SNR data from each beam, tilt and temperature readings.

The **Raw Data** screen includes the following variables,

a) Velocity,
b) SNR,
c) Temperature,
d) Tilt,
e) Battery.

*f) To **select** a variable,*
i). Use up or down scroll arrows keys to view a variable.

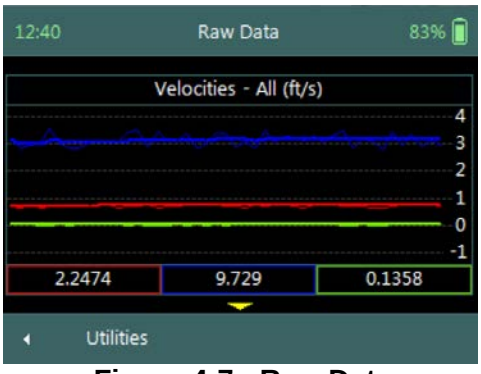


Figure 4:7 - Raw Data

*g) To **navigate** to Utilities menu,*

i). Press the Left Soft Key.

Raw Data displayed in this function are NOT stored but enable the user to verify if the flow conditions are ideal for measurements**.**

4.4.1 Velocity Raw Data

The **Velocity** variable displays the individual velocity components of the one second measured raw velocity data.

a) Velocity data can be expected to show notable variations (most of which are real), and should be indicative of the general conditions in the water,
b) The raw velocity data are updated once per second,
c) The FlowTracker2 Probe Coordinate System is outlined in Figure 4:8.

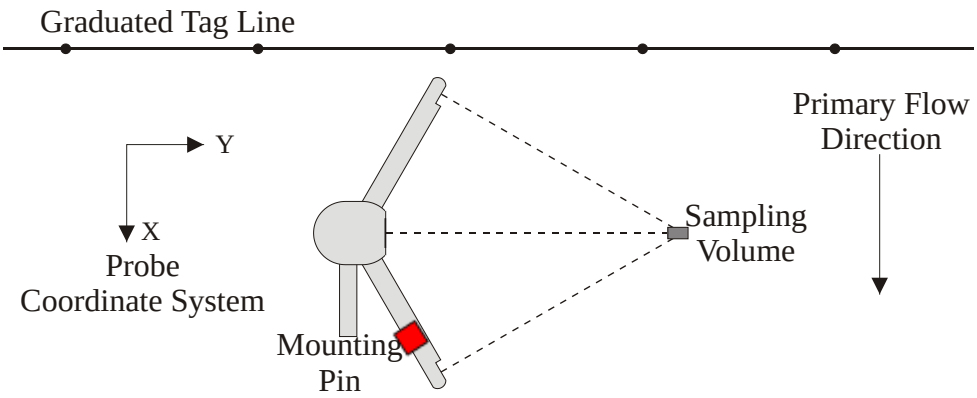
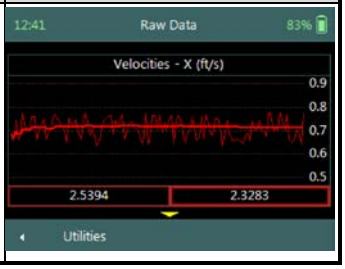
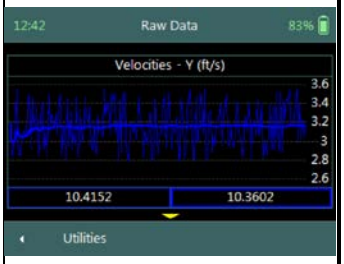
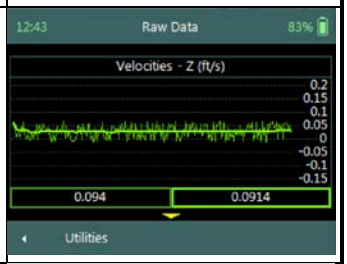
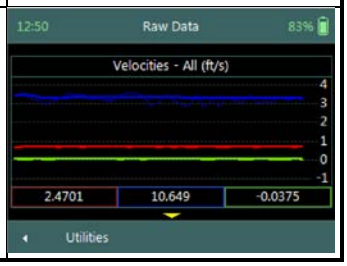


Figure 4:8 - FlowTracker2 Coordinate System

d) The velocity components of FlowTraker2 and display options for individual or all velocity components are listed in Table 4:3. The shortcut key on the keypad determines which velocity component will be displayed.

Table 4:3 - Raw Velocity Display

Velocity Component	Description	Line Color	Keypad Key	Graphic Display
X - Velocity	The positive X-axis is defined perpendicular to both the probe's stem and the axis of the transmit transducer in the direction of receiver arm #1 (marked with a red band).	Red		

Velocity Component	Description	Line Color	Keypad Key	Graphic Display
Y - Velocity	The positive Y-axis is defined along the axis of the transmit transducer from the transmitter towards the sampling volume (making a right-handed coordinate system).	Blue		
Z - Velocity	The positive Z-axis is defined as vertically up in the direction of the probe's stem.	Green		
All Velocities	All of the above	Red / Blue / Green		

e) The continuous lines displayed in the graphics are defined under the following categories,

   i). **Thin** continuous line represents the one second raw velocity data,
   ii). **Thick** continuous line represents moving average of the one second raw velocity data.

f) The velocity values displayed in the rectangular boxes for each velocity component below the graphical display are defined under the following categories,

   i). **Thin** box outline, instantaneous one second raw velocity data,
   ii). **Thick** box outline, represents moving average of the one second raw velocity data.

4.4.2 SNR Raw Data

The **SNR** variable displays the individual Beam SNR measurements from the one second measured raw data.

a) SNR is primarily a function of the amount of particulate matter in the water. For good conditions, SNR should be at least 10 dB. The system can operate effectively with SNR as low as 2-3 dB, although the noise in individual velocity measurements will increase,
b) The SNR data is updated once per second,

c) The display options for individual or all beam SNR values are listed in Table 4:4. The shortcut key on the keypad determines which beam SNR will be displayed,

Table 4:4 - Beam SNR Display

Beam	SNR	Line Color	Keypad Key
Beam1	SNR1	Red	1
Beam2	SNR2	Blue	2
Beam3	SNR3	Green	3
All Beams	All SNR	All	4

d) The continuous lines displayed in the graphics are defined under the following categories,

   i). **Thin** continuous line represents the one second raw SNR data,
   ii). **Thick** continuous line represents moving average of the one second raw SNR data.

e) The SNR values displayed in the rectangular boxes for each beam below the graphical display are defined under the following categories,

   i). **Thin** box outline, instantaneous one second raw SNR data,
   ii). **Thick** box outline, represents moving average of the one second raw SNR data.

4.4.3 Temperature Raw Data

The **Temperature** variable displays the temperature measurements from the one second measured raw data.

a) Temperature data are used for sound speed calculations and can affect velocity data.
b) Check temperature data to be sure the values are reasonable for the environment.
c) The Temperature data are updated once per second.

4.4.4 Tilt Raw Data

The **Tilt** variable displays the angle of the wading rod from the vertical based on one second measured raw data.

a) The Tilt information is calculated from the internal pitch and roll sensor in the FlowTracker2 probe.
b) The Pitch and Roll data is recorded once per second.

4.4.5 Battery Indicator

The **Battery** variable displays the real time battery voltage level of the batteries housed in the FlowTracker2 handheld.

a) The FlowTracker2 uses eight AA batteries contained in a battery pack.

b) Cold weather can greatly affect battery voltage and capacity; always check battery voltage after the system has acclimated to outside temperatures.
c) The Battery data are updated once per second.
d) Comparison of Battery types are listed in Table 4:5

Table 4:5 – Battery Specification

Category	Alkaline	NiMH
General description	Single use	Rechargeable
Nominal battery capacity (typical)	1500 mAh	1900mAh
New battery voltage	12V	11V
Drained battery voltage	8V	9V



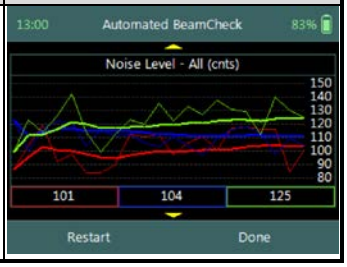
When the remaining capacity of the battery reaches **0%**, the FlowTracker2 handheld will supply the following message, "*Battery level critically low – shutting down*". The user will be required to replace the batteries before continuing with operations.

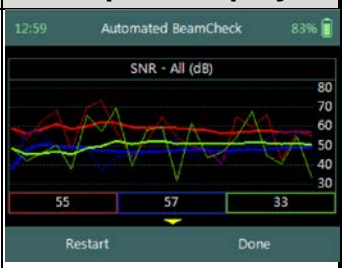
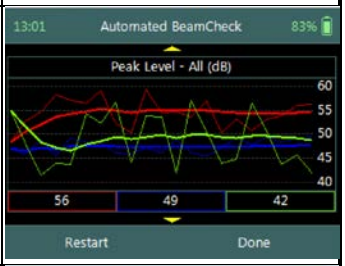
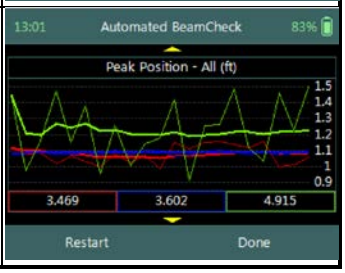
4.5. Automated Beam Check

The Automated Beam Check function performs a number of quality control checks on the Beam Check data collected during the required time frame. The Automated Beam Check is an automated version of Beam Check function described in Beam Check. In the Original FlowTracker, the Automated Beam Check was known as "Auto QC Test".

a) Place the probe in moving water such that the probe is submerged and well away from any underwater obstacles,
   i). The FlowTracker2 collects data until It has 20 diagnostic samples (not time based),
   ii). The beam data are analyzed on several criteria outlined in Table 4:6.
b) The automated beam check quality control criteria used in the evaluation of the beam check data are listed in Table 4:6,

Table 4:6 - Automated Beam Check Quality Control Criteria

Quality Control	Criteria	QC Warning	Graphic Display
Noise Level	• Measured electronics noise level is compared to reference data. Any significant deviation causes a warning, • A large change in noise level may indicate damage to the probe.	Noise Level > QC	

Quality Control	Criteria	QC Warning	Graphic Display
SNR	• The SNR is checked as sufficient for reliable data collection, • Each beam SNR is compared to be sure all beams perform equally, • A warning is issued for low SNR < 4 dB, • A warning is issued for 4 dB > SNR <7dB, • Beam SNR values differ.	SNR	
Peak Level	• The shape of the sampling volume curve is compared to the expected shape. Any significant deviation causes a warning, • This criterion can only be checked with sufficient SNR (> 7 dB).	Peak Level > QC	
Peak Location	• The physical location of the sampling volume is compared to the expected location. Any significant deviation causes a warning. • This criterion can only be checked for sufficient SNR (> 7 dB).	Peak Location > QC	

c) If any warnings are issued, the warnings will be displayed at the bottom of the graphics. The user have the option to repeat the test if warnings are issued.

i). We recommend repeating the test at least once, after you verify that the probe and sampling volume are well away from any underwater obstacles.

ii). If multiple warnings are received, run manual Beam Check to evaluate FlowTracker2 performance in more detail.

d) The display options for individual or all beam check data are listed in Table 4:7. The shortcut key on the keypad determines which beam SNR will be displayed,

Table 4:7 - Automated Beam Check Display

Beam	Line Color	Keypad Key
Beam1	Red	1
Beam2	Blue	2
Beam3	Green	3
All Beams	All	4

*e) To **select** a Quality Control Criteria,*

i). Use up or down scroll arrows keys to view quality control criteria.

*f) To **accept** Automated Beam Check,*

i). Press the Right Soft Key,

ii). The software will continue to the Data Collection screen.

*g) To **RESTART** Automated Beam Check,*

i). Press the Left Soft Key.

4.6. Beam Check

Beam Check operates by sending a pulse of sound into the water, and then plots the signal to noise ratio of the return signal versus range for each of the FlowTracker's receivers. This information can be evaluated to determine the effective measurement range, to look for interference from boundaries/structures, to survey a deployment site, or to observe the quality of the returned signal.

a) The Beam Check function can be accessed from the Utilities menu,

b) Beam Check file will be recorded in the handheld recorder for each Beam Check performed. The file naming convention for beam check files consists of the following,

i). File Extension: .ft_beamcheck

ii). Naming Convention: yyyymmdd-hhmmss

c) The maximum number of samples that can be recorded during a Beam Check is 30.

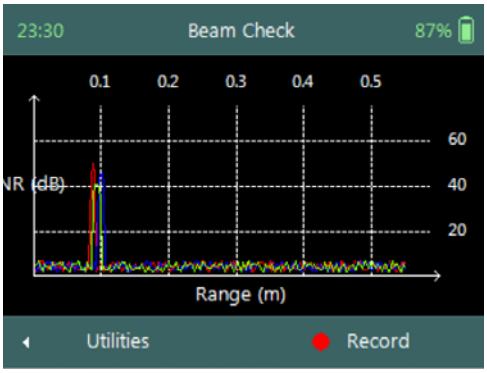


Figure 4:9 – Beam Check

d) Place the probe in either a small tank, bucket of water or measurement section in canal or river such that the probe is submerged and there is a boundary (surface, side, or bottom) within view,

*e) To **record or stop recoding** of Beam Check,*

i). Press the Right Soft Key,

*f) To **navigate** to Utilities menu,*

i). Press the Left Soft Key.

4.7. GPS Data

GPS Data function display the Global Positioning System data received from the internal GPS receiver in the FlowTracker2 handheld. The GPS data displayed consist of satellite time, satellite information and coordinates.

The **GPS Data** screen includes the following variables,

a) Device Date UTC,
b) Device Time UTC,
c) Satellite Date UTC,
d) Satellite Time UTC,
e) # Satellites,
f) Fix Quality,
g) Latitude,
h) Longitude,
i) Altitude,
j) HDOP.

*k) To **navigate** to Utilities menu,*

i). Press the Left Soft Key.

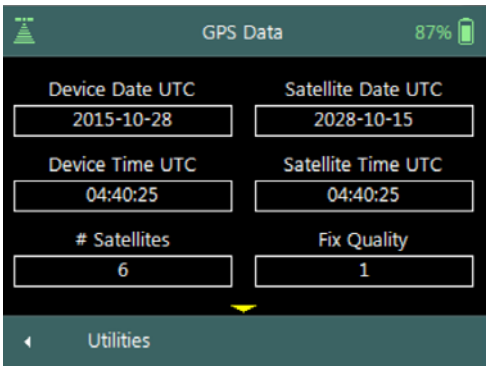


Figure 4:10 - GPS Data

Properties associated with the variables in displayed GPS Data screen are defined in Table 4:8,

Table 4:8 - GPS Data - Properties

Variable	Description	Format \ Units
Device Date UTC	The FlowTracker2 handheld internal date set to Coordinated Universal Time (UTC).	yyyy-mm-dd
Device Time UTC	The FlowTracker2 handheld internal time set to Coordinated Universal Time (UTC).	hh:mm:ss
Satellite Date UTC	Current satellite date based on Coordinated Universal Time (UTC).	yyyy-mm-dd
Satellite Time UTC	Current satellite time based on Coordinated Universal Time (UTC).	hh:mm:ss
# Satellites	Number of satellites in view of GPS receiver in the FlowTracker2 handheld	n/a
Fix Quality	GPS Quality indicator (0=no fix, 1=GPS fix, 2=Dif. GPS fix)	n/a
Latitude	GPS derived Latitude	DDD° MM' SS.SS
Longitude	GPS derived Longitude	DDD° MM' SS.SS
Altitude	GPS derived altitude above mean sea level.	m
HDOP	Horizontal dilution of position is a GPS term used to describe the geometric strength of satellite configuration on GPS accuracy. HDOP values are typically between 1 and 2 although the ideal is a HDOP value of 1.	n/a

4.8. System Maintenance

System Maintenance function enables the user to perform number of maintenance tasks on the FlowTracker2 handled and probe firmware.

System Maintenance screen includes the following functions,

a) Force Probe Upgrade,

*b) To **select** a variable,*
   i). Use up or down scroll arrows keys to view a variable.

*c) To **navigate** to Utilities menu,*
   i). Press the Left Soft Key.



Figure 4:11 – System Maintenance

4.8.1 Force Probe Upgrade

The **Force Probe Upgrade** function allows the user to either upload or downgrade the firmware on the probe. This function is normally used when communication problems are experienced with the probe or when the probe firmware needs to be downgraded.

Warning screen of **Force Probe Upgrade** function displays the warnings associated with downgrading probe firmware,

*a) To **CANCEL** force probe upgrade,*
   i). Press the Left Soft Key.

*b) To **continue** with force probe upgrade,*
   i). Press the Right Soft Key.

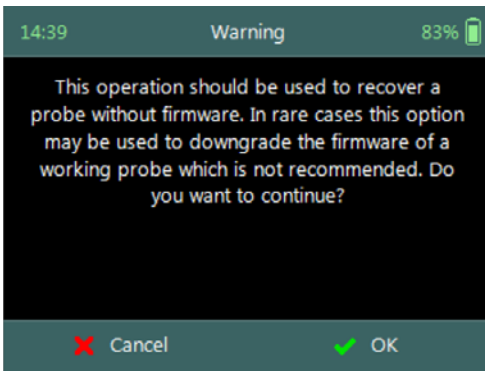


Figure 4:12 – Force Probe Upgrade Warning

In case where the probe firmware version is newer than the firmware installed on the handheld, the handheld will supply a warning message before each velocity measurement is performed: "The Probe firmware is newer than expected – please consider upgrading the Handheld firmware to the latest version available"

Section 5. Data Collection Modes

The FlowTracker2 provides two data collection modes that the user can apply in the collection of velocity data. The Discharge and General modes available in FlowTracker2 has different field applications and the method of each mode is described in this section.

5.1. Discharge Mode

Discharge Mode is for applications where the primary goal is to measure river/stream discharge. The technique involves taking a series of velocity measurements at different locations throughout the cross section. These measurements are combined with location and water depth information to compute the total discharge.

5.1.1 Measurement Technique

The basic **Measurement Technique** used for performing discharge measurement using the Discharge Mode is briefly discussed under the following points and this measurement process should be read in conjunction with Site Selection Requirements.

a) A measurement site is selected based on criteria stipulated in Site Selection Requirements. The site selection process is a crucial part of collecting discharge measurement data.
   i). Ideal measurement site, the flow should be perpendicular to the tag line at all points with no flow reversals or obstructions.
   ii). The measurement site should encompass the minimum measurement site and hydraulic requirements discussed in Site Selection Requirements.
   iii). Flow conditions at the measurement site are the most important factor in determining overall accuracy of the measurement.

b) A graduated tag line is strung across the river.
c) The operator starts at one edge, recording the starting-edge location and water depth.
d) The river cross section is split into several stations. At each station, the operator records the station location and water depth, and then performs velocity measurements at one or more depths to determine the mean velocity at that station.
e) During velocity measurements, the probe's X-axis is maintained perpendicular to the tag line (Figure 5:1); the red band (receiver arm #1) should face downstream. Only the X-component of velocity (**Vx**) is used to in the discharge calculation, regardless of the flow direction (flow direction is also measured and recorded).

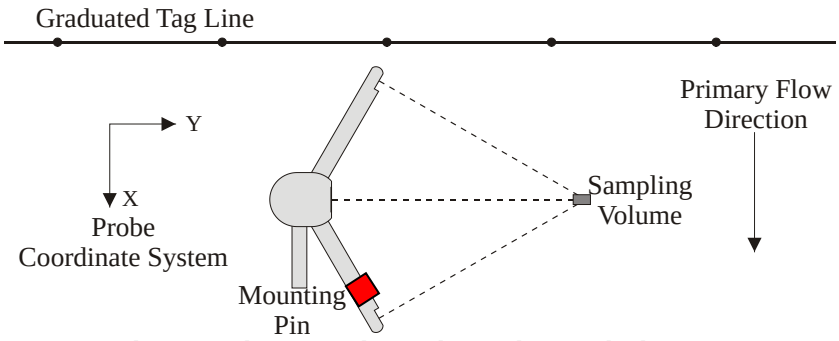


Figure 5:1 – FlowTracker2 Probe Orientation Relative to Stream Flow

f) When all station measurements are completed, the operator records the ending-edge location and water depth.
g) The total discharge is the sum of all station discharge values.

5.1.2 Discharge Calculation Methods

The discharge calculation methods implemented in FlowTracker2 are based on established methods that are documented in international standards and are widely used by government agencies, hydrologists and hydrographers. The discharge calculation methods were originally developed for current meter instruments. The FlowTracker2 makes use of the same measuring technique and for this reason the same calculation methods can be used to determine the total discharge.

The methods implemented for calculation of discharge are based on the following literature,

- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- WMO-No. 1044, Volume I – Fieldwork, 2010.
- Japanese Literature

The FlowTracker2 supports several discharge calculating methods for calculating discharge following the basic measuring technique outlined above.

- **Mid-Section** equation (see 5.1.2.1),
- **Mean-Section** equation (see 5.1.2.2),
- The **Japanese** equation (see 5.1.2.3).

5.1.2.1 Mid-Section Equation

The **Mid-Section** method is based on a measurement section that is divided into a number of stations with panels created for each station across the section. The average velocity of a panel is assumed to be equal to the average velocity in the vertical calculated from the point velocity measurements made. The equation of the Mid-Section method is given in Equation 5:1.

This method is used by the U.S. Geological Survey (USGS), the primary U.S. government agency responsible for river discharge monitoring.

Equation 5:1 - Mid-Section Method

$$Q = \sum \overline{v}_0 d_0 \left(\frac{b_1 - b_0}{2}\right) + \overline{v}_1 d_1 \left(\frac{b_2 - b_0}{2}\right) + \overline{v}_n d_n \left(\frac{b_{n+1} - b_{n-1}}{2}\right)$$

Edge	Open water	Open Water

where, $\overline{v}$ *is the average velocity in the vertical or at the station,*
d is the water depth measured at the station,
b is the location of the station.

The application of the Mid-Section equation within a measurement section is graphically shown in Figure 5:2. The principle of the Mid-Section method is highlighted in the figure below where the panel width (W_2) is calculated based on the station locations (L_2) with the station as the center of the panel.

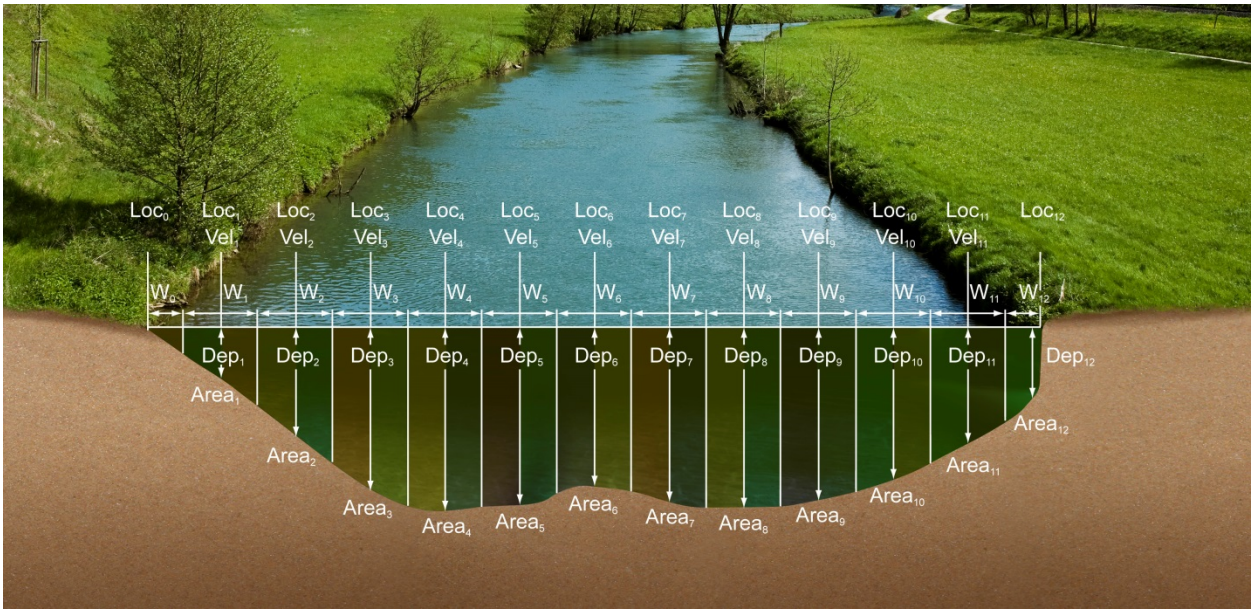


Figure 5:2 - Mid-Section Method

There are few special cases to consider when applying the Mid-Section method in calculating of total discharge.

a) **Edges**

i). Edge can be either the Left Bank or Right Bank,
ii). Edge calculations are handled differently from stations in open water with reference to the first component of Equation 5:1,
iii). The mean velocity at the edge is scaled from the adjacent station by a user defined correction factor (CF),
iv). Edge water depth of zero will result in zero flow for the edge calculation.

b) **Islands** (multiple channels)

i). If a river is split into multiple channels, any internal island(s) must be accounted for in the discharge calculation,

ii). The stations at each edge of the island(s) are treated as an Island Edge,
iii). Island edge calculations are handled the same as 66 with reference to the first component of Equation 5:1,
iv). The mean velocity at the island edge is scaled from the adjacent station by a user defined correction factor (CF),
v). Edge water depth of zero will result in zero flow for the edge calculation.

5.1.2.2 Mean-Section Equation

The **Mean-Section** method is based on a measurement section that is divided into number of stations with panels created in between adjacent stations across the section. The average velocity of a panel is assumed to be the average velocity of the two adjacent stations velocities in the vertical calculated from point velocity measurements made. The equation of the Mean-Section method is given in Equation 5:2.

Equation 5:2 - Mean-Section Method

$$Q = \sum (b_1 - b_0)\left(\frac{d_1 + d_0}{2}\right)\left(\frac{\overline{v}_1 + \overline{v}_0}{2}\right) + (b_2 - b_1)\left(\frac{d_2 + d_1}{2}\right)\left(\frac{\overline{v}_2 + \overline{v}_1}{2}\right) + (b_{n+1} - b_n)\left(\frac{d_{n+1} + d_n}{2}\right)\left(\frac{\overline{v}_{n+1} + \overline{v}_n}{2}\right)$$

Edge	Open water	Open Water

where, $\overline{v}$ *is the average velocity in the vertical or at the station,*
d *is the water depth measured at the station,*
b *is the location of the station.*

The application of the Mean-Section equation within a measurement section is graphically shown in Figure 5:3. The principle of the Mean-Section method is shown in the figure below where panel width (W) is calculated based on the station locations between adjacent stations across the section.

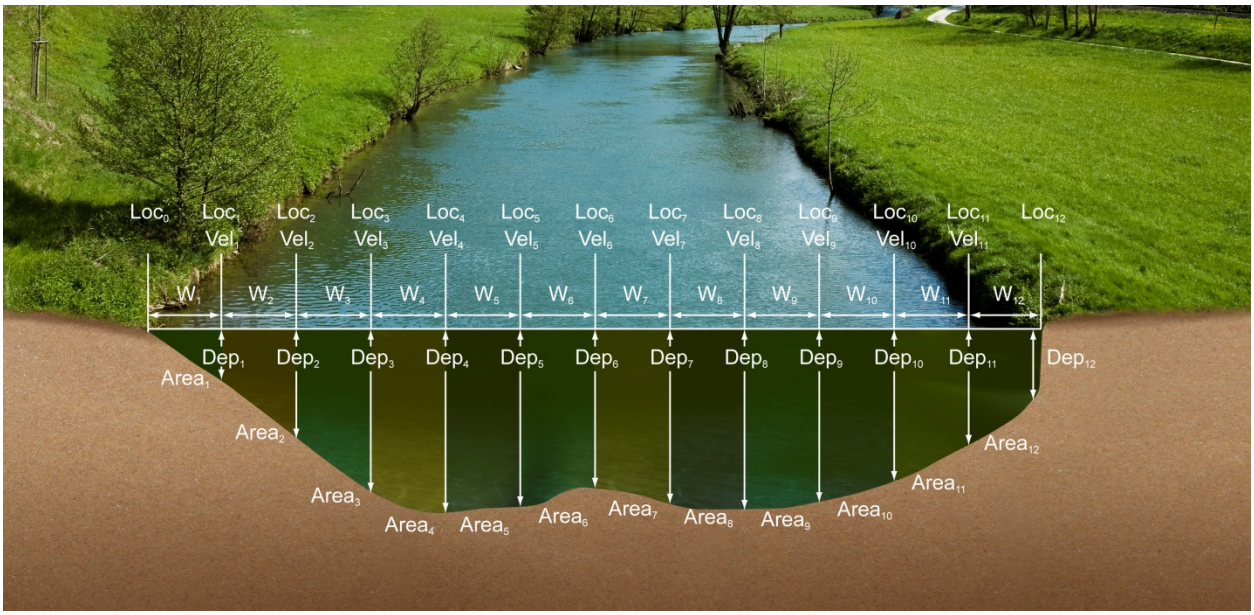


Figure 5:3 - Mean-Section Method

There are few special cases to consider when applying the Mean-Section method in calculating of total discharge.

a) **Edges**

i). Edge can be either the Left Bank or Right Bank,
ii). Edge calculations are handled exactly the same from stations in open water with reference to the first component of Equation 5:2,
iii). Correction factor (CF) is NOT applied in Mean-Section method to scale the mean velocity at the edges from the adjacent station,
iv). The discharge on the edges can be determined by applying Equation 5:2 on the assumption that the velocity at the edges is zero.

b) **Islands** (multiple channels)

i). If a river is split into multiple channels, any internal island(s) must be accounted for in the discharge calculation,
ii). The stations at each edge of the island(s) are treated as an Island Edge,
iii). Island edge calculations are handled the same as 68 with reference to the first component of Equation 5:2,
iv). Correction factor (CF) is NOT applied in Mean-Section method to scale the mean velocity at the edges from the adjacent station,
v). The discharge on the edges can be determined by applying Equation 5:2 on the assumption that the velocity at the edges is zero.

5.1.2.3 Japanese Equation

The **Japanese** method is similar to both the Mean-Section and Mid-Section methods in some respects with its own unique measuring technique. The most significant feature of the Japanese method is the duplicate measurements performed of each depth and point velocity measurements at a station. The Japanese national standard guideline for determining the measurement interval for depth and velocity are dependent on the measurement section width and are supplied in Table 5:1.

Table 5:1 - Predetermination of Measuring Intervals

River Width, B (m)	Measuring Interval of Depth, M (m)	Measuring Interval of Velocity, N (m)
Less than 10m	10 – 15% of B	N=M
10-20	1	2
20-40	2	4
40-60	3	6
60-80	4	8
80-100	5	10
100-150	6	12
150-200	10	20
200 over	15	30

The Japanese method has two separate equations for determining the total discharge based on the measurement section width. The equation of the Japanese method for measurement section greater than 10m is given in Equation 5:3.

Equation 5:3 - Japanese Method > 10m

$$Q = \sum \left\{ \left[(b_1 - b_0) \times 0.5 \left(\frac{d_1 + d_1'}{2} + \frac{d_0 + d_0'}{2} \right) + (b_2 - b_1) \times 0.5 \left(\frac{d_2 + d_2'}{2} + \frac{d_1 + d_1'}{2} \right) \right] \times \left(\frac{\overline{v}_1 + \overline{v}_1'}{2} \right) \right\} +$$

Edge

$$\left\{ \left[(b_n - b_{n-1}) \times 0.5 \left(\frac{d_n + d_n'}{2} + \frac{d_{n-1} + d_{n-1}'}{2} \right) + (b_{n+1} - b_n) \times 0.5 \left(\frac{d_{n+1} + d_{n+1}'}{2} + \frac{d_n + d_n'}{2} \right) \right] \times \left(\frac{\overline{v}_n + \overline{v}_n'}{2} \right) \right\}$$

Open Water

The equation of the Japanese method for measurement section smaller than 10m is given in Equation 5:4.

Equation 5:4 - Japanese Method < 10m

$$Q = \sum \left\{ \left[(b_1 - b_0) \times 0.5 \left(\frac{d_1 + d_1'}{2} + \frac{d_0 + d_0'}{2} \right) + \left(\frac{b_2 - b_1}{2} \right) \times 0.5 \left(\frac{d_2 + d_2'}{2} + \frac{d_1 + d_1'}{2} \right) \right] \times \left(\frac{\overline{v}_1 + \overline{v}_1'}{2} \right) \right\} +$$

Edge

$$\left\{ \left[\left(\frac{b_2 - b_1}{2} \right) \times 0.5 \left(\frac{d_2 + d_2'}{2} + \frac{d_1 + d_1'}{2} \right) + \left(\frac{b_3 - b_2}{2} \right) \times 0.5 \left(\frac{d_3 + d_3'}{2} + \frac{d_2 + d_2'}{2} \right) \right] \times \left(\frac{\overline{v}_2 + \overline{v}_2'}{2} \right) \right\} +$$

Open Water

$$\left\{ \left[\left(\frac{b_n - b_{n-1}}{2} \right) \times 0.5 \left(\frac{d_n + d_n'}{2} + \frac{d_{n-1} + d_{n-1}'}{2} \right) + \left(\frac{b_{n+1} - b_n}{2} \right) \times 0.5 \left(\frac{d_{n+1} + d_{n+1}'}{2} + \frac{d_n + d_n'}{2} \right) \right] \times \left(\frac{\overline{v}_n + \overline{v}_n'}{2} \right) \right\}$$

Open Water

The application of the Japanese equation within a measurement section that is greater than 10m is graphically shown in Figure 5:4.

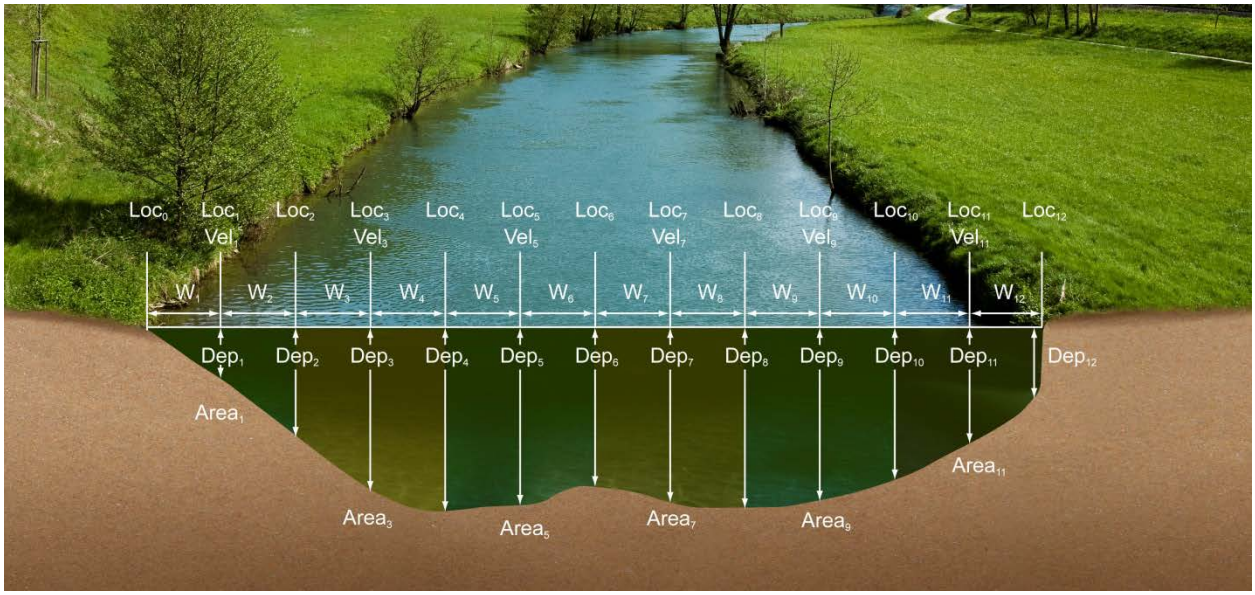


Figure 5:4 - Japanese Method >10m

There are few special cases to consider when applying the Japanese method in calculating of total discharge.

a) **Edges**

i). Edge can be either the Left Bank or Right Bank,
ii). Edge calculations are handled exactly the same from stations in open water with reference to the first component of Equation 5:3,
iii). Correction factor (CF) is NOT applied in Japanese method to scale the mean velocity at the edges from the adjacent station,

b) **Islands** (multiple channels)

i). If a river is split into multiple channels, any internal island(s) must be accounted for in the discharge calculation,
ii). The stations at each edge of the island(s) are treated as an Island Edge,
iii). Island edge calculations are handled the same as 70 with reference to the first component of Equation 5:3,
iv). Correction factor (CF) is NOT applied in Japanese method to scale the mean velocity at the edges from the adjacent station,

5.1.3 Determining Mean Station Velocity

The **Mean Station Velocity** or **Mean Velocity in a Vertical** determines how mean velocity is determined at each station. The measurement techniques used involves variations in the number of point velocity measurements taken at a range of measurement depts. The method used to calculate the mean velocity in a vertical depends on the number of point velocity measurements made within a vertical.



Methods implemented for determining mean station velocity in a vertical are based on the following literature,

- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- WMO-No. 1044, Volume I – Fieldwork, 2010.

The methods implemented in FlowTracker2 for determining the Mean Station Velocity are defined in Table 5:2.

Table 5:2 - Determining Mean Station Velocity

Method	Measurement Depth	Mean Velocity Equation
0.6	0.6 * depth	$V_{mean} = CF * V_{0.6}$
0.2/0.8 **0.8/0.2**	0.2 * depth 0.8 * depth	$V_{mean} = CF * ((V_{0.2} + V_{0.8}) / 2)$
.2/.6/.8 **.8/.6/.2**	0.2 * depth 0.6 * depth 0.8 * depth	$V_{mean} = CF * ((V_{0.2} + 2*V_{0.6} + V_{0.8}) / 4)$

Method	Measurement Depth	Mean Velocity Equation
Ice 0.6	0.6 * effective depth	$V_{mean} = 0.92*V_{0.6}$ (Correction Factor 0.92 can be changed by user)
Ice 0.5	0.5 * effective depth	$V_{mean} = 0.88*V_{0.5}$ (Correction Factor 0.88 can be changed by user)
Ice 2/8 **Ice 8/2**	0.2 * effective depth 0.8 * effective depth	$V_{mean} = CF * ((V_{0.2} + V_{0.8}) / 2)$
Kreps 2- **Kreps 2+**	0.0 (near surface) 0.62 * depth	$V_{mean} = CF * (0.31*V_{0.0} + 0.634*V_{0.62})$
5 Point+ **5 Point-**	0.0 (near surface) 0.2 * depth 0.6 * depth 0.8 * depth 1.0 (near bottom)	$V_{mean} = CF * ((V_{0.0} + 3*V_{0.2} + 3*V_{0.6} + 2*V_{0.8} + V_{1.0}) / 10)$
6 Point+ **6 Point-**	0.0 (near surface) 0.2 * depth 0.4 * depth 0.6 * depth 0.8 * depth 1.0 (near bottom)	$V_{mean} = CF * ((V_{0.0} + 2*V_{0.2} + 2*V_{0.4} + 2*V_{0.6} + 2*V_{0.8} + V_{1.0}) / 10)$
Vertical Velocity Curve	Any number of points at user-specified depths	V_{mean} = CF * Integrated velocity Measurements can be made in any order; they are sorted by depth to calculate the integrated mean velocity. Repeat measurements at the same depth are averaged prior to calculating the integrated velocity.
None	No velocity measurement	$V_{mean} = CF * V_{adjacent}$ Mean velocity is based on the velocity from the adjacent station(s), multiplied by a user-specified correction factor. This method is used when velocity measurements cannot be made or with the Japanese method.
Input V	User input velocity	$V_{mean} = V_{input}$ User enters an estimated velocity value. This method is used when velocity measurement is not possible, most commonly due to weed growth along a riverbank.

Methods involving more than one measurement can be done in either direction (from surface to the bottom, or from the bottom towards the surface).

5.1.3.1 Method None

The method **None** is used in a number of different scenarios from assigning zero velocity to channel banks, stations where no measurements are possible to Japanese method where the measurement section is wider than 10m.

a) **Channel Banks**

i). Edges describing the left or Right bank of a channel,
ii). Island Edges describing the banks of island\s,
iii). The method **None** is assigned automatically for Edges and Island Edges by the software.

b) **Station Measurement not Possible**

i). The measuring site conditions do not allow velocity measurement (perhaps due to weed growth),

ii). Velocity for this station is based on the mean station velocity from the adjacent station(s) with velocity measurements multiplied by the user-specified correction (**CF**) factor for this station.

c) **Japanese Method**

i). Japanese measuring technique for measurement sections wider than 10m require velocity measurements only at every second station,

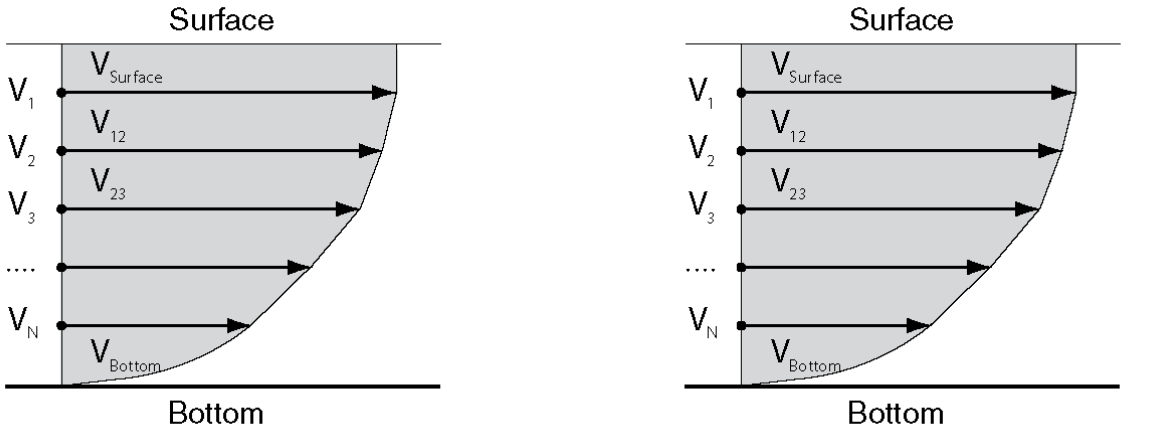
ii). A velocity method of "Depth Only" is assigned to **None** velocity stations.

5.1.3.2 Vertical Velocity Curve

The **Vertical Velocity Curve** method is a series of point velocity measurements that are well distributed between the water surface and channel bed. Normally observation is made at 0.1 depth increments between 0.1 and 0.9 of the total water depth. Point velocity measurements at the standard 0.2, 0.6 and 0.8 depths are required to compare the vertical velocity curve method against standard methods.

a) For each measurement, you must manually enter the measurement depth.

b) The mean station velocity (mean velocity in vertical) is calculated by integrating all velocity measurements considering their location as illustrated in Figure 5:5.



Mid and Mean Section Integration

$V_{Surface} = V_1$

$V_{i(i+1)} = (V_i + V_{i+1})/2$

$V_{Bottom} = (6/7)*V_N$ (1/6 power law)

Japanese Equation Integration

$V_{Surface} = V_1$

$V_{i(i+1)} = (V_i + V_{i+1})/2$

$V_{Bottom} = (1/2)*V_N$ (Linear velocity change)

Figure 5:5 - Vertical Velocity Curve

c) If multiple measurements are made at the same measurement depth, these measurements are averaged prior to calculating the velocity integration.

5.1.3.3 Correction Factor

The **Correction Factor** (CF) is a user supplied parameter used to scale the mean station velocity or velocity in the vertical.



Be careful when selecting a **Correction Factor**, as the mean station velocity is always scaled by this value. Incorrect use of this parameter will affect the final discharge measurement.

a) The **CF** is most commonly used at edges, internal islands, and other method **None** stations to scale the velocity from the adjacent station(s).
   i). The default **CF** value is 1.00.
   ii). Any value from -1.00 to 1.00, except 0.0, is allowed.

b) The **CF** can be entered for any station and the mean station velocity will be multiplied by the CF.

c) Special conditions near edge measurements in very narrow streams.
   i). The orientation of the FlowTracker2 probe can be reversed by 180° to allow measurement closer to the edge.
   ii). A **CF** of -1.00 should be entered to correct the FlowTracker2 X-velocity.

5.1.4 Discharge Uncertainty Calculation

Discharge Uncertainty Calculation is performed on every discharge measurement to determine the overall measurement uncertainty.

a) The uncertainty calculation methods implemented in FlowTracker2 is based on the **Interpolated Variance Estimator (IVE)** and **ISO** methods,
   i). The **Interpolated Variance Estimator (IVE)** uncertainty calculation method uses a method developed by researchers at the U.S. Geological Survey. The IVE uncertainty calculation is the default method as it provides the most reliable indicator of measurement quality,
   ii). The **ISO** method is based on the international standard. It provides users with the results of a published, standard technique; however, in some cases this calculation may not provide a reliable indicator of data quality.

The uncertainty analysis implemented for determining the overall discharge uncertainty are based on the following literature,



- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- Cohn, T., Kiang, J., and Mason, R., Jr. (2013). ”Estimating Discharge Measurement Uncertainty Using the Interpolated Variance.

b) The application of uncertainty calculation methods to discharge calculation methods are defined,
   i). The uncertainty calculation methods implemented are only applicable to the “Mid-Section” and “Mean-Section” discharge calculation methods.

ii). The Japanese method does not incorporate discharge uncertainty calculations and a method "None" is assigned.

c) The uncertainty calculations are based on several different parameters. In addition to overall uncertainty, the FlowTracker2 also looks at the contribution of each of the following parameters.

i). **Accuracy**: The accuracy of the FlowTracker2 calibration (this is generally negligible),

ii). **Depth**

- In the **IVE** calculation, this term includes both uncertainty in the depth measurement and the effect of changes in depth between stations,
- In the **ISO** calculation, this term includes only the uncertainty in depth measurements.

iii). **Velocity**

- In the **IVE** calculation, this term includes both uncertainty in the velocity measurement and the effect of changes in velocity between stations,
- In the **ISO** calculation, this term includes only the uncertainty in velocity measurements.

iv). **Width**

- Estimated uncertainty in width measurements.

v). **Method:** Determining Mean Station Velocity.

- Use for the **ISO** method only.

vi). **Number of stations**

- Use for the **ISO** method only.

5.1.5 Under Ice Measurements

The discharge calculation methods discussed previously in this section are also applicable for **Under Ice Measurements.** It is recommended that the operator refer to existing literature describing under ice measurements as there are number of aspects that need to be taken into account.



"Standard Operating Procedures for under ice discharge measurements using ADCPs", Water Survey of Canada, Environment Canada, is a good reference guide for performing under ice measurements

There are a couple of additional requirements for calculating total discharge in addition to what was discussed under Discharge Calculation Methods when performing under ice measurements,

a) Additional measurements required during under ice measurements,

i). Ice thickness,
ii). Water surface to bottom of ice,
iii). Water surface to bottom of slush (if slush is present).

b) Calculating of effective depth. The effective depth is defined by the distance between the streambed and the bottom of the ice or slush in the case slush is present,

i). 0.2 depth setting = a + 0.2C

ii). 0.8 depth setting = b – 0.2C

iii). 0.6 depth setting = b – 0.4C

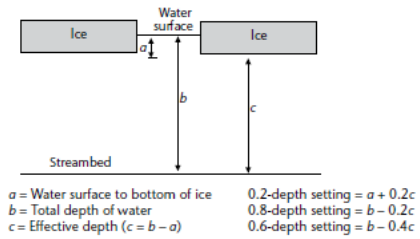


Figure 5:6 - Effective Depth

c) Station area is calculated by multiplying the effective depth and station width.

5.1.6 Weighted Gauge Height

The **Weighted Gauge Height** during a discharge measurement is the mean water level calculated at the monitoring site during the measurement time. It is important that an accurate mean gauge height is determined as this is used with the discharge measured to develop stage-discharge relationship for the monitoring site. The methods implemented in FlowTracker2 for determining the weighted gauge height during a discharge measurement is the **average** of both the **Discharge Weighted** and **Time Weighted** gauge height.

a) The discharge weighted process is based on the discharge calculated within the time interval associated with each set of gauge height readings. The equation of the discharge weighted method is given in Equation 5:5.

Equation 5:5 - Discharge Weighted

$$H = \frac{q_1 h_1 + q_2 h_2 + q_3 h_3 + q_n h_n}{Q}$$

where, H *is the mean gauge height,*
Q *is the total discharge,*
q *is the discharge measured between time interval of gauge height readings,*
h *is the average gauge height readings taken between time interval.*

b) The time weighted process is based on the arithmetic mean of the gauge height calculated within the time interval associated with each set of gauge height readings.

Equation 5:6 - Time Weighted

$$H = \frac{t_1 h_1 + t_2 h_2 + t_3 h_3 + t_n h_n}{T}$$

where, H *is the mean gauge height,*
T *is the total time for the measurement,*
t *is the duration of time interval between gauge height readings,*
h *is the average gauge height readings taken between time interval.*



The method for determining the weighted gauge height are based on the following literature,

- Measurement and Computation of Stream flow: Volume 1. Measurement of Stage and Discharge. Page 170. By S. E. RANTZ and others

5.2. General Mode

The **General Mode** of data collection is for applications that need a series of velocity measurements at different locations that do not require a standard discharge output.

5.2.1 Measurement Technique

The basic **Measurement Technique** used for performing velocity measurements using General Mode is briefly discussed below. The measurement technique differs from the Discharge Mode where the objective is to determine water velocity at specific locations.

a) The measurement location is not required to comply with any measurement site or hydraulic requirements stipulated in Site Selection Requirements.
b) The flow conditions at the measurement location should be within the FlowTracker2 specifications.
c) Station is created for each point velocity measurement assigned a unique X and Y coordinate.
d) Station velocity measurement performed at user defined location and depth.

5.2.2 Determining Mean Velocity

The **Mean Velocity** outputs generated from velocity measurements performed in General Mode consist of Mean Station Velocity and Mean Velocity of All Stations.

a) The **Mean Station Velocity** is the average of the velocity measurements performed over a user defined sampling interval at a specific measurement depth.
b) The **Mean Velocity of All Stations** is the average of all the station measurements performed each at its own unique location and measurement depth.

Section 6. Quality Control

Quality Control (QC) is continuously performed on all variables collected during a measurement in both Discharge and General Modes. The Quality Control Parameters are automatically reviewed at different stages of a measurement and if any values exceed the expected criteria a warning is supplied.

6.1. Quality Control Parameters

Quality Control Parameters used to analyze the variables collected during a measurement are discussed in the following section. The quality control parameters with its expected values are supplied in Table 6:1. All quality control parameters can be adjusted or disabled based on measurement site and or user requirements.

Table 6:1 - Quality Control Parameters

Parameter	Description	Expected
SNR	**SNR** is the most important Quality Control parameter, • It measures the strength of the acoustic reflection from particles in the water, • Without sufficient SNR, the FlowTracker2 cannot measure velocity.	Ideally > 10 dB Minimum ≥ 4 dB
Velocity Standard Error	**σV** (velocity standard error) is a direct measure of the accuracy of velocity data, • It includes the effects of turbulence in the river and instrument uncertainty.	Typically < 0.01m/s (0.03 ft/s). Higher in turbulent environment.
Boundary Interference	**Boundary** QC evaluates the measurement environment for interference from underwater obstacles, • **FAIR** or **POOR** results may indicate significant interference from an underwater obstacle.	• BEST, • GOOD, • FAIR, • POOR.
Velocity Spike Filtering	**Spikes** in FlowTracker2 velocity data are removed using a spike filter, • Some spikes are common and no cause for concern, • Too many spikes indicate a problem in the measurement environment (e.g., interference from underwater obstacles or highly aerated water).	Typically < 5% of total samples. Should be < 10% of total samples.
Velocity Angle	**Angle** is the direction of the measured velocity relative to the FlowTracker2 X-axis, • Used for discharge measurements only, • A good site should have small velocity angles, • Large angles may be unavoidable at some sites.	Ideally < 20º

Parameter	Description	Expected
Tilt Angle	**Angle** of the wading rod relative to the vertical, • Used for both discharge and general mode, • A good measurement should have small tilt angles, • Large tilt angles may be unavoidable at some sites.	Ideally < 5º
Station Percent Discharge	**%Q** is the percentage of the total discharge in a single measurement station, • Most agencies have criteria for the maximum **%Q**.	Typical criteria: Ideally < 5% Maximum < 10%
Station Water Depth	**Depth** is the maximum percentage variation in depth between adjacent stations.	Typical criteria: Maximum < 50%
Station Location	**Location** is the maximum percentage variation in location between adjacent stations.	Typical criteria: Maximum < 100%
Velocity Profile 0.2 \ 0.8	**0.2 \ 0.8 Velocity Profile** evaluated against expected velocity distribution, • Used for discharge measurements only, • Suggest 0.6 depth measurement if set criteria is complied with.	Ideally: near-surface velocity > n Velocity

6.1.1 Signal to Noise Ratio (SNR)

Signal to Noise Ratio (SNR) is a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the FlowTracker2. SNR is the most important quality control data provided by the FlowTracker2.

a) SNR is reported in logarithmic units (dB). It is recorded with each one-second velocity sample.
b) For the best operating conditions, SNR should be greater than 10 dB.
c) The FlowTracker2 can operate reliably with SNR as low as 4 dB, although the noise in individual measurements will increase.
d) Low SNR indicates a lack of suspended material in the water. For clear water, seeding material can be introduced to increase SNR. Seeding is typically only required in large laboratory tanks. Most field applications have sufficient natural scattering material.

SNR Data Display

e) The SNR data displayed during and after a point velocity measurement and when a station and or stations are completed in both General and Discharge Modes are supplied in Table 6:2. Individual beam SNR data can be accessed by exporting the raw data in either JSON or CSV format from FlowTracker2 desktop software,

Table 6:2 – SNR Data Types

Mode	Reporting	Type	Description
All	Graphical	Raw Data	One second SNR data is displayed for each beam and color codes based on the beam

Mode	Reporting	Type	Description
			number (see Table 4:4).
		Moving Average	Moving average is calculated of the one second SNR data and is graphically displayed with the raw SNR data.
	Real Time	Raw Data	Instantaneous one second raw SNR data is displayed with the graphical display.
Discharge	Review Point Measurement	Mean Point Measurement SNR	The point measurement SNR is the mean of beam 1 and 2 at the point measurement. Receiver 3 (if installed) is not used in the mean calculation because we assume the probe is side-looking (either a 2D or 2D/3D probe), and only Vx and Vy are of interest. Receiver 3, which is only used for Vz, is irrelevant.
	Review Station	Mean Station SNR	The station SNR is the mean of all point measurements at a station.
	Discharge Summary	Mean Section SNR	The discharge summary SNR is the mean of all the station mean SNR within the section
General	Review Point Measurement	Mean Beam SNR at Point Measurement	The point measurement SNR is the mean of one second SNR data for each individual beam (2 or 3 depending on probe type) at the point measurement.
	Review Station	Mean Beam SNR at Station	The station SNR is the mean for each individual beam (2 or 3 depending on probe type) of all point measurements at a station.
	General Summary	Mean SNR	The general summary SNR is the mean of all individual beam SNRs at all point measurements.

SNR Data Evaluate

f) SNR is the most important quality control data provided by the FlowTracker2. SNR is evaluated against number of quality control criteria and at the end of each velocity point measurement, the following SNR checks are run in General mode and Discharge mode.

i). SNR from all beams must be greater than 4 dB for reliable data collection.

ii). **Low SNR**. If the SNR of any beam is below 4.0 dB, *"Low SNR"* alert will be given at the end of point and section measurement.

- For 2D systems, if the SNR of either beam is low, this will affect all velocity data even if the other beam shows higher SNR values.
- For 2D/3D systems, if only the SNR of Beam 3 is low, vertical velocity data (Vz) are affected; the horizontal velocity data (Vx and Vy) may still be valid. This can occur if Beam 3 is out of the water in very shallow water.

iii). **Approach Low SNR**. If the SNR is between 4 and 7 dB, *"Approach Low SNR"* alert will be given at the end of point and section measurement.

iv). **Beam SNRs Not Similar**. When the difference between any two beams is greater than SNR Threshold,

- This may indicate interference from an underwater obstacle or a potential problem with the probe,
- At the first alert, repeat the measurement (perhaps after moving probe location),
- If the problem persists, run Beam Check to evaluate FlowTracker2 operation in more detail.

v). **Large SNR Variation**. When the standard deviation of the SNR of each beam during the measurement is greater than a fixed threshold of 5 dB,

- This may indicate interference from an underwater obstacle, a highly turbulent environment, or highly aerated water,
- At the first alert, repeat the measurement (perhaps after moving probe location),
- If the problem persists, evaluate the measurement environment. In some cases, large variations may be unavoidable and may not impact the quality of velocity data.

vi). **SNR Threshold Variation**. When SNR for a new measurement differs from the mean of three or more completed stations in this measurement by more than SNR Threshold,

- This may indicate interference from an underwater obstacle or some other dramatic change in stream conditions,
- At the first alert, repeat the measurement (perhaps after moving probe location),
- If the problem persists, evaluate the measurement environment to look for any potential cause for the change in SNR.

vii). **SNR Threshold** is checked with the completion of a point velocity measurement and measurement section (see Timing of Warning Messages)**.**

- User is notified of any stations that exceed the above criteria.
- If desired, user can delete suspect stations and repeat the measurements.

g) The SNR checks are re-run (Discharge mode and General mode measurement) to ensure the warnings are set with the most current data.

h) This criterion can be adjusted or disabled under Quality Control Settings.



SNR is primarily a function of the amount and type of particulate matter in the water. SNR cannot be immediately converted to sediment concentration, it provides an excellent qualitative picture of sediment fluctuations and with proper calibration, SNR can be used to estimate sediment concentration.

6.1.2 Velocity Standard Error

Standard Error of Velocity (**σV**) is a direct measure of the accuracy of the mean velocity data.

a) **σV** can be directly interpreted as the accuracy of the mean velocity.
b) **σV** is calculated by dividing the standard deviation of one-second samples by the square root of the number of samples.
c) **σV** is normally dominated by real variations in the flow and will vary depending on the measurement environment (see Principle of Operations).

σV Data Display

d) The **σV** displayed after a point velocity measurement, station and or stations are completed in both General and Discharge Modes are supplied in Table 6:3.

Table 6:3 – σV Data Types

Mode	Reporting	Type	Description
Discharge	Review Point Measurement	σV Point Measurement	X-component velocity standard error.
	Review Station	Mean Station σV	The station σV is the mean of the X-component velocity standard error from each point velocity measurement.
	Discharge Summary	Mean Section σV	The discharge summary σV is the mean of all stations average X-component velocity standard error.
General	Review Point Measurement	Beam σV at Point Measurement	The point measurement σV for each individual beam (2 or 3 depending on probe type) at the point measurement.
	Review Station	Mean Beam σV at Station	The station σV is the mean for each individual beam (2 or 3 depending on probe type) of all point measurements at a station.
	General Summary	Mean σV	The general summary σV is the mean of all stations average X-component velocity standard error.

σV Data Evaluate

e) **σV** is evaluated against number of quality control criteria and at the end of each velocity point measurement, the following velocity standard error checks are run in General mode and Discharge mode.

i). The standard error threshold for each measurement is the greater of the following,

- **σV Threshold** (default 0.01 m/s / 0.033 ft/s),
- If the mean **σVx** for three or more completed stations measurements is greater than **σV Threshold**, then increment the **σV Threshold** by the mean value (**Mean σVx + σV Threshold**),

- If the **σV Threshold** is larger than 0.250m/s, then set **σV Threshold** equal to 0.250m/s.
- If the mean spike filtered X-component velocity (high velocity has higher **σVx**) is larger than **σV Threshold** then set **σV Threshold** to 5% of X-component velocity.

ii). When σVx is greater than the standard error threshold for that measurement,

- This may indicate interference from an underwater obstacle, a highly turbulent environment, or highly aerated water,
- At the first alert, repeat the measurement (perhaps after moving probe location),
- If the problem persists, evaluate the measurement environment. In some cases, large variations may be unavoidable (e.g., in highly turbulent waters).

iii). **σV Threshold** is checked with the completion of a point velocity measurement and measurement section (see Timing of Warning Messages)**.**

- User is notified of any stations that exceed the above criteria.
- If desired, user can delete suspect stations and repeat the measurements.

f) If the point measurements X-component velocity standard error is 0 or if it exceeds the updated **σV Threshold** then a **Standard Error > QC** warning is given.
g) The velocity standard error checks are re-run (Discharge mode and General mode measurement) to ensure the warnings are set with the most current data.
h) This criterion can be adjusted or disabled under Quality Control Settings.

6.1.3 Boundary Interference

The **Boundary Interference** quality control looks for interference from underwater objects that are in or close to the FlowTracker2 sampling volume. The system tries to avoid this interference, but you must be aware of system limitations.

a) The impact of underwater objects and or boundaries on the measurement is related to the FlowTracker2 principle of operation.

i). Reflections can occur from the bottom, the water surface, or submerged objects (e.g., rocks).
ii). The FlowTracker2 measures velocity in a sampling volume 10 cm (4 in) from the probe tip.
iii). If the sampling volume is on top of or beyond an underwater object, velocity data will be meaningless.

b) When working in very shallow water or near underwater obstacles (with the sampling volume within 15 cm (6 in) of the obstacle), acoustic reflections can potentially affect velocity data.

i). At each measurement location, the FlowTracker2 looks for these conditions, and if necessary, adapts its operation to avoid interference.

ii). For most locations, any required changes do not affect system performance.
iii). In some environments, changes may result in a lower maximum velocity.

Boundary Display

c) The FlowTracker2 records any changes required to avoid acoustic interference. It reports this as **Boundary QC**. This value describes the effect (if any) of boundary adjustments on performance. The **Boundary QC** variable (**Bnd**) can have the following values (0 and 1 are the most common).

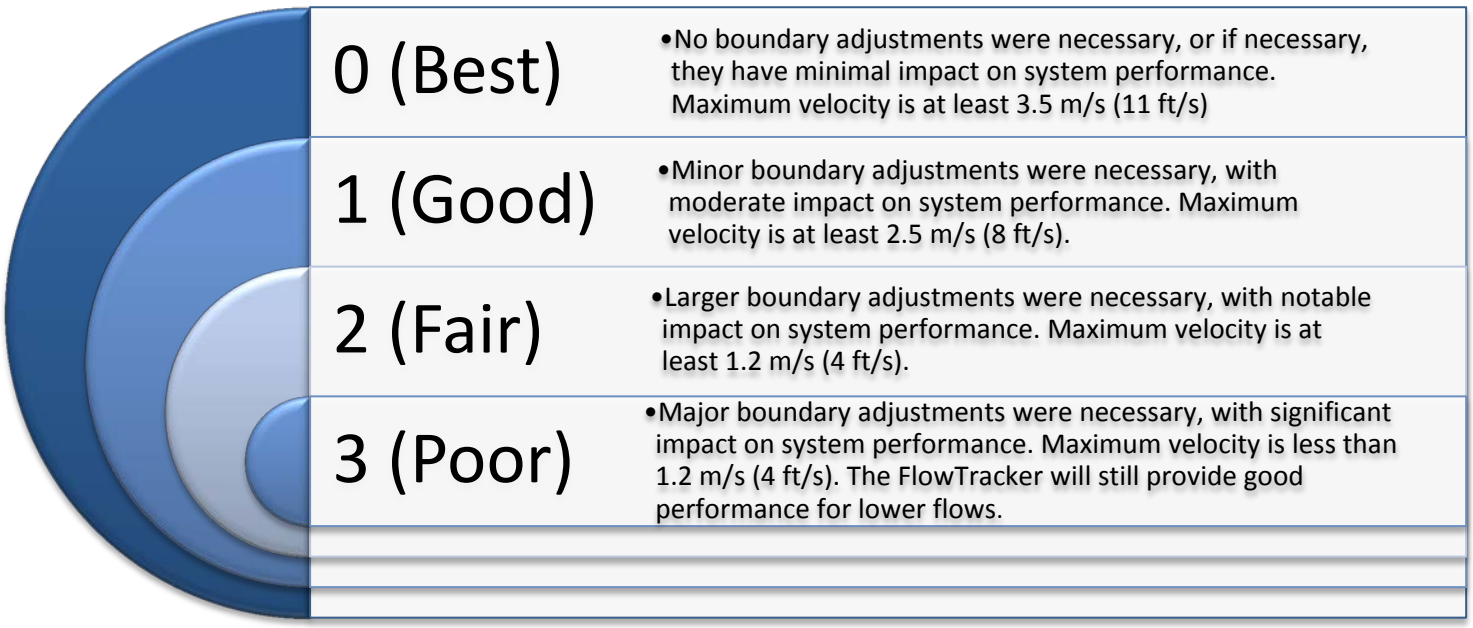


Figure 6:1 - Boundary QC Conditions

Boundary Data Evaluate

d) The **Boundary Interference** check looks for interference with underwater objects that are in or close to the FlowTracker2 sampling volume. The FlowTracker2 automatically adapts its pinging to minimize boundary interference, but it can only adapt so much, and the resulting pings could still be influenced by the boundary. The FlowTracker2 software receives two values from the firmware to use in determining the amount of boundary interference: velocity ambiguity and the best single ping precision, both available in m/s.

i). If the **Boundary QC** results are **FAIR** or **POOR**, this indicates possible interference, and the FlowTracker2 will issue an alert before the measurement is made.

- User is prompted to consider moving the probe to avoid this interference.
- If the probe is moved, repeat the boundary test prior to data collection.
- If repeated Boundary QC tests do not give improved results, user can proceed with the measurement, but should carefully evaluate velocity data.

ii). The **Boundary Interference** is checked before a point velocity measurement is made and if the condition is not “Best”, then the Boundary Interference warning is given (see Timing of Warning Messages).

e) This criterion can be adjusted or disabled under Quality Control Settings.

6.1.4 **Velocity Spike Filter**

The **Velocity Spike Filter** quality control is applied to each point velocity measurements in both General mode and Discharge mode. Spikes in velocity data occur with any acoustic Doppler velocity sensor such as the FlowTracker. Spikes may have a variety of causes – large particles, air bubbles, or acoustic anomalies.

Filter Method

a) The FlowTracker2 spike filter is a variation on a method called "Tukey's Outlier. Just like in Tukey's method, the data are sorted in ascending order, then divided into 4 quartiles.

   i). A histogram of each velocity component is calculated.
   ii). The FlowTracker2 determines the 1st Quartile (**Q1**) velocity value where 25% of the samples are less than this value. The 3rd Quartile (**Q3**) is the velocity value where 75% of the samples are smaller than this value. The Interquartile Range (**IQR**) is defined as the spread between the 1st Quartile and the 3rd Quartile (**IQR = Q3-Q1**).
   iii). If the **IQR** is less than 0.015 m/s, **IQR** is set to 0.015 m/s.
   iv). Any value less than (**Q1–2*IQR**) or greater than (**Q3+2*IQR**) is considered a spike and is not used for mean velocity calculations.

b) Spikes are filtered based on all velocity components (Vx, Vy, and Vz). If any velocity component falls outside the above limits, that sample is not used for the mean velocity, standard deviation or velocity standard error calculation.

c) No other filtering or editing is done to FlowTracker2 velocity data.

Spike Data Display

d) The number of spikes is displayed and recorded at the end of each measurement.

e) Raw, one-second velocity data are recorded with each measurement station. This allows you to evaluate unedited velocity data for each station.

Spike Data Evaluate

f) The **Velocity Spike Filter** is applied to each point velocity measurements in both General mode and Discharge mode, but the filter is not attempted unless there are at least 10 samples in a measurement. The **Spike Threshold** (default 10%) is used as follows to determine the number of velocity spikes present in the data.

   i). If the number of spikes is a greater percentage of the total number of points than specified by the **Spike Threshold**, a warning is given.

   - This may indicate interference from an underwater obstacle, a highly turbulent environment, or highly aerated water.
   - At the first alert, repeat the measurement (perhaps after moving probe location).
   - If the problem persists, evaluate the measurement environment – a large number of spikes may be unavoidable, but may not overly impact the quality of velocity data.

ii). The **Spike Threshold** is checked with the completion of a point velocity measurement and measurement section (see Timing of Warning Messages)**.**

- User is notified of any stations that exceed the above criteria.
- If desired, user can go back and delete suspect stations and repeat the measurements.

g) The **Velocity Spike Filter** is checked at the end of each point velocity measurement and if the number of velocity spikes is larger than allowed by the **Spike Threshold**, then give the **High % Spikes** warning.

h) The velocity spike filter check is re-run (Discharge mode and General mode measurement) to ensure the warnings are set with the most current data.

f) This criterion can be adjusted or disabled under Quality Control Settings.

6.1.5 Velocity Angle

The **Velocity Angle** quality control parameter is applied to each point velocity measurement in **Discharge** mode.

a) For an ideal discharge measurement site, flow should be perpendicular to the tag line used to define the cross section.

b) A good measurement site will typically show some flow variations, but with all angles less than about 20°.

c) The ability of the FlowTracker2 to measure the 2D flow eliminates the need to estimate the flow direction with each measurement, as is required for most 1D current meters. This reduces a potential source for error in velocity measurements.

Velocity Angle Method

d) Velocity angle is defined as the direction of flow relative to the X direction, and is calculated as **atan(Vy/Vx)**.

i). The FlowTracker's X-axis is always held perpendicular to the tag line.

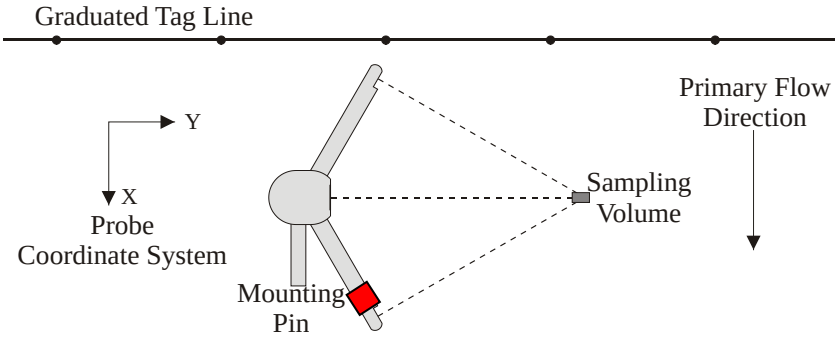


Figure 6:2 – FlowTracker2 Probe Orientation Relative to Stream Flow

ii). An angle of 0° means flow direction is perpendicular to the tag line (as desired for an ideal measurement location).

iii). Only the X component of velocity (Vx) is used for discharge calculations. This ensures proper discharge measurements regardless of the flow direction.

Velocity Angle Evaluate

e) The Velocity Angle measured is evaluated to ensure reliable data collection. The velocity angle for a point measurement is computed from the de-spiked point measurement mean velocity components as angle = atan2(Vy, Vx). The **Max Angle** criterion (default 20º) is used as follows.

i). Velocity angle is checked only if velocity is greater than a fixed threshold (0.02 m/s; 0.07 ft/s).

ii). When measured angle is greater than **Max Angle**, a warning is given.

- Evaluate the measurement site to verify the measured angle is reasonable.
- Consider repeating the measurement if the angle does not appear reasonable (perhaps after moving probe location).
- For large velocity angles, consider moving the measurement site.

iii). The **Max Angle** is checked with the completion of a point velocity measurement and measurement section (see Timing of Warning Messages)**.**

- User is notified of any stations that exceed the above criteria.
- If desired, user can go back and delete suspect stations and repeat the measurements.

f) The Velocity Angle is checked at the end of each point velocity measurement and if the measurement's mean velocity X component is at least 0.02 m/s and if the velocity angle is larger than **Max Velocity Angle**, then give the **Velocity Angle > QC** warning.

g) The velocity angle check is re-run (Discharge mode and General mode measurement) to ensure the warnings are set with the most current data.

h) **Max Angle** is active only in **Discharge** data collection mode.

i) This criterion can be adjusted or disabled under Quality Control Settings.

6.1.6 Tilt Angle

The **Tilt Angle** quality control is applied to each point velocity measurements in both General mode and Discharge mode

a) A good measurement will typically show variations in wading rod angle, but with all angles less than about 5°.

Tilt Method

b) Tilt angle is defined as the angle of the wading rod relative to the vertical.

i). The tilt angle of 0° means that the wading rod is vertical.

ii). The tilt angle is only an indicator and not used in any calculations

Tilt Evaluate

c) If the wading rod angle exceeds **Max Wading Rod Angle**, a warning is issued; you are prompted to realign the wading rod.

i). When measured angle is greater than **Max Angle**, a warning is given.

- Evaluate the measurement to verify the measured angle is reasonable.

- Consider repeating the measurement if the angle does not appear reasonable (perhaps after moving probe location).

ii). The **Max Wading Rod Angle** is checked with the completion of a point velocity measurement and measurement section (see Timing of Warning Messages)**.**

- User is notified of any point velocity measurement that exceeds the above criteria.
- If desired, user can go back and delete suspect point velocity measurement and repeat the measurements.

d) The tilt angle is checked at the end of every point velocity measurement and if the wading rod angle > **Max Wading Rod Angle**, then give the **Velocity Angle > QC** warning.
e) The tilt angle is checked at the end of a section and reports the stations where the tilt angle exceeds **Max Wading Rod Angle**.
f) This criterion can be adjusted or disabled under Discharge Settings.

6.1.7 Station Percent Discharge

Most agencies that perform discharge measurements expect that no individual station should contain more than a certain percentage of the total discharge. The **Max Station Q** criterion (default 10%) alerts you if this standard is exceeded.

% Stn Q Method

a) The user can set the discharge reference to either “rated” or “measured”. The reference is used when computing the discharge percent to display. When the discharge percent is calculated,

i). The rated discharge is used only at the end of each station,
ii). The measured discharge is used only at the end of a section.

% Stn Q Evaluate

b) If the station discharge exceeds **Max Station Q** percent of the rated flow, a warning is issued; you are prompted to consider adding another station.

i). If rated flow is entered, the discharge from each station is checked against this rated value when the station is completed.

ii). **Max Station Discharge** is checked at the end of each station and measurement section (see Timing of Warning Messages).

- User is notified of any stations that exceed the Max Depth Change criterion.
- User is prompted to verify the depth value or re-enter the depth.

c) The maximum station discharge is checked at the end of a station and if the ratio of station discharge to rated discharge > **Max Station Discharge**, then give the **High Stn % Discharge** warning.
d) The maximum station discharge is checked at the end of a section and reports the stations where the percent of station discharge to total discharge exceeds **Max Station Discharge**.
e) **Max Station Discharge** is active only in **Discharge** data collection mode.
f) This criterion can be adjusted or disabled under Discharge Settings.

6.1.8 Station Water Depth

The **Max Depth Change** criterion (default 50%) is intended to avoid data entry errors.

a) It is assumed that depth changes between stations will be gradual.

Max Depth Evaluate

b) If the entered depth is different from a reference by more than Max Depth Change (and at least 0.20 m; 0.66 ft) an alert is issued to be sure the depth was not incorrectly entered.
   i). If only the previous station is available, the newly entered depth is compared to the depth from the previous station.
   ii). If depth data are available on both sides of this station, the newly entered depth is compared to an interpolated depth between the two adjacent stations.
   iii). **Max Depth Change** is checked during station configuration and at the end of a measurement section (see Timing of Warning Messages).
      - User is notified of any stations that exceed the Max Depth Change criterion.
      - User is prompted to verify the depth value or re-enter the depth.

c) Water depth is checked of each station and if the water depth varies from the reference depth by a percentage larger than **Max Depth Change**, then give the **Water Depth Change > QC** warning.

d) The station water depth check is re-run (only for Discharge mode) to ensure the warnings are set with the most current data.

e) **Max Depth Change** is active only in **Discharge** data collection mode.

f) This criterion can be adjusted or disabled under Discharge Settings.

6.1.9 Station Location

The **Max Spacing Change** criterion (default 100%) is intended to avoid data entry errors.

a) It is assumed that the spacing of adjacent stations will be nearly constant across the river.

Max Station Evaluate

b) If spacing between stations has changed by more than **Max Spacing Change**, an alert is issued to be sure the location was not incorrectly entered. A 100% **Max Spacing Change** means the new station spacing is more than two times the previous station spacing.

   i). Determine if the station location trend is expected to be increasing or decreasing by comparing the location of the first two stations. All stations are expected to match this trend.

   ii). Any time a station location is changed, the location is compared to adjacent value(s) to see if the station is out of order.
      - If the trend in location from the previous station to this station does not match the expected trend, then give the **Station Order** warning.
      - If the trend in location from this station to the next station does not match the expected trend, then give the **Station Order** warning.

- Collecting an out-of-order station is allowed. However, when an out-of-order station is entered we verify the location value since the station is sorted into the correct place within the stream.

iii). Any time a station location is changed, the location is compared to the starting edge location. If the new location is outside the starting edge, a **Location Outside Edge** warning is given.

iv). **Max Station Change** is checked during station configuration (see Timing of Warning Messages).

- User is notified of any stations that exceed the Max Station Change criterion.
- User is prompted to verify the location value or re-enter the location.

c) The expected station spacing is computed from the previous two station locations. If the station spacing from the previous station to this location is more than **Max Spacing Change** percent of the expected station spacing, then give the **Stn Spacing > QC** warning. A warning will be triggered only if the station spacing is too big (there is no warning that it is too small).
d) The station location check is re-run (only for Discharge mode) to ensure the warnings are set with the most current data.
e) **Max Spacing Change** is active only in **Discharge** data collection mode.
f) This criterion can be adjusted or disabled under Discharge Settings.

6.1.10 Velocity Profile 0.2 \ 0.8

The **Velocity Profile 0.2 \ 0.8** criterion is intended to identify unusual velocity distribution within the measurement profile. .

a) For an ideal discharge measurement site, the velocity distribution in the measurement profile should follow 1/6 power-law.

Velocity Profile Evaluate

b) The velocity measurements performed at 0.2 time depth and 0.8 time depth are evaluated against expected velocity profile. If any of the following conditions are true, this indicates an unusual velocity profile, and the user is given the option to add a third velocity measurement at 0.6 time depth.

i). The magnitude of the near-surface velocity (0.2 times depth) is less than the magnitude of the near-bottom velocity (0.8 times depth).

ii). The magnitude of the near-surface velocity (0.2 times depth) is more than two times the magnitude of the near-bottom velocity (0.8 times depth).

iii). The near-surface velocity (0.2 times depth) and near-bottom velocity (0.8 times depth) show flow in the opposite direction.

6.2. Quality Control Warning Messages

6.2.1 Types of Warning Messages

Quality Control Warning Message is supplied when measured variable exceeds the expected criteria of each parameter in Quality Control Parameters. The quality control

warning messages implemented in the Quality Control process are supplied in Table 6:4. The table layout describing the quality control warning messages consist of the following key components,

a) **Warning**, the warning supplied when the parameter is exceeded,
b) **Reporting**, aspect of the measurement process relate to the quality control warning message,
c) **QC Criteria**, quality control criteria based on SonTek default values or user specified.

Table 6:4 - Quality Control Warning Messages

Warning	Reporting	QC Criteria	Description	Suggested Action
Low SNR	Point Velocity	Low SNR	SNR below 4 dB	• Improve SNR
Approach Low SNR	Point Velocity	Approach Low SNR	SNR between 4db and 7 dB	• Improve SNR
Beam SNRs Not Similar	Point Velocity	SNR Threshold	Difference in SNR for any 2 beams is > **SNR Threshold**.	• Look for underwater obstacles; repeat measurement. • Check probe operation
Large SNR Variation	Point Velocity	SNR Variation	One-second SNR data varies more than expected during a measurement. May indicate underwater interference or a highly aerated environment.	• Look for underwater obstacles; repeat measurement. • Look for environmental sources (e.g., aerated water).
SNR Threshold Variation	Point Velocity	SNR Threshold	SNR more than **SNR Threshold** different from previous measurements; major change in measurement conditions.	• Look for underwater obstacles or other changes in river condition. • Repeat measurement
Standard Error > QC	Point Velocity	σV Threshold	**σV** > **σV Threshold**; adjusted based on previous data and measured velocity. May indicate interference or a highly turbulent environment.	• Look for underwater obstacles or a change in conditions. • Consider real turbulence levels in river. • Repeat measurement.
Boundary Interference	Point Velocity	Boundary Interference	**Boundary QC** is **FAIR** or **POOR**. Indicates possible interference from underwater obstacles.	• Consider re-locating probe and repeating test. • Measurement can proceed if results are consistent.
High % Spikes	Point Velocity	Spike Threshold	**Spikes** > **Spike Threshold** percent of samples. May indicate poor measurement conditions.	• Look for underwater obstacles or unusual conditions (e.g., aerated water). • Repeat measurement.
Velocity Angle > QC	Point Velocity	Max Velocity Angle	**Angle** > **Max Velocity Angle**. May only indicate non-ideal measurement environment.	• Consider if measured angle is realistic. • Repeat measurement if needed.

Warning	Reporting	QC Criteria	Description	Suggested Action
Rod Angle > QC	Point Velocity	Max Wading Rod Angle	**Angle** > **Max Wading Rod Angle**. May indicate non-ideal measurement method.	• Consider if measured angle is realistic. • Repeat measurement if needed.
High Stn % Discharge	Station	Max Station Discharge	**%Q** > **Max Station Discharge**. Station contains a large portion of the total discharge.	• Consider adding more stations.
Water Depth > QC	Station	Max Depth Change	Station depth differs from adjacent stations by more than **Max Depth Change** %. This may indicate data entry problem.	• Verify station depth value. • Re-enter if needed.
Stn Spacing > QC	Station	Max Spacing Change	Spacing between stations has changed by more than **Max Spacing Change** %. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.
Station Order	Station	None	Station location out of sequence or outside river edge. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.
Location Outside Edge	Station	None	Station location out of sequence or outside river edge. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.
Fractional Depth > 1	Point Velocity	None	**Fractional Depth < 1.** Verify ratio between measurement depth and total depth and this should not >1	• Verify fractional depth value. • Re-enter if needed.

6.2.2 Timing of Warning Messages

The quality control warning messages are supplied at certain stages of the measurement process for both the Discharge and General Modes. The timing of the quality control warning messages are supplied in Table 6:5. *"D" indicates Discharge mode and "G" indicates General mode.*

Table 6:5 - Timing of Quality Control Warning Messages

Warning Messages	Station Setup	Pre Measurement	Post Measurement	Post Station	Post Section
Low SNR			**D,G**		**D,G**
Approach Low SNR			**D,G**		**D,G**
Beam SNRs Not Similar			**D,G**		**D,G**
Large SNR Variation			**D,G**		**D,G**
SNR Threshold Variation			**D,G**		**D,G**
Standard Error > QC			**D,G**		**D,G**
Boundary Interference		**D,G**			
High % Spikes			**D,G**		**D,G**
Velocity Angle > QC			**D**		**D**
Rod Angle > QC			**D,G**		**D,G**

Warning Messages	Station Setup	Pre Measurement	Post Measurement	Post Station	Post Section
High Stn % Discharge				**D**	**D**
Water Depth > QC	**D**				**D**
Stn Spacing > QC	**D**				
Station Order	**D**				
Location Outside Edge	**D**				
Fractional Depth > 1		**D,G**			**D,G**

6.3. Beam Check

Beam Check operates by sending a pulse of sound into the water, and then plots the signal to noise ratio of the return signal versus range for each of the FlowTracker2 receivers. This information can be evaluated to determine the effective measurement range, to look for interference from boundaries/structures, to survey a deployment site, or to observe the quality of the returned signal.

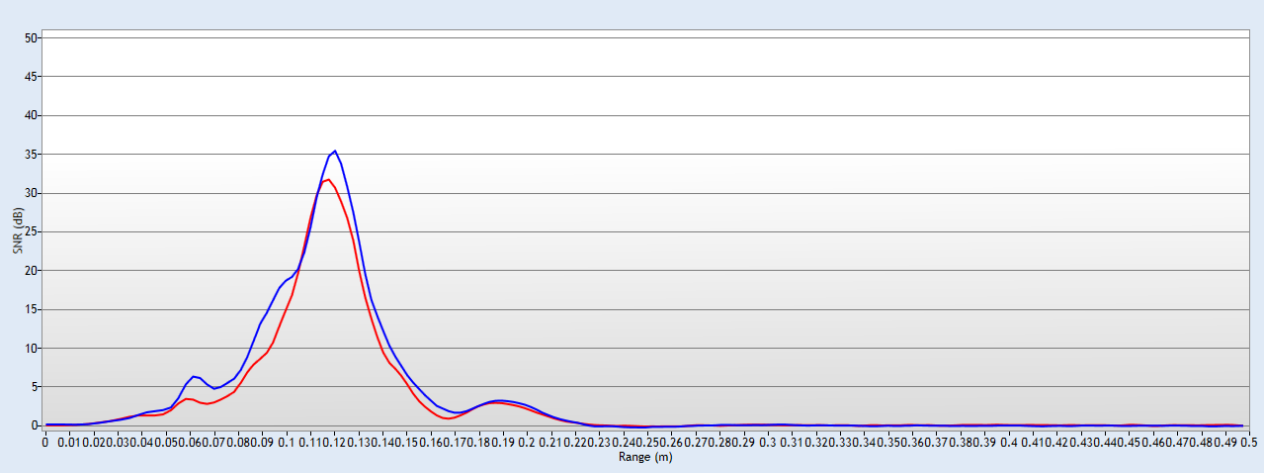


Figure 6:3 - Beam Check

6.3.1 Beam Check Overview

The FlowTracker2 transmits a pulse of sound, it then receives the return signal to noise ratio for each of the 2 (or 3) receivers as a function of time following the transmit pulse. Features in the signal to noise ratio profile verify different aspects of system performance,

a) The horizontal axis indicates the range from the FlowTracker2 probe (in m).
b) The vertical axis is in signal to noise ratio units called SNR (in dB).
c) Ringing from the transmit pulse appears on the left side of the graph.
d) The location of the sampling volume is indicated by increased signal to noise ratio in a bell-shaped curve,

   i). The sampling volume curve corresponds to the transmit pulse passing through the focal point of the receivers,
   ii). The peak of this curve corresponds to the center of the sampling volume,

iii). The location of the sampling volume varies from probe to probe, but is typically 10-12 cm,
iv). All receivers (2 or 3) should see the peak in the same location, although there will be variation in the height and shape of the curve.

e) A sharp spike indicates a boundary reflection (if a boundary is within range),

i). If the probe is close to a boundary, a sharp reflection should be seen,
ii). The size and shape of this reflection will vary depending on the nature of the boundary, its distance from the FlowTracker2 and the acoustic conditions of the water,
iii). We can estimate the distance from the probe to the boundary by the location of the boundary reflection.

f) After the boundary reflection, the signal to noise ratio flattens out in the region where there is no reflected signal from the water,

i). Signal to noise ratio decreases to the electronic noise level past the boundary and is typically about 30-70 counts,
ii). An easy way to measure the instrument noise level is to run Beam Check when the probe is not in the water. In this case, the entire plot should show a constant return at the instrument's noise level.

g) When using Beam Check, it is important to understand that the output plot will vary considerably because of the nature of acoustic scattering,

i). The shape and height of the return signal, particularly the bell curve for the sampling volume, will show considerable variation between updates,
ii). Each of the items described above should be visible (Figure 6:1),
iii). If no sampling volume peak can be seen, try adding some fine dirt or other Seeding material and stirring the water to increase the signal to noise ratio.
iv). If the Beam Check output differs significantly from the sample shown here, refer to Diagnosing Measurements with Beam Check for more details about interpreting this data.

6.3.2 Beam Check Features

- **Sample -** Indicates the number of the transmitted pulse that is currently being displayed on the graph and in the tabular data boxes. If real-time or previously recorded (archived) data is being displayed, only the current sample number is displayed.
- **Sample Averaged -** When **Averaging** has been selected, this box indicates the number of samples that have been averaged together for the currently displayed graph and tabular data.
- **Noise Level -** Shows the electronics noise level for the receiver of each beam. This value is determined by the signal to noise ratio when the instrument is not receiving any return reflections from the water. This value should match the signal to noise ratio for the flat portion of the graph. The noise level is displayed in SNR.

- **Peak Position -** This is the location of the center of the peak for the sampling volume for each of the receivers. The position of the peak should be about the same for each receiver.
- **Peak Level -** This is the height of the peak for the sampling volume for each of the receivers. This will vary depending on the amount of scattering material in the water.
- **Graph Range** (X-axis) - The graph itself shows a plot of the signal to noise ratio for each beam as a function of range following the transmit pulse. The range portion is shown along the graph's X-axis and the value can be shown in centimeters, meters, etc.
- **Graph SNR** (Y-axis) - The graph itself shows a plot of the signal to noise ratio (SNR) for each beam as a function of range following the transmit pulse. The SNR portion is shown along the graph's Y-axis and the value is shown in SNR.

6.3.3 Beam Check Operation

Beam Check can be performed in either a small tank, bucket of water or measurement section in canal or river such that the probe is submerged and there is a boundary (surface, side, or bottom) within view.

a) Hold the FlowTracker2 that the boundary is located approximately 20-30 cm (8-12 in) from the probe.
b) User may need to add a small amount of fine dirt or other seeding material and stir the bucket well for good test conditions. Regular tap water usually does not have enough scatterers (seeding) for a valid test.

*c) To **perform** a Beam Check,*
i). Use the down scroll arrow keys to select Utilities on the main menu,
ii). Use the down scroll arrow keys to select Beam Check on the Utilities menu.

*d) To **record or stop recoding** of Beam Check,*
ii). Press the Right Soft Key,

*e) To **navigate** to Utilities menu,*
ii). Press the Left Soft Key.

6.3.4 Diagnosing Measurements with Beam Check

Beam Check function can be used to detect measurement conditions and or hardware related issues that can affect the measurement accuracy and precision.

6.3.4.1 Low Scattering Strength

Lack of scattering material in the water normally encountered during measurements at springs or under ice will result in a small or non-existing sampling volume peak (see Figure 6:4). In cases where there is not sufficient backscatter, place a small amount of seeding material in the water to act as scattering material (see Seeding).

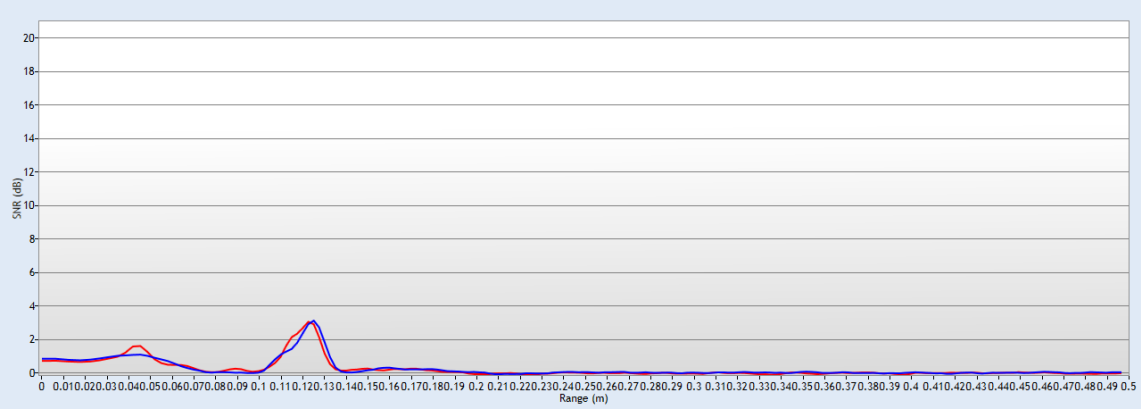


Figure 6:4 - Low Scattering Strength

6.3.4.2 Strong Scattering Strength

Most river systems and or irrigation canals have sufficient scattering material in the water and will result in a well-defined sampling volume peak (see Figure 6:5).

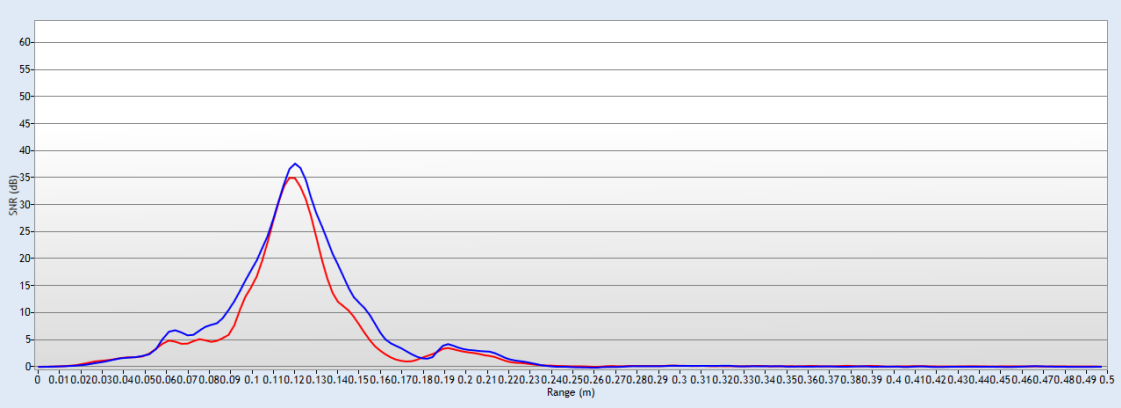


Figure 6:5 - Strong Scattering Strength

6.3.4.3 Boundary Detected within Beam Check

When a boundary is within 50cm from the FlowTracker2 transducer, the boundary will be detected by FlowTracker2 when performing a Beam Check (see Figure 6:6). The boundary was detected about 40cm away from the transducer

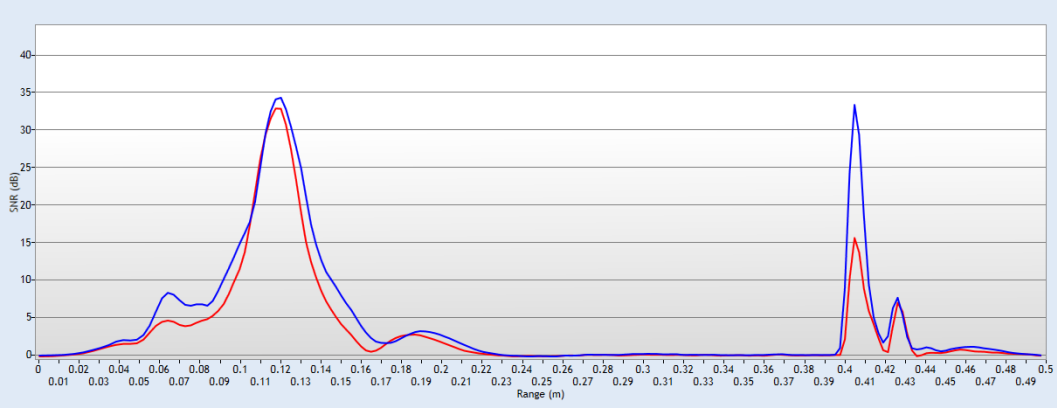


Figure 6:6 - Boundary Detected - 40cm

The Beam Check supplied in Figure 6:7 indicates that boundary was detected at 30cm away from the transducer.

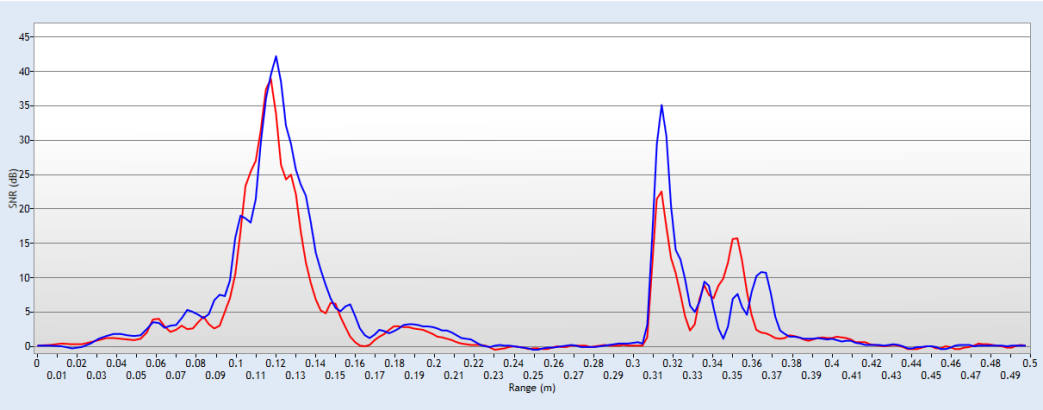


Figure 6:7 - Boundary Detected - 30cm

The Beam Check supplied in Figure 6:8 indicates that boundary was detected at 30cm away from the transducer.

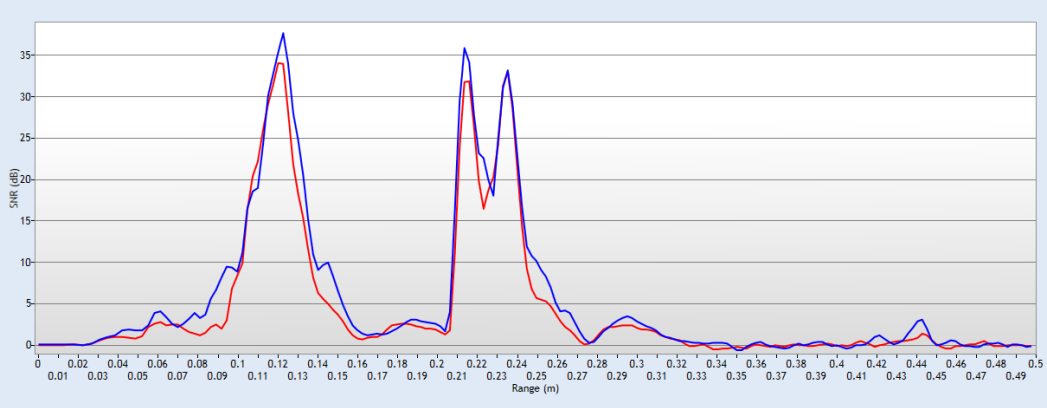


Figure 6:8 - Boundary Detected - 20cm

Boundary that is located within 27cm from the FlowTracker2 transducer can affect the accuracy and precision of velocity measurement. It is recommended when working close to boundaries to determine the location of the boundary in relation to the transducer and sampling volume. This can be achieved by performing a manual Beam Check or Automated Beam Check.

6.3.4.4 Boundary in Sampling Volume

Boundary in Sampling Volume occurs when the boundary is located at the same position from the transducer than the sampling volume. There are number of unique features shown in Figure 6:9 that can be used to identify if boundary is located within the sampling volume.

a) The SNR of the peak located at the sampling volume is two to three times higher than previous measurements performed.
b) Three peaks are displayed in the Beam Check, spaced at equal distances.

c) The SNR of each peak reduces as distance increase form the transducer.

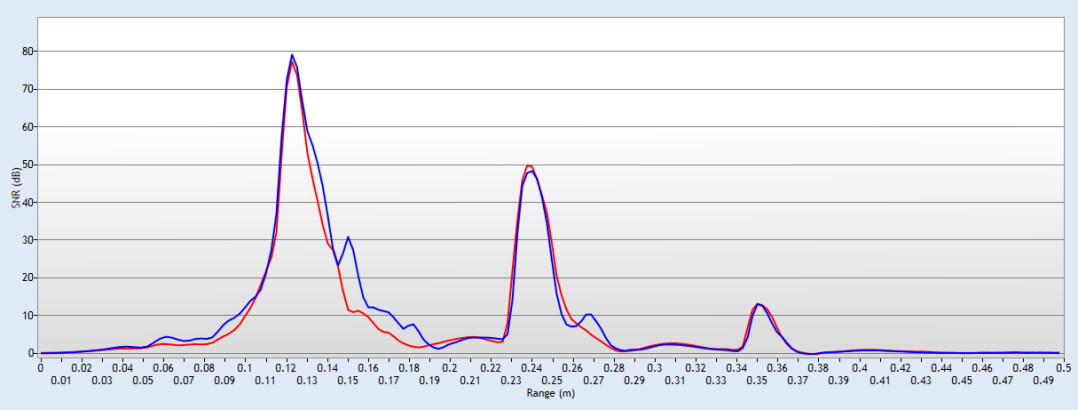


Figure 6:9 - Boundary within Sampling Volume

Section 7. Measurement Process

The **Measurement Process** involved for performing field measurements using a FlowTracker2 instrument consists of number of components. It is important for both the novice and experienced user that each of the components is followed to ensure that the data collected during the measurement process is within acceptable standards and quality. The main components that is the basis of the overall measurement process are the following,

- Office Procedures,
- Measurement Site Information,
- Pre Measurement Diagnostics,
- Measurement Procedure,
- Post Measurement Requirements.



Components within the Measurement Process should not be neglected due to lack of operational experience, time or workload as this will compromise the data quality and accuracy.

7.1. Office Procedures

The **Office Procedures** lists the steps that need to be performed to confirm the condition and operation of the equipment and accessories before departure for field measurements.



The verification of instruments and accessories before leaving the office is normally neglected. It is highly recommended that instrumentation are inspected and tested before each field measurement exercise.

7.1.1 Equipment List

Equipment List is an essential part in the planning and preparation stages of a field measurement exercise. It is recommended that a comprehensive list is designed based on user and or organizational requirements as this will ensure that all equipment is prepared and packed before departing from the office. The equipment required for field measurements are categorized under FlowTracker2 Instrument and user defined measurement gear.

a) The FlowTracker2 Instrument and related accessories is detailed under FlowTracker2 Case section. A reference sheet of the contents is supplied within the FlowTracker2 carry case.
b) The user defined measurement gear is a list of items required in addition to the FlowTracker2 Instrument to perform a field measurement.
c) Recommended measurement equipment list containing FlowTracker2 instrument, measurement gear, safety gear and reference instruments are supplied in Appendix D.

The safety gear listed in Appendix D is only a recommendation. It is imperative that the user follow their respective organization and or local authority guidelines in the use of safety gear during field measurements.

7.1.2 Hardware Inspection

Hardware Inspection can identify any damage to the hardware components that occurred during previous application. It is recommended that the hardware checks listed in Table 7:1 are performed before departure from the office. Any instrument problems experienced as a result of the damage can be resolved by exchanging the hardware components or using a different FlowTracker2 instrument.

The FlowTracker2 probe or handheld can be exchanged with another instrument if required. The software registers the serial number of probe and handheld with each point velocity measurement.

Table 7:1 - Hardware Inspection

Component	Inspection
Handheld	• Inspect the handheld for any external damage to the housing, LCD screen and keypad, • Battery cap and O-ring, • Connectors of battery cartridge, • USB port.
Probe	• Mounting between receiver arms and probe body, • Scratched transducer face, • Dented or bent probe stem.
Probe Cable	• Kinks or dents in probe cable, • Damaged or bent pins on probe cable connector.
Top Setting Rod	• Bent top setting rod, • Bent S bracket or screw.

7.1.3 Office Diagnostic

Office Diagnostic is a basic verification process of the FlowTracker2 to confirm that the instrument is operational before departure from the office. The diagnostic tests consist of the evaluation of a number of functions to verify the internal operations and probe performance of the FlowTracker2.

a) The functions that are evaluated during diagnostic test process are located under the Utilities menu.
b) The diagnostic test process is mainly categorized under Internal Systems, Raw Data and Beam Check functions.

   i). Internal System functions comprise of internal clock, recorder, battery and GPS data. These functions can be verified manually by evaluating the information displayed or using external reference if required.
   ii). Raw data function includes Velocity, SNR, Temperature, Battery and Tilt data that is graphically displayed. These functions can be verified by manually interpreting the information displayed or against a reference instrument.

The velocity data displayed under Raw Data for the Office Diagnostic tests should be ignored as the data is not based on actual measurements conditions.

iii). Beam Check function is performed to verify the FlowTracker2 probe performance. The procedure for performing a Beam Check must be followed as stipulated in Beam Check Operation.

c) *To verify* the GPS Data functions place the FlowTracker2 handheld outside in an open area with a clear view of the sky. The accuracy of the GPS data is directly related to the number of satellites and HDOP value.

d) *To verify* the Raw Data and Beam Check functions place the FlowTracker2 probe in a bucket of water (see Beam Check Operation).

e) The variables that are evaluated during the diagnostic tests are listed in Table 7:2.

Table 7:2 - Office Diagnostics

Function	Variable	Verification
System Clock	• Date • Time • UTM Offset	• System Clock function show the current internal time of the FlowTracker2 instrument, • Verify if the internal system clock date and time is correctly set and adjust if required.
Recorder	• Memory Available	• The Recorder function indicates the percentage of available memory, • If the available memory is insufficient download all measurement files. Ensure that all measurement files downloaded are stored in a secure area, • Format Recorder or delete Data Files to increase available memory.
Battery Data	• Battery Type • Percentage Full	• Battery Data function display the type of battery, voltage and percentage full, • Make sure the correct battery type is selected.
GPS Data	• Latitude • Longitude • Altitude • Date • Time	• The GPS Data function displays the GPS information from the internal GPS, • Compare GPS data supplied with external reference such as Survey Bench Mark, handheld GPS or mobile device equipped with GPS.
Raw Data Display	• Velocity • SNR • Temperature • Tilt • Battery Indicator	• The Raw Data function display raw data for each variable, • Evaluate each variable data that are graphically displayed or compare against a reference instrument in the case of temperature measurements,
Automated Beam Check Beam Check	• Peak Level • Peak Position • Peak Location	• The Automated Beam Check and Beam Check functions serve two purposes, verifying the probe performance and measurement conditions, • Evaluate the Quality Control reports supplied during the test.

7.2. Measurement Site Information

Measurement Site Information or normally referred as *"Metadata"* should be documented before any measurements are performed with the FlowTracker2 instrument. In most organizations FlowTracker2 measurements are related to a measurement site and secondary data sets and it's essential that the information collected is accurate. The measurement site information that should be collected during a field measurement exercise is listed in Table 7:3.



Unique entry fields were developed in the FlowTracker2 software for the measurement site information defined in this section. The dedicated fields ensure that information is captured correctly and assigned to respective variables, which promote good data management practices.

Table 7:3 – Measure Site Information

Variable	Description	Unique Field
Site Number	Site number allocated to measurement site. Most organizations use a unique number system (e.g. associated with catchment).	File Properties
Site Name	Site name allocated for measuring site. Most organizations use a unique naming convention (e.g. combination of river and place name).	File Properties
Operator	Operator that performed the measurement	File Properties
Start Date and Time	Start date and time of measurement.	Internally recorded
End Date and Time	End date and time of measurement.	Internally Recorded
Start Staff Gauge Readings	Staff gauge reading taken before a FlowTracker2 measurement is performed.	Supplemental Data
End Staff Gauge Readings	Staff gauge reading taken after a FlowTracker2 measurement is completed.	Supplemental Data
GPS Position	GPS position of start and end location of measurement	Internally Recorded
Photographs	Photographs of the measurement section, upstream conditions and downstream conditions are essential for identifying possible influences on the field measurements.	None



Organizations that make use of hydrological databases, unique monitoring site identifiers and import routines, would find the Site Number very useful to automatically link the data to a specific monitoring site during the import process.

7.3. Pre Measurement Diagnostics

Pre Measurement Diagnostics is an essential step in the measurement process to ensure accurate and consistent measurement results. The functions evaluated in pre measurement diagnostics are the same as discussed in *Office Diagnostics*.

a) The functions that are evaluated during diagnostic test process are located under the Utilities menu.
b) The functions that are of key importance during the pre-measurement diagnostic tests are System Clock, Velocity Data, SNR Data and Beam Check functions.
c) It is recommended that Pre Measurement Diagnostics should be performed before each measurement is started.
d) *To verify* the Internal System, Raw Data and Beam Check functions place the FlowTracker2 probe in moving water well away from any underwater obstacles in the region of the measurement section.
e) The variables that are evaluated during the diagnostic tests are listed in Table 7:4.

Table 7:4 - Pre Measurement Diagnostics

Function	Verification
System Clock	• Verify if the internal system clock date and time is correctly set and adjust if required. • All data sets recorded during a FlowTracker2 measurement receive a date and time stamp, • Date and Time is essential Metadata in the processing and application of measurement results.
Recorder	• Verify if the available memory is sufficient for performing a measurement, • Insufficient memory on the recorder could affect the measurement operation and or recording of measurement file.
Battery Data	• Evaluate the battery voltage and capacity based on the battery type selected, • Insufficient power supply could affect the measurement operation.
GPS Data	• Evaluate the GPS information received, with the focus on number of satellites, and HDOP values. This will indicate the level of accuracy of the GPS measurement.
Raw Data Display	• The raw data displayed of all variables is updated once per second. • **Velocity,** data should appear reasonable for the environment (short term variations are expected and are most likely real). • **SNR,** data should ideally be above 10 (units are dB), but measurements can be made as low as 3-4 dB. • **Temperature**, data should reasonable to the environment. Temperature data is used for sound speed calculations and can affect velocity data (see Principle of Operations).
Automated Beam Check	• Place the probe in moving water well away from any underwater obstacles; follow the on screen instructions for the test. Perform Beam Check measurement as described in Beam Check Operation. • **Automated Beam Check**, review of Automated Beam Check results see Automated Beam Check, • **Beam Check**, review of Beam Check results see Beam Check.
Beam Check	

7.4. Measurement Procedure

Basic outline of the **Measurement Procedure** required to perform a Discharge measurement with a FlowTracker2 instrument is supplied in the following section. The

measurement procedure is based on wading principles, which is suited for low to medium flow conditions depending on water velocity and depth.

a) Collect and verify Measurement Site Information before discharge measurement commences as stipulated under Measurement Site Information.
b) Select the measurement site based on the criteria stipulated under Site Selection Requirements. Site and flow conditions does change over time and it is recommend that existing measurement site is evaluated during each field measurement exercise.
c) It is recommended for new measurement sites that the user perform spot checks across the section at certain locations to get an estimation of the velocity range, water depth and channel geometry.
d) Perform Pre Measurement Diagnostic tests in the region of the proposed measurement section. Place the probe in moving water well away from any underwater obstacles.
e) A graduated tagline or measuring tape should be spanned across the measurement section to determine the station location. The graduated tagline or measuring tape should be perpendicular to the main flow direction and channel orientation.
f) Staff gauge readings with time should be taken at the start the discharge measurement. If the discharge measurement is over extended period or at a measurement site with rapid changing stage, intermediate readings should be taken.
g) Enter Rated discharge (if applicable) of measurement site to calculate percentage flow of each panel.
h) Divide the measurement section into a minimum of 23 stations (for sections >5m). The number of stations required is dependent on the measurement section width (see ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats for recommendation of number of stations). The flow per panel should not exceed 10% of the total flow, with 5% as the ideal distribution.
i) The water depth at each station is measured using a top setting or universal rod. A staff gauge board can also be used to determine the water depth at the location of the station or sampling volume of the FlowTracker2.
j) The averaging time interval for data collection normally varies between 40 to 60 seconds for velocity measurements depending on flow conditions.
k) Determining Mean Station Velocity method for each station. The software suggests either a six-tenths or two-point method depending on the threshold in 0.6 Method Depth and the measured water depth. The minimum distance between the channel bed and water surface and instrument must be within the instrument specifications.

l) The FlowTracker2 must be perpendicular to the graduated tagline or measuring tape that was setup across the measurement section.

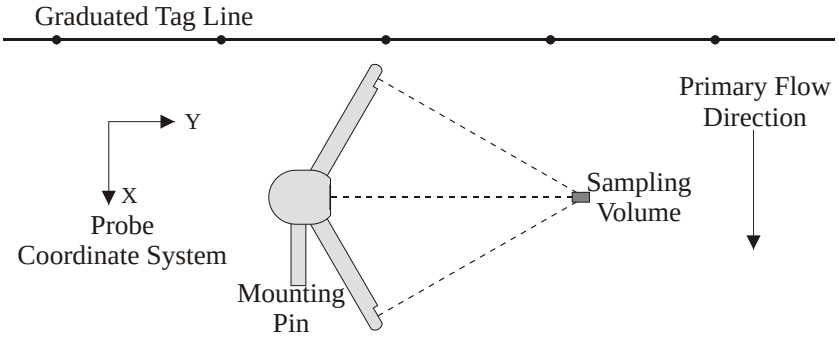


Figure 7:1 - FlowTracker2 Probe Orientation Relative to Stream Flow

m) Keep the FlowTracker2 probe free of plant material at all times as this can impact the velocity measurements significantly.
n) Continuously evaluate the measurement results with measurements performed at previous stations. The variation in measurement results should reflect the flow conditions at the measurement site.
o) Review the instrument configuration during the measurement, especially the quality control parameters and adjust if required.
p) Automated Beam Check can be performed during any stage of the measurement to verify the probe performance and measurement conditions.
q) Comments can be entered at each station or at the end of the discharge measurement to describe the flow conditions or any influences that may impact the measurement quality.
r) Staff gauge reading with time should be taken at the end of the discharge measurement.

7.5. Post Measurement Requirements

Post Measurement Requirements consists of number of tasks that need to be performed when a field measurement is completed. The tasks that forms the framework of the post measurement requirements are grouped under the following main categories,

- Review of Measurement Site Information,
- Review Measurement Summary
- Data Management,
- Storage.

7.5.1 Review of Measurement Site Information

Review of Measurement Site Information before departure from the measurement site is important to ensure that all associated Metadata is accurate. It is recommended that

the user verify each variable populated during the measurement process with the main focus on the measurement site reference.



It is not good data management practice to leave both measurement site references empty or with abbreviate terms. It is recommended that the user makes use of accurate site descriptions.

7.5.2 **Review Measurement Summary**

Review Measurement Summary is the evaluation of the measurement results and if the results are expected from the flow conditions present at the measurement site. There are a number of variables that can be evaluated after the measurement is completed and it is recommended that the following process is followed during the evaluation.



The evaluation of measurement results should be performed during the measurement and the review of measurement summary is just an overview of what was already identified during a measurement. It is recommended to repeat a point velocity or station measurement if any of the data collected during a measurement are not consistent with the flow conditions present.

a) Point velocity measurements with regard to mean velocity, standard error and quality control reports correspond within a station measurement and adjacent stations.
b) Station measurements with regard to location, depth, mean velocity and panel discharge correspond to adjacent stations and what is expected from the flow conditions.
c) The total width based on station locations does that correspond with the actual width of the measurement section.
d) The total discharge, area and mean velocity measured is within the expected flow conditions.
e) Review measurement results against historical measurements performed at the measurement site during similar flow conditions and or staff gauge readings (if available).
f) Review total discharge measured against discharge reading from developed Stage - Discharge Relationship (if available). Most organizations use a 5% error band to determine if the measurement results are within the required measurement standards.



The review process is a key component of overall data quality and it is recommended that this process be completed in the field directly after the measurement. Most organizations supply their hydrographers or hydrologists a copy of hydrological database or other data formats to perform this process in the field.

7.5.3 **Data Management**

Data Management consists of the process involved in managing the information collected during field measurements. The steps required to ensure data continuity and safe keeping after field measurements are completed are the following.

a) Download measurement files after measurements are completed at the measurement site or by the end of the work day using the FlowTracker2 desktop software. The files types created during a measurement are dependent if a measurement and or Beam Check tests were performed. For more information on file types see Table 4:2.
b) Create a secondary backup of the measurement files at the end of each workday by copying the files to an external USB drive. The USB drive should be stored separately from the PC or Tablet.
c) Photographs taken with Camera or Phone during the field measurements should also be downloaded and stored on an external USB drive.



The internal recorder of the FlowTracker2 handheld should not be used as the main storage device for safe keeping of measurement files. It is good data management practice to download the measurement files at least once per day.

7.5.4 **Storage**

Storage guidelines of FlowTracker2 instrument and accessories are essential to ensure the safe keeping of the instrument during transport or storage at the office. The FlowTracker2 instrument is supplied in a pelican case with foam inserts, designed to house each individual component. The recommend guidelines for packing of instrument in the pelican case are the following,

a) Place each component of the FlowTracker2 and accessories in the designated foam inserts.
b) The probe cable must be disconnected form the handheld before it is placed in the foam inserts.
c) The probe cable should be coiled in such a manner that it fits into the designated insert. Care should be taken that the cable is not kinked or the pelican case lid is pressing on the cable.
d) Battery cartridge should be removed from the handheld by the end of each workday. In the case where the FlowTracker2 instrument is not used, it is recommended that the batteries are removed from the pelican case.



Batteries should not be left in the FlowTracker2 handheld for prolonged periods as damage can occur to the handheld if the batteries are leaking. It is recommended that batteries are removed from the handheld if the instrument is not used.

Section 8. Discharge Measurement

Discharge Measurement is the measurement technique involved in collecting data for discharge calculation based on the Discharge Mode (see Data Collection Modes). The data collection framework for discharge measurement is a well-designed workflow (see Software Flow Diagram) between setting up of measurements parameters, creating a measurement section, the collection of raw data and generating individual station and measurement section reports. The discharge data collection process consists of the following main components, with discussions of each component.

- Create Measurement,
- Automated Beam Check,
- Data Collection,
- Discharge Summary.

8.1. Create Measurement

Creating a new measurement consist of number of steps before the data collection can be performed. The first step involved is to either select an existing Configuration Template or create a new template with user defined configuration parameters. The template then needs to be associated with a measurement file that is created by the user. When the measurement file is created, the software is ready for data collection.

8.1.1 Measurement

The **Measurement** function enables the user to create a new measurement in either Discharge or General mode. The Discharge mode used for the collection of discharge data during field measurements will be focused on in this section.

a) The Measurement function can be accessed from the Main Menu on the bottom banner,

*b) To **select** the Measurement function,*
i). Press the Right Soft Key.

c) *The software will Navigate to the New File Type or Mode screen.*

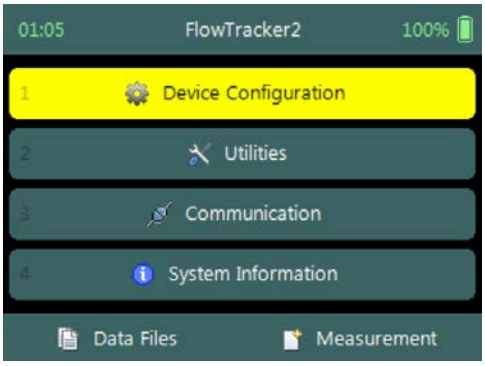


Figure 8:1 - Main Menu

8.1.2 New File Type

The **New File Type** function enables the user to determine if the new measurement file should be based on either Discharge or General mode.

The **New File Type** screen consists of the following options,

a) Discharge,
b) General,
c) *To **select** discharge mode,*
   i). Use up or down scroll arrows keys to select Discharge and press enter key.
d) *The software will Navigate to the New File Template screen.*
e) *To **navigate** to Home menu,*
   i). Press the Left Soft Key.

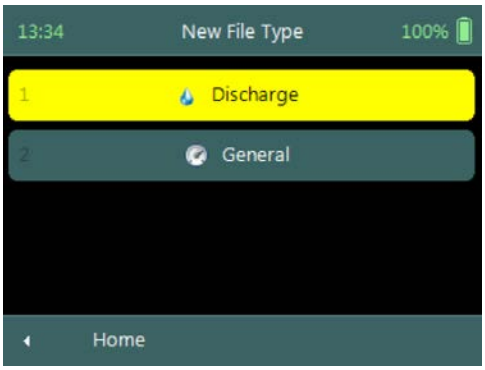


Figure 8:2 - New File Type

8.1.3 New File Template

New File Template function enables the user to create a new configuration template based on SonTek default settings or select an existing Configuration Template created by the user. The configuration template is based on user defined parameters that are dependent on measurement site details, flow conditions and organizational requirements. The configuration template selected will be assigned to the measurement file and the parameters defined in the template will be applied during the Discharge measurement.

The **New File Template** screen consists of the following options,

a) **(default)**, the template will be based on SonTek default settings.
b) Configuration Templates, created under "Device Configuration". A list of available templates created by the user will be displayed under the "(default)" option.
c) *To **select** a template,*
   i). Use up or down scroll arrows keys to select template and press enter key.
d) *The software will navigate to the New Data File screen.*
e) *To **navigate** to File Type menu,*
   i). Press the Left Soft Key.

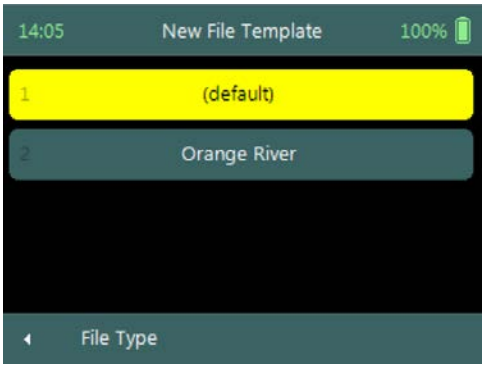


Figure 8:3 - New File Template

8.1.4 New Data File

New Data File function enables the user to populate the measurement site and operator details. The information entered for each parameter should be accurate as this information is recorded in each measurement file and used in both the File Naming and Folder Naming conventions.

- Existing templates created under “Device Configuration”, parameters will be prepopulated from File Properties information that was captured,
- Templates based on SonTek default configuration will have no information populated and the user will need to enter the required details for each parameter.



It is not good data management practice for both measurement site references to be empty or with abbreviate terms. It is recommended that the user makes use of accurate site descriptions.

The **New Data File** screen consists of the following parameters,

a) Site Number,
b) Site Name,
c) Operator,
d) Comment.

*e) To **select** a parameter,*
i). Use up or down scroll arrows keys to select a parameter.

*f) To **accept** the new data file configuration,*
i). Press the Right Soft Key,
ii). The software will navigate to Automated Beam Check screen.

*g) To **CANCEL** new data file configuration,*
i). Press the Left Soft Key,
ii). The software will return to New File Template.

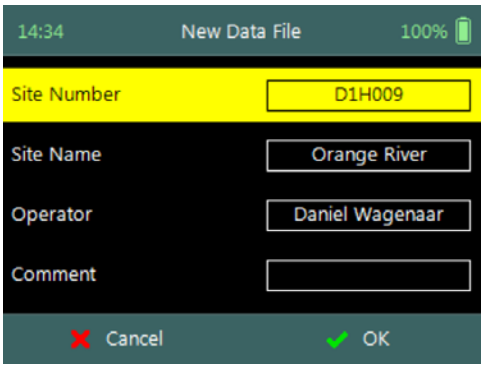


Figure 8:4 - New Data File

8.2. Automated Beam Check

The **Automated Beam Check** function allows the user to perform a Beam Check in the region of the measurement section before data collection starts. The automated beam check perform a number of quality control checks on the data collected to determine if the flow conditions are suitable for discharge measurements. The Automated Beam Check is an automated version of Beam Check function described in Beam Check.



Automated Beam Check can be performed during any stage of the data collection process. The Automated Beam Check functions are available before data collection start and during the discharge measurement from the “Data Collection Menu” (see Data Collection Screen).

8.2.1 Start Automated Beam Check

The FlowTracker2 probe should be placed in the region of the measurement section in moving water such that the probe is submerged and well away from any underwater obstacles. The FlowTracker2 collects data for about 20 seconds.

The **Automated Beam check** screen shows the steps involved in performing an automated beam check.

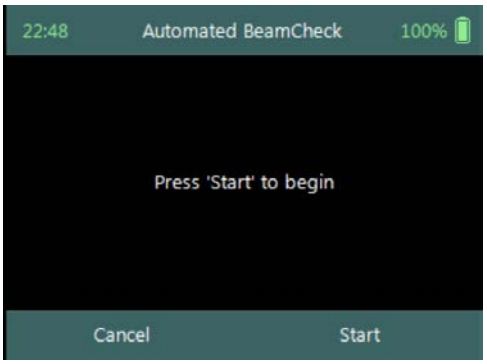


Figure 8:5 - Automated Beam Check

*a) To **start** the automated beam check,*
i). Press the Right Soft Key.

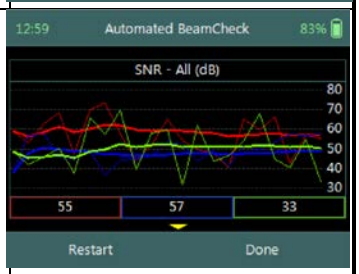
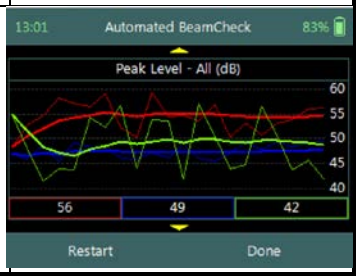
*b) To **CANCEL** automated beam check,*
i). Press the Left Soft Key,
ii). The software will navigate to Data Collection window.

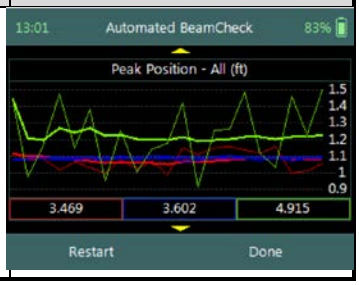
*c) To **accept** Automated Beam Check,*
i). Press the Right Soft Key,
ii). The software will navigate to the Data Collection window.

8.2.2 Evaluate Beam Check Results

The automated beam check quality control criteria used in the evaluation of the beam check data are listed in Table 8:1,

Table 8:1 - Automated Beam Check Quality Control Criteria

Quality Control	Criteria	QC Warning	Graphic Display
Noise Level	• Measured electronics noise level is compared to reference data. Any significant deviation causes a warning, • A large change in noise level may indicate damage to the probe.	Noise Level > QC	
SNR	• The SNR is checked as sufficient for reliable data collection, • Each beam SNR is compared to be sure all beams perform equally, • A warning is issued for low SNR < 4 dB, • A warning is issued for 4 dB > SNR <7dB, • Beam SNR values differ.	SNR	
Peak Level	• The shape of the sampling volume curve is compared to the expected shape. Any significant deviation causes a warning, • This criterion can only be checked with sufficient SNR (> 7 dB).	Peak Level > QC	

Quality Control	Criteria	QC Warning	Graphic Display
Peak Location	• The physical location of the sampling volume is compared to the expected location. Any significant deviation causes a warning. • This criterion can only be checked for sufficient SNR (> 7 dB).	Peak Location > QC	

a) If any warnings are issued, the warnings will be displayed at the bottom of the graphics. The user have the option to repeat the test if warnings are issued.
   i). We recommend repeating the test at least once, after you verify that the probe and sampling volume are well away from any underwater obstacles,
   ii). If multiple warnings are received, run manual Beam Check to evaluate FlowTracker2 performance in more detail.

b) The display options for individual or all beam check data are listed in Table 8:2. The shortcut key on the keypad determines which beam SNR will be displayed,

Table 8:2 - Automated Beam Check Display

Beam	Line Color	Keypad Key
Beam1	Red	1
Beam2	Blue	2
Beam3	Green	3
All Beams	All	4

*c) To **select** a Quality Control Criteria,*
   i). Use up or down scroll arrows keys to view quality control criteria.

8.3. Data Collection

Data Collection function for Discharge mode is the process involved in collecting data during a discharge measurement. The data collection process is a systematic workflow designed to follow the actual measurement process in the field. The process consist of the following main components that also describes each individual aspect of the field measurement,

- Data Collection Window,
- Station Types,
- Station Measurement,
- Data Collection Menu.

8.3.1 Data Collection Window

The **Data Collection Window** can be defined as the "*control center*" of the data collection process during a discharge measurement. All the software functions required to perform a discharge measurement is available from the data collection screen. The key features of the data collection window are explained in Figure 8:6.

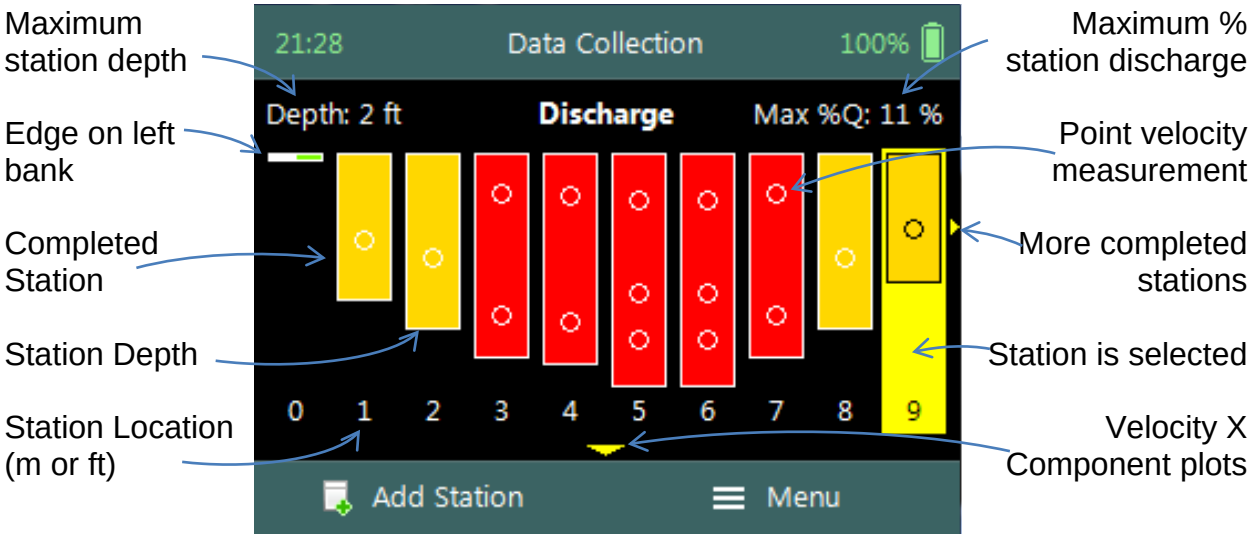


Figure 8:6 - Data Collection Window

The operations and functions available of the Data Collection Window will be discussed throughout this section with the main functions described in Figure 8:7.

Data Collection Window screen of the consists of the following,

a) Station Management area defined in rectangle,
b) Add Station,
c) Data Collection Menu *(Menu).*

*d) To **add** a station,*
i). Press the Left Soft Key.

*e) To **select** the data collection **menu**,*
i). Press the Right Soft Key,
ii). The software will display a popup menu screen.

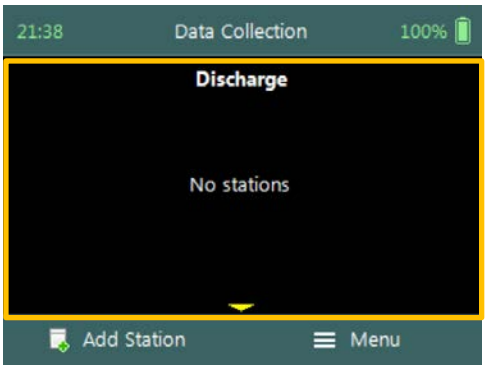


Figure 8:7 - Functions Data Collection Window

8.3.1.1 Add Station

The **Add Station** function allows the user to add a station to the measurement section based on the station types defined for Discharge Measurement technique. The parameters required for creating a station is defined by the station type as discussed under Station Types. There are several common parameters that are applicable to all station types of which are listed below.

Add Station screen consist of the following common parameters that are required for all station types,

a) Location,
b) Depth,
c) Station Type,
d) Correction Factor,
e) Comment.

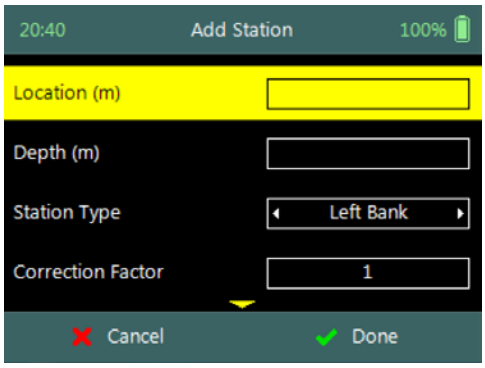


Figure 8:8 - Add Station

The standard **functions** available for each station type are,

f) Add Gauge Height,
g) Record GPS Location (function availability, see GPS Station Tagging).

*h) To **add** a station or start velocity measurement,*
i). Press the Right Soft Key.

*i) To **CANCEL** add station,*
i). Press the Left Soft Key.

8.3.1.2 Delete Station

Deleting a station is performed from the **Data Collection Window** by selecting the station within the viewable window.

The station delete process is not reversible and the user must ensure that the correct station is selected. Selected station will be highlighted with a yellow background.

Delete Station is performed from the **Data Collection Window**. Up to ten completed stations will be displayed at any time,

*a) To **select** a station,*
i). Use the left or right arrow key to scroll through the completed stations,

*b) To **DELETE** a station,*
i). Press the backspace key.
ii). The software will navigate to the Confirmation screen.

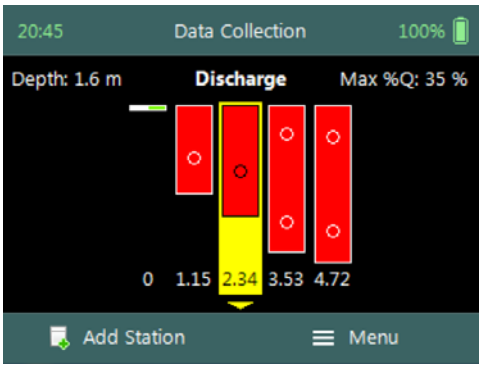


Figure 8:9 - Select Station

Confirmation screen requests confirmation of deleting the selected station by the FlowTracker2 handheld software.

*a) To **confirm** station delete,*
i). Press the Right Soft Key,

*b) To **CANCEL** station delete,*
i). Press the Left Soft Key,

c) *The software will navigate to the Data Collection Window.*

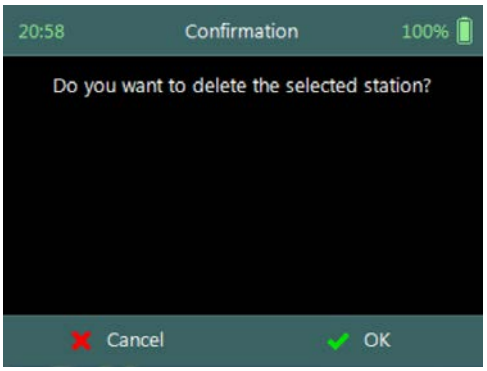


Figure 8:10 - Confirm Delete

8.3.1.3 Edit Station

Editing station parameters is performed from the **Data Collection Window** by selecting the station within the viewable window. The station editing process allows the user to change all the parameters original configured when the station was created from the "Add Station" screen.

Editing should not be performed on the **Velocity Method** after extended time has passed since the initial point velocity measurements were performed. The flow conditions could change during the lapsed time and additional point velocity measurements will not be representative. It's recommended that all the station measurements be repeated if additional measurements are required.

Step 1

Open Station is performed from the **Data Collection Window**. Up to ten completed stations will be displayed at any time,

*a) To **select** a station,*
   i). Use the left or right arrow key to scroll through the completed stations,

*b) To **open** a station,*
   i). Press the enter key.

c) *The software will navigate to the Review Station screen.*

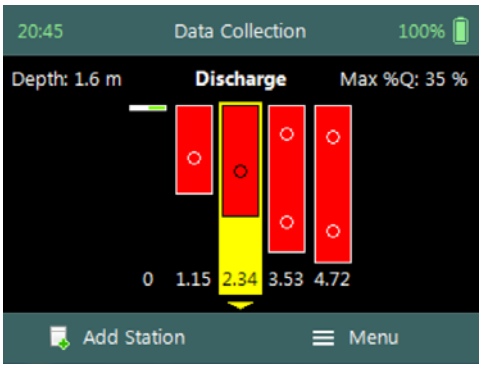


Figure 8:11 - Open Station

Step 2

Review Station screen display summary of the selected station. The review station allows the user to review the measurement results before editing is performed.

*a) To **EDIT** station,*
   i). Press the Left Soft Key.

*b) To **close** review station or **CANCEL** edit station,*
   i). Press the Right Soft Key.

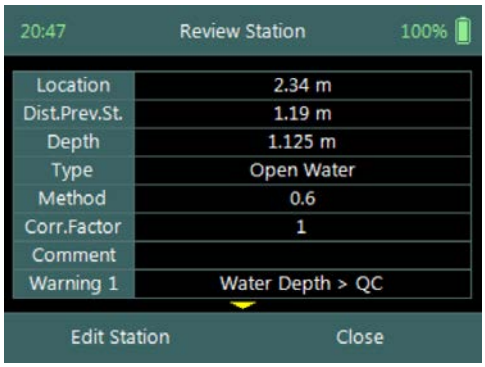


Figure 8:12 - Review Station

Step 3

Edit Station screen allows the user to change parameters during the original configuration. The *"Edit Station"* screen is similar to the *"Add Station"* screen.

*a) To **confirm** edit station,*
   i). Press the Right Soft Key.

*b) To **CANCEL** edit station,*
   i). Press the Left Soft Key.

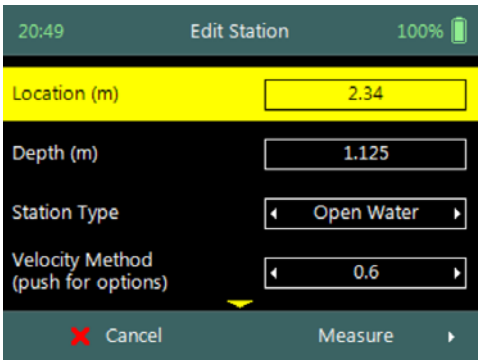


Figure 8:13 - Edit Station

Step 4

Confirmation screen request confirmation of discarding all incompatible point velocity measurements by the FlowTracker2 handheld software.

*a) To **confirm** discarding incompatible point velocity measurements,*

i). Press the Right Soft Key.

b) The software will navigate to the Data Collection Window.

*c) To **CANCEL** incompatible point velocity measurements delete,*

i). Press the Left Soft Key.

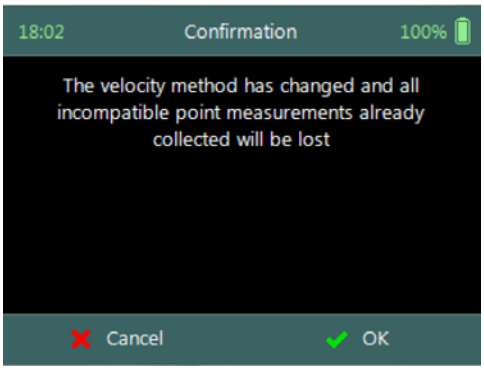


Figure 8:14 - Confirmation Discarding Measurements

When changes are made to the Velocity Method and Station Type, existing point velocity measurements will be lost if the velocity method is incompatible with the proposed selection.

Some scenarios of velocity measurements that could be affected if changes are made to the Velocity Method and or Station Type are listed in Table 8:3.

Table 8:3 - Incompatible Velocity Methods and Station Types

Parameter	Configuration		Compatibility Result
	Initial	Proposed	
Velocity Method	0.6	0.2 / 0.8	0.6 Measurement will be discarded. The 0.2 / 0.8 measurements must be performed.
Velocity Method	0.6	0.2 / 0.6 / 0.8	0.6 Measurement will remain. The 0.2 / 0.8 measurements must be performed.
Velocity Method	0.2 / 0.8	0.6	0.2 / 0.8 Measurements will be discarded. The 0.6 measurement must be performed.
Station Type	Open water	Edge	All velocity measurements will be discarded. Edge station type is assigned a “none” velocity method.

The deleting of incompatible point velocity measurements is not reversible and the user must be certain of the decision in changing the Velocity Method and or Station Type.

8.3.2 Station Types

The **Station Types** developed for the Discharge Measurement technique provides practical solutions for the different measurement scenarios that exists during field measurements. There are several common parameters that are applicable to all station types as well as specific parameters, unique to each station type that will be discussed in

this is section. The station types implemented for the discharge measurement are the following,

- Bank (left or right),
- Island Edge,
- Open Water,
- Ice.

8.3.2.1 Bank (left or right)

The **Bank** station type is used to create a station for both the left and right banks. The one noticeable difference between the Bank station type and other station types is the fact that no velocity measurement is performed. The Discharge Calculation Methods implements a zero velocity on the bank when the depth is zero or against a boundary in the case of vertical bank based on hydraulic principles.

Bank station type parameters available on the **Add Station** screen consists of the following,

a) Location,
b) Depth,
c) Station Type,
d) Correction Factor,
e) Comment.

f) To select a station type,
i). Use the left or right arrow key to scroll through the station types,

*g) To **add** bank station,*
i). Press the Right Soft Key.

*h) To **CANCEL** add bank station,*
i). Press the Left Soft Key.

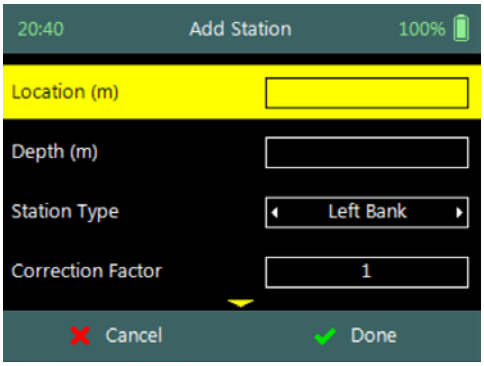


Figure 8:15 - Bank Station Type

Properties associated with the parameters for bank station type are defined in Table 8:4,

Table 8:4 - Bank Station Type - Properties

Parameter	Min	Max	Default	Decimals	Units	Required
Location	-1000	1000	empty	3	m or ft	Yes
Depth	0	100	empty	3	m or ft	Yes
Station Type			Left Bank			Yes
Correction Factor	-1	1	1	2		Yes
Comment	0	250	empty			No

The Left Bank will always be displayed on the left side of the Data Collection Window independent on which bank the measurement was started. If the measurement was

started on the left bank the data collection window will be populated from the left, if the measurement was started on the right bank, the window will be populated from the right.

8.3.2.2 Island Edge

The **Island Edge** station type is used to create a station for Island Edges. Similar to Bank station types, the one noticeable difference between Island Edge station type and other station types is the fact that no velocity measurement is performed. The Discharge Calculation Methods assumes that the velocity on the bank is zero when the depth is zero or against a boundary in the case of vertical bank.

Island Edge station type parameters available on the **Add Station** screen consists of the following,

a) Location,
b) Depth,
c) Station Type,
d) Correction Factor,
e) Comment.

*f) To **select** a station type,*
i). Use the left or right arrow key to scroll through the station types,

*g) To **add** island edge station,*
i). Press the Right Soft Key.

*h) To **CANCEL** add island station,*
i). Press the Left Soft Key.

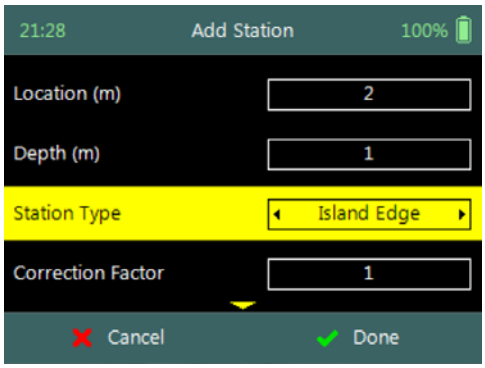


Figure 8:16 - Island Edge Station Type

Properties associated with the parameters for island edge station type are defined in Table 8:5,

Table 8:5 - Island Edge Station Type - Properties

Parameter	Min	Max	Default	Decimals	Units	Required
Location	-1000	1000	empty	3	m or ft	Yes
Depth	0	100	empty	3	m or ft	Yes
Station Type			Island Edge			Yes
Correction Factor	-1	1	1	2		Yes
Comment	0	250	empty			No

The Island Edge station type is normally selected after “Open Water” or “Ice” station types. The station type after the first Island Edge is completed will be set to “Island Edge” by default. The station type after the second Island Edge is completed will be set to “Open Water” by default.

8.3.2.3 Open Water

The **Open Water** station type is used to create a station for open water conditions, performing velocity measurements within a vertical at a station. Open Water is the main station type that will be used during most discharge measurements and the number of stations required is 23 stations for measurement sections wider than 5m.

The number of stations recommended based on measurement section width are available in the following literature,

- ISO 748 – 2007, Hydrometry - Measurement of liquid flow in open channels using current meters or floats,
- WMO-No. 1044, Volume I – Fieldwork, 2010.

Open Water station type parameters available on the **Add Station** screen consists of the following,

a) Location,
b) Depth,
c) Station Type,
d) Velocity Method,
e) Correction Factor,
f) Comment.

*g) To **select** a station type and or velocity method,*
i). Use the left or right arrow key to scroll through the station types and or velocity methods,

*h) To **add** open water station and continue to velocity measurement,*
i). Press the Right Soft Key.

*i) To **CANCEL** add open water station,*
i). Press the Left Soft Key.

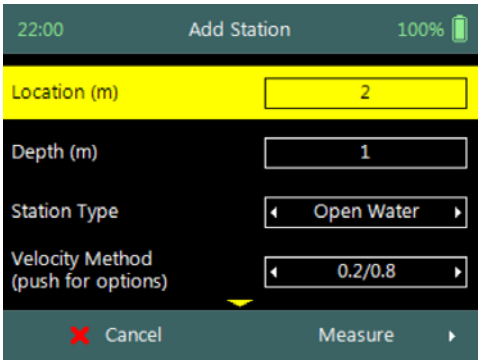


Figure 8:17 - Open Water Station Type

Properties associated with the parameters for open water station type are defined in Table 8:6,

Table 8:6 - Open Water Station Type - Properties

Parameter	Min	Max	Default	Decimals	Units	Required
Location	-1000	1000	empty	3	m or ft	Yes
Depth	0	100	empty	3	m or ft	Yes
Station Type			Open Water			Yes
Velocity Method						Yes
Correction Factor	-1	1	1	2		Yes
Comment	0	250	empty			No

The default velocity method selection is performed on two methods, the Six-Tenths and Two-Point methods. The default method selection is based on water depth with the following criteria,

- Six-Tenths method for water depths below user specified depth,
- Two-Point method for water depths above user specified depth.

The default velocity method is only recommendation and the user can change the method based on their requirements.

8.3.2.4 Ice

The **Ice** station type is used to create a station for under ice conditions, performing velocity measurements within a vertical at a station. Ice station type is used for discharge measurements where an ice layer covers the water surface. The Ice station type has specific parameters for incorporating parameters associated with the ice layer.

Ice station type parameters available on the **Add Station** screen consists of the following,

a) Location,
b) Depth,
c) Station Type,
d) Velocity Method,
e) Ice Thickness,
f) Water Surface to Bottom of Ice,
g) Water Surface to Bottom of Slush
h) Correction Factor,
i) Comment.

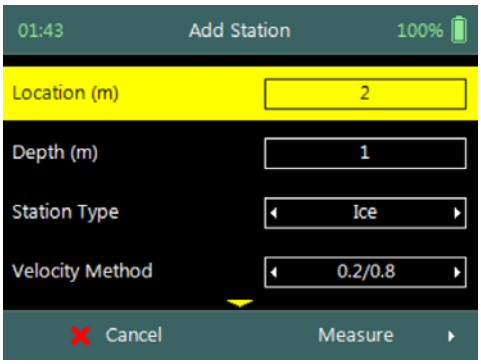


Figure 8:18 - Ice Station Type

*j) To **select** a station type and or velocity method,*
i). Use the left or right arrow key to scroll through the station types and or velocity methods,

*k) To **add** ice station and continue to velocity measurement,*
i). Press the Right Soft Key.

*l) To **CANCEL** add ice station,*
i). Press the Left Soft Key.

Properties associated with the parameters for ice station type are defined in Table 8:7,

Table 8:7 - Ice Station Type - Properties

Parameter	Min	Max	Default	Decimals	Units	Required
Location	-1000	1000	empty	3	m or ft	Yes
Depth	0	100	empty	3	m or ft	Yes
Station Type			Ice			Yes
Velocity Method						Yes
Ice Thickness	0	100	empty	3	m or ft	Yes
Water Surface to	0	100	empty	3	m or ft	Yes

Parameter	Min	Max	Default	Decimals	Units	Required
Bottom of Ice						
Water Surface to Bottom of Slush	0	100	empty	3	m or ft	No
Correction Factor	-1	1	1	2		Yes
Comment	0	250	empty			No

8.3.3 Station Measurement

Station Measurement is performed at each station that was created from the subdivision of the measurements section into number of stations. The station measurements consists of collecting a number of different parameters and variables required for the Discharge Calculation Methods. Each station is unique with respect to the selection of the location, width between adjacent stations, velocity method, averaging interval used for velocity measurements and quality control parameters.

8.3.3.1 Station Parameters

The **Station Parameters** that need to be determined before a decision is made on what velocity method will be used are the station location with respect to the starting point on the tag line or measuring tape and the total water depth.

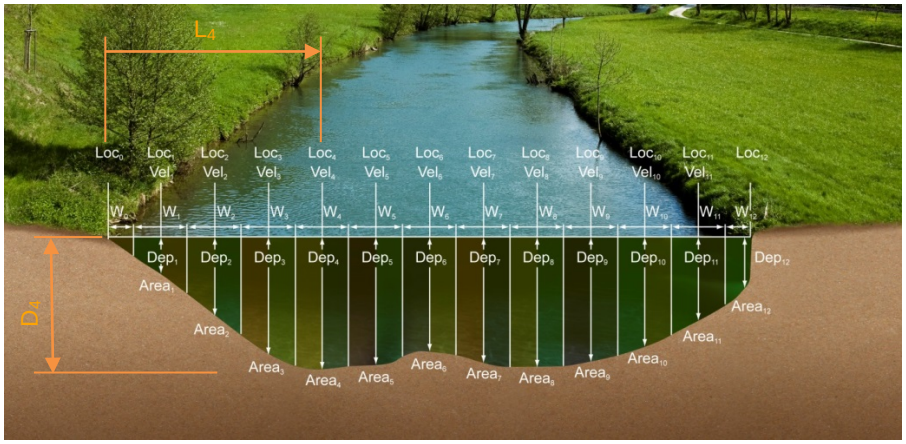


Figure 8:19 - Station Parameters

L_4, is the distance from the start location on the tag line or measuring tape.

D_4, is the water depth measured from the water surface to the channel bed.

The value of the start location on the tagline or measuring tape is not required to be zero (0.000m). The station location can also be entered in negative direction, with the start location at a larger value (e.g. 7.956m) and the end location at a smaller value (e.g. 0.532m). This feature assist when a measurement is performed from the left bank to the right bank and then back using the same tag line setup.

Start location of measurement at 0.532m

0.532 1.23 2.23 3.23 3.23 4.23 5.23 6.23 7.23 7.956

Start location of measurement at 7.956m

8.3.3.2 Point Velocity Measurement

The **Velocity Method** (see Determining Mean Station Velocity) selected for a station is based on the water depth, hydraulic conditions and the flow distribution within the measurement section.

- The number of point velocity measurements required within a vertical is dependent on the type of velocity method selected.
- The point velocity measurements are performed at a defined fractional depth based on the velocity method selected.

Step 1

Station parameters defined for **Velocity Measurement,** e.g., parameters of station 2m defined for velocity measurements are the following,

a) Station location: 2m,
b) Water Depth: 1m,
c) Station Type: "Open Water",
d) Velocity Method: Two Point.

*e) To **add** open water station and continue to velocity measurement,*
i). Press the Right Soft Key.

*f) To **CANCEL** a new station,*
i). Press the Left Soft Key.

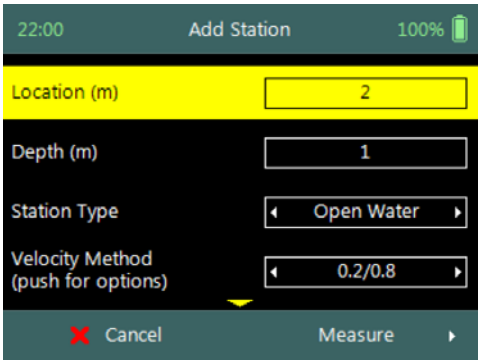


Figure 8:20 - Velocity Measurement

Step 2

Measurement screen display the point velocity measurements required at each fractional depth, e.g., the fractional depths for the two point method at station 2m with a water depth of 1m are the following,

- 0.2 x water depth, 0.2m
- 0.8 x water depth, 0.8m

*a) To **select** a fractional measurement depth,*
i). Use the up or down arrow key to scroll through the measurement options,

*b) To **continue** to velocity measurement,*
i). Press the enter key.

*c) To **open** data collection menu,*
i). Press the Right Soft Key.

*d) To **REVERT** to add station screen,*
i). Press the Left Soft Key.

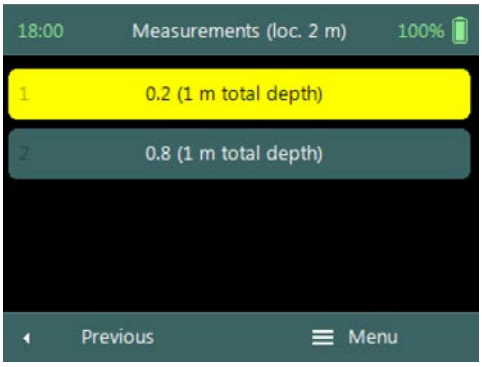
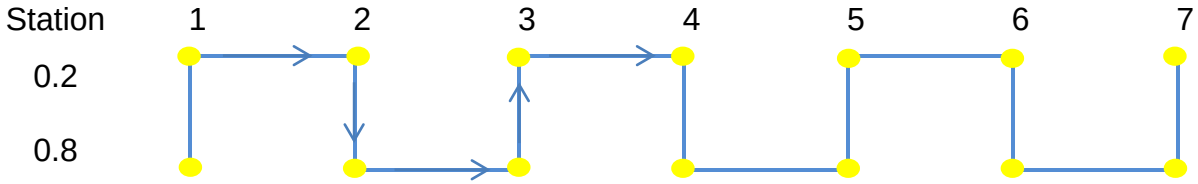


Figure 8:21 - Measurements

The order in how the point velocity measurements are performed at each fractional depth is not set and the user can perform the measurements in any order. The

software highlights the same fractional depth that was measured at the previous station. This method reduces the number of key strokes and unnecessary adjustments on the wading rod.



Selecting the same fractional depth that was measured at the previous station improves the overall efficiency of the measurement. The example that is shown above shows a measurement where two-point method is performed at each station, keeping the order of measurements synced between stations improves the workflow.

Step 3

Setting Fractional Depth screen allow the setting and placement of the wading rod before velocity measurement is started,

a) Wading rod setting,
b) Beam Check,
c) Boundary QC,
d) Tilt,
e) Velocity angle.

*f) To **start** a velocity measurement,*
i). Press the Right Soft Key.

*g) To **REVERT** to measurement screen,*
i). Press the Left Soft Key.

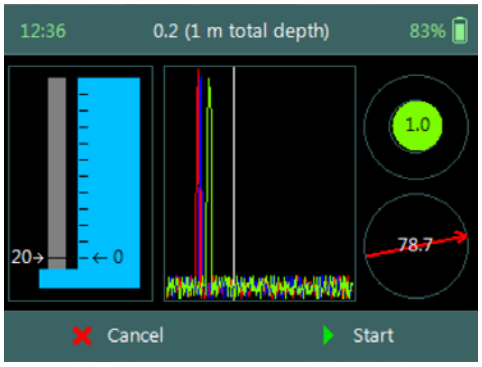


Figure 8:22 - Setting Fractional Depth

The key features of the **Setting Fractional Depth** are explained in Figure 8:23.

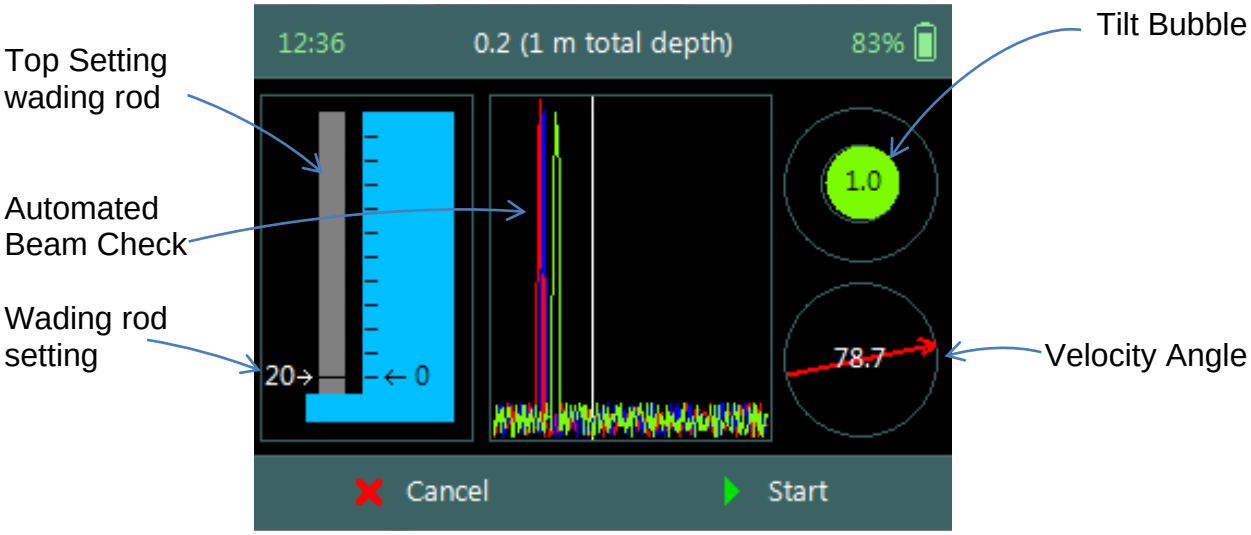


Figure 8:23 - Features of Setting Fractional Depth

Step 4

Fractional Depth Measurement screen displays graphical display of raw data of the following variables during a velocity measurement,

a) Velocity,
b) SNR,
c) Temperature,
d) Battery,
e) Tilt,

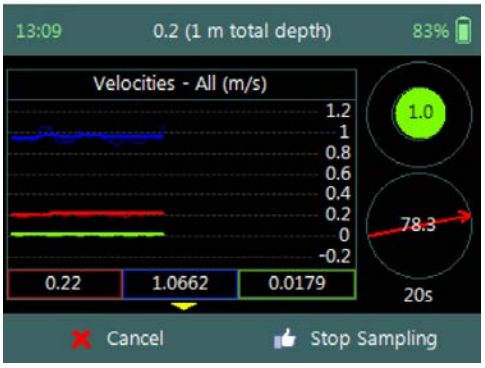


Figure 8:24 - Fractional Depth Measurement

Tilt and Velocity Angle indicators are situated on the right hand side of the screen.

f) Tilt,
g) Velocity Angle,
h) Averaging Time left.

*i) To **select** a variable graphical display,*
i). Use up or down scroll arrows keys to view a variable.

*j) To **stop sampling**,*
i). Press the Right Soft Key.

*k) To **CANCEL** velocity measurement,*
i). Press the Left Soft Key.

The conventions and graphic display features used for displaying Velocity and SNR raw data are defined under Raw Data Display.

8.3.3.3 Review Point Measurement

Review Point Measurement is a report supplied at the end of each point velocity measurement. The report consists of two components, tabular summary of numerical calculations performed on the raw data collected and graphical display of raw data.

Review Point Measurement screen consists of the following tabular summary and graphical displays,

Tabular Display

a) Review Point Measurement, Table 8:8

Graphical Display of raw data are based on the following variables,

b) Velocity,
c) SNR,
d) Temperature,
e) Tilt,
f) Velocity Angle,
g) Battery.

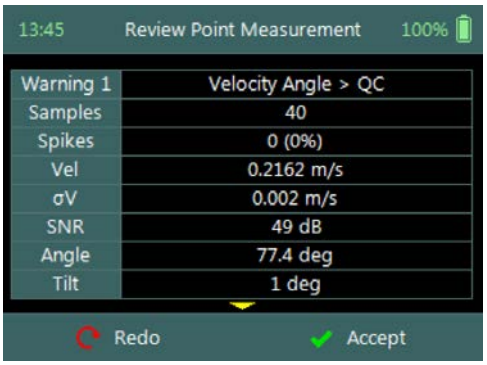


Figure 8:25 - Review Point Measurement

*h) To **select** a variable,*

i). Use the up or down arrow key to view a variable.

*i) To **accept** the velocity measurement,*

i). Press the Right Soft Key.

*j) To **REDO** velocity measurement,*

i). Press the Left Soft Key.

The conventions and graphic display features used for displaying Velocity and SNR raw data are defined under Raw Data Display.

Properties associated with the variable output from the numerical calculations performed on raw data collected is defined in Table 8:8,

Table 8:8 - Review Point Measurement

Variable	Description	Units	Decimal
Samples	Total number of samples received.	number	n/a
Spikes	Number of spikes removed from mean velocity.	number	n/a
Vel	Mean X velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
σV	Standard error of X velocity component.	m/s or ft/s	4
SNR	Mean signal to noise ratio. Average of beam 1 and 2 SNR during point measurement.	dB	3
Angle	Flow angle relative to X direction. Angle between the mean X velocity component and mean Y velocity component.	Degree	2
Tilt	Mean wading rod angle during point velocity measurement.	Degree	2
Temp	Mean temperature during point measurement.	°C or °F	2
Bnd	Boundary QC value.	n/a	n/a

8.3.3.4 Review Station Measurement

Review Station measurement is tabular report supplied at the completion of all point velocity measurements at a station. The variables supplied in the report are dependent on the features activated on the handheld, velocity method selected and the discharge calculation method.

Review Station screen consists of tabular summary of all measurements performed at the station,

a) Review Station, Table 8:9.

*b) To **close** the review station report,*

i). Press the Right Soft Key.

ii). The software will navigate to the Data Collection Window.

*c) To **EDIT** station,*

i). Press the Left Soft Key.

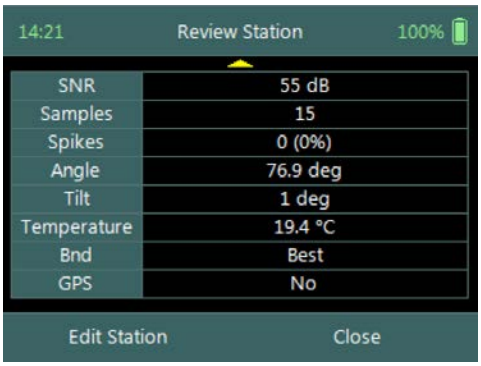


Figure 8:26 - Review Station

Properties associated with the variables and numerical calculations performed on the raw data collected at the station is defined in Table 8:9,

Table 8:9 - Review Station

Variable	Description	Units	Decimal
Location	Station location measured from the start location on tag line or measuring tape.	m or ft	3
Dist. Prev. St.	Distance between current and previous station.	m or ft	3
Depth	Measured water depth or effective depth (for Ice method).	m or ft	3
Type	Station type (see Station Types).	n/a	n/a
Method	Discharge measurement method or velocity method (see Determining Mean Station Velocity).	n/a	n/a
Ice	Ice Thickness (only for Ice method).	m or ft	3
WS to BI	Water surface to bottom of ice (only for Ice method).	m or ft	3
WS to BS	Water surface to bottom of slush ice (only for Ice method).	m or ft	3
Corr. Factor	Mean station velocity (mean velocity in vertical) correction factor.		2
Comment	Text entered in comment fields during measurement.	n/a	n/a
%Q	Station discharge as a percent of the, • weighted rated discharge, of rated discharge entries in supplement data or, • measured discharge up to that station.	%	2
StnQ	Station or panel discharge, per discharge method.	m^3/s or ft^3/s	4
TotalQ	Total discharge is the sum of all completed station or panel discharges, per discharge method.	m^3/s or ft^3/s	4
PanelVel	Panel velocity calculated based on discharge calculation method.	m^3/s or ft^3/s	4

Variable	Description	Units	Decimal
MeanStVel	Mean Station Velocity or **Mean Velocity in Vertical**, X velocity component computed per velocity method. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
σV	Mean standard error of X velocity component of all point measurements.	m/s or ft/s	4
SNR	Mean signal to noise ratio of beams 1, 2 of all point measurements.	dB	3
Samples	Total number of samples received.	number	n/a
Spikes	Total number of spikes removed from mean velocity.	number	n/a
Angle	Mean flow angle relative to X direction. Average the velocity angle from each point measurement.	Degree	2
Tilt	Mean wading rod angle of all point velocity measurements.	Degree	2
Temperature	Mean Temperature of all point measurements.	°C or °F	2
Bnd	Lowest Boundary QC value.	n/a	n/a
GPS	Indicating if GPS was used during station measurement.	n/a	n/a

8.3.4 Data Collection Menu

Data Collection Menu allows the user to adjust measurement settings, enter staff gauge readings and rated discharge data and view measurement summary. The data collection menu can be accessed in between point velocity measurements or stations and this ensures that the instrument is configured for current flow conditions present.

Data Collection Menu screen consists of the following functions that are available in Discharge Mode,

a) Settings,
b) Supplemental Data,
c) Discharge Summary,
d) Stations Summary,
e) Automated Beam Check,
f) Complete Measurement,
g) Discard Measurement,
h) Go to Home Screen.

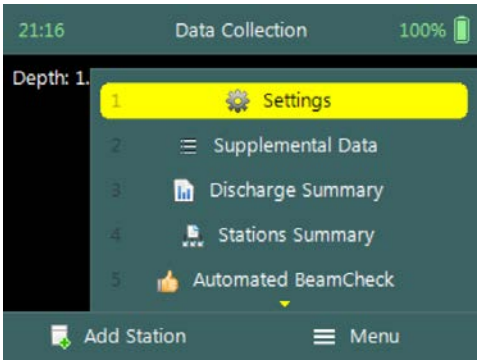


Figure 8:27 - Data Collection Menu

*i) To **select** a function,*
   i). Use the up or down arrow key to scroll through the functions,

*j) To **open** or **CLOSE** the data collection menu,*
   i). Press the Right Soft Key.

8.3.4.1 Settings

The **Settings** menu option gives the user access to the initial measurement settings that were configured during the configuration of the discharge template.

Settings screen consists of the following functions for configuring measurement settings,

a) File Properties,
b) Data Collection Settings,
c) Quality Control Settings
d) Discharge Settings.

*e) To **select** a function,*
   i). Use the up or down arrow key to scroll through the functions,

*f) To **CLOSE** the settings menu,*
   i). Press the Left Soft Key.

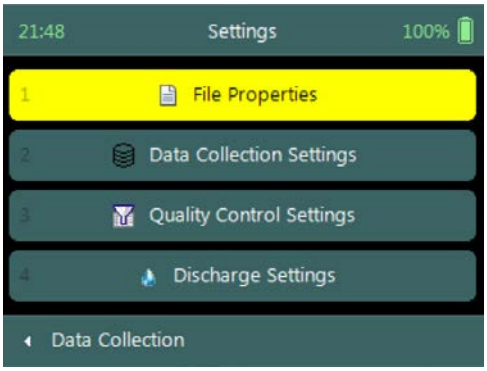


Figure 8:28 - Settings Menu

The measurement settings functions supplied in the Settings option in data collection menu are defined under Template Functions.

8.3.4.2 Supplemental Data

Supplemental Data function enables the user to enter staff gauge readings and rated discharge during the discharge measurement. The staff gauge readings and rated discharge are used to compute Weighted Gauge Height. The rated discharge is also used to determine percentage discharge at each station or panel during a discharge measurement.

Supplemental Data screen display the supplemental data entered and is sorted by the time the staff gauge readings were taken. The supplemental data can be entered during any stage of the measurement before the "Complete Measurement" function is selected.

*a) To **add** supplemental data,*
   i). Press the Right Soft Key,

*b) To **CLOSE** supplemental data,*
   i). Press the Left Soft Key.



Figure 8:29 - Supplemental Data

The time and date entered for each supplemental dataset should be the time when the staff gauge reading was taken and not the time when the data was entered.

Add Gauge Height screen consists of the following variables required in supplemental data,

a) Date,
b) Time,
c) Gauge Height,
d) Rated Discharge,
e) Comment.

*c) To **accept** supplemental data,*

i). Press the Right Soft Key,

*d) To **CANCEL** supplemental data entry,*

i). Press the Left Soft Key.

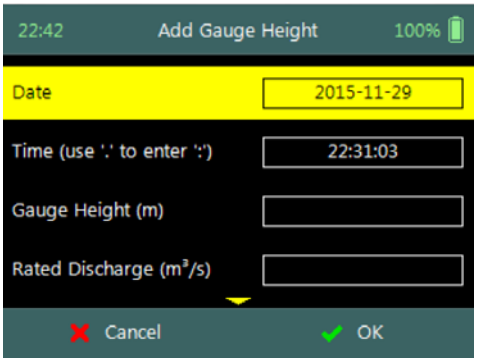


Figure 8:30 - Add Gauge Height

The staff gauge readings, rated discharge and associated data captured in Supplemental Data should be accurate and complete. It is important that these variables are entered correctly for accurate calculation of weighted gauge height and or percentage discharge.

8.3.4.3 Discharge Summary

Discharge Summary from the data collection menu displays the discharge and other variables measured from all completed stations. Discharge summary requires at least one station with velocity measurements to populate the main variables in the table.

Discharge Summary screen consists of tabular summary of discharge and other variables measured up to specific point,

a) Discharge Summary, Table 8:10.

*b) To **close** the discharge summary report,*

i). Press the Left Soft Key.

ii). The software will navigate to the Data Collection Window.

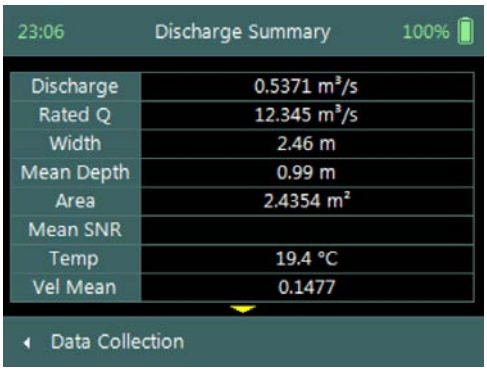


Figure 8:31 - Discharge Summary

Properties associated with the variables and numerical calculations performed on the raw data collected is defined in Table 8:10,

Table 8:10 - Discharge Summary

Variable	Description	Units	Decimal
Discharge	Total discharge is the sum of all station or panel discharges, per discharge method.	m^3/s or ft^3/s	4
RatedQ	Rated discharge entered in supplemental data.	m^3/s or ft^3/s	4
Width	Total width calculated from all stations and or panels, per discharge method.	m or ft	3
Mean Depth	Average depth calculated from the total area and width.	m or ft	3

Variable	Description	Units	Decimal
Area	Total area calculated from all stations or panels, per discharge method.	m^2 or ft^2	4
Mean SNR	Average SNR of all completed stations. Require at least 3 stations.	dB	n/a
Temp	Average temperature of all completed stations.	°C or °F	2
Vel Mean	Average station velocity, X velocity component	m/s or ft/s	4
Vel Min	Minimum station velocity, X velocity component	m/s or ft/s	4
Vel Max	Maximum station velocity, X velocity component	m/s or ft/s	4
Height, Start	Start staff gauge reading.	m or ft	3
Height, End	End staff gauge reading.	m or ft	3
Uncertainty	Uncertainty in discharge measurement.	%	2
Largest Uncertainty	Largest uncertainty in the discharge uncertainty calculation.	%	2

8.3.4.4 Station Summary

The **Station Summary** from the data collection menu displays the completed stations in table format. The station summary is a good reference when evaluating measurements performed at a station against adjacent stations.

Station Summary screen consists of tabular view of all completed stations,

a) Station Summary, Table 8:11.

*b) To **close** the discharge summary report,*

i). Press the Left Soft Key.

ii). The software will navigate to the Data Collection Window.



Figure 8:32 - Station Summary

Properties associated with the variables and numerical calculations performed on the raw data collected is defined in Table 8:11,

Table 8:11 - Station Summary

Variable	Description	Units	Decimal
Loc	Station location measured from the start location on tag line or measuring tape.	m or ft	3
Depth	Measured water depth or effective depth (for Ice method).	m or ft	3
Type	Station type (see Station Types).	n/a	n/a
Method	Discharge measurement method or velocity method (see Determining Mean Station	n/a	n/a

Variable	Description	Units	Decimal
	Velocity).		
Corr. Factor	Mean station velocity (mean velocity in vertical) correction factor.	None	3
Panel Vel	Panel velocity calculated based on discharge calculation method.	m/s or ft/s	4
MeanStVel	Mean Station Velocity or **Mean Velocity in Vertical**, X velocity component computed per velocity method. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
Width	Panel width, per discharge method.	m or ft	3
Area	Panel area, per discharge method.	m^2/s or ft^2/s	4
Flow	Panel discharge, per discharge method.	m^3/s or ft^3/s	4
%Q	Station discharge as a percent of the, • weighted rated discharge, of rated discharge entries in supplement data or, • measured discharge up to that station.	%	2
Angle	Mean flow angle relative to X direction. Average the velocity angle from each point measurement	Degree	2
Tilt	Mean wading rod angle of all point velocity measurements.	Degree	2
Temp	Mean Temperature of all point measurements.	°C or °F	2
GPS	Indicating if GPS was used during station measurement.	n/a	n/a

8.3.4.5 Automated Beam Check

Automated Beam Check function in the data collection menu allows the user to perform beam check during any stage of the discharge measurement. The Automated Beam Check function operations, conventions and graphic display features are defined under Automated Beam Check.



Automated Beam Checks performed during the discharge measurement are stored in FlowTracker2 file (.ft) that was created for the measurement site.

8.3.4.6 Complete Measurement

The **Complete Measurement** function closes the measurement file and the user will not be able to add additional stations and or make any changes to the data captured. The complete measurement function is a three-step process, firstly to determine if the user is satisfied with the discharge measurement, secondly to perform quality control checks against all measurement data and lastly to review discharge summary.

The Complete Measurement process allows the user to review the measurement data before the complete function is selected at Summary screen. The user will not be able to make any to changes to the measurement file from the handheld when this function is selected.

Step 1

Confirmation screen of **Complete Measurement** function confirms if the user wants to close the measurement file. User will not be able to add stations or make any changes to the data

*a) To **confirm** complete measurement operation,*
i). Press the Right Soft Key.

*b) To **CANCEL** complete measurement operation,*
i). Press the Left Soft Key.

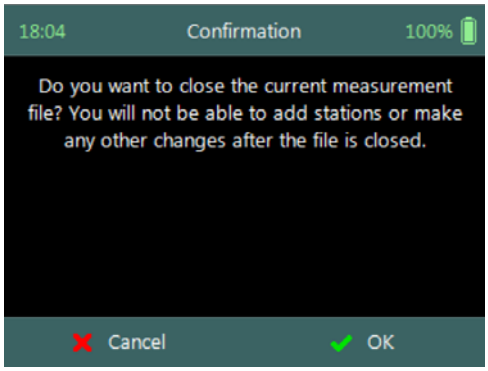


Figure 8:33 - Confirmation Complete Measurement

Step2

Confirmation screen with **Quality Control** warning messages based on quality control checks performed on measurement data.

*a) To **accept** quality control warning messages,*
i). Press the Right Soft Key.

*b) To **CANCEL** complete measurement operation,*
i). Press the Left Soft Key.

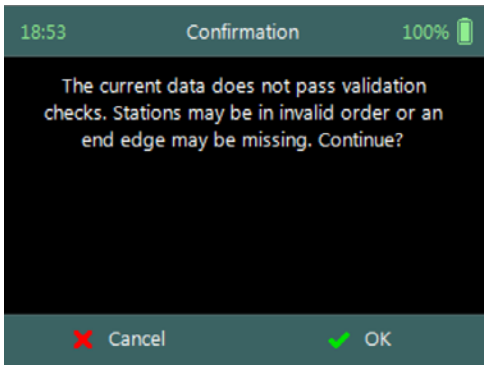


Figure 8:34 - Confirmation Quality Control Messages

Step3

Summary screen displays the discharge summary report before the measurement file is closed for further data entry and editing.

*a) To **confirm** complete measurement operation,*
i). Press the Right Soft Key.
ii). The software will navigate to the Main Menu.

*b) To **CANCEL** complete measurement operation,*
i). Press the Left Soft Key.



Figure 8:35 - Summary Discharge Measurement

8.3.4.7 Discard Measurement

The **Discard Measurement** function will discard all configuration settings, stations and other data related with the measurement.

Discarding a measurement will result in deleting all data of the measurement site that is related to the specific measurement file.

Warning screen of **Discard Measurement** function displays the warnings associated with discarding measurement file.

*a) To **DISCARD** measurement,*
i). Press the Right Soft Key.
ii). The software will navigate to the Main Menu.

*b) To **CANCEL** discard measurement operation,*
i). Press the Left Soft Key.

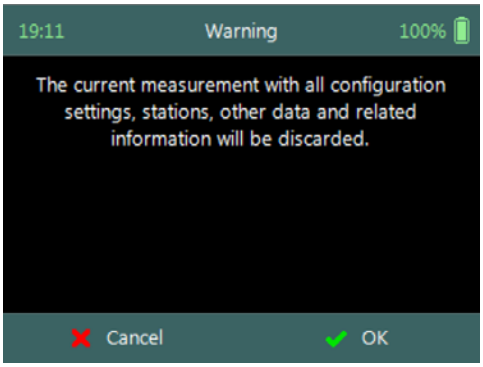


Figure 8:36 - Warning Discard Measurement

8.3.4.8 Go to Home Screen

The **Go to Home Screen** function will navigate the software to the main menu and the user will have the ability to access software functions that are not related to Discharge Mode function.

The discharge measurement can be accessed during any stage by selecting the "Data Collection" function with the Right Soft Key. The software will continue with the measurement at the exact stage when the user navigated away from the discharge mode.

8.4. Measurement Summary

Measurement Summary is supplied when the Complete Measurement function is selected and displays all the measurement results. The Measurement Summary is the last verification of the measurement results before the measurement file is closed for any further measurements or changes.

Measurement Summary screen consists of tabular summary of discharge measurement results,

a) Discharge Summary, Table 8:12.

*b) To **CANCEL** the discharge summary report,*
i). Press the Left Soft Key.
ii). The software will navigate to the Data Collection Window.

*c) To **COMPLETE** the discharge measurement,*
i). Press the Right Soft Key.
ii). The software will close the measurement file and navigate to the main menu.

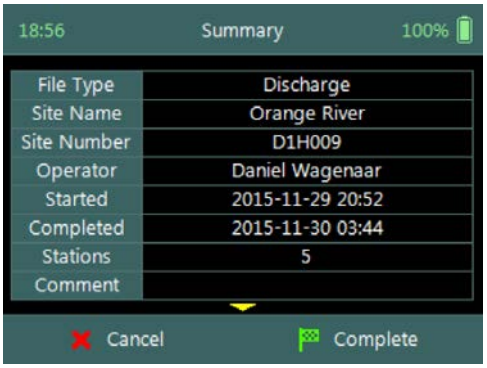


Figure 8:37 - Measurement Summary

Properties associated with the variables and numerical calculations performed on the raw data collected is defined in Table 8:12,

Table 8:12 - Measurement Summary

Variable	Description	Units	Decimal
File Type	File type based on discharge or general mode	n/a	n/a
Site Name	Site name populated by user	n/a	n/a
Site Number	Site number populated by user	n/a	n/a
Operator	Operator name populated by user	n/a	n/a
Started	Start date and time when measurement was created	yyyy-mm-dd hh:mm	
Completed	End data and time when measurement was completed	yyyy-mm-dd hh:mm	
Stations	Total number of stations within the measurement	n/a	n/a
Comment	General comment captured against measurement	n/a	n/a
Discharge	Total discharge calculated	m^3/s or ft^3/s	4
Rated Q	Rated discharge entered by user	m^3/s or ft^3/s	4
Width	Total width of the measurement section	m or ft	3
Mean Depth	The mean depth of the measurement section calculated from the total area and width.	m or ft	3
Area	Total area of the measurement section	m^2 or ft^2	4
Mean SNR	Average signal to noise ration	dB	
Temp	Average temperature measured	°C or °F	
Vel Mean	Average station velocity, X velocity component	m/s or ft/s	4
Vel Min	Minimum station velocity, X velocity component	m/s or ft/s	4
Vel Max	Maximum station velocity, X velocity component	m/s or ft/s	4
Height, Start	First staff gauge reading	m or ft	3
Height, End	Last staff gauge reading	m or ft	3
Uncertainty	Uncertainty in discharge measurement	%	2
Largest Uncertainty	Largest uncertainty in the discharge uncertainty calculation	%	2

Section 9. General Measurement

General Measurement is the measurement technique involved in collecting velocity data based on the General Mode (see Data Collection Modes). The data collection framework designed for collecting velocity data is detailed in Software Flow Diagram. Velocity data collection process consists of the following main components, with discussions of each component.

- Create Measurement,
- Automated Beam Check,
- Data Collection,
- Discharge Summary.

9.1. Create Measurement

Creating a new measurement consist of number of steps before the data collection can be performed. The first step involved is to either select an existing Configuration Template or create a new template with user defined configuration parameters. The template then needs to be associated with a measurement file that is created by the user. When the measurement file is created, the software is ready for data collection.

9.1.1 Measurement

The **Measurement** function enables the user to create a new measurement in either Discharge or General mode. The General mode used for the collection of velocity data during field measurements will be focused on in this section.

a) The Measurement function can be accessed from the Main Menu on the bottom banner,

*b) To **select** the Measurement function,*
i). Press the Right Soft Key.

c) *The software will navigate to the New File Type or Mode screen.*

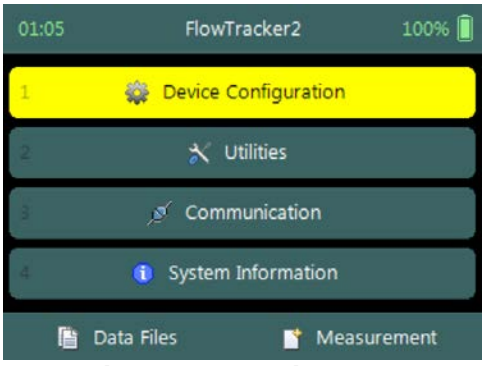


Figure 9:1 - Main Menu

9.1.2 New File Type

The **New File Type** function enables the user to determine if the new measurement file should be based on either Discharge or General mode.

The **New File Type** screen consists of the following options,

a) Discharge,
b) General,
c) *To **select** discharge mode,*
   i). Use up or down scroll arrows keys to select Discharge and press enter key.
d) *The software will navigate to the New File Template screen.*
e) *To **navigate** to Home menu,*
   i). Press the Left Soft Key.

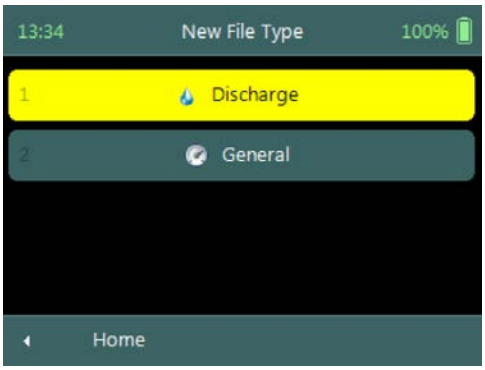


Figure 9:2 - New File Type

9.1.3 New File Template

New File Template function enables the user to create a new configuration template based on SonTek default settings or select an existing Configuration Template created by the user. The configuration template is based on user defined parameters that are dependent on measurement site details, flow conditions and organizational requirements. The configuration template selected will be assigned to the measurement file and the parameters defined in the template will be applied during the Velocity measurement.

The **New File Template** screen consists of the following options,

a) **(default)**, the template will be based on SonTek default settings.
b) Existing Templates, created under "Device Configuration". A list of available templates created by the user will be displayed under the "(default)" option.
c) *To **select** a template,*
   i). Use up or down scroll arrows keys to select template and press enter key.
d) *The software will navigate to the New Data File screen.*
e) *To **navigate** to File Type menu,*
   i). Press the Left Soft Key.

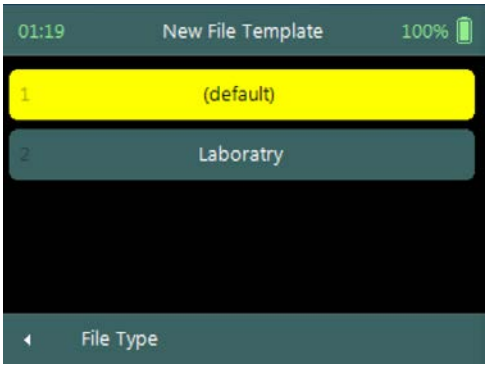


Figure 9:3 - New File Template

9.1.4 New Data File

New Data File function enables the user to populate the measurement site and operator details. The information entered for each parameter should be accurate as this information is recorded in each measurement file and used in both the File Naming and Folder Naming conventions.

- Existing templates created under “Device Configuration”, parameters will be prepopulated from File Properties information that was captured,
- Templates based on SonTek default configuration will have no information populated and the user will need to enter the required details for each parameter.



It is not good data management practice for both measurement site references to be empty or with abbreviate terms. It is recommended that the user makes use of accurate site descriptions.

The **New Data File** screen consists of the following parameters,

a) Site Number,
b) Site Name,
c) Operator,
d) Comment.

*e) To **select** a parameter,*
i). Use up or down scroll arrows keys to select a parameter.

*f) To **accept** the new data file configuration,*
i). Press the Right Soft Key,
ii). The software will navigate to Automated Beam Check screen.

*g) To **CANCEL** new data file configuration,*
i). Press the Left Soft Key,
ii). The software will return to New File Template.

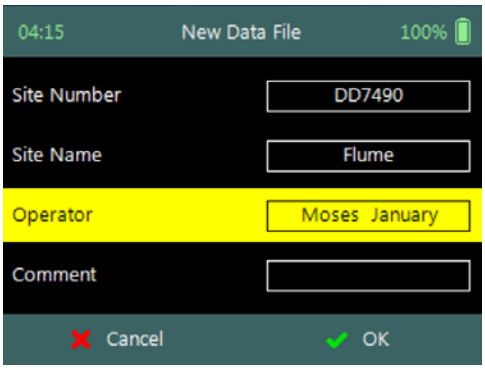


Figure 9:4 - New Data File

9.2. Automated Beam Check

The **Automated Beam Check** function allows the user to perform a Beam Check in the region of the measurement location before data collection starts. The automated beam check perform a number of quality control checks on the data collected to determine if the flow conditions are suitable for velocity measurements. The Automated Beam Check is an automated version of Beam Check function described in Beam Check.



Automated Beam Check can be performed during any stage of the data collection process. The Automated Beam Check functions are available before data collection start and during velocity measurement from the “Data Collection Menu” (see Data Collection Screen).

9.2.1 Start Automated Beam Check

The FlowTracker2 probe should be placed in the region of the measurement location in moving water such that the probe is submerged and well away from any underwater obstacles. The FlowTracker2 collects data for about 30 seconds.

The **Automated Beam check** screen shows the steps involved in performing an automated beam check.

*a) To **start** the automated beam check,*
i). Press the Right Soft Key.

*b) To **CANCEL** automated beam check,*
i). Press the Left Soft Key,
ii). The software will navigate to Data Collection window.

*c) To **accept** Automated Beam Check,*
i). Press the Right Soft Key,
ii). The software will navigate to the Data Collection window.

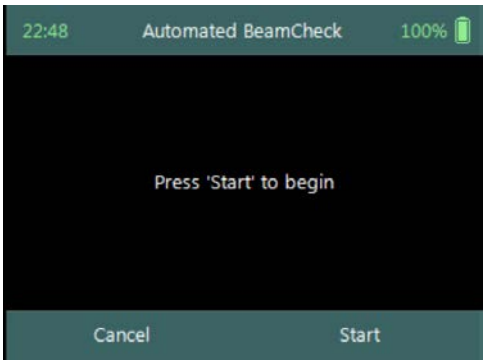
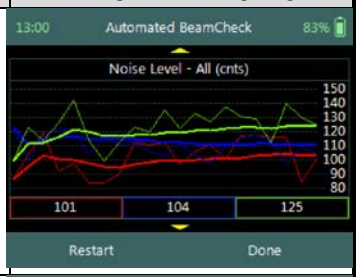
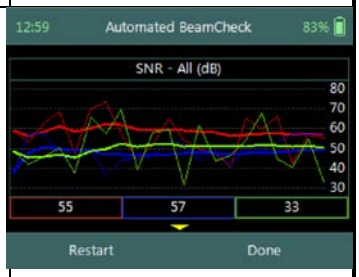
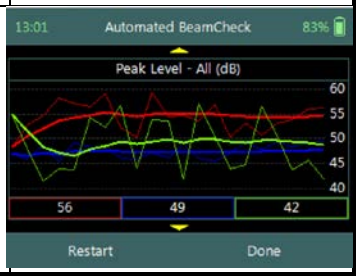


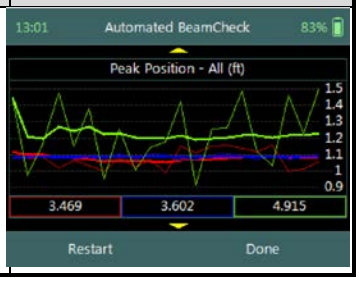
Figure 9:5 - Automated Beam Check

9.2.2 Evaluate Beam Check Results

The automated beam check quality control criteria used in the evaluation of the beam check data are listed in Table 9:1,

Table 9:1 - Automated Beam Check Quality Control Criteria

Quality Control	Criteria	QC Warning	Graphic Display
Noise Level	• Measured electronics noise level is compared to reference data. Any significant deviation causes a warning, • A large change in noise level may indicate damage to the probe.	Noise Level > QC	
SNR	• The SNR is checked as sufficient for reliable data collection, • Each beam SNR is compared to be sure all beams perform equally, • A warning is issued for low SNR < 4 dB, • A warning is issued for 4 dB > SNR <7dB, • Beam SNR values differ.	SNR	
Peak Level	• The shape of the sampling volume curve is compared to the expected shape. Any significant deviation causes a warning, • This criterion can only be checked with sufficient SNR (> 7 dB).	Peak Level > QC	

Quality Control	Criteria	QC Warning	Graphic Display
Peak Location	• The physical location of the sampling volume is compared to the expected location. Any significant deviation causes a warning. • This criterion can only be checked for sufficient SNR (> 7 dB).	Peak Location > QC	

a) If any warnings are issued, the warnings will be displayed at the bottom of the graphics. The user have the option to repeat the test if warnings are issued.

i). We recommend repeating the test at least once, after you verify that the probe and sampling volume are well away from any underwater obstacles,

ii). If multiple warnings are received, run manual Beam Check to evaluate FlowTracker2 performance in more detail.

b) The display options for individual or all beam check data are listed in Table 9:2. The shortcut key on the keypad determines which beam SNR will be displayed,

Table 9:2 - Automated Beam Check Display

Beam	Line Color	Keypad Key
Beam1	Red	1
Beam2	Blue	2
Beam3	Green	3
All Beams	All	4

*c) To **select** a Quality Control Criteria,*

i). Use up or down scroll arrows keys to view quality control criteria.

9.3. Data Collection

Data Collection function for General mode is the process involved in collecting velocity data. The data collection process is a systematic workflow designed to follow the actual measurement process in the field. The process consist of the following main components that also describes each individual aspect of the field measurement,

- Data Collection Window,
- Station Measurement,
- Data Collection Menu.

9.3.1 Data Collection Window

The **Data Collection Window** can be defined as the "*control center*" of the data collection process during velocity measurements. All the software functions required to perform velocity measurements is available from the data collection screen. The key features and some of the variables are explained in **Figure 9:6**.

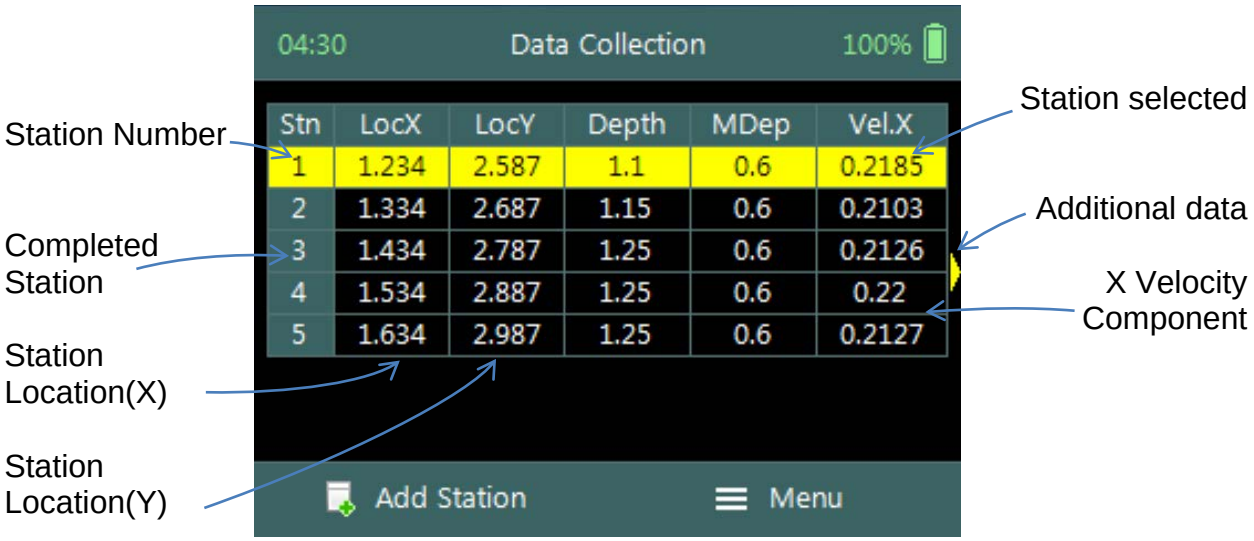


Figure 9:6 - Data Collection Window

The operations and functions available of the Data Collection Window will be discussed throughout this section with the main functions described in Figure 8:7.

Data Collection Window screen of the consists of the following,

a) Station Management area defined in rectangle,
b) Add Station,
c) Data Collection Menu *(Menu).*

*d) To **add** a station,*
i). Press the Left Soft Key.

*e) To **select** the data collection **menu**,*
i). Press the Right Soft Key,
ii). The software will display a popup menu screen.

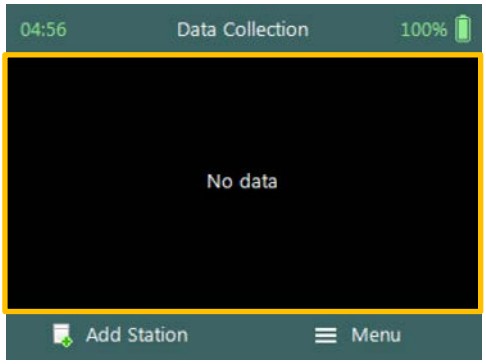


Figure 9:7 - Functions Data Collection Window

9.3.1.1 Add Station

Add Station function creates a station for each measurement location identified for velocity measurements. The process separates point velocity measurements with the same position and or different measurement locations.

Add Station screen consist of the following parameters that are required to create a station,

a) Location X,
b) Location Y,
c) Water Depth,
d) Measurement Depth,
e) Comment.

The standard **functions** available for each station type are,

f) Record GPS Location (function availability, see

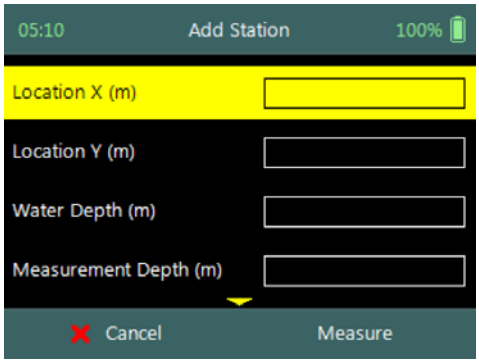


Figure 9:8 - Add Station

GPS Station Tagging).

*g) To **add** a station or start velocity measurement,*

i). Press the Right Soft Key.

*h) To **CANCEL** add station,*

i). Press the Left Soft Key.

Unique station number is assigned to each point velocity measurement. This allows the user to perform multiple measurements at the same location without assigning a unique number or name to differentiate between the measurements.

Properties associated with the parameters for station are defined in Table 9:3,

Table 9:3 - Station - Properties

Parameter	Min	Max	Default	Decimals	Units	Required
Location X	-1000	1000	empty	3	m or ft	Yes
Location Y	-1000	1000	empty	3	m or ft	Yes
Water Depth	0	100	empty	3	m or ft	Yes
Measurement Depth	0	100	empty	3	m or ft	Yes
Comment	0	250	empty			No

9.3.1.2 Delete Station

Deleting a station is performed from the **Data Collection Window** by selecting the station within the viewable window.

The station delete process is not reversible and the user must ensure that the correct station is selected. Selected station will be highlighted with a yellow background.

Delete Station is performed from the **Data Collection Window**. Up to ten completed stations will be displayed at any time,

*a) To **select** a station,*

i). Use the up or down arrow key to scroll through the completed stations,

*b) To **DELETE** a station,*

i). Press the backspace key.

ii). The software will navigate to the Confirmation screen.

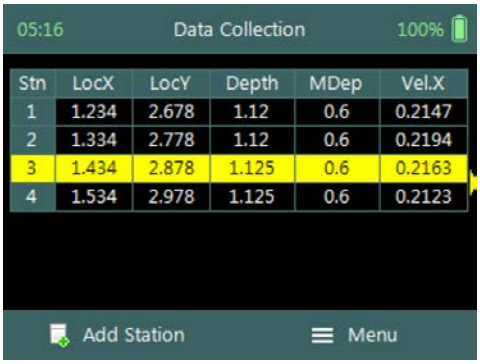


Figure 9:9 - Select Station

Confirmation screen requests confirmation of deleting the selected station.

*a) To **confirm** station delete,*
i). Press the Right Soft Key,

*b) To **CANCEL** station delete,*
i). Press the Left Soft Key,

c) *The software will navigate to the Data Collection Window.*

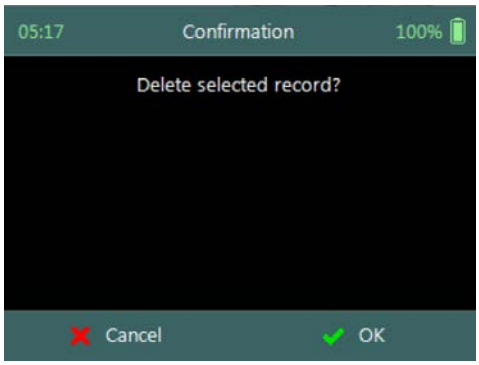


Figure 9:10 - Confirm Delete

9.3.2 Station Measurement

Station Measurement is performed at each Station based on measurement requirements. The measurement locations can either be structured such in laboratory environment where the position of the instrument is determined accurately or random where velocities on channel banks are investigated. The station measurements consist of collecting a number of different parameters and variables required by the General mode.

9.3.2.1 Point Velocity Measurement

Point Velocity Measurement in General mode is not bound to any measurement techniques and or guidelines as required in Discharge mode. The location of the station, number of point velocity measurements and depth of point velocity measurements is dependent on the user requirements.

If the velocity measurements are used to perform hydraulic analyzes of the flow conditions in a channel, either a laboratory or natural channel, it is recommended that ISO 748 – 2007 guidelines are used.

Step 1

Station parameters defined for **Velocity Measurement,** e.g., parameters of station defined for velocity measurement are the following,

a) Location X: 1.534m,
b) Location Y: 2.978m,
c) Water Depth: 1,125m,
d) Measurement Depth: 0.6m,
e) Velocity Method: Two Point,
f) Comment.

*g) To **add** station and continue to velocity measurement,*
i). Press the Right Soft Key.

*h) To **CANCEL** a new station,*
i). Press the Left Soft Key.

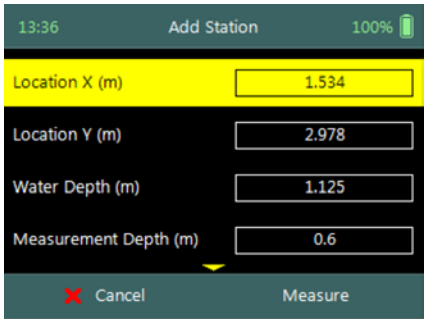


Figure 9:11 - Velocity Measurement

Step 2

Setting Measurement Depth screen allow the setting and placement of the wading rod before velocity measurement is started,

a) Wading rod setting,
b) Beam Check,
c) Boundary QC,
d) Tilt,
e) Velocity angle.

*f) To **start** a velocity measurement,*
i). Press the Right Soft Key.

*g) To **REVERT** to measurement screen,*
i). Press the Left Soft Key.

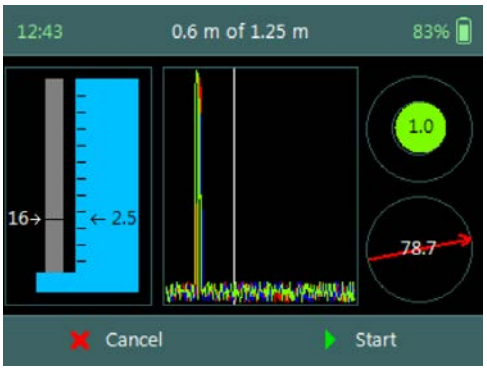


Figure 9:12 - Setting Measurement Depth

The key features of the **Setting Measurement Depth** are explained in Figure 9:13.

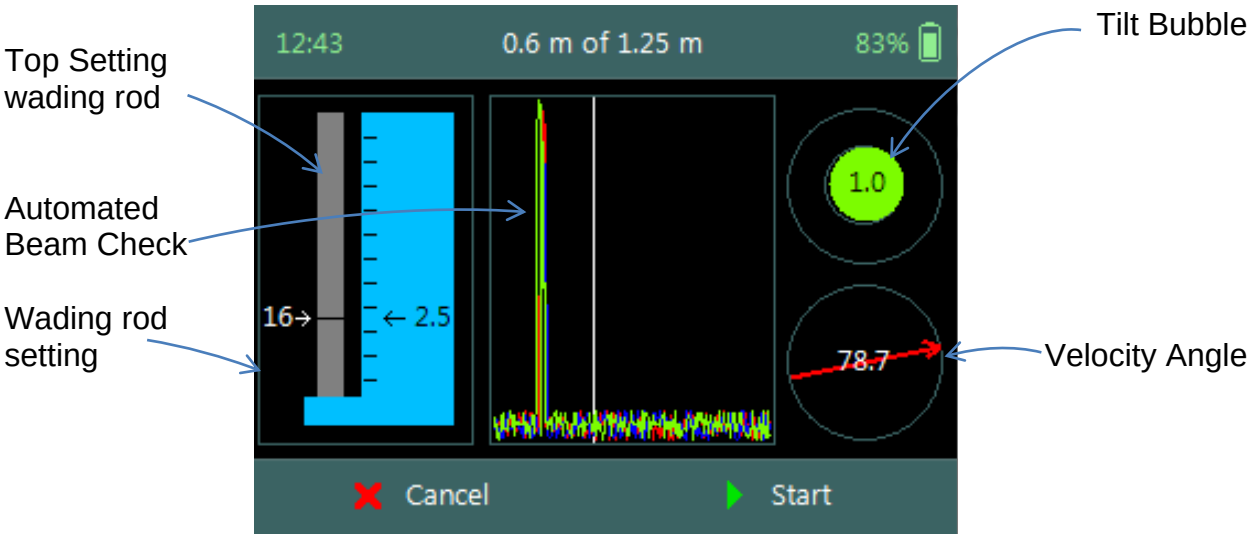


Figure 9:13 - Features of Setting Measurement Depth

Step 4

Velocity Measurement screen displays graphical display of raw data of the following variables during a velocity measurement,

a) Velocity,
b) SNR,
c) Temperature,
d) Battery,
e) Tilt,

Tilt and Velocity Angle indicators are situated on the right hand side of the screen.

f) Tilt,
g) Velocity Angle,
h) Averaging Time left.

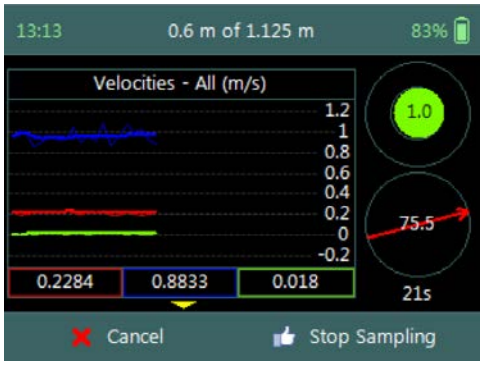


Figure 9:14 - Velocity Measurement

i) *To **select** a variable graphical display,*
   i). Use up or down scroll arrows keys to view a variable.

j) *To **stop sampling**,*
   i). Press the Right Soft Key.

k) *To **CANCEL** velocity measurement,*
   i). Press the Left Soft Key.

The conventions and graphic display features used for displaying Velocity and SNR raw data are defined under Raw Data Display.

9.3.2.2 Review Point Measurement

Review Point Measurement is a report supplied at the end of each point velocity measurement. The report consists of two components, tabular summary of numerical calculations performed on the raw data collected and graphical display of raw data.

Review Point Measurement screen consists of the following tabular summary and graphical displays,

Tabular Display

a) Review Point Measurement, Table 9:4

Graphical Display of raw data are based on the following variables,

b) Velocity,
c) SNR,
d) Temperature,
e) Tilt,
f) Velocity Angle,
g) Battery.

h) *To **select** a variable,*
   i). Use the up or down arrow key to view a variable,

i) *To **accept** the velocity measurement,*
   i). Press the Right Soft Key.

j) *To **REDO** velocity measurement,*
   i). Press the Left Soft Key.

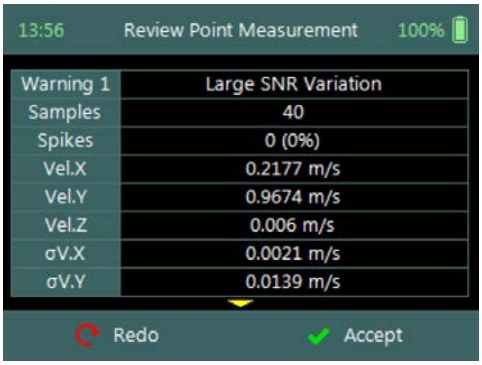


Figure 9:15 - Review Point Measurement

The conventions and graphic display features used for displaying Velocity and SNR raw data are defined under Raw Data Display.

Properties associated with the variable output from the numerical calculations performed on raw data collected is defined in Table 9:4,

Table 9:4 - Review Point Measurement

Variable	Description	Units	Decimal
Warning	Warning supplied based on quality control criteria	n/a	n/a
Samples	Total number of sample received	number	n/a
Spikes	Number of spikes removed from mean velocity	number	n/a
Vel. X	Mean X velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
Vel. Y	Mean Y velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
Vel. Z	Mean Z velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
σV. X	Standard error of X velocity component.	m/s or ft/s	4
σV. Y	Standard error of Y velocity component.	m/s or ft/s	4
σV. Z	Standard error of Z velocity component.	m/s or ft/s	4
SNR. 1	Signal to noise ratio of Beam 1	dB	3
SNR. 2	Signal to noise ratio of Beam 2	dB	3
SNR. 3	Signal to noise ratio of Beam 3	dB	3
Angle	Flow angle relative to X direction	Degree	2
Tilt	Mean wading rod angle during point velocity measurement	Degree	2
Temp	Mean temperature during measurement	°C or °F	2
Bnd	Boundary QC value	n/a	n/a

9.3.2.3 Review Station Measurement

Review Station measurement is a tabular report that is available from the data collection window at the completion of point velocity measurement of a station.

Review Station screen consists of tabular summary of measurements performed at the station,

a) Review Station, Table 9:5.

*b) To **access** review station report,*

i). Select the station in the data collection window,

ii). Press the enter key.

*c) To **EXIT** review station report,*

i). Press the Left Soft Key.

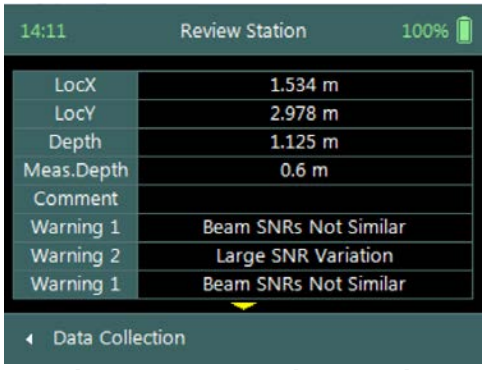


Figure 9:16 - Review Station

Properties associated with the variables and numerical calculations performed on the raw data collected at the station is defined in Table 9:5,

Table 9:5 - Review Station

Variable	Description	Units	Decimal
Loc X	Location X coordinate	m or ft	3

Variable	Description	Units	Decimal
Loc Y	Location Y coordinate	m or ft	3
Depth	Measured water depth	m or ft	3
Meas. Depth	Velocity measurement depth	m or ft	3
Comment	Comment supplied before the measurement	n/a	n/a
Warning	Warning supplied based on quality control criteria	n/a	n/a
Samples	Total number of sample received	number	n/a
Spikes	Number of spikes removed from mean velocity	number	n/a
Vel. X	Mean X velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
Vel. Y	Mean Y velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
Vel. Z	Mean Z velocity component of all samples. Velocity is despiked and mounting correction applied (if applicable).	m/s or ft/s	4
σV. X	Standard error of X velocity component.	m/s or ft/s	4
σV. Y	Standard error of Y velocity component.	m/s or ft/s	4
σV. Z	Standard error of Z velocity component.	m/s or ft/s	4
SNR. 1	Signal to noise ratio of Beam 1	dB	3
SNR. 2	Signal to noise ratio of Beam 2	dB	3
SNR. 3	Signal to noise ratio of Beam 3	dB	3
Angle	Flow angle relative to X direction	Degree	2
Tilt	Mean wading rod angle during velocity measurement	Degree	2
Temp	Mean temperature during measurement	°C or °F	2
Bnd	Boundary QC value	n/a	n/a
GPS	Indicating if GPS was used during station measurement	n/a	n/a

9.3.3 **Data Collection Menu**

Data Collection Menu allows the user to adjust measurement settings, view measurement summary, perform automated beam check and complete measurement. The data collection menu can be accessed between station measurements and this ensures that the instrument is configured for current flow conditions present.

Data Collection Menu screen consists of the following functions that are available in Discharge Mode,

a) Settings,
b) Measurement Summary,
c) Automated Beam Check,
d) Complete Measurement,
e) Discard Measurement,
f) Go to Home Screen.

*g) To **select** a function,*
i). Use the up or down arrow key to scroll through the functions,

*h) To **open** or **CLOSE** the data collection menu,*
i). Press the Right Soft Key.

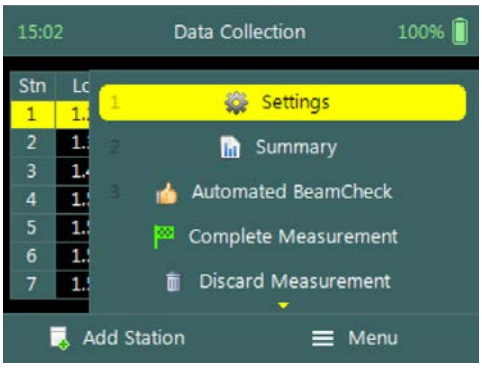


Figure 9:17 - Data Collection Menu

9.3.3.1 Settings

The **Settings** menu option gives the user access to the initial measurement settings that were configured during the configuration of the general template.

Settings screen consists of the following functions for configuring measurement settings,

a) File Properties,
b) Data Collection Settings,
c) Quality Control Settings.

d) To select a function,
i). Use the up or down arrow key to scroll through the functions,

e) To CLOSE the settings menu,
i). Press the Left Soft Key.

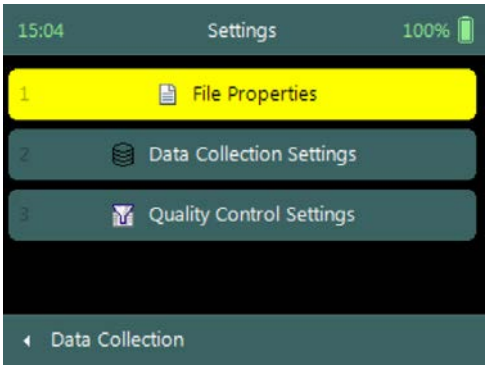


Figure 9:18 - Settings Menu

The measurement settings functions supplied in the Settings option in data collection menu are defined under Template Functions.

9.3.3.2 Velocity Summary

Velocity Summary from the data collection menu displays the mean velocity and other variables measured from all completed stations. The velocity summary requires at least one station with velocity measurements to populate the main variables in the table.

Velocity Summary screen consists of tabular summary of velocity and other variables measured up to specific point,

a) Velocity Summary, Table 8:10.

*b) To **close** the velocity summary report,*

i). Press the Left Soft Key,

ii). The software will navigate to the Data Collection Window.

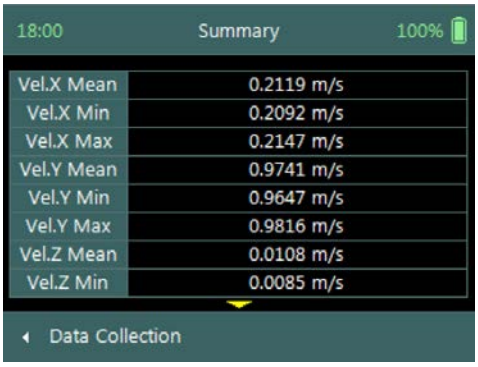


Figure 9:19 - Velocity Summary

Properties associated with the variables and numerical calculations performed on the raw data collected is defined in Table 8:10,

Table 9:6 - Velocity Summary

Variable	Description	Units	Decimal
Vel. X Mean	Average station velocity, X velocity component of all stations.	m/s or ft/s	4
Vel. X Min	Minimum station velocity, X velocity component.	m/s or ft/s	4
Vel. X Max	Maximum station velocity, X velocity component.	m/s or ft/s	4
Vel. Y Mean	Average station velocity, Y velocity component of all stations.	m/s or ft/s	4
Vel. Y Min	Minimum station velocity, Y velocity component.	m/s or ft/s	4
Vel. Y Max	Maximum station velocity, Y velocity component.	m/s or ft/s	4
Vel. Z Mean	Average station velocity, Z velocity component of all stations.	m/s or ft/s	4
Vel. Z Min	Minimum station velocity, Z velocity component.	m/s or ft/s	4
Vel. Z Max	Maximum station velocity, Z velocity component.	m/s or ft/s	4
σV. Mean	Average standard error, X velocity component of all stations.	m/s or ft/s	4
σV. Min	Minimum standard error, X velocity component of all stations.	m/s or ft/s	4
σV. Max	Maximum standard error, X velocity component of all stations.	m/s or ft/s	4
SNR Mean	Average SNR of all stations.	dB	2

9.3.3.3 Automated Beam Check

Automated Beam Check function in the data collection menu allows the user to perform beam check during any stage of the velocity measurement. The Automated Beam

Check function operations, conventions and graphic display features are defined under Automated Beam Check.

Automated Beam Checks performed during the discharge measurement are stored in FlowTracker2 file (.ft) that was created for the measurement site.

9.3.3.4 Complete Measurement

The **Complete Measurement** function closes the measurement file and the user will not be able to add additional stations and or make any changes to the data captured. The complete measurement function is a three-step process, firstly to determine if the user is satisfied with the velocity measurements, secondly to perform quality control checks against all measurement data and lastly to review measurement summary.

The Complete Measurement process allows the user to review the measurement data before the complete function is selected at Summary screen. The user will not be able to make any to changes to the measurement file from the handheld when this function is selected.

Step 1

Confirmation screen of **Complete Measurement** function confirms if the user wants to close the measurement file. User will not be able to add stations or make any changes to the data

*a) To **confirm** complete measurement operation,*
i). Press the Right Soft Key.

*b) To **CANCEL** complete measurement operation,*
i). Press the Left Soft Key.

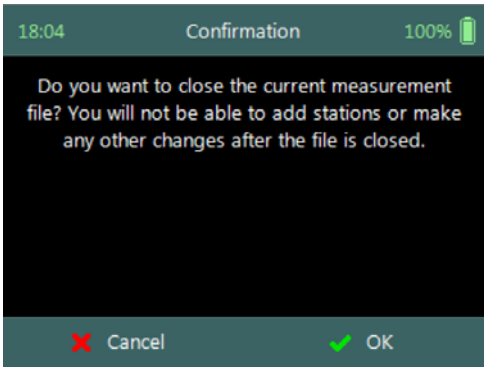


Figure 9:20 - Confirmation Complete Measurement

Step2

Confirmation screen with **Quality Control** warning messages based on quality control checks performed on measurement data.

Figure 9:21 - Confirmation Quality Control Messages

*a) To **accept** quality control warning messages,*
i). Press the Right Soft Key.

*b) To **CANCEL** complete measurement operation,*
i). Press the Left Soft Key.

Step3

Summary screen displays the velocity summary report before the measurement file is closed for further data entry and editing.

*a) To **confirm** complete measurement operation,*
i). Press the Right Soft Key,
ii). The software will navigate to the Main Menu.

*b) To **CANCEL** complete measurement operation,*
i). Press the Left Soft Key.

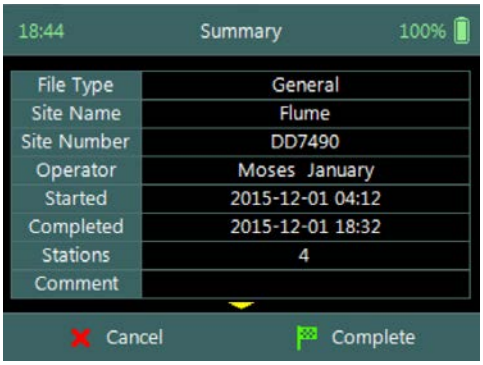


Figure 9:22 - Summary Discharge Measurement

9.3.3.5 Discard Measurement

The **Discard Measurement** function will discard all configuration settings, stations and other data related with the measurement.

Discarding a measurement will result in deleting all data of the measurement site that is related to the specific measurement file.

Warning screen of **Discard Measurement** function displays the warnings associated with discarding measurement file.

*a) To **DISCARD** measurement,*
i). Press the Right Soft Key.
ii). The software will navigate to the Main Menu.

*b) To **CANCEL** discard measurement operation,*
i). Press the Left Soft Key.

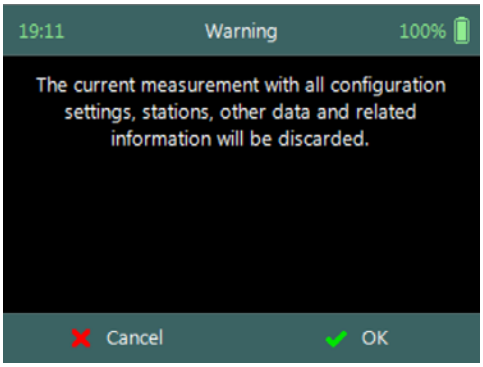


Figure 9:23 - Warning Discard Measurement

9.3.3.6 Go to Home Screen

The **Go to Home Screen** function will navigate the software to the main menu and the user will have the ability to access software functions that are not related to General Mode function.

The velocity measurements can be accessed during any stage by selecting the “Data Collection” function with the Right Soft Key. The software will continue with the measurement at the exact stage when the user navigated away from the general mode.

9.4. Measurement Summary

Measurement Summary is supplied when the Complete Measurement function is selected and displays all the measurement results. The Measurement Summary is the last verification of the measurement results before the measurement file is closed for any further measurements or changes.

Measurement Summary screen consists of tabular summary of velocity measurement results,

a) Velocity Summary, Table 9:7.

*b) To **CANCEL** the general summary report,*

i). Press the Left Soft Key.

ii). The software will navigate to the Data Collection Window.

*c) To **COMPLETE** the general measurement,*

i). Press the Right Soft Key.

ii). The software will close the measurement file and navigate to the main menu.

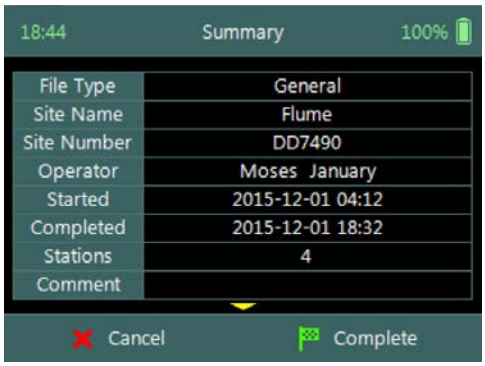


Figure 9:24 - Measurement Summary

Properties associated with the variables and numerical calculations performed on the raw data collected is defined in Table 9:7,

Table 9:7 - Measurement Summary

Variable	Description	Units	Decimal
File Type	File type based on discharge or general mode	n/a	n/a
Site Name	Site name populated by user	n/a	n/a
Site Number	Site number populated by user	n/a	n/a
Operator	Operator name populated by user	n/a	n/a
Started	Start date and time when measurement was created	yyyy-mm-dd hh:mm	
Completed	End data and time when measurement was completed	yyyy-mm-dd hh:mm	
Stations	Total number of stations within the measurement	n/a	n/a
Comment	General comment captured against measurement	n/a	n/a
Vel. X Mean	Average station velocity, X velocity component of all stations.	m/s or ft/s	4
Vel. X Min	Minimum station velocity, X velocity component.	m/s or ft/s	4
Vel. X Max	Maximum station velocity, X velocity component.	m/s or ft/s	4
Vel. Y Mean	Average station velocity, Y velocity component of all stations.	m/s or ft/s	4
Vel. Y Min	Minimum station velocity, Y velocity component.	m/s or ft/s	4
Vel. Y Max	Maximum station velocity, Y velocity component.	m/s or ft/s	4
Vel. Z Mean	Average station velocity, Z velocity component of all stations.	m/s or ft/s	4
Vel. Z Min	Minimum station velocity, Z velocity	m/s or ft/s	4

Variable	Description	Units	Decimal
	component.		
Vel. Z Max	Maximum station velocity, Z velocity component.	m/s or ft/s	4
σV. Mean	Average standard error, X velocity component of all stations.	m/s or ft/s	4
σV. Min	Minimum standard error, X velocity component of all stations.	m/s or ft/s	4
σV. Max	Maximum standard error, X velocity component of all stations.	m/s or ft/s	4
SNR Mean	Average SNR of all stations.	dB	2

Section 10. FlowTracker2 Hardware

10.1. ADV Probe

The FlowTracker2 ADV Probe and internal sensors that were implemented specifications are listed in Table 10:1,

Table 10:1- ADV Probe Specifications

Hardware		Specification
Velocity Range		±0.001 to 4.0m/s (0.003 to 13ft/s)
Velocity Resolution		0.0001m/s (0.0003ft/s)
Velocity Accuracy		±1% of measured velocity, 0.25 cm/s
Acoustic Frequency		10.0MHz
Sampling Volume Location		10cm (3.93in) from the center transducer
Minimum Depth		0.02m (0.79in)
Temperature Sensor		Resolution: 0.01°C, Accuracy: 0.1°C
Tilt Sensor		Accuracy: 1.0°
Communication Protocol		RS-232
Temperature	Operating	-20° to 40°C (-4°F to 104°F)
	Storage	-30° to 70°C (-22°F to 158°F)
Physical Specifications	Probe Head Dimensions	(L)13.3cm (5.22in); (W) 6.1cm (2.39in); (H) 2.3cm (0.90in)
	Standard Cable Length	1.500m (4.92ft)
	Weight in Air	0.90kg (1.98lbs)
	Weight in Water	0.30kg (0.66lbs)

10.2. Handheld

The FlowTracker2 Handheld and internal sensors implemented specifications are listed in Table 10:2,

Table 10:2- Handheld Specifications

Hardware			Specification
Battery Power	Input Battery Voltage		8 - 12 VDC
	Power Supply	Alkaline	8 x size AA/LR6 Alkaline batteries
		NiMH	8 x size AA, Type BK200AAB, 1.2Vdc, 1900mAh
	⚠		The use of NiMH Rechargeable Batteries is only CE certified per IEC 62133 for FlowTracker2 part number FT2-HH-2 and above.
	⚠		Only this type of NiMH rechargeable batteries with IEC 62133 approval can be used, or else warranty and safety protection will be void.

Hardware			Specification
	Battery Life	8 x size AA	15 hours continuous use, typical settings*
		*Defined as power on with screen on at 100% brightness, ADV sensor pinging 50% of the time, GPS off, and no sleep periods. Actual battery life will vary depending on FT2 settings, manner of use and brand of battery.	
	Power Consumption		1 W (Average)
Coin cell	Type		*Coin Cell type is ML2020 Manganese Lithium*
GPS	Horizontal Position Accuracy		<2.5m (8.2ft)
	Frequency		L1 (1.575 MHz), SBAS compensation (WAAS, EGNOS, MSAS, GAGAN)
LCD	Resolution		320 X 240 TFT Trans missive
	LED Backlight Luminance		450 cd / m2
Probe Interface	Battery Power to Probe		8 - 12 VDC
	Data Transfer		RS-232
	Data Storage		16 GB. Up to 10k discharge measurements. Up to 10 million velocity samples
Physical Specifications	Waterproof Rating		IP-67 (1m submersible)
	Handheld Dimensions		(L)10.4cm (4.1in); (W) 6.4cm (2.5in); (H) 23.7cm (9.3in)
	Weight in Air		0.75kg (1.65lbs)
	Weight in Water		-0.25kg (-0.55lbs)
Operating Altitude	Maximum operating altitude is 2000m		
Temperature	Operating		-20° to 40°C (-4°F to 104°F)
	Storage		-30° to 70°C (-22°F to 158°F)
			Remove batteries from FlowTracker2 handheld if storage temperatures exceeds 40°C (104°F)
Bluetooth	Class		Class 2, Range = 10m (32.8ft) nominal
	FCC		Intentional radiator (FCC Part 15.247 Subpart C; ANSI C-63.4-2003 RSS-210 and ISSUE No. :8 Date :2010) a. FCC IDENTIFIER: S7AIW03 b. Labeling requirements (FCC ID on product & text in manual) c. Drop in, use as intended from OEM – use OEM's FCC ID (eg, FlowTracker 2 Bluetooth) d. Modify use or signal/output – Analytics Site applies for FCC ID • Takes 3-4 weeks through Nemko e. Operate at specific frequency w/o

Hardware		Specification
		interference • Will require FCC license to operate
USB	Micro USB, IP-67	

10.3. Cables and Connectors

The FlowTracker2 cable and connector specifications are listed in Table 10:3,

Table 10:3- Cable and Connector Specifications

Hardware	Specification
Connector type	MCIL-8-MP wet-mate able
Standard length	1.500m (4.92ft)
Extension cable lengths	1.500m (4.920ft), 3.500m (11.5ft), 8.500m (27.9ft)
Maximum operating length	10m (32.8ft)

10.4. Certifications

The FlowTracker2 and all related hardware components comply with the following certification.

- For P/N FT2-HH-1
  - CE (per IEC/EN 61010-1:2010 3rd ed, EMC directive 2004/108/EC EN61326-1) for AA Alkaline batteries, FCC, IP-67

- For P/N FT2-HH-2
  - CE (per IEC/EN 61010-1:2010 3rd ed, EMC directive 2004/108/EC EN61326-1) for AA Alkaline batteries, FCC, IP-67
  - CE (per IEC/EN 61010-1:2010 3rd ed, EMC directive 2004/108/EC EN61326-1) for NiMH rechargeable batteries that are certified to IEC 62133*, FCC, IP-67

For further questions on certification standards, contact support@sontek.com.
Approved batteries are discussed further in Section 4.3.1.

10.5. PC System Requirements

The PC System Requirements for operating FlowTracker2 desktop software are summarized under the following criteria,

- Microsoft Windows 7 or newer
- 1GHz processor or better (2 GHz recommended)
- 2GB memory (4GB recommended)
- 500 MB available disk space (1GB recommended)

- Monitor capable of 1024x768 resolution, or better

Section 11. Operational Considerations

The procedures outlined for operating of the FlowTracker2 instrument and the maintenance requirements should be followed to ensure that the instrumentation is in a working condition.

The user should follow operating instructions as outlined in this manual, failure to do so can void manufacturer's warranty.

11.1. Software Upgrade

The FlowTracker2 handheld and ADV are operating on unique software and firmware respectively developed specifically for the FlowTracker2 instrument. Periodic updates will be supplied by SonTek to users that are normally associated with either improvement on existing or new features. The periodic update will consist of FlowTracker2 installation file that includes the Desktop Software, Handheld Software and ADV Firmware files. The FlowTracker2 installation file will be available from the SonTek website (http://www.sontek.com) or by contacting SonTek Technical Support.

11.1.1 Upgrading Handheld Software

The upgrading of handheld software and or ADV firmware is performed by uploading a single firmware file with .ft_firmware extension onto the handheld from the FlowTracker2 desktop software. The handheld upgrade is a three-step process, firstly activate handheld communication function, secondly connect desktop software with handheld using either bluetooth or USB and lastly upgrade the handheld.

Step 1 - Handheld

Activate **Communication** function on handheld to allow the user to connect to FlowTracker2 desktop software using either bluetooth or USB.

a) To select communication function,

i). Use the up or down arrow key to scroll through the functions,

ii). Press the enter key to activate the communication function.

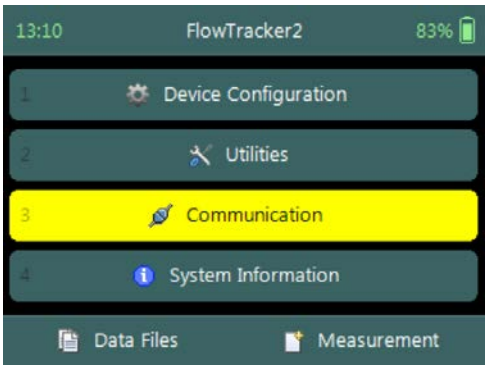


Figure 11:1 - Communication Function

The communication window displays the following instructions to enable connection between the handheld and FlowTracker2 desktop software,

a) Open FlowTracker2 desktop software,
b) Select "Device" menu option,
c) Is USB cable connected or Bluetooth enabled,
d) Select communication medium.

*e) To **CLOSE** the communication function,*
i). Press the Left Soft Key.

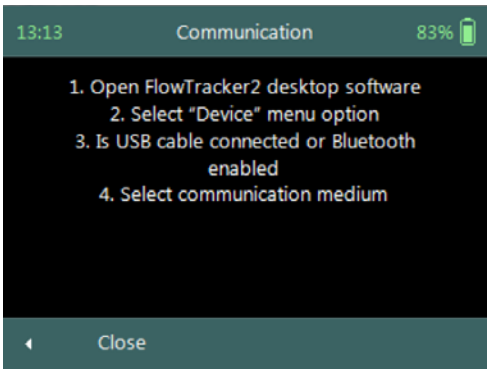


Figure 11:2 - Communication Window

Step2 – Desktop Software

Connect FlowTracker2 desktop software with handheld using either USB or Bluetooth communication.

*a) **Connect** to FlowTracker2 handheld Device,*
i). Select "Device" menu option on main menu banner,
ii). Connection window will appear on software window with USB and Bluetooth communication options.

*b) **Select** communication medium,*
i). USB - Make sure USB cable is connected before USB option is selected,
ii). Bluetooth – Select handheld serial number from dropdown list and select the "Connect" function.

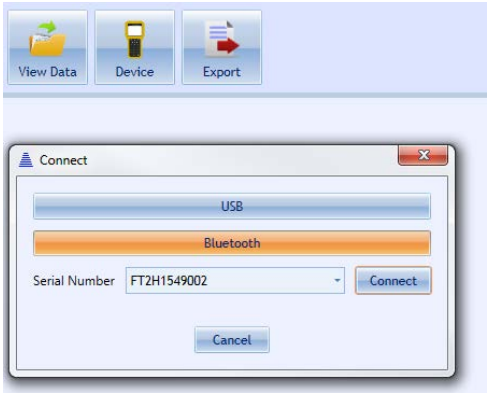


Figure 11:3 - Device Communication Window

If the handheld serial number is not listed, select the content in the box using mouse and start typing the serial number. When the serial number is entered, select "Connect" function. The desktop software will connect to the handheld using bluetooth and the serial number will be stored for future use.

Step3 – Desktop Software

Perform **Upgrade** of handheld software and or ADV firmware by selecting the upgrade function on the FlowTracker2 desktop software.

*a) Perform **Upgrade** of FlowTracker2 device,*
i). Select "Upgrade" menu option,
ii). Open file window will appear with the available firmware file.
iii). Select the firmware file within the "Open File" window and select "Open" function.

*b) Upgrade progress **Status***

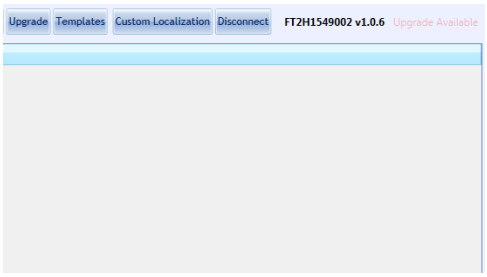


Figure 11:4 - Upgrade Function

i). The FlowTracker2 desktop software gives progress status in percentage of the upgrade.

11.1.2 Upgrading ADV Firmware

The ADV firmware upgrade is performed separately from the FlowTracker2 handheld software upgrade. The user is required to either request system information or initiate data collection from the ADV to activate the firmware upgrade process.

Requesting the **Probe System Information** under System Information (Main Menu)on the handheld is the most efficient way of activating the ADV to initiate the ADV firmware upgrade process.

11.2. Mounting and Installation

The FlowTracker2 is commonly mounted on a top-setting wading rod. The probe and handheld mounting have been designed with wading rod use in mind, but the design is flexible enough to allow a variety of mounting arrangements. Top-setting wading rods are available from SonTek.

11.2.1 FlowTracker2 Handheld

The handheld should be secured during operation and it is recommended that the handheld is mounted to the wading rod during measurements. If the FlowTracker2 is not in use, the handheld should be stored in the carry case supplied.

The protective yellow jacket that is supplied with the FlowTracker2 handheld should stay on during operation. The jacket supply protection to the handheld casing, battery cap, USB port and LCD screen.

11.2.2 Handheld Mounting Bracket

Top Setting Rod mounting bracket to connect the handheld to the top of top setting wading rod.

a) A mounting bracket compatible with the mounting pin on a top-setting wading rod is available from SonTek.

b) The handheld includes one threaded insert on the back, which secures the SonTek-supplied mounting brackets.

c) The handheld mounting simplifies the measurement process and allow the user to focus on the measurement and orientation of the probe.



Figure 11:5 - Top Setting Rod Handheld Mounting

Universal Rod mounting bracket to connect the handheld to the universal wading rod.

d) A mounting bracket compatible with a 20mm universal-style wading rod is available from SonTek.

e) Neck/shoulder strap for the handheld which fits the threaded insert is available from SonTek.



Figure 11:6 - Universal Rod Handheld Mounting

The threaded insert can also be used to secure a user-supplied mounting bracket. The size of the threaded insert is ¼-20. User-supplied mounting brackets should avoid direct contact with the keypad and screen.

11.2.3 **Probe Mounting Bracket**

Top Setting Rod J-Bracket to connect the 2D or 2D/3D Flowtraker2 probe to the top setting wading rod.

a) The J-Bracket is available for mounting the probe from a top-setting wading rod. Both the bracket and complete wading rods are available from SonTek.

b) The J-Bracket offsets the probe to one side of the wading rod, placing the sampling volume closer to the wading rod, approximately 5 cm (2 in) to one side.

c) The bracket allows the wading rod to be used in its standard “forward” orientation.



Figure 11:7 - Top Setting Rod J-Bracket

Universal Rod J-Bracket to connect the 2D or 2D/3D Flowtraker2 probe to the universal wading rod.

d) A J-Bracket compatible with a 20mm universal-style wading rod is available from SonTek.



Figure 11:8 – Universal Rod J-Bracket

11.3. Routine Maintenance

11.3.1 Battery Power Supply

Batteries should be checked on a routine basis and it is recommend that the following tasks are performed during routine maintenance and or completion of measurement exercise,

a) The battery voltage level should be verified by using the battery raw data graphics displayed in Battery Indicator.

Batteries should not be left in the FlowTracker2 handheld for prolonged periods as damage can occur to the handheld if the batteries are leaking. It is recommended that batteries are removed from the handheld if the instrument is not used.

b) The use-by date should be recorded and referenced during routine maintenance and it is recommended that expired batteries should not be used in FlowTracker2.

Battery manufacturer guidelines must be followed during normal use, long term storage and charging requirements. The disposal of batteries must be done with care and it is recommended that local authority guidelines be used.

11.3.2 Cleaning Instrument

11.3.2.1 Handheld

The handheld will require some cleaning after use as the accumulation of dirt on the handheld can damage the component such as the LCD screen, USB port, probe cable connector and keypad. It is recommended that a cloth is used to wipe the handheld or soft brush.

In the case where the handheld was submerged under water or where it is covered in mud and need to be rinsed, the following guidelines should be followed,

a) Do not remove the probe cable or battery cap while the handheld is under water or drenched.

b) Use a dry cloth and remove excess moisture on the outside of the handheld.

c) Remove the “yellow Jacket” from the handheld casing and apply a dry cloth to the handheld casing.

d) Remove the probe cable and inspect if the connector pins are dry. This can indicate if there was water ingress into the connector.

e) Remove the battery cap and battery cartridge. Inspect both the battery cap and cartridge for moisture as this can indicate water ingress.

f) Remove batteries from battery cartridge and inspect for moisture.

g) Place handheld, battery cartridge, batteries and yellow jacket on a dry place (not in direct sunlight) and allow to dry.



If water ingress was identified during inspection in the battery compartment or probe cable connector contact SonTek. It is not recommended to use the instrument if there is moisture in the battery compartment.

11.3.2.2 Transducers

Biological growth on the transducers does not affect velocity measurements, but can decrease acoustic signal strength and potentially increase noise in velocity data in clear water.

a) Periodic cleaning of the FlowTracker2 transducers may be needed to maintain optimal performance in areas of high biological activity,

b) FlowTracker2 transducers are encapsulated in an epoxy that is impervious to damage from barnacles or other types of growth,

c) To remove growth, simply clean with a cloth or stiff (non-metallic) brush. The transducer epoxy is very durable and cannot be easily damaged except by direct impact.

11.3.3 **Cable Maintenance**

The FlowTracker2 probe cable is often the most vulnerable part of the system.

a) The cable uses a durable polyurethane jacket that provides excellent long-term wear and abrasion resistance,

b) Any cable is susceptible to damage and reasonable precautions should be taken,

c) Inspect the cable and all connectors on a regular basis,

d) This cable is highly noise-sensitive and should not be modified by the user.

11.3.4 **O-rings**

The FlowTracker2 handheld makes use of two O-ring seals and it is important that the following guidelines are followed.

11.3.4.1 Housing

a) The handheld is designed to withstand temporary submersion, but is not intended for underwater operation.

b) We do not recommend opening the handheld housing without specific instructions from SonTek.

11.3.4.2 Battery Cap

a) The O-ring located on the battery cap prevents moisture entering the battery compartment.

b) Inspection of the O-ring should be during Hardware Inspection for any cracks or defects that may exist on the O-ring.

c) The batter cap, O-ring and battery compartment must be inspected for any moisture, dirt or material that can damage the O-ring, battery or battery connectors.

11.3.5 **Condensation in FlowTracker2 Housing**

Moisture in the air can potentially damage FlowTracker2 electronics if allowed to condense inside the handheld housing.

a) The handheld is shipped with a desiccant pack inside to absorb moisture,

b) We do not recommend opening the handheld housing without specific instructions from SonTek. If the housing has not been opened, the desiccant should not need to be replaced.

11.3.6 **Zinc Anodes for Corrosion Protection**

When using the FlowTracker2 in salt water, additional precautions must be taken to prevent corrosion.

a) A sacrificial zinc anode should be installed on the probe (attached to the metal portion of the probe stem),

b) Anode condition should be inspected regularly, and the anode should be replaced when necessary. Zinc anodes are available from SonTek,

c) To check anode condition, try to chip away part of the anode with a screwdriver. If large portions of the anode easily fall away, the anode should be replaced,

d) The probe and cable should be thoroughly rinsed with fresh water after each use.

11.4. Seeding

11.4.1 Scattering Material

If FlowTracker2 velocity data appears “noisy”, the most common cause is a lack of scattering material in the water.

a) Acoustic Doppler Velocimeters require scattering material for velocity measurements (see Principle of Operations),

b) A lack of scattering material can increase noise in velocity data. If insufficient scattering material is present, the FlowTracker2 will not be able to accurately measure velocity,

c) In most field applications, there is sufficient scattering material naturally present,

d) Large, quiet laboratory tanks often have insufficient natural scattering material,

e) To evaluate seeding requirements, use the raw data display from the handheld interface,

   i). For ideal operating conditions, the SNR should be above 10 dB,

   ii). The FlowTracker2 can operate reliably with SNR as low as 3-4 dB.

f) A lack of scattering material can be remedied by adding seeding.

11.4.2 Field Applications

For field applications, seeding can be introduced by stirring the bottom (e.g., walking across the river upstream of the measurement location). In some situations, seeding material will need to be introduced. An ideal seeding material should have the following qualities.

- Neutrally buoyant (to remain in suspension for a long period),
- Mean particle diameter of 10-20 µm (for peak sensitivity of the acoustic signal),
- Inexpensive, readily available, with no adverse effects on the operating environment.

The best seeding material we have found (from an acoustics point of view) are hollow glass spheres with a mean diameter about 10 µm and a mean density close to that of water.

- Small quantities of this material are available from SonTek,
- Larger quantities can be purchased from the manufacturer at the address below,

Potters Industries
Valley Forge PA USA
Phone: +1-610-651-4700
Internet: www.pottersbeads.com
Part name: Potters Sphericel

For most applications, a more practical seeding material is lime or pulverized limestone (the chalk commonly used on athletic fields).

- Large bags are inexpensive and readily available from most hardware stores,
- While not perfect, the acoustic performance is sufficient for most applications,
- A variety of distribution arrangements can be arranged to seed even very large tanks,
- A note of caution: repeated addition will gradually increase the pH in a tank (in addition to creating a layer of lime/limestone on the bottom of the tank).

11.5. Troubleshooting

This section provides suggestions for diagnosing problems with the FlowTracker2. If you have trouble finding the source of a problem, please contact SonTek.

11.5.1 Cannot Turn System On

FlowTracker power-up problems are usually related to the power supply.

a) Check or replace the existing batteries.

b) Verify that all batteries are correctly oriented as shown on the battery holder.

c) Ensure the battery cap is threaded correctly and securely screwed-down.

d) Press the On/Off power button for at least one second.

e) Try to establish direct communication using USB cable.

11.5.2 Cannot Communicate with the FlowTracker2

If you are unable to establish external communications with the FlowTracker2 using the FlowTracker2 desktop software, the following may be helpful in identifying the cause.

11.5.2.1 Handheld

a) Verify the power supply of the FlowTracker2 handheld by reviewing the battery indicator in the top banner or Battery Data under Utilities menu.

b) The Communication function on the main menu must be selected.

11.5.2.2 Communication

a) If using USB connection,

   i). Inspect the cable and connectors for any defects,
   ii). Verify both cable connectors between the FlowTracker2 and PC are securely connected.
   iii). Verify the PC's USB port is functioning correctly by communicating with a different USB device.
   iv). If the communication is still unsuccessful use a different USB cable and or PC.

b) If using Bluetooth connection,

   i). Verify the PC's Bluetooth function is turned on and enabled.

ii). In the FlowTracker2 software, ensure the instrument serial number is typed in correctly, in the “Connect” dialog box.
iii). Ensure the FlowTracker2 and PC is within nominal range of each other (10m or 32.8 ft). If possible, decrease the distance between the FlowTracker2 and PC.
iv). Verify the PC’s Bluetooth is functioning correctly by communicating with a different Bluetooth device.
v). If communication is still unsuccessful use a different PC.

11.5.3 **Cannot Retrieve Data from Internal Recorder**

- Verify through the FlowTracker2 handheld screen that the data files are present on the recorder.
- Ensure you are waiting an adequate amount of time for the download to complete. Download times can vary with computer hardware.

11.5.4 **Velocity Data Appears Noisy or Unreasonable**

If the velocity data from the FlowTracker2 do not seem reasonable, the following list may help establish the cause.

a) Lack of scattering material in the water is the most common problem (particularly in large laboratory tanks). See the FlowTracker2 Principles of Operation for details about seeding requirements.
b) Run Beam Check as described in Beam Check. This can address all aspects of FlowTracker2 operation, in particular, signal strength (scattering/seeding issues) and probe operation.
c) Inspect the FlowTracker2 to be sure debris is not fouling the probe.
d) Verify the FlowTracker2 mounting is stable and that instrument motion is not causing noise in the velocity data.
e) Consider any possible environmental influences, particularly flow interference from underwater structures or obstacles.
f) Consider the measurement environment. Highly turbulent or highly aerated water will greatly affect FlowTracker2 operation. In highly aerated water, the FlowTracker2 may not be able to operate reliably.
g) Consider the orientation of the probe with respect to the flow direction to be sure the probe is not causing flow interference in the sampling volume.

11.5.5 **Recovery Mode**

The FlowTracker2 handheld software has a "recovery" feature that is used in case the software becomes non-operational. Several precautions have been taken during the design process of the software to minimize the possibility of this occurring. The recovery mode process are described under the following steps,

a) Power the device ON,

b) Hold the '5' button,

c) Recovery mode will load (you need to keep holding '5' until it loads),

d) Recovery mode is only in English (not translated),

e) Enabled functions:

   i). Communication - use Desktop software to download files or upgrade handheld software and or probe firmware,

   ii). Reset to factory defaults - will format the SD card and return to factory state (all files will be deleted, the upgraded handheld software and or probe firmware will be erased as well).

11.6. Health and Safety

Safety in the work environment is a key requirement in most organizations and this also applies to the application of FlowTracker2 instrument. The following aspects need to be considered when planning to perform discharge measurements using FlowTracker2 instrument.



It is imperative that the user follow their respective organization and or local authority guidelines in Health and Safety requirements in the work environment.

11.6.1 **Planning Field Work**

Planning and developing a field trip itinerary is the first step of the discharge measurement process. The following components should be included in the field trip itinerary,

a) Contact number (mobile or satellite phone),

b) Personnel included in field trip,

c) Vehicle description (make, model, registration),

d) Departure and Return date from field trip,

e) Date of visiting measurement site and or group of sites,

f) Measurement Site Location and or Hydrographic Site Numbers,

g) Work to be performed at each measurement site,

h) Contact details of accommodation (if overnight destination is required)

11.6.2 **Communication**

Field communication is essential for operational purposes and it improves the Health and Safety process. It is suggested that the following criteria be followed where feasible,

a) Contact office before and after measurement is completed. Normally this is only required during flood events to inform the office that the measurements were completed and all personnel is safely off the water,

b) Contact office at scheduled times when staying overnight, e.g., 8am and or 4pm every day. This allows the field personnel to give feedback on fieldwork and or measurements, discussing additional work that need to be performed and verify health and safety aspects,

c) Property owners such as farmers, local authority, etc. require persons to acquire approval in advance before accessing their property. In certain cases it is also required to contact the property owner when departing and this need to be verified with the owner.

11.6.3 **Measurement Site Conditions**

Measurement site conditions encapsulate a number of hydraulic and physical factors that determines if it is feasible to perform a discharge measurement. The application of the FlowTracker2 instrument using the "wading" method is directly related to these conditions. The following are some aspects that need to be taken into account before a measurement is undertaken,

a) Total water depth,

b) Maximum water velocity,

c) Surface waves present,

d) Moving bed present(sediment or rocks)

e) Debris on water surface

f) Wild life (Alligators, Crocodiles, etc.)

If measurement site conditions are such that it is unsafe to perform a wading measurement with a FlowTracker2 instrument it is suggested that a different approach is taken in determining the discharge.



Figure 11:9 – RiverSurveyor M9 – Moving Boat Method

SonTek manufactures RiverSurveyor S5 and M9 instruments that are based on the Acoustic Doppler Current Profiler principle. These instruments can be used from multiple platforms such hydroboards, manned boats or remote control boats in the following discharge measurement methods,

i). Moving Boat Measurement,

ii). Stationary Measurement.

Section 12. FlowTracker2 File Format

12.1. FlowTracker2 JSON File

The FlowTracker2 measurement file was developed on the JSON format. The handheld and desktop software uses the FlowTracker2 measurement files structure (see Table 4:2) as the primary format for the storage of system information, configuration, raw data, calculations and post processing. The measurement files with .ft extension created from the FlowTracker2 handheld can be directly imported into the FlowTracker2 desktop software for evaluation and post processing if required.

The FlowTracker2 measurement file with .ft extension is essentially a ZIP file that combines the different JSON files created during the measurement.

Changing the extension from .ft to .zip should not be performed on the original FlowTracker2 measurement file. It is recommended that if this action is required a duplicate copy of the measurement file is created. It is expected that this action is only required by advanced users to extract the data in either a database or 3rd party evaluation software.

The FlowTracker2 measurement file consists of three different file types given below. The Beam Check and Point measurement files are placed in sub folders to separate from the main Data File.

a) Beam Check,
b) Point Measurements
c) Data File

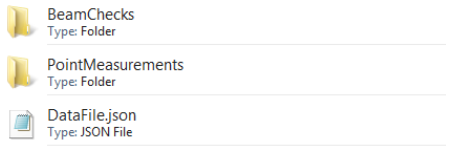


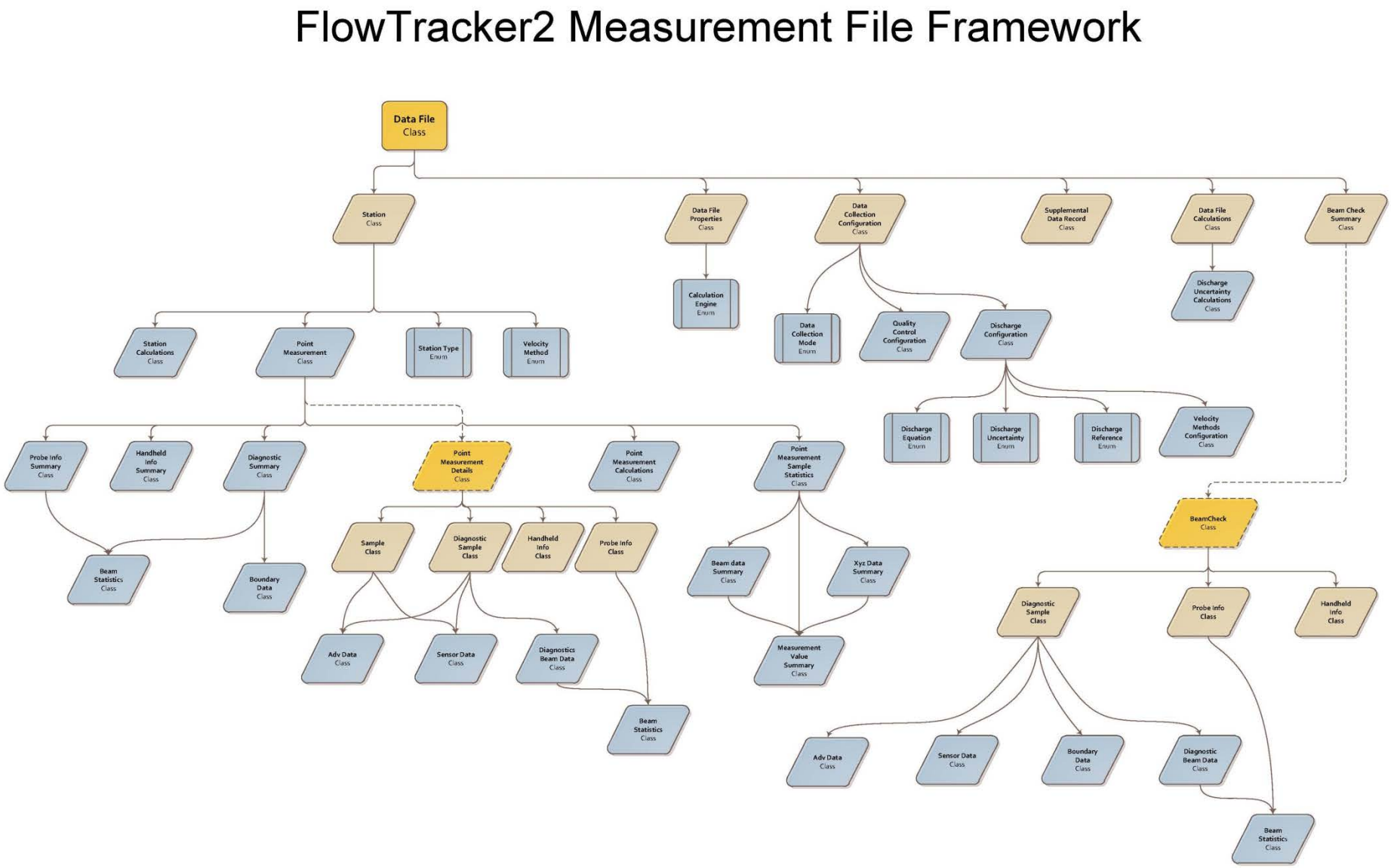
Figure 12:1 - FlowTracker2 Measurement File

JSON file is created for each Beam Check and Point Measurement performed during the FlowTracker2 measurement and stored in respective sub folders. The number of point measurement files can be significant depending on the number of point velocity measurement performed in Discharge or General Mode.

KISTERS developed an import script for the FlowTracker2 measurement file (JSON) for both Hydstra and WISKI Time Series Data Management Systems. SonTek involved KISTERS from the initial development stage of the measurement file structure to ensure that the import of FlowTracker2 data is seaming less.

Further information on the JSON format can be accessed from the JSON website (www.json.org/).

12.1.1 **Measurement File Framework**



12.1.2 **Measurement File Structure**

DataFile						Base Type	Description
Main Tier	**1st Tier**	**2nd Tier**	**3rd Tier**	**4th Tier**	**5th Tier**		
Properties: DataFileProperties	StartTime					DateTime	
	EndTime					DateTime	
	SiteNumber					String	
	SiteName					String	
	Operator					String	
	Comment					String	
	LocalTimeUtcOffset					TimeSpan	
	CalculationsEngine					CalculationsEngine	
Configuration: DataCollectionConfiguration	DataCollectionMode					DataCollectionMode	
	AveragingTime					TimeSpan	
	SamplingRate					Double	
	Salinity					Double	
	Temperature					Double	
	SoundSpeed					Double	
	MountingCorrection					Double	
	QualityControl: QualityControlConfiguration	SnrThreshold				Double	
		StdErrorThreshold				Double	
		SpikeThreshold				Double	
		VelocityAngleForWarning				Double	
		TiltAngleForWarning				Double	
	Discharge: DischargeConfiguration (optional)	DischargeEquation				DischargeEquation	
		DischargeUncertainty				DischargeUncertainty	
		DischargeReference				DischargeReference	
		MaxStationDischargeForWarning				Double	
		MaxDepthChangeForWarning				Double	
		MaxSpacingChangeForWarning				Double	
		SixTenthsMethodDepth				Double	
		VelocityMethods: VelocityMethodsConfiguration	TwoTenthsSixTenthsEightTenths			Boolean	
			Kreps			Boolean	
			FivePoint			Boolean	
			SixPoint			Boolean	
			VerticalVelocityCurve			Boolean	
HandheldInfo: HandheldInfo							
Stations: List<Station>	Id					Guid	
	CreationTime					DateTime	
	Gps					GpsRecord (optional)	
	Location					Double	
	LocationY					Double (optional)	
	Depth					Double	
	Depth2					Double (optional)	
	StationType					StationType	

DataFile						Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier	5th Tier		
	VelocityMethod					VelocityMethod	
	ManualVelocity					Double (optional)	
	IceThickness					Double (optional)	
	WaterSurfaceToBottomOfIce					Double (optional)	
	WaterSurfaceToBottomOfSlush					Double (optional)	
	CorrectionFactor					Double	
	Comment					String	
	PointMeasurements: List<PointMeasurement>(optional)	Id				Guid	
		FractionalDepth				Double	
		DistanceFromBottom				Double	
		StartTime				DateTime	
		EndTime				DateTime	
		SampleStatistics: PointMeasurementSampleStatistics	OriginalVelocity: XyzDataSummary	X: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
				Y: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
				Z: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
			DespikedVelocity: XyzDataSummary	X: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
				Y: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
				Z: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
			Temperature: MeasurementValueSummary	Min		Double	
				Max		Double	

DataFile						Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier	5th Tier		
				Average		Double	
				StandardDeviation		Double	
				Count		Int32	
			Pressure: MeasurementValueSummary	Min		Double	
				Max		Double	
				Average		Double	
				StandardDeviation		Double	
				Count		Int32	
			BatteryVoltage: MeasurementValueSummary	Min		Double	
				Max		Double	
				Average		Double	
				StandardDeviation		Double	
				Count		Int32	
			Tilt: MeasurementValueSummary	Min		Double	
				Max		Double	
				Average		Double	
				StandardDeviation		Double	
				Count		Int32	
			Snr: BeamDataSummary	Beam0: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
				Beam1: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
				Beam2: MeasurementValueSummary	Min	Double	
					Max	Double	
					Average	Double	
					StandardDeviation	Double	
					Count	Int32	
		Calculations: PointMeasurementCalculations	Warnings			QualityControlWarnings	
			Velocity			XyzData	
			VelocityStandardError			XyzData	
			FlowAngle			Double	
			Snr			BeamData	
			SnrStandardDeviation			BeamData	
			Samples			Int32	
			Spikes			Int32	
			Tilt			Double	
			BoundaryAvoidance			BoundaryAvoidanceStatus	

DataFile						Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier	5th Tier		
		Diagnostics: DiagnosticsSummary	Boundary: BoundaryData	BoundaryRange		Double	
				VelocityAmbiguity		Double	
				VelocityResolution		Double	
			Beams: ReadOnlyCollection< BeamStatistics>	NoiseLevel		Double	
				PeakLocation		Double	
				PeakLevel		Double	
		HandheldInfo: HandheldInfoSummary	SoftwareVersion:			String	
			WadingRod			WadingRod	
			Units			UnitType	
		ProbeInfo: ProbeInfoSummary	SerialNumber			String	
			FirmwareVersion			String	
			NumberOfBeams			Int32	
			NominalBeamStatistics: ReadOnlyCollection<BeamStatistics>	NoiseLevel		Double	
				PeakLocation		Double	
				PeakLevel		Double	
	Calculations: StationCalculations	Warnings				QualityControlWarnings	
		MeanVelocityInVertical				XyzData	
		MeanPanelVelocity				XyzData	
		Width				Double	
		Area				Double	
		Discharge				Double	
		FractionOfTotalDischarge				Double	
		Snr				BeamData	
		Temperature				Double	
		VelocityAngle				Double	
		BoundaryAvoidance				BoundaryAvoidanceStatus	
		Samples				Int32	
		Spikes				Int32	
		Tilt				Double	
		VelocityStandardError				XyzData	
SupplementalDataRecord: List<SupplementalDataRecord> (optional)	Time					DateTime	
	GaugeHeight					Double	
	RatedDischarge					Double	
	Comment					String	
Calculations: DataFileCalculations	Warnings					QualityControlWarnings	
	Area					Double	
	Discharge					Double	
	Width					Double	
	Velocity					XyzData	
	VelocityStandardError					XyzData	
	Depth					Double	
	Snr					Double	
	Temperature					Double	

DataFile						Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier	5th Tier		
	RatedDischarge					Double	
	GaugeHeight					Double	
	UncertaintyIso: DischargeUncertaintyCalculations	Accuracy				Double	
		Depth				Double	
		Velocity				Double	
		Width				Double	
		Method				Double	
		NumberOfStations				Double	
		Overall				Double	
	UncertaintyIve: DischargeUncertaintyCalculations	Accuracy				Double	
		Depth				Double	
		Velocity				Double	
		Width				Double	
		Method				Double	
		NumberOfStations				Double	
		Overall				Double	
BeamChecks: List<BeamCheckSummary>	Id					Guid	
	Time					DateTime	
	NumberofSamples					Int32	
	AutoQualityControlWarnings					QualityControlWarnings	

Point Measurement Details					Base Type	Description
Main Tier	**1st Tier**	**2nd Tier**	**3rd Tier**	**4th Tier**		
Id					Guid	
SamplingRate					Double	
Samples: ReadOnlyCollection<Sample>	Time				DateTime	
	Adv: AdvData	Velocity			XyzData	
		Snr			Double	
	Sensors: SensorData	Temperature			Double	
		SoundSpeed			Double	
		Pressure			Double	
		Voltage			Double	
		Accelerometer			XyzData	
Diagnostics: DiagnosticsSample	Time				DateTime	
	Adv: AdvData	Velocity			XyzData	
		Snr			Double	
	Sensors: SensorData	Temperature			Double	
		SoundSpeed			Double	
		Pressure			Double	
		Voltage			Double	
		Accelerometer			XyzData	
	Boundary				BoundaryData	
	ProfileRange: ReadOnlyCollection				Double	
	Beams: ReadOnlyCollection<DiagnosticsBeamData>	Statistics: BeamStatistics	NoiseLevel		Double	
			PeakPosition		Double	
			PeakLevel		Double	
		Profile: ReadOnlyCollection			Double	
DataCollectionConfiguration: DataCollectionConfiguration (optional)						
HandheldInfo: HandheldInfo	SerialNumber				String	
	SoftwareVersion				String	
	BoardsInfo				String	
	CpuSerialNumber				String	
	OperatingSystem				String	
	Settings				Object (optional)	
ProbeInfo: ProbeInfo	InstrumentType				String	
	SerialNumber				String	
	FirmwareVersion				String	
	NumberOfBeams				Int32	
	NominalBeamStatistics: ReadOnlyCollection<BeamStatistics>	NoiseLevel			Double	
		PeakPosition			Double	
		PeakLevel			Double	
	RawConfiguration				Object (optional)	
Spikes: ReadOnlyCollection					Int32	

Beam Check					Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier		
Id					Guid	
HandheldInfo: HandheldInfo	SerialNumber				String	
	SoftwareVersion				String	
	BoardsInfo				String	
	CpuSerialNumber				String	
	OperatingSystem				String	
	Settings				Object (optional)	
ProbeInfo: ProbeInfo	InstrumentType				String	
	SerialNumber				String	
	FirmwareVersion				String	
	NumberOfBeams				Int32	
	NominalBeamStatistics: ReadOnlyCollection<BeamStatistics>	NoiseLevel			Double	
		PeakPosition			Double	
		PeakLevel			Double	
	RawConfiguration				Object (optional)	
Samples: ReadOnlyCollection<DiagnosticSample>	Time				DateTime	
	Adv: AdvData	Velocity			XyzData	
		Snr			Double	
	Sensors: SensorData	Temperature			Double	
		SoundSpeed			Double	
		Pressure			Double	
		Voltage			Double	
		Accelerometer			XyzData	
	Boundary: BoundaryData	BoundaryRange			Double	
		VelocityAmbiguity			Double	
		MaxPingPrecision			Double	
	ProfileRange: ReadOnlyCollection				Double	
	Beams: ReadOnlyCollection<DiagnosticsBeamData>	Statistics: BeamStatistics	NoiseLevel		Double	
			PeakPosition		Double	
			PeakLevel		Double	
		Profile: ReadOnlyCollection			Double	
AutoQualityControlWarnings					QualityControlWarnings	

XyzData					Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier		
X					Double	
Y					Double	
Z					Double	

BeamData					Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier		
Beam0					Double	
Beam1					Double	
Beam2					Double	

GpsRecord					Base Type	Description
Main Tier	1st Tier	2nd Tier	3rd Tier	4th Tier		
DeviceTime					DateTime	
SatelliteTime					TimeSpan	
Latitude					Double	
Longitude					Double	
FixQuality					Int32	
NumberOfSatellites					Int32	
Hdop					Double	
Altitude					Double	
GeoidalSeparation					Double	

12.2. FlowTracker2 CSV Output

Comma Separated Values (CSV) file format is a basic output designed for easy access and interpretation of the data with the most common variables of FlowTracker2 incorporated.

The variables included in the CSV format are similar to Original FlowTracker2 ASCII exports and existing users will be familiar with the layout and content.

12.2.1 CSV File Structure

The **Comma Separated Values** files created during the export process consists of four CSV files, defined by unique file name that summarizes the content of the file as described in Table 12:1.

Table 12:1 - CSV File Types

File	Name	Description	Data Layout
ctl	Control	System configuration data	Rows
dat	Raw Data	Raw, one-second velocity and SNR data	Columns
dis	Discharge	Final data results in a self-explanatory form that is easy to integrate with database utilities	Rows, Columns
sum	Summary	Velocity and quality control data from all measurements	Columns

The layout of the data in each of the CSV files is organized based on Rows, Columns or a combination of both. The data descriptions for the Row or Column layout are defined in Table 12:2.

The Desktop Software Build Version is written in the first row of each CSV file independent if the file layout is based on Row or Columns. The units included for each variable in the CSV files are separated from the file name and data.

Table 12:2 - CSV Row and Column

Type	Number	Description
Row \ Column	1st	Row contain Desktop Software Build version
Column	2nd	Row contain the variable \ parameter name
	3rd	Row contain the units
	4th	Row contain the first data line
Row	2nd	Column contain variable \ parameter name
	3rd	Column contain the units
	4th	Column contain X component or Beam 1
	5th	Column contain Y component or Beam 2

12.2.2 **CSV Variables**

The **Variables** that are exported in each of the Comma Separated Values files are defined in the following tables with the variable name, description and applicability to either the Discharge or General Modes.

The **Control** file consists of all the system information for both the handheld and probe and the quality control parameter settings based on either default or user configuration. The variables exported in the control file are given in Table 12:3.

Table 12:3 - Control File Variables

Variable	Mode	Description
Desktop_Software_Build_Version	D, G	Version of desktop software
Number_Of_Stations	D, G	Station number
Start_Time	D, G	Start time of measurement
End_Time	D, G	End time of measurement
Local_Time_UTC_Offset_Hours	D, G	Local time offset for UTC in hours
Handheld_Serial_Number	D, G	Handheld serial number
Handheld_CPU_Serial_Number	D, G	Handheld CPU serial number
Handheld_Boards_Info	D, G	Handheld boards info
Handheld_Software_Version	D, G	Handheld software version
Handheld_Operating_System	D, G	Handheld operating system
Wading Rod	D	Type of wading rod
ADV_System_Frequency	D, G	ADV system frequency
ADV_Serial_Number	D, G	ADV serial number
ADV_Firmware_Version	D, G	ADV firmware version
ADV_Number_Of_Beams	D, G	ADV number of beams
ADV_Noise_Level	D, G	ADV noise level
ADV_Peak_Position	D, G	ADV peak position
ADV_Peak_Level	D, G	ADV peak level
Configuration_Data_Collection_Mode	D, G	Data collection mode
Configuration_Averaging_Time	D, G	Averaging time
Configuration_Sampling_Rate	D, G	Sampling rate
Configuration_Salinity	D, G	Salinity measured using external sensor
Configuration_Temperature	D, G	Temperature internal or external measured
Configuration_Sound_Speed	D, G	Sound Speed calculated or external measured
Configuration_Mounting_Correction	D, G	Mounting Correction in percentage
Configuration_Quality_Control_SNR_Threshold	D, G	SNR Threshold for quality control process
Configuration_Quality_Control_Std_Error_Threshold	D, G	Std Error Threshold for quality control process
Configuration_Quality_Control_Spike_Threshold	D, G	Spike Threshold for quality control process
Configuration_Quality_Control_Velocity_Angle_For_Warning	D, G	Velocity Angle for quality control process
Configuration_Quality_Control_Tilt_Angle_For_Warning	D, G	Tilt Angle for quality control process
Configuration_Discharge_Equation	D	Discharge equation used for discharge calculation

Variable	Mode	Description
		in measurement section
Configuration_Discharge_Reference	D	Specify type of external discharge used to reference discharge measurement
Configuration_Discharge_Quality_Control_Max_Station_Discharge_For_Warning	D	Max station discharge for quality control process
Configuration_Discharge_Quality_Control_Max_Depth_Change_For_Warning	D	Max depth change for quality control process
Configuration_Discharge_Quality_Control_Max_Spacing_Change_For_Warning	D	Max spacing change for quality control process
Configuration_Discharge_Velocity_Methods	D	Discharge velocity methods used in determining mean velocity

The **Raw Data** file consists of the one second velocity, SNR and acceleration data with date and time stamp. The variables exported in the raw data file are given in Table 12:4.

Table 12:4 - Raw Data File Variables

Variable	Mode	Description
#	D, G	Burst or measurements number
Year	D, G	Year
Month	D, G	Month
Day	D, G	Day
Hour	D, G	Hour
Minute	D, G	Minute
Second	D, G	Second
VelX	D, G	Raw 1 second X velocity
VelY	D, G	Raw 1 second Y velocity
VelZ	D, G	Raw 1 second Z velocity
SNR1	D, G	Signal-to-Noise Ratio beam 1
SNR2	D, G	Signal-to-Noise Ratio beam 2
SNR3	D, G	Signal-to-Noise Ratio beam 3
AccX	D, G	Raw 1 second X acceleration
AccY	D, G	Raw 1 second Y acceleration
AccZ	D, G	Raw 1 second Z acceleration

The **Discharge** file consists of system information, site details, quality control checks, Beam Checks, uncertainty calculations, supplemental data and all station data related to discharge measurement. The variables exported in the discharge file are given in Table 12:5.

Table 12:5 - Discharge File Variables

Variable	Mode	Description
Desktop_Software_Build_Version	D, G	Version of desktop software
Site_Name	D, G	Name of measurement site
Site_Number	D, G	Number of measurement site
Local_Start_Time	D, G	Local start time of measurement

Variable	Mode	Description
Local_End_Time	D, G	Local end time of measurement
Local_Time_UTC_Offset_Hours	D, G	Local time offset for UTC in hours
Operator	D, G	Operator
Handheld_Serial_Number	D, G	Serial number of handheld
Handheld_Software_Version	D, G	Software version of handheld
Wading Rod	D	Type of wading rod
Handheld_Units_System	D, G	Metric or English
Number_Of_Probes	D, G	Number of ADV used during measurement. Software allows user to interchange ADV during measurement
ADV_Serial_Number	D, G	Serial number of ADV
ADV_Firmware_Version	D, G	Firmware version of ADV
ADV_Number_Of_Beams	D, G	Number of beams
Comment	D, G	Comment entry field
Calculations_Engine	D, G	Calculation engine
Number_Of_Stations	D, G	Number of stations in a measurement
Discharge_Equation	D	Discharge equation used for calculation
Rated_Discharge	D	Rated flow based on measuring site stage discharge relationship
Rated_Height	D	Gauge Height taken for water level reference
Minimum_Boundary_Status	D, G	Undefined or lowest of boundary conditions found
Total_Width	D	Total width of measurement section
Total_Area	D	Total area of measurement section
Total_Discharge	D	Total discharge of measurement
Mean_Depth	D, G	Average depth of the section
Mean_Velocity_Vx	D	The area-weighted panel velocity averaged over the entire section for X velocity
	G	Mean Vx is the mean of the X velocity of all point velocity measurements.
Mean_Velocity_Vy	D	The area-weighted panel velocity averaged over the entire section for Y velocity
	G	Mean Vy is the mean of the Y velocity of all point velocity measurements.
Mean_Velocity_Vz	D	The area-weighted panel velocity averaged over the entire section for Z velocity
	G	Mean Vz is the mean of the Z velocity of all point velocity measurements.
Mean_SNR	D, G	Mean SNR of all point velocity measurements
Mean_VxErr	D	Mean Vx Standard Error of each station X velocity standard error.
	G	Mean Vx Standard Error is the mean of the X velocity standard error of all point velocity measurements.
Mean_VyErr	D	Mean Vy Standard Error of each station Y velocity standard error.
	G	Mean Vy Standard Error is the mean of the Y velocity standard error of all point velocity

Variable	Mode	Description
		measurements.
Mean_VzErr	D	Mean Vz Standard Error of each station Z velocity standard error.
	G	Mean Vz Standard Error is the mean of the Z velocity standard error of all point velocity measurements.
Mean_Temp	D	Mean Temperature is the mean of all the station temperature measurements
	G	Mean Temperature of all point temperature measurements
Quality_Control_Checks	D, G	**Quality_Control_Checks**
Station_Spacing	D	Spacing between stations has changed by more than Max Location Change **%.**
Station_Order	D	Station location out of sequence or outside river edge.
Water_Depth	D, G	Station depth differs from adjacent stations by more than Max Depth Change **%.**
Boundary_Interference	D, G	Evaluates the measurement environment for interference from underwater obstacles
Fractional_Depth	D	Verify ratio between measurement depth and total depth and this should not >1
Low_SNR	D, G	Warning if SNR below 4dB
Approaching_Low_SNR	D, G	Warning if SNR between 4dB and 7 dB
Beam_SNRs_Not_Similar	D, G	Difference in SNR for any 2 beams is > SNR Threshold
Large_SNR_Variation	D, G	One-second SNR data varies more than expected during a measurement along a single beam.
SNR_Threshold_Variation	D	SNR more than SNR Threshold different previous measurements
Velocity_Standard_Error	D, G	σV (standard error of velocity) is a direct measure of the accuracy of velocity data.
Percent_Of_Spikes	D, G	The percentage of spikes within a point velocity measurement.
Velocity_Angle	D, G	The flow angle towards the ADV.
Rod_Angle	D, G	The angle of the wading rod from the vertical
Station_Discharge	D	Station contains a large portion of the total discharge.
End_Edge_Location	D	Station location out of sequence or outside river edge.
Noise_Level	D, G	Shows the electronics noise level for the receiver of each beam
Peak_Location	D, G	The physical location of the sampling volume
Peak_Shape	D, G	The shape of the sampling volume
Pre_Calculation_Validation	D, G	Consistency check on station data (e.g. edges, island edges, etc.)
Discharge_Uncertainty_ISO	D	**Discharge_Uncertainty_ISO**
Overall	D	Overall
Accuracy	D	Accuracy

Variable	Mode	Description
Depth	D	Depth
Velocity	D	Velocity
Width	D	Width
Method	D	Method
#_Stations	D	Number of Stations
Discharge_Uncertainty_IVE	D	**Discharge_Uncertainty_IVE**
Overall	D	Overall
Accuracy	D	Accuracy
Depth	D	Depth
Velocity	D	Velocity
Width	D	Width
Supplemental_Data	D	**Supplemental_Data**
Record_Number	D	Sequence number assigned to each data entry
Date_And_Time	D, G	Date and time when the supplement data was recorded.
Gauge_Height (m)	D, G	Gauge height reading
Rated_Discharge (m^3/s)	D, G	Rated flow based on stage discharge relationship
Comments	D, G	Comments regarding supplement data
Automated_BeamCheck	D, G	**Automated_BeamCheck**
Record_Number	D, G	Sequence number assigned to each automated beam check.
Date_And_Time	D, G	Date and time of automated beam check.
Noise_Level_Check	D, G	Measured electronics noise level is compared to reference data.
SNR_Check	D, G	The SNR is checked as sufficient for reliable data collection
Peak_Location_Check	D, G	The physical location of the sampling volume is compared to the expected location
Peak_Shape_Check	D, G	The shape of the sampling volume curve is compared to the expected shape.
Station Data	D, G	**Station Data**
St	D, G	Station number
Clock	D, G	Measurement time from FlowTracker2 clock
GPSLat	D, G	GPS Latitude
GPSLon	D, G	GPS Longitude
Loc	D, G	Station location
LocY	D, G	Station location Y
FinalD	D, G	Mid and Mean Section methods, same as Depth. Japanese method, average of Depth and Depth2
IceD	D, G	Ice thickness
WsIceD	D, G	Water surface to bottom of ice
WsSlushD	D, G	Water surface to bottom of slush
%Dep	D, G	Measurement depth location, as fraction of the effective depth
MeasD	D, G	Point measurement depth, measured form the water surface

Variable	Mode	Description
Npts	D, G	Number of samples in measurement; one sample collected per second
Spike	D, G	Number of spikes removed before calculating mean values
VelX	D, G	Mean X velocity component of point velocity measurement
VelY	D, G	Mean Y velocity component of point velocity measurement
VelZ	D, G	Mean Z velocity component of point velocity measurement
Angle	D, G	Velocity angle calculated as atan (Vy/Vx)
VxErr	D, G	Standard error of X velocity
VyErr	D, G	Standard error of Y velocity
VzErr	D, G	Standard error of Z velocity
SNR1	D, G	Signal-to-Noise Ratio beam 1
SNR2	D, G	Signal-to-Noise Ratio beam 2
SNR3	D, G	Signal-to-Noise Ratio beam 3
Bnd	D, G	Boundary QC measurement
Temp	D, G	Water temperature
CorrFact	D, G	Correction factor used to scale mean station velocity
Tilt	D, G	Mean wading rod angle during point velocity measurement
MeanV	D	Mean panel velocity based on panel discharge and area.
	G	Mean V is the mean of the X velocity of all point velocity measurements.
Area	D	Station area
Flow	D	Station discharge
%Q	D	Percent of total discharge

The **Summary** file consists of the velocity method, velocity, SNR and standard error data of each point velocity measurement. The variables exported in the summary file are given in Table 12:6.

Table 12:6 - Summary File Variables

Variable	Mode	Description
Desktop_Software_Build_Version	D, G	Version of desktop software
#	D, G	Burst or measurements number
St	D, G	Station Number
Method	D, G	Discharge Measurement Method
%Dep	D, G	Measurement depth location, as fraction of the effective depth
MeasD	D, G	Point measurement depth, measured form the

Variable	Mode	Description
		water surface
Npts	D, G	Number of samples in measurement; one sample collected per second
Spike	D, G	Number of spikes removed before calculating mean values
CorrFact	D, G	Correction factor used to scale mean station velocity
Loc	D, G	Station location
LocY	D, G	Station location Y
Depth1	D, G	Total Water Depth1
Depth2	D, G	Total Water Depth2
FinalD	D, G	Mid and Mean Section methods, same as Depth. Japanese method, average of Depth and Depth2
IceD	D, G	Ice thickness
WsIceD	D, G	Water surface to bottom of ice
WsSlushD	D, G	Water surface to bottom of slush
VelX	D, G	Mean X velocity component of point velocity measurement
VelY	D, G	Mean Y velocity component of point velocity measurement
VelZ	D, G	Mean Z velocity component of point velocity measurement
Angle	D, G	Velocity angle calculated as atan (Vy/Vx)
VxErr	D, G	Standard error of X velocity
VyErr	D, G	Standard error of Y velocity
VzErr	D, G	Standard error of Z velocity
SNR1	D, G	Signal-to-Noise Ratio beam 1
SNR2	D, G	Signal-to-Noise Ratio beam 2
SNR3	D, G	Signal-to-Noise Ratio beam 3
SNRStd1	D, G	Standard Deviation of Signal-to-Noise Ratio beam 1
SNRStd2	D, G	Standard Deviation of Signal-to-Noise Ratio beam 2
SNRStd3	D, G	Standard Deviation of Signal-to-Noise Ratio beam 3
Temp	D, G	Water temperature
Batt	D, G	Battery Voltage
Tilt	D, G	Mean wading rod angle during point velocity measurement

12.3. Original FlowTracker ASCII vs JSON

Data File			Variable	Comment
Next of Kin	**Variable**	**Base Type**		
Properties: DataFileProperties	StartTime	DateTime	DIS.StartDateAndTime	
	EndTime	DateTime	last DAT.ymdhms, or other	
	SiteNumber	String	--	
	SiteName	String	DIS.SiteName	
	Operator	String	DIS.Operators	
	Comment	String		
	LocalTimeUtcOffset	TimeSpan		
	CalculationsEngine	CalculationsEngine	CalculationsEngine FlowTracker1	
Configuration: DataCollectionConfiguration	DataCollectionMode	DataCollectionMode	CTL.KeypadMode	
	AveragingTime	TimeSpan	CTL.SamplesPerBurst	
	SamplingRate	Double	CTL.SampleInterval	
	Salinity	Double	CTL.DefaultSalinity	
	Temperature	Double	CTL.DefaultTemperature, or NaN if CTL.TemperatureMode is MEASURED	
	SoundSpeed	Double	CTL.DefaultSoundSpeed, or NaN if CTL.TemperatureMode is MEASURED	
	MountingCorrection	Double	CTL.MountingCorrection	
QualityControl: QualityControlConfiguration	SnrThreshold	Double	--	
	StdErrorThreshold	Double	--	
	SpikeThreshold	Double	--	
	VelocityAngleForWarning	Double	--	
	TiltAngleForWarning	Double	--	
Discharge: DischargeConfiguration (optional)	DischargeEquation	DischargeEquation	DIS.DischargeEquation	
	DischargeUncertainty	DischargeUncertainty	--	Not exported (not useful)
	DischargeReference	DischargeReference	DIS.Rated if any supplemental data recs, else Measured	
	MaxStationDischargeForWarning	Double	--	
	MaxDepthChangeForWarning	Double	--	
	MaxSpacingChangeForWarning	Double	--	
VelocityMethods: VelocityMethodsConfiguration	TwoTenthsSixTenthsEightTenths	Boolean	--	
	Kreps	Boolean	--	
	FivePoint	Boolean	--	
	SixPoint	Boolean	--	

Data File			Variable	Comment
Next of Kin	**Variable**	**Base Type**		
	VerticalVelocityCurve	Boolean	--	
HandheldInfo: HandheldInfo			--	
Stations: List<Station>	Id	Guid	--	Not exported
	CreationTime	DateTime	DIS.StartDateAndTime plus first DIS.Clock	Exported when no point measurements at this station.
	Gps	GpsRecord (optional)	--	Only GPS lat/lon exported
	Location	Double	SUM.Loc (or DIS.Loc) (General mode: SUM.Loc1 or DIS.Loc1)	
	LocationY	Double (optional)	SUM.Loc2 or DIS.Loc2	
	Depth	Double	DIS.Depth or DIS.Depth1	Only final depth exported
	Depth2	Double (optional)	DIS.Depth2	Only final depth exported
	StationType	StationType	uses DIS.IceD, DIS.NPts, and DIS.Vel to decide	Not exported
	VelocityMethod	VelocityMethod	Guessed from DIS.FractionalDepth and DIS.Vel	
	ManualVelocity	Double (optional)	Guessed from DIS.FractionalDepth and DIS.Vel	Not exported separately but can be inferred
	IceThickness	Double (optional)	DIS.IceD	
	WaterSurfaceToBottomOfIce	Double (optional)	DIS.IceD	
	WaterSurfaceToBottomOfSlush	Double (optional)	--	
	CorrectionFactor	Double	DIS.CorrFact	
	Comment	String	--	Not exported
PointMeasurements: List<PointMeasurement>>(optional)	Id	Guid	--	Not exported
	FractionalDepth	Double	DIS.FractionalDepth	
	DistanceFromBottom	Double	DIS.MeasD	Distance from water surface exported
	StartTime	DateTime	first DAT.ymdhms	
	EndTime	DateTime	last DAT.ymdhms	Not exported
OriginalVelocity: X: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Not exported
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
OriginalVelocity: Y: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Not exported
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
OriginalVelocity: Z: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported

Data File			Variable	Comment
Next of Kin	Variable	Base Type		
	Average	Double	Calculated from DAT file samples	Not exported
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
DespikedVelocity: X: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Export
DespikedVelocity: Y: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Export
DespikedVelocity: Z: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Export
Temperature: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
Pressure: MeasurementValueSummary	Min	Double	--	Not exported
	Max	Double	--	Not exported
	Average	Double	--	Not exported
	StandardDeviation	Double	--	Not exported
	Count	Int32	--	Not exported
	StandardError	Double	--	Not exported
BatteryVoltage: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Not exported
	Count	Int32	Calculated from DAT file samples	Not exported

Data File			Variable	Comment
Next of Kin	Variable	Base Type		
	StandardError	Double	Calculated from DAT file samples	Not exported
Tilt: MeasurementValueSummary	Min	Double	--	Not exported
	Max	Double	--	Not exported
	Average	Double	--	Export
	StandardDeviation	Double	--	Not exported
	Count	Int32	--	Not exported
	StandardError	Double	--	Not exported
Beam0: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Export
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
Beam1: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Export
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
Beam2: MeasurementValueSummary	Min	Double	Calculated from DAT file samples	Not exported
	Max	Double	Calculated from DAT file samples	Not exported
	Average	Double	Calculated from DAT file samples	Export
	StandardDeviation	Double	Calculated from DAT file samples	Export
	Count	Int32	Calculated from DAT file samples	Not exported
	StandardError	Double	Calculated from DAT file samples	Not exported
Calculations: PointMeasurementCalculations	Warnings	QualityControlWarnings	--	Not exported
	Velocity	XyzData	SUM.Vel (VelX, VelY, VelZ in General mode)	
	VelocityStandardError	XyzData	SUM.Verr (VxErr, VyErr, VzErr in General mode)	
	FlowAngle	Double	DIS.Angle	
	Snr	BeamData	SUM.Snr (Snr1, Snr2, Snr3 in General mode)	
	SnrStandardDeviation	BeamData	SUM.ASD1, ASD2, ASD3	
	Samples	Int32	DIS.NPts	
	Spikes	Int32	DIS.Spike	
	Tilt	Double	--	
	BoundaryAvoidance	BoundaryAvoidanceStatus	DIS.Bnd	
Boundary: BoundaryData	BoundaryRange	Double	--	Not exported

Data File			Variable	Comment
Next of Kin	**Variable**	**Base Type**		
	VelocityAmbiguity	Double	--	Not exported
	VelocityResolution	Double	--	Not exported
Beams: ReadOnlyCollection< BeamStatistics>	NoiseLevel	Double	--	
	PeakLocation	Double	--	
	PeakLevel	Double	--	
HandheldInfo: HandheldInfoSummary	SoftwareVersion:	String	DIS.SoftwareVer	Not exported (pmd value exported)
	WadingRod	WadingRod	WadingRod.Unknown	Unknown is assigned, wading rod not defined in FT1
	Units	UnitType	DIS.UnitSystem	
ProbeInfo: ProbeInfoSummary	SerialNumber	String	CTL.AdvSerialnumber	
	FirmwareVersion	String	CTL.CpuFirmwareVersion	
	NumberOfBeams	Int32	CTL.AdvNumberOfBeams	
NominalBeamStatistics: ReadOnlyCollection<BeamStatistics>	NoiseLevel	Double	--	
	PeakLocation	Double	--	
	PeakLevel	Double	--	
Calculations: StationCalculations	Warnings	QualityControlWarnings	--	Not exported
	MeanVelocityInVertical	XyzData	--	Not exported
	MeanPanelVelocity	XyzData	DIS.MeanV	Only Vx is exported
	Width	Double	--	Not exported
	Area	Double	DIS.Area	
	Discharge	Double	DIS.Flow	
	FractionOfTotalDischarge	Double	DIS.%Q	
	Snr	BeamData	--	Not exported
	Temperature	Double	--	Not exported
	VelocityAngle	Double	--	Not exported
	BoundaryAvoidance	BoundaryAvoidanceStatus	DIS.Bnd	Not exported
	Samples	Int32	--	Not exported
	Spikes	Int32	--	Not exported
	Tilt	Double	--	Not exported
	VelocityStandardError	XyzData	--	Not exported
SupplementalDataRecord: List<SupplementalDataRecord> (optional)	Time	DateTime	record yyyy/MM/dd HH:mm:ss	
	GaugeHeight	Double	record GaugeHeigh	
	RatedDischarge	Double	record RatedDischarge	
	Comment	String	record Comment	
Calculations: DataFileCalculations	Warnings	QualityControlWarnings	use the final DIS.BeamCheck as AutoQC, plus the DIS.MeanBoundary as SmartQC, plus FT2	

Data File			Variable	Comment
Next of Kin	**Variable**	**Base Type**		
			SmartQC.	
	Area	Double	DIS.TotalArea	
	Discharge	Double	DIS.TotalDischarge	
	Width	Double	DIS.TotalWidth	
	Velocity	XyzData	DIS.MeanVelocity (or DIS.MeanVelocityVx, DIS.MeanVelocityVy in General Mode)	
	VelocityStandardError	XyzData	DIS.MeanVerr	
	Depth	Double	DIS.MeanDepth	
	Snr	Double	DIS.MeanSnr	
	Temperature	Double	DIS.MeanTemperature	
	RatedDischarge	Double	--	
	GaugeHeight	Double	--	
UncertaintyIso: DischargeUncertaintyCalculations	Accuracy	Double	DIS.UncertaintyIso.Accuracy	
	Depth	Double	DIS.UncertaintyIso.Depth	
	Velocity	Double	DIS.UncertaintyIso.Velocity	
	Width	Double	DIS.UncertaintyIso.Width	
	Method	Double	DIS.UncertaintyIso.Method	
	NumberOfStations	Double	DIS.UncertaintyIso.#_Stations	
	Overall	Double	DIS.UncertaintyIso.Overall	
UncertaintyIve: DischargeUncertaintyCalculations	Accuracy	Double	DIS.UncertaintyIve.Accuracy	
	Depth	Double	DIS.UncertaintyIve.Depth	
	Velocity	Double	DIS.UncertaintyIve.Velocity	
	Width	Double	DIS.UncertaintyIve.Width	
	Method	Double	DIS.UncertaintyIve.Method	Not exported (not in IVE)
	NumberOfStations	Double	DIS.UncertaintyIve.#_Stations	Not exported (not in IVE)
	Overall	Double	DIS.UncertaintyIve.Overall	
BeamChecks: List<BeamCheckSummary>	Id	Guid	--	
	Time	DateTime	DIS.BeamCheck	
	NumberofSamples	Int32	--	
	AutoQualityControlWarnings	QualityControlWarnings	DIS.BeamCheck	

Point Measurement Details			Variable	Comment
Next of Kin	**Variable**	**Base Type**		
	Id	Guid	--	Not exported
	SamplingRate	Double	1.0/CTL.SampleInterval	Not exported
Samples: ReadOnlyCollection<Sample>	Time	DateTime	DAT.ymdhms	
Adv: AdvData	Velocity	XyzData	DAT.VelX, VelY, VelZ	
	Snr	Double	DAT.Snr1, Snr2, Snr3	
Sensors: SensorData	Temperature	Double	SUM.Temp	Not exported
	SoundSpeed	Double	--	Not exported
	Pressure	Double	--	Not exported
	Voltage	Double	SUM.Batt	Not exported
	Accelerometer	XyzData	--	
Diagnostics: DiagnosticsSample	Time	DateTime	--	Not exported
Adv: AdvData	Velocity	XyzData	--	Not exported
	Snr	Double		Not exported
Sensors: SensorData	Temperature	Double	SUM.Temp	Not exported
	SoundSpeed	Double	--	Not exported
	Pressure	Double	--	Not exported
	Voltage	Double	SUM.Batt	Not exported
	Accelerometer	XyzData	--	Not exported
Diagnostics: DiagnosticsSample	Boundary	BoundaryData	--	Not exported
	ProfileRange: ReadOnlyCollection	Double	--	
Statistics: BeamStatistics	NoiseLevel	Double	--	Not exported
	PeakPosition	Double	--	Not exported
	PeakLevel	Double	--	Not exported
Beams: ReadOnlyCollection<DiagnosticsBeamData>	Profile: ReadOnlyCollection	Double	--	Not exported
DataCollectionConfiguration: DataCollectionConfiguration (optional)			--	
HandheldInfo: HandheldInfo	SerialNumber	String	CTL.SerialNumber	
	SoftwareVersion	String	CTL.SoftwareVer	
	BoardsInfo	String	CTL.CpuBoardRev	Not exported
	CpuSerialNumber	String	--	
	OperatingSystem	String	--	
	Settings	Object	--	Not exported
ProbeInfo: ProbeInfo	InstrumentType	String	CTL.AdvProbeType	Not exported

Point Measurement Details			Variable	Comment
Next of Kin	**Variable**	**Base Type**		
	SerialNumber	String	CTL.AdvSerialNumber	Not exported
	FirmwareVersion	String	CTL.CpuFirmwareVersion	Not exported
	NumberOfBeams	Int32	CTL.AdvNumberOfBeams	Not exported
NominalBeamStatistics: ReadOnlyCollection<BeamStatistics>	NoiseLevel	Double	--	Not exported
	PeakPosition	Double	--	Not exported
	PeakLevel	Double	--	Not exported
ProbeInfo: ProbeInfo	RawConfiguration	Object (optional)	--	Not exported
	Spikes: ReadOnlyCollection	Int32	Set by FT2 de-spike	Not exported

Section 13. Principle of Operations

13.1. FlowTracker2 Overview

The FlowTracker2 Handheld ADV is a single-point Doppler current meter designed for field velocity measurements. The FlowTracker2 uses the proven Doppler technology of the SonTek Acoustic Doppler Velocimeter (ADV), the leading high-resolution velocity sensor. ADV technology provides several advantages.

- Accurate velocity measurements in a remote sampling volume,
- 2D or 3D velocity measurements (depending on probe configuration),
- Invariant factory calibration, no periodic recalibration required,
- Rapid response time,
- Simple operation,
- Excellent performance for low and high flows – accuracy 1% of measured velocity,
- Built-in temperature sensor.

The FlowTracker2 offers ADV performance from a simple handheld interface, allowing rapid data collection without the use of a computer. Some common applications include:

- River discharge measurements (using established methodology, including USGS/ISO),
- Open-channel flow measurements,
- Current measurements in large pipes,
- Rapid, multi-point current surveys,
- Current monitoring in water treatment facilities.

13.2. The Doppler Shift

The FlowTracker2 uses a highly sophisticated form of this technique, which processes underwater sound (sonar) reflected from particulate matter suspended in the water.

a) The Doppler principle says that if a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmit frequency.

$$F_{doppler} = F_{source} \times \left(\frac{V}{C}\right)$$

where, $F_{doppler}$ *= change in received frequency (Doppler shift),*
F_{source} *= frequency of transmitted sound,*
V *= velocity of source relative to receiver,*
C *= speed of sound.*

b) The velocity, V, represents the relative speed between source and receiver (motion that changes the distance between the two).

   i). If the distance between the two objects is decreasing, frequency increases.

   ii). If the distance is increasing, frequency decreases.

   iii). Motion perpendicular to the line connecting source and receiver does not introduce a Doppler shift.

13.3. Bistatic Doppler Current Meters

13.3.1 Bistatic Doppler Operation

The FlowTracker2 is a Bistatic Doppler current meter with the 2D side looking probe design and sampling volume shown in Figure 13:1.

a) Bistatic means separate acoustic transducers are used for transmitter and receiver.

b) The transmitter generates sound concentrated in a narrow beam.

c) The receivers are sensitive to sound coming from a narrow beam.

d) The receivers are mounted such that the beams intersect at a volume of water located a fixed distance (10 cm; 4 in) from the tip of the probe.

e) The beam intersection determines the location of the sampling volume (the volume of water in which measurements are made).

13.3.2 The FlowTracker2 Measurement Principle

a) The transmitter generates a short pulse of sound at a known frequency.

b) The sound travels through the water along the transmitter beam axis.

c) As the pulse passes through the sampling volume, sound is reflected in all directions by particulate matter (sediment, small organisms, bubbles).

d) Some portion of the reflected energy travels back along the receiver beam axes.

e) The reflected signal is sampled by the acoustic receivers.

f) The FlowTracker2 measures the change in frequency (Doppler shift) for each receiver.

g) The Doppler shift is proportional to the velocity of the particles along the bistatic axis of the receiver and transmitter. The bistatic axis is located halfway between transmit and receive axes.

h) Knowing the relative orientation of the bistatic axes allows the FlowTracker2 to calculate 2D or 3D water velocity.

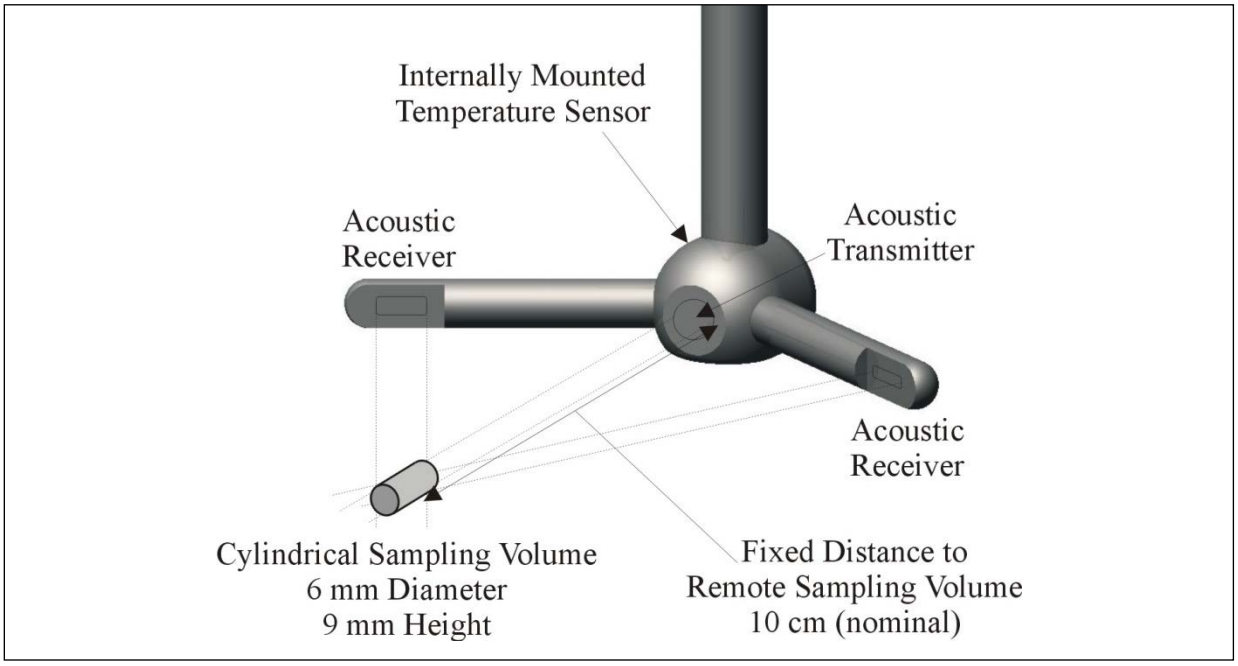


Figure 13:1 - 2D Side Looking Probe and Sampling Volume

13.3.3 Signal to Noise Ratio Profile

The signal to noise ratio versus time profile plot for the FlowTracker2 is shown in Figure 13:2.

a) The horizontal axis shows time after the transmit pulse.

b) The vertical axis shows the return signal strength measured by one receiver.

c) As the transmit pulse travels through the water, sound is reflected in all directions.

d) Immediately following the transmit pulse, reflections come from outside the receiver beam. The receiver measures only the ambient noise level.

e) As the pulse propagates along the transmit axis, it moves closer to the receiver beam. The receiver sees an increase in signal strength.

f) Signal strength reaches a maximum at the intersection of transmit and receive beams.

g) By sampling the return signal at its peak, the FlowTracker2 makes measurements in the sampling volume defined by the intersection of transmit and receive beams.

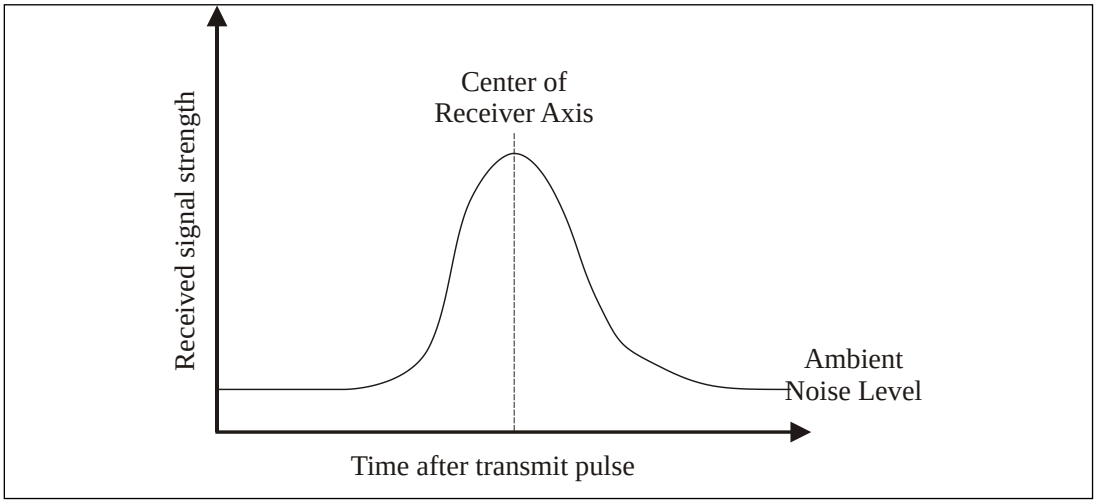


Figure 13:2 - Signal to Noise Ratio Profile

13.4. Pulse-Coherent Processing

This section does not attempt to provide a detailed description of pulse-coherent processing. It presents a simple overview with a focus on how this affects FlowTracker2 operation. SonTek can provide additional information on request.

The description of FlowTracker2 operation given in Bistatic Doppler Current Meters is an oversimplification.

- Bistatic Doppler Current Meters describes incoherent Doppler processing in which the transducer sends a single pulse of sound and measures the frequency change of the return signal.
- The FlowTracker2 uses a technique called pulse-coherent processing.

Pulse-coherent processing provides the best possible performance of any Doppler processing technique. In the simplest terms, pulse-coherent processing works as follows.

a) The FlowTracker2 sends two pulses of sound separated by a time lag (τ).

b) Each receiver measures the phase (ϕ) of the return signal from each pulse.

c) The change in phase ($\phi 2 - \phi 1$) divided by the time lag (τ) is proportional to velocity.

d) Because of the nature of the phase measurement (which can only be determined from -180° to +180°), the system has an inherent maximum velocity limitation.

e) The FlowTracker2 velocity algorithms have been optimized to give the best possible performance over a wide velocity range of ±4.0 m/s (±13 ft/s).

f) FlowTracker2 processing provides unmatched results for low flows (<1 cm/s; <0.03 ft/s).

FlowTracker2 processing has been designed to give the best possible performance in all environments. However, there is a situation where system performance may be affected by operating conditions.

- When working near boundaries or underwater obstacles, the system may need to adapt its operation to avoid acoustic interference.
- This is called boundary adjustment and is performed automatically by the system at each measurement location.
- The system reports a quality control parameter with each measurement location that tells you if the environment has any effect on FlowTracker2 performance. This quality control parameter is described in Boundary Interference.

13.5. Beam Geometry and 3D Velocity Measurements

A single transmit/receive pair measures the projection of the 3D water velocity onto the bistatic axis.

a) The bistatic axis is halfway between transmit and receive beam axes (see Figure 13:3).

b) The velocity measured by each receiver is called the bistatic velocity.

c) The FlowTracker2 uses one transmitter and two or three receivers (for 2D or 3D probes).

d) See Probe Configurations for other FlowTracker2 probe configurations.

e) Receivers intersect with the transmit beam pattern at a common sampling volume.

f) Bistatic velocities are converted to Cartesian (XYZ) velocities using the probe geometry (the relative angles of transmit and receive beams). Cartesian velocities give the 2D or 3D velocity relative of the FlowTracker2 probe.

g) During the manufacturing process, probe geometry is precisely determined by a calibration procedure.

h) This calibration only needs to be performed once.

i) No periodic re-calibration is required.

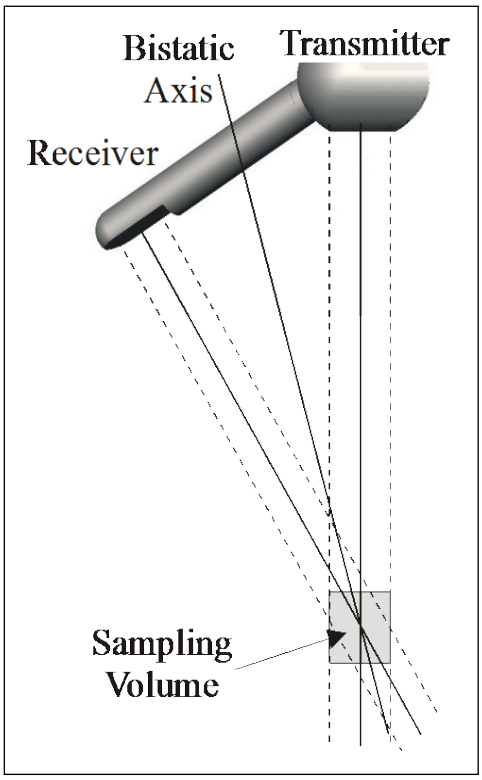


Figure 13:3 - Bistatic Axis

13.6. Sampling Volume Definition

The FlowTracker2 sampling volume is defined based on the following criteria,

a) The sampling volume is nominally 10 cm (4 in) from the tip of the probe.

b) The exact location varies ±1.0 cm (±0.4 in) from probe to probe.

c) Precise sampling volume location is fixed for any given probe.

d) The physical size of the sampling volume is a cylinder 6 mm (0.24 in) in diameter by 9mm (0.35 in) in length (see Figure 13:1).

13.7. Velocity Data Coordinate System

FlowTracker2 velocity measurements are reported using a right-hand Cartesian coordinate system relative to the probe. The XYZ coordinate systems for each probe type are shown below.

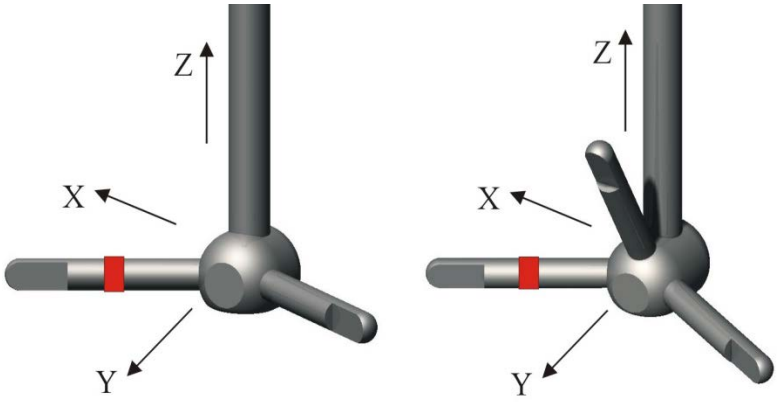


Figure 13:4 - FlowTracker2 Probe XYZ Coordinate System

13.7.1 2D Side-Looking Probe (Figure 30a)

a) The positive Z-axis is defined as vertically up in the direction of the probe's stem.

b) The positive X-axis is defined perpendicular to both the probe's stem and the axis of the transmit transducer in the direction of receiver arm #1 (marked with a red band).

c) The positive Y-axis is defined along the axis of the transmit transducer from the transmitter towards the sampling volume (making a right-handed coordinate system).

13.7.2 2D/3D Side-Looking Probe (Figure 30b)

a) The positive Z-axis is defined as vertically up in the direction of the probe's stem.

b) The positive X-axis is defined perpendicular to both the probe's stem and the axis of the transmit transducer in the direction of receiver arm #1 (marked with a red band).

c) The positive Y-axis is defined along the axis of the transmit transducer from the transmitter towards the sampling volume (making a right-handed coordinate system).

13.8. FlowTracker2 Data

13.8.1 Basic Sampling Strategy

The FlowTracker2 collects a burst of velocity data at each measurement location.

a) An individual measurement of the 2D or 3D velocity is referred to as a ping.

b) The FlowTracker2 pings 10 times per second, averaging these pings for a single velocity sample.

c) Velocity data are recorded once per second during the averaging time.

d) The averaging time at each location is user-specified (10 to 1000 seconds).

e) The system collects a fixed-length time-series of velocity at each measurement location.

f) You are prompted to enter location, depth, and other data at each measurement location to document the data set.

g) Velocity data are collected at each measurement location over the user-specified time. Raw one-second velocity, mean velocity, and quality control data are recorded with each station.

h) For river discharge measurements, the FlowTracker2 combines velocity data with station location, water depth, and other data to determine total discharge in real-time.

When each measurement location is complete, you are presented with a summary of the velocity and quality control data. All data are stored to the internal recorder for later downloading to a computer for display, archiving, and further analysis.

13.8.2 **Velocity Data**

The FlowTracker2 provides several important performance advantages.

a) It can measure 2D or 3D water velocities from 0.0001 to 4.0 m/s (0.0003 to 13 ft/s).

b) Velocity data are accurate to 1% of the measured velocity in a one-second sample.

c) Velocity data can be used immediately without any post processing corrections.

d) True 2D or 3D velocity data are output in Cartesian coordinates (XYZ) relative to probe orientation.

e) The FlowTracker2 calibration will not change unless the probe is physically damaged. No periodic calibration is required.

f) Diagnostic software is included to evaluate system performance periodically.

13.8.3 **Accuracy of Velocity Data**

13.8.3.1 Optimizing of FlowTracker2

The FlowTracker2 has been optimized to provide the best possible velocity data.

a) Velocity data are accurate to 1% of measured velocity for each one-second sample.

b) Variations in velocity data are dominated by true variations in water velocity.

c) Instrument noise does not normally have an impact on velocity data.

d) The averaging time required to determine the true mean velocity at a given location is a function of the real variations in velocity at that site.

13.8.3.2 Factors Influencing Accuracy

Two factors influence accuracy of FlowTracker2 velocity data – sound speed and probe geometry.

a) The effect of sound speed is discussed in Sound Speed. With properly specified salinity data, sound speed errors are negligible (less than 0.25%).

b) Probe geometry is calibrated at the factory for each FlowTracker; no recalibration is required unless the probe has been physically damaged.

c) The FlowTracker2 calibration procedure is specified to ±1.0% of the measured velocity.

d) There is no potential for zero offset or zero drift in velocity measurements. There is no inherent minimum measurable velocity.

e) The FlowTracker2 is very well suited to low-flow applications to less than 1 cm/s (0.03 ft/s).

13.8.4 **Quality Control Data**

In addition to velocity, the FlowTracker2 records quality control data with each measurement station to quickly evaluate velocity data quality. The quality control parameter details are discussed in Quality Control Parameters, Section 6, Quality Control.

13.9. Special Considerations

13.9.1 **Probe Configurations**

Several FlowTracker2 probe configurations are available for different applications (see Figure 13:4).

13.9.1.1 Probe mounting

a) The probe is mounted from a 1.500m (4.92ft) flexible cable. A 3.500m (11.5ft) or 8.500m (27.9ft) extension cable is available. However, it is not possible to upgrade an existing system to a different cable length.

b) It is not advised to exceed an overall cable length of 10.000m (32.8ft).

c) The cable is custom built to reduce electronic noise. It should not be modified by the user.

d) Take care to avoid damage to the cable, as this can affect system operation.

13.9.1.2 Probe type

a) Two probe types are available (see Figure 13:4).

b) The standard FlowTracker2 uses a 2D side-looking probe. The sampling volume is located 10 cm (4 in) to the side of the probe, and can operate in as little as 2 cm (1 in) of water.

c) To work in both shallow and deeper water, a combination 2D/3D side-looking probe is available. This has a sampling volume located 10 cm (4 in) to the side of the probe, and can operate in as little as 2 cm (1 in) of water. It measures 2D velocity in shallow water (with only two arms submerged), and 3D velocity in deeper water (with all three arms submerged).

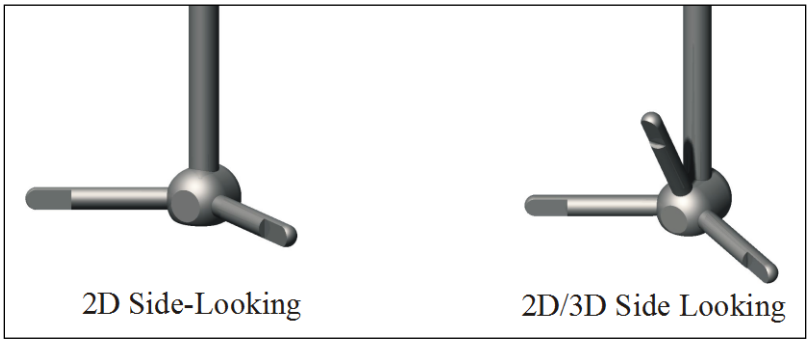


Figure 13:5 - FlowTracker2 Probe Configuration

13.10. Sound Speed

The FlowTracker2 uses sound speed to compute velocity from the measured Doppler shift, and to precisely determine the location of the sampling volume.

13.10.1 **Sound Speed Function**

The speed of sound in water is primarily a function of temperature and salinity.

a) Temperatures change of 5°C (9°F) results in a sound speed change of ≈1%.

b) A salinity change of 12 results in a change in sound speed of ≈1%.

c) A 1% error in sound speed results in a ≈2% error in velocity data.

13.10.2 **Compensate for Changes**

To compensate for changing sound speed, the FlowTracker2 does the following.

a) The FlowTracker2 includes a temperature sensor for automatic sound speed corrections. Resolution is ±0.01°C (±0.02°F).

b) A user-input value of salinity is used for sound speed calculations.

c) If accurate salinity data has been specified by the user (±2), sound speed changes can be assumed to have no impact on velocity data.

13.10.3 **Environmental Conditions**

Doppler current meters, such as the FlowTracker2, do not measure movement of water, but actually the movement of particles **in** the water,

- We must assume that the movement of the particles in the water is representative of the movement of the water itself,
- If there are no particles (other than the water molecules themselves) present in the water, Doppler current meters will not work. Natural streams almost always have something else other than just “water” (even if just tiny air bubbles), and the technology is such that even a small amount of particles in the water is usually enough for good measurements.

Visual inspection is **not** an acceptable method for determining the amount of particles in the water and no simple relationship exists with turbidity.

- We cannot say that for a given turbidity level your water is too clear for a Doppler-based measurement.
- The amount of particles in the water is not the only factor affecting signal amplitudes. Particle size, shape, distribution, and type also control these values, and these conditions vary from site to site.
- Therefore, one stream may meet these conditions, but another with the same turbidity may not.

If the site conditions seems unsuitable for FlowTracker2 measurement due to lack of particles in the water it is recommended to perform an Automated Beam Check. If the results are within the instrument specifications and quality control parameters user can start with velocity measurements. The FlowTracker2 can return reliable measurements down to about 3 dB (in SNR), although we recommend 10 dB and above for best operating conditions.

13.11. Flow Interference

The FlowTracker measures velocity in a small sampling volume nominally located 10 cm (4 in) from the tip of the probe (see Sampling Volume Definition). The placement of the sampling volume relative to other structures in the water must be considered when measuring velocity to avoid flow interference.

13.11.1 Structures

a) The FlowTracker probe should be located away from any underwater structures or obstacles, particularly those upstream.

b) Consider the size and location of nearby structures and obstacles, and the probable magnitude and direction of flow, when choosing a measurement location.

13.11.2 Probe orientation relative to flow

a) The FlowTracker should be oriented so the axis of the transmit transducer is roughly perpendicular to the expected direction of flow (see Figure 13:6).

b) For side-looking probes (2D and 2D/3D), the probe should be oriented looking across the expected direction of flow (so the X-axis aligns with the expected flow).

c) FlowTracker probes have been tested and have shown negligible flow interference with the probe as much as 40-50° away from the preferred alignment. At higher angles, the FlowTracker may see flow interference in the sampling volume.

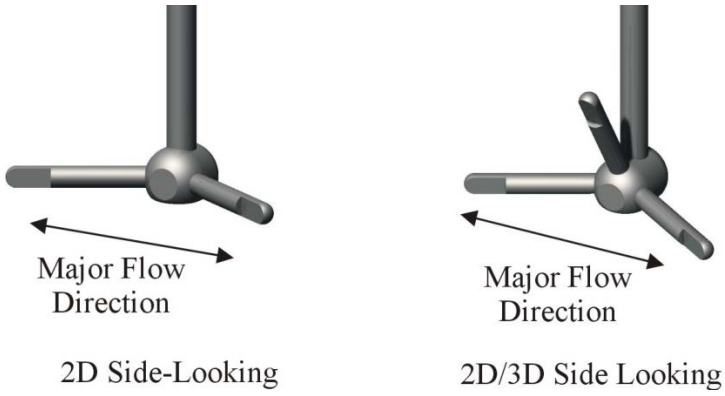


Figure 13:6 - Preferred Flow Direction to Avoid Flow Interference

13.11.3 **Mounting Correction**

Laboratory tow tank tests have indicated the FlowTracker2 probe and mount create flow disturbance that may have a small impact (approximately 1.0%) on measured velocity data. The mount is most commonly a top-setting wading rod using an S or J offset bracket. Additional tests and modeling have looked at whether flowing water shows the same flow disturbance effect seen in a tow tank (where the FlowTracker2 is towed through a pool of stationary water).

By default, no correction for flow disturbance is applied to FlowTracker2 data. If you are using a standard top-setting wading rod, and have decided to apply a correction, SonTek typically recommends using a correction of 1.0%. For additional information about the flow disturbance effect, contact SonTek directly.

To apply a flow disturbance correction, set the Mounting Correction from the Data Collection Settings menu.

13.11.3.1 No Correction

- With the default setting of No Correction, the FlowTracker2 velocity data is used directly without any correction for flow disturbance.

13.11.3.2 Custom Correction

- This is selected when you want to apply a correction to account for flow disturbance from the FlowTracker mount. With this option, you must specify the value of the Mounting Correction within the range -5% to +5%.
- When applied, the most common value for a standard top setting wading rod is 1.0%. A 1.0% correction means that measured velocity data is increased by 1.0% to account for the effect of flow disturbance from the wading rod.

Section 14. FlowTracker2 Desktop Software

14.1. Overview of Software Features and Functions

The FlowTracker2 Desktop Software is designed to work in conjunction with the FlowTracker2 Handheld ADV. With this software, you will be able to:

- **View, post-process**, and **export** FlowTracker Data,
- **Connect** to a FlowTracker Handheld ADV to download data and perform recorder functions.

The layout of the FlowTracker2 Desktop Software upon startup is shown in Figure 14:1. Each function and feature of the software will be addressed in the subsequent sections.

Specific software functions will have the sequence of buttons or tabs taken to reach that function next to the function title (in blue italic font). This sequence will always start at the startup page shown in Figure 14:1.

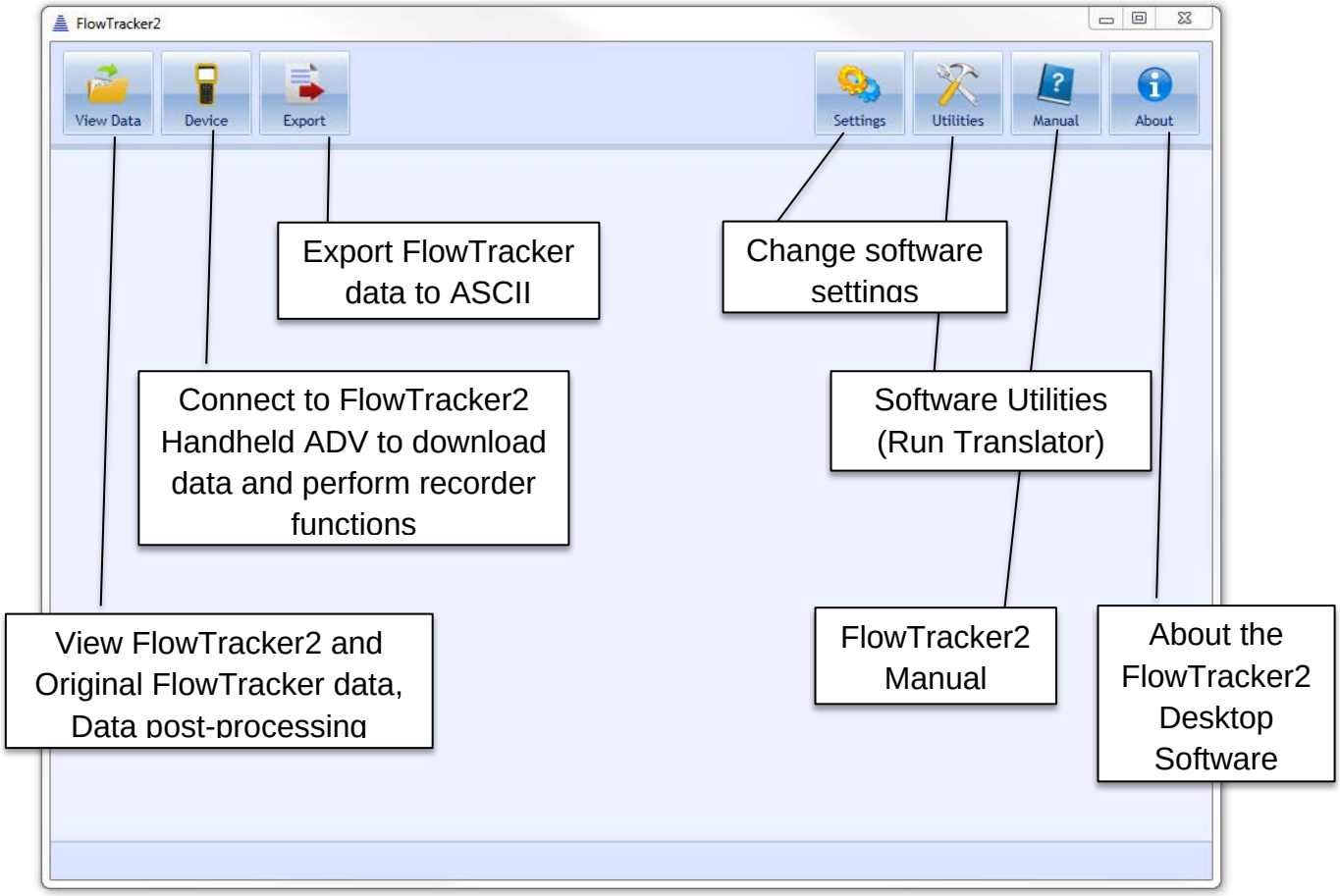


Figure 14:1 - Layout of FlowTracker2 Desktop Software upon startup

14.2. Installing Software

The FlowTracker2 Desktop Software installation file is included with the USB thumb drive that ships with your FlowTracker2 Handheld ADV. It is also available from the SonTek website (http://www.sontek.com). Run the **Windows Installer Package (.msi)** file corresponding to the type of computer on which you wish to install the software (**32-bit** or **64-bit**). Accept the terms in the License Agreement (shown in Figure 14:2) and click Install.

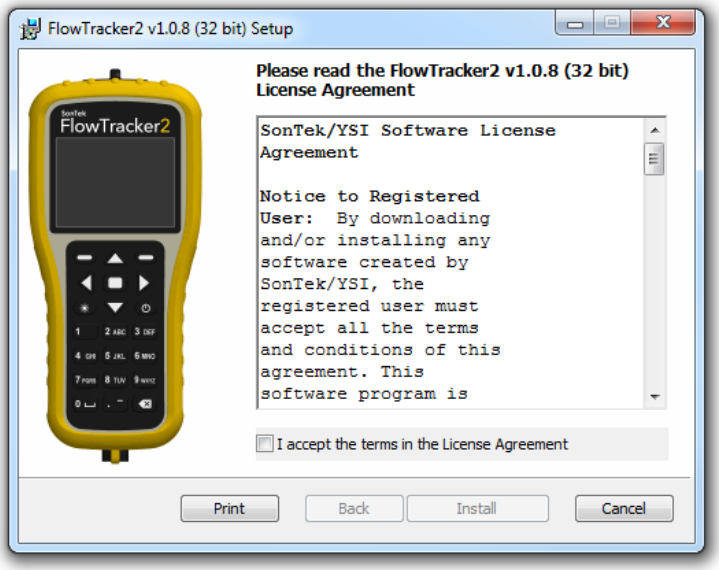


Figure 14:2. Installation Dialog for FlowTracker2 Desktop Software

During the process, you will be prompted to install a driver with the message shown in Figure 14:3. **This driver must be installed in order to communicate with the FlowTracker2 Handheld ADV.**



Figure 14:3. Driver Installation

14.3. Changing Settings

The Settings button opens a dialog (shown in Figure 14:4) providing options to change various software and user settings.

14.3.1 User Interface Tab

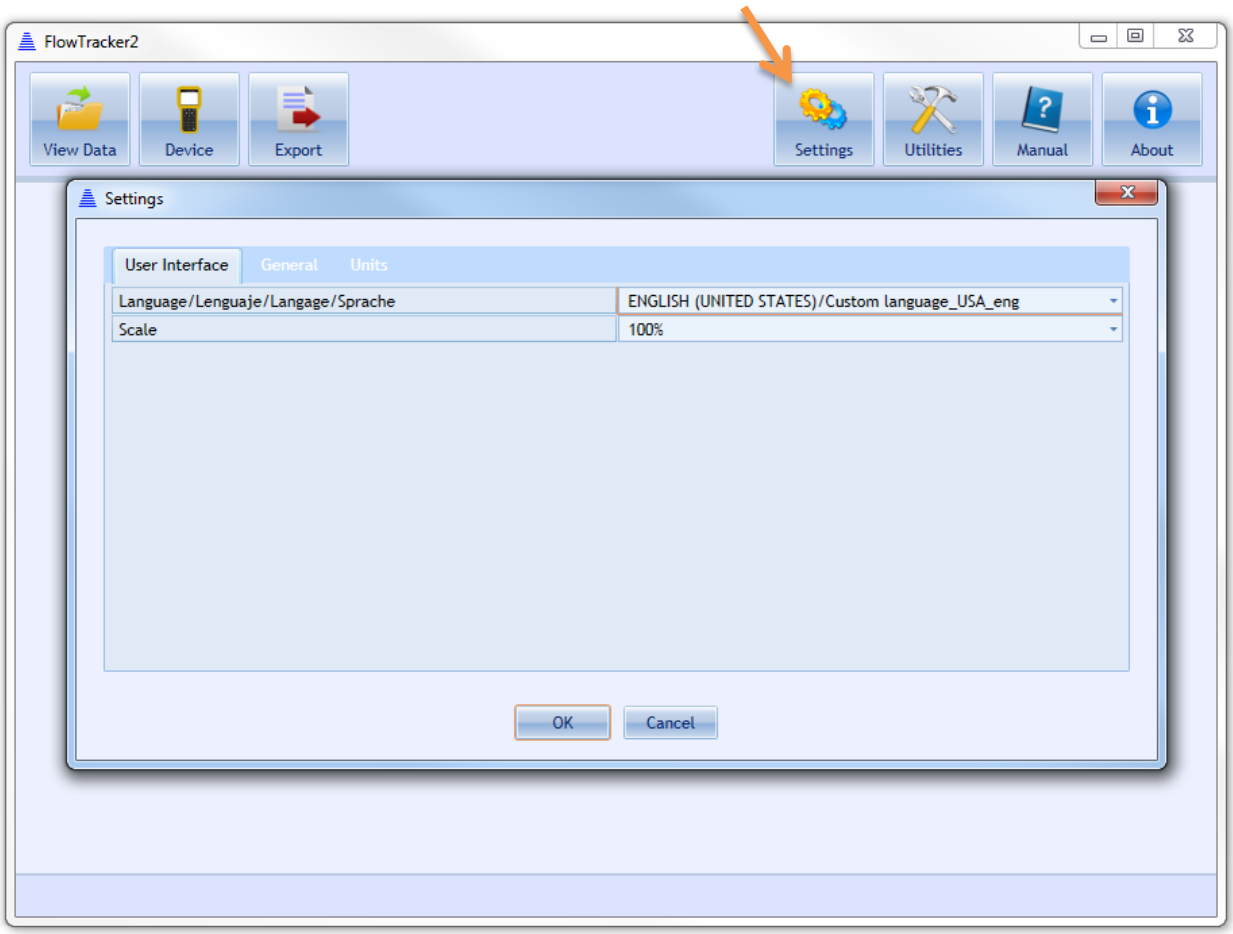


Figure 14:4. Changing User Interface Settings

14.3.1.1 Changing Language (Settings > User Interface > Language)

The **software language** can be changed through the **User Interface** tab in the **Settings** dialog. The language choices include:

- Auto Detect (using your computer settings)
- Catalan
- Chinese (simplified and traditional)
- English
- French
- German
- Greek
- Italian
- Japanese
- Korean
- Portuguese
- Romanian
- Russian
- Spanish
- Custom

For languages not included in this list (Custom), different language tools are available. These are described in detail in Run Translator.

14.3.1.2 Changing Scale and Font Size (Settings > User Interface > Scale)

The **scale** of all the text and buttons can be changed through the **User Interface** tab in the **Settings dialog**. The font size and buttons can be increased up to 150% and decreased down to 60%. The software will restart automatically to implement the changes.

14.3.2 General Tab

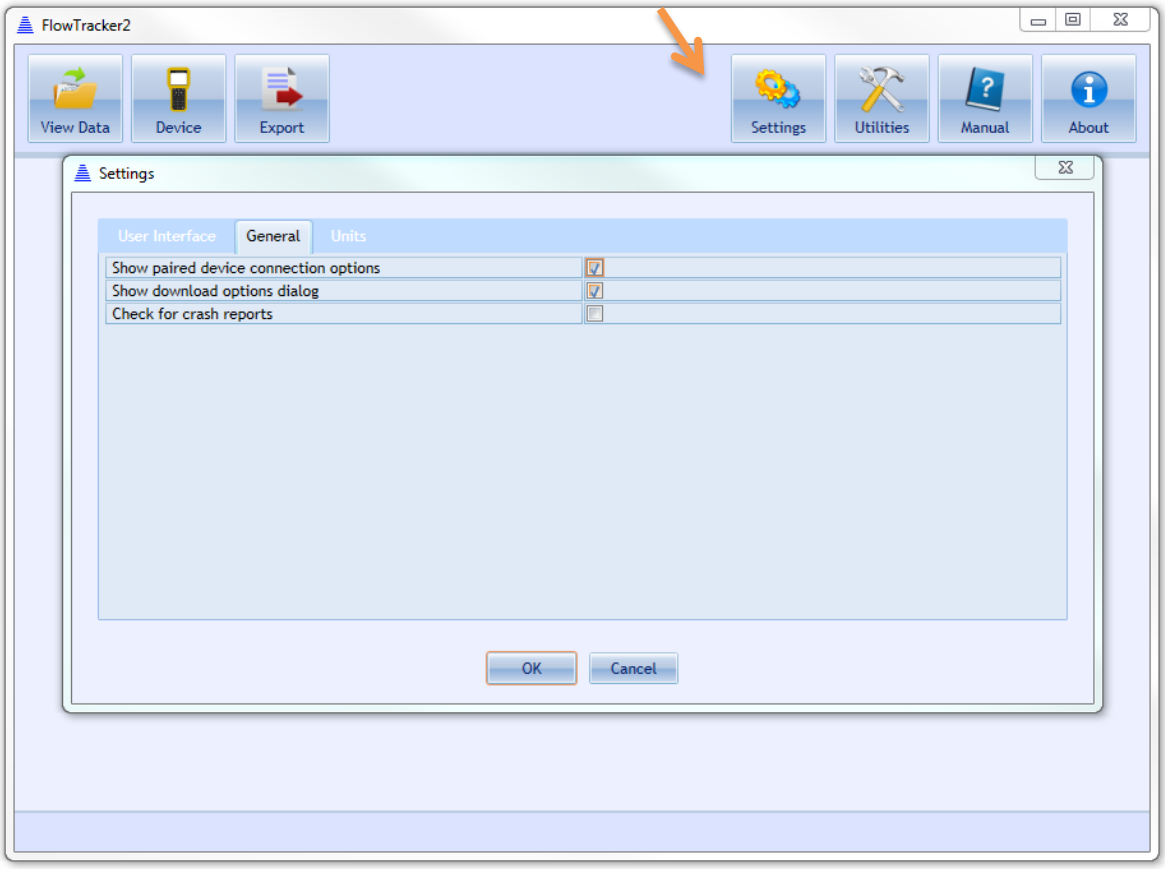


Figure 14:5. Changing General Settings

14.3.2.1 Show paired device connection options (Settings > General > Show paired device connection options)

Checking this box will provide more options during device communication using Bluetooth. It allows you to select a COM port manually if you already have a Bluetooth device paired. It is recommended that this box be left unchecked unless you are contacting Technical Support and are troubleshooting Bluetooth connectivity issues.

14.3.2.2 Show Download Options Dialog (Settings > General > Show download options dialog)

When downloading data files from the FlowTracker2 Handheld ADV, a dialog with various options appears by default. These options are described in Download Data Files. This dialog can be enabled/disabled using this check box.

14.3.2.3 Check for Crash Reports and Send to SonTek Support (Settings > General > Check for crash reports)

Crash reports are automatically generated by the FlowTracker2 software. If the **Check for crash reports** option is toggled on, upon startup, the software will search for crash reports. If crash reports are found, the dialog in Figure 14:6 will appear, prompting for the option to send crash reports to SonTek Technical Support.

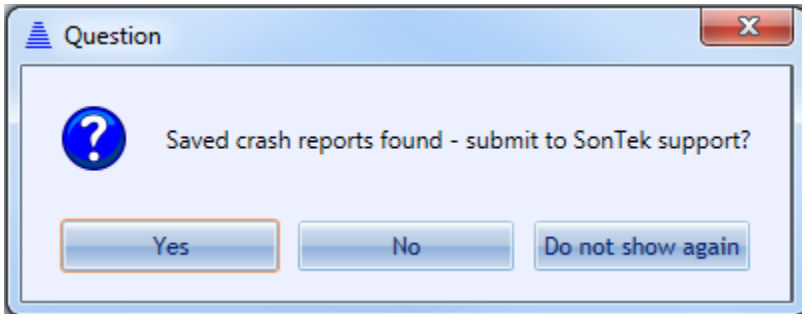


Figure 14:6. Crash report dialog

Toggling this option off will disable this prompt upon startup of the software. Clicking **Do not show again** will uncheck the box in the General Settings tab.

14.3.3 **Units Tab**

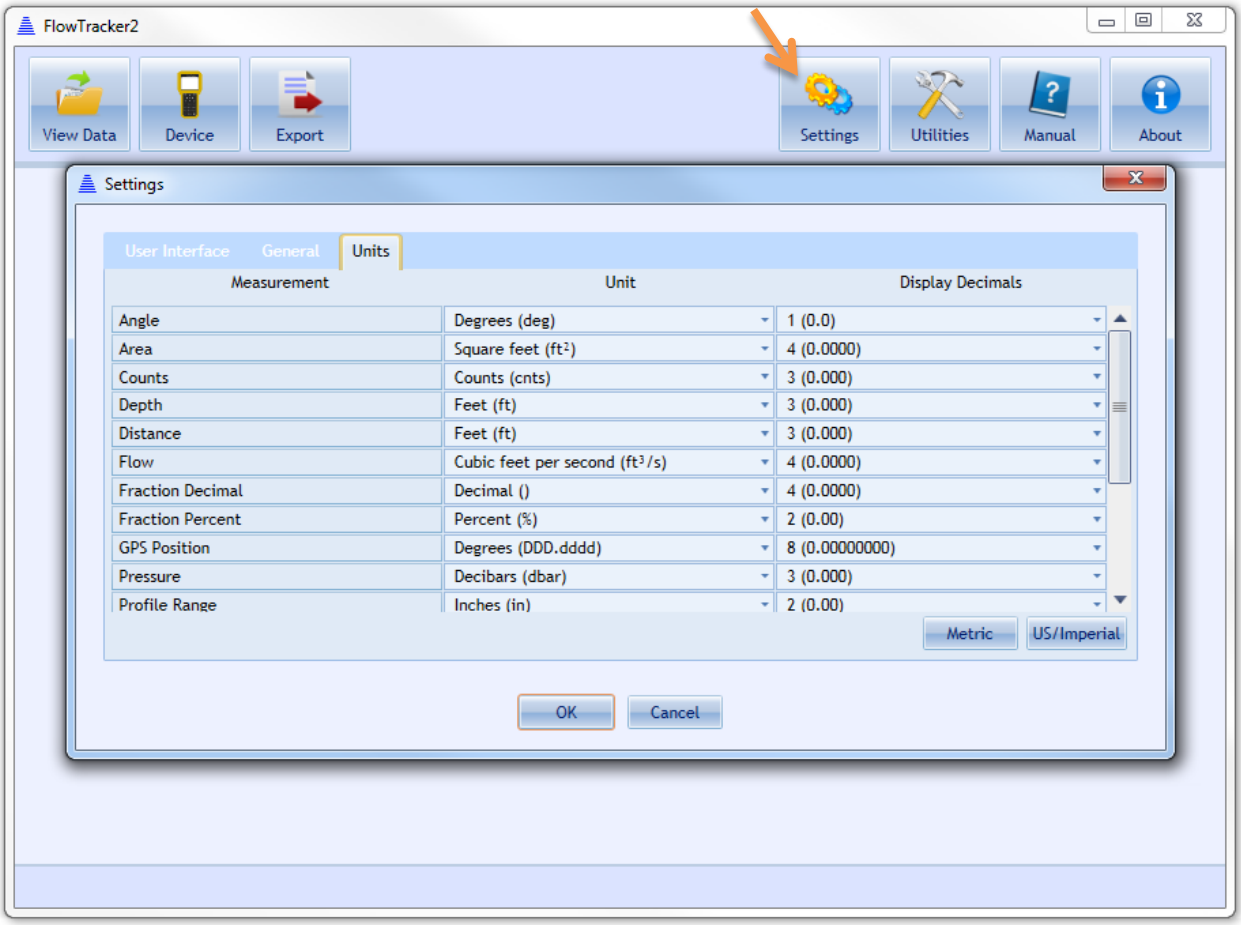


Figure 14:7. Changing Units

14.3.3.1 Changing Software Units (Settings > Units)

The units displayed by the software for various parameters can be changed independently. Table 14:1 summarizes the changeable parameters and what unit options are available.

Table 14:1- Units Available for Software Parameters

Measurement	Unit Options
Angle	Degrees (deg), Radians (rad)
Area	Square feet (ft^2), Square meters (m^2)
Counts	Counts (cnts)
Depth	Centimeters (cm), Fathoms (fms), Feet (ft), Inches (in), Kilometers (km), Meters (m), Miles (miles), Millimeters (mm), Yards (yd)
Distance	Centimeters (cm), Fathoms (fms), Feet (ft), Inches (in), Kilometers (km), Meters (m), Miles (miles), Millimeters (mm), Yards (yd)
Flow	Acre feet per day (acre ft/day), Acre feet per hour

Measurement	Unit Options
	(acre ft/hour), Cubic feet per second (ft^3/s), Cubic meters per second (m^3/s), Liters per second (L/s), Megaliters per day (ML/day), Million UK gallons per day (Million UK gallons/day), Million US gallons per day (Million US gallons/day), UK gallons per minute (UK gallons/min), US gallons per minute (US gallons/min)
Fraction Decimal	Decimal (), Percent (%)
Fraction Percent	Decimal (), Percent (%)
Pressure	Bar (bar), Decibars (dbar), Feet of water (ft H_2O), Meters of water (m H_2O), Pascal (Pa), Pound Force per Square Inch (psi)
Salinity	Practical Salinity Scale (pss)
SNR	Decibels (dB)
Sound Speed	Centimeters per second (cm/s), Feet per second (ft/s), Furlongs per fortnight (furlongs/fortnight), Inches per second (in/s), Kilometers per hour (km/h), Knots (kt), Meters per second (m/s), Miles per hour (mph), Millimeters per second (mm/s), Yards per second (yd/s)
Temperature	Celsius (^oC), Fahrenheit (^oF), Kelvin (^oK)
Time Span	Seconds (s)
Voltage	Millivolts (mV), Volts (V)
Water Velocity	Centimeters per second (cm/s), Feet per second (ft/s), Furlongs per fortnight (furlongs/fortnight), Inches per second (in/s), Kilometers per hour (km/h), Knots (kt), Meters per second (m/s), Miles per hour (mph), Millimeters per second (mm/s), Yards per second (yd/s)

To change units, click on the appropriate drop-down menu and select the unit desired. There is an option on the lower right to change all relevant units to Metric or US/Imperial. Click OK, and the software will automatically restart to apply the changes.

14.3.3.2 Changing Software Display Decimals (Settings > Units)

The number of decimals displayed by the software for various parameters can be changed independently. Display decimals can be changed for all parameters listed in Table 14:1. The display decimals range from 0 (0) to 9 (0.000000000). To change the number of decimals displayed, click on the appropriate drop-down menu and select the value desired. When display decimals are changed, the software will automatically restart to apply those changes.

14.4. Utilities

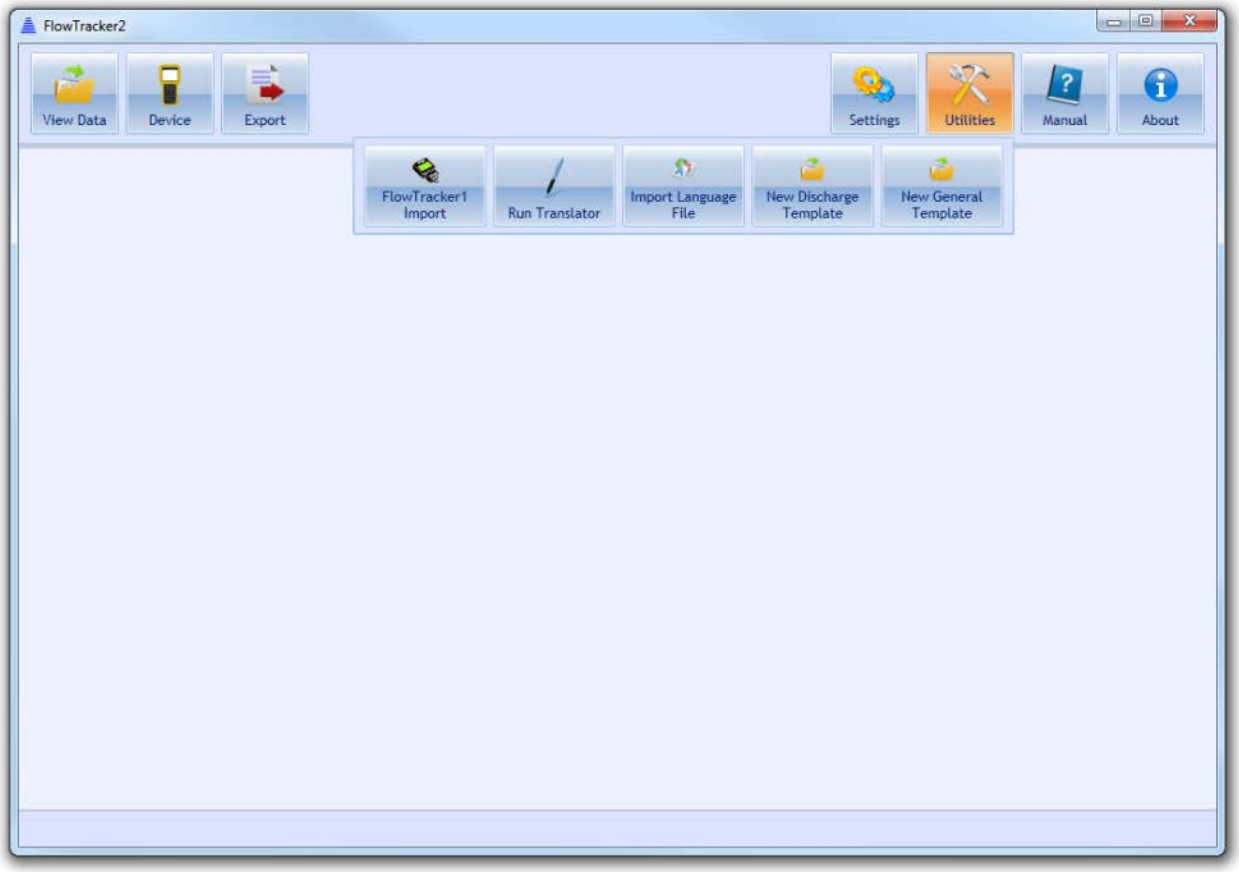


Figure 14:8. Utilities Dialog

14.4.1 **FlowTracker1 Import** (Utilities > FlowTracker1 Import)

This is a conversion tool allowing users to open measurements taken by the Original FlowTracker Handheld ADV instrument with the .wad extension. Please see Opening Original FlowTracker Handheld ADV Data Files (.WAD files) for instructions on how to use this feature.

14.4.2 **Run Translator** (Utilities > Run Translator)

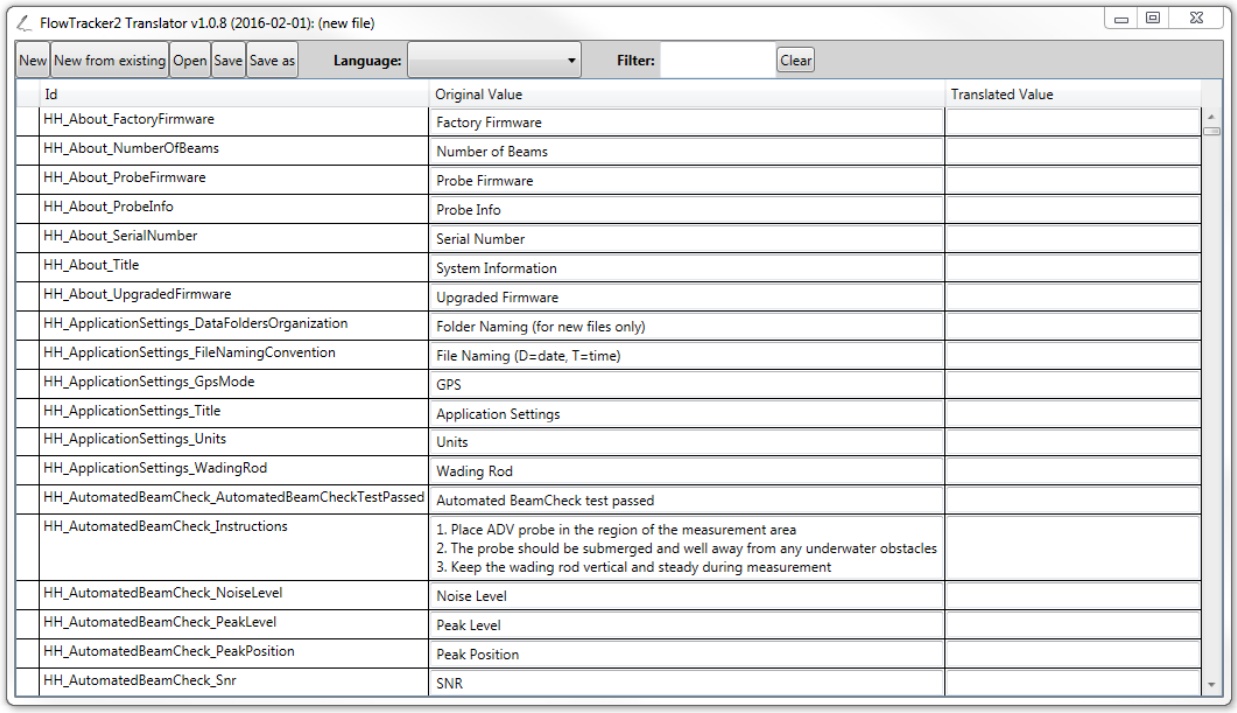


Figure 14:9 - Run Translator Dialog

The Run Translator Dialog (Figure 14:9) allows a user to customize a language translation to suit specific purposes or to translate to a language not included in the standard language list. An extensive list of variables used by the software appears under the “Id” column, with its description or association in the “Original Value” column. The user can enter their translated value into the “Translated Value” column. A “Filter” function at the top of the dialog allows users to search for specific terms to be translated.

To save a translation file for future use, first pick a language from the drop-down menu at the top. Then, click the “Save” or “Save As” button, and specify the name of the language file you wish to create. A **.lang** file will be created in the directory of choice.

14.4.3 **Import Language File** (Utilities > Import Language File)

Once a **.lang** file is created (see previous section), this file can be applied to the software using the Import Language File dialog. You will be prompted to open the **.lang** file that you have created. The FlowTracker2 software will then restart to apply the changes associated with the custom **.lang** file.

14.4.4 **New Discharge Template** (Utilities > New Discharge Template)

To create a new Discharge Template, press the New Discharge Template button under the Utilities Menu. Choose a template name and destination for the template on your computer. A new template with extension .ft_template will be created. To configure an

existing or new template upload to FlowTracker2 Handheld device, please refer to Uploading and Downloading Templates.

14.4.5 **New General Template** (Utilities > New General Template)

To create a new General Template (template associated with General Mode measurements), follow the same instructions in the previous section for creating a Discharge Template.

14.5. Connecting to the FlowTracker2 Handheld ADV

The FlowTracker2 Desktop Software is designed to connect to the FlowTracker2 Handheld ADV only. User will not be able to use FlowTracker2 desktop software to connect to an Original FlowTracker Handheld ADV. User will also not be able to use the Original FlowTracker software or SonUtils to connect to the FlowTracker2.

The FlowTracker2 Handheld ADV can connect to your PC in two ways: using a direct **USB to micro-USB connection**, or using your PC's **Bluetooth radio**. To connect, click on the **Device** button, shown in Figure 14:10. Instructions for each connection type follow in the subsequent sections.

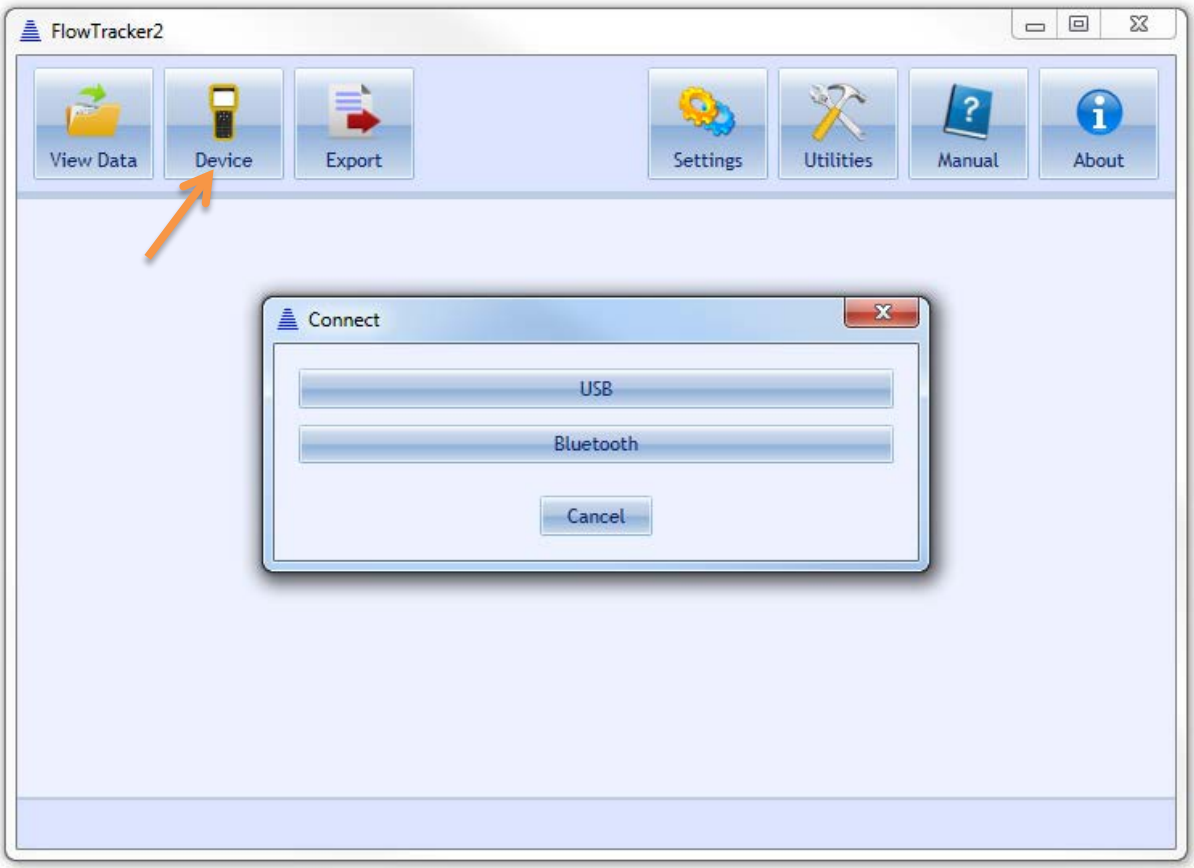


Figure 14:10. Connecting to FlowTracker2

14.5.1 **USB Connection** (Device > USB)

To connect to the FlowTracker2 Handheld ADV using the **USB to micro-USB connection**,

a) Plug the micro-USB connector to the communications connector at the bottom of the Handheld unit (see Figure 1:1).

b) Plug the USB cable end into a USB port of your PC.

c) Ensure that you have the battery pack installed in the Handheld device with sufficient battery power, and turn on your FlowTracker2.

d) From the main menu, navigate to the Communications button (Left panel of Figure 14:11) and click the Center Key. The FlowTracker2 will wait for a signal from the PC, showing the screen in the right panel of Figure 14:11.

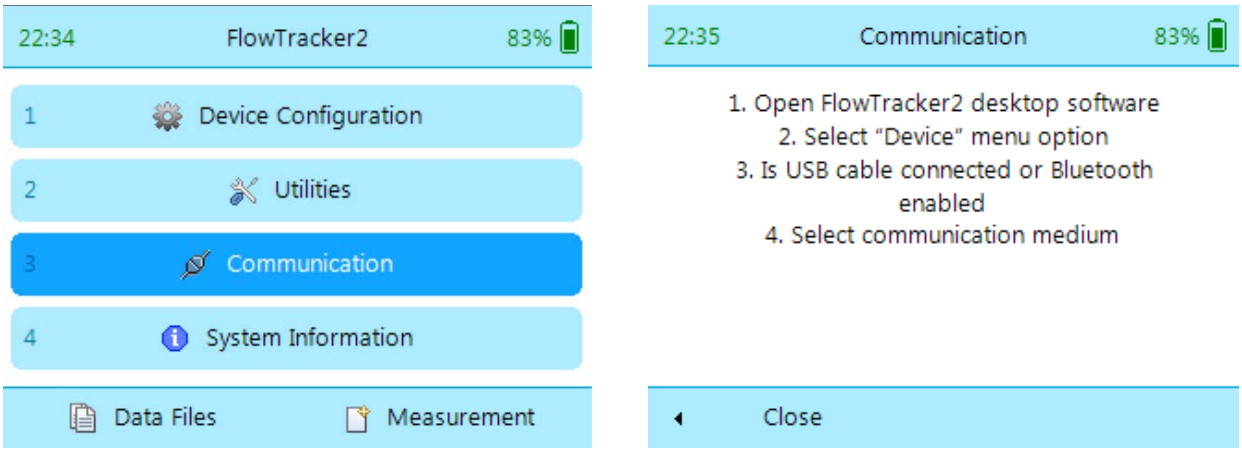


Figure 14:11. Communication dialog

e) From the FlowTracker2 Desktop Software, in the Device dialog, click the USB button. The software will attempt to connect automatically with the FlowTracker2.

f) Once successfully connected, the FlowTracker2 data files will be listed, as shown in Figure 14:13. The handheld will indicate that it is connected to your computer.

14.5.2 **Bluetooth Connection**



Do not use your Windows Bluetooth manager to pair the FlowTracker2 device to your computer's Bluetooth radio. The software will perform the pairing automatically.

To connect to the FlowTracker2 using **Bluetooth**,

a) Ensure that you have the battery pack installed in the Handheld device with sufficient battery power, and turn on your FlowTracker2.

b) From the main menu, navigate to the Communications button (Left panel of Figure 14:11) and click the Center Key. The FlowTracker2 will wait for a signal from the PC, showing the screen in the right panel of Figure 14:11.

c) Ensure that your computer Bluetooth radio (wireless communications) is turned on.

d) Enter the full serial number of your FlowTracker2 device in the Input box that appears (see Figure 14:12).

e) Click the Connect button. A dialog will appear with updates on the Bluetooth connection status.

f) Once successfully connected, the FlowTracker2 data files will be listed, as shown in Figure 14:13. The handheld will indicate that it is connected to your computer.

The FlowTracker2 software will remember different devices after they are first connected using Bluetooth. To remove a device, open the Serial Number drop-down menu and click “remove.”

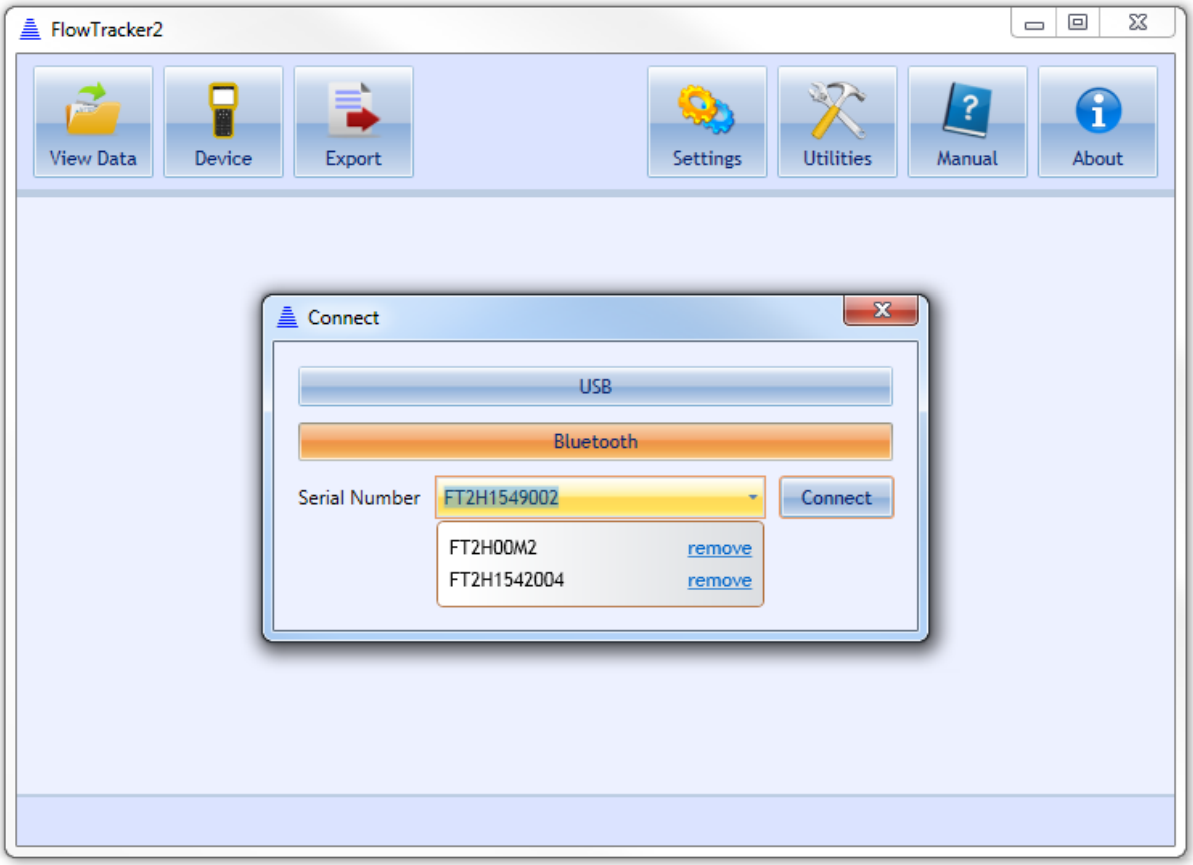


Figure 14:12. Bluetooth Connection Dialog

14.6. Device Menu and Functions

Once connected with the FlowTracker2, there are a number of functions available that allow you to download data and interact with the handheld device. These functions are indicated in Figure 14:13 and are described below.

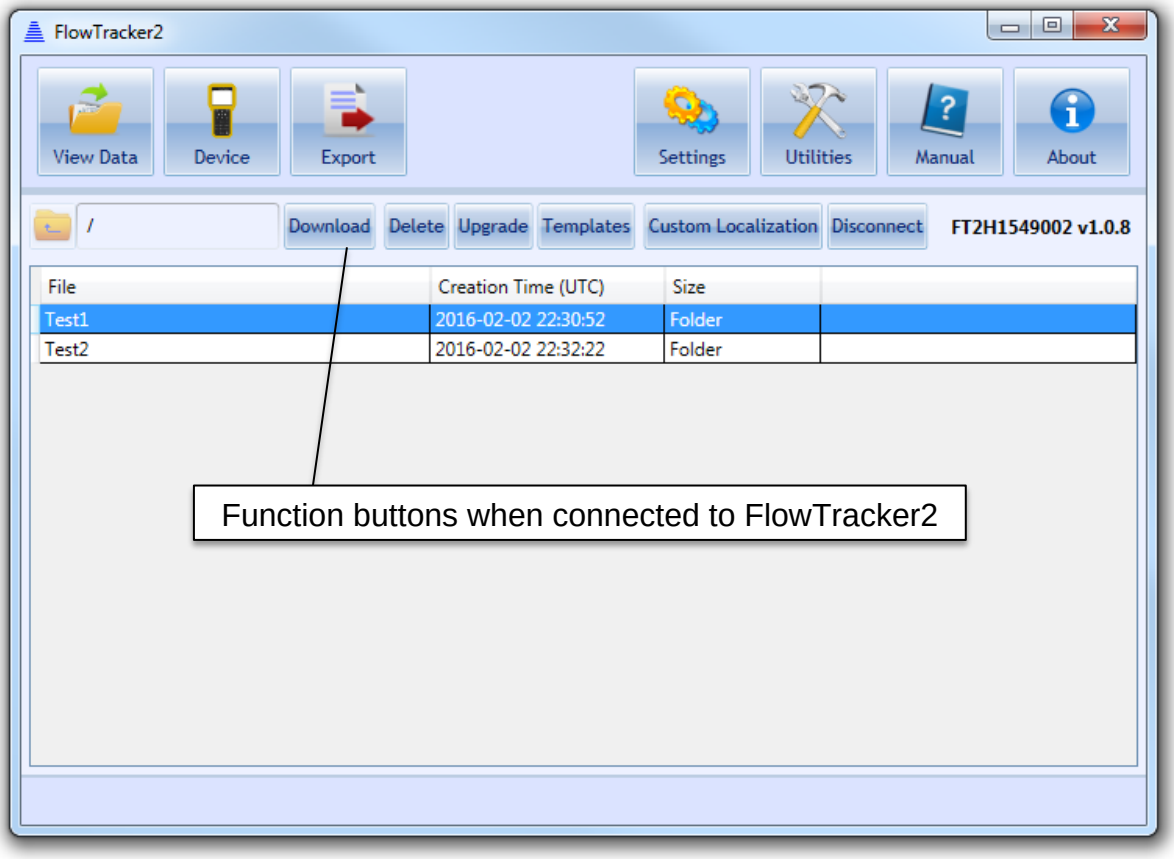


Figure 14:13. Device Menu after successful connection

14.6.1 **Download Data Files** (Device > [Choose your connection] > Download)

To download data files, you must click on a file or multiple files.

- To select a single file, click on that file.
- To select a range of files, hold the **SHIFT** key and select your files.
- To select multiple specific files, hold the **CTRL** key and select your files. You can also de-select files using the **CTRL** key.

Once the files are selected, the **Download** button will be activated. Click the **Download** button. The Download dialog, shown in Figure 14:14, will appear.

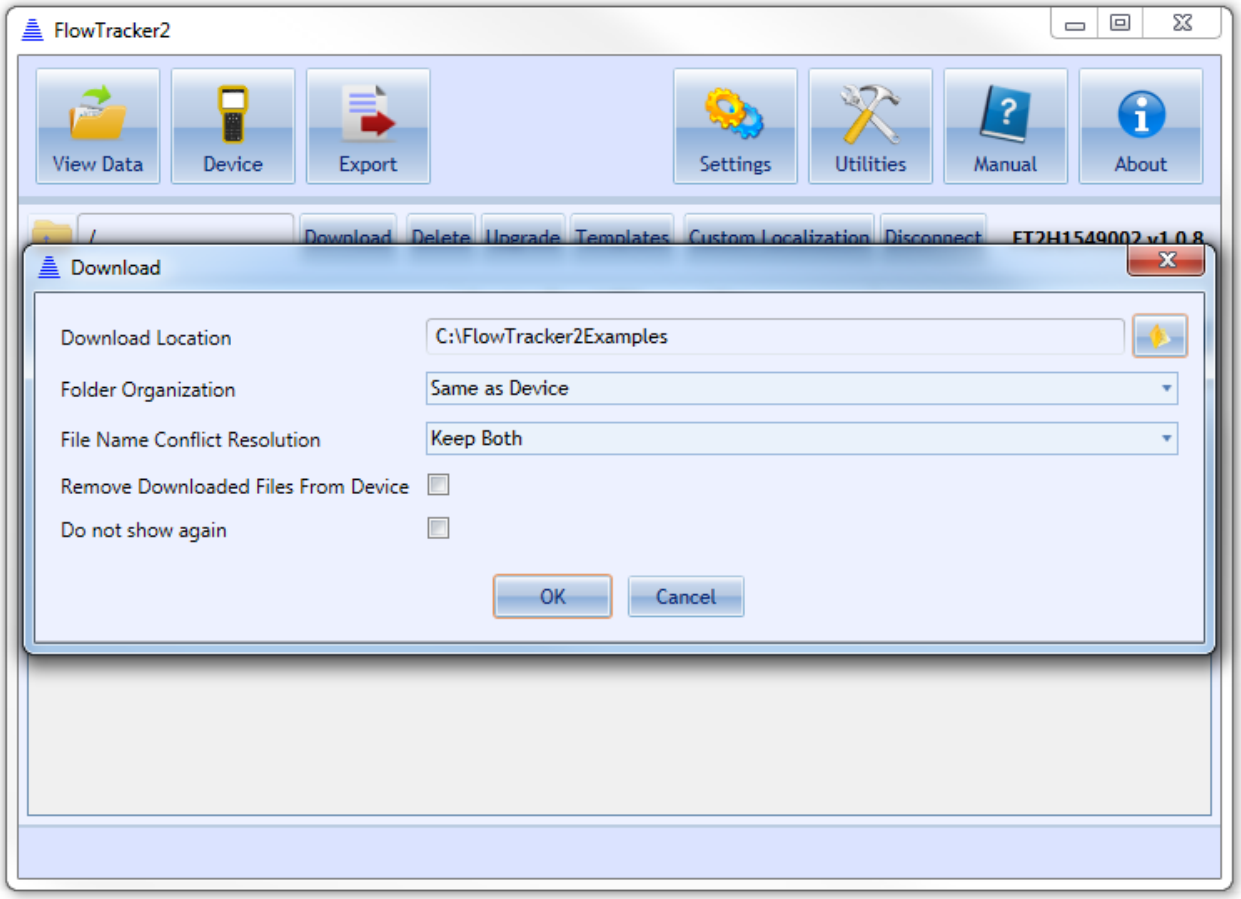


Figure 14:14. Download Data dialog

a) The **Download Location** can be changed by clicking the folder button on the right.

b) The **Folder Organization** option dictates with what type of folder structure data files are stored:

   i). **Same as Device** – Each data file will have its own folder with the same naming convention as on the device.

   ii). **By Device Serial Number** – files are stored in a folder indicated by the device serial number.

   iii). **Single Folder** – all files stored in single folder indicated by the Download Location.

c) The File Name Conflict Resolution provides options when downloading a file from the device with the same file name as one existing in the Download Location directory. The choices are to:

   i). **Keep Both** – both files placed in same folder and newest file will have name with incrementally growing number extensions (i.e. "_2.ft", "_3.ft", etc.).

   ii). **Skip** – skips downloading duplicate files.

iii). **Overwrite** – overwrites existing file on PC with newly downloaded file of same name.

d) Checking the **Remove Downloaded Files From Device** box will delete any files from the handheld recorder that have been downloaded onto the PC.

e) Checking the **Do not show again** box will save your downloading preferences, and data will automatically be downloaded according to those preferences when the Download button is pushed. To re-enable the dialog box, see Show Download Options Dialog.

14.6.2 **Delete Data files** (Device > [Choose your connection] > Delete)

To delete data files from the handheld device, select the files to be removed. A prompt will appear to confirm file deletion.

14.6.3 **Upgrading FlowTracker2 Firmware** (Device > [Choose your connection] > Upgrade)

Periodic firmware updates will be released. The firmware files will be available from the SonTek website (http://www.sontek.com) or by contacting SonTek Technical Support. If you have upgraded your desktop software, but not your firmware, the software will notify you that a firmware upgrade is available upon connection with the FlowTracker2 (shown in Figure 14:15). The firmware file needs to first be downloaded and saved onto the computer used to connect to the FlowTracker2. The **Upgrade** function will open a dialog to select the FlowTracker2 firmware file. Select the appropriate file and click 'Open' – the firmware upgrade will begin automatically. First, the firmware file will be uploaded to the handheld device. Then, the handheld device will disconnect automatically from the computer, and will perform the upgrade. When the upgrade is complete, the handheld will restart automatically.

Occasional firmware upgrade files may or may not include an upgrade to the FlowTracker2 probe firmware. Because the ADV probe has its own set of electronics, it has its own firmware that may periodically need updating. When the Handheld firmware is upgraded using the software, the probe firmware is not automatically performed until the Handheld queries the probe. This means that when the probe is accessed (to take a measurement, see its firmware version, perform a beam check, etc.), the probe firmware will automatically be updated, and requires no additional steps by the user. The user will see a pop-up on the Handheld software indicating that the probe firmware upgrade is taking place.

⚠ Do not manually disconnect or turn off the device during a firmware upgrade process. Doing so will interrupt the firmware upgrade and potentially cause serious corruptions on the handheld device. It is recommended to use the USB direct connection when upgrading firmware to avoid possible wireless connection interruptions.

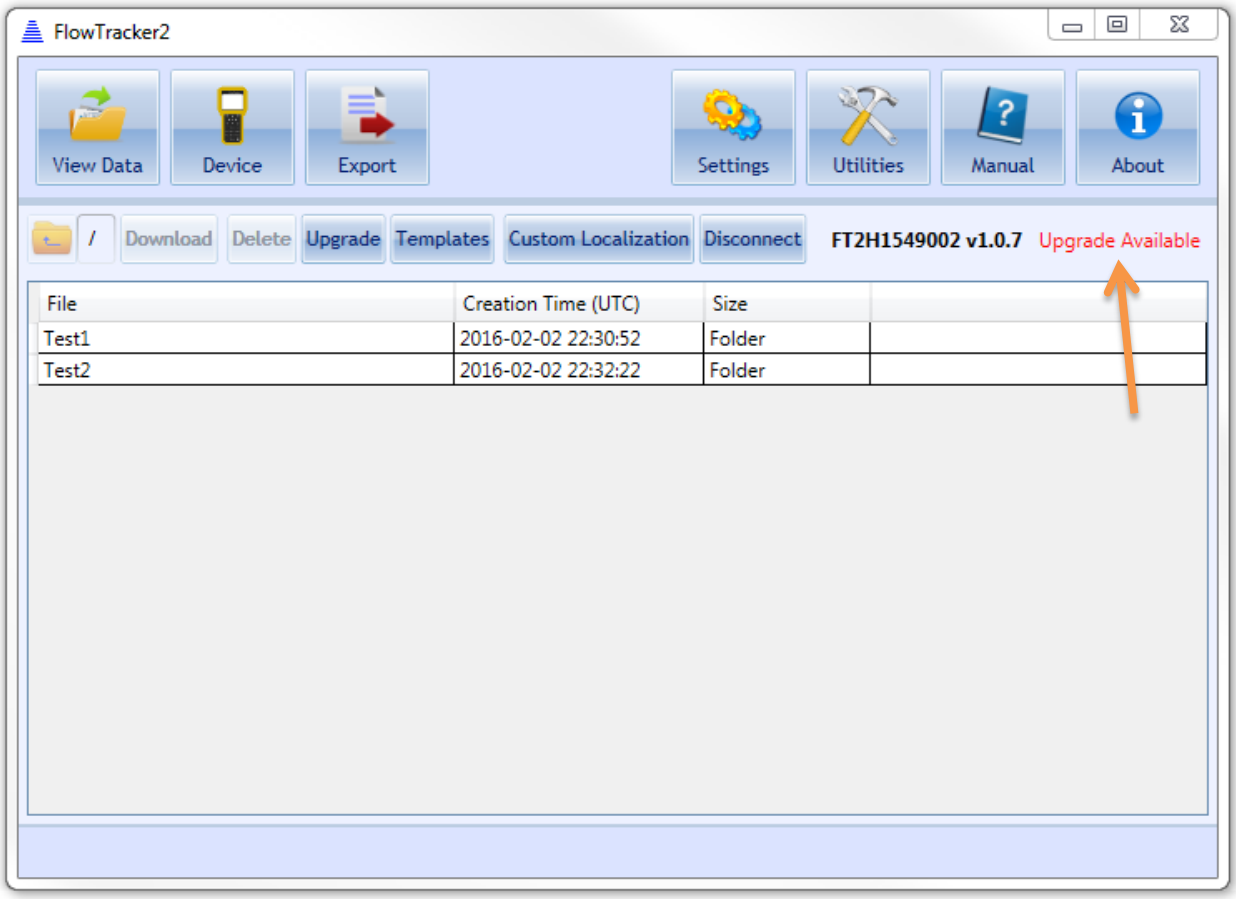


Figure 14:15. Firmware Upgrade Alert

14.6.4 **Uploading and Downloading Templates** (Device > [Choose your connection] > Templates)

The ability to use templates is a new feature in the FlowTracker2 Handheld ADV operation, allowing the user to easily store and load data that are applicable to multiple measurements (such as site name, site number, operator, etc.). This feature allows faster operation because the user will not need to input certain values for each measurement. Please see Configuration Templates on how to create and manipulate templates from the FlowTracker2 Handheld device.

To **download** an existing template from the FlowTracker2, click the Templates button after connecting with a unit. The available templates stored on the device will appear. Select the appropriate files, click Download to PC, and choose a destination on your computer to save the files. The template files will be saved with the extension .ft_template.

To **upload** an existing template from your computer to the FlowTracker2, click Templates > Upload to Device, and select the appropriate .ft_template file. The template file will be added to the list of templates on your device that appears.

Templates can be either created on the Handheld device and modified on a computer, or created through the desktop software and uploaded to the device. Please refer to New Discharge Template for instructions on how to create a template file using the software. Please refer to Opening FlowTracker2 Template Files (.ft_template) for instructions on opening and editing template files.

14.6.5 **Custom Localization**

Custom Localization allows a user to import Language files onto the handheld device. Please see Run Translator for instructions on creating a Language file (.lang).

14.6.6 **Disconnecting the FlowTracker2**

To disconnect the FlowTracker2 from the computer, click the **Disconnect** button.

14.7. Opening a Data File

To view FlowTracker data files, click the **View Data** button to turn View Data on. The first time this button is clicked, a dialog will appear to select a file. To open more files, click the **'+' tab** shown in Figure 14:16. The Open File dialog (Figure 14:17) will appear. The FlowTracker2 software is capable of opening the following file types:

- FlowTracker File (.ft)
- FlowTracker Beamcheck File (.ft_beamcheck)
- FlowTracker Template File (.ft_template)

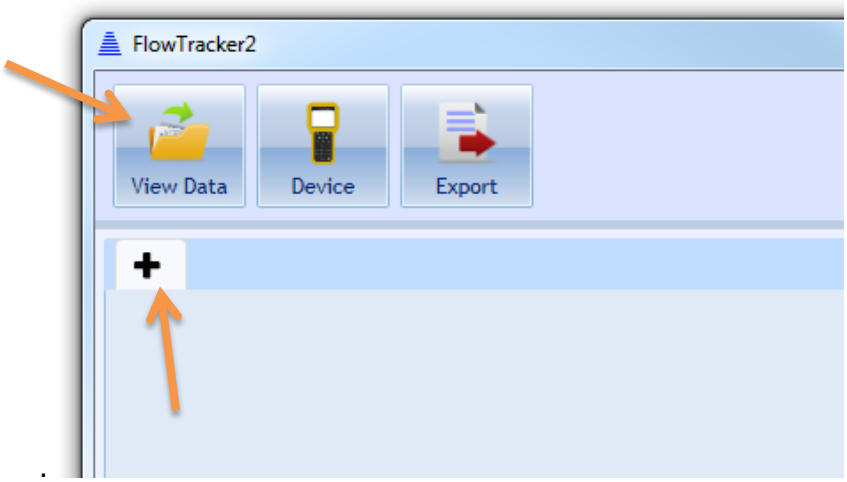


Figure 14:16. + Tab to open additional data files

The FlowTracker2 Desktop software is capable of opening FlowTracker2 (.ft) files only. In order to open files from the Original FlowTracker (.wad), please follow the steps specifically for .wad files in subsequent sections.

14.7.1 **Opening FlowTracker2 Handheld ADV Data Files (.ft files)**

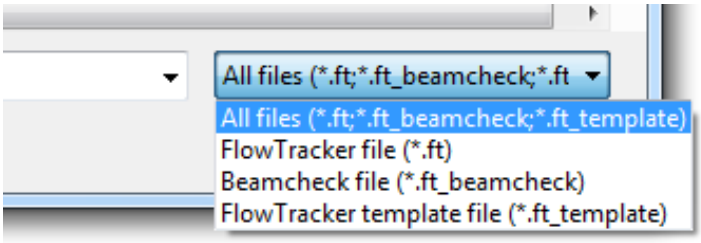


Figure 14:17. Open File Dialog.

The FlowTracker2 .ft file is the main data file that contains your Discharge or General Mode measurement. To open a ft file from the Open File dialog, navigate to the appropriate folder, select "All files" or "FlowTracker file" in the drop-down menu on the lower right, select the appropriate .ft file to be opened from the list populated, and click the **Open** button.

Sample data files are included with the USB that came with your FlowTracker2 package and are located in the "FlowTracker2 Example Data" folder on the USB drive.

14.7.2 **Opening FlowTracker2 BeamCheck Files (.ft_beamcheck)**

During a measurement, the FlowTracker2 will save BeamCheck information within the .ft file. The FlowTracker2 also has the option of recording a separate BeamCheck which results in a .ft_beamcheck file.

The FlowTracker2 BeamCheck (.ft_beamcheck) file results from a user requesting a BeamCheck to be done separately from a measurement. To open a .ft_beamcheck file, follow the same instructions for opening a .ft file, but select "Beamcheck file (*.ft_beamcheck)" in the drop-down menu, or select an appropriate .ft_beamcheck file from the "All files" drop-down option.

Opening a Beamcheck file produces the screen shown in Figure 14:18. The time stamp on the top of the file dialog corresponds to when the beam check was started, in local time. Handheld information, probe information, beam check statistics, and quality control warnings are displayed in the first row of panels. For each sample, Sample information and statistics are displayed in the second row of panels. A plot of the SNR (dB) against the distance from the ADV receiver is shown at the bottom. To toggle between samples, press the "Previous sample" and "Next sample" buttons. "Show average" will show the average SNR profile over all samples in the beam check file.

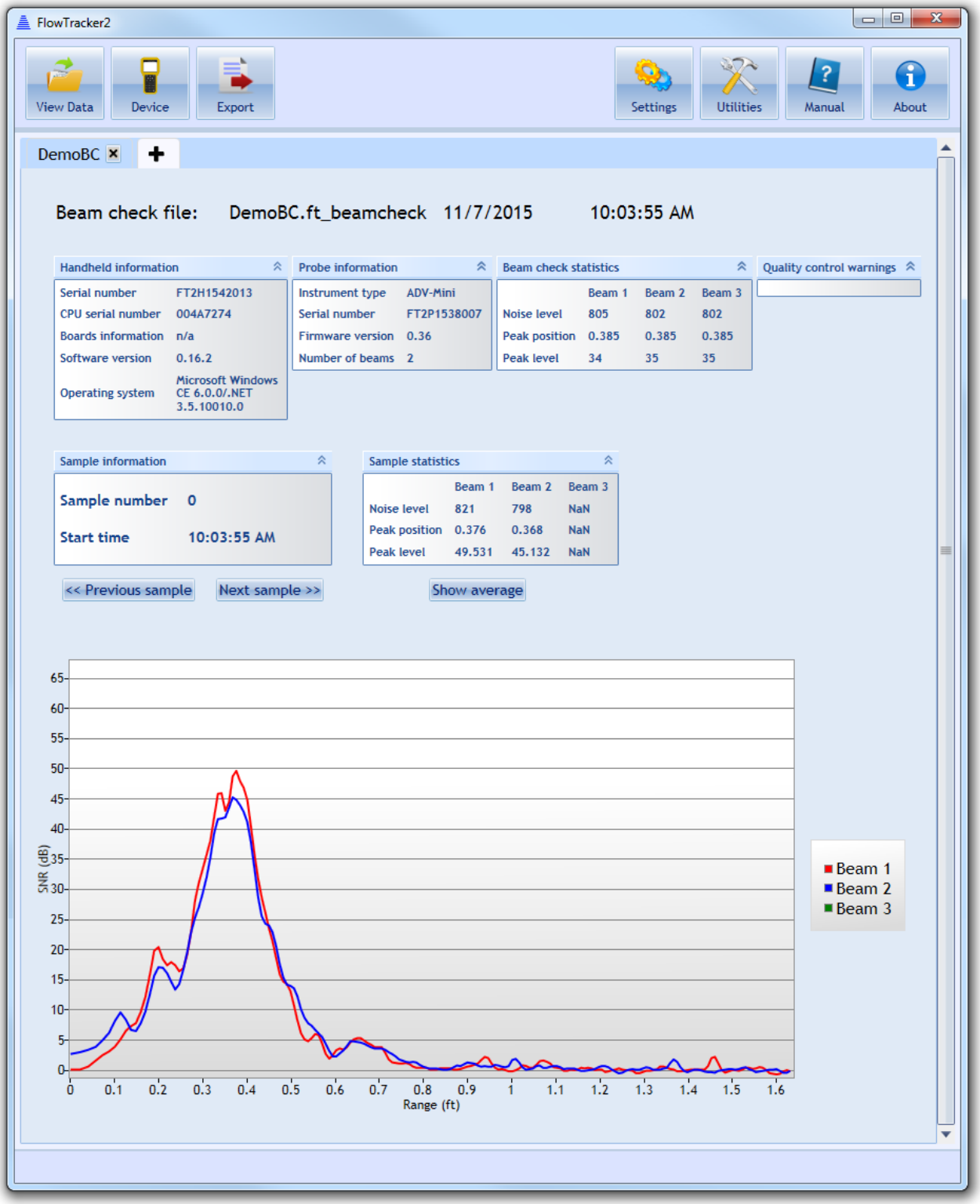


Figure 14:18. Viewing a Beamcheck File

14.7.3 **Opening FlowTracker2 Template Files (.ft_template)**

The FlowTracker2 software allows you to open and edit template files separately from the Handheld unit. To open a template (.ft_template) file, follow the same instructions for

opening a .ft file, but select “FlowTracker template file (*.ft_template)” or select an appropriate .ft_template file from the “All files” drop-down option.

When a Discharge template is opened, the screen shown in Figure 14:19 will appear. Fields that can be edited will show input boxes. When a General Mode template is opened, similar fields to the Discharge template will appear, with the exception that Discharge Settings, Station Warning Settings, and Displayed Velocity Methods fields will not be available. To save changes to the template, click the **Save Template File** button.

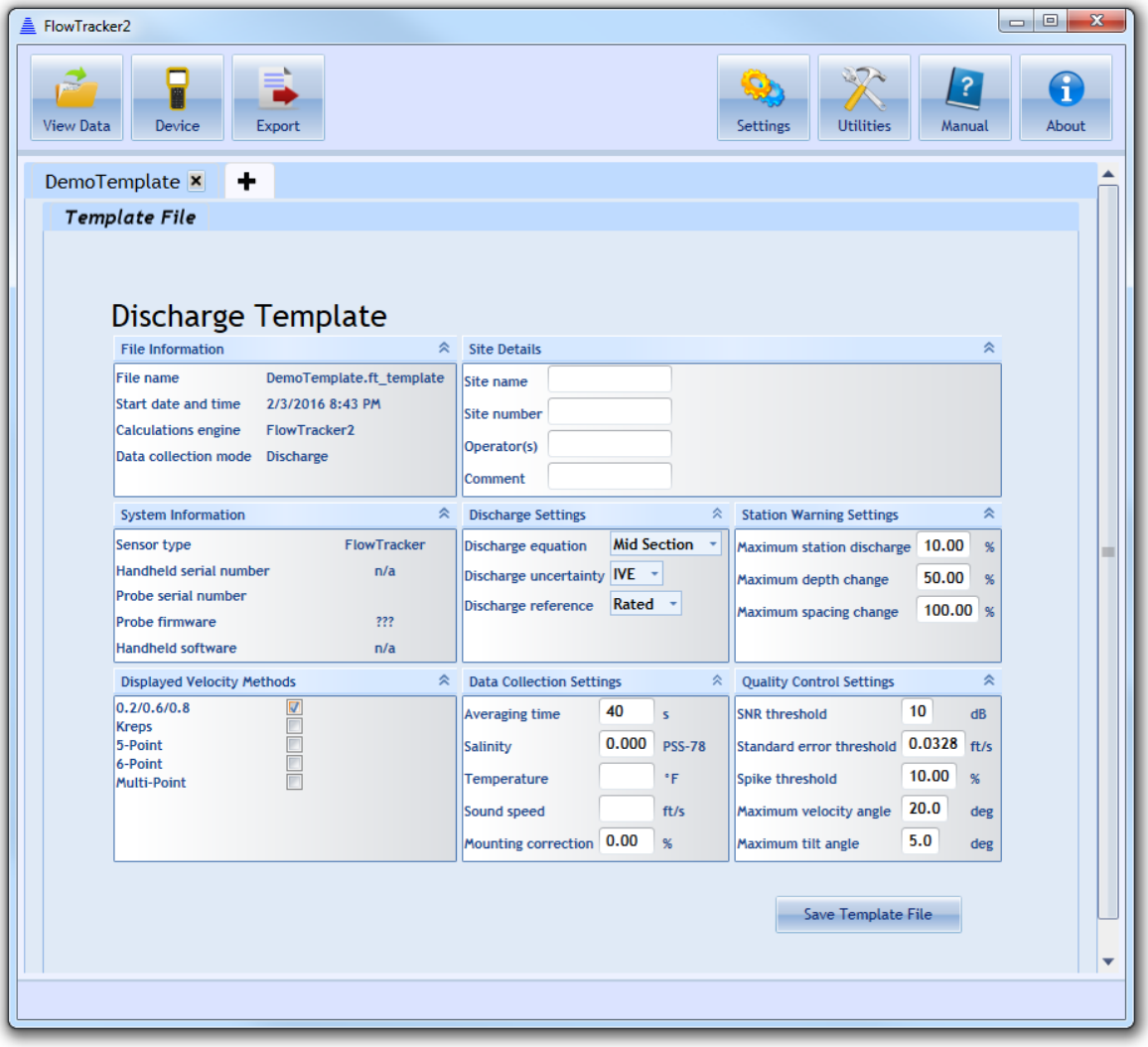


Figure 14:19 - Discharge Template

14.7.4 **Opening Original FlowTracker Handheld ADV Data Files (.WAD files)**

In order to open Original FlowTracker Handheld ADV Data Files (.wad), they must first be converted to .ft files.

The FlowTracker2 software cannot open Original FlowTracker Handheld ADV data files (.wad) directly. However, the software provides a tool to convert .wad files to the .ft that can be opened using the software.

In order to use the tool, the ASCII exports associated with the .wad file must be present in the same folder as the .wad file. The four (4) ASCII files with the following file extensions must all be present:

- **.DIS**
- **.SUM**
- **.CTL**
- **.DAT**

These data files are exported using the Original FlowTracker desktop software. Please refer to the manual for the Original FlowTracker for instructions on how to export these ASCII files.

Once the ASCII files associated with the .wad file are created and are in the same folder as the .wad file, the converter tool can be used. To access the converter, click **Utilities > FlowTracker1 Import**, shown in Figure 14:20.



Figure 14:20. Original FlowTracker .wad File Conversion Tool

You will have two options: **Import File** or **Import Folder**.

- **Import File** – Select the .wad file you would like to convert. The ASCII exports must be associated with this file, or you will receive an error message during the data import. The resulting file converted will have the same file name, but the .wad extension will be replaced with **.FlowTracker1.ft**.
- **Import Folder** – Select the folder containing multiple .wad files you would like to convert. The tool will look within subfolders recursively to convert all .wad files with associated ASCII exports. If the ASCII exports do not exist in the same folder(s) as the .wad files, an error message will appear. The resulting files converted will have the same file name, but the .wad extension will be replaced with **.FlowTracker1.ft.**

You can then open the **.FlowTracker1.ft** file the same way you would open a regular .ft file.

14.8. Overview of View Data Options

When a FlowTracker data file is opened, three panes will appear (Figure 14:21): the Measurement Summary pane, the main viewing pane (including tabs offering various views), and the Settings pane.



Figure 14:21. Layout of Data Viewing Window and Section Tab

14.8.1 Measurement Summary Pane

The Measurement Summary Pane values are summarized in Table 14:2.

Table 14:2. Measurement Summary Pane

Category	Value	Description
File Information	File name	File name
	Start date and time	Start date and time of measurement
	Calculations engine	Identifies which calculation algorithm was used: Original FlowTracker (FlowTracker1) or FlowTracker2
	Data collection mode	Discharge or General Mode

Category	Value	Description
System Information	Sensor type	Top setting, Universal, or Ice (not available with Original FlowTracker)
	Handheld serial number	Handheld device serial number
	Probe serial number	Probe serial number (not available with Original FlowTracker)
	Probe firmware	Probe firmware
	Handheld software	Handheld software version
Discharge Summary	# Stations	Number of stations measured
	Mean depth	Mean depth over all stations
	Mean velocity	Mean velocity over all velocity measurements
	Mean SNR	Mean Signal to Noise Ratio over all velocity measurements
	Mean temp	Mean temperature over all measurements
	Avg interval	Probe averaging interval per sample (in seconds)
	Total width	Total transect width
	Total area	Total transect area
	Total discharge	Total discharge
Discharge Uncertainty	Category	ISO or IVE
	Accuracy	Accuracy (%)
	Depth	Uncertainty on depth (%)
	Velocity	Uncertainty on velocity (%)
	Width	Uncertainty on width (%)
	Method	Uncertainty on method used (%)
	# Stations	Uncertainty on number of stations (%)
	Overall	Total uncertainty
View Controls	Chart size + / Chart size -	Increase or decrease size of all plots within software
	Reset all	Reset size of all plots to default

14.8.2 **Main Viewing Pane**

The main viewing pane consists of seven tabular views in Discharge Mode, and 6 tabs in General Mode. The contents of each tab are described below.

14.8.2.1 Section

The Section plots (Figure 14:21) are shown with respect to station location. The left bank is always shown at the left regardless of whether measurements were taken starting at the left or right bank. Plots available are:

- **Station discharge** – discharge per station
- **Velocity** – mean velocity per sample. Blue vectors indicate the mean velocity measured (in the X-direction with respect to the ADV probe). If multiple points exist, the blue vector represents the vertical average. The red vector(s) indicate actual velocity measured at each point, incorporating the Y-component of flow to indicate the skew ness of the flow with respect to the X-axis.
- **Depth** – depth measured at each station (from user input at each station). The actual measurement depths are indicated by dots. Hovering over the dots produces a pop-up showing the actual depth those measurements were made.

14.8.2.2 Stations

The Stations tab (Figure 14:22) shows detailed data for each station. The station in active view is highlighted in blue. Clicking on a different station line will highlight that station, and its available data will be displayed. Fields in the Station tab can be edited. For details on how to edit various parameters, please refer to Section 8.9 .Plots/data available are:

- **Point velocities** – X,Y, (and Z, if using a 3D probe) velocities measured during that station spanning the chosen sampling period
- **Point SNR** – mean beam SNR measured during that station spanning the chosen sampling period
- **Station information** – Station information summary. Values displayed are described in Table 14:3. The number of rows and columns that are viewable can be changed by using the four arrows that appear above the station information summary table in the software.

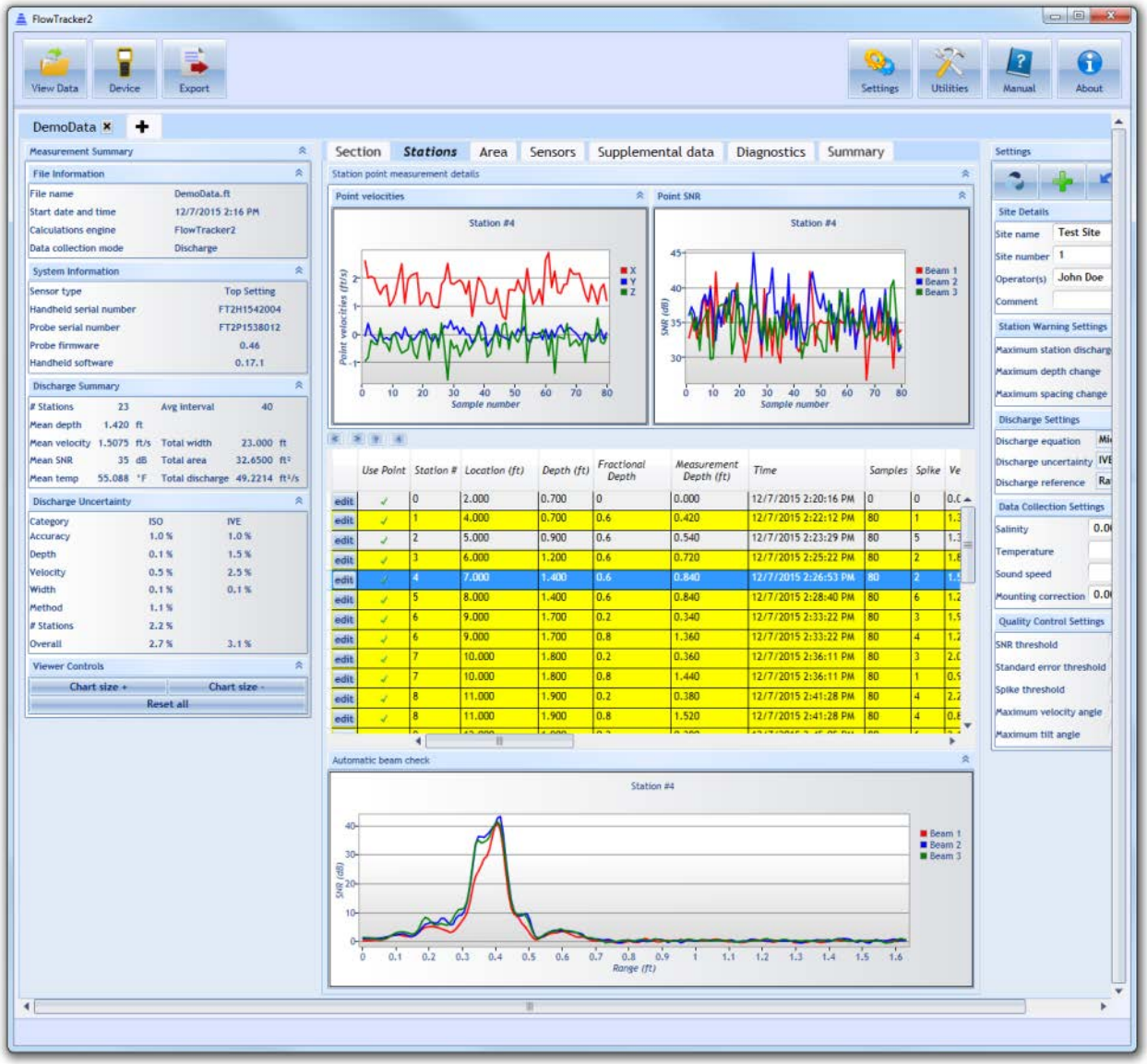


Figure 14:22. Layout of Stations Tab.

Table 14:3: Station Information Values Available

Edit	Orig. FT	FT2	Value	Description
✓	✓	✓	Use Point	Indicates whether the station is used in the discharge calculation. This feature can be edited.
	✓	✓	Station #	Station number
✓	✓	✓	Location	Station location along tag line
✓	✓	✓	Depth	Depth at each station (from user input during measurement)
	✓	✓	Fractional Depth	Fractional depth
	✓	✓	Measurement Depth	Actual measurement depth
	✓	✓	Time	Time at start of station

Edit	Orig. FT	FT2	Value	Description
	✓	✓	Samples	Number of samples in station
	✓	✓	Spike	Number of spikes during measurement period
✓	✓	✓	Velocity	Measured mean velocity
	✓	✓	SNR	Mean SNR (all beams)
	✓	✓	Velocity angle	Mean velocity angle with respect to FlowTracker probe X axis
	✓	✓	Velocity standard error	Velocity standard error
	✓	✓	Boundary interference	Boundary interference quality parameter (Best, Good, Fair, Poor)
		✓	Tilt	Mean Tilt
✓	✓	✓	Correction factor	User entered correction factor
	✓	✓	Width	Width of section
	✓	✓	Area	Area of section
	✓	✓	Mean velocity	Mean velocity calculated by dividing discharge by area
	✓	✓	Station discharge	Station discharge
✓	✓	✓	Temperature	Mean station temperature
	✓	✓	Warnings	Warnings associated with each station. Stations with warnings are highlighted in yellow.
✓	✓	✓	Comment	Comments from user input during measurement
✓	✓	✓	Station type	Station type (OpenWater, LeftBank, RightBank, IslandEdge, Ice)
✓	✓	✓	Velocity method	Velocity method used
		✓	GPS Latitude	GPS Latitude if GPS fix was recorded
		✓	GPS Longitude	GPS Longitude if GPS fix was recorded
		✓	Altitude	GPS Altitude if GPS fix was recorded
		✓	Number of satellites	GPS number of satellites if GPS fix was recorded
		✓	Fix quality	GPS fix quality if GPS fix was recorded
		✓	HDOP	HDOP if GPS fix was recorded

- **Automatic beam check** – For each station, the mean beam check data is displayed below the station information summary table. The SNR for each ADV beam is plotted with distance ("Range") from the sample volume.

14.8.2.3 Area



Figure 14:23. Layout of Area Tab

The Area tab (Figure 14:23) contains the following plots:

- **Area** – the Area plotted with respect to the tagline location of each station
- **Width** – the transect Width plotted with respect to the tagline location of each station
- **Velocity angle** – the angle of the flow with respect to the X-axis of the ADV probe plotted with respect to the tagline location of each station. The mean is calculated over all station samples. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.

14.8.2.4 Sensors



Figure 14:24. Layout of Sensors Tab

The Sensors tab (Figure 14:24) contains the following plots:

- **Temperature** – the mean temperature recorded during each station plotted with respect to the tagline location of each station. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.
- **Tilt** – the mean tilt recorded during each station plotted with respect to the tagline location of each station. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.
- **Battery** - the mean battery voltage recorded during each station plotted with respect to the tagline location of each station. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.

14.8.2.5 Supplemental Data

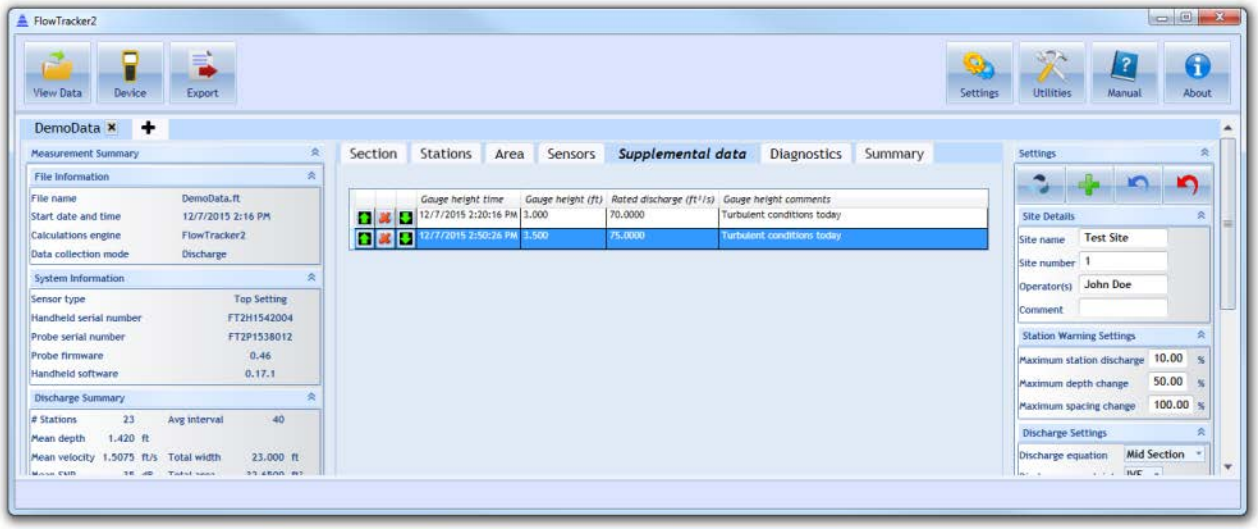


Figure 14:25. Layout of Supplemental Data Tab

Any supplemental data added during the measurement will appear in the Supplemental Data tab (Figure 14:25). Multiple supplemental data entries can be available during a measurement. Supplemental data values are the following:

- **Gauge height time** – time at which gauge height is taken
- **Gauge height** – gauge height read from external source
- **Rated discharge** – rated discharge acquired from external source
- **Gauge height comments** – any comments associated with gauge height or rated discharge reading

Supplemental data can be added after the measurement is collected in Post-Processing. Please refer to Section 14.9 for post-processing instructions.

14.8.2.6 Diagnostics



Figure 14:26. Layout of Diagnostics Tab

The Diagnostics tab (Figure 14:26) shows data pertaining to the quality of the measurement. The following plots are available:

- **SNR** – the mean SNR at the ADV sample volume over all samples and all beams at each station. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.
- **Spike** – the number of spikes that were detected over all samples at each station. Spikes are removed from the velocity measurement. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.
- **Velocity standard error** – the velocity standard error calculated over all samples at each station. In the case of multiple point measurements per station, a value will appear for each point measurements at a given station location.
- **Samples** – the number of samples collected per station

14.8.2.7 Summary

The Summary tab shows a comprehensive overview of the measurement. The information presented in the other tabs and panes are summarized in this tab. Please refer to other sections for descriptions of the specific values presented in this tab.

One feature in the Summary tab is the ability to export the measurement to a PDF file. Please see Export Discharge Summary to PDF for details on how to use this function.

14.8.3 **Settings Pane**

The Settings pane contains general information about the site, the measurement, and user input values. Much of this information is editable – please refer to Post-Processing FlowTracker Measurements regarding how to edit these values. The information presented in the Settings Pane is summarized in Table 14:4.

Table 14:4. Summary of Settings Pane Values

Category	Edit	Value	Description
Site Details	✓	Site Name	Site name
	✓	Site Number	Site number
	✓	Operator(s)	Operators(s)
	✓	Comment	Comments
Station Warning Settings	✓	Maximum station discharge	Maximum % discharge at each station after which a warning will be issued
	✓	Maximum depth change	Maximum % depth change between consecutive stations after which a warning will be issued
	✓	Maximum spacing change	Maximum % spacing change between consecutive stations after which a warning will be issued
Discharge Settings	✓	Discharge equation	Discharge equation used in discharge calculation (MidSection, MeanSection, Japanese)
	✓	Discharge uncertainty	Discharge uncertainty calculation used to calculate uncertainty (Iso, Ive, None)
	✓	Discharge reference	Discharge reference (Measured, Rated)
Data Collection Settings	✓	Salinity	Salinity used in velocity measurement
	✓	Temperature	Temperature used in velocity measurement. If left blank, will use measured

Category	Edit	Value	Description
			temperature in velocity calculation. If value is entered, this value will be used.
	✓	Sound speed	Sound speed used in velocity measurement. If left blank, will use measured temperature and entered salinity in calculation of sound speed used in velocity calculation. If value is entered, this value will be used.
	✓	Mounting correction	Mounting correction (%) applied to velocity value.
Quality Control Settings	✓	SNR threshold	SNR threshold (dB). If mean SNR at sample volume is below this value, a warning will be issued.
	✓	Standard error threshold	Standard error threshold (in velocity units). If standard error over all samples at each station exceeds this threshold, a warning will be issued.
	✓	Spike threshold	Spike threshold (in counts). If number of spikes at a station exceeds this value, a warning will be issued.
	✓	Maximum velocity angle	Maximum velocity angle (in degrees). If mean angle of flow with respect to ADV X-axis exceeds this value at a station, a warning will be issued.
	✓	Maximum tilt angle	Maximum tilt angle (in degrees). If mean tilt at a station exceeds this value, a warning will be issued.

14.9. Post-Processing FlowTracker Measurements

A powerful new feature in the FlowTracker2 now allows the user to edit most values associated with a measurement after the measurement is taken. This section provides instructions on the post-processing ability of the FlowTracker2 software.

Measurements taken with the Original FlowTracker Handheld ADV can also be edited with the FlowTracker2 software.

14.9.1 **Enable Editing**

14.9.1.1 FlowTracker2 .ft File Editing

By default, any measurement taken with the FlowTracker2 will have editing enabled. The editing pane appears in the top right corner of the software, shown in Figure 14:27.

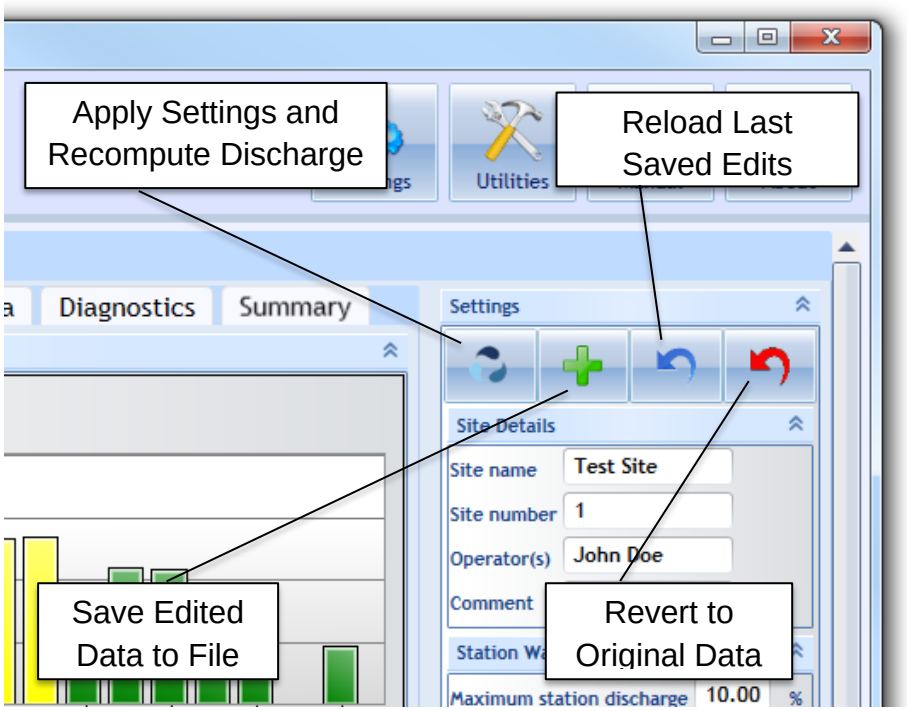


Figure 14:27. FlowTracker 2 Editing Buttons

Functions include:

- **Apply Settings and Recompute Discharge** – after any changes in the Settings Pane (right pane), hitting this button will apply those changes and recalculate discharge.
- **Save Edited Data to File** – after hitting the Apply Settings and Recompute Discharge button, changes will appear in the values displayed in the software, but these changes will not be saved to a file unless the Save Edited Data to File is pressed. A file containing edits will be created in the same folder where the .ft file resides with a "_edited" extension. Once this file is created, opening the .ft file will open the edited file showing the last saved edits.
- **Reload Last Saved Edits** – after performing multiple edits that are not saved, this button is used to revert back to the last saved edits.

- **Revert to Original Data** – reverts to the original .ft file that was downloaded from the FlowTracker2 Handheld unit. The original .ft file will always be preserved regardless of new edits saved.

14.9.1.2 Original FlowTracker .wad File Editing

To edit .wad files produced by the Original FlowTracker, the .wad files need to first be converted to .ft format. Please refer to Opening Original FlowTracker Handheld ADV Data Files (.WAD files) regarding how to convert these files. Once converted, open the .ft file. The Editing Pane will include an extra button when a .ft file is opened that was produced by the Original FlowTracker, as shown in Figure 14:28.

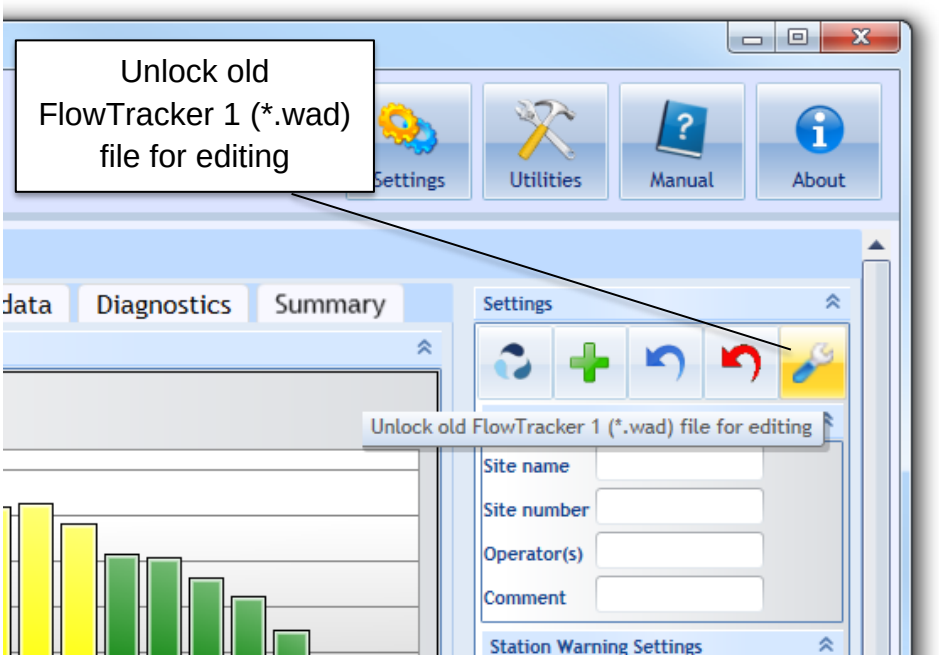


Figure 14:28. Original FlowTracker Editing Buttons

The unlock button exists because the Original FlowTracker discharge calculation algorithms differ from the FlowTracker2 discharge algorithms. Unlocking the Original FlowTracker file for editing will result in a recalculation of the discharge with the FlowTracker2 algorithms. To edit files created by the Original FlowTracker, first unlock the file for editing. The editing pane will then change to the same one that appears for .ft files taken with the FlowTracker2.

14.9.2 **Editing through the Settings Pane**

The values in the Settings Pane are summarized in Table 14:4. All of these values can be edited. To edit, type in the appropriate changes in the input boxes and press **the Apply Settings and Recompute Discharge** button. Changes will update all necessary parameters displayed in all panes and tabs in the software data view. As shown in

Figure 14:29, changed values will appear in the appropriate panes, with their original value included in square brackets.

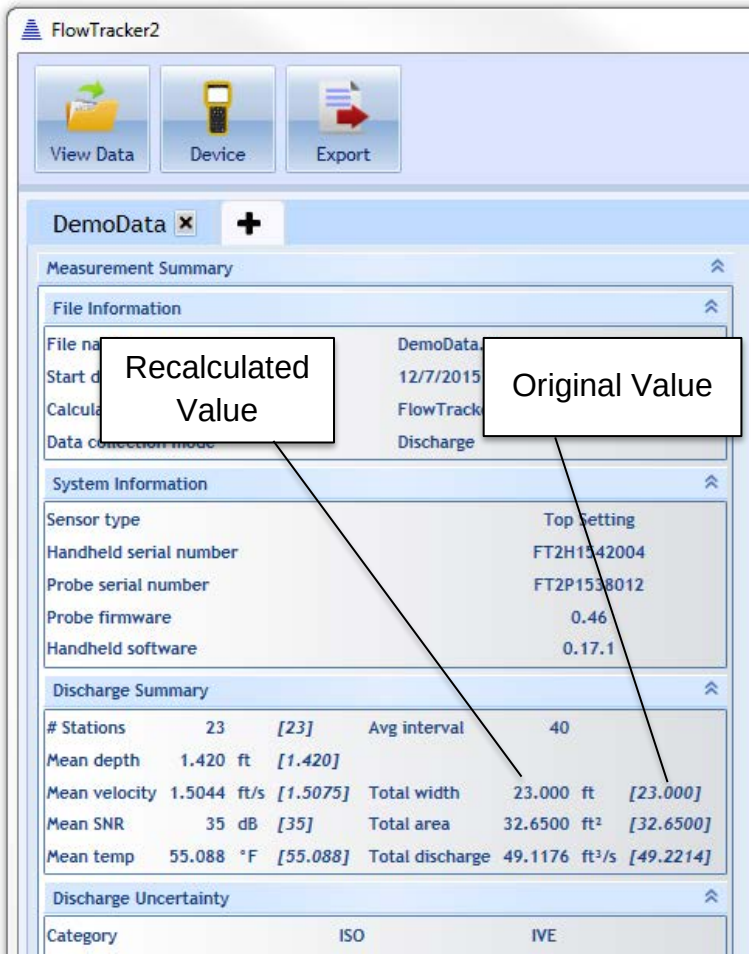
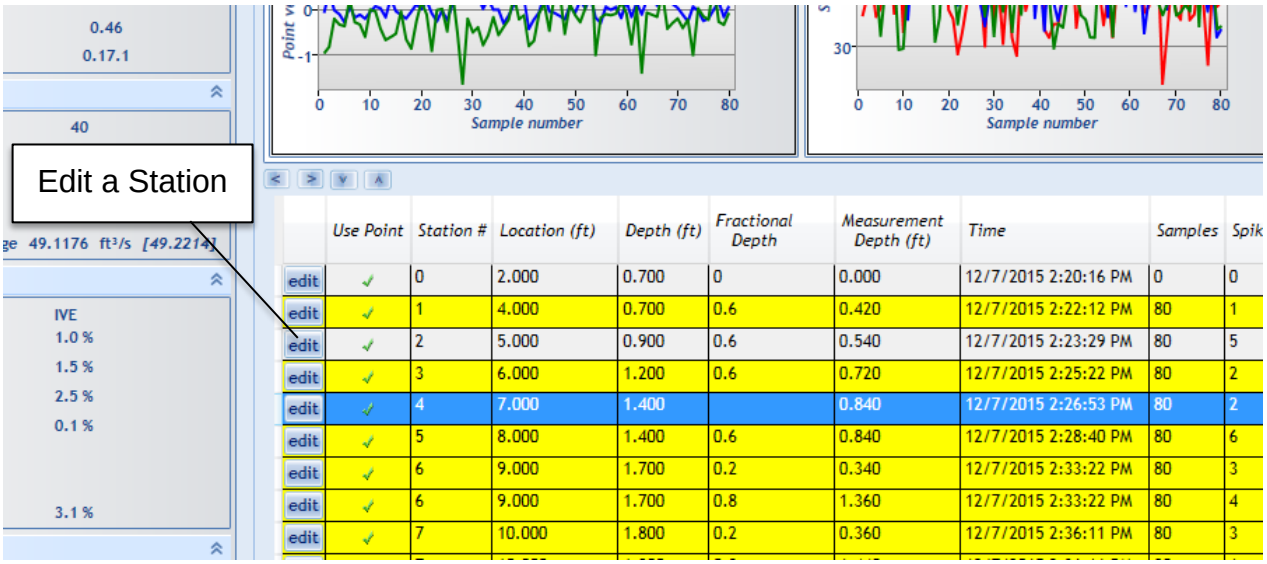


Figure 14:29. Edited Values Updated

14.9.3 **Editing by Station**

To edit values associated with individual stations within a measurement, first go to the Stations tab. The editable values associated with each station are indicated in Table 14:3. Identify the station you wish to edit, and press the Edit button on the left of that station line, shown in Figure 14:30.



	Use Point	Station #	Location (ft)	Depth (ft)	Fractional Depth	Measurement Depth (ft)	Time	Samples	Spik
edit	✓	0	2.000	0.700	0	0.000	12/7/2015 2:20:16 PM	0	0
edit	✓	1	4.000	0.700	0.6	0.420	12/7/2015 2:22:12 PM	80	1
edit	✓	2	5.000	0.900	0.6	0.540	12/7/2015 2:23:29 PM	80	5
edit	✓	3	6.000	1.200	0.6	0.720	12/7/2015 2:25:22 PM	80	2
edit	✓	4	7.000	1.400		0.840	12/7/2015 2:26:53 PM	80	2
edit	✓	5	8.000	1.400	0.6	0.840	12/7/2015 2:28:40 PM	80	6
edit	✓	6	9.000	1.700	0.2	0.340	12/7/2015 2:33:22 PM	80	3
edit	✓	6	9.000	1.700	0.8	1.360	12/7/2015 2:33:22 PM	80	4
edit	✓	7	10.000	1.800	0.2	0.360	12/7/2015 2:36:11 PM	80	3

Figure 14:30. Edit by Station

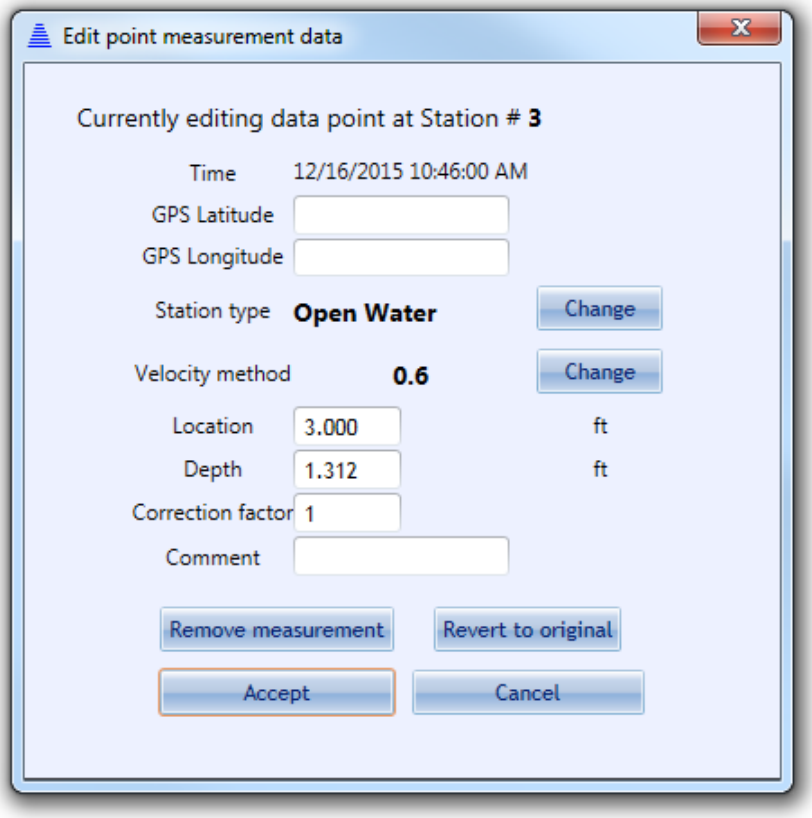


Figure 14:31. Station Editing Dialog

A pop-up editing dialog will appear when the **Edit** button is pressed, shown in Figure 14:31. Within this dialog, the following items can be edited:

- **GPS Latitude** – GPS latitude if known from external source
- **GPS Longitude** – GPS longitude if known from external source

- **Station Type** – Change station type (LeftBank, RightBank, IslandEdge, OpenWater, Ice). Please note: when changing station types, there are some station type combinations that will result in an error and the software will be unable to compute discharge. For example, inputting two Left Bank station types for the section will result in an error. Please refer to your discharge measurement method guide for specific rules regarding what station types are valid for your measurement.
- **Velocity Method (enter Manual Velocity or None)** – the option exists to enter a manual velocity if it is known at the station and not measured by the ADV. To enter a manual velocity, click the **Change** button and select the "Enter Velocity" option, and hit **Accept**. A new input box will appear in the main dialog to enter a manual velocity value. To select **None** for the Velocity Method, select the "None" option, and hit **Accept**.
- **Location** – Change the location at which the station was taken. Please note: if location does not satisfy the **Maximum Spacing Change** criteria set in the Settings Pane, a warning will appear.
- **Depth** – Change the water depth at the station. Please note: if the depth does not satisfy the **Maximum Depth Change** criteria set in the Settings Pane, a warning will appear.
- **Correction Factor** – Change the correction factor applied to the velocity value. The correction factor is a fraction ranging from [-1:1].
- **Comment** – Change or add a comment associated with station
- **Remove Measurement** – Removing a station removes it from being used in the discharge calculation. Please note: some rules apply to what types of stations can be removed, and are specific to the velocity method used. For example, if the original measurement were a 0.2/0.8 measurement, removing the 0.2 measurement will result in an automatic removal of the 0.8 measurement. If a 0.2/0.6/0.8 measurement is taken, removing the 0.6 measurement will result in removing the 0.6 measurement only, as a 0.2/0.8 is still a valid measurement type. However, for this 0.2/0.6/0.8 measurement, if the 0.2 measurement is removed, all three measurements associated with this station will be removed (0.2, 0.6, and 0.8). Please consult the rules specific to each measurement type.
- **Revert to Original** – Revert to original values associated with the station when the data file was downloaded from the FlowTracker unit.

After any changes to these editable values, click the **Apply Changes** button. Discharge will be recalculated and new values will be appearing in the appropriate areas.

14.9.4 **Editing Supplemental Data**

Supplemental data can be added or edited after the measurement is taken and the file is closed in the handheld device. To add or edit supplemental data, first navigate to the Supplemental Data tab (Figure 14:25). To edit existing supplemental data, simply double click on the field you wish to edit, and enter in a new value. To add a line of supplemental data, click the Add Supplemental Data button. To add additional lines of supplemental data, use the green up/down arrows to add rows above/below the current line, respectively.

14.10. Data Export and File Formats

Data can be exported from the FlowTracker2 desktop software. Formats available are PDF and ASCII files.

14.10.1 **Export Discharge Summary to PDF**

To export the Discharge Summary to PDF, navigate to the Summary tab and click the **Save PDF of Summary** button. A PDF will be produced and opened using a PDF viewer the user has installed on the computer. An example of a discharge summary is shown in Figure 14:32. The user can then choose to save or print the PDF file.

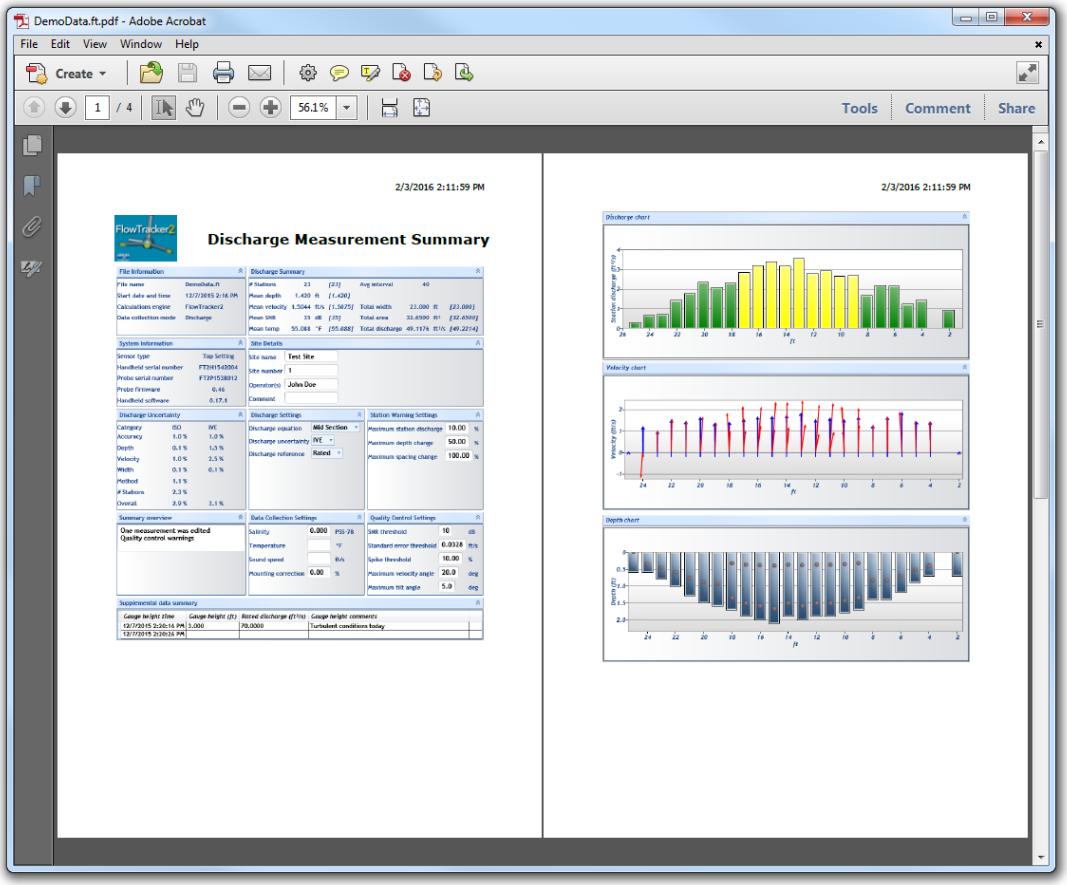


Figure 14:32. PDF Discharge Summary File

14.10.2 Export Files to ASCII

To export .ft files to ASCII format readable by text editors and spreadsheet software (Microsoft Excel, Word, etc.), click the Export button, shown in Figure 14:33.



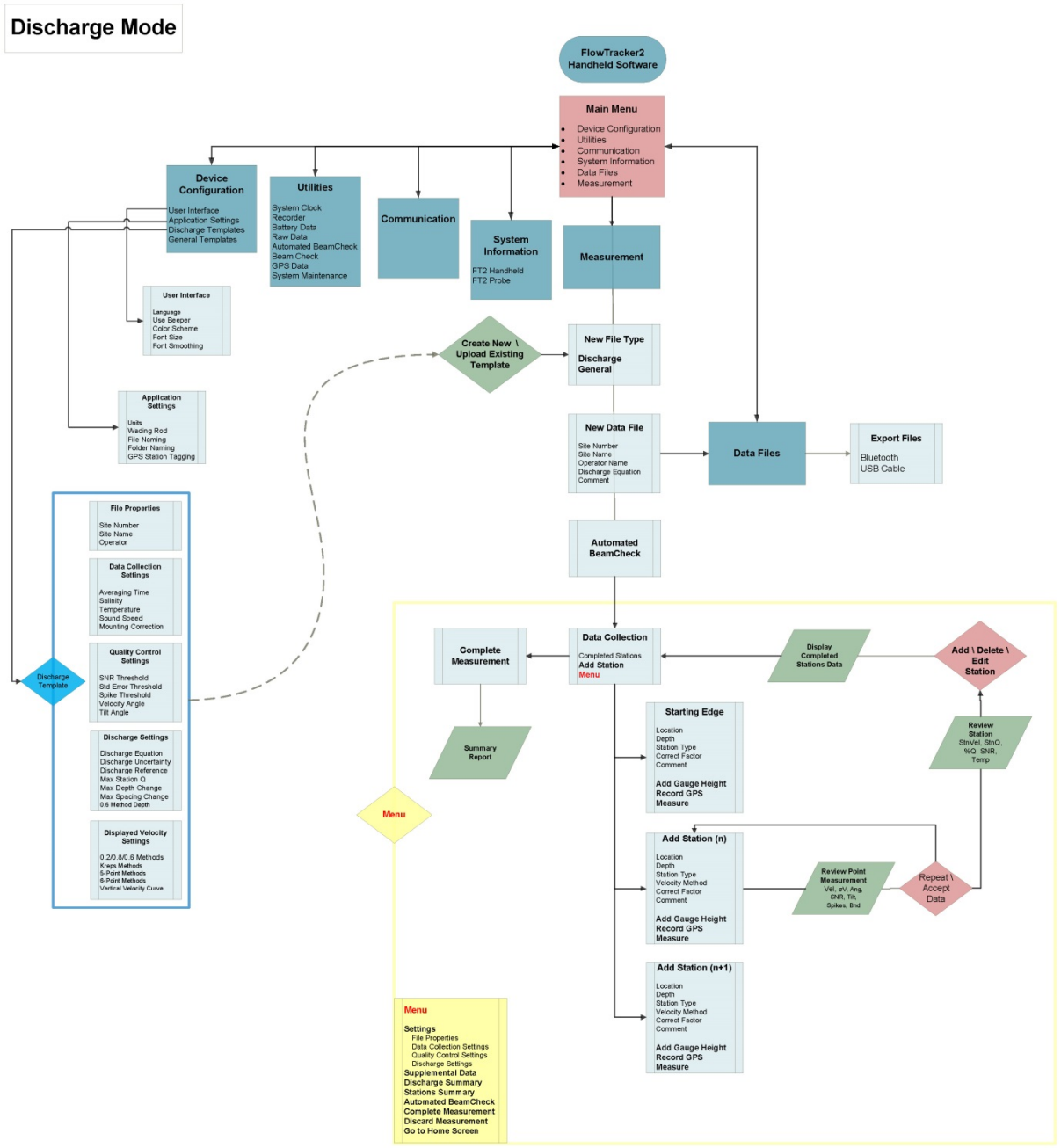
Figure 14:33. Export to ASCII Button

A dialog will appear with the options to Show Headers and Export in English Language. The export function will not automatically export the data you have opened for viewing. Instead, a dialog will appear to select the .ft file you wish to export, and following this, you will select a folder to where the export will save the ASCII files. Four ASCII files will be created in the selected folder. The contents and format of the ASCII files is summarized in FlowTracker2 CSV Output.

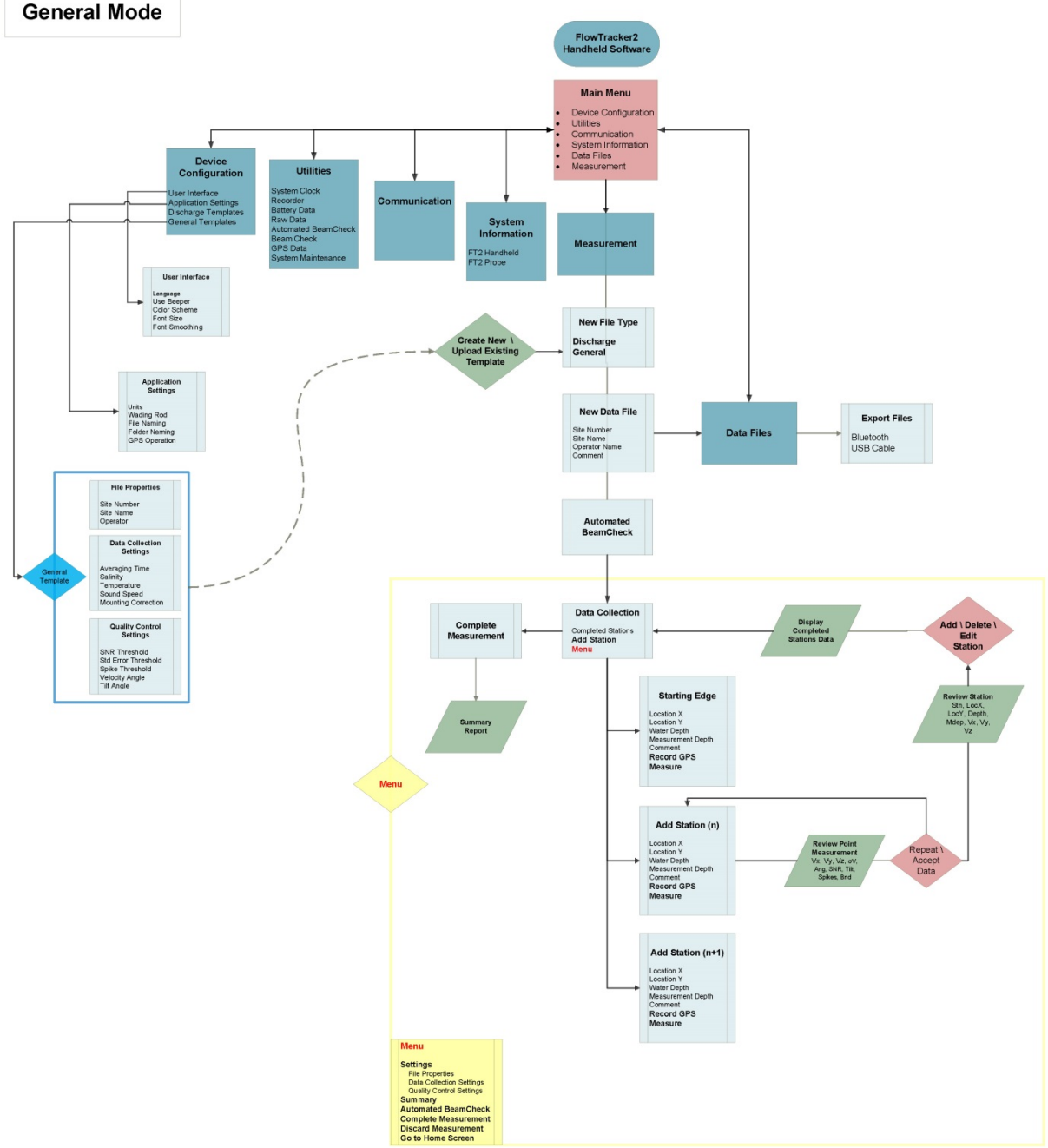
14.10.3 Matlab Tools for JSON files

Although the FlowTracker2 software does not have a specific Matlab export, a number of Matlab tools exist to parse and convert JSON format files to Matlab-readable format, and are readily available through various third-party websites. If help is needed in using Matlab to read the FlowTracker .ft files into Matlab, please contact SonTek (support@sontek.com).

Appendix A. Software Flow Diagram



General Mode



Appendix B. Site Selection Requirements

The **Site Selection Requirements** for performing discharge measurements using a FlowTracker2 instrument are based on a number of measurement site and hydraulic requirements. The measurement site and hydraulic requirements are similar to what a Hydrologists or Hydrographer will use in the selection of monitoring site for either natural or artificial control. The site and hydraulic requirements that need to be taken in into account with every discharge measurement are summarized under the following points.

a) Uniform flow conditions throughout the measurement section,

b) Straight length of channel with uniform cross-section and slope (10 times section width).

c) Flow in the channel should be confined to a single well-defined channel with stable banks.

d) Avoid a site with wide shallow sections or secondary side channels.

e) Bends upstream of site should be avoided as this will result in angular flow towards tagline,

f) Steep slopes upstream should be avoided as this could result in high approach velocities at the measurement site causing turbulent flow conditions.

g) Avoid measurement sections with deep pools as the reduction in velocity normally diverge from uniform flow conditions,

h) Avoid prominent obstructions in a pool or excessive plant growth that can affect the flow pattern.

i) Turbulent flow conditions should be avoided if possible.

j) Negative and or back flow should be avoided at all times.

k) Flow conditions must be within the instrument and equipment specifications

Appendix C. Japanese Method Example

The measurement example of the Japanese method given in Appendix C is based on an actual field measurement that was manually calculated to give an overview of the various steps involved. The section of the measurement site was greater than 10m and based on the Japanese Method, the measuring technique applicable is Equation 5:3.

Equation 5:1 - Japanese Method > 10m

$$Q = \sum\left\{\left[(b_1 - b_0) \times 0.5\left(\frac{d_1+d_1'}{2} + \frac{d_0+d_0'}{2}\right) + (b_2 - b_1) \times 0.5\left(\frac{d_2+d_2'}{2} + \frac{d_1+d_1'}{2}\right)\right] \times \left(\frac{\overline{v}_1+\overline{v}_1'}{2}\right)\right\} +$$

Edge

$$\left\{\left[(b_n - b_{n-1}) \times 0.5\left(\frac{d_n+d_n'}{2} + \frac{d_{n-1}+d_{n-1}'}{2}\right) + (b_{n+1} - b_n) \times 0.5\left(\frac{d_{n+1}+d_{n+1}'}{2} + \frac{d_n+d_n'}{2}\right)\right] \times \left(\frac{\overline{v}_n+\overline{v}_n'}{2}\right)\right\}$$

Open Water

Items to be field in the field survey										Items to be filled after survey						
Stn no	Dist from Bank (m)	Depth (m)			Velocity					Velocity		Station Area				Disc. (m^3/s)
		When going	When back	Average	Meas depth	Sound no.	Meas. Time (s)			Vel. (m/s)	Ave. (m/s)	Ave. Depth	Ave Width	Area (m^2)	Sum (m^2)	
							1st	2nd	Ave							
0	0	0.00	0.00	0.00								0.58	2.00	1.16		
1	2	1.15	1.16	1.16	0.23	9	25.0	25.6	25.3	1.20	1.16				3.32	3.85
					0.92	9	26.6	28.2	27.4	1.11		1.08	2.00	2.16		
2	4	1.00	1.00	1.00								0.90	2.00	1.80		
3	6	0.80	0.80	0.80	0.16	9	21.8	22.0	21.9	1.38	1.20				3.26	3.91
					0.64	9	30.8	29.4	30.1	1.01		0.73	2.00	1.46		
4	8	0.66	0.65	0.66								0.60	2.00	1.20		
5	10	0.54	0.54	0.54	0.32	6	23.1	23.0	23.0	0.88	0.88				2.20	1.94
					--	--	--	--	--	--		0.50	2.00	0.92		
6	12	0.45	0.45	0.45								0.46	2.00	0.92		

Appendix D. Measurement Equipment List

Cat.	Items	Quantity	Description
FlowTracker2	Probe	1	FlowTracker2 probe with cable
	Handheld	1	FlowTracker2 handheld
	Battery Cartridge	2	Battery cartridge for FlowTracker2
	Handheld Bracket	1	Handheld bracket to mount handheld to Top Setting Rod
	Top Setting Rod	1	Top setting wading rod
	S Bracket Screw	1	Screw to clamp probe to S bracket
	USB Cable	1	USB cable to download data from FlowTracker2
Safety Gear	Mobile \ Satellite Phone	1	Contact office, local authorities or emergency services
	Drink Water	1pp	5L drink water per person per day
	Night-day Safety Vest	1pp	Required when working during low visibility or from bridges \ culverts
	Road Signs	2	Required when working from bridges \ culverts
	Sun Hat	1pp	Large brim hat
	Rain Jacket	1pp	Only to be used when raining
	Wader or Water Boots	1pp	Select type of water proof boots based on the water depth.
	Life Jacket	1pp	When entering water an approved life jacket must be worn.
	First Aid Kit	1	Require first aid certificate
	Sunscreen	1	
	Insect repellent	1	Midge and Mosquito
Measurement Gear	Measuring Tape	1	Measuring tape length dependent on section width.
	Pocket Tape	1	Verify water depth or instrument setting.
	Steel Pegs	2	To anchor the measuring tape on both banks
	Hammer	1	5lb
	Shovel \ Rake	1	Shovel \ Rake to clean measurement section
	Camera	1	Photographs of measurement site and flow conditions
Reference	Laptop \ Tablet	1	Download measurements at measurement site to evaluate on desktop software
		1	**CastAway**, Verify water temperature and salinity (see Principle of Operations).

pp – per person

Appendix E. CE Declaration of Conformity

Declaration of Conformity

Manufacturer's Name: SonTek, a Xylem brand
Manufacturer's Address: 9940 Summers Ridge Road
San Diego, CA 92121-3091 U.S.A.

SonTek, a Xylem brand declares that the product(s):

Equipment Type: Flow Meter
Model: FlowTracker2 (including P/N's FT2-HH-1, FT2-PR-1, FT2-PR-3)

Conforms to the following FCC, European Union, and Korean Directives and Standards as of 2/12/16:

FCC Part 18, CFR 47, Section 18.309

KN 61326-1 and KN 11

IEC/EN 61010-1:2010 3rd ed,

EMC Directive 2004/108/EC EN61326-1: 2013
In accordance with the following documents and standards:
-EN 55011: 2009+A1: 2010, A
-EN 61000-3-2: 2006 +A1:2009 +A2:2009
-EN 61000-3-3: 2008
-EN 61000-3-3: 2013
-EN 61000-4-2: 2009
-EN 61000-4-3: 2006 +A1:2008 +A2:2010
-EN 61000-4-4: 2004+A1:2010
-EN 61000-4-5: 2006
-EN 61000-4-6: 2009
-EN 61000-4-8: 2010
-EN 61000-4-11:2004

Hakan Erdem
General Manager
SonTek – a Xylem brand

Declaration of Conformity

Manufacturer's Name: SonTek, a Xylem brand
Manufacturer's Address: 9940 Summers Ridge Road
San Diego, CA 92121-3091 U.S.A.

SonTek, a Xylem brand declares that the product(s):

Equipment Type: Flow Meter
Model: FlowTracker2 (including P/N's FT2-HH-2 and higher, FT2-PR-1, FT2-PR-3)

Conforms to the following FCC, European Union, and Korean Directives and Standards as of 2/12/16:

FCC Part 18, CFR 47, Section 18.309

KN 61326-1 and KN 11

IEC/EN 61010-1:2010 3rd ed, for use with NiMH rechargeable batteries that are certified to IEC 62133

EMC Directive 2004/108/EC EN61326-1: 2013
In accordance with the following documents and standards:
-EN 55011: 2009+A1: 2010, A
-EN 61000-3-2: 2006 +A1:2009 +A2:2009
-EN 61000-3-3: 2008
-EN 61000-3-3: 2013
-EN 61000-4-2: 2009
-EN 61000-4-3: 2006 +A1:2008 +A2:2010
-EN 61000-4-4: 2004+A1:2010
-EN 61000-4-5: 2006
-EN 61000-4-6: 2009
-EN 61000-4-8: 2010
-EN 61000-4-11:2004

Hakan Erdem
General Manager
SonTek – a Xylem brand

INDEX

A

Accessing Templates · 36
accuracy · 199
Add Station · 112, 139
ADV Firmware · 155
Alkaline · 54
Application Settings · 30
Automated Beam Check · 59, 109, 130, 136, 147
Automatic · 34
Averaging Time · 18, 40

B

Bank (left or right) · 116
Base Template · 37
Battery Cap · 161
Battery Compartment · 16
Battery Data · 54
Battery Indicator · 58
Battery Type · 54
Battery Voltage · 55
Beam Check · 61, 92
Beam Check Features · 93
Beam Check Operation · 94
Beam Check Overview · 92
Beam Geometry · 197
Beeper · 29
bistatic · 197
bottom · 31
Bottom banner · 22
boundary adjustment · 197

C

Cable Maintenance · 160
Cartesian (xyz) · 197
CastAway-CTD · 40
Channel Banks · 71
Color Scheme · 29
Comma Separated Values · 177
Communication · 24
Communication Connector · 16
Complete Measurement · 130, 148
Condensation · 161
conductivity · 40
Configuration Templates · 35
Confirmation · 113, 115, 141
considerations · 200
Correction Factor · 73
Create Measurement · 107, 134

D

Data Collection · 111, 138
Data Collection Menu · 126, 145
Data Collection Modes · 64
Data Collection Settings · 39
Data Collection Window · 112, 138
Data Files · 26
Data Management · 105
Delete Station · 113, 140
Deleting · 113, 140
Depth · 74
Depth Only · 72
Desktop Software · 155
Determining Mean Station Velocity · 70
Determining Mean Velocity · 76
Device Configuration · 23, 28
Diagnosing Measurements with Beam Check · 94
Disabled · 35
Discard Measurement · 131, 149
Discharge · 37
Discharge Calculation Methods · 65, 116, 117, 120
Discharge Equation · 45
Discharge Measurement · 107
Discharge Mode · 64
Discharge Reference · 46
Discharge Settings · 44
Discharge Summary · 128
Discharge Uncertainty · 46
Discharge Uncertainty Calculation · 73
Discharge Velocity Methods · 48
Displayed Velocity Methods · 48

E

Edges · 66, 68, 70
Edit Station · 114
Editing · 114
English · 31
Equipment List · 98
Erase Recorder · 53
Evaluate Beam Check Results · 110, 137

F

Field Applications · 162
File Format · 167
File Framework · 168
File Naming · 32
File Properties · 38
File Structure · 169
Flow Interference · 202
Folder Naming · 33
Follow Number · 33
Font Size · 29
Font Smoothing · 30
Fractional Depth Measurement · 123

G

General · 37
General Measurement · 134
Go to Home Screen · 132, 149
GPS Data · 61
GPS Station Tagging · 33
Graph Range · 94
Graph SNR · 94

H

Handheld · 16, 18
Handheld Mounting Bracket · 157
Handheld Software · 155
Hardware Inspection · 99
Health and Safety · 165
Housing · 161

I

Ice · 119
Interpolated Variance Estimator · 46
Interpolated Variance Estimator (IVE) · 73
Island Edge · 117
Islands · 66, 68, 70
ISO · 73
ISO 748 - 2007 · 46

J

Japanese Method · 45
JSON File · 167

K

Keypad · 16, 20

L

Language · 28
LCD Screen · 16
Left Bank · 116
Left Soft Key · 22

M

Main · 22
Manage Recorder · 52
Manual · 34
Manual Change · 50
Max Depth Change for Warning · 47
Max Spacing Change for Warning · 47
Max Station Q for Warning · 47
Mean-Section Equation · 67
Mean-Section Method · 45
Measured Discharge · 46
Measurement · 25, 107, 134
Measurement Location · 18
Measurement Procedure · 102
Measurement Process · 98
Measurement Site Information · 101
Measurement Summary · 132, 149
Measurement Technique · 64, 76
Method None · 71
Metric · 31
Mid-Section Equation · 65
Mid-Section Method · 45
Mounting Correction · 42
mounting, probe · 200

N

New Data File · 108, 135
New File Type · 107, 134
New Template · 37
NiMH · 54
Noise Level · 93

O

Office Diagnostic · 99
Office Procedures · 98
On/Off Switch · 20
Open Station · 114
Open Water · 118
O-rings · 161

P

Peak Level · 94
Peak Position · 94
Percentage Full · 55
Ping · 18
Ping Rate · 18
Point Velocity Measurement · 121, 141
Post Measurement Requirements · 104
Practical Salinity Scale · 40
Pre Measurement Diagnostics · 101
Predefined Languages · 28
Probe · 16
Probe cable · 16
probe configurations · 200
Probe Mounting Bracket · 158
Probe orientation · 202
Properties · 39, 42, 45, 48, 51, 52, 62, 116, 117, 118, 119, 124, 125, 128, 129, 132, 140, 144, 145, 147, 150
pulse-coherent · 196

Q

quality control · 200
Quality Control · 77
Quality Control Data · 18
Quality Control Parameters · 77
Quality Control Settings · 42
Quality Control Warning Message · 89

R

Rated Discharge · 46
Raw Data Display · 55
receivers · 194
Receivers · 17
Record GPS Location · 34
Recorder · 52
reference · 41
Review Measurement Summary · 105
Review of Measurement Site Information · 104
Review Point Measurement · 123, 143
Review Station · 114
Review Station Measurement · 124, 144
Right Soft Key · 22
Routine Maintenance · 159

S

Salinity · 18, 40
Sample · 18, 93
Sample Averaged · 93
sampling strategy · 198
sampling volume · 194
Sampling volume · 17
Sampling Volume · 197
Scattering Material · 162
Screen Layout · 22
Seeding · 162
Selecting Template · 37
Setting Fractional Depth · 122, 142
Setting Measurement Depth · 142
Settings · 127, 146
Signal Strength · 18
Signal to Noise Ratio · 78, 195
Signal-to-Noise Ratio (SNR) · 18

SNR · 78
SNR Raw Data · 57
SNR Threshold · 43
soft key · 20
Software Upgrade · 155
Sound Speed · 18, 41
Sound Velocimeters · 40, 41
Spike Threshold · 43
Stage - Discharge Relationship · 105
Standard Error · 43
Start Automated Beam Check · 109, 136
Station Measurement · 120, 141
Station Parameters · 120
Station Summary · 129
Station Type · 115
Station Types · 115
Std Error Threshold · 43
Storage · 106
Structures · 202
Supplemental Data · 127
Sync with GPS Time · 51
System Clock · 50
System Information · 24
System Maintenance · 63
System Operation · 20

T

Temperature · 19, 41
Temperature Raw Data · 58
Temperature sensor · 17
Template Functions · 37
Template Main Screen · 36
Template Name · 37
Templates · 36
The Doppler Shift · 193
Tilt Angle Warning · 44
Tilt Raw Data · 58
Timing of Warning Messages · 91
Top banner · 22
Transducers · 160
transmitter · 194
Transmitter · 17

U

Units · 30
Units System · 30
Upgrading ADV Firmware · 157
Upgrading Handheld Software · 155
User Interface · 28
UTC · 19
Utilities · 23, 50

V

Velocity · 74
Velocity Angle for Warning · 44
velocity data · 199
Velocity Measurement · 142
Velocity Method · 114, 115, 121
Velocity Raw Data · 56
Velocity Standard Error · 81
Velocity Summary · 146
Vertical Velocity Curve · 72

W

Wading Rod · 31
water surface · 31
Width · 74

Z

Zinc Anodes · 161

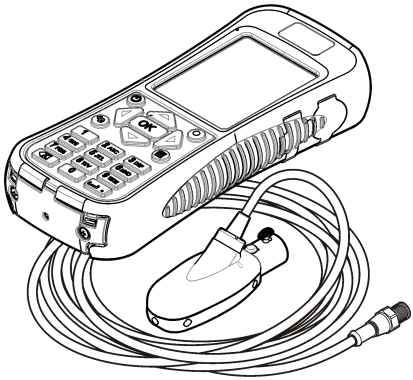
ATTACHMENT D
HACH FH950® Technical Manual

DOC026.53.80210

FH950

04/2018, Edition 5

User Manual



Specifications 3
Sensor specifications 3
Portable meter specifications 3
User interface specifications 4
General specifications 4

General information 4
Safety information 5
Use of hazard information 5
Precautionary labels 5
Certification 5
Product overview 6
System overview 6
Sensor overview 7
Meter overview 8
Product components 9

Installation 9
Installation with optional accessories 9
Install the sensor on the universal sensor mount 9
Lithium battery safety 10
Install the battery 10
Charge the battery 11
Connect the sensor to the meter 12
Attach the lanyard 12
Attach the velcro strap 13

User interface and navigation 13
Keypad and key functions 13
Status bar 14
Navigation and Main Menu 15

Startup and self-test 19
Sleep mode 19

Operation 20
Stream profiles 20
Stations and station spacing 20
Measure velocity 20
Measure velocities in a cross-section 21
Insert or delete a station 23
Conduit profiles 24
0.9 x Vmax measurement method 24
0.2/0.4/0.8 method 24
Velocity/Level Integration measurement method 25
2D measurement method 26
Download data 27
Delete data files 27

Maintenance 27
Download the PVM utility 27

Update the firmware 27
Clean the sensor 28
Clean the meter 29
Replace the battery 29

Troubleshooting 29
Diagnostics 29
Troubleshoot errors 30

Replacement parts and accessories 30

Appendix 32
Mean-section and Mid-section methods 32
Profiles and measurements 33
Site selection 34
Do a velocity calibration 34
Wet/Dry threshold 34

Specifications

Specifications are subject to change without notice.

Sensor specifications

Specification	Details
Velocity measurement	
Method	Electromagnetic
Range	0 to 6.09 m/s (0 to 20 ft/s)
Minimum water depth	3.18 cm (1.25 in.)
Accuracy	±2% of reading ±0.015 m/s (±0.05 ft/s) 0 to 3.04 m/s (0 to 10 ft/s); ± 4% of reading from 3.04 to 4.87 m/s (10 to 16 ft/s)
Resolution	0.01 value < 100; 0.1 value < 1000; 1.0 value ≥ 1000
Zero stability	±0.015 m/s (±0.05 ft/s)
Material	ABS, glass filled
Enclosure rating	IP68
Dimensions (L x W x H)	11.9 x 4.3 x 6.3 cm (4.7 x 1.7 x 2.5 in.)
Cable material	Polyurethane jacketed
Cable lengths	1.5, 6.1, 12.2 and 30.5 m (5, 20, 40 and 100 ft)
Depth measurement	
Method	Diaphragm type: absolute pressure with single point calibration
Accuracy (static)	The larger of ± 2% of reading or ± 0.015 m (± 0.504 inches). Steady state temperature and static non-flowing water.
Range	3.05 m (0-10 ft)
Resolution	0.01 value < 100; 0.1 value < 1000; 1.0 value ≥ 1000

Portable meter specifications

Specification	Details
Pollution degree	2
Protection class	II
Charging temperature	0 to 40 ºC (32 to 104 ºF)
Operating temperature	–20 to 55 ºC (-4 to 131 ºF)
Storage temperature	–20 to 60 ºC (-4 to 140 ºF)
Enclosure rating	IP67
Battery life gauge	Five-segment bar graph
Battery type	Rechargeable lithium ion, 3.6 V, 5.0 Ah, 18 Wh
Battery life	18 hours heavy typical day use[1]; 20 ºC (68 ºF)

[1] Defined as 30 minutes of set up, six 1-hour periods of continuous use with an active sensor and the display at maximum brightness and 30 minutes of sleep mode between use periods, data download and power off.

Specification	Details
Battery charger	External power adapter, energy efficiency VI, 100–240 VAC, 50–60 Hz, 0.5 A input; 12 VDC, 1.25 A output
Dimensions (L x W x H)	21.8 x 9.3 x 5.3 cm (8.6 x 3.7 x 2.1 in.)
USB connector	Type Mini-B, 5-pin, rated to IP67 when capped
Material	Polycarbonate with a thermoplastic elastomer (TPE) overmold

User interface specifications

Specification	Details
Graphics display	Color, LCD 3.5" QVGA transflective (readable in direct sunlight)
Measurement resolution	0.01 value < 100; 0.1 value < 1000; 1.0 value ≥ 1000
Keypad	Alpha-numeric
Operating modes	Real time, profiling
Profile types	Stream, conduit
Conduit shapes	Circular, rectangular, trapezoidal, 2/3 egg, inverted 2/3 egg
Stream entries	Fixed, non-fixed stations
Noise rejection	User-selectable, 50 Hz or 60 Hz
Units of measure	Velocity: ft/s, m/s, cm/s, mm/s
	Flow: ft^3/sec, million gal/day, gal/day, gal/min, m^3/s, m^3/min, m^3/hour, m^3/day, liters/s, liters/min
	Depth: in., ft, m, cm, mm
Stream flow calculation	Mean-section or mid-section method
Diagnostics	Self test, keypad, display, event log
Conduit profiling methods	0.9 x Vmax, 0.2/0.4/0.8, velocity and level integrator, 2D
Stream profiling methods	1, 2, 3, 5 and 6 point (velocity method - USGS and ISO)
File types	Real-time, profiling, event log
Languages	English, French, Spanish, German, Italian, Dutch, Danish, Swedish, Chinese, Polish, Japanese, Korean, Portuguese, Slovak, Russian, Hungarian, Bulgarian, Romanian, Czech, Turkish, Finnish, Greek

General specifications

Specification	Details
Profiles	Data storage for up to 10 profiles with 32 stations per profile
Maximum number of real-time files	Three each with up to 75 readings captured by the user.
Firmware	The sensor and portable meter are field upgradeable via USB

General information

In no event will the manufacturer be liable for direct, indirect, special, incidental or consequential damages resulting from any defect or omission in this manual. The manufacturer reserves the right to make changes in this manual and the products it describes at any time, without notice or obligation. Revised editions are found on the manufacturer's website.

Safety information

NOTICE

The manufacturer is not responsible for any damages due to misapplication or misuse of this product including, without limitation, direct, incidental and consequential damages, and disclaims such damages to the full extent permitted under applicable law. The user is solely responsible to identify critical application risks and install appropriate mechanisms to protect processes during a possible equipment malfunction.

Please read this entire manual before unpacking, setting up or operating this equipment. Pay attention to all danger and caution statements. Failure to do so could result in serious injury to the operator or damage to the equipment.

Make sure that the protection provided by this equipment is not impaired. Do not use or install this equipment in any manner other than that specified in this manual.

Use of hazard information

⚠ DANGER

Indicates a potentially or imminently hazardous situation which, if not avoided, will result in death or serious injury.

⚠ WARNING

Indicates a potentially or imminently hazardous situation which, if not avoided, could result in death or serious injury.

⚠ CAUTION

Indicates a potentially hazardous situation that may result in minor or moderate injury.

NOTICE

Indicates a situation which, if not avoided, may cause damage to the instrument. Information that requires special emphasis.

Precautionary labels

Read all labels and tags attached to the instrument. Personal injury or damage to the instrument could occur if not observed. A symbol on the instrument is referenced in the manual with a precautionary statement.

	This is the safety alert symbol. Obey all safety messages that follow this symbol to avoid potential injury. If on the instrument, refer to the instruction manual for operation or safety information.
	This symbol indicates the presence of devices sensitive to Electro-static Discharge (ESD) and indicates that care must be taken to prevent damage with the equipment.
	Electrical equipment marked with this symbol may not be disposed of in European domestic or public disposal systems. Return old or end-of-life equipment to the manufacturer for disposal at no charge to the user.

Certification

Canadian Radio Interference-Causing Equipment Regulation, IECS-003, Class A:

Supporting test records reside with the manufacturer.

This Class A digital apparatus meets all requirements of the Canadian Interference-Causing Equipment Regulations.

Cet appareil numérique de classe A répond à toutes les exigences de la réglementation canadienne sur les équipements provoquant des interférences.

FCC Part 15, Class "A" Limits

Supporting test records reside with the manufacturer. The device complies with Part 15 of the FCC Rules. Operation is subject to the following conditions:

1. The equipment may not cause harmful interference.
2. The equipment must accept any interference received, including interference that may cause undesired operation.

Changes or modifications to this equipment not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment. This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to Part 15 of the FCC rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference, in which case the user will be required to correct the interference at their expense. The following techniques can be used to reduce interference problems:

1. Disconnect the equipment from its power source to verify that it is or is not the source of the interference.
2. If the equipment is connected to the same outlet as the device experiencing interference, connect the equipment to a different outlet.
3. Move the equipment away from the device receiving the interference.
4. Reposition the receiving antenna for the device receiving the interference.
5. Try combinations of the above.

Product overview

The portable velocity system is used in the field, laboratory and municipalities. Turbulent, noisy and low flows can be measured with this system.

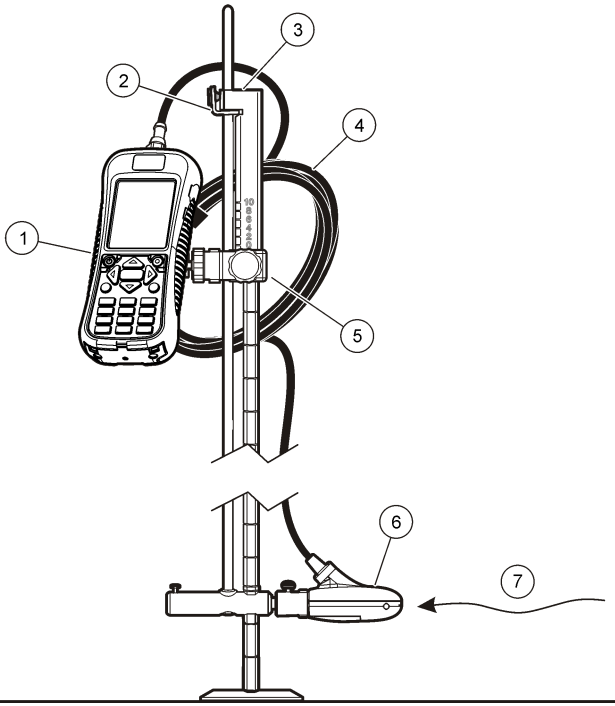
The meter and sensor get velocity information in conduits and streams. These measurements are important for calibration in municipal wastewater industries, as well as for environmental-impact evaluations.

Two types of sensor are available: velocity-only and velocity plus depth. This manual covers both types of sensors. If information applies to a specified type of sensor, this fact is noted in the text.

System overview

An overview of an assembled system is shown in Figure 1. Refer to the documentation supplied with the individual components or accessories for more information.

Figure 1 Assembled components

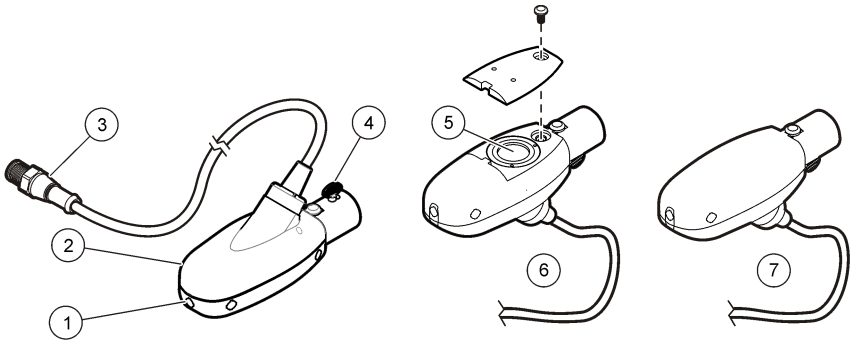


1 Portable meter	**5** Adjustable mount for portable meter
2 Sensor height lock/release device	**6** Sensor assembly
3 Top setting wading rod (accessory)	**7** Flow direction
4 Sensor cable	

Sensor overview

Figure 2 shows the main sensor components. Instructions for how to attach the sensor on a standard or top-setting wading rod are supplied with the accessory.

Figure 2 Sensor components

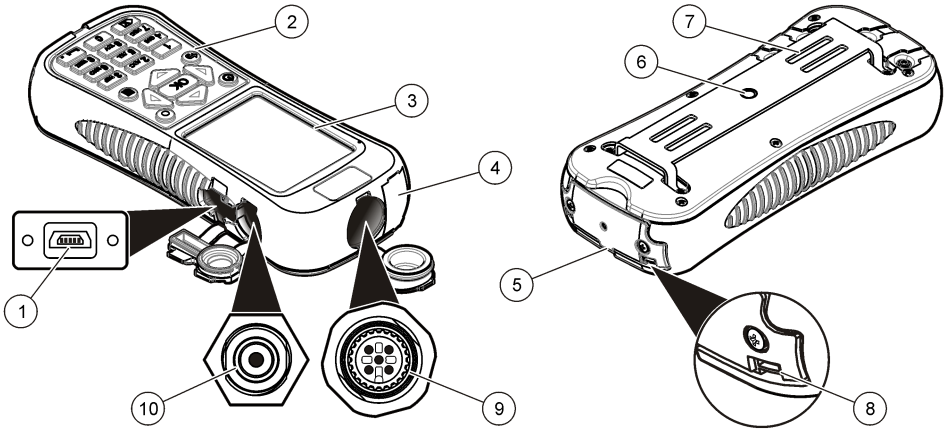


1 Sensor electrodes	**5** Pressure cell (sensors with depth option)
2 Sensor body	**6** Sensor with depth option
3 Sensor connection plug	**7** Sensor without depth option
4 Sensor attachment thumb screw	

Meter overview

Figure 3 shows the features of the meter.

Figure 3 Meter components



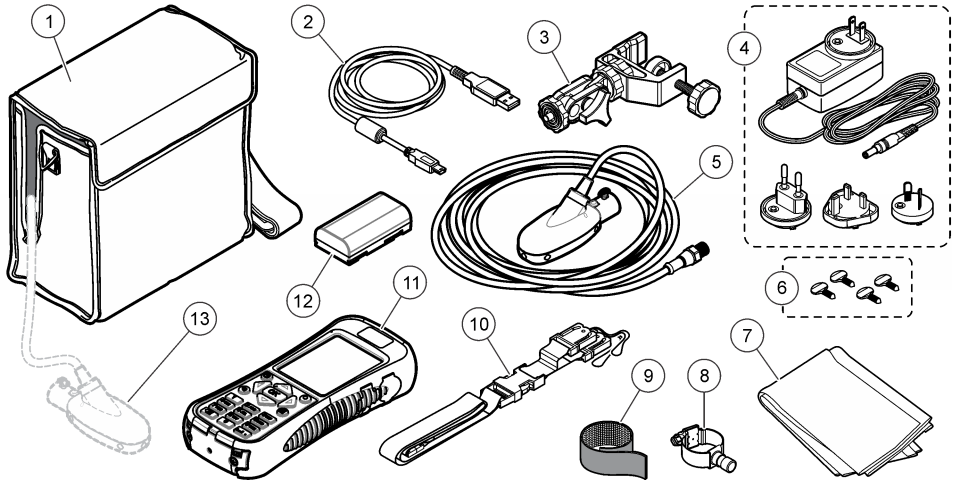
1 USB connection port[2]	**6** Threaded hole for adjustable meter mount
2 Keypad	**7** Slots for velcro or strap attachment
3 Meter display	**8** Slot for neck strap attachment threads (2x)
4 Expansion port (not used)	**9** Sensor connection port
5 Battery compartment cover	**10** Battery charger connector

[2] Do not use the USB connection to charge the battery.

Product components

When purchasing a complete system, refer to Figure 4 to make sure that all components have been received. If any of these items are missing or damaged, contact the manufacturer or a sales representative immediately.

Figure 4 System components



1 Carrying case (with slot for sensor cable)	**8** Universal sensor mount
2 USB cable with mini-USB connector, 1 m (3 ft)	**9** Velcro strap
3 Adjustable portable meter mount	**10** Lanyard
4 Battery charger, 100–240 VAC	**11** Portable meter
5 Sensor	**12** Lithium battery pack
6 Extra thumb screws (4x)	**13** Sensor as connected to meter inside case
7 Cloth to dry the sensor	

Installation

Installation with optional accessories

Mount the meter on an optional wading rod for use in low-stage stream environments where the stream can be waded. Optional accessories let the user take measurements from a bridge or cable over a stream. A torpedo shaped weight attached below the sensor keeps the sensor in place when under water. For more information, refer to the documentation supplied with the accessory.

Install the sensor on the universal sensor mount

Use the universal sensor mount to attach the sensor to poles 1 inch or less in diameter. For correct operation and accurate readings, the front of the sensor must be pointed upstream with the electrodes in full contact with the flow.

Note: *Keep the sensor electrodes free from nonconductive substances such as oil and grease. To remove sensor contamination, refer to* Clean the sensor *on page 28.*

1. The front part of the sensor is round and contains three electrodes. The sensor has a mounting hole in back and a thumbscrew on top. Put the mounting shaft of the universal mount in the

mounting hole at the back of the sensor. Make sure that the mounting shaft is completely engaged with the mounting hole and the thumbscrew is engaged with the groove.

2. Hand tighten the thumbscrew.
3. Move a pole 1 inch or less in diameter through the clamp of the universal sensor mount. Tighten the clamp.
   Note: *Instructions for how to mount the sensor on a standard or top setting wading rod are supplied with the accessory.*

Lithium battery safety

⚠ WARNING
 Fire and explosion hazard. Lithium batteries may get hot, explode or ignite and cause serious injury if exposed to abuse conditions.

- Do not use the battery if there is visible damage.
- Do not use the battery after strong shock or vibration occurs.
- Do not expose the battery to fire.
- Keep the battery at temperatures less than 60 ºC (140 ºF).
- Keep the battery dry and away from water.
- Prevent contact between the positive and negative battery terminals.
- Do not let unauthorized persons touch the battery.
- Discard the battery in accordance with local, regional and national regulations.
- Do not use or store the instrument in direct sunlight, near a heat source or in high temperature environments such as a closed vehicle in direct sunlight.

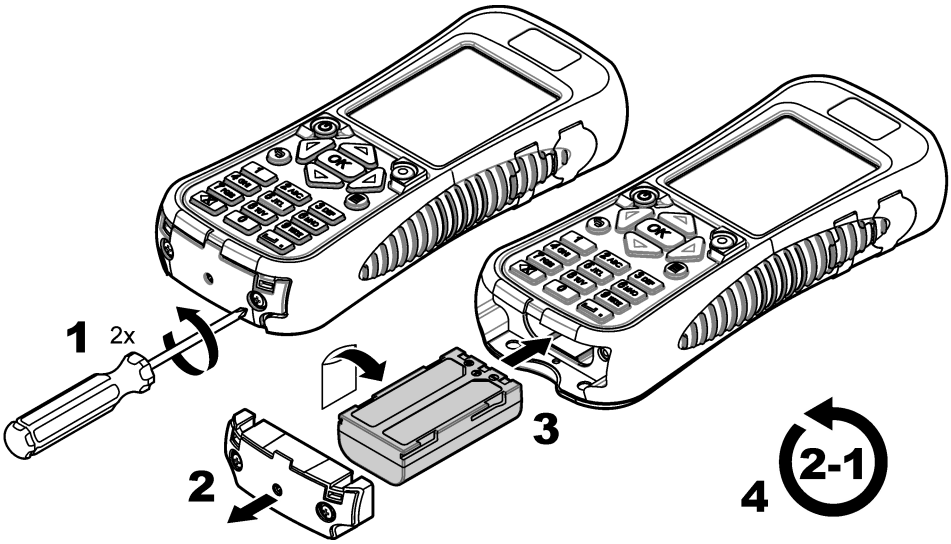
Install the battery

⚠ WARNING
 Fire and explosion hazard. This equipment contains a high energy lithium battery which can ignite and cause fire or explosion, even without power. To maintain the safety provided by the instrument enclosure, the instrument enclosure covers must be installed and secured with the supplied hardware.

⚠ WARNING
 Explosion and fire hazard. Battery substitution is not permitted. Use only batteries that are supplied by the instrument manufacturer.

Install the supplied lithium battery as shown in Figure 5.

Figure 5 Install the battery



Charge the battery

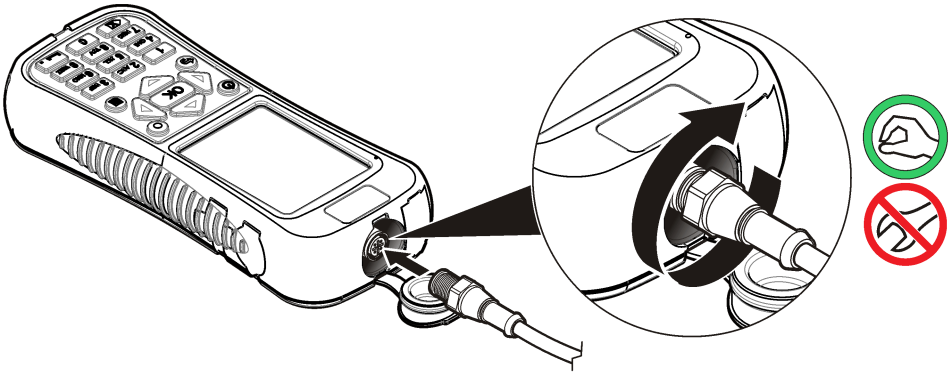
Note: *Battery charger substitution is not permitted. Use only the charger specified in the list of parts and accessories for the instrument. Refer to* Replacement parts and accessories *on page 30.*

Before initial use, fully charge the instrument battery with the supplied battery charger. A discharged battery is fully charged in approximately 8 hours.

A full battery charge will supply power to the system for approximately 10–11 hours with constant use. When the level of battery charge drops to 3.4 V or less, the display shows a warning and the meter automatically powers off. The battery must be charged before the unit becomes functional again.

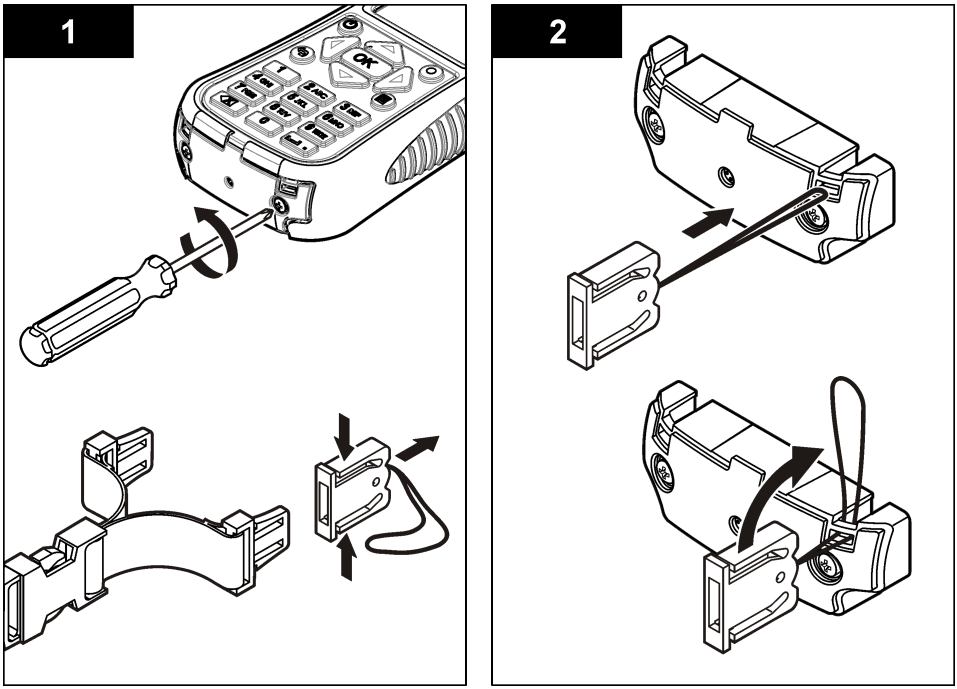
1. Make sure that the correct type of plug for the geographic location is installed on the battery charger.
2. Connect the battery charger to an electrical outlet with earth ground.
3. Connect the battery charger to the battery charger connector on the instrument. Refer to Meter overview on page 8. The battery level shows on the display.
   A blue light shows around the charge port while the battery charges. When the charge process is complete, the blue light goes off.
   Note: *The meter is not operational while the battery charges. The battery does not charge through the USB cable connection.*

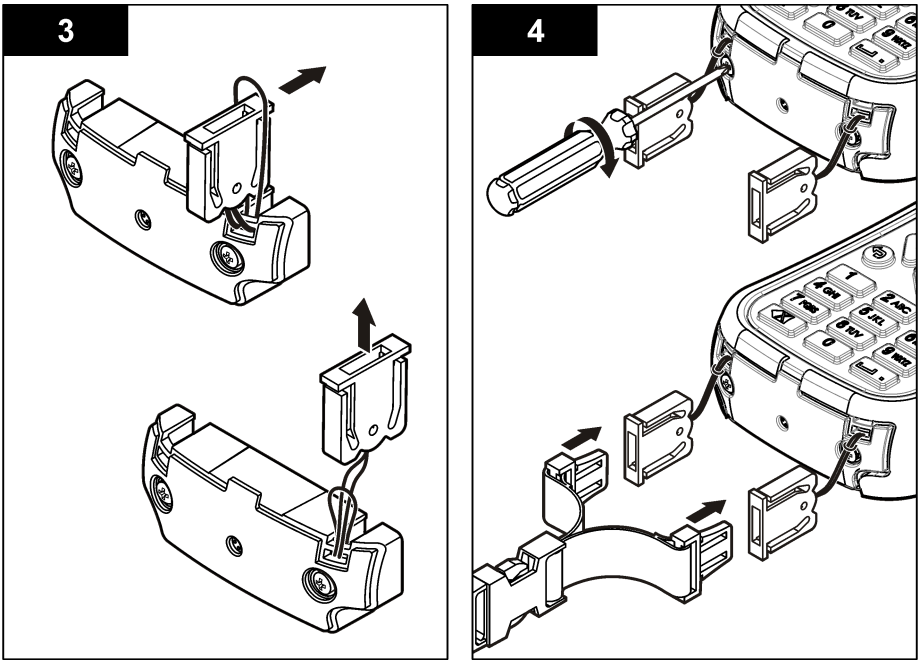
Connect the sensor to the meter



Attach the lanyard

Attach the lanyard to wear the meter safely around the neck.

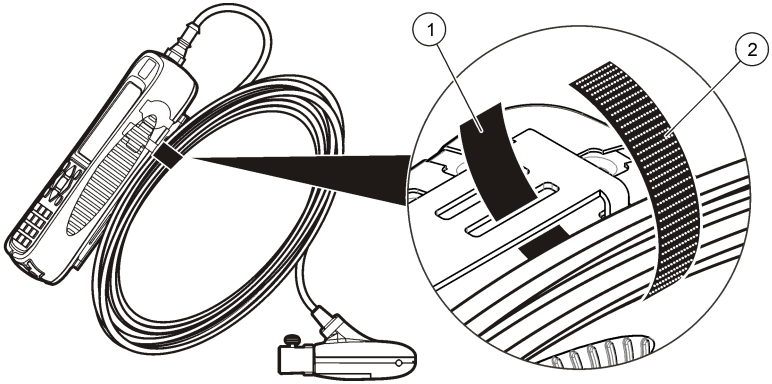




Attach the velcro strap

Use the velcro strap to hold the extra cable. Refer to Figure 6.

Figure 6 Attach the velcro strap



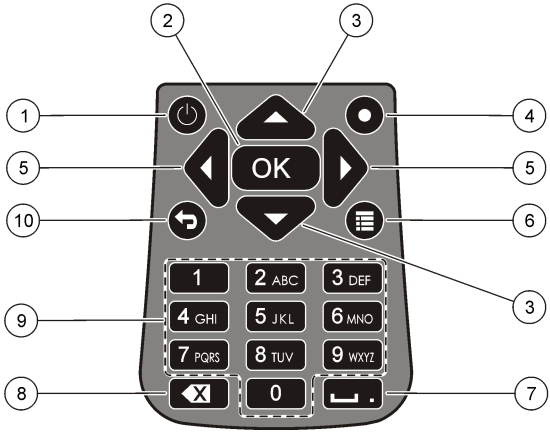
1 Loop side	**2** Hook side

User interface and navigation

Keypad and key functions

Figure 7 shows the meter keypad. Table 1 gives the functions of each key or key type.

Figure 7 Keypad



1 Power On/Off	**6** Main Menu
2 OK	**7** Underscore or decimal
3 Up and Down arrows	**8** Backspace
4 Quick Jump	**9** Alpha-numeric
5 Right and Left arrows	**10** Previous menu

Table 1 Key description

Key	Description
Power On/Off	Energizes and de-energizes the meter.
OK	Confirms an entry or highlighted menu option.
Up and Down arrows	Moves up or down in the display. If the cursor is at the top or bottom of the display, the cursor wraps to the bottom or top when the UP or DOWN arrow is pushed.
Quick Jump	In normal operation, this key jumps to the Select conduit shape screen. If the auto-zero feature is disabled, hold this key for five seconds to do a manual zero of the depth sensor. In Real-Time mode, the Quick Jump key toggles between the digital and graph views.
Right and Left arrows	Moves to the right or left in the display.
Main Menu	Moves to the Main Menu from any submenu or screen.
Underscore or decimal	Puts in an underscore or decimal character. In numeric-only fields, this key automatically puts a decimal point in the cursor position.
Backspace	Moves the cursor back one space.
Alpha-numeric	Puts in the key alpha or numeric value. Values are put in the order shown on the key. After 2 seconds, the value shown in the display is stored and the cursor advances.
Previous menu	Moves to the previous screen.

Status bar

A status bar is shown in the top of the display. Descriptions of the information in the status bar are given in Table 2.

Table 2 Status bar indicators

Indicator	Description
Time and Date	Shows the current time and date.
USB	Shows when a USB cable is connected. If a USB cable is connected and this indicator does not show in the status bar, the USB cable is not fully engaged. Make sure that the USB cable is pushed in completely and makes full contact with the connection port.
Conductivity	If the sensor is out of the water and non-conductive, a blue ring appears next to the battery icon. If the sensor is in the water and conductive, the indicator is a solid blue circle.
Battery	A five-bar graph shows the level of charge in the battery.
File access	Shows while the meter gets access to a file.
Auto zero depth indicator	If the depth sensor was zeroed in the last 30 minutes, a solid green circle shows next to the Conductivity indicator. If the depth sensor was not zeroed in the last 30 minutes, this indicator flashes red.

Navigation and Main Menu

Push **OK** to confirm a selected menu option or a value shown in the display. Select More and push **OK** to see additional screens and options if available. Push the Main Menu button to go to the Main Menu from a submenu.

Note: *Some operations cannot be completed unless a sensor is connected to the meter. If these operations are tried when there is no sensor connected, the display shows an error message. Connect a sensor and try the operation again.*

1. **Real time**—Select this option to get real-time velocity and depth information. (A sensor with depth capability is necessary to read depth). An example of a Real Time screen for sensors with velocity only is shown in Figure 8. Real time screens for sensors with both velocity and depth is shown in Figure 9. The format of the information and options shown depends on the type of sensor used. In Real Time mode, the Quick Jump key toggles between digital and graphic views of Real Time information. The velocity is updated in FPA filter mode according to fixed period averaging time. In RC filter mode, the velocity is updated continuously on the screen every 250 ms.

Option	Description
Capture	Stores the depth and velocity information shown in memory. The information is saved until power is cycled, the memory is saved to a non-volatile real-time file, or the user exits from real-time mode.
Save	Saves captured measurements in the volatile memory to a non-volatile real-time file. A message will show if the number of files is greater than the maximum possible. Files are stored in tab delimited (.tsv) format.
Done or OK	Exits the real-time mode and returns to the Main Menu. If there is unsaved data in volatile memory, a confirmation message asks the user to confirm the exit without saving the data.
Clear	Clears captured measurements from the volatile memory buffer. The user can choose from Clear Last, Clear All or Cancel options.

Option	Description
Setup	Allows the user to modify the main filter parameters and enable and program the Maximum Depth sensor positioning feature. The Maximum depth feature allows a user to enter system parameters for depth measurement in Real Time mode. The user can choose to enter a maximum depth value taken directly with a ruler measurement (manual), or taken indirectly with the depth measurement (automatic). Both methods enable the Maximum Depth sensor positioning feature. In automatic mode setup, the user directly enters the distance from the bottom of the channel to the bottom of the sensor mount (offset). The setup interface will continuously show the current depth value returned by the sensor plus the offset. The meter stores this value as the Maximum Depth when the OK button is pushed. In all other cases, the depth values shown do not include the offset. The Maximum depth feature requires a sensor with velocity plus depth.
Files or View	Shows a summary of each real-time file stored in non-volatile memory. Files can be individually viewed and deleted.

Figure 8 Real time screen

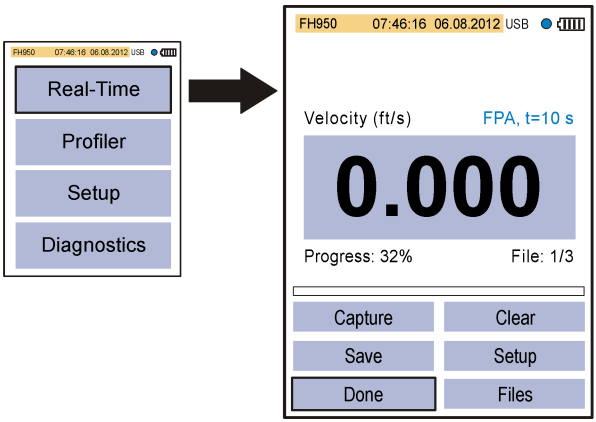
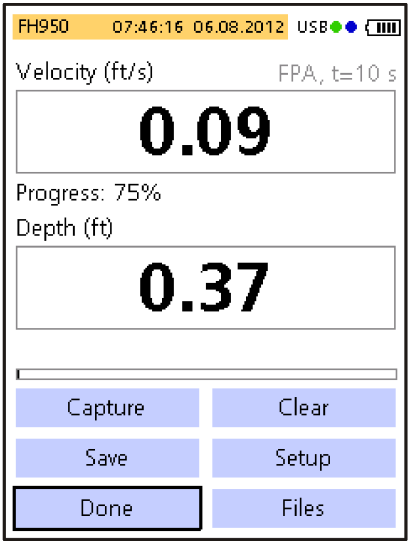


Figure 9 Real time screen for sensor with depth



2. **Profiler—** Select this option to do stream or conduit velocity measurements. The meter shows prompts when user input is necessary. The meter saves up to 10 profiles with up to 32 stations per profile. This number can be greater if data acquisition time is less than the maximum. A percentage of the remaining memory is given in 1% resolution. Refer to the Appendix on page 32 for more information about profiles.

Option	Description
Stream	This option is used to set up a profile for a stream or flowing channel. Do velocity measurements to calculate total discharge based on ISO 748 or USGS standards for Mid-section or Mean-section methods.
Conduit	This option is used to set up a profile for a conduit.
Files	This option is used to view or delete stored files. Files can be deleted all at once or individually.
Setup	This option is used to set up or change the settings for filter parameters and the Maximum Depth feature.

3. **Set up**—Select this option to change general system settings and preferences.

Option	Description
Velocity calibration	Calibrates the sensor. Adds a field offset to the factory calibration. Refer to the Appendix on page 32 for more information.

Option	Description
Filter parameters	Applies a data acquisition filter (Main filter or Pre-filter). The user can select the filter parameters. **Main filter** • Fixed Period Averaging (FPA)—Fixed Period Averaging averages data over a user selectable fixed period of time (1 to 480 seconds). The default is 10 seconds. If the FPA value is 5, the velocity value shown in the display is updated once every 5 seconds. • RCA time constant—The RC filter helps smooth out turbulence through the use of a selected time constant in the filter algorithm. This mode is useful when searching for a maximum velocity, for example in the common 0.9 x Vmax profile method. High RC filter time constants give higher degrees of smoothing. The time constant can be set from 2 to 20 seconds, with a default value of 6. At 1 time constant, the filter settles to approximately 60% of the final value. At 5 time constants, the filter settles to 99.9% of the final value. Thus, if the RC value is set to 2, the final value shows after 10 seconds. **Pre-filter** • Median filter—The filtering process is done in the sensor. The feature can be disabled. However, the recommended (default) value is 5. Enable the feature to enter or change this value.
Wet/dry threshold	Sets the sensor submersion threshold for wet and dry conditions. The default value is 20%. Refer to Wet/Dry threshold on page 34 for more information.
Auto zero depth	Sets the Auto Zero feature to On or Off. If set to On, the instrument does an air calibration when the sensor is removed from the water and is in the air. To do the air calibration, the instrument automatically zeroes the sensor. If set to Off, the user can manually zero the sensor. To do this, remove the sensor from the flow, then push and hold the Quick Jump key for five seconds. When the sensor has been in the flow for 30 minutes, the green circle in the upper right corner goes from green to red. This is a prompt to the user to remove and zero the sensor again.
EMI	Sets the local line frequency for ambient noise rejection to 50 Hz or 60 Hz (default).
Clock	Sets the date and time of the portable meter in 24-hour format. Daylight savings time is not supported.
USB	Sets the USB mode. • Mass Storage (default)—This mode operates like a memory stick or hard drive. Files are read-only. • CDC—This mode is used to update firmware.
Language	Selects the language used in the menus.
Units	Sets the units for velocity, flow and depth measurements. Options are Metric or English (default).
Beeper	On (default) or Off. If set to On, the meter makes an audible tone when the sensor is at the correct depth for applicable profile methods. The meter also makes an audible tone when an inactive button is pushed in any menu. This feature is available only with the optional depth sensor.
Flow calculation	Selects the method of flow calculation for open water segment (stream profiles only). Options are Mean-section or Mid-section. Refer to the Appendix on page 32 for more information.

Option	Description
Station entry	• Fixed—The operator puts in the width of the stream and the number of stations for measurements. The meter divides the cross-section into evenly spaced distances between the station verticals. • Non-fixed (default)—The operator selects the spacing between station verticals. This is the more commonly used option as it lets the operator include obstructions and other restrictions in the cross section.
Restore defaults	Sets all meter options to the factory default values.

4. **Diagnostics—** Select this option to troubleshoot problems with the meter or an attached sensor. For more information about the Diagnostics options, refer to Diagnostics on page 29.

Startup and self-test

⚠ DANGER



Chemical or biological hazards. If this instrument is used to monitor a treatment process and/or chemical feed system for which there are regulatory limits and monitoring requirements related to public health, public safety, food or beverage manufacture or processing, it is the responsibility of the user of this instrument to know and abide by any applicable regulation and to have sufficient and appropriate mechanisms in place for compliance with applicable regulations in the event of malfunction of the instrument.

⚠ WARNING



Fire and explosion hazards. Do not use or store the instrument in direct sunlight, near a heat source or in high temperature environments such as a closed vehicle in direct sunlight. Failure to take this precaution can make the battery overheat and cause a fire or explosion.

The battery must be installed in the meter and charged before use. For more information about battery installation and replacement, refer to Install the battery on page 10. For information on how to charge the battery, refer to Charge the battery on page 11.
Note: *The meter is not operational while the battery charges.*

1. Push the meter power button until an audible beep is heard.
   The meter does a self test and the display shows the results. If the meter fails the self-test, the display shows FAIL next to the failed parameter. If the sensor fails, attach a different sensor if available.
2. When the self test is complete, push **OK** to go to the Main Menu.
3. To de-energize the meter, push the power button again. In the Confirmation screen, select Yes and push **OK**.
   If the portable meter becomes unresponsive, push and hold the power button for more than 3 seconds to force the power off. Do not force off the power in normal operation or when the file access icon is visible.

Sleep mode

The meter backlight goes dim after 30 seconds of no activity and goes into sleep mode after 60 seconds of no activity. These actions do not occur if the meter is in real-time mode or while the meter is measuring. After 30 minutes in sleep mode, the meter power goes off.

To cancel the sleep mode, push any key. The display brightness goes back to the normal level and all keys go back to their normal functions.

Operation

Stream profiles

Stations and station spacing

For a well-chosen cross-section, division into 25 to 30 partial sections is typically sufficient. If the cross-section is very smooth and the velocity distribution very consistent, it is possible to decrease the number of stations.

Make the distance between the partial stations so that no individual station contains more than 10% of the discharge. The ideal measurement is one in which each partial station contains 5% or less (≤ 5%) of the total discharge, but this is rarely possible when 25 stations are used. Partial stations should not have equal widths across the entire cross-section unless the discharge is well-distributed.

Distances between stations are generally smaller where water depth and flow velocities change significantly. Places where depth and velocities frequently change significantly include bank areas, vertical or steep slopes, ledges in divided cross-sections and transitions from the main stream bed to the foreland. Stations should also be located at points of significant changes in the stream bed profile.

The measurement cross-section must be set at right angles to the direction of flow. Cross-sections must not contain still areas, counter currents or eddies. Do not put the sensor in deep pools, below large inflows, or near ship moorings, ferries or sluices.

Use Table 3 as a guide for the number of stations necessary for an acceptable measurement. The information is based on EN - ISO 748 standards.

Table 3 Number of stations in relation to the waterway width

Feet	Meters	Number of stations
< 1.6	< 0.5	5 to 6
> 1.6 and < 3.3	> 0.5 and < 1	6 to 7
> 3.3 and < 9.8	> 1 and < 3	7 to 12
> 9.8 and < 16.4	> 3 and < 5	13 to 16
> 16.4	≥ 5	≥ 22

Measure velocity

Measurement quality is dependent on the correct selection of a measurement cross-section. Select a section of stream with the following characteristics:

- The flow directions at each measurement point across the stream are parallel to the bank and perpendicular to the cross-section.
- The streambed is stable and free of large rocks, weeds and protruding obstructions such as piers that cause turbulence.

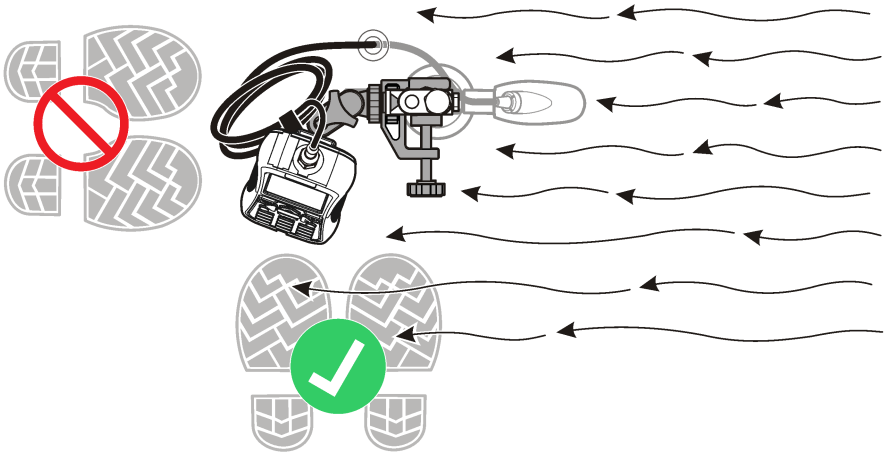
It is often not possible to completely satisfy all of these conditions. Use the criteria to select the best possible section and then select a cross-section.

The general procedure to take velocity measurements in river and stream profiles is described below. Make the first measurement in a stream profile at the top or bottom. Make each subsequent measurement below the last one.

- In fixed mode, divide the channel into stations of equal width.
- Conduct a velocity measurement at each station. The portable meter shows and stores the depth and measured velocity information.
- When the stream profile is completed, the meter automatically calculates the total flow.

For accurate measurement results, stand to the side of the instrument. Refer to Figure 10.

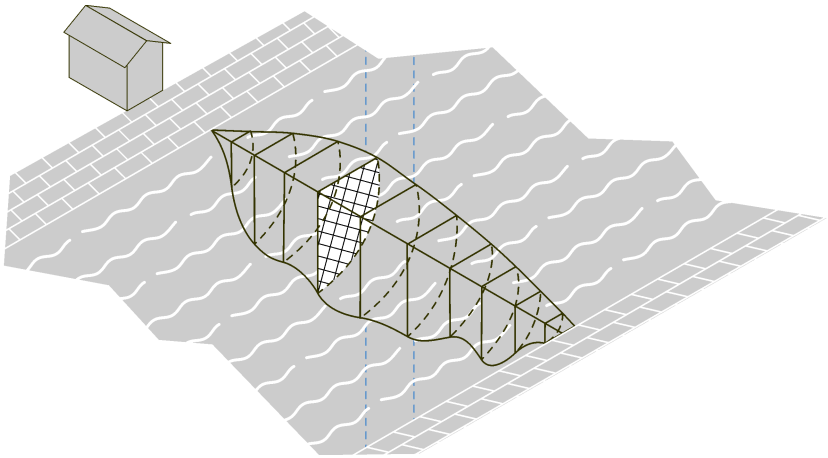
Figure 10 Position of user in the flow



Measure velocities in a cross-section

A typical stream cross-section is shown in Figure 11.

Figure 11 Example of a typical cross section



To measure velocities in a cross-section:

1. In the Main Menu, select Profiler.
2. Enter the Operator name. A list of options will show.

Option	Description
Stream	Used for measurements in a stream profile.
Conduit	Used for measurements in a conduit profile.

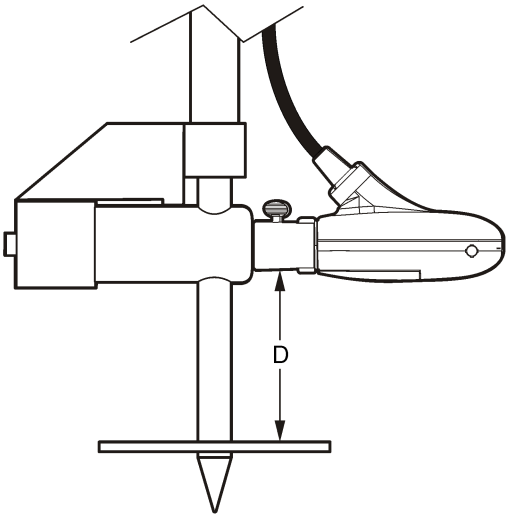
Option	Description
Files	Used to view or delete files.
Setup	Used to set up filter parameters and the Maximum depth feature.

3. Select Setup > Maximum depth. Select Manual or Automatic.

Option	Description
Manual	In this mode, the instrument prompts the user to manually enter the maximum depth of each vertical. This value is normally obtained from a wading rod.
Automatic	In this mode (available only on sensors with the depth option), the instrument uses the pressure transducer to measure the maximum depth at each vertical.

   a. If Automatic is selected, enter the distance from the bottom of the channel to the bottom of the sensor mount.
   b. Put the sensor at the lowest position on the wading rod.
   c. Enter the minimum depth (measured from the bottom) that the sensor can read. Refer to Figure 12.

Figure 12 Minimum depth



4. Select Top or Bottom for the measurement reference then push **OK**.
5. If necessary, change or update the filter parameters in Profiler Setup.
6. In the Profiler menu, select Stream.
7. Enter a name for the stream profile. Make profile names alpha-numeric with a maximum of 11 characters. Push **OK** to save the profile name or select Clear to delete all current stream profile data.
8. Enter the stage reference. This is typically an elevation value from an immovable object such as a survey marker or bridge, etc.

9. In the Station menu, select Edge/Obstruction. Select one of the options.

Option	Description
Left	Select this option if the station is at the left edge of the water or an obstruction (i.e, sandbar, pylon or large boulder).
Right	Use this option if the station is at the right edge of water or an obstruction (i.e., sandbar, pylon or large boulder).
Open water	Use this option to configure the edge as an open water environment (default).

10. Select Distance to Vertical and enter the information.
11. Select Set Depth and enter the information. If at an edge, the meter automatically sets this value to 0.00.
    a. If Manual mode was selected in the Profiler setup, enter the total depth of water at this vertical position.
    b. If Automatic mode was selected in the Profiler setup, push **OK** to set the maximum flow depth at the value shown.
12. If Left or Right was selected in Step 9, enter an edge factor for the vertical. Select a factor from the list or User-defined. For User-defined values, enter a roughness factor between 0.50 (very rough) and 1.00 (smooth). The roughness factor is relevant only for right angled cross sections. It is used as a factor in the calculation of the discharge proportion of edge areas. For example:
    - Smooth edge with no vegetation (e.g., concrete, steel, cement)— 0.8 to 0.9
    - Brick sides with vegetation— 0.7
    - Rough walls with heavy vegetation—0.6 to 0.5
13. Select Measure Velocity. Select the number of points on the vertical to collect.
14. Select a measurement point from the list. Obey the instrument prompts and adjust the sensor to the correct depth. If the sensor has a depth option, adjust the sensor depth until the depth box is green. This means the sensor is in at the correct position.
    Note: *Red indicates more adjustment is necessary. Yellow indicates the depth is close to the correct depth.*
15. Select Capture to start the measurement process.
16. If necessary, the setup can be changed and the measurement can be repeated. When the measurement is complete, push **OK** to store the data.
17. Repeat steps 13–16 for the other measurement points on the vertical.
18. When all measurements for the station are complete, select Main or Verify. results. Push **OK** to return to the list of measurement points.

Option	Description
Main	Returns to the station menu.
Verify	Shows the average velocity reading for the station based on the measurement method.

19. Select Next to go to the next station.
20. Repeat steps 10–19 for the remaining stations.
21. When all measurements for all stations in the profile are complete, select Channel Summary to view the results.
    Note: *A warning flag will show if the discharge in one or more segments is > 5% of the total discharge.*

Insert or delete a station

Prev, **Next**, **Ins** and **Del** options show at the bottom of the display in the Station screen. **Prev** and **Next** are used to navigate to a previous or subsequent station. **Ins** and **Del** are used to insert or delete a station.

For example, after measurements have been done at 10 stations, a user may wish to insert a new station between stations 3 and 4. The steps below describe how to do this. These steps can be applied in similar situations.

1. Select **Prev** and push **OK** until the display shows the information for Station 3.
2. Select **Ins** and push **OK**.
   The instrument adds a new station named Station 4. Subsequent stations are automatically given new sequential numbers.
3. To delete the current station (when in non-fixed mode), select **Del** and push **OK**.

Conduit profiles

It is possible to use all of the methods for conduit profiles in this section in sites with a typical profile shape and sufficient depth to measure 3-point velocities. The 0.9 x Vmax method can also be used when the depth is not sufficient for multi-point profiles.

Note: *In typical conduit profiles, the first measurement is made at the bottom. Subsequent measurements are made above the one made before. A different procedure may be necessary for some profiles.*

1. In the Main Menu, select Profiler.
2. Enter the operator name.
3. In the list of options, select Conduit.
4. Enter a name for the new Conduit profile.
5. Select the conduit shape.
   Note: *The input screens that show next depend on the shape selected.*
6. Enter values at the screen prompts.
   When the necessary values have been entered, the display shows the Select Method menu.
7. Select a profile method and do the steps for the method.

Option	Description
0.9 x Vmax	The meter calculates flow based on 90% of the fastest velocity. This is the recommended method when the depth is less than 12.7 cm (5 in.) or when the velocity is not stable.
0.2/0.4/0.8	The meter calculates the flow value based on velocity measurements taken at 0.2, 0.4 and 0.8 x the depth. One and two-point versions of this method are also possible.
Vel./Lev. Integ.	The meter integrates 10 separate velocity and level measurements to calculate the flow level.
2D	The sensor collects information while constantly moved through the flow in a specified pattern. The meter calculates the flow value when the user selects Save. This method is recommended for flows where a difference of 30% or more exists between the right and left side velocities.

0.9 x Vmax measurement method

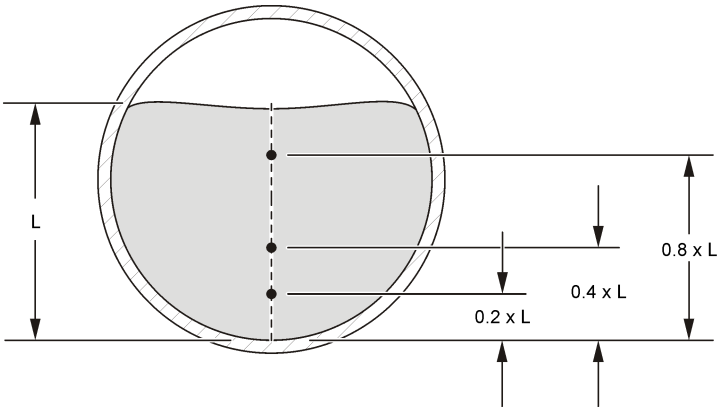
The meter uses the maximum velocity measurement in the conduit and multiplies this value by 0.9 to calculate the total flow.
Note: *The RC filter mode with a value of 2 to 4 seconds is recommended for this method.*

1. In the Select Method menu, select 0.9 x Vmax.
2. With the sensor in the flow, select Measure Velocity to get a velocity measurement.
   The measured values are shown on the graph.
3. Move the sensor until a point of maximum velocity is found, then push **OK**.
   The meter calculates and shows the flow, maximum and average velocity values.
4. Select Save.
   The information is saved to a data file.

0.2/0.4/0.8 method

Do measurements at one, two or three points to calculate an average velocity. Each point represents a percentage of the maximum depth as measured on the center line as shown in Figure 13.

Figure 13 2-4-8 profile



1. In the Select Method menu, select **0.2/0.4/0.8**.
2. Select one of the options.

Option	Description
One point	One-point measurement at 0.4 x maximum depth
Two point	Two-point measurement at 0.2 and 0.8 x maximum depth
Three point	Three-point measurement at 0.2, 0.4 and 0.8 x maximum depth

3. For the selected option, select a measurement point. The meter shows the sensor adjustment information.
4. If necessary, adjust the sensor as necessary.
5. Select Capture.
   The meter gets information from the sensor and shows the velocity value in numerical and graphical form.
6. If necessary, select Setup to change the Y-axis range or the data filter parameters.
7. Push **OK**.
8. Do steps 3–7 for all of the other measurement points then push **OK** to return to the list of measurement points.
9. Select Flow.
10. Select Save to save the information to a data file.

Velocity/Level Integration measurement method

Measurements are done at 10 different depths. The results from all segments are integrated to calculate the flow value.

- Select Prev or Next to go to another measurement.
- Select Main to return to the Select Method menu.

1. In the Select method menu, select Vel./Lev. Integ.
   The display shows the first measurement screen.
2. Select Measure Velocity.
   The sensor depth information is shown.
3. If necessary, adjust the sensor depth as shown.
4. Select Capture.

The handheld unit gets information from the sensor and shows the average velocity value in numeric and graphical form.

5. If necessary, select Setup to change the Y-axis range in FPA filtering mode, the X and Y-axis range when in RC filtering mode or the data filter parameters.
6. Push **OK** to confirm the information.
7. Select Next. The next measurement screen in the series appears.
8. Do steps 2–7 for the other measurement depths.
9. Select one of the options at the bottom of the screen.

Option	Description
Save	Calculates the current flow value and saves this information to a data file.
Units	Changes the unit type (English or Metric).

2D measurement method

Velocity is measured while the sensor is moved through the flow as shown in Figure 14.

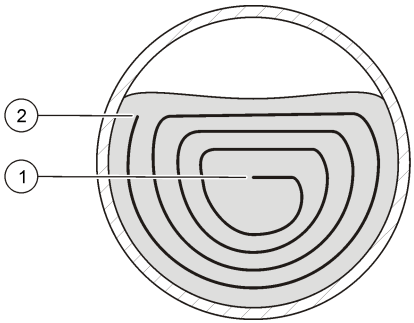
Select Cancel at any time to cancel the measurement and return to the Select Method menu.

Note: *The RC filter mode with a value of 2 to 4 seconds is recommended for this method.*

1. In the Select method menu, select 2D.
   The sensor depth information is shown.
2. If necessary, adjust the sensor depth.
3. Select Capture. While the sensor collects data, move the sensor through the entire cross-section in the pattern shown in Figure 14.
4. If necessary, select Setup to change the Y-axis range in FPA filtering mode, the X and Y-axis range when in RC filtering mode or the data filter parameters.
5. Push **OK**.
6. Select one of the options shown at the bottom of the screen.

Option	Description
Save	Calculates the current flow value and saves this information to a data file.
Units	Changes the unit type (English or Metric).

Figure 14 Path of the sensor in the flow



1 Start	**2** Finish

Download data

The meter directory is Read Only. In Windows, the meter operates as a mass storage device or removable hard drive.

1. Set the meter to USB Mass Storage mode.
2. To edit the data in a file, drag and drop the file to a laptop or PC. File names are limited to eight characters.
3. Data files are kept in the tab separated variable (.TSV) format. To see files in Microsoft® Excel, double or right-click a file and open the file with Excel.
   Real time files are stored in a directory called RT. Stream and conduit profile files are stored in a directory called P.

Delete data files

1. To delete all files from USB memory:
   a. Go to Main Menu > Diagnostics > Delete Files.
   b. In the confirmation window, select Yes.
   c. Push **OK** once to delete the files, then one more time to return to the previous screen.
2. To delete Real Time files:
   a. Go to Main Menu > Real-Time > Files.
   b. Select Delete All or use the UP or DOWN arrow to select a file in the list.
   c. Push **OK** once to delete the files, then one more time to return to the previous screen.
3. To delete Profiler files:
   a. Go to Main Menu > Profiler > Files.
   b. Select Delete All or use the UP or DOWN arrow to select a file in the list.
   c. Push **OK** once to delete the files, then one more time to return to the previous screen.

Maintenance

Download the PVM utility

The PVM utility is used to update the firmware in the portable meter. The PVM Utility is available at http://www.hach.com or http://www.hachflow.com. Do the steps listed for the selected URL.

1. Go to http://www.hach.com.
2. Search for FH950.
3. Select the product.
4. Click the Downloads tab.
5. Click the download link.
6. Click PVMSetup.msi.
7. Select Save or Run.

1. Go to http://www.hachflow.com.
2. Click Data Management.
3. Click Software Download Center.
4. Click the FH950 link.
5. Click PVMSetup.msi.
6. Select Save or Run.

Update the firmware

Note: *All data files in mass storage are lost when the firmware is updated. To download data, refer to* Download data *on page 27.*

The PVM Utility is necessary for this procedure. To download the PVM Utility, refer to Download the PVM utility on page 27.

This is the general procedure to update firmware for the meter and sensor. To update the sensor firmware, the sensor must be connected to the meter.

1. Double-click the PVM Utility desktop icon.
2. Push the power button on the meter. When the meter self-test is complete, push **OK**.
3. In the Main Menu, select Setup, then push **OK**.
4. Select USB>CDC, then push **OK**.
5. Connect the USB cable to the portable meter and the PC.
6. In the PVM Utility window, select Connect.
7. In the drop-down menu, select the PVM (COM X) port, where COM X is the virtual port number assigned to the PVM by Windows. Push **OK**.
8. In the left-side panel, select Firmware Update, then select the Meter or Sensor tab.
9. Select the correct firmware version, then click Start.
   The firmware download starts. A "Firmware update successful" message shows when the download is complete. For meter updates, the instrument display turns off until the instrument completes the update. Then, the instrument automatically resets and powers up again after a few minutes. Do not try to make the instrument power on or off before the update process is complete.
10. In the Main Menu, select Diagnostics > About. Make sure that the firmware versions for both the Handheld Boot and the Handheld Application are correct.

Clean the sensor

⚠ WARNING



Chemical exposure hazard. Obey laboratory safety procedures and wear all of the personal protective equipment appropriate to the chemicals that are handled. Refer to the current safety data sheets (MSDS/SDS) for safety protocols.

Clean the sensor when unexpected increases or decreases in flow or level trends occur and after use in sandy or muddy waterways.

For heavy contamination, soak the sensor in clear water for a few minutes to help make the contamination easy to remove.

Disconnect the sensor from the meter before it is cleaned. Use only solutions listed as acceptable in Table 4 to clean the sensor. For sensors with a pressure cell (i.e., velocity plus depth sensors), make sure the holes for the pressure cell chambers are washed out and clear of contamination. Rinse the sensor with clean water before re-attaching the sensor to the assembly.

Table 4 Acceptable and unacceptable cleaning solutions

Acceptable	Do not use
Dish detergent and water	Concentrated bleach
Window cleaner	Kerosene
Isopropyl alcohol	Gasoline
	Aromatic hydrocarbons

Clean the meter

1. Push the power button to de-energize the meter.
2. Use a clean, moist cloth to clean the meter exterior. Mix the water with a mild detergent if necessary.
3. Dry the meter exterior with a clean cloth. Let the meter dry in air completely before it is energized again.
   Note: *Do not use paper-based cloths to clean the display. This type of cloth can cause damage to the display screen.*

Replace the battery

⚠ WARNING



Fire and explosion hazard. This equipment contains a high energy lithium battery which can ignite and cause fire or explosion, even without power. To maintain the safety provided by the instrument enclosure, the instrument enclosure covers must be installed and secured with the supplied hardware.

⚠ WARNING



Explosion and fire hazard. Battery substitution is not permitted. Use only batteries that are supplied by the instrument manufacturer.

Replace the battery when the battery does not hold power when charged.

Note: *If the instrument must be returned to the factory for repair or maintenance, remove the battery and put the battery in a protective cover before shipment.*

1. Set the power to off.
2. Remove the battery. Refer to Install the battery on page 10.
3. Discard the battery in accordance with local, regional and national regulations.
4. Install a new battery in the same location and with the same orientation. Refer to Install the battery on page 10.

   Use only batteries that are supplied by the instrument manufacturer.
5. Install the battery cover. Make sure that the cover is secure to keep the enclosure rating.
6. Charge the battery if necessary. Refer to Charge the battery on page 11.

Troubleshooting

Diagnostics

In the Main Menu, select Diagnostics to see information about the meter and do the diagnostic tests in Table 5.

Table 5 Meter diagnostics

Option	Description
About	Shows information about the meter and the sensor. Includes the serial number and the firmware version.
Delete files	Deletes all files from memory to make space for new measurements. Make sure that the data is downloaded to a PC before this option is selected. The system automatically reformats the memory after file deletion.
Sensor	Shows diagnostic information about the sensor.

Table 5 Meter diagnostics (continued)

Option	Description
Self test	Makes the meter do a diagnostic self test.
Key pad test	Does a test of any button to make sure that the button is functional.
Display test	Does a test on the display to make sure that the display is functional.
Event log	Lets the user see, delete or export the event log. Export the event log to make the contents available as an accessible file through USB mass storage. This option is used primarily by factory service.

Troubleshoot errors

The meter and sensor contain no user-serviceable parts. For the errors and messages listed, try the corrective action.

If the problem does not go away or a problem occurs that is not in the list, contact the manufacturer.

Message or problem	Solution
Sensor is not connected	Connect a sensor and try the action again.
Value is out of range	Change the measurement parameters or put in a different value, then try the action again.
Sensor data is known to be not correct or not accurate	Clean the sensor and test.
Sensor is not recognized	Check the sensor connection. Make sure that the lock nut on the connection port is tight (finger-tighten only).
Display is dim or is not visible	Push a key on the keypad.
Data is not available or access to the data is not possible	Make sure that the USB option (Main Menu) is set to Mass Storage.
Meter is unresponsive	Push and hold the power button for at least 3 seconds. This de-energizes the meter. Energize the meter again. ***Note:*** *Do not use this method to power off while in normal operation or if the file access icon is visible in the display.*

Replacement parts and accessories

⚠ WARNING

Personal injury hazard. Use of non-approved parts may cause personal injury, damage to the instrument or equipment malfunction. The replacement parts in this section are approved by the manufacturer.

Note: *Product and Article numbers may vary for some selling regions. Contact the appropriate distributor or refer to the company website for contact information.*

Replacement parts

Table 6 Velocity only sensor

Description	Item no.
Sensor with 1.5 m (5 ft) cable	EM950.0005
Sensor with 6.1 m (20 ft) cable	EM950.0020
Sensor with 12.2 m (40 ft) cable	EM950.0040
Sensor with 30.5 m (100 ft) cable	EM950.0100

Table 7 Velocity with depth sensor

Description	Item no.
Sensor with 1.5 m (5 ft) cable	EM950.1005
Sensor with 6.1 m (20 ft) cable	EM950.1020
Sensor with 12.2 m (40 ft) cable	EM950.1040
Sensor with 30.5 m (100 ft) cable	EM950.1100

Table 8 Handheld meter

Description	Item no.
English/Metric	FH950.1

Accessories

Table 9 Wading rods

Description	Item no.
Standard wading rod kit, English	75002
Standard wading rod kit, Metric (includes the bullet items below)	75002M
• Bottom section for wading rod, English/Metric	43000M/43001M
• Intermediate section for wading rod, English/Metric	43010M/43011M
• Base plate for wading rod, English/Metric	43015M
• Double-end hanger for wading rod, English/Metric	43020M
Top set wading rod kit, English	75013
Top set wading rod kit, Metric	75013M

Table 10 General accessories

Description	Item no.
Absorbent wipe	9073500
Adjustable meter mount	9071700
Battery charger	8760200
Carrying case	9073400
Lanyard, double ended loop	9072700
Lithium battery pack	9073600
Suspension cable kit (includes bulleted items below)[3]	75003
• Sensor mount	42033

[3] Cable is ordered separately by the foot.

Table 10 General accessories (continued)

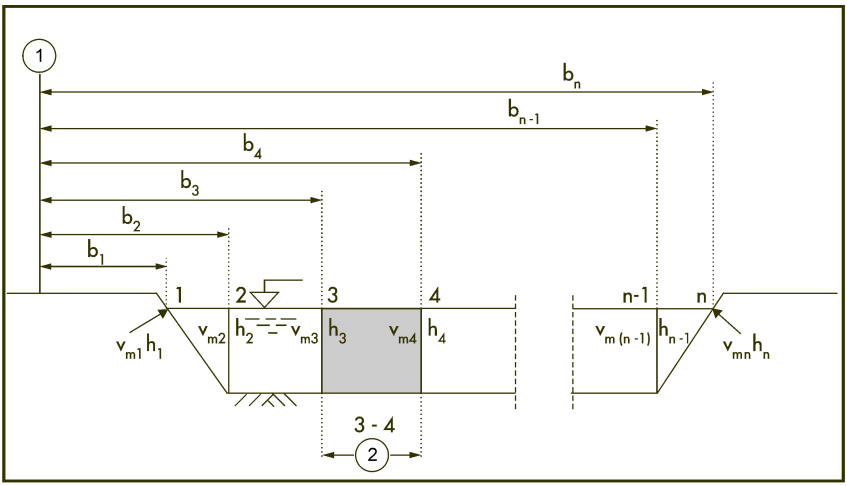
Description	Item no.
• Link connector	43025
• Weight hanger	43030XX01
• Weight pin	43035M
• 6.8 kg (15 lb) lead weight	43040
Thumb screw kit (includes four thumb screws)	9073200
Universal sensor mount	75015
USB cable	9070800

Appendix

Mean-section and Mid-section methods

The user can select the Mean-section or the Mid-section method for flow calculations. The Mean-section method divides the cross-section into individual flow segments. Pairs of adjacent verticals are the limits of the segments. The two edges of the cross-section are given values of 0 for the velocity and depth. The total flow is the sum of the partial flows of all segments. Figure 15 shows the definitions and the equation for the Mean-section method.

Figure 15 Mean-section method



$$q_{3-4} = \left(\frac{V_{m3} + V_{m4}}{2}\right) \times \left(\frac{h_3 + h_4}{2}\right) \times (b_4 - b_3)$$

Where:

V = velocity at vertical

b = distance to vertical from bank

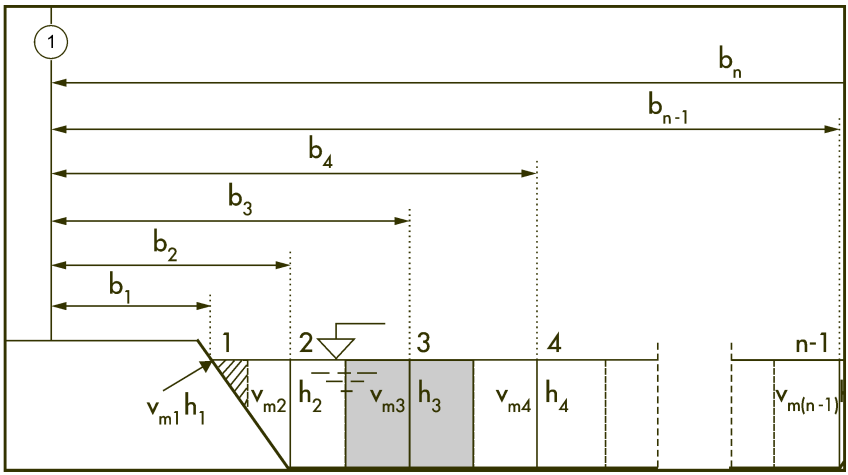
h = depth at vertical

q = flow at vertical

The Mid-section method also divides the cross-section into individual flow segments. With the Mid-section method, the segments are not between verticals but are defined by half of the distance to neighbor verticals in each case. For this reason, the first and last verticals should be as near to the edges as possible (i.e., left edge of water (LEW) and right edge of water (REW)). Boundary conditions dictate the proximity of the first and last vertical to the edge of water.

Experience shows that the Mid-section method gives more exact results compared to the Mean-section method so it is the default setting. Figure 16 shows the definitions and equation for the Mid-section method.

Figure 16 Mid-section method



$$q_3 = V_{m3} \times \left(\frac{(b_3 - b_2) + (b_4 - b_3)}{2} \right) \times h_3$$

Where:

m = station number

n = total number of stations

V = velocity at vertical

b = distance to vertical from bank

h = depth at vertical

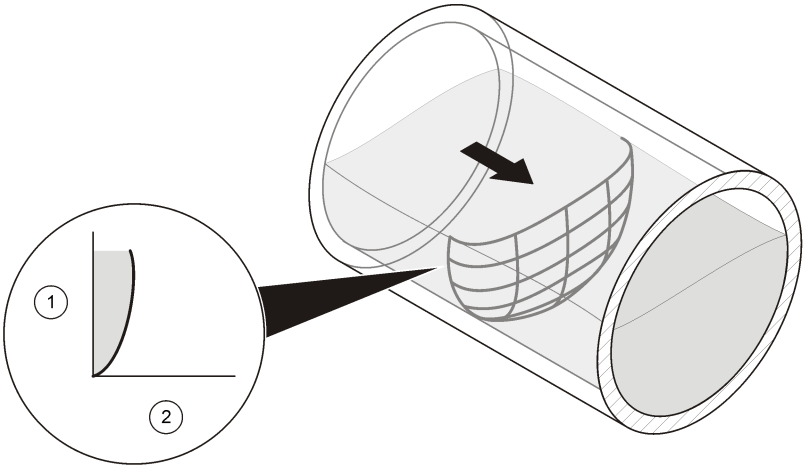
q = flow at vertical

Profiles and measurements

Profiles can be set up for streams or conduits. Figure 17 shows an example of a typical profile shape in a conduit. In a typical profile, velocity is less near a wall or edge than at the center and decreases near the surface. Multiple velocity measurements in the profile are averaged to calculate the total flow. Measurements for conduit profiles are made from the bottom up. Measurements for stream profiles are made from the top down or bottom up.

In the Main Menu, select Profiler. The meter prompts for the operator name, the type of profile (stream or conduit) and the profile name. Do the instructions for the selected profile type.

Figure 17 Typical profile



1 Depth	**2** Velocity

Site selection

A site with the typical profile shape gives the most accurate results. Visual inspection is typically sufficient to identify problem sites. Use the information in these guidelines to help select the best site.

These guidelines apply to conduit and stream profiles.

- The channel should have as much straight run as possible. If the length of the straight run is limited, the length upstream from the profile should be two times the downstream length.
- The channel should be free of flow disturbances. The site must not have protruding pipe joints, sudden changes in diameter, contributing side-streams, outgoing side-streams or obstructions. Remove all rocks, sediment or other debris from the bottom of the pipe.
- The flow should not have visible swirls, eddies, vortices, back-flow or dead zones.
- Do not select areas immediately downstream from sharp bends or obstructions.
- Do not select areas with converging or diverging flow (approaches to a flume) or vertical drops.
- Do not select areas immediately downstream from sluice gates or places where the channel spills into a body of stationary water.

Do a velocity calibration

Use this feature to remove a velocity offset if necessary. The velocity offset stays active until the meter power is switched off.

1. Collect a bucket of water from the water in the profile area. The bucket must be non-metallic and at least 20.32 cm (8 in.). The water depth must be at least 15.24 cm (6 in.).
2. Put the sensor in the center of the bucket so that it does not touch the sidewall or the bottom of the bucket.
3. Let the water become still.
4. Let the velocity reading stabilize.
5. Select Zero Velocity.

Wet/Dry threshold

The wet/dry threshold is the trigger point for the meter to know when the sensor is in or out of the water. This information is important because if the meter does not know that the sensor is under the

surface of the water, the meter sets the velocity value to zero. For a profile or real-time reading, the meter prompts the user to submerge the sensor in the water.

If the specific conductivity of the water being measured is very low, adjust the threshold value for the best performance. Go to Setup Menu>Wet/Dry Threshold.

For troubleshooting, the present reading is used as a guide to set a custom threshold. Get a reading in the water (wet) and then out of the water (dry). The threshold value must be between the wet and dry value. For example, if the actual wet value is 17 and the actual dry value is 2, put in a threshold value half way between 2 and 17. The default value is 20.



HACH COMPANY World Headquarters
P.O. Box 389, Loveland, CO 80539-0389 U.S.A.
Tel. (970) 669-3050
(800) 368-2723 (U.S.A. only)
U.S.A. – orders@hach.com
International – international@hach.com
flowtechsupport@hach.com
www.hachflow.com

© Hach Company/Hach Lange GmbH, 2012, 2014, 2018.
All rights reserved.

ATTACHMENT E
Task Hazard Analysis (THA)

TASK HAZARD ANALYSIS (THA)

Geosyntec HS Procedures referenced herein are available on Geosyntec's H&S SharePoint site and should be consulted, as appropriate, per project-specific needs. This THA prepared per HS-106-Accident Prevention Program, HS-204-Task Hazard Analysis.

PART 1 – SITE SAFETY PLAN

A. PROJECT/TASK INFORMATION

TASK:	Perform stream gaging and low flow release activities		
Project Name:	Stony Brook Flow Restoration	**Project Number/Org:**	BW0317/02
Approximate Project Address (latitude, longitude):	Forge Pond Location – 42.580759, -71.484746 Mill Pond Location – 42.535207, -71.494060 Spectacle Pond Location – 42.566619, -71.507935 Stony Brook Location – 42.595952, -71.465586		
Description of Task & Worksite:	At each stream, the following tasks will be performed. Create cross section of stream, dividing each section into smaller intervals. Use velocity meter and wading rod to collect channel depth and velocity of stream and calculate discharge.In addition, mobilization to Forge Pond (and possibly other Pond locations) may be required to perform low flow releases by removing stop logs and/or to observe in-stream conditions. These activities require working in water or in close proximity to water.		

Geosyntec Personnel	**Name**	**Office Phone**	**Cell Phone**
Site Lead/HS Officer	Marisa Zellmer	978-206-5754	225-620-6425
Project Manager	Adam Questad	617-992-9073	617-529-8615
Project Director	Andrea Braga	617-992-9059	978 509-4793
HS Coordinator	Susan Welt	978-206-5776	518-951-9212
Regional HS Mngr.	Mark P. Malchik	978-206-5777	781-392-5440
Corp. HS Director	Dale Prokopchak	804-332-6376	804-349-8067
Client Contact(s):	Mark Warren (WWD) 978-399-2455; Corey Godfrey (LWD) 978-540-2282		
Subcontractor(s):	☒ Not Applicable ☐ Applicable, provide contact information below:		

B. SUMMARY OF WORK STEPS, HAZARDS, CONTROLS

Based on **PART 2, "HAZARD ANALYSIS,"** and on worksite/client/project factors.

Abstract of work steps/hazards/controls, with references to applicable Sections in Part 2 for greater detail:

Water at each sites are impacted by siltation/mud and may make entering water hazardous. In addition, access to all locations are adjacent to active roads; walking from the parking areas at Forge Pond, Mill Pond, and Spectacle Pond to the project areas include walking across active roads. Access to Mill Pond requires walking between a chainlink fence and the top of a culvert. **Adhere to the following at all times:**

- Carry light equipment loads and always leave one hand free to grab onto the fence when accessing Mill Pond.
- Be careful and don't rush when entering and wading in streams.
- Wear high visibility vest at all times.
- Always have at least one additional person in close proximity when working near or in water

WORK STEPS	**HAZARDS**	**CONTROLS**
Driving to and from the Sites	*Routine Driving Hazards*	*See Section A (Driving Hazards)*
Accessbility	*Site Access – Road Hazards, Rough Terrain, Slips, Tricks, and Falls)*	*See Section A (General Safety Precautions)* *See Section D (Fall Hazards)*
Create cross section and collect measurements	*Use of hand tools* *Working around water* *Electrical Hazards*	*See Section A (General Safety Precautions)* *See Section C (Water/Boating Hazards)*

C. H&S EQUIPMENT LIST

List HS equipment needed at the worksite to control/manage hazards identified in **PART 2, "HAZARD ANALYSIS."**

EXPLANATORY NOTES, CLARIFICATIONS:

☒	**BASIC PPE AND SAFETY GEAR**	☒ Standard work clothes & footwear, appropriate for task ☒ Hard-toed boots/shoes ☐ Hardhat ☐ Safety glasses	☐ Work gloves appropriate for task ☐ Noise/hearing protection ☒ High-visibility/reflective vest ☒ First aid kit
		☐ Basic PPE for limited protection from chemical contact & low-hazard dust inhalation – nitrile gloves, Tyvek suit, dust mask, boot covers.	

☐	**OTHER H&S EQUIPMENT/GEAR**	☐ Fire extinguisher ☐ Traffic control warning devices ☐	☐ Vehicle emergency kit (flares, lights, reflective device) ☐ Buoyant object with retrieval rope ☐	
		☐ Other:		
☒	**ADDITIONAL PERSONAL PROTECTIVE EQUIPMENT (PPE)**	Eye/face protection ☐ Goggles ☐ Face shield Chemical protective clothing ☐ Gloves, type: ☐ Coveralls, type: ☐ Outer boots, boot covers	Respiratory Protection ☐ Disposable n-95 face mask ☐ Half-face air-purifying respirator ☐ Full-face air-purifying respirator ☐ Respirator cartridge, type: ☐	☒ Personal flotation device ☐ Personal fall apparatus ☐ Fire retardant clothing ☐ Arc Flash Protection ☐ Electrical-Hazard-rated boots, gloves ☐
		☐ Other:		
☐	**SPECIAL HAZARD CONTROLS**	☐ Portable GFCI ☐	☐ Lockout/tagout equipment ☐	☐ Ventilation equipment (fan, blower) ☐
☐	**DECON, PPE DISPOSAL**	☐ Waste receptacle for disposable PPE	☐ Hand washing provisions	☐ Decon solution, misc. supplies
		☐ Additional information:		
☐	**AIR MONITORING EQUIPMENT**	List needed air monitoring equipment below. See Part 2, Sections M, N and O for chemical hazard evaluation, action levels.		

D. EMERGENCY RESPONSE

Based on **PART 2, "HAZARD ANALYSIS,"** and on worksite factors, client requirements.

SUMMARY of Recognized Emergency Risk Factors & Response Procedures *(fire/explosion, medical , chemicals/spills, security, site conditions/topography, prevailing weather, other concerns)*: This work will include wading through streams. Site personnel should be prepared to assist those who enter water should an emergency arise.

To Summon Police, Fire, Ambulance in an Emergency	☒ DIAL 911 ☐ use alternate procedure:	
Nearest Emergency Medical Services - Mill Pond - Stony Brook	Hospital Name: Emerson Hospital Address: 133 Old Road To 9 Acre Corner, Concord, MA 01742 Phone #: 978-369-1400	☒ See Attached Directions
For **Non-Emergency Urgent Care**:	Contact WorkCare, 24/7 at: 800-455-6155, menu option "3"	
Other Emergency Contacts, as needed *(such as security, spill responder, utility):*		
Job-site **Evacuation** Procedure, Rally Point, Place of refuge:	Meet at the location where vehicles are parked	
Means of alerting on-site personnel in case of emergency:	☒ Verbal ☐ Radio ☒ Cell Phone ☐ Other:	
Special Equipment, as applicable (such as PPE, first aid, eyewash):	Personal flotation device, waders, rescue flotation device, first aid kit	

IMPORTANT: After initial emergency response actions and incident stabilization, contact appropriate project personnel (see Part 1.A.).

PART 2 – HAZARD ANALYSIS *Complete Section A. Then complete Sections B thru O, as applicable to your project. Provide comments in each section under "Explanatory Notes, Clarifications" to sufficiently describe **site-specific** hazards and safety measures.*

A. BASIC HAZARD PREPAREDNESS This section required for all Tasks.

Explanatory Notes, Clarifications: Field work outside in rough terrain with potential habitat for vectors such as ticks.

Basic Personal Protection

☐ **Overhead Hazards** - Wear hardhat or "bump cap" as appropriate for hazard.
☐ **Hand injury hazards** - Wear protective work gloves appropriate for the hazard and work tasks.
☐ **Eye injury hazards** - Wear safety glasses (with side shield or wrap around, either clear or shaded for sun protection).
☒ **Foot hazards, rough terrain** - Wear work boots/shoes with hard toes, ankle support, puncture resistance, traction, as appropriate for conditions.
☐ **Noise** – use hearing protection, (earplugs, earmuffs, or both) as appropriate for conditions, at a minimum where noise levels exceed 85dBA.
☐ **Chemical/biological agents, low hazard and/or "passive" exposure** - use appropriate PPE and precautions; describe above.
☐ **Chemical/biological agents, elevated hazard and/or "active use" exposure** – see Part 2, Section(s) M, N, O, as applicable.

Geosyntec Procedures: *HS-109-Hearing Conservation, HS-113-Personal Protective Equipment, HS-210-Walking and Working Surfaces*

General Safety Precautions

☒ **General premises** hazards - housekeeping, rough terrain, trip hazards, steep slope, remote location; describe specific hazards and controls above. Carry light equipment loads, always leave one hand free to grab onto the fencing along the edge of the Mill Pond Site.
☒ **Weather/climate-related hazards** - heat cold protection, fluids, breaks, shade, sun screen, multiple layers, discontinue use of aerial lift/ladder in high wind, "30/30 rule" for lightning safety, protection from hail, seek place of refuge for extreme weather
☒ **Plant/Insect/Animal Hazards** - Precautions: poison ivy wash; insect repellant; check for ticks; hornet nest spray; animal precautions.
☒ **Traffic** – Implement measures to protect personnel (high visibility/reflective clothing, on-person lighting, traffic control measures).
☐ **Illumination hazards/night work** - Illuminate work areas and/or access routes, use reflective/hi-visibility clothing or on-person lighting, as appropriate.

☐ **Manual hand tools** - proper tool for the job, maintain in good condition, use vice/clamp to hold work piece, proper follow thru

☐ **Machinery hazards, passive exposure** – keep safe distance, heed warning signs, use appropriate PPE (such as eye/hearing protection), secure long hair, loose clothing, jewelry near moving parts. For active use of equipment machinery as part of the work, see Part 2, Section E "Powered Tools, Equipment, Machinery"

☒ **Lifting, manual material handling** – use proper lifting procedures, seek help for >50 lbs.

Geosyntec Procedures: *HS-127-Ticks, HS-124-Heat Stress, HS-125-Cold Stress, HS-210-Walking and Working Surfaces, HS-208-Housekeeping, HS-401-Back Injury Prevention, HS 517 Traffic Safety*

Security

☐ **High crime, urban** – Use appropriate measures for personal security (such as buddy system, security service, work scheduling, other measures)

☐ **Working alone** - Establish "check in" procedure with supervisor/project manager.

Geosyntec Procedures: *HS-207-Working Alone*

Driving Hazards

☒ **Routine work travel** - Use routine safe/defensive driving practices (seat belts, safe speeds, eyes ahead, no tailgating, limit distractions, safe cell phone use, no texting, clear windows, account for weather/road conditions, adequate sleep, other measures as appropriate).

☒ **Unfamiliar location** - Plan travel route before driving (assemble maps, enter destination in GPS).

☐ **Long Distance or During Sleep Hours** – Minimize fatigue: rest breaks, light snacks (avoid heavy meals), stay hydrated, fresh air, no loud music, clean windshield.

☐ **Unfamiliar vehicle** – Become familiar with vehicle operational controls before operating vehicle.

☐ **Special hazards** - see Part2, Section B, "Special Driving/Traffic/Transportation Hazards"

Geosyntec Procedures: *HS-105-Driver and Vehicle Safety*

B. SPECIAL DRIVING/TRAFFIC/TRANSPORTATION HAZARDS ☒Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:

☐	**SPECIAL DRIVING HAZARDS** Off-Road Driving or use of non-typical vehicle, ATV Hazards: Worker injury due to vehicle collision, rollover	☐ For off road driving, do not exceed capability of vehicle, beware of wet conditions, speed low, avoid unsafe orientation on slopes. ☐ Follow ATV specific procedures for training, safety equipment, operation, manufacturer's instructions. ☐ Special Skills Required for Vehicle type - For vehicles requiring special skills (such as windowless van, heavy work vehicle, utility vehicle, similar) ensure operator is provided training and/or has appropriate operator skills through experience. ***Geosyntec Procedure(s):*** *HS-510-All Terrain Vehicles*
☐	**TRANSPORTING MATERIALS, TOWING/HAULING LOADS** Hazards: Vehicle accident, occupant injury from shifting load, unsafe equipment.	☐ Ensure load is firmly secured (rope, straps, load configuration) to prevent shifting during travel. ☐ Slings, chains, strap, rope and related equipment used for towing, hauling, load-securing shall be appropriate for use, and used in a manner as to prevent an unsafe condition. ☐ For trailer use, verify signal/braking lights operational, rear-view mirrors effective, hitch/safety chains secure.
☒	**WORKSITE IN/NEAR VEHICLE THOROUGHFARE** Hazards: Worker injury from being struck by vehicle traveling in thoroughfare.	☒ Wear reflective vests where exposed to traffic hazards. ☒ Where possible, park vehicles as protective shield from oncoming traffic. ☒ Configure work area and support vehicles to minimize worker exposure to traffic hazards. ☐ Use DOT signal devices to re-route vehicles around work area, site entrances/exits. ☐ Use DOT-trained flaggers or police detail where appropriate or required. ***Geosyntec Procedure(s):*** *HS-517-Traffic Safety*
☐	**RAILROAD HAZARD** Hazard: Worker injury from being struck by train in R.R. right-of-way	☐ Coordinate with rail company and implement required safety and security measures. ☐ Site workers to receive safety training for railroad work. **Geosyntec Procedure(s):** HS-305-Rail Operations
☐	**WATER TRANSPORTATION**	☐ Follow HS 312 "Water Transportation Safety," and Section C, "Water/Boating Hazards." **Geosyntec Procedure(s):** HS-312-Water Transportation Safety
☐	**AIRPORT, AIRCRAFT** Worker injury when working on/near airport runway, or use of helicopter, light aircraft	☐ Coordinate safety requirements with Airport personnel and implement required safety measures. ☐ Site workers to receive safety training for railroad/airport work. ☐ Follow HS 310 "Helicopter Safety" and/or HS 311 "General Aviation (Small Aircraft) Safety." ***Geosyntec Procedure(s):*** *HS-310-Helicopter Safety, HS 311-General Aviation (Small Aircraft) Safety*
☐	**HEAVY EQUIPMENT TRAFFIC/VEHICLE HAZARDS AT CONSTRUCTION SITE**	☐ See Section G, "Construction, Heavy Equipment, Lift Equipment"

C. WATER/BOATING HAZARDS ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: Channel depth and velocity measurements will be collected while wading in streams. If streams are considered unwadable (e.g., channel too deep, water moving too quickly), personnel should not enter water and

☐	**OPERATOR OF WATER CRAFT OR PASSENGER/WORKER ON WATER CRAFT OR PLATFORM** Hazards: Drowning, hypothermia, collision, motor/fuel hazards, navigation	☒ Wear regulatory-approved personal flotation device (PFD) or buoyant work vest at all times when in vicinity of water. ☒ Maintain a constant connection with a retrieval safety rope attached to a buoyant object when working in vicinity of water. ☐ Do not enter the water at anytime during the installation. ☐ Bring emergency rescue equipment (ring buoy, reaching device, flares). Use "reach, throw, row, go" strategy. ☐ Use fuel safety practices, fire extinguisher present in boat. ☐ Have lifesaving skiff/boat available.
☒	**WORK NEAR WATER HAZARDS OR ENTERING WATER** Hazards: drowning, hypothermia from water immersion, related injuries. ☒ Work in vicinity of water (fall or slip hazard into water with mud/silt bottom) ☒ Wading, wetland, mud/silt ☐ Dam release, flash flood, tide ☐ Diving ☐ Ice on/near water body	☒ Monitor weather, develop float plan, ensure navigation/communication equipment operable. ☒ For tidal, flash flood, dam release hazards, plan/locate work accordingly, other precautions as appropriate. ☐ Where ice/slip hazards are present adjacent to water body, and for working directly on ice over water, wear ice creepers, sand work area, or take other appropriate measures to address slip hazard. ☐ For high-hazard work over very cold water, have immersion survival suit available, as appropriate. ☒ For electrical hazards associated with water/wet locations, see Section H, "Electrical Hazards." ***Geosyntec Procedure(s):*** *HS-306-Working on/near Water and Ice, HS-312-Water Transportation Safety*

D. FALL HAZARDS ☐ Applicable	☒ Not Applicable, Not Anticipated
E. POWERED TOOLS, EQUIPMENT, MACHINERY ☐ Applicable	☒ Not Applicable, Not Anticipated
F. DRILLING ☐ Applicable	☒ Not Applicable, Not Anticipated
G. CONSTRUCTION, HEAVY EQUIPMENT, LIFT EQUIPMENT ☐ Applicable	☒ Not Applicable, Not Anticipated
H. ELECTICAL HAZARDS ☒ Applicable	☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: A velocity meter will be used to collect measurement while standing in a stream. The meter is built to be in water, but still be careful when handling while wet or standing in water.

☒	**ELECTRICAL HAZARDS (GENERAL)** Equipment/tool use/operation, use of extension cords, working near electrical equipment. Hazards: Electrical shock, secondary hazards (falls, other injuries).	☒ Follow safe work practices: • Control water-related/wet-location hazards in a manner appropriate for the job tasks/equipment/tool. • Never touch electrical equipment if you are wet, or standing in water or on wet surfaces. • Use extension cords/power cords properly, prevent damage, take out of service if damaged. • Inspect tool/equipment/extension cords/power cords/welding cables before each use; do not use if damaged. • Use GFCI-protected outlet or portable GFCI in wet locations, outdoors, basements. • Ensure live parts are guarded, enclosures secure. • Enclosures, circuits properly labeled. ***Geosyntec Procedure(s):*** *HS-121-Electrical Safety*
☐	**HANDS-ON WORK ON ELECTRICAL CIRCUITS:** ☐ Voltage < 50 v ☐ Voltage 50-600v ☐ Voltage > 600v ☐ AC ☒ DC ☐ 3-phase ☐ Battery and/or solar power ☐ Capacitor/transformer	☐ Implement electrical safe work practices pertaining to: • Worker training/qualification (Level 1, Level 2, Level 3) • General electrical safe work practices, grounding, use of GFCIs • Safe work practices during diagnostics/troubleshooting, maintenance, repair • Safe design features for electrical equipment • Arc flash protection ☐ For utility-related hazards, see Section I, "Utility Related Hazards") ***Geosyntec Procedure(s):*** *HS-121-Electrical Safety, HS-129-High Voltage Electricity Safety*
☐	**LOCKOUT/TAGOUT OF ELECTRICAL ENERGY**	☐ Implement control-of-hazardous-energy practices (lockout/tagout), provide lockout/tagout locks and devices, training workers, designate "authorized" personnel, notify "affected" personnel. ***Geosyntec Procedure(s):*** *HS-119-Lockout Tagout*

I. UTILITY RELATED HAZARDS ☐ Applicable	☒ Not Applicable, Not Anticipated
J. CONFINED SPACE ENTRY, HAZARDOUS ENCLOSED SPACES ☐ Applicable	☒ Not Applicable, Not Anticipated
K. STORAGE OF BULK MATERIALS ☐ Applicable	☒ Not Applicable, Not Anticipated
L. INFECTIOUS / ALLERGENIC BIOHAZARDS ☐ Applicable	☒ Not Applicable, Not Anticipated
M. PROJECT USE OF COMMERCIAL CHEMICAL PRODUCTS ☐ Applicable	☒ Not Applicable, Not Anticipated
N. SITE CONTAMINANTS, CHEMICAL WASTES ☐ Applicable	☒ Not Applicable, Not Anticipated
O. AIR MONITORING ☐ Applicable	☒ Not Applicable, Not Anticipated
P. RADIATION HAZARDS (Other than Sunlight) ☐ Applicable	☒ Not Applicable, Not Anticipated

PART 3 – APPROVALS, ACKNOWLEDGEMENTS

A. THA PREPARATION, REVIEW/APPROVAL SIGNATURES - THA typically prepared by project staff, reviewed/approved by Project Manager, Supervisor, qualified/knowledgeable designee, with support of HS personnel as deemed appropriate for the work and associated hazards.			
	Printed Name	*Signature*	*Date*
THA PREPARED BY: (minimum one person)	Marisa Zellmer	MHZ	4/17/2019
	Printed Name	*Signature*	*Date*
THA REVIEWED/ APPROVED BY: (minimum one person)	Adam Questad	ADQ	04/22/19

>>> Please See Section B, “Field Crew Acknowledgements,” on Following Page <<<

B. FIELD CREW ACKNOWLEDGEMENTS

GEOSYNTEC FIELD CREW

Please sign below to acknowledge you reviewed and understand this THA, participated in project safety briefing and had an opportunity to ask questions about the information herein.

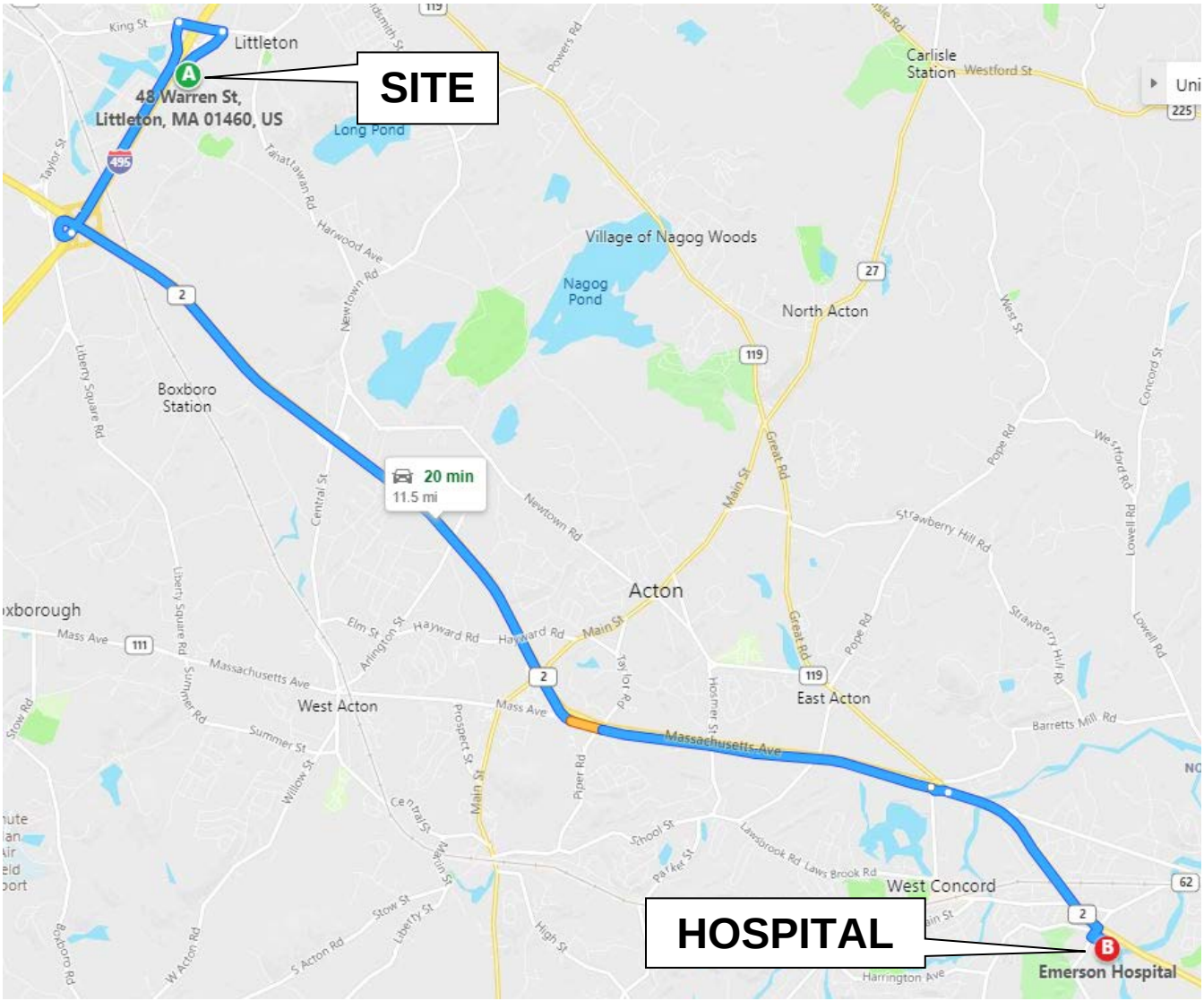
Print Name:	Signature:	Employee No.	Date:

SUBCONTRACTOR'S FIELD CREW

Please sign below to acknowledge that this THA was made available to you, and you had an opportunity to ask questions about the information herein.

Print Name:	Signature:	Company Name:	Date:

ROUTE TO HOSPITAL – Mill Pond

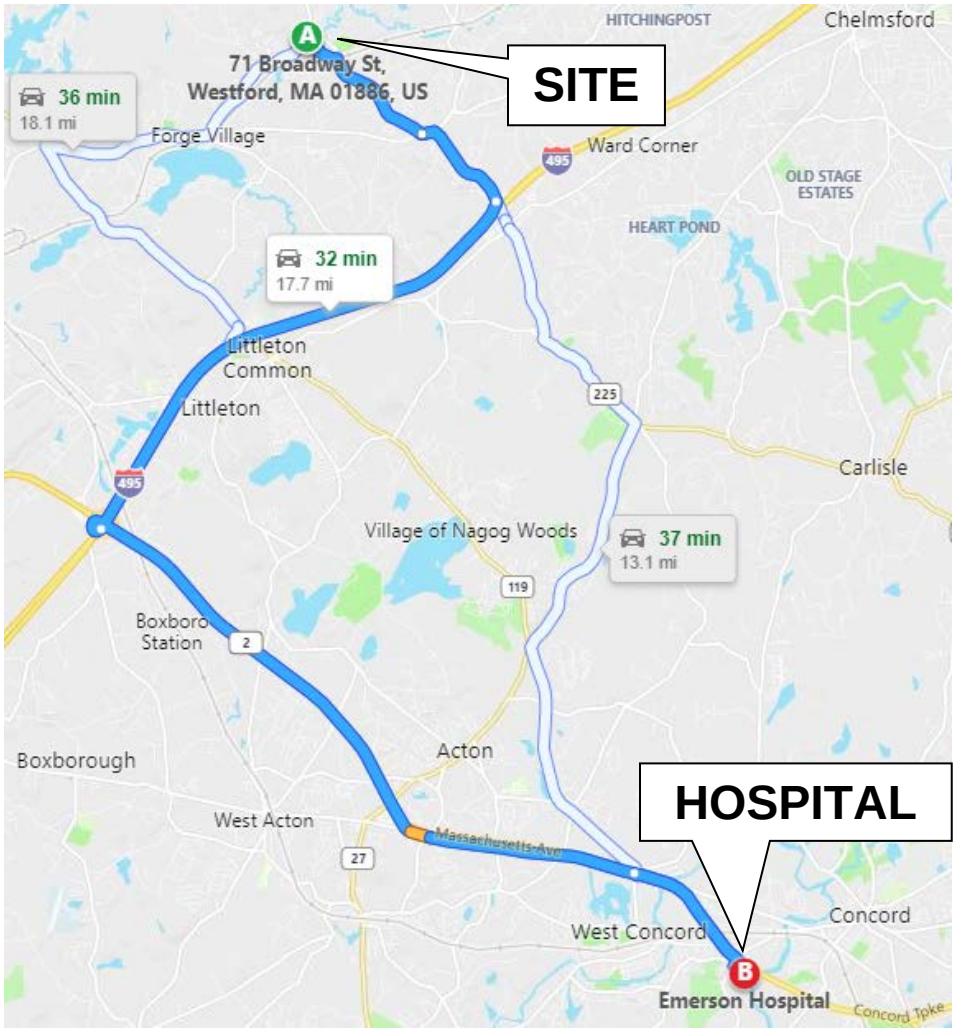


HOSPITAL NAME
Emerson Hospital
133 Old Road to 9 Acre Corner
Concord, MA

Written Directions to Hospital from Site:

1. Depart Mill Rd toward Warren St (364 ft).
2. Road name changes to Warren St (0.4 mi).
3. Turn left onto RT-110 / RT-2A / King St (0.3 mi).
4. Take ramp left for I-495 S (1.6 mi).
5. At exit 29A, take ramp right for RT-2 East toward Boston (7.4 mi).
6. At roundabout, take 2nd exit onto RT-2 E / RT-2A E / Concord Tpke / Elm St (0.1 mi).
7. Keep straight onto RT-2A / RT-2 / Elm St / Concord Tpke (1.4 mi).
8. Turn right onto Old Road to 9 Acre Corner (394 ft).
9. Turn left onto road (0.1 mi).
10. Keep right onto road (203 ft).
11. Arrive.

ROUTE TO HOSPITAL – Stony Brook

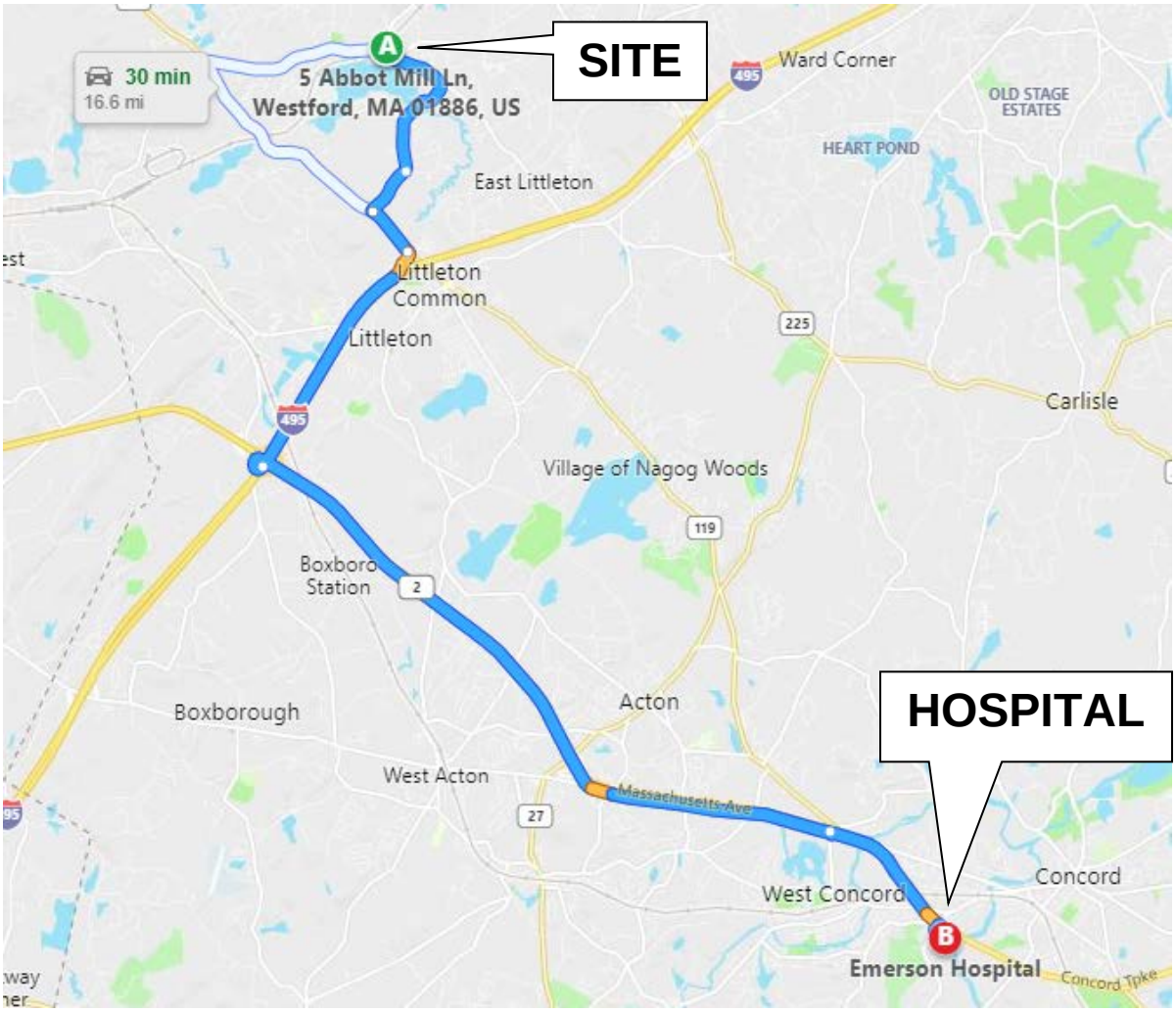


HOSPITAL NAME
Emerson Hospital
133 Old Road to 9 Acre Corner
Concord, MA

Written Directions to Hospital from Site:

1. Depart Broadway St toward Church St (0.4 mi).
2. Turn right onto River St (69 ft).
3. Road name changes to Graniteville Rd (1.2 mi).
4. Bear left onto Main St (0.1 mi).
5. Bear right onto Boston Rd (1.0 mi).
6. Take ramp right for I-495 S (5.7 mi).
7. At exit 29A, take ramp right for RT-2 East toward Boston (7.4 mi).
8. At roundabout, take 2nd exit onto RT-2 E / RT-2A E / Concord Tpke / Elm St (0.1 mi).
9. Keep straight onto RT-2A / RT-2 / Elm St / Concord Tpke (1.4 mi).
10. Turn right onto Old Road to 9 Acre Corner (394 ft).
11. Turn left onto road (0.1 mi).
12. Keep right onto road (203 ft).
13. Arrive.

ROUTE TO HOSPITAL – Forge Pond

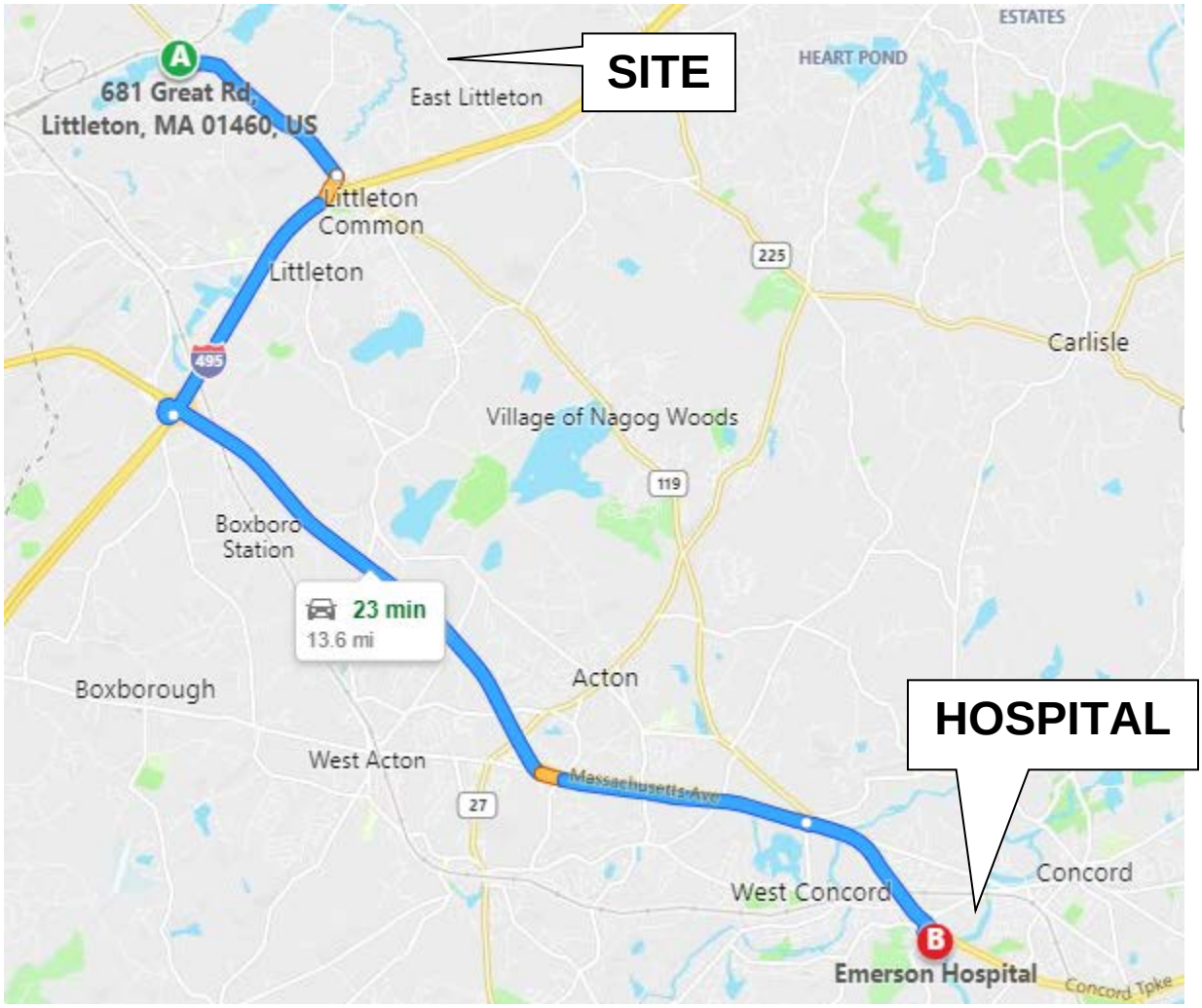


HOSPITAL NAME
Emerson Hospital
133 Old Road to 9 Acre Corner
Concord, MA

Written Directions to Hospital from Site:

1. Depart Abbot Mill Ln toward RT-225 / Pleasant St (0.1 mi).
2. Turn left onto RT-225 / Pleasant St (0.7 mi).
3. Turn right onto Beaverbrook Rd (1.1 mi).
4. Road name changes to Beaver Brook Rd (0.5 mi).
5. Turn left onto RT-119 / Great Rd (0.6 mi).
6. Take ramp right for I-495 S (2.6 mi).
7. At exit 29A, take ramp right for RT-2 East toward Boston (7.4 mi).
8. At roundabout, take 2nd exit onto RT-2 E / RT-2A E / Concord Tpke / Elm St (0.1 mi).
9. Keep straight onto RT-2A / RT-2 / Elm St / Concord Tpke (1.4 mi).
10. Turn right onto Old Road to 9 Acre Corner (394 ft).
11. Turn left onto road (0.1 mi).
12. Keep right onto road (203 ft).
13. Arrive.

ROUTE TO HOSPITAL – Spectacle Pond



HOSPITAL NAME
Emerson Hospital
133 Old Road to 9 Acre Corner
Concord, MA

Written Directions to Hospital from Site:

1. Depart RT-119 / Great Rd toward Hartwell Ave (1.8 mi).
2. Take ramp right for I-495 S (2.6 mi).
3. At exit 29A, take ramp right for RT-2 East toward Boston (7.4 mi).
4. At roundabout, take 2nd exit onto RT-2 E / RT-2A E / Concord Tpke / Elm St (0.1 mi).
5. Keep straight onto RT-2A / RT-2 / Elm St / Concord Tpke (1.4 mi).
6. Turn right onto Old Road to 9 Acre Corner (394 ft).
7. Turn left onto road (0.1 mi).
8. Keep right onto road (203 ft).
9. Arrive.

Appendix D

Stream Gaging Field Forms

RIFLS FIELD DATA SHEET

Site: Spectacle pond * **Crew:** KB, mc, CG, MW, AQ, MZ
Date: 04/23/2019 **Weather:** overcast, light rain
Start time: 10:25 **End time:** 11:50
Gage start (ft): 1.75 **Gage end (ft):** 1.79 * difficult to read - water uneven on gage
Photos? (Y)/N (circle one) **Survey?** Y/(N) (circle one)

Transducer download? Y/(N) (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes:
water level area optic sensor = 1.89ft (rod placed directly under pvc housing)

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? (Y)/N (circle one)
Transect 1 User: KB, MC *Transect 2* User: _____
Equipment: FT Quality: good Equipment: _____ Quality: _____
File Name: 423SPEC1 File Name: _____
Total Q: 29.603 Total Q: _____
Notes:

PZF?
Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Mill pond **Crew:** KB, mc
Date: 04/23/2019 **Weather:** overcast
Start time: 13:00 **End time:** 14:06
Gage start (ft): _____ **Gage end (ft):** see notes
Photos? (Y)/N (circle one) **Survey?** Y/(N) (circle one)

Transducer download? Y/(N) (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes:
1.70 ft gage in creek on RR mainhall
2.07/2.08 ft gage at corner OR RR

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? (Y)/N (circle one)
Transect 1 User: KB, CG, MW *Transect 2* User: mc, AQ
Equipment: FT2 Quality: good Equipment: FT1 Quality: good
File Name: 423MILL1 File Name: 423MILL2
Total Q: 55.947 Total Q: 55.710
Notes:

PZF?
Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site:	Forge Pond	**Crew:**	KB, MC, MW, NZ
Date:	4/23/2019	**Weather:**	overcast
Start time:	14:55	**End time:**	16:13
Gage start (ft):	2.1	**Gage end (ft):**	2.1
Photos?	(Y)/N (circle one)	**Survey?**	(Y)/N (circle one)

Transducer download?	(Y)/N (circle one)		
Transducer time:		Battery status (volts):	
Transducer temp (F):		Battery change?	Y/N (circle one)
Transducer pressure (ft/psi):		Desiccant change?	Y/N (circle one)
Notes:			

Data corrected for:	Barometric pressure?	Y/N	Daylight savings?	Y/N
Data entered into:	Aquarius?	Y/N	Database?	Y/N

Discharge measurement?	(Y)/N (circle one)					
Transect 1	User:	KB, MW	*Transect 2*	User:	MC	
Equipment:	FT2	Quality: fair	Equipment:	FT1	Quality: fair	
File Name:	423 Forge 1		File Name:	Forg		
Total Q:	73.551		Total Q:	86.43		
Notes:						
PZF?	—					

Data entered into:	Excel?	Y/N	Aquarius?	Y/N	Database?	Y/N

RIFLS FIELD DATA SHEET

Site:	Forge Pond	**Crew:**	KB, CG, JG
Date:	05/16/19	**Weather:**	partly cloudy
Start time:	8:13	**End time:**	9:40
Gage start (ft):	~1.7	**Gage end (ft):**	~1.7
Photos?	Y/N (circle one)	**Survey?**	Y/N (circle one)

Transducer download?	Y/N (circle one)		
Transducer time:		Battery status (volts):	
Transducer temp (F):		Battery change?	Y/N (circle one)
Transducer pressure (ft/psi):		Desiccant change?	Y/N (circle one)
Notes:			

Data corrected for:	Barometric pressure?	Y/N	Daylight savings?	Y/N
Data entered into:	Aquarius?	Y/N	Database?	Y/N

Discharge measurement? Y/N (circle one)

Transect 1	User:	KB	*Transect 2*	User:	CG, JG
Equipment:	FT	Quality: good	Equipment:	FT2	Quality: good
File Name:	515 FORG01		File Name:	515 Forge	
Total Q:	56.972		Total Q:	54.1306	
Notes:					
PZF?	—				

Data entered into:	Excel?	Y/N	Aquarius?	Y/N	Database? Y/N

RIFLS FIELD DATA SHEET

Site: Spectacle Pond **Crew:** KB, CG, JG

Date: 05/15/2019 **Weather:** partly cloudy

Start time: 10:00 **End time:** 11:07

Gage start (ft): 1.52 gage **Gage end (ft):** ~1.42 gage

Photos? (Y)/N (circle one) **Survey?** Y/(N) (circle one)

Transducer download? Y/(N) (circle one)

Transducer time: _____ Battery status (volts): _____

Transducer temp (F): _____ Battery change? Y/N (circle one)

Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)

Notes:

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N

Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? (Y)/N (circle one)

Transect 1 User: KB *Transect 2* User: JG

Equipment: FT Quality: good Equipment: FT2 Quality: good

File Name: 515 SPEC1 File Name: 515 spec

Total Q: 19.370 Total Q: 18.3493

Notes:

PZF? ~

Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Mill Pond | **Crew:** KB, ~~DAVE~~, CG, JG

Date: 05/15/2019 | **Weather:** partly sunny

Start time: 11:45 | **End time:** 12:46 // 13:38

Gage start (ft): | **Gage end (ft):** 2.1 / 2.45 // 2.09 / 2.44

Photos? Y/N (circle one) | **Survey?** Y/N (circle one)

Transducer download? Y/N (circle one)

Transducer time: | Battery status (volts):

Transducer temp (F): | Battery change? Y/N (circle one)

Transducer pressure (ft/psi): | Desiccant change? Y/N (circle one)

Notes:

Data corrected for: Barometric pressure? Y/N | Daylight savings? Y/N

Data entered into: Aquarius? Y/N | Database? Y/N

Discharge measurement? Y/N (circle one)

Transect 1 User: KB | *Transect 2* User: JG

Equipment: FT1 | Quality: good | Equipment: FT2 | Quality: good

File Name: 515 MILL1 | File Name:

Total Q: 21.693 | Total Q: 25.7419 515MILL

Notes: transect 3: 23.960 515MILL3 transect 4. 22.89 515MILL

PZF? — Q1+Q2 = 10% diff → measured Q3+Q4 at T2 ~5ft US T1

Data entered into: Excel? Y/N | Aquarius? Y/N | Database? Y/N

V20
15.7

RIFLS FIELD DATA SHEET

Site:	Mill Pond	**Crew:**	KB, CG, JG, MW
Date:	05/28/2019	**Weather:**	overcast
Start time:	8:45	**End time:**	10:29 // 11.21
Gage start (ft):		**Gage end (ft):**	1.86 // 1.86
Photos?	Y/N (circle one)	**Survey?**	Y/N (circle one) 1.70 in direct 2.02 on corner

Transducer download? Y/N (circle one)

Transducer time:		Battery status (volts):	
Transducer temp (F):		Battery change?	Y/N (circle one)
Transducer pressure (ft/psi):		Desiccant change?	Y/N (circle one)

Notes: installed gage + transducer to RR mignally perch, dace in pool near gage

Data corrected for:	Barometric pressure?	Y/N	Daylight savings?	Y/N
Data entered into:	Aquarius?	Y/N	Database?	Y/N

Discharge measurement? Y/N (circle one)

Transect 1	User:	MW	*Transect 2*	User:	JG
Equipment:	FT	Quality: good	Equipment:	FT2	Quality: good
File Name:	528 MILL1		File Name:	528 MILL2	
Total Q:	11.651		Total Q:	9.1411	

Notes: KB ~~Q3 same T1 3.561 cfs poor quality - scared negative value~~ do not use Q4 diff T2 ~40 ft ~~as~~ same + size as Q3

PZF? —

Data entered into:	Excel?	Y/N	Aquarius?	Y/N	Database?	Y/N

RIFLS FIELD DATA SHEET

Site: Spectacle Pond **Crew:** CG, JG
Date: 5/28/2019 **Weather:** overcast to rain
Start time: _____ **End time:** 12:05
Gage start (ft): _____ **Gage end (ft):** 1.07
Photos? Y/N (circle one) **Survey?** Y/N (circle one)

Transducer download? Y/N (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes: gage + transducer installed on DS side of culvert

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? Y/N (circle one)

Transect 1
User: JG
Equipment: FT2 Quality: good
File Name: 528 BvBk2
Total Q: 4.7903

Transect 2
User: JG
Equipment: FT2 Quality: good
File Name: 528 BvBk1
Total Q: 10.5791

Notes:

PZF? —

Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Stony Brook dam **Crew:** KB, MW
Date: 05/28/2019 **Weather:** rain
Start time: 12:04 **End time:** 13:30
Gage start (ft): _____ **Gage end (ft):** _____
Photos? (Y)/N (circle one) **Survey?** Y/(N) (circle one)

Transducer download? Y/(N) (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes:

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? (Y)/N (circle one)

Transect 1	User: MW	*Transect 2*	User: KB
Equipment: FT	Quality: good	Equipment: FT2	Quality: good
File Name: STONY1		File Name: STONY2	
Total Q: 24.671		Total Q: 26.156	

Notes:

PZF?

Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Stony Brook **Crew:** AQ, JG, MZ
Date: 6/5/19 **Weather:** 60s Sunny
Start time: 9:05 **End time:** 10:20 & 11:40
Gage start (ft): 2.10" **Gage end (ft):** 2' 8.5"
Photos? Y/N (circle one) **Survey?** Y/N (circle one)

Transducer download? Y/N (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes:

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? Y/N (circle one)

Transect 1				*Transect 2*			
User:	JG			User:	JG		
Equipment:	FT2	Quality:		Equipment:	FT2	Quality:	
File Name:				File Name:			
Total Q:	29.8609			Total Q:	26.53605		

Notes:
PZF? flowtracker = 14.95 cfs
Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Farge Pond **Crew:** AQ, BS, MZ
Date: 6/5/19 **Weather:** 60s Sunny
Start time: 12:30 **End time:** 2:00
Gage start (ft): 1.0' **Gage end (ft):** 0.9'
Photos? Y/N (circle one) **Survey?** Y/N (circle one)

Transducer download? Y/N (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes:

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? Y/N (circle one)

Transect 1				*Transect 2*			
User:	AQ			User:	MZ, BS		
Equipment:	FT	Quality:		Equipment:	FT2	Quality:	
File Name:				File Name:			
Total Q:	30.03			Total Q:	28.72		

Notes:
PZF?
Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Spectacle Pond **Crew:** BS, AQ, MZ
Date: 6/05/19 **Weather:** 60s sunny
Start time: 14:45 **End time:** 15:15
Gage start (ft): 1.00' **Gage end (ft):** 0.99'
Photos? Y/N (circle one) **Survey?** Y/N (circle one)

Transducer download? Y/N (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes: height above transducer: 1'1"

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? Y/N (circle one)

Transect 1		*Transect 2*	
User:	BS	User:	AQ
Equipment:	FT2	Equipment:	FT
Quality:		Quality:	
File Name:		File Name:	
Total Q:	9.02 cfs	Total Q:	7.7

Notes:

PZF?

Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

RIFLS FIELD DATA SHEET

Site: Mill Pond **Crew:** AQ, MZ
Date: 6/5/19 **Weather:** 60s sunny
Start time: 15:50 **End time:** 16:40
Gage start (ft): 1.78 **Gage end (ft):** 1.78
Photos? Y/N (circle one) **Survey?** Y/N (circle one)

Transducer download? Y/N (circle one)
Transducer time: _____ Battery status (volts): _____
Transducer temp (F): _____ Battery change? Y/N (circle one)
Transducer pressure (ft/psi): _____ Desiccant change? Y/N (circle one)
Notes:

Data corrected for: Barometric pressure? Y/N Daylight savings? Y/N
Data entered into: Aquarius? Y/N Database? Y/N

Discharge measurement? Y/N (circle one)

Transect 1		*Transect 2*	
User:	AQ	User:	MZ
Equipment:	FT	Equipment:	FT2
Quality:		Quality:	
File Name:		File Name:	
Total Q:	6.514	Total Q:	7.26

Notes:

PZF?

Data entered into: Excel? Y/N Aquarius? Y/N Database? Y/N

Appendix E

Spectacle Pond Addendum to Stony Brook Flow Restoration Project

289 Great Road, Suite 202
Acton, Massachusetts 01750
PH 978.206.5746
FAX 978.263.9594
www.geosyntec.com

Memorandum

Date:	July 3, 2018
To:	Corey Godfrey, Littleton Water Department; Mark Warren, Westford Water Department; Leon Weaver, Littleton Clean Lakes Committee
From:	David Roman, Hayley O'Grady Geosyntec Consultants
Subject:	Stony Brook Flow Restoration Project – Spectacle Pond Addendum
Attachments	Revised DAM Dashboard Lookup Tables

This memorandum amends previous work performed during the Stony Brook Flow Restoration Project (Geosyntec Consultants, 2018) and the DAM Dashboard Pilot Project (Geosyntec Consultants, 2017). Specifically, the configuration of the outlet control structure at Spectacle Pond as it relates to stop log configurations and their associated elevations is clarified. The secondary purpose of this memorandum is to indicate how the online dashboard ("DAM Dashboard") will be updated to support these revisions.

Outlet Control Structure

The Spectacle Pond outlet control structure consists of two stop log-type weirs (referred to as the east weir and west weir) that discharge to a dual 48 in concrete culvert under Great Road (**Figure 1**). According to personal communication with LCLC, the east weir is not typically modified except for emergency situations. Analysis of potential discharge from previous work assumes that stop logs are configured such that all water spills over the west weir.

The west weir is adjusted based on current needs by removing or adding concrete stop logs to adjust the water level and outflow from Spectacle Pond. Adjustments can be made with up to six (6) concrete stop logs. Adjustments are typically made to accommodate spring refill ("summer configuration") and winter drawdown ("winter configuration").



Figure 1. Spectacle Pond Outlet Control Structure

Summary of Outlet Control Structure Changes

Based on personal communication with LCLC following completion of the Stony Brook Flow Restoration Project, it was determined that nomenclature and elevations used for modeling and analysis were not consistent with the records of LCLC. The previous analysis did not account for a partially buried stop log which changes the number of installed stop logs in the structure and their resulting top elevation values by approximately 0.5 feet. In addition, the top elevation of the weir structure (see **Figure 1**) was updated based on field measurements performed by LCLC on the week ending 6/29/2018. Refer to **Figures 2a** and **2b** for the original and revised stop log configuration and elevations, respectively.

These changes have implications to future implementation of recommendations from the Stony Brook Flow Restoration Project. There are potential anecdotal navigation issues below the typical three stop log "summer configuration" and potential anecdotal flooding issues above a configuration of four stop logs.

To support recommended low flow releases at Spectacle Pond, the stop log configuration of the pond would be set to four stop logs and could be adjustable down to the top elevation of three stop logs via a low flow orifice; however, extreme caution would be required to avoid potential upstream flooding as follows:

1. Approval of potentially affected property owners would be required prior to implementation;
2. Additional protocols would be developed that, at minimum, would dictate removal of the fourth stop log prior to a significant forecast storm. The protocols would include the probability and quantity of expected precipitation that would necessitate removal of the fourth stop log, the required pre-storm removal timing (for example, at least 2 days prior to the forecast event), and responsible personnel for implemenation.

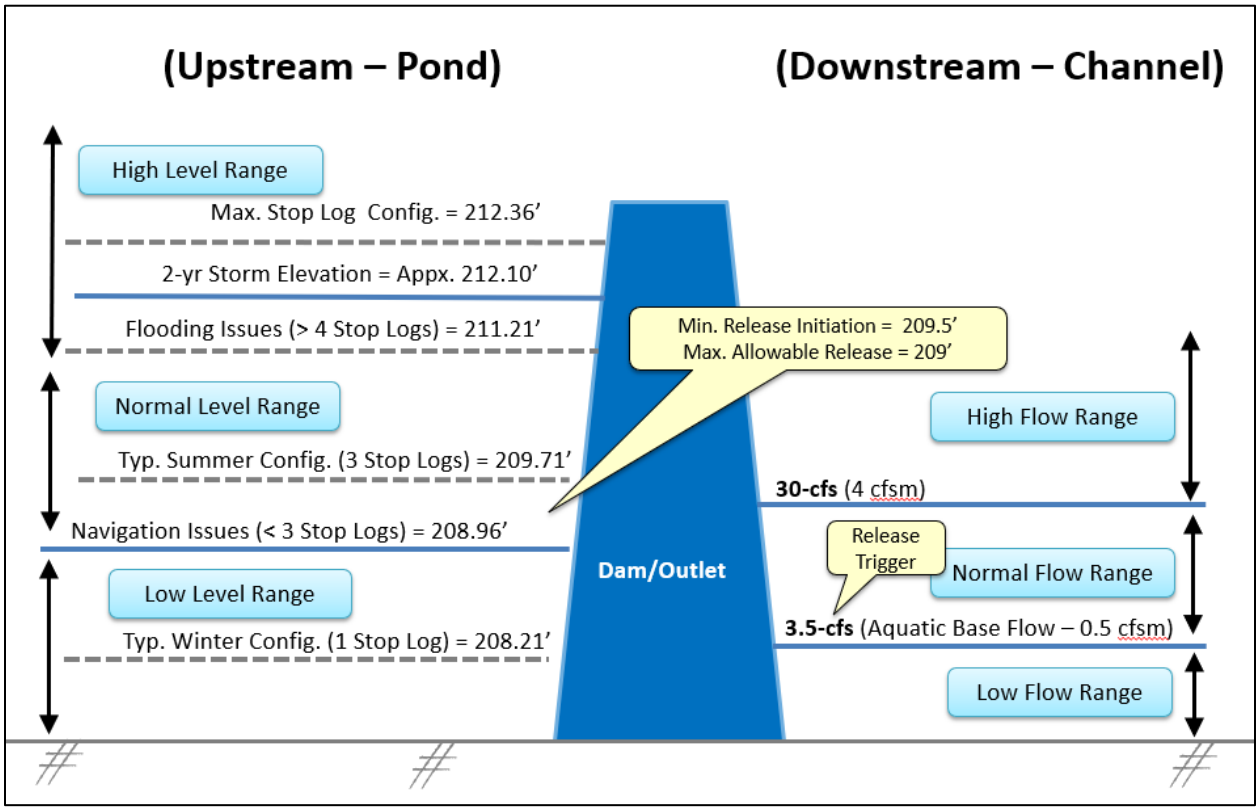


Figure 2a. Spectacle Pond Reference Configuration – Original Schematic

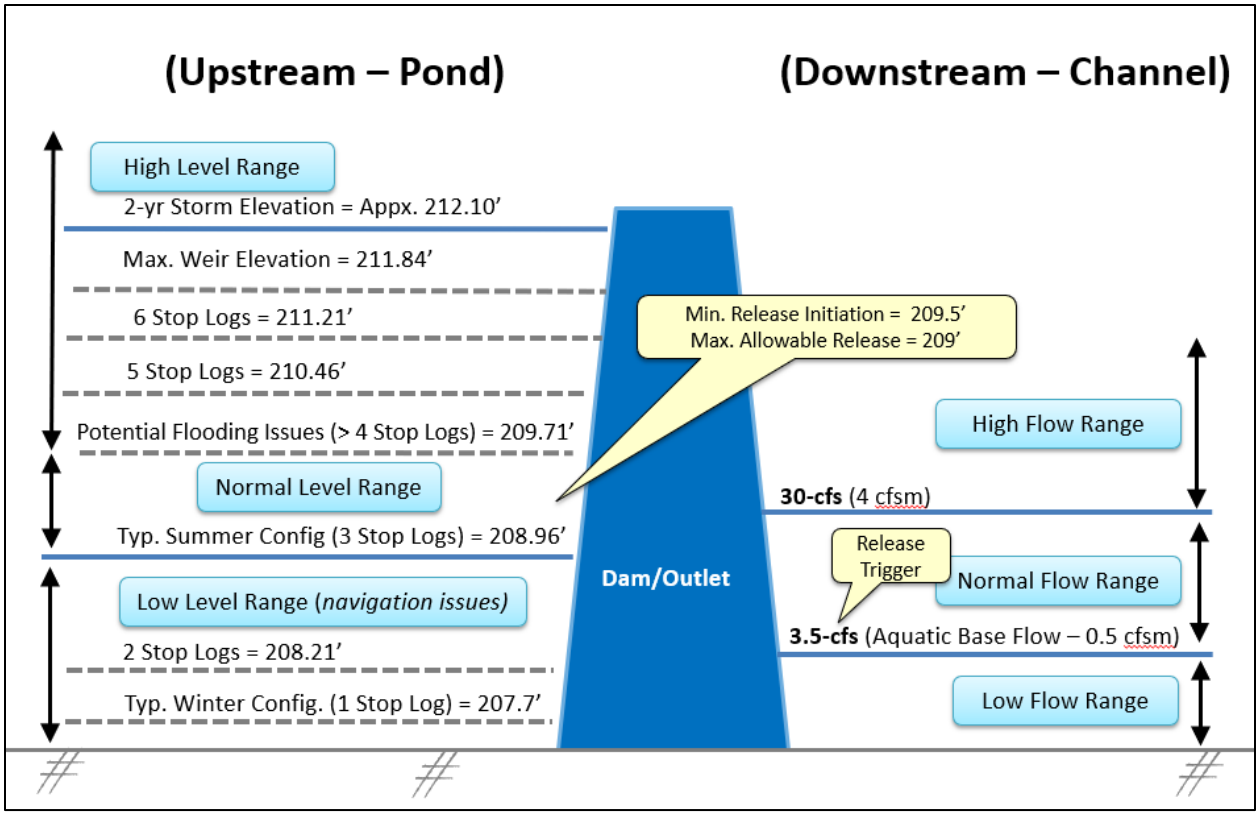


Figure 2a. Spectacle Pond Reference Configuration – Amended Schematic

Summary of DAM Dashboard Changes

To accommodate these changes, the underlying lookup tables that inform the Spectacle Pond dashboard were updated. Affected values included: horizontal reference values for the elevation of each stop log, calculated discharge over each stop log, and approximated storage volume relative to the summer, winter, and maximum weir configurations. See **Attachment 1** for updated lookup values.

References

Geosyntec Consultants (2017). DAM Dashboard: Desktop Analysis and Modeling Summary for Forge Pond and Spectacle Pond, technical memorandum, last revised August 25, 2017.

Geosyntec Consultants (2018). Stony Brook Flow Restoration Project, Streamflow Restoration Plan, Final Report, June 2018.

Spectacle Pond Lookup Values - revised on 7/3/2018 per Addendum Memorandum to reflect updated stop log configurations and their corresponding elevations

1. Estimated Inflow

Coefficient, C:	0.28
Area, A (acres):	4584.64

*Compute from ratonial method derivative (Q = CiA)

Vol = Precip*A

48-hour Precipitation (inch)	Exp. Inflow (ac-ft)
0.25	26.74
12	1283.70
1	106.97
1.5	160.46
2	213.95
3	320.92
4	427.90
5	534.87
6	641.85
7	748.82
8	855.80
9	962.77
10	1069.75

2. Weir Configurations [revised to reflect updated elevations]

Configuration	El. (NAVD88, ft)
Max Weir Height	211.84
Six Stop Logs	211.21
Five Stop Logs	210.46
Four Stop Logs (Flooding)	209.71
Three Stop Logs (Summer)	208.96
Two Stop Logs	208.21
One Stop Log (Winter)	207.70

*Based on number of in-place stop logs

2a. U/S Sensor Elevation / Calibration

Parameter	Value
Water Depth from Sensor Inv. (in)	6.960
Winter Config Water Depth (in)	3.500
Winter Config. El (in)	208.210
U/S Water El. (ft)	208.502
U/S Sensor El. (ft)	207.922
Probable Flow (cfs)	3.368

*Based on 8/15/2017 field measurements at 12pm

2b. D/S Sensor Elevation

Parameter	Value
Water Depth from Sensor Inv. (in)	10.800
D/S Culvert Inv. (ft)	206.000
Water Depth from D/S Culv. Inv. (in)	10.000
Hydraulic Drop (in)	3.000
D/S Water El. (ft)	206.583
D/S Sensor El. (ft)	205.683

*Based on 8/15/2017 field measurements at 3:30 pm

4b. Discharge Thresholds

Minimum Discharge During Refill (cfs)	3.58175
Maximum Discharge During Drawdown (cfs)	28.654

1. DEP guidelines - max = 4-cfs per sq. mi. of watershed; min = 0.5 cfs per sq.mi of watershed

3. Stage - Volume - Storage [revised to reflect updated elevations]

Upstream Water Depth	Upstream Water Elevation (NAVD88, ft)	Slope	Y Intercept	Stored Volume	Percent Full (%)	Available Storage - Max. Config. (ac-ft)	Available Storage - Summer Config. (ac-ft)	Available Storage - Winter Config. (ac-ft)
0.00	207.92	118.56	-24063.00	588.00	51.56%	464.76	123.30	-26.08
0.25	208.17	118.56	-24063.00	617.64	54.16%	435.12	93.66	-55.72
0.50	208.42	118.56	-24063.00	647.28	56.75%	405.48	64.02	-85.36
0.75	208.67	118.56	-24063.00	676.92	59.35%	375.84	34.38	-115.00
1.00	208.92	118.56	-24063.00	706.56	61.95%	346.20	4.74	-144.64
1.25	209.17	118.56	-24063.00	736.20	64.55%	316.56	-24.90	-174.28
1.50	209.42	118.56	-24063.00	765.84	67.15%	286.92	-54.54	-203.92
1.75	209.67	118.56	-24063.00	795.48	69.75%	257.28	-84.18	-233.56
2.00	209.92	118.56	-24063.00	825.12	72.35%	227.64	-113.82	-263.20
2.25	210.17	118.56	-24063.00	854.76	74.95%	198.00	-143.46	-292.84
2.50	210.42	118.56	-24063.00	884.40	77.55%	168.36	-173.10	-322.48
2.75	210.67	118.56	-24063.00	914.04	80.14%	138.72	-202.74	-352.12
3.00	210.92	118.56	-24063.00	943.68	82.74%	109.08	-232.38	-381.76
3.25	211.17	118.56	-24063.00	973.32	85.34%	79.44	-262.02	-411.40
3.50	211.42	118.56	-24063.00	1002.96	87.94%	49.80	-291.66	-441.04
3.75	211.67	118.56	-24063.00	1032.60	90.54%	20.16	-321.30	-470.68
4.00	211.92	118.56	-24063.00	1062.24	93.14%	-9.48	-350.94	-500.32
4.25	212.17	118.56	-24063.00	1091.88	95.74%	-39.12	-380.58	-529.96
4.50	212.42	118.56	-24063.00	1121.52	98.34%	-68.76	-410.22	-559.60
4.66	212.58	118.56	-24063.00	1140.48	100.00%	-87.73	-429.19	-578.57

1. Volume based on computed relationship from "Stage Storage Curve"

2. Water Depth of 0' corresponds to Elevation of 207.92 NAVD88ft (installed elevation of upstream sensor)

3a - Downstream Water Elevation

Downstream Water Depth	Downstream Water Elevation (NAVD88, ft)
0.00	205.68
0.25	205.93
0.50	206.18
0.75	206.43
1.00	206.68
1.25	206.93
1.50	207.18
1.75	207.43
2.00	207.68
2.25	207.93
2.50	208.18
2.75	208.43
3.00	208.68
3.25	208.93
3.50	209.18
3.75	209.43
4.00	209.68
4.25	209.93
4.50	210.18
4.66	210.34
4.82	210.50
4.98	210.66

1. Based on downstream sensor invert elevation of 205.683 NAVD88ft from 8/15/2017 field measurements at 3:30pm

4a. Discharge Calculations [revised to reflect updated elevations]

Upstream Water Depth (ft)	Upstream Water Elevation (NAVD88, ft)	Weir Width - b (ft)	Discharge Coefficient - Cs	Estimated Discharge - Max. Config. - Q (cfs)	Estimated Discharge - Six Stop Logs - Q (cfs)	Estimated Discharge - Five Stop Logs - Q (cfs)	Estimated Discharge - Four Stop Logs - Q (cfs)	Estimated Discharge - Three Stop Logs (Summer) - Q (cfs)	Estimated Discharge - Two Stop Logs - Q (cfs)	Estimated Discharge - One Stop Log (Winter) - Q (cfs)
0.00	207.92	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.00	2.24
0.05	207.97	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.00	3.03
0.10	208.02	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.00	3.90
0.15	208.07	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.00	4.85
0.20	208.12	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.00	5.86
0.25	208.17	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.00	6.93
0.30	208.22	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.03	8.06
0.35	208.27	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.33	9.24
0.40	208.32	6.42	3.33	0.00	0.00	0.00	0.00	0.00	0.80	10.48
0.45	208.37	6.42	3.33	0.00	0.00	0.00	0.00	0.00	1.39	11.77
0.50	208.42	6.42	3.33	0.00	0.00	0.00	0.00	0.00	2.09	13.11
0.55	208.47	6.42	3.33	0.00	0.00	0.00	0.00	0.00	2.87	14.49
0.60	208.52	6.42	3.33	0.00	0.00	0.00	0.00	0.00	3.72	15.93
0.65	208.57	6.42	3.33	0.00	0.00	0.00	0.00	0.00	4.65	17.40
0.70	208.62	6.42	3.33	0.00	0.00	0.00	0.00	0.00	5.65	18.92
0.75	208.67	6.42	3.33	0.00	0.00	0.00	0.00	0.00	6.71	20.48
0.80	208.72	6.42	3.33	0.00	0.00	0.00	0.00	0.00	7.83	22.08
0.85	208.77	6.42	3.33	0.00	0.00	0.00	0.00	0.00	9.00	23.72
0.90	208.82	6.42	3.33	0.00	0.00	0.00	0.00	0.00	10.23	25.40
0.95	208.87	6.42	3.33	0.00	0.00	0.00	0.00	0.00	11.51	27.11
1.00	208.92	6.42	3.33	0.00	0.00	0.00	0.00	0.00	12.84	28.87
1.05	208.97	6.42	3.33	0.00	0.00	0.00	0.00	0.03	14.21	30.66
1.10	209.02	6.42	3.33	0.00	0.00	0.00	0.00	0.33	15.64	32.48
1.15	209.07	6.42	3.33	0.00	0.00	0.00	0.00	0.80	17.10	34.34
1.20	209.12	6.42	3.33	0.00	0.00	0.00	0.00	1.39	18.61	36.23
1.25	209.17	6.42	3.33	0.00	0.00	0.00	0.00	2.09	20.16	38.16
1.30	209.22	6.42	3.33	0.00	0.00	0.00	0.00	2.87	21.75	40.12
1.35	209.27	6.42	3.33	0.00	0.00	0.00	0.00	3.72	23.39	42.12
1.40	209.32	6.42	3.33	0.00	0.00	0.00	0.00	4.65	25.06	44.14
1.45	209.37	6.42	3.33	0.00	0.00	0.00	0.00	5.65	26.77	46.20
1.50	209.42	6.42	3.33	0.00	0.00	0.00	0.00	6.71	28.51	48.29
1.55	209.47	6.42	3.33	0.00	0.00	0.00	0.00	7.83	30.29	50.40
1.60	209.52	6.42	3.33	0.00	0.00	0.00	0.00	9.00	32.11	52.55
1.65	209.57	6.42	3.33	0.00	0.00	0.00	0.00	10.23	33.97	54.73
1.70	209.62	6.42	3.33	0.00	0.00	0.00	0.00	11.51	35.85	56.94
1.75	209.67	6.42	3.33	0.00	0.00	0.00	0.00	12.84	37.77	59.17
1.80	209.72	6.42	3.33	0.00	0.00	0.00	0.03	14.21	39.73	61.44
1.85	209.77	6.42	3.33	0.00	0.00	0.00	0.33	15.64	41.72	63.73
1.90	209.82	6.42	3.33	0.00	0.00	0.00	0.80	17.10	43.73	66.05
1.95	209.87	6.42	3.33	0.00	0.00	0.00	1.39	18.61	45.78	68.40
2.00	209.92	6.42	3.33	0.00	0.00	0.00	2.09	20.16	47.87	70.78
2.05	209.97	6.42	3.33	0.00	0.00	0.00	2.87	21.75	49.98	73.18
2.10	210.02	6.42	3.33	0.00	0.00	0.00	3.72	23.39	52.12	75.61
2.15	210.07	6.42	3.33	0.00	0.00	0.00	4.65	25.06	54.29	78.06
2.20	210.12	6.42	3.33	0.00	0.00	0.00	5.65	26.77	56.49	80.54
2.25	210.17	6.42	3.33	0.00	0.00	0.00	6.71	28.51	58.73	83.05
2.30	210.22	6.42	3.33	0.00	0.00	0.00	7.83	30.29	60.98	85.58
2.35	210.27	6.42	3.33	0.00	0.00	0.00	9.00	32.11	63.27	88.14
2.40	210.32	6.42	3.33	0.00	0.00	0.00	10.23	33.97	65.59	90.72
2.45	210.37	6.42	3.33	0.00	0.00	0.00	11.51	35.85	67.93	93.33
2.50	210.42	6.42	3.33	0.00	0.00	0.00	12.84	37.77	70.30	95.96
2.55	210.47	6.42	3.33	0.00	0.00	0.03	14.21	39.73	72.70	98.62
2.60	210.52	6.42	3.33	0.00	0.00	0.33	15.64	41.72	75.12	101.30
2.65	210.57	6.42	3.33	0.00	0.00	0.80	17.10	43.73	77.57	104.00
2.70	210.62	6.42	3.33	0.00	0.00	1.39	18.61	45.78	80.05	106.73
2.75	210.67	6.42	3.33	0.00	0.00	2.09	20.16	47.87	82.55	109.48
2.80	210.72	6.42	3.33	0.00	0.00	2.87	21.75	49.98	85.08	112.26
2.85	210.77	6.42	3.33	0.00	0.00	3.72	23.39	52.12	87.63	115.06
2.90	210.82	6.42	3.33	0.00	0.00	4.65	25.06	54.29	90.21	117.88
2.95	210.87	6.42	3.33	0.00	0.00	5.65	26.77	56.49	92.81	120.72
3.00	210.92	6.42	3.33	0.00	0.00	6.71	28.51	58.73	95.44	123.58
3.05	210.97	6.42	3.33	0.00	0.00	7.83	30.29	60.98	98.09	126.47
3.10	211.02	6.42	3.33	0.00	0.00	9.00	32.11	63.27	100.76	129.38
3.15	211.07	6.42	3.33	0.00	0.00	10.23	33.97	65.59	103.46	132.31
3.20	211.12	6.42	3.33	0.00	0.00	11.51	35.85	67.93	106.19	135.27
3.25	211.17	6.42	3.33	0.00	0.00	12.84	37.77	70.30	108.93	138.24
3.30	211.22	6.42	3.33	0.00	0.03	14.21	39.73	72.70	111.70	141.24
3.35	211.27	6.42	3.33	0.00	0.33	15.64	41.72	75.12	114.49	144.26
3.40	211.32	6.42	3.33	0.00	0.80	17.10	43.73	77.57	117.31	147.30
3.45	211.37	6.42	3.33	0.00	1.39	18.61	45.78	80.05	120.15	150.36
3.50	211.42	6.42	3.33	0.00	2.09	20.16	47.87	82.55	123.01	153.44
3.55	211.47	6.42	3.33	0.00	2.87	21.75	49.98	85.08	125.89	156.54
3.60	211.52	6.42	3.33	0.00	3.72	23.39	52.12	87.63	128.80	159.67
3.65	211.57	6.42	3.33	0.00	4.65	25.06	54.29	90.21	131.73	162.81
3.70	211.62	6.42	3.33	0.00	5.65	26.77	56.49	92.81	134.68	165.97
3.75	211.67	6.42	3.33	0.00	6.71	28.51	58.73	95.44	137.65	169.16
3.80	211.72	6.42	3.33	0.00	7.83	30.29	60.98	98.09	140.64	172.36
3.85	211.77	6.42	3.33	0.00	9.00	32.11	63.27	100.76	143.65	175.59
3.90	211.82	6.42	3.33	0.00	10.23	33.97	65.59	103.46	146.69	178.83
3.95	211.87	6.42	3.33	0.12	11.51	35.85	67.93	106.19	149.75	182.09
4.00	211.92	6.42	3.33	0.50	12.84	37.77	70.30	108.93	152.82	185.38
4.05	211.97	6.42	3.33	1.02	14.21	39.73	72.70	111.70	155.92	188.68
4.10	212.02	6.42	3.33	1.66	15.64	41.72	75.12	114.49	159.04	192.00
4.15	212.07	6.42	3.33	2.39	17.10	43.73	77.57	117.31	162.18	195.34
4.20	212.12	6.42	3.33	3.20	18.61	45.78	80.05	120.15	165.34	198.70
4.25	212.17	6.42	3.33	4.09	20.16	47.87	82.55	123.01	168.52	202.08
4.30	212.22	6.42	3.33	5.05	21.75	49.98	85.08	125.89	171.72	205.48
4.35	212.27	6.42	3.33	6.07	23.39	52.12	87.63	128.80	174.94	208.90
4.40	212.32	6.42	3.33	7.15	25.06	54.29	90.21	131.73	178.18	212.33
4.45	212.37	6.42	3.33	8.29	26.77	56.49	92.81	134.68	181.44	215.79
4.50	212.42	6.42	3.33	9.49	28.51	58.73	95.44	137.65	184.72	219.26
4.55	212.47	6.42	3.33	10.74	30.29	60.98	98.09	140.64	188.02	222.75
4.60	212.52	6.42	3.33	12.04	32.11	63.27	100.76	143.65	191.33	226.26
4.65	212.57	6.42	3.33	13.38	33.97	65.59	103.46	146.69	194.67	229.79
4.70	212.62	6.42	3.33	14.78	35.85	67.93	106.19	149.75	198.03	233.34
4.75	212.67	6.42	3.33	16.22	37.77	70.30	108.93	152.82	201.41	236.90
4.80	212.72	6.42	3.33	17.70	39.73	72.70	111.70	155.92	204.80	240.49
4.85	212.77	6.42	3.33	19.23	41.72	75.12	114.49	159.04	208.21	244.09
4.90	212.82	6.42	3.33	20.79	43.73	77.57	117.31	162.18	211.65	247.71
4.95	212.87	6.42	3.33	22.40	45.78	80.05	120.15	165.34	215.10	251.34
5.00	212.92	6.42	3.33	24.05	47.87	82.55	123.01	168.52	218.57	254.99
5.05	212.97	6.42	3.33	25.74	49.98	85.08	125.89	171.72	222.05	258.67
5.10	213.02	6.42	3.33	27.46	52.12	87.63	128.80	174.94	225.56	262.35
5.15	213.07	6.42	3.33	29.22	54.29	90.21	131.73	178.18	229.09	266.06
5.20	213.12	6.42	3.33	31.02	56.49	92.81	134.68	181.44	232.63	269.78
5.25	213.17	6.42	3.33	32.85	58.73	95.44	137.65	184.72	236.19	273.52
5.30	213.22	6.42	3.33	34.72	60.98	98.09	140.64	188.02	239.77	277.28
5.35	213.27	6.42	3.33	36.62	63.27	100.76	143.65	191.33	243.37	281.06
5.40	213.32	6.42	3.33	38.55	65.59	103.46	146.69	194.67	246.98	284.85
5.45	213.37	6.42	3.33	40.52	67.93	106.19	149.75	198.03	250.61	288.66
5.50	213.42	6.42	3.33	42.52	70.30	108.93	152.82	201.41	254.26	292.48

1. Measured Depth at 0' corresponds to Elevation of 207.922' (invert elevation of upstream sensor as measured on 8/15/2017)

2.Discharge computed from Weir equation - $Q = Cs \cdot b \cdot H^{3/2}$

Appendix F

STRMDELP08 Data

STRMDEPL08 Well Inputs and Maximum Daily Pump Rates

Town	Well Name	Well ID	Distance to Surface Water Body (ft)	Transmissivity (ft2/day)	Storage Coefficient	Diffusivity (ft2/s)	Maximum Daily Pump Rate (MGD)
Littleton	Whitcomb Avenue #3/4	2158000-01G	149	17142	0.215	0.923	0.864
	Whitcomb Avenue #1	2158000-02G	80	17142	0.215	0.923	
	Beaver Brook Wellfield	2158000-05G	617	8288	0.282	0.340	0.648
		2158000-06G	592				
		2158000-07G	609				
	Spectacle Pond	2158000-04G	182	34560	0.014	28.571	0.936
Westford	Forge Village Wellfield	3330000-01G	1191	11500	0.050	2.662	0.34
		3330000-09G	1277				
		3330000-10G	1230				
		3330000-11G	1174				
		3330000-12G	1054				
	Nutting Satellites	3330000-17G	4513	7134	0.068	1.214	0.648
		3330000-18G	4597				
	Depot Road	3330000-03G	2481	8818	0.068	1.501	0.72
	Forge Village 2	3330000-05G	907	11500	0.050	2.662	0.59
	Howard Wellfield	3330000-06G	859	4000	0.068	0.681	0.43
		3330000-13G	684				
		3330000-14G	737				
		3330000-15G	785				
		3330000-16G	871				
	Cote	3330000-07G	758	5681	0.100	0.658	0.648
	Fletcher	3330000-08G	440	8818	0.068	1.501	0.69
	Stepinski	3330000-20G	143	21790	0.140	1.801	1.22
	Country Road 2	3330000-19G	1842	9358	0.090	1.203	0.61

Notes:

1. Diffusivity was calculated by dividing the transmissivity by the storage coefficient of an aquifer near the well.
2. If aquifer data was missing for a Littleton well, the average value of that variable of the other Littleton wells was used. These wells are highlighted in the table.
3. If aquifer data was missing for a Westford well, the average value of that variable of the other Westford wells was used. These wells are highlighted in the table.
4. It was assumed that each well within a wellfield would have the same transmissivity and storage coefficient values.
5. For wellfields, the average distance from each well to the closest surface water body was used as the input.

Abbreviations:

ft: feet

MGD: million gallons per day

s: second

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.928	0.913	0.278	0.305	0.000	0.183	0.250	0.185
1/2/18	0.943	0.931	0.801	0.786	0.185	0.173	0.250	0.189
1/3/18	0.000	0.052	0.000	0.043	0.195	0.171	0.147	0.192
1/4/18	0.000	0.035	0.000	0.030	0.191	0.173	0.134	0.189
1/5/18	0.000	0.028	0.000	0.025	0.192	0.175	0.135	0.184
1/6/18	0.000	0.024	0.000	0.022	0.197	0.176	0.144	0.180
1/7/18	0.000	0.021	0.000	0.019	0.196	0.178	0.138	0.176
1/8/18	0.686	0.660	0.573	0.554	0.194	0.179	0.250	0.175
1/9/18	0.935	0.905	0.850	0.821	0.202	0.180	0.250	0.179
1/10/18	1.196	1.158	1.098	1.062	0.197	0.182	0.250	0.184
1/11/18	1.300	1.265	1.190	1.158	0.195	0.182	0.250	0.189
1/12/18	0.000	0.056	0.000	0.052	0.204	0.183	0.165	0.193
1/13/18	0.000	0.035	0.000	0.033	0.198	0.184	0.148	0.191
1/14/18	0.000	0.027	0.000	0.025	0.195	0.184	0.144	0.187
1/15/18	0.000	0.023	0.000	0.021	0.196	0.185	0.148	0.182
1/16/18	0.000	0.020	0.000	0.019	0.196	0.185	0.147	0.179
1/17/18	0.000	0.018	0.000	0.017	0.195	0.185	0.143	0.176
1/18/18	1.350	1.278	1.246	1.180	0.197	0.185	0.250	0.175
1/19/18	1.364	1.316	1.255	1.211	0.194	0.185	0.250	0.179
1/20/18	1.367	1.330	1.271	1.236	0.200	0.186	0.250	0.185
1/21/18	1.383	1.350	1.271	1.242	0.195	0.186	0.250	0.190
1/22/18	1.362	1.335	1.258	1.234	0.195	0.186	0.250	0.194
1/23/18	1.381	1.356	1.272	1.249	0.193	0.186	0.250	0.197
1/24/18	1.400	1.376	1.296	1.274	0.199	0.186	0.250	0.200
1/25/18	1.316	1.299	1.210	1.195	0.197	0.186	0.250	0.202
1/26/18	1.393	1.372	1.298	1.278	0.200	0.187	0.250	0.205
1/27/18	0.000	0.072	0.000	0.067	0.196	0.187	0.144	0.205
1/28/18	0.000	0.046	0.000	0.043	0.193	0.187	0.143	0.200
1/29/18	1.354	1.302	1.247	1.199	0.195	0.187	0.250	0.195
1/30/18	1.396	1.360	1.280	1.248	0.193	0.187	0.250	0.197
1/31/18	0.000	0.063	0.000	0.059	0.194	0.187	0.146	0.199
2/1/18	1.379	1.331	1.272	1.227	0.195	0.186	0.250	0.196
2/2/18	1.396	1.363	1.291	1.261	0.197	0.187	0.250	0.198
2/3/18	0.000	0.065	0.000	0.060	0.193	0.187	0.137	0.200
2/4/18	0.000	0.042	0.000	0.039	0.195	0.187	0.148	0.196
2/5/18	1.351	1.295	1.239	1.189	0.193	0.187	0.250	0.192
2/6/18	1.392	1.355	1.273	1.239	0.191	0.187	0.250	0.194
2/7/18	1.401	1.371	1.310	1.281	0.198	0.186	0.250	0.198
2/8/18	1.335	1.314	1.241	1.222	0.199	0.187	0.250	0.201
2/9/18	1.399	1.376	1.296	1.275	0.202	0.187	0.250	0.204
2/10/18	0.000	0.071	0.000	0.066	0.200	0.187	0.143	0.205
2/11/18	0.000	0.046	0.000	0.043	0.200	0.188	0.161	0.201
2/12/18	1.459	1.399	1.351	1.297	0.196	0.188	0.250	0.197
2/13/18	1.477	1.438	1.371	1.335	0.196	0.188	0.250	0.199
2/14/18	0.417	0.456	0.311	0.353	0.197	0.188	0.250	0.202
2/15/18	1.375	1.336	1.264	1.228	0.192	0.188	0.250	0.204
2/16/18	0.000	0.063	0.000	0.058	0.196	0.188	0.137	0.206
2/17/18	0.000	0.042	0.000	0.038	0.197	0.188	0.148	0.201
2/18/18	0.000	0.033	0.000	0.030	0.194	0.188	0.146	0.195
2/19/18	0.000	0.028	0.000	0.026	0.199	0.188	0.156	0.191
2/20/18	1.317	1.255	1.195	1.140	0.195	0.188	0.250	0.188

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	1.393	1.349	0.743	0.737	0.000	0.186	0.250	0.191
2/22/18	1.337	1.307	1.200	1.165	0.184	0.176	0.250	0.196
2/23/18	1.439	1.408	1.336	1.301	0.190	0.173	0.250	0.200
2/24/18	0.000	0.067	0.000	0.059	0.198	0.175	0.152	0.202
2/25/18	0.000	0.043	0.000	0.038	0.198	0.177	0.153	0.198
2/26/18	1.354	1.299	1.261	1.208	0.197	0.179	0.250	0.195
2/27/18	1.395	1.358	1.300	1.264	0.201	0.180	0.250	0.197
2/28/18	1.342	1.317	1.243	1.219	0.197	0.182	0.250	0.200
3/1/18	1.395	1.370	1.293	1.269	0.199	0.183	0.250	0.203
3/2/18	0.000	0.069	0.000	0.064	0.193	0.183	0.134	0.205
3/3/18	0.000	0.045	0.000	0.041	0.194	0.184	0.140	0.200
3/4/18	1.282	1.233	1.187	1.141	0.199	0.184	0.250	0.195
3/5/18	1.378	1.342	1.267	1.234	0.195	0.185	0.250	0.197
3/6/18	1.302	1.279	1.187	1.167	0.194	0.185	0.250	0.200
3/7/18	0.000	0.065	0.000	0.060	0.197	0.185	0.158	0.202
3/8/18	0.000	0.043	0.000	0.039	0.194	0.185	0.135	0.199
3/9/18	0.000	0.033	0.000	0.031	0.196	0.185	0.150	0.194
3/10/18	0.000	0.028	0.000	0.026	0.196	0.186	0.141	0.189
3/11/18	0.000	0.024	0.000	0.022	0.196	0.186	0.141	0.185
3/12/18	1.413	1.343	1.302	1.237	0.196	0.186	0.250	0.183
3/13/18	0.000	0.047	0.000	0.043	0.199	0.186	0.160	0.186
3/14/18	0.000	0.030	0.000	0.028	0.190	0.186	0.127	0.185
3/15/18	0.000	0.024	0.000	0.022	0.198	0.186	0.149	0.181
3/16/18	0.000	0.021	0.000	0.019	0.192	0.186	0.140	0.178
3/17/18	0.000	0.019	0.000	0.017	0.193	0.186	0.147	0.176
3/18/18	0.000	0.017	0.000	0.016	0.193	0.186	0.131	0.174
3/19/18	0.000	0.016	0.000	0.015	0.195	0.186	0.148	0.171
3/20/18	0.000	0.015	0.000	0.014	0.188	0.186	0.126	0.170
3/21/18	1.352	1.279	0.702	0.670	0.000	0.184	0.250	0.169
3/22/18	1.397	1.346	0.747	0.725	0.000	0.172	0.250	0.174
3/23/18	0.000	0.051	0.000	0.032	0.000	0.158	0.000	0.178
3/24/18	0.000	0.031	0.000	0.021	0.000	0.147	0.000	0.168
3/25/18	0.000	0.024	0.000	0.017	0.000	0.137	0.000	0.155
3/26/18	0.000	0.020	0.000	0.015	0.000	0.128	0.000	0.144
3/27/18	0.000	0.017	0.000	0.014	0.000	0.121	0.000	0.134
3/28/18	1.381	1.306	0.731	0.696	0.000	0.115	0.250	0.129
3/29/18	1.377	1.328	0.727	0.705	0.000	0.109	0.250	0.137
3/30/18	0.000	0.051	0.000	0.031	0.000	0.105	0.000	0.146
3/31/18	0.000	0.031	0.000	0.021	0.000	0.100	0.000	0.141
4/1/18	1.308	1.247	0.658	0.632	0.000	0.097	0.250	0.135
4/2/18	1.099	1.072	0.909	0.877	0.165	0.095	0.250	0.141
4/3/18	1.298	1.263	1.178	1.137	0.197	0.102	0.250	0.152
4/4/18	1.377	1.343	1.261	1.225	0.198	0.113	0.250	0.161
4/5/18	0.000	0.061	0.000	0.052	0.198	0.123	0.132	0.167
4/6/18	0.000	0.039	0.000	0.032	0.193	0.131	0.123	0.166
4/7/18	0.000	0.029	0.000	0.024	0.197	0.137	0.124	0.163
4/8/18	0.000	0.024	0.000	0.020	0.197	0.143	0.125	0.159
4/9/18	0.000	0.021	0.000	0.017	0.197	0.148	0.132	0.157
4/10/18	0.000	0.019	0.000	0.015	0.194	0.151	0.126	0.155
4/11/18	0.000	0.017	0.000	0.014	0.197	0.155	0.126	0.153
4/12/18	0.935	0.890	0.813	0.773	0.195	0.157	0.250	0.153

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.921	0.893	0.801	0.776	0.199	0.160	0.250	0.159
4/14/18	0.925	0.903	0.803	0.784	0.195	0.162	0.250	0.167
4/15/18	0.917	0.901	0.791	0.776	0.192	0.164	0.250	0.174
4/16/18	0.977	0.958	0.869	0.851	0.202	0.165	0.250	0.179
4/17/18	0.000	0.048	0.000	0.042	0.200	0.167	0.137	0.183
4/18/18	0.000	0.031	0.000	0.027	0.192	0.169	0.122	0.179
4/19/18	0.000	0.024	0.000	0.021	0.195	0.170	0.130	0.174
4/20/18	0.000	0.020	0.000	0.018	0.194	0.171	0.121	0.169
4/21/18	0.000	0.018	0.000	0.016	0.195	0.171	0.126	0.165
4/22/18	0.000	0.016	0.000	0.014	0.196	0.172	0.124	0.162
4/23/18	0.000	0.015	0.000	0.013	0.201	0.173	0.138	0.159
4/24/18	0.000	0.014	0.000	0.012	0.194	0.174	0.123	0.158
4/25/18	0.000	0.013	0.000	0.011	0.000	0.173	0.000	0.154
4/26/18	0.912	0.864	1.178	1.112	0.404	0.166	0.250	0.148
4/27/18	0.000	0.029	0.336	0.347	0.439	0.178	0.250	0.153
4/28/18	0.000	0.019	0.338	0.342	0.439	0.196	0.250	0.161
4/29/18	0.000	0.015	0.342	0.345	0.446	0.214	0.250	0.169
4/30/18	0.819	0.779	1.158	1.107	0.441	0.230	0.250	0.175
5/1/18	0.000	0.028	0.342	0.359	0.441	0.242	0.250	0.181
5/2/18	0.000	0.018	0.348	0.356	0.444	0.253	0.250	0.185
5/3/18	0.000	0.015	0.324	0.331	0.431	0.262	0.250	0.189
5/4/18	0.000	0.013	0.335	0.339	0.434	0.270	0.250	0.192
5/5/18	0.000	0.012	0.338	0.342	0.439	0.276	0.250	0.195
5/6/18	0.000	0.011	0.337	0.341	0.444	0.283	0.250	0.197
5/7/18	0.000	0.010	0.320	0.324	0.433	0.288	0.250	0.199
5/8/18	0.000	0.010	0.000	0.025	0.000	0.288	0.000	0.199
5/9/18	0.882	0.834	0.232	0.235	0.000	0.266	0.250	0.188
5/10/18	1.210	1.157	0.560	0.543	0.000	0.239	0.250	0.187
5/11/18	1.393	1.341	0.743	0.720	0.000	0.216	0.250	0.191
5/12/18	1.369	1.330	0.719	0.705	0.000	0.197	0.250	0.194
5/13/18	0.000	0.055	0.000	0.035	0.000	0.181	0.000	0.195
5/14/18	0.000	0.033	0.000	0.023	0.000	0.168	0.000	0.182
5/15/18	1.363	1.298	0.713	0.684	0.000	0.156	0.250	0.170
5/16/18	1.404	1.358	0.754	0.734	0.000	0.147	0.250	0.172
5/17/18	1.364	1.331	0.714	0.702	0.000	0.138	0.250	0.178
5/18/18	1.405	1.373	0.755	0.742	0.000	0.131	0.250	0.184
5/19/18	0.000	0.063	0.000	0.038	0.000	0.124	0.000	0.186
5/20/18	1.410	1.357	0.760	0.735	0.000	0.119	0.250	0.177
5/21/18	1.375	1.342	0.725	0.712	0.000	0.114	0.250	0.179
5/22/18	1.380	1.352	0.730	0.719	0.000	0.109	0.250	0.184
5/23/18	1.409	1.382	1.303	1.256	0.197	0.107	0.250	0.188
5/24/18	1.380	1.358	1.315	1.280	0.216	0.115	0.250	0.193
5/25/18	1.412	1.390	1.354	1.322	0.219	0.127	0.250	0.196
5/26/18	0.000	0.071	0.000	0.061	0.220	0.137	0.194	0.198
5/27/18	0.000	0.046	0.000	0.038	0.222	0.146	0.198	0.197
5/28/18	0.000	0.035	0.000	0.028	0.218	0.153	0.191	0.196
5/29/18	0.000	0.029	0.000	0.023	0.217	0.159	0.191	0.194
5/30/18	0.000	0.025	0.000	0.020	0.219	0.164	0.186	0.192
5/31/18	1.378	1.310	1.168	1.109	0.221	0.168	0.250	0.191
6/1/18	1.442	1.394	1.232	1.189	0.219	0.171	0.250	0.194
6/2/18	0.000	0.057	0.000	0.048	0.217	0.174	0.037	0.195

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	1.387	1.332	1.171	1.124	0.217	0.177	0.250	0.187
6/4/18	1.402	1.364	1.193	1.160	0.219	0.179	0.250	0.188
6/5/18	0.000	0.061	0.000	0.051	0.222	0.181	0.045	0.190
6/6/18	0.000	0.039	0.000	0.032	0.199	0.182	0.151	0.182
6/7/18	1.329	1.272	1.227	1.172	0.196	0.183	0.250	0.179
6/8/18	1.408	1.366	1.308	1.267	0.196	0.182	0.250	0.183
6/9/18	1.357	1.328	1.258	1.229	0.195	0.182	0.250	0.188
6/10/18	1.415	1.386	1.308	1.280	0.194	0.182	0.250	0.192
6/11/18	1.412	1.388	1.310	1.285	0.195	0.182	0.250	0.196
6/12/18	1.418	1.396	1.316	1.293	0.197	0.182	0.250	0.199
6/13/18	1.385	1.367	1.284	1.266	0.196	0.182	0.250	0.202
6/14/18	1.387	1.369	1.289	1.271	0.197	0.182	0.250	0.204
6/15/18	1.404	1.386	1.307	1.289	0.198	0.182	0.250	0.206
6/16/18	1.405	1.388	1.313	1.296	0.196	0.183	0.250	0.208
6/17/18	1.408	1.391	1.307	1.291	0.194	0.183	0.250	0.209
6/18/18	1.381	1.367	1.281	1.267	0.195	0.183	0.250	0.211
6/19/18	1.404	1.388	1.295	1.280	0.195	0.183	0.250	0.212
6/20/18	1.392	1.378	1.252	1.241	0.188	0.183	0.250	0.213
6/21/18	1.400	1.386	1.307	1.292	0.200	0.183	0.250	0.214
6/22/18	1.377	1.365	1.276	1.264	0.196	0.183	0.250	0.215
6/23/18	1.398	1.384	1.296	1.283	0.198	0.183	0.250	0.215
6/24/18	0.000	0.078	0.000	0.072	0.196	0.184	0.153	0.215
6/25/18	1.375	1.338	1.250	1.216	0.187	0.184	0.250	0.211
6/26/18	1.402	1.377	1.301	1.277	0.196	0.184	0.250	0.211
6/27/18	1.376	1.359	1.276	1.259	0.195	0.184	0.250	0.212
6/28/18	1.373	1.358	1.266	1.252	0.195	0.184	0.250	0.214
6/29/18	0.999	1.009	0.887	0.899	0.193	0.184	0.250	0.215
6/30/18	1.318	1.302	1.213	1.197	0.193	0.184	0.250	0.216
7/1/18	1.328	1.314	1.221	1.209	0.192	0.184	0.250	0.217
7/2/18	1.350	1.337	1.251	1.237	0.196	0.184	0.250	0.218
7/3/18	1.279	1.271	1.186	1.178	0.199	0.184	0.250	0.218
7/4/18	1.328	1.317	1.212	1.202	0.189	0.184	0.250	0.219
7/5/18	1.327	1.316	1.231	1.221	0.196	0.184	0.250	0.220
7/6/18	0.000	0.076	0.000	0.070	0.198	0.184	0.154	0.219
7/7/18	1.326	1.291	1.225	1.192	0.196	0.185	0.250	0.215
7/8/18	1.332	1.311	1.232	1.212	0.198	0.185	0.250	0.215
7/9/18	1.382	1.362	1.283	1.265	0.199	0.185	0.250	0.216
7/10/18	1.329	1.316	1.229	1.217	0.198	0.185	0.250	0.217
7/11/18	1.367	1.353	1.272	1.258	0.197	0.186	0.250	0.218
7/12/18	1.396	1.381	1.295	1.281	0.195	0.186	0.250	0.219
7/13/18	1.402	1.388	1.302	1.289	0.196	0.186	0.250	0.220
7/14/18	1.413	1.400	1.318	1.305	0.198	0.186	0.250	0.221
7/15/18	1.342	1.334	1.235	1.228	0.193	0.186	0.250	0.221
7/16/18	1.431	1.417	1.334	1.320	0.196	0.186	0.250	0.222
7/17/18	1.354	1.346	1.252	1.245	0.196	0.186	0.250	0.222
7/18/18	1.599	1.574	1.499	1.475	0.197	0.186	0.250	0.223
7/19/18	1.295	1.295	1.197	1.197	0.199	0.186	0.250	0.223
7/20/18	1.335	1.328	1.235	1.230	0.195	0.186	0.250	0.224
7/21/18	1.308	1.303	1.209	1.204	0.197	0.186	0.250	0.224
7/22/18	1.336	1.328	1.224	1.218	0.192	0.186	0.250	0.224
7/23/18	1.311	1.306	1.204	1.199	0.193	0.186	0.250	0.225

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.000	0.079	0.000	0.073	0.197	0.186	0.148	0.224
7/25/18	1.364	1.329	1.260	1.227	0.192	0.186	0.250	0.219
7/26/18	1.418	1.394	1.317	1.295	0.196	0.186	0.250	0.218
7/27/18	0.000	0.075	0.000	0.069	0.194	0.186	0.142	0.218
7/28/18	0.000	0.051	0.000	0.047	0.192	0.186	0.138	0.213
7/29/18	0.000	0.040	0.000	0.037	0.000	0.184	0.000	0.204
7/30/18	1.370	1.315	0.720	0.705	0.000	0.172	0.250	0.193
7/31/18	1.127	1.110	1.012	0.988	0.195	0.160	0.250	0.193
8/1/18	1.099	1.087	0.991	0.977	0.195	0.160	0.250	0.198
8/2/18	1.360	1.334	1.261	1.233	0.196	0.164	0.250	0.202
8/3/18	1.327	1.309	1.218	1.200	0.194	0.168	0.250	0.206
8/4/18	0.000	0.071	0.000	0.064	0.192	0.170	0.130	0.208
8/5/18	0.000	0.047	0.000	0.042	0.198	0.172	0.154	0.203
8/6/18	0.916	0.894	0.818	0.798	0.202	0.175	0.250	0.199
8/7/18	1.266	1.233	1.166	1.134	0.200	0.177	0.250	0.201
8/8/18	1.370	1.340	1.261	1.233	0.193	0.178	0.250	0.205
8/9/18	0.000	0.066	0.000	0.060	0.190	0.179	0.135	0.207
8/10/18	1.331	1.288	1.229	1.189	0.195	0.179	0.250	0.203
8/11/18	1.437	1.404	1.344	1.311	0.201	0.180	0.250	0.205
8/12/18	0.000	0.068	0.000	0.063	0.191	0.181	0.133	0.206
8/13/18	1.317	1.276	1.220	1.181	0.194	0.181	0.250	0.203
8/14/18	1.406	1.375	1.296	1.267	0.193	0.181	0.250	0.204
8/15/18	1.336	1.316	1.231	1.213	0.194	0.182	0.250	0.207
8/16/18	1.342	1.325	1.236	1.220	0.191	0.182	0.250	0.209
8/17/18	1.352	1.336	1.241	1.226	0.192	0.182	0.250	0.212
8/18/18	1.337	1.324	1.225	1.213	0.193	0.182	0.250	0.214
8/19/18	1.332	1.320	1.238	1.226	0.199	0.182	0.250	0.215
8/20/18	1.224	1.219	1.125	1.121	0.198	0.183	0.250	0.217
8/21/18	1.304	1.293	1.194	1.184	0.194	0.183	0.250	0.218
8/22/18	0.000	0.075	0.000	0.069	0.196	0.184	0.142	0.218
8/23/18	0.562	0.576	0.459	0.475	0.195	0.184	0.250	0.213
8/24/18	0.000	0.051	0.000	0.045	0.195	0.184	0.149	0.212
8/25/18	1.264	1.220	1.160	1.119	0.196	0.184	0.250	0.208
8/26/18	1.285	1.258	1.178	1.153	0.195	0.184	0.250	0.209
8/27/18	1.411	1.383	1.309	1.282	0.193	0.185	0.250	0.211
8/28/18	1.194	1.186	1.097	1.090	0.195	0.185	0.250	0.214
8/29/18	1.219	1.208	1.117	1.107	0.194	0.185	0.250	0.216
8/30/18	1.233	1.222	1.134	1.124	0.196	0.185	0.250	0.217
8/31/18	1.236	1.226	1.140	1.130	0.197	0.185	0.250	0.218
9/1/18	0.000	0.071	0.000	0.065	0.196	0.185	0.148	0.218
9/2/18	0.000	0.048	0.000	0.044	0.194	0.185	0.144	0.213
9/3/18	1.150	1.113	1.042	1.010	0.195	0.185	0.250	0.208
9/4/18	1.216	1.191	1.108	1.086	0.192	0.185	0.250	0.208
9/5/18	1.226	1.208	1.127	1.110	0.197	0.185	0.250	0.211
9/6/18	1.214	1.200	1.117	1.103	0.198	0.185	0.250	0.213
9/7/18	1.275	1.259	1.171	1.156	0.195	0.186	0.250	0.215
9/8/18	1.263	1.250	1.158	1.146	0.194	0.186	0.250	0.217
9/9/18	0.142	0.203	0.032	0.095	0.195	0.186	0.250	0.218
9/10/18	1.281	1.248	1.157	1.126	0.213	0.186	0.250	0.219
9/11/18	0.000	0.063	0.000	0.057	0.245	0.187	0.153	0.219
9/12/18	0.000	0.043	0.000	0.039	0.240	0.191	0.153	0.214

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	1.265	1.217	1.163	1.119	0.242	0.194	0.250	0.209
9/14/18	1.301	1.270	1.193	1.165	0.237	0.196	0.250	0.210
9/15/18	0.000	0.062	0.000	0.057	0.235	0.198	0.144	0.211
9/16/18	1.199	1.162	1.106	1.071	0.246	0.200	0.250	0.208
9/17/18	1.295	1.266	1.199	1.172	0.242	0.202	0.250	0.209
9/18/18	1.273	1.253	1.157	1.140	0.234	0.203	0.250	0.212
9/19/18	0.000	0.066	0.000	0.061	0.233	0.204	0.134	0.213
9/20/18	0.000	0.044	0.000	0.040	0.232	0.205	0.128	0.207
9/21/18	0.000	0.035	0.000	0.032	0.238	0.205	0.139	0.201
9/22/18	0.000	0.029	0.000	0.027	0.237	0.206	0.141	0.195
9/23/18	0.000	0.026	0.000	0.024	0.237	0.207	0.141	0.191
9/24/18	1.409	1.341	1.303	1.240	0.239	0.208	0.250	0.188
9/25/18	1.432	1.387	1.326	1.284	0.239	0.208	0.250	0.192
9/26/18	0.000	0.059	0.000	0.054	0.235	0.209	0.142	0.196
9/27/18	0.000	0.038	0.000	0.035	0.237	0.210	0.138	0.194
9/28/18	0.000	0.030	0.000	0.027	0.236	0.210	0.138	0.189
9/29/18	0.000	0.025	0.000	0.023	0.238	0.210	0.140	0.186
9/30/18	0.000	0.022	0.000	0.020	0.236	0.211	0.143	0.182
10/1/18	0.881	0.844	0.768	0.737	0.236	0.211	0.250	0.181
10/2/18	0.877	0.856	0.758	0.741	0.236	0.211	0.250	0.185
10/3/18	1.320	1.275	0.670	0.663	0.000	0.209	0.250	0.191
10/4/18	1.390	1.352	1.244	1.201	0.168	0.197	0.250	0.196
10/5/18	0.000	0.061	0.000	0.050	0.233	0.192	0.131	0.199
10/6/18	1.374	1.323	1.262	1.212	0.238	0.193	0.250	0.196
10/7/18	1.368	1.335	1.258	1.225	0.238	0.196	0.250	0.198
10/8/18	0.000	0.063	0.000	0.056	0.240	0.199	0.145	0.200
10/9/18	0.000	0.040	0.000	0.036	0.240	0.202	0.145	0.197
10/10/18	1.422	1.360	1.312	1.254	0.239	0.204	0.250	0.193
10/11/18	1.455	1.414	1.350	1.310	0.242	0.206	0.250	0.196
10/12/18	0.000	0.063	0.000	0.057	0.240	0.207	0.147	0.198
10/13/18	0.000	0.040	0.000	0.036	0.236	0.209	0.144	0.196
10/14/18	0.000	0.031	0.000	0.028	0.238	0.209	0.144	0.191
10/15/18	0.000	0.026	0.000	0.024	0.240	0.210	0.142	0.187
10/16/18	1.330	1.266	1.226	1.167	0.239	0.211	0.250	0.185
10/17/18	1.361	1.318	1.228	1.190	0.228	0.212	0.250	0.188
10/18/18	0.000	0.056	0.000	0.051	0.224	0.211	0.118	0.192
10/19/18	0.000	0.036	0.000	0.032	0.241	0.211	0.144	0.188
10/20/18	0.000	0.028	0.000	0.025	0.240	0.212	0.142	0.185
10/21/18	0.000	0.023	0.000	0.021	0.239	0.212	0.142	0.181
10/22/18	1.340	1.274	1.229	1.167	0.237	0.213	0.250	0.180
10/23/18	1.352	1.308	1.241	1.201	0.237	0.214	0.250	0.184
10/24/18	1.198	1.174	1.069	1.049	0.227	0.214	0.250	0.189
10/25/18	0.000	0.057	0.000	0.052	0.233	0.214	0.138	0.193
10/26/18	0.000	0.037	0.000	0.033	0.240	0.214	0.142	0.190
10/27/18	0.000	0.028	0.000	0.026	0.230	0.214	0.131	0.186
10/28/18	0.000	0.024	0.000	0.022	0.196	0.214	0.052	0.181
10/29/18	1.318	1.253	1.151	1.095	0.208	0.212	0.250	0.174
10/30/18	1.331	1.288	1.216	1.176	0.234	0.210	0.250	0.177
10/31/18	1.338	1.305	1.232	1.200	0.237	0.210	0.250	0.183
11/1/18	0.000	0.059	0.000	0.054	0.236	0.211	0.142	0.188
11/2/18	0.000	0.038	0.000	0.034	0.238	0.212	0.143	0.186

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.000	0.029	0.000	0.026	0.231	0.213	0.129	0.182
11/4/18	1.312	1.251	1.193	1.137	0.236	0.213	0.250	0.179
11/5/18	1.337	1.296	1.234	1.196	0.240	0.214	0.250	0.183
11/6/18	0.000	0.055	0.000	0.051	0.244	0.214	0.151	0.187
11/7/18	1.336	1.284	1.228	1.180	0.237	0.215	0.250	0.187
11/8/18	1.353	1.317	1.245	1.212	0.238	0.216	0.250	0.190
11/9/18	0.000	0.060	0.000	0.055	0.241	0.216	0.143	0.193
11/10/18	0.000	0.038	0.000	0.035	0.237	0.217	0.150	0.190
11/11/18	0.000	0.030	0.000	0.027	0.000	0.214	0.000	0.185
11/12/18	1.302	1.242	0.652	0.632	0.000	0.200	0.250	0.175
11/13/18	1.342	1.301	0.692	0.679	0.000	0.183	0.250	0.177
11/14/18	1.385	1.351	0.735	0.723	0.000	0.169	0.250	0.183
11/15/18	0.000	0.062	0.000	0.039	0.000	0.157	0.000	0.186
11/16/18	0.000	0.039	0.000	0.027	0.000	0.147	0.000	0.175
11/17/18	0.000	0.030	0.000	0.022	0.000	0.138	0.000	0.162
11/18/18	1.339	1.277	0.689	0.663	0.000	0.130	0.250	0.152
11/19/18	1.343	1.303	1.217	1.168	0.226	0.126	0.250	0.157
11/20/18	0.000	0.057	0.000	0.044	0.238	0.135	0.137	0.165
11/21/18	0.000	0.036	0.000	0.028	0.240	0.146	0.144	0.166
11/22/18	0.000	0.028	0.000	0.022	0.238	0.157	0.135	0.165
11/23/18	0.000	0.023	0.000	0.019	0.237	0.165	0.135	0.164
11/24/18	0.000	0.021	0.000	0.016	0.000	0.169	0.000	0.161
11/25/18	0.000	0.019	0.000	0.015	0.000	0.160	0.000	0.151
11/26/18	1.332	1.263	1.207	1.142	0.233	0.151	0.250	0.143
11/27/18	0.000	0.041	0.000	0.036	0.241	0.154	0.147	0.148
11/28/18	1.335	1.274	1.228	1.171	0.237	0.162	0.250	0.152
11/29/18	1.328	1.287	1.217	1.179	0.238	0.169	0.250	0.160
11/30/18	1.342	1.309	1.236	1.204	0.238	0.175	0.250	0.168
12/1/18	0.000	0.060	0.000	0.054	0.235	0.180	0.138	0.174
12/2/18	0.000	0.037	0.000	0.033	0.237	0.183	0.146	0.173
12/3/18	1.328	1.270	1.223	1.168	0.238	0.187	0.250	0.172
12/4/18	1.336	1.298	1.242	1.205	0.248	0.190	0.250	0.176
12/5/18	1.134	1.117	1.023	1.008	0.240	0.193	0.250	0.181
12/6/18	1.285	1.260	1.175	1.151	0.237	0.195	0.250	0.186
12/7/18	0.000	0.062	0.000	0.056	0.234	0.197	0.129	0.189
12/8/18	0.000	0.040	0.000	0.036	0.239	0.199	0.143	0.185
12/9/18	0.000	0.031	0.000	0.028	0.240	0.200	0.138	0.180
12/10/18	1.268	1.211	0.618	0.601	0.000	0.199	0.250	0.177
12/11/18	1.356	1.314	0.706	0.692	0.000	0.186	0.250	0.181
12/12/18	1.368	1.336	1.243	1.199	0.225	0.173	0.250	0.186
12/13/18	0.000	0.062	0.000	0.049	0.241	0.173	0.144	0.189
12/14/18	0.000	0.039	0.000	0.031	0.237	0.178	0.139	0.186
12/15/18	0.000	0.030	0.000	0.024	0.241	0.183	0.143	0.182
12/16/18	0.000	0.025	0.000	0.020	0.240	0.188	0.142	0.178
12/17/18	0.000	0.022	0.000	0.018	0.234	0.191	0.138	0.175
12/18/18	0.000	0.020	0.000	0.016	0.241	0.194	0.149	0.172
12/19/18	1.307	1.240	1.195	1.132	0.235	0.197	0.250	0.171
12/20/18	0.000	0.041	0.000	0.036	0.241	0.199	0.151	0.175
12/21/18	0.000	0.026	0.000	0.023	0.243	0.201	0.153	0.175
12/22/18	0.000	0.021	0.000	0.018	0.238	0.202	0.137	0.173
12/23/18	0.000	0.018	0.000	0.016	0.238	0.204	0.144	0.171

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Spectacle 04				Beaver 05			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.000	0.016	0.000	0.014	0.238	0.205	0.147	0.168
12/25/18	0.000	0.015	0.000	0.013	0.236	0.206	0.135	0.167
12/26/18	0.000	0.014	0.000	0.012	0.241	0.207	0.142	0.165
12/27/18	0.000	0.013	0.000	0.011	0.236	0.208	0.135	0.164
12/28/18	0.000	0.013	0.000	0.011	0.236	0.208	0.141	0.162
12/29/18	0.000	0.012	0.000	0.010	0.240	0.209	0.142	0.161
12/30/18	0.000	0.011	0.000	0.010	0.236	0.209	0.134	0.160
12/31/18	0.000	0.011	0.000	0.010	0.239	0.210	0.144	0.159

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.000	0.161	0.200	0.164	0.000	0.123	0.200	0.125
1/2/18	0.182	0.152	0.200	0.166	0.142	0.117	0.200	0.130
1/3/18	0.197	0.152	0.200	0.168	0.155	0.117	0.200	0.135
1/4/18	0.190	0.156	0.200	0.170	0.152	0.120	0.200	0.139
1/5/18	0.192	0.159	0.200	0.172	0.150	0.122	0.200	0.143
1/6/18	0.197	0.162	0.200	0.173	0.151	0.125	0.200	0.146
1/7/18	0.194	0.164	0.200	0.174	0.148	0.126	0.200	0.149
1/8/18	0.194	0.166	0.200	0.175	0.150	0.128	0.200	0.151
1/9/18	0.203	0.168	0.200	0.176	0.160	0.129	0.200	0.153
1/10/18	0.199	0.170	0.200	0.177	0.156	0.131	0.200	0.155
1/11/18	0.195	0.171	0.200	0.178	0.150	0.132	0.200	0.157
1/12/18	0.203	0.172	0.200	0.178	0.158	0.133	0.200	0.158
1/13/18	0.197	0.174	0.200	0.179	0.153	0.134	0.200	0.159
1/14/18	0.197	0.175	0.200	0.179	0.153	0.134	0.200	0.160
1/15/18	0.199	0.175	0.200	0.180	0.153	0.135	0.200	0.161
1/16/18	0.197	0.176	0.200	0.180	0.153	0.135	0.200	0.162
1/17/18	0.196	0.176	0.200	0.181	0.153	0.136	0.200	0.163
1/18/18	0.197	0.177	0.200	0.181	0.152	0.136	0.200	0.164
1/19/18	0.193	0.177	0.200	0.181	0.154	0.136	0.200	0.165
1/20/18	0.199	0.177	0.200	0.182	0.154	0.137	0.200	0.165
1/21/18	0.193	0.178	0.200	0.182	0.151	0.137	0.200	0.166
1/22/18	0.196	0.178	0.200	0.182	0.155	0.137	0.200	0.167
1/23/18	0.194	0.178	0.200	0.182	0.154	0.138	0.200	0.167
1/24/18	0.196	0.178	0.200	0.183	0.151	0.138	0.200	0.168
1/25/18	0.195	0.179	0.200	0.183	0.152	0.138	0.200	0.168
1/26/18	0.201	0.179	0.200	0.183	0.153	0.138	0.200	0.169
1/27/18	0.196	0.180	0.200	0.183	0.152	0.139	0.200	0.169
1/28/18	0.195	0.180	0.200	0.183	0.155	0.139	0.200	0.170
1/29/18	0.193	0.180	0.200	0.184	0.155	0.139	0.200	0.170
1/30/18	0.191	0.180	0.200	0.184	0.150	0.139	0.200	0.171
1/31/18	0.198	0.180	0.200	0.184	0.154	0.140	0.200	0.171
2/1/18	0.193	0.180	0.200	0.184	0.154	0.140	0.200	0.171
2/2/18	0.195	0.180	0.200	0.184	0.153	0.140	0.200	0.172
2/3/18	0.192	0.180	0.200	0.184	0.151	0.140	0.200	0.172
2/4/18	0.197	0.180	0.200	0.185	0.156	0.140	0.200	0.172
2/5/18	0.196	0.180	0.200	0.185	0.150	0.140	0.200	0.173
2/6/18	0.191	0.181	0.200	0.185	0.149	0.140	0.200	0.173
2/7/18	0.203	0.181	0.200	0.185	0.159	0.140	0.200	0.173
2/8/18	0.202	0.181	0.200	0.185	0.156	0.141	0.200	0.174
2/9/18	0.192	0.182	0.200	0.185	0.153	0.141	0.200	0.174
2/10/18	0.189	0.182	0.200	0.185	0.154	0.141	0.200	0.174
2/11/18	0.203	0.181	0.200	0.185	0.157	0.141	0.200	0.174
2/12/18	0.195	0.182	0.200	0.185	0.152	0.142	0.200	0.175
2/13/18	0.195	0.182	0.200	0.186	0.153	0.142	0.200	0.175
2/14/18	0.196	0.182	0.200	0.186	0.152	0.142	0.200	0.175
2/15/18	0.194	0.182	0.200	0.186	0.154	0.142	0.200	0.175
2/16/18	0.193	0.182	0.200	0.186	0.149	0.142	0.200	0.175
2/17/18	0.198	0.182	0.200	0.186	0.154	0.142	0.200	0.176
2/18/18	0.193	0.182	0.200	0.186	0.159	0.142	0.200	0.176
2/19/18	0.200	0.182	0.200	0.186	0.157	0.142	0.200	0.176
2/20/18	0.188	0.182	0.200	0.186	0.146	0.142	0.200	0.176

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.000	0.179	0.200	0.186	0.000	0.140	0.200	0.176
2/22/18	0.186	0.168	0.200	0.186	0.143	0.132	0.200	0.177
2/23/18	0.201	0.167	0.200	0.186	0.156	0.130	0.200	0.177
2/24/18	0.199	0.170	0.200	0.187	0.155	0.132	0.200	0.177
2/25/18	0.199	0.172	0.200	0.187	0.156	0.134	0.200	0.177
2/26/18	0.199	0.174	0.200	0.187	0.160	0.136	0.200	0.177
2/27/18	0.201	0.176	0.200	0.187	0.153	0.137	0.200	0.177
2/28/18	0.200	0.178	0.200	0.187	0.155	0.138	0.200	0.178
3/1/18	0.197	0.179	0.200	0.187	0.152	0.139	0.200	0.178
3/2/18	0.192	0.179	0.200	0.187	0.149	0.139	0.200	0.178
3/3/18	0.194	0.180	0.200	0.187	0.152	0.139	0.200	0.178
3/4/18	0.200	0.180	0.200	0.187	0.156	0.140	0.200	0.178
3/5/18	0.193	0.180	0.200	0.187	0.151	0.140	0.200	0.178
3/6/18	0.192	0.181	0.200	0.187	0.149	0.140	0.200	0.178
3/7/18	0.204	0.181	0.200	0.187	0.157	0.140	0.200	0.179
3/8/18	0.193	0.181	0.200	0.187	0.149	0.141	0.200	0.179
3/9/18	0.199	0.182	0.200	0.187	0.155	0.141	0.200	0.179
3/10/18	0.195	0.182	0.200	0.187	0.151	0.141	0.200	0.179
3/11/18	0.195	0.182	0.200	0.187	0.151	0.141	0.200	0.179
3/12/18	0.194	0.182	0.200	0.187	0.149	0.141	0.200	0.179
3/13/18	0.199	0.182	0.200	0.188	0.162	0.141	0.200	0.179
3/14/18	0.186	0.182	0.200	0.188	0.151	0.142	0.200	0.179
3/15/18	0.197	0.182	0.200	0.188	0.154	0.142	0.200	0.179
3/16/18	0.195	0.182	0.200	0.188	0.153	0.142	0.200	0.180
3/17/18	0.199	0.182	0.200	0.188	0.156	0.142	0.200	0.180
3/18/18	0.191	0.183	0.200	0.188	0.147	0.142	0.200	0.180
3/19/18	0.197	0.183	0.200	0.188	0.155	0.142	0.200	0.180
3/20/18	0.191	0.183	0.200	0.188	0.147	0.142	0.200	0.180
3/21/18	0.000	0.180	0.200	0.188	0.000	0.140	0.200	0.180
3/22/18	0.000	0.166	0.200	0.188	0.000	0.130	0.200	0.180
3/23/18	0.000	0.152	0.000	0.185	0.000	0.120	0.000	0.178
3/24/18	0.000	0.140	0.000	0.171	0.000	0.110	0.000	0.165
3/25/18	0.000	0.129	0.000	0.156	0.000	0.102	0.000	0.151
3/26/18	0.000	0.121	0.000	0.144	0.000	0.096	0.000	0.139
3/27/18	0.000	0.114	0.000	0.133	0.000	0.090	0.000	0.128
3/28/18	0.000	0.108	0.200	0.127	0.000	0.085	0.200	0.122
3/29/18	0.000	0.102	0.200	0.134	0.000	0.081	0.200	0.127
3/30/18	0.000	0.098	0.000	0.139	0.000	0.078	0.000	0.133
3/31/18	0.000	0.093	0.000	0.133	0.000	0.074	0.000	0.127
4/1/18	0.000	0.090	0.200	0.126	0.000	0.071	0.200	0.121
4/2/18	0.167	0.089	0.200	0.132	0.129	0.070	0.200	0.126
4/3/18	0.199	0.098	0.200	0.140	0.134	0.076	0.200	0.133
4/4/18	0.201	0.110	0.200	0.147	0.135	0.083	0.200	0.140
4/5/18	0.200	0.120	0.200	0.153	0.135	0.090	0.200	0.145
4/6/18	0.196	0.129	0.200	0.157	0.135	0.095	0.200	0.150
4/7/18	0.193	0.136	0.200	0.161	0.133	0.099	0.200	0.153
4/8/18	0.197	0.141	0.200	0.164	0.131	0.103	0.200	0.156
4/9/18	0.199	0.145	0.200	0.166	0.137	0.105	0.200	0.159
4/10/18	0.198	0.149	0.200	0.168	0.135	0.108	0.200	0.161
4/11/18	0.197	0.153	0.200	0.170	0.132	0.110	0.200	0.163
4/12/18	0.199	0.155	0.200	0.172	0.134	0.112	0.200	0.164

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.198	0.158	0.200	0.173	0.134	0.113	0.200	0.166
4/14/18	0.200	0.160	0.200	0.174	0.133	0.114	0.200	0.167
4/15/18	0.198	0.162	0.200	0.175	0.133	0.115	0.200	0.168
4/16/18	0.203	0.164	0.200	0.176	0.137	0.116	0.200	0.169
4/17/18	0.201	0.166	0.200	0.177	0.135	0.118	0.200	0.170
4/18/18	0.196	0.167	0.200	0.178	0.134	0.118	0.200	0.171
4/19/18	0.199	0.168	0.200	0.178	0.136	0.119	0.200	0.172
4/20/18	0.194	0.169	0.200	0.179	0.133	0.120	0.200	0.172
4/21/18	0.197	0.170	0.200	0.180	0.133	0.120	0.200	0.173
4/22/18	0.194	0.171	0.200	0.180	0.134	0.121	0.200	0.173
4/23/18	0.200	0.171	0.200	0.181	0.136	0.121	0.200	0.174
4/24/18	0.194	0.172	0.200	0.181	0.134	0.122	0.200	0.174
4/25/18	0.000	0.170	0.000	0.178	0.000	0.121	0.000	0.172
4/26/18	0.406	0.163	0.200	0.168	0.107	0.114	0.200	0.163
4/27/18	0.440	0.177	0.200	0.167	0.108	0.111	0.200	0.161
4/28/18	0.441	0.198	0.200	0.170	0.109	0.111	0.200	0.164
4/29/18	0.438	0.217	0.200	0.172	0.108	0.111	0.200	0.166
4/30/18	0.441	0.232	0.200	0.174	0.107	0.111	0.200	0.168
5/1/18	0.440	0.245	0.200	0.176	0.111	0.111	0.200	0.169
5/2/18	0.445	0.255	0.200	0.177	0.109	0.111	0.200	0.171
5/3/18	0.434	0.265	0.200	0.178	0.109	0.111	0.200	0.172
5/4/18	0.443	0.273	0.200	0.179	0.108	0.111	0.200	0.173
5/5/18	0.441	0.280	0.200	0.180	0.109	0.111	0.200	0.174
5/6/18	0.436	0.286	0.200	0.181	0.108	0.111	0.200	0.174
5/7/18	0.430	0.291	0.200	0.181	0.107	0.111	0.200	0.175
5/8/18	0.000	0.289	0.000	0.179	0.000	0.109	0.000	0.173
5/9/18	0.000	0.262	0.200	0.168	0.000	0.102	0.200	0.163
5/10/18	0.000	0.234	0.200	0.168	0.000	0.095	0.200	0.162
5/11/18	0.000	0.210	0.200	0.170	0.000	0.088	0.200	0.164
5/12/18	0.000	0.190	0.200	0.173	0.000	0.082	0.200	0.167
5/13/18	0.000	0.174	0.000	0.172	0.000	0.077	0.000	0.166
5/14/18	0.000	0.161	0.000	0.159	0.000	0.073	0.000	0.155
5/15/18	0.000	0.149	0.200	0.149	0.000	0.070	0.200	0.145
5/16/18	0.000	0.140	0.200	0.151	0.000	0.067	0.200	0.146
5/17/18	0.000	0.131	0.200	0.156	0.000	0.064	0.200	0.151
5/18/18	0.000	0.124	0.200	0.161	0.000	0.061	0.200	0.155
5/19/18	0.000	0.118	0.000	0.162	0.000	0.059	0.000	0.157
5/20/18	0.000	0.112	0.200	0.154	0.000	0.057	0.200	0.149
5/21/18	0.000	0.107	0.200	0.155	0.000	0.055	0.200	0.150
5/22/18	0.000	0.103	0.200	0.159	0.000	0.054	0.200	0.154
5/23/18	0.196	0.101	0.200	0.163	0.151	0.054	0.200	0.157
5/24/18	0.216	0.112	0.200	0.166	0.153	0.062	0.200	0.160
5/25/18	0.219	0.124	0.200	0.169	0.154	0.072	0.200	0.163
5/26/18	0.219	0.135	0.200	0.171	0.156	0.080	0.200	0.165
5/27/18	0.222	0.144	0.200	0.173	0.155	0.087	0.200	0.167
5/28/18	0.217	0.152	0.200	0.174	0.156	0.093	0.200	0.168
5/29/18	0.217	0.157	0.200	0.175	0.156	0.098	0.200	0.169
5/30/18	0.218	0.162	0.200	0.176	0.149	0.102	0.200	0.171
5/31/18	0.219	0.166	0.200	0.177	0.000	0.103	0.200	0.172
6/1/18	0.221	0.169	0.200	0.178	0.000	0.097	0.200	0.172
6/2/18	0.221	0.173	0.200	0.179	0.000	0.088	0.200	0.173

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.217	0.175	0.200	0.179	0.000	0.081	0.200	0.174
6/4/18	0.222	0.177	0.200	0.180	0.000	0.075	0.200	0.174
6/5/18	0.223	0.179	0.200	0.180	0.000	0.070	0.200	0.175
6/6/18	0.202	0.181	0.200	0.181	0.151	0.068	0.200	0.175
6/7/18	0.197	0.181	0.200	0.181	0.154	0.074	0.200	0.176
6/8/18	0.199	0.181	0.200	0.182	0.156	0.082	0.200	0.176
6/9/18	0.199	0.181	0.200	0.182	0.157	0.089	0.200	0.177
6/10/18	0.195	0.181	0.200	0.182	0.154	0.095	0.200	0.177
6/11/18	0.197	0.181	0.200	0.183	0.155	0.100	0.200	0.177
6/12/18	0.198	0.181	0.200	0.183	0.153	0.104	0.200	0.178
6/13/18	0.198	0.181	0.200	0.183	0.156	0.107	0.200	0.178
6/14/18	0.199	0.181	0.200	0.184	0.157	0.110	0.200	0.178
6/15/18	0.200	0.181	0.200	0.184	0.155	0.113	0.200	0.179
6/16/18	0.202	0.182	0.200	0.184	0.160	0.115	0.200	0.179
6/17/18	0.199	0.182	0.200	0.184	0.156	0.117	0.200	0.179
6/18/18	0.199	0.182	0.200	0.184	0.157	0.119	0.200	0.179
6/19/18	0.195	0.183	0.200	0.185	0.151	0.120	0.200	0.179
6/20/18	0.181	0.182	0.200	0.185	0.141	0.121	0.200	0.180
6/21/18	0.200	0.181	0.200	0.185	0.157	0.122	0.200	0.180
6/22/18	0.198	0.182	0.200	0.185	0.154	0.123	0.200	0.180
6/23/18	0.198	0.182	0.200	0.185	0.153	0.124	0.200	0.180
6/24/18	0.200	0.182	0.200	0.185	0.157	0.125	0.200	0.180
6/25/18	0.190	0.183	0.200	0.186	0.149	0.126	0.200	0.181
6/26/18	0.199	0.182	0.200	0.186	0.155	0.126	0.200	0.181
6/27/18	0.198	0.183	0.200	0.186	0.156	0.127	0.200	0.181
6/28/18	0.195	0.183	0.200	0.186	0.154	0.128	0.200	0.181
6/29/18	0.194	0.183	0.200	0.186	0.151	0.129	0.200	0.181
6/30/18	0.198	0.183	0.200	0.186	0.154	0.129	0.200	0.181
7/1/18	0.197	0.183	0.200	0.186	0.155	0.130	0.200	0.181
7/2/18	0.200	0.183	0.200	0.186	0.155	0.130	0.200	0.181
7/3/18	0.203	0.184	0.200	0.187	0.156	0.131	0.200	0.182
7/4/18	0.193	0.184	0.200	0.187	0.152	0.132	0.200	0.182
7/5/18	0.201	0.184	0.200	0.187	0.157	0.132	0.200	0.182
7/6/18	0.201	0.184	0.200	0.187	0.156	0.133	0.200	0.182
7/7/18	0.201	0.185	0.200	0.187	0.152	0.133	0.200	0.182
7/8/18	0.197	0.185	0.200	0.187	0.154	0.133	0.200	0.182
7/9/18	0.198	0.185	0.200	0.187	0.155	0.134	0.200	0.182
7/10/18	0.197	0.185	0.200	0.187	0.156	0.134	0.200	0.182
7/11/18	0.201	0.185	0.200	0.187	0.157	0.135	0.200	0.182
7/12/18	0.200	0.185	0.200	0.187	0.154	0.135	0.200	0.183
7/13/18	0.200	0.185	0.200	0.187	0.155	0.135	0.200	0.183
7/14/18	0.199	0.186	0.200	0.187	0.159	0.136	0.200	0.183
7/15/18	0.194	0.186	0.200	0.188	0.156	0.136	0.200	0.183
7/16/18	0.201	0.185	0.200	0.188	0.157	0.136	0.200	0.183
7/17/18	0.198	0.186	0.200	0.188	0.154	0.137	0.200	0.183
7/18/18	0.197	0.186	0.200	0.188	0.157	0.137	0.200	0.183
7/19/18	0.199	0.186	0.200	0.188	0.154	0.137	0.200	0.183
7/20/18	0.200	0.186	0.200	0.188	0.156	0.137	0.200	0.183
7/21/18	0.198	0.186	0.200	0.188	0.156	0.138	0.200	0.183
7/22/18	0.194	0.186	0.200	0.188	0.152	0.138	0.200	0.183
7/23/18	0.196	0.186	0.200	0.188	0.153	0.138	0.200	0.183

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.197	0.186	0.200	0.188	0.154	0.138	0.200	0.183
7/25/18	0.196	0.186	0.200	0.188	0.158	0.138	0.200	0.184
7/26/18	0.198	0.186	0.200	0.188	0.155	0.138	0.200	0.184
7/27/18	0.197	0.186	0.200	0.188	0.151	0.139	0.200	0.184
7/28/18	0.196	0.186	0.200	0.188	0.150	0.139	0.200	0.184
7/29/18	0.000	0.183	0.000	0.185	0.000	0.137	0.000	0.181
7/30/18	0.000	0.169	0.200	0.174	0.000	0.127	0.200	0.171
7/31/18	0.195	0.157	0.200	0.173	0.145	0.118	0.200	0.170
8/1/18	0.195	0.158	0.200	0.176	0.152	0.118	0.200	0.172
8/2/18	0.199	0.163	0.200	0.178	0.157	0.121	0.200	0.174
8/3/18	0.195	0.167	0.200	0.180	0.153	0.124	0.200	0.175
8/4/18	0.190	0.170	0.200	0.181	0.149	0.126	0.200	0.177
8/5/18	0.199	0.172	0.200	0.182	0.156	0.128	0.200	0.178
8/6/18	0.198	0.174	0.200	0.183	0.152	0.130	0.200	0.179
8/7/18	0.197	0.175	0.200	0.184	0.154	0.131	0.200	0.179
8/8/18	0.196	0.177	0.200	0.184	0.152	0.132	0.200	0.180
8/9/18	0.194	0.178	0.200	0.185	0.151	0.133	0.200	0.180
8/10/18	0.197	0.178	0.200	0.185	0.156	0.134	0.200	0.181
8/11/18	0.198	0.179	0.200	0.186	0.158	0.134	0.200	0.181
8/12/18	0.192	0.180	0.200	0.186	0.150	0.135	0.200	0.182
8/13/18	0.200	0.180	0.200	0.186	0.158	0.136	0.200	0.182
8/14/18	0.194	0.181	0.200	0.186	0.153	0.136	0.200	0.182
8/15/18	0.198	0.181	0.200	0.187	0.153	0.137	0.200	0.182
8/16/18	0.196	0.182	0.200	0.187	0.157	0.137	0.200	0.183
8/17/18	0.195	0.182	0.200	0.187	0.152	0.137	0.200	0.183
8/18/18	0.195	0.182	0.200	0.187	0.151	0.138	0.200	0.183
8/19/18	0.200	0.182	0.200	0.187	0.158	0.138	0.200	0.183
8/20/18	0.197	0.183	0.200	0.187	0.156	0.138	0.200	0.183
8/21/18	0.195	0.183	0.200	0.188	0.151	0.139	0.200	0.183
8/22/18	0.195	0.183	0.200	0.188	0.151	0.139	0.200	0.183
8/23/18	0.197	0.183	0.200	0.188	0.154	0.139	0.200	0.184
8/24/18	0.199	0.183	0.200	0.188	0.155	0.139	0.200	0.184
8/25/18	0.197	0.184	0.200	0.188	0.154	0.139	0.200	0.184
8/26/18	0.196	0.184	0.200	0.188	0.153	0.139	0.200	0.184
8/27/18	0.199	0.184	0.200	0.188	0.157	0.140	0.200	0.184
8/28/18	0.201	0.184	0.200	0.188	0.157	0.140	0.200	0.184
8/29/18	0.199	0.185	0.200	0.188	0.154	0.140	0.200	0.184
8/30/18	0.199	0.185	0.200	0.188	0.156	0.140	0.200	0.184
8/31/18	0.199	0.185	0.200	0.188	0.158	0.141	0.200	0.184
9/1/18	0.196	0.186	0.200	0.189	0.156	0.141	0.200	0.184
9/2/18	0.195	0.185	0.200	0.189	0.155	0.141	0.200	0.184
9/3/18	0.194	0.185	0.200	0.189	0.154	0.141	0.200	0.185
9/4/18	0.198	0.185	0.200	0.189	0.152	0.141	0.200	0.185
9/5/18	0.197	0.185	0.200	0.189	0.157	0.141	0.200	0.185
9/6/18	0.201	0.185	0.200	0.189	0.155	0.141	0.200	0.185
9/7/18	0.198	0.186	0.200	0.189	0.153	0.142	0.200	0.185
9/8/18	0.196	0.186	0.200	0.189	0.155	0.142	0.200	0.185
9/9/18	0.194	0.186	0.200	0.189	0.152	0.142	0.200	0.185
9/10/18	0.168	0.185	0.200	0.189	0.145	0.142	0.200	0.185
9/11/18	0.153	0.183	0.200	0.189	0.155	0.141	0.200	0.185
9/12/18	0.156	0.180	0.200	0.189	0.157	0.141	0.200	0.185

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.153	0.177	0.200	0.189	0.153	0.142	0.200	0.185
9/14/18	0.151	0.175	0.200	0.189	0.155	0.142	0.200	0.185
9/15/18	0.157	0.173	0.200	0.189	0.152	0.142	0.200	0.185
9/16/18	0.155	0.171	0.200	0.189	0.157	0.142	0.200	0.185
9/17/18	0.155	0.170	0.200	0.189	0.157	0.142	0.200	0.185
9/18/18	0.150	0.169	0.200	0.189	0.150	0.142	0.200	0.185
9/19/18	0.150	0.167	0.200	0.189	0.151	0.142	0.200	0.185
9/20/18	0.149	0.166	0.200	0.189	0.148	0.142	0.200	0.185
9/21/18	0.149	0.165	0.200	0.189	0.152	0.142	0.200	0.185
9/22/18	0.152	0.164	0.200	0.189	0.153	0.142	0.200	0.186
9/23/18	0.152	0.163	0.200	0.189	0.153	0.142	0.200	0.186
9/24/18	0.152	0.163	0.200	0.189	0.153	0.142	0.200	0.186
9/25/18	0.155	0.162	0.200	0.190	0.151	0.142	0.200	0.186
9/26/18	0.153	0.162	0.200	0.190	0.155	0.142	0.200	0.186
9/27/18	0.149	0.161	0.200	0.190	0.153	0.142	0.200	0.186
9/28/18	0.151	0.161	0.200	0.190	0.151	0.142	0.200	0.186
9/29/18	0.151	0.160	0.200	0.190	0.151	0.142	0.200	0.186
9/30/18	0.152	0.160	0.200	0.190	0.156	0.142	0.200	0.186
10/1/18	0.150	0.159	0.200	0.190	0.151	0.142	0.200	0.186
10/2/18	0.148	0.159	0.200	0.190	0.147	0.142	0.200	0.186
10/3/18	0.000	0.156	0.200	0.190	0.000	0.140	0.200	0.186
10/4/18	0.168	0.148	0.200	0.190	0.168	0.132	0.200	0.186
10/5/18	0.148	0.148	0.200	0.190	0.150	0.132	0.200	0.186
10/6/18	0.150	0.149	0.200	0.190	0.151	0.133	0.200	0.186
10/7/18	0.150	0.150	0.200	0.190	0.151	0.135	0.200	0.186
10/8/18	0.152	0.151	0.200	0.190	0.153	0.136	0.200	0.186
10/9/18	0.152	0.152	0.200	0.190	0.153	0.137	0.200	0.186
10/10/18	0.153	0.152	0.200	0.190	0.149	0.138	0.200	0.186
10/11/18	0.151	0.153	0.200	0.190	0.152	0.138	0.200	0.186
10/12/18	0.156	0.153	0.200	0.190	0.152	0.139	0.200	0.186
10/13/18	0.154	0.154	0.200	0.190	0.153	0.139	0.200	0.186
10/14/18	0.152	0.154	0.200	0.190	0.154	0.139	0.200	0.186
10/15/18	0.151	0.154	0.200	0.190	0.151	0.140	0.200	0.186
10/16/18	0.153	0.154	0.200	0.190	0.154	0.140	0.200	0.186
10/17/18	0.144	0.154	0.200	0.190	0.145	0.140	0.200	0.186
10/18/18	0.145	0.153	0.200	0.190	0.149	0.140	0.200	0.186
10/19/18	0.151	0.153	0.200	0.190	0.152	0.140	0.200	0.186
10/20/18	0.151	0.153	0.200	0.190	0.151	0.140	0.200	0.186
10/21/18	0.151	0.153	0.200	0.190	0.152	0.141	0.200	0.186
10/22/18	0.150	0.153	0.200	0.190	0.151	0.141	0.200	0.186
10/23/18	0.151	0.153	0.200	0.190	0.151	0.141	0.200	0.187
10/24/18	0.147	0.153	0.200	0.190	0.147	0.141	0.200	0.187
10/25/18	0.152	0.153	0.200	0.190	0.152	0.141	0.200	0.187
10/26/18	0.150	0.153	0.200	0.190	0.153	0.141	0.200	0.187
10/27/18	0.148	0.153	0.200	0.190	0.153	0.141	0.200	0.187
10/28/18	0.126	0.152	0.200	0.190	0.130	0.141	0.200	0.187
10/29/18	0.136	0.150	0.200	0.190	0.140	0.140	0.200	0.187
10/30/18	0.150	0.150	0.200	0.190	0.150	0.139	0.200	0.187
10/31/18	0.155	0.150	0.200	0.190	0.152	0.139	0.200	0.187
11/1/18	0.154	0.150	0.200	0.190	0.152	0.140	0.200	0.187
11/2/18	0.151	0.151	0.200	0.190	0.154	0.140	0.200	0.187

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.150	0.151	0.200	0.190	0.148	0.140	0.200	0.187
11/4/18	0.148	0.151	0.200	0.190	0.147	0.141	0.200	0.187
11/5/18	0.152	0.151	0.200	0.190	0.155	0.140	0.200	0.187
11/6/18	0.153	0.151	0.200	0.190	0.154	0.141	0.200	0.187
11/7/18	0.154	0.152	0.200	0.190	0.151	0.141	0.200	0.187
11/8/18	0.153	0.152	0.200	0.190	0.151	0.141	0.200	0.187
11/9/18	0.150	0.152	0.200	0.190	0.152	0.141	0.200	0.187
11/10/18	0.156	0.152	0.200	0.190	0.157	0.142	0.200	0.187
11/11/18	0.000	0.150	0.000	0.188	0.000	0.140	0.000	0.185
11/12/18	0.000	0.139	0.200	0.177	0.000	0.131	0.200	0.174
11/13/18	0.000	0.128	0.200	0.176	0.000	0.120	0.200	0.173
11/14/18	0.000	0.118	0.200	0.178	0.000	0.111	0.200	0.175
11/15/18	0.000	0.110	0.000	0.177	0.000	0.103	0.000	0.174
11/16/18	0.000	0.104	0.000	0.165	0.000	0.096	0.000	0.163
11/17/18	0.000	0.098	0.000	0.151	0.000	0.090	0.000	0.150
11/18/18	0.000	0.093	0.200	0.143	0.000	0.086	0.200	0.141
11/19/18	0.152	0.091	0.200	0.147	0.146	0.083	0.200	0.144
11/20/18	0.149	0.098	0.200	0.154	0.150	0.089	0.200	0.151
11/21/18	0.151	0.106	0.200	0.159	0.152	0.096	0.200	0.156
11/22/18	0.148	0.112	0.200	0.164	0.149	0.103	0.200	0.161
11/23/18	0.147	0.117	0.200	0.168	0.151	0.108	0.200	0.164
11/24/18	0.000	0.119	0.000	0.168	0.000	0.110	0.000	0.165
11/25/18	0.000	0.112	0.000	0.156	0.000	0.104	0.000	0.154
11/26/18	0.146	0.106	0.200	0.146	0.146	0.098	0.200	0.144
11/27/18	0.153	0.109	0.200	0.149	0.154	0.100	0.200	0.146
11/28/18	0.153	0.114	0.200	0.155	0.153	0.105	0.200	0.152
11/29/18	0.151	0.119	0.200	0.160	0.151	0.110	0.200	0.156
11/30/18	0.151	0.123	0.200	0.164	0.155	0.114	0.200	0.160
12/1/18	0.151	0.126	0.200	0.167	0.153	0.117	0.200	0.164
12/2/18	0.155	0.129	0.200	0.170	0.154	0.120	0.200	0.166
12/3/18	0.153	0.131	0.200	0.172	0.153	0.122	0.200	0.168
12/4/18	0.155	0.133	0.200	0.174	0.153	0.124	0.200	0.170
12/5/18	0.150	0.135	0.200	0.175	0.149	0.126	0.200	0.172
12/6/18	0.151	0.136	0.200	0.177	0.151	0.127	0.200	0.173
12/7/18	0.147	0.137	0.200	0.178	0.148	0.128	0.200	0.174
12/8/18	0.151	0.137	0.200	0.179	0.153	0.129	0.200	0.175
12/9/18	0.148	0.138	0.200	0.180	0.151	0.130	0.200	0.176
12/10/18	0.000	0.137	0.200	0.180	0.000	0.129	0.200	0.177
12/11/18	0.000	0.127	0.200	0.181	0.000	0.120	0.200	0.178
12/12/18	0.149	0.118	0.200	0.182	0.150	0.112	0.200	0.178
12/13/18	0.151	0.120	0.200	0.182	0.152	0.112	0.200	0.179
12/14/18	0.150	0.124	0.200	0.183	0.151	0.116	0.200	0.179
12/15/18	0.153	0.127	0.200	0.183	0.150	0.119	0.200	0.180
12/16/18	0.150	0.130	0.200	0.184	0.152	0.122	0.200	0.180
12/17/18	0.153	0.132	0.200	0.184	0.151	0.124	0.200	0.181
12/18/18	0.155	0.134	0.200	0.184	0.154	0.126	0.200	0.181
12/19/18	0.148	0.136	0.200	0.185	0.154	0.128	0.200	0.181
12/20/18	0.154	0.137	0.200	0.185	0.157	0.129	0.200	0.182
12/21/18	0.153	0.138	0.200	0.185	0.156	0.130	0.200	0.182
12/22/18	0.149	0.139	0.200	0.185	0.151	0.132	0.200	0.182
12/23/18	0.151	0.139	0.200	0.186	0.155	0.132	0.200	0.182

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Beaver 06				Beaver 07			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.156	0.140	0.200	0.186	0.154	0.133	0.200	0.183
12/25/18	0.147	0.141	0.200	0.186	0.152	0.134	0.200	0.183
12/26/18	0.150	0.141	0.200	0.186	0.150	0.134	0.200	0.183
12/27/18	0.149	0.142	0.200	0.186	0.151	0.135	0.200	0.183
12/28/18	0.153	0.142	0.200	0.187	0.153	0.135	0.200	0.183
12/29/18	0.150	0.142	0.200	0.187	0.151	0.135	0.200	0.184
12/30/18	0.149	0.143	0.200	0.187	0.149	0.136	0.200	0.184
12/31/18	0.152	0.143	0.200	0.187	0.153	0.136	0.200	0.184

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.000	0.049	0.361	0.305	0.723	0.667	0.361	0.363
1/2/18	0.000	0.035	0.374	0.330	0.748	0.704	0.374	0.373
1/3/18	0.000	0.028	0.316	0.297	0.633	0.615	0.316	0.324
1/4/18	0.000	0.024	0.267	0.262	0.535	0.532	0.267	0.281
1/5/18	0.000	0.022	0.267	0.259	0.535	0.529	0.267	0.277
1/6/18	0.000	0.020	0.267	0.259	0.534	0.527	0.267	0.275
1/7/18	0.000	0.018	0.267	0.258	0.535	0.527	0.267	0.274
1/8/18	0.000	0.017	0.268	0.259	0.535	0.527	0.268	0.274
1/9/18	0.000	0.016	0.267	0.258	0.534	0.526	0.267	0.273
1/10/18	0.000	0.015	0.423	0.369	0.846	0.789	0.423	0.404
1/11/18	0.000	0.014	0.394	0.362	0.788	0.755	0.394	0.386
1/12/18	0.000	0.014	0.373	0.350	0.745	0.723	0.373	0.369
1/13/18	0.000	0.013	0.370	0.349	0.740	0.719	0.370	0.367
1/14/18	0.000	0.013	0.374	0.353	0.748	0.727	0.374	0.371
1/15/18	0.000	0.012	0.375	0.355	0.749	0.729	0.375	0.372
1/16/18	0.000	0.012	0.371	0.353	0.742	0.724	0.371	0.369
1/17/18	0.000	0.011	0.000	0.091	0.000	0.101	0.000	0.057
1/18/18	0.000	0.011	0.000	0.060	0.000	0.067	0.000	0.040
1/19/18	0.000	0.011	0.000	0.047	0.000	0.052	0.000	0.033
1/20/18	0.000	0.011	0.000	0.039	0.000	0.044	0.000	0.028
1/21/18	0.000	0.010	0.000	0.034	0.000	0.038	0.000	0.025
1/22/18	0.000	0.010	0.000	0.030	0.000	0.034	0.000	0.023
1/23/18	0.000	0.010	0.000	0.027	0.000	0.030	0.000	0.021
1/24/18	0.000	0.010	0.000	0.025	0.000	0.028	0.000	0.020
1/25/18	0.000	0.009	0.000	0.023	0.000	0.026	0.000	0.018
1/26/18	0.000	0.009	0.000	0.021	0.000	0.024	0.000	0.017
1/27/18	0.000	0.009	0.000	0.020	0.000	0.023	0.000	0.017
1/28/18	0.000	0.009	0.000	0.019	0.000	0.021	0.000	0.016
1/29/18	0.000	0.009	0.000	0.018	0.000	0.020	0.000	0.015
1/30/18	0.000	0.008	0.000	0.017	0.000	0.019	0.000	0.015
1/31/18	0.000	0.008	0.000	0.016	0.000	0.018	0.000	0.014
2/1/18	0.000	0.008	0.000	0.016	0.000	0.018	0.000	0.014
2/2/18	0.000	0.008	0.000	0.015	0.000	0.017	0.000	0.013
2/3/18	0.000	0.008	0.000	0.014	0.000	0.016	0.000	0.013
2/4/18	0.000	0.008	0.000	0.014	0.000	0.016	0.000	0.013
2/5/18	0.000	0.008	0.000	0.013	0.000	0.015	0.000	0.012
2/6/18	0.000	0.008	0.000	0.013	0.000	0.015	0.000	0.012
2/7/18	0.000	0.007	0.000	0.013	0.000	0.014	0.000	0.012
2/8/18	0.000	0.007	0.000	0.012	0.000	0.014	0.000	0.011
2/9/18	0.000	0.007	0.000	0.012	0.000	0.014	0.000	0.011
2/10/18	0.000	0.007	0.000	0.012	0.000	0.013	0.000	0.011
2/11/18	0.000	0.007	0.000	0.011	0.000	0.013	0.000	0.011
2/12/18	0.579	0.418	0.290	0.216	0.000	0.013	0.290	0.254
2/13/18	0.622	0.496	0.311	0.255	0.000	0.012	0.311	0.285
2/14/18	0.641	0.535	0.321	0.274	0.000	0.012	0.321	0.300
2/15/18	0.610	0.529	0.305	0.271	0.000	0.012	0.305	0.291
2/16/18	0.535	0.483	0.267	0.248	0.000	0.011	0.267	0.261
2/17/18	0.533	0.482	0.266	0.248	0.000	0.011	0.266	0.261
2/18/18	0.000	0.106	0.000	0.060	0.000	0.011	0.000	0.037
2/19/18	0.631	0.513	0.316	0.263	0.000	0.011	0.316	0.291
2/20/18	0.641	0.554	0.321	0.283	0.000	0.011	0.321	0.304

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.630	0.561	0.315	0.286	0.000	0.010	0.315	0.304
2/22/18	0.617	0.559	0.309	0.285	0.000	0.010	0.309	0.300
2/23/18	0.546	0.513	0.273	0.262	0.000	0.010	0.273	0.271
2/24/18	0.537	0.504	0.268	0.257	0.000	0.010	0.268	0.266
2/25/18	0.534	0.501	0.267	0.256	0.000	0.010	0.267	0.265
2/26/18	0.000	0.122	0.000	0.067	0.000	0.010	0.000	0.040
2/27/18	0.000	0.079	0.000	0.045	0.000	0.009	0.000	0.028
2/28/18	0.000	0.060	0.000	0.035	0.000	0.009	0.000	0.023
3/1/18	0.634	0.498	0.317	0.254	0.000	0.009	0.317	0.286
3/2/18	0.627	0.538	0.314	0.274	0.000	0.009	0.314	0.296
3/3/18	0.000	0.111	0.000	0.060	0.000	0.009	0.000	0.037
3/4/18	0.000	0.069	0.000	0.039	0.000	0.009	0.000	0.025
3/5/18	0.000	0.052	0.000	0.031	0.000	0.009	0.000	0.020
3/6/18	0.000	0.043	0.000	0.026	0.000	0.009	0.000	0.018
3/7/18	0.000	0.036	0.265	0.211	0.530	0.454	0.265	0.238
3/8/18	0.000	0.032	0.374	0.308	0.749	0.662	0.374	0.342
3/9/18	0.000	0.029	0.374	0.325	0.748	0.683	0.374	0.351
3/10/18	0.000	0.026	0.290	0.274	0.580	0.552	0.290	0.285
3/11/18	0.000	0.024	0.290	0.272	0.580	0.551	0.290	0.284
3/12/18	0.000	0.022	0.266	0.256	0.531	0.512	0.266	0.264
3/13/18	0.000	0.021	0.000	0.066	0.000	0.065	0.000	0.040
3/14/18	0.000	0.019	0.355	0.296	0.711	0.639	0.355	0.326
3/15/18	0.000	0.018	0.373	0.329	0.747	0.692	0.373	0.352
3/16/18	0.000	0.017	0.338	0.313	0.676	0.643	0.338	0.328
3/17/18	0.000	0.016	0.255	0.256	0.510	0.506	0.255	0.259
3/18/18	0.000	0.016	0.164	0.186	0.327	0.347	0.164	0.179
3/19/18	0.000	0.015	0.214	0.212	0.427	0.421	0.214	0.216
3/20/18	0.000	0.014	0.259	0.244	0.517	0.497	0.259	0.254
3/21/18	0.000	0.014	0.321	0.292	0.641	0.605	0.321	0.308
3/22/18	0.000	0.013	0.333	0.307	0.666	0.633	0.333	0.322
3/23/18	0.000	0.013	0.410	0.365	0.819	0.767	0.410	0.389
3/24/18	0.000	0.012	0.416	0.379	0.833	0.788	0.416	0.399
3/25/18	0.000	0.012	0.427	0.392	0.855	0.813	0.427	0.411
3/26/18	0.000	0.012	0.428	0.396	0.855	0.818	0.428	0.413
3/27/18	0.000	0.011	0.343	0.338	0.686	0.678	0.343	0.344
3/28/18	0.506	0.370	0.518	0.458	0.530	0.542	0.518	0.488
3/29/18	0.539	0.435	0.270	0.294	0.000	0.087	0.270	0.286
3/30/18	0.607	0.504	0.303	0.304	0.000	0.059	0.303	0.307
3/31/18	0.641	0.547	0.321	0.313	0.000	0.046	0.321	0.320
4/1/18	0.642	0.561	0.321	0.313	0.000	0.038	0.321	0.320
4/2/18	0.638	0.567	0.319	0.311	0.000	0.033	0.319	0.318
4/3/18	0.000	0.121	0.000	0.085	0.000	0.029	0.000	0.049
4/4/18	0.000	0.073	0.000	0.058	0.000	0.026	0.000	0.034
4/5/18	0.638	0.506	0.319	0.272	0.000	0.024	0.319	0.296
4/6/18	0.641	0.550	0.321	0.293	0.000	0.022	0.321	0.308
4/7/18	0.641	0.567	0.321	0.300	0.000	0.021	0.321	0.312
4/8/18	0.642	0.577	0.321	0.304	0.000	0.019	0.321	0.314
4/9/18	0.637	0.580	0.319	0.304	0.000	0.018	0.319	0.314
4/10/18	0.637	0.584	0.319	0.305	0.000	0.017	0.319	0.314
4/11/18	0.642	0.591	0.321	0.308	0.000	0.016	0.321	0.317
4/12/18	0.636	0.590	0.318	0.307	0.000	0.016	0.318	0.315

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.000	0.141	0.000	0.082	0.000	0.015	0.000	0.048
4/14/18	0.000	0.090	0.000	0.056	0.000	0.014	0.000	0.033
4/15/18	0.000	0.068	0.000	0.044	0.000	0.014	0.000	0.027
4/16/18	0.000	0.055	0.000	0.037	0.000	0.013	0.000	0.023
4/17/18	0.641	0.501	0.320	0.260	0.000	0.013	0.320	0.290
4/18/18	0.642	0.549	0.321	0.283	0.000	0.012	0.321	0.303
4/19/18	0.641	0.568	0.321	0.293	0.000	0.012	0.321	0.308
4/20/18	0.641	0.579	0.321	0.298	0.000	0.012	0.321	0.311
4/21/18	0.637	0.583	0.319	0.299	0.000	0.011	0.319	0.311
4/22/18	0.620	0.575	0.310	0.295	0.000	0.011	0.310	0.305
4/23/18	0.633	0.587	0.317	0.301	0.000	0.011	0.317	0.311
4/24/18	0.633	0.590	0.316	0.302	0.000	0.010	0.316	0.311
4/25/18	0.641	0.598	0.321	0.306	0.000	0.010	0.321	0.315
4/26/18	0.641	0.601	0.321	0.307	0.000	0.010	0.321	0.316
4/27/18	0.641	0.602	0.320	0.308	0.000	0.010	0.320	0.316
4/28/18	0.000	0.149	0.000	0.081	0.000	0.010	0.000	0.047
4/29/18	0.000	0.098	0.000	0.055	0.000	0.009	0.000	0.033
4/30/18	0.000	0.075	0.000	0.044	0.000	0.009	0.000	0.026
5/1/18	0.000	0.061	0.000	0.037	0.000	0.009	0.000	0.022
5/2/18	0.000	0.052	0.168	0.151	0.336	0.291	0.168	0.161
5/3/18	0.000	0.046	0.214	0.195	0.429	0.385	0.214	0.206
5/4/18	0.000	0.041	0.214	0.202	0.428	0.395	0.214	0.210
5/5/18	0.000	0.037	0.214	0.205	0.427	0.401	0.214	0.212
5/6/18	0.000	0.034	0.214	0.207	0.428	0.405	0.214	0.213
5/7/18	0.000	0.031	0.274	0.251	0.549	0.509	0.274	0.264
5/8/18	0.000	0.029	0.375	0.328	0.749	0.685	0.375	0.352
5/9/18	0.000	0.027	0.374	0.339	0.748	0.698	0.374	0.358
5/10/18	0.000	0.026	0.374	0.345	0.748	0.705	0.374	0.361
5/11/18	0.000	0.024	0.367	0.343	0.734	0.697	0.367	0.356
5/12/18	0.000	0.023	0.370	0.347	0.739	0.704	0.370	0.360
5/13/18	0.000	0.022	0.374	0.352	0.748	0.715	0.374	0.364
5/14/18	0.000	0.021	0.374	0.354	0.749	0.717	0.374	0.365
5/15/18	0.000	0.020	0.374	0.355	0.748	0.719	0.374	0.366
5/16/18	0.000	0.019	0.375	0.356	0.749	0.721	0.375	0.367
5/17/18	0.000	0.018	0.374	0.357	0.749	0.722	0.374	0.367
5/18/18	0.000	0.018	0.374	0.358	0.749	0.723	0.374	0.368
5/19/18	0.000	0.017	0.374	0.358	0.749	0.725	0.374	0.368
5/20/18	0.000	0.016	0.374	0.359	0.748	0.725	0.374	0.368
5/21/18	0.000	0.016	0.374	0.360	0.749	0.727	0.374	0.369
5/22/18	0.000	0.015	0.235	0.261	0.471	0.493	0.235	0.252
5/23/18	0.000	0.015	0.370	0.346	0.739	0.707	0.370	0.359
5/24/18	0.000	0.014	0.445	0.406	0.891	0.842	0.445	0.426
5/25/18	0.000	0.014	0.445	0.414	0.891	0.851	0.445	0.431
5/26/18	0.000	0.014	0.445	0.418	0.891	0.856	0.445	0.433
5/27/18	0.000	0.013	0.446	0.421	0.891	0.859	0.446	0.434
5/28/18	0.000	0.013	0.403	0.393	0.807	0.790	0.403	0.400
5/29/18	0.000	0.013	0.367	0.364	0.733	0.726	0.367	0.368
5/30/18	0.000	0.012	0.409	0.391	0.818	0.794	0.409	0.401
5/31/18	0.000	0.012	0.445	0.419	0.890	0.857	0.445	0.433
6/1/18	0.000	0.012	0.446	0.423	0.891	0.862	0.446	0.435
6/2/18	0.000	0.011	0.445	0.424	0.890	0.864	0.445	0.436

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.000	0.011	0.445	0.426	0.891	0.866	0.445	0.437
6/4/18	0.000	0.011	0.420	0.408	0.839	0.824	0.420	0.416
6/5/18	0.000	0.011	0.381	0.379	0.762	0.757	0.381	0.382
6/6/18	0.471	0.345	0.601	0.532	0.730	0.726	0.601	0.565
6/7/18	0.609	0.481	0.304	0.338	0.000	0.109	0.304	0.325
6/8/18	0.534	0.457	0.267	0.295	0.000	0.074	0.267	0.284
6/9/18	0.610	0.520	0.305	0.312	0.000	0.058	0.305	0.311
6/10/18	0.535	0.481	0.267	0.283	0.000	0.049	0.267	0.278
6/11/18	0.595	0.526	0.298	0.300	0.000	0.042	0.298	0.301
6/12/18	0.620	0.552	0.310	0.309	0.000	0.037	0.310	0.311
6/13/18	0.614	0.555	0.307	0.307	0.000	0.034	0.307	0.309
6/14/18	0.579	0.535	0.290	0.294	0.000	0.031	0.290	0.294
6/15/18	0.534	0.504	0.267	0.276	0.000	0.028	0.267	0.274
6/16/18	0.610	0.555	0.305	0.300	0.000	0.026	0.305	0.305
6/17/18	0.558	0.524	0.279	0.283	0.000	0.025	0.279	0.283
6/18/18	0.551	0.519	0.276	0.279	0.000	0.023	0.276	0.280
6/19/18	0.535	0.507	0.267	0.272	0.000	0.022	0.267	0.272
6/20/18	0.534	0.506	0.267	0.271	0.000	0.021	0.267	0.271
6/21/18	0.532	0.505	0.563	0.479	0.593	0.519	0.563	0.519
6/22/18	0.000	0.127	0.327	0.336	0.655	0.597	0.327	0.334
6/23/18	0.000	0.084	0.334	0.332	0.668	0.622	0.334	0.335
6/24/18	0.000	0.064	0.334	0.330	0.668	0.631	0.334	0.334
6/25/18	0.000	0.053	0.334	0.329	0.668	0.636	0.334	0.333
6/26/18	0.000	0.045	0.334	0.329	0.668	0.640	0.334	0.333
6/27/18	0.000	0.040	0.331	0.327	0.663	0.638	0.331	0.331
6/28/18	0.000	0.035	0.334	0.328	0.668	0.645	0.334	0.333
6/29/18	0.000	0.032	0.334	0.328	0.668	0.647	0.334	0.333
6/30/18	0.000	0.029	0.334	0.328	0.668	0.648	0.334	0.333
7/1/18	0.000	0.027	0.334	0.328	0.668	0.649	0.334	0.333
7/2/18	0.000	0.025	0.338	0.331	0.676	0.657	0.338	0.336
7/3/18	0.000	0.024	0.362	0.348	0.723	0.698	0.362	0.356
7/4/18	0.000	0.022	0.361	0.350	0.723	0.700	0.361	0.357
7/5/18	0.000	0.021	0.362	0.351	0.724	0.703	0.362	0.358
7/6/18	0.000	0.020	0.362	0.352	0.723	0.704	0.362	0.358
7/7/18	0.000	0.019	0.362	0.352	0.723	0.705	0.362	0.358
7/8/18	0.000	0.018	0.361	0.353	0.723	0.705	0.361	0.358
7/9/18	0.000	0.017	0.362	0.353	0.723	0.706	0.362	0.359
7/10/18	0.000	0.017	0.362	0.353	0.724	0.707	0.362	0.359
7/11/18	0.510	0.378	0.593	0.517	0.676	0.667	0.593	0.553
7/12/18	0.535	0.437	0.267	0.306	0.000	0.098	0.267	0.290
7/13/18	0.535	0.458	0.267	0.288	0.000	0.066	0.267	0.280
7/14/18	0.534	0.469	0.267	0.281	0.000	0.052	0.267	0.276
7/15/18	0.536	0.478	0.268	0.278	0.000	0.043	0.268	0.275
7/16/18	0.063	0.148	0.031	0.107	0.000	0.038	0.031	0.075
7/17/18	0.525	0.441	0.262	0.250	0.000	0.034	0.262	0.257
7/18/18	0.531	0.470	0.266	0.262	0.000	0.031	0.266	0.265
7/19/18	0.577	0.512	0.288	0.280	0.000	0.028	0.288	0.286
7/20/18	0.545	0.500	0.273	0.272	0.000	0.026	0.273	0.274
7/21/18	0.591	0.535	0.295	0.288	0.000	0.024	0.295	0.293
7/22/18	0.555	0.516	0.278	0.278	0.000	0.023	0.278	0.279
7/23/18	0.515	0.489	0.258	0.263	0.000	0.021	0.258	0.262

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.548	0.510	0.642	0.534	0.737	0.640	0.642	0.584
7/25/18	0.000	0.125	0.389	0.385	0.777	0.707	0.389	0.389
7/26/18	0.000	0.081	0.380	0.371	0.759	0.708	0.380	0.377
7/27/18	0.000	0.062	0.361	0.356	0.722	0.685	0.361	0.360
7/28/18	0.000	0.051	0.361	0.354	0.722	0.689	0.361	0.359
7/29/18	0.000	0.043	0.000	0.097	0.000	0.085	0.000	0.055
7/30/18	0.000	0.038	0.367	0.328	0.735	0.672	0.367	0.347
7/31/18	0.000	0.034	0.388	0.359	0.776	0.728	0.388	0.374
8/1/18	0.000	0.031	0.388	0.367	0.776	0.738	0.388	0.378
8/2/18	0.000	0.028	0.389	0.371	0.777	0.744	0.389	0.381
8/3/18	0.000	0.026	0.371	0.360	0.741	0.717	0.371	0.367
8/4/18	0.000	0.024	0.374	0.362	0.747	0.723	0.374	0.369
8/5/18	0.000	0.023	0.388	0.373	0.776	0.749	0.388	0.381
8/6/18	0.000	0.022	0.388	0.375	0.776	0.752	0.388	0.383
8/7/18	0.000	0.020	0.389	0.376	0.777	0.754	0.389	0.383
8/8/18	0.000	0.019	0.388	0.376	0.776	0.755	0.388	0.384
8/9/18	0.000	0.018	0.388	0.377	0.776	0.756	0.388	0.384
8/10/18	0.000	0.018	0.388	0.377	0.777	0.757	0.388	0.384
8/11/18	0.000	0.017	0.388	0.377	0.775	0.757	0.388	0.384
8/12/18	0.000	0.016	0.388	0.377	0.775	0.757	0.388	0.384
8/13/18	0.000	0.016	0.365	0.361	0.730	0.719	0.365	0.365
8/14/18	0.000	0.015	0.000	0.101	0.000	0.104	0.000	0.057
8/15/18	0.000	0.015	0.000	0.070	0.000	0.070	0.000	0.040
8/16/18	0.000	0.014	0.000	0.056	0.000	0.055	0.000	0.032
8/17/18	0.000	0.014	0.000	0.048	0.000	0.046	0.000	0.028
8/18/18	0.000	0.013	0.000	0.042	0.000	0.040	0.000	0.024
8/19/18	0.000	0.013	0.000	0.038	0.000	0.035	0.000	0.022
8/20/18	0.000	0.013	0.376	0.301	0.752	0.664	0.376	0.336
8/21/18	0.000	0.012	0.388	0.338	0.777	0.717	0.388	0.363
8/22/18	0.000	0.012	0.389	0.351	0.777	0.732	0.389	0.370
8/23/18	0.000	0.012	0.388	0.358	0.777	0.740	0.388	0.374
8/24/18	0.000	0.011	0.389	0.363	0.777	0.745	0.389	0.376
8/25/18	0.000	0.011	0.388	0.366	0.775	0.747	0.388	0.377
8/26/18	0.000	0.011	0.388	0.368	0.775	0.749	0.388	0.378
8/27/18	0.000	0.011	0.389	0.370	0.777	0.753	0.389	0.380
8/28/18	0.000	0.010	0.411	0.388	0.822	0.793	0.411	0.400
8/29/18	0.000	0.010	0.424	0.400	0.847	0.817	0.424	0.412
8/30/18	0.000	0.010	0.388	0.377	0.776	0.761	0.388	0.384
8/31/18	0.000	0.010	0.385	0.374	0.770	0.755	0.385	0.381
9/1/18	0.000	0.010	0.436	0.409	0.871	0.839	0.436	0.423
9/2/18	0.000	0.010	0.470	0.438	0.941	0.902	0.470	0.455
9/3/18	0.000	0.009	0.446	0.426	0.893	0.867	0.446	0.437
9/4/18	0.000	0.009	0.396	0.391	0.792	0.783	0.396	0.395
9/5/18	0.477	0.347	0.595	0.529	0.713	0.714	0.595	0.561
9/6/18	0.457	0.373	0.229	0.285	0.000	0.109	0.229	0.261
9/7/18	0.437	0.374	0.218	0.254	0.000	0.074	0.218	0.239
9/8/18	0.480	0.413	0.240	0.259	0.000	0.059	0.240	0.252
9/9/18	0.498	0.435	0.249	0.262	0.000	0.049	0.249	0.257
9/10/18	0.481	0.431	0.240	0.254	0.000	0.043	0.240	0.249
9/11/18	0.501	0.449	0.251	0.258	0.000	0.038	0.251	0.256
9/12/18	0.512	0.462	0.256	0.261	0.000	0.035	0.256	0.260

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.489	0.450	0.245	0.253	0.000	0.032	0.245	0.251
9/14/18	0.441	0.417	0.221	0.234	0.000	0.029	0.221	0.230
9/15/18	0.450	0.422	0.225	0.235	0.000	0.027	0.225	0.232
9/16/18	0.484	0.446	0.242	0.245	0.000	0.026	0.242	0.245
9/17/18	0.465	0.436	0.233	0.239	0.000	0.024	0.233	0.238
9/18/18	0.409	0.397	0.570	0.477	0.730	0.636	0.570	0.521
9/19/18	0.000	0.103	0.433	0.408	0.867	0.784	0.433	0.421
9/20/18	0.000	0.068	0.453	0.423	0.906	0.838	0.453	0.438
9/21/18	0.000	0.052	0.453	0.427	0.907	0.851	0.453	0.440
9/22/18	0.000	0.043	0.415	0.402	0.830	0.794	0.415	0.410
9/23/18	0.000	0.037	0.453	0.428	0.906	0.860	0.453	0.441
9/24/18	0.000	0.032	0.434	0.418	0.869	0.835	0.434	0.427
9/25/18	0.000	0.029	0.396	0.390	0.791	0.772	0.396	0.394
9/26/18	0.000	0.026	0.396	0.388	0.791	0.770	0.396	0.393
9/27/18	0.000	0.024	0.417	0.402	0.833	0.806	0.417	0.410
9/28/18	0.000	0.022	0.396	0.389	0.793	0.774	0.396	0.394
9/29/18	0.000	0.021	0.367	0.367	0.735	0.725	0.367	0.369
9/30/18	0.000	0.019	0.346	0.349	0.692	0.687	0.346	0.349
10/1/18	0.000	0.018	0.371	0.365	0.743	0.727	0.371	0.369
10/2/18	0.000	0.017	0.355	0.353	0.709	0.700	0.355	0.355
10/3/18	0.000	0.016	0.334	0.337	0.667	0.664	0.334	0.337
10/4/18	0.000	0.016	0.333	0.334	0.666	0.660	0.333	0.335
10/5/18	0.000	0.015	0.334	0.334	0.668	0.661	0.334	0.335
10/6/18	0.000	0.014	0.333	0.332	0.667	0.659	0.333	0.334
10/7/18	0.000	0.014	0.319	0.322	0.638	0.635	0.319	0.322
10/8/18	0.000	0.013	0.274	0.288	0.547	0.557	0.274	0.283
10/9/18	0.000	0.013	0.294	0.298	0.588	0.587	0.294	0.298
10/10/18	0.000	0.012	0.301	0.302	0.602	0.598	0.301	0.303
10/11/18	0.000	0.012	0.246	0.263	0.492	0.506	0.246	0.257
10/12/18	0.000	0.012	0.246	0.258	0.493	0.501	0.246	0.254
10/13/18	0.000	0.011	0.245	0.255	0.490	0.496	0.245	0.252
10/14/18	0.000	0.011	0.244	0.253	0.489	0.494	0.244	0.250
10/15/18	0.000	0.011	0.247	0.254	0.494	0.496	0.247	0.252
10/16/18	0.242	0.182	0.366	0.338	0.491	0.494	0.366	0.352
10/17/18	0.456	0.354	0.228	0.249	0.000	0.080	0.228	0.241
10/18/18	0.489	0.404	0.245	0.253	0.000	0.057	0.245	0.251
10/19/18	0.502	0.429	0.251	0.256	0.000	0.047	0.251	0.255
10/20/18	0.512	0.447	0.256	0.259	0.000	0.040	0.256	0.259
10/21/18	0.517	0.458	0.258	0.261	0.000	0.036	0.258	0.261
10/22/18	0.506	0.457	0.253	0.257	0.000	0.032	0.253	0.257
10/23/18	0.446	0.417	0.223	0.235	0.000	0.030	0.223	0.231
10/24/18	0.452	0.420	0.226	0.234	0.000	0.028	0.226	0.232
10/25/18	0.469	0.433	0.235	0.239	0.000	0.026	0.235	0.238
10/26/18	0.480	0.443	0.240	0.243	0.000	0.024	0.240	0.243
10/27/18	0.483	0.448	0.241	0.244	0.000	0.023	0.241	0.244
10/28/18	0.488	0.454	0.244	0.246	0.000	0.022	0.244	0.246
10/29/18	0.478	0.448	0.239	0.242	0.000	0.021	0.239	0.242
10/30/18	0.422	0.410	0.211	0.222	0.000	0.020	0.211	0.218
10/31/18	0.000	0.106	0.000	0.070	0.000	0.019	0.000	0.040
11/1/18	0.481	0.411	0.240	0.222	0.000	0.019	0.240	0.231
11/2/18	0.529	0.469	0.264	0.250	0.000	0.018	0.264	0.258

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.590	0.525	0.295	0.277	0.000	0.017	0.295	0.287
11/4/18	0.574	0.525	0.287	0.277	0.000	0.017	0.287	0.283
11/5/18	0.552	0.514	0.276	0.271	0.000	0.016	0.276	0.275
11/6/18	0.000	0.124	0.000	0.075	0.000	0.016	0.000	0.043
11/7/18	0.595	0.502	0.298	0.264	0.000	0.015	0.298	0.280
11/8/18	0.570	0.515	0.285	0.270	0.000	0.015	0.285	0.278
11/9/18	0.564	0.519	0.282	0.272	0.000	0.015	0.282	0.278
11/10/18	0.566	0.525	0.283	0.275	0.000	0.014	0.283	0.280
11/11/18	0.583	0.541	0.291	0.282	0.000	0.014	0.291	0.288
11/12/18	0.592	0.551	0.296	0.287	0.000	0.014	0.296	0.292
11/13/18	0.564	0.534	0.282	0.278	0.000	0.013	0.282	0.281
11/14/18	0.578	0.544	0.289	0.283	0.000	0.013	0.289	0.287
11/15/18	0.584	0.551	0.796	0.644	1.009	0.861	0.796	0.714
11/16/18	0.000	0.138	0.280	0.319	0.560	0.530	0.280	0.303
11/17/18	0.000	0.091	0.164	0.214	0.329	0.335	0.164	0.193
11/18/18	0.000	0.070	0.117	0.163	0.233	0.247	0.117	0.143
11/19/18	0.000	0.058	0.090	0.132	0.179	0.195	0.090	0.114
11/20/18	0.000	0.050	0.067	0.107	0.134	0.152	0.067	0.090
11/21/18	0.000	0.044	0.317	0.277	0.633	0.568	0.317	0.296
11/22/18	0.000	0.039	0.274	0.264	0.549	0.517	0.274	0.270
11/23/18	0.000	0.035	0.390	0.349	0.781	0.717	0.390	0.369
11/24/18	0.000	0.032	0.454	0.405	0.908	0.839	0.454	0.429
11/25/18	0.000	0.030	0.454	0.416	0.908	0.852	0.454	0.435
11/26/18	0.000	0.028	0.417	0.395	0.834	0.797	0.417	0.407
11/27/18	0.000	0.026	0.386	0.374	0.772	0.746	0.386	0.381
11/28/18	0.000	0.025	0.000	0.099	0.000	0.097	0.000	0.056
11/29/18	0.000	0.023	0.000	0.067	0.000	0.062	0.000	0.038
11/30/18	0.000	0.022	0.000	0.053	0.000	0.047	0.000	0.030
12/1/18	0.000	0.021	0.000	0.045	0.000	0.038	0.000	0.025
12/2/18	0.000	0.020	0.000	0.039	0.000	0.033	0.000	0.022
12/3/18	0.000	0.019	0.000	0.035	0.000	0.029	0.000	0.020
12/4/18	0.000	0.018	0.000	0.032	0.000	0.026	0.000	0.019
12/5/18	0.000	0.018	0.391	0.307	0.783	0.682	0.391	0.346
12/6/18	0.000	0.017	0.395	0.340	0.790	0.723	0.395	0.367
12/7/18	0.000	0.016	0.329	0.307	0.659	0.627	0.329	0.318
12/8/18	0.000	0.016	0.273	0.269	0.546	0.534	0.273	0.272
12/9/18	0.000	0.015	0.277	0.269	0.554	0.539	0.277	0.274
12/10/18	0.000	0.015	0.334	0.310	0.667	0.634	0.334	0.322
12/11/18	0.000	0.014	0.333	0.314	0.665	0.639	0.333	0.324
12/12/18	0.000	0.014	0.352	0.330	0.703	0.674	0.352	0.341
12/13/18	0.000	0.014	0.333	0.321	0.667	0.647	0.333	0.328
12/14/18	0.000	0.013	0.306	0.302	0.613	0.602	0.306	0.305
12/15/18	0.000	0.013	0.302	0.297	0.603	0.592	0.302	0.300
12/16/18	0.000	0.013	0.292	0.289	0.583	0.575	0.292	0.291
12/17/18	0.000	0.012	0.325	0.311	0.649	0.629	0.325	0.319
12/18/18	0.000	0.012	0.182	0.213	0.365	0.393	0.182	0.200
12/19/18	0.000	0.012	0.236	0.240	0.472	0.471	0.236	0.239
12/20/18	0.000	0.012	0.279	0.270	0.557	0.543	0.279	0.275
12/21/18	0.000	0.011	0.212	0.226	0.425	0.435	0.212	0.221
12/22/18	0.000	0.011	0.226	0.231	0.451	0.452	0.226	0.230
12/23/18	0.000	0.011	0.281	0.270	0.562	0.545	0.281	0.276

Littleton Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Whitcomb 01				Whitcomb 02			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.000	0.011	0.273	0.267	0.546	0.535	0.273	0.271
12/25/18	0.000	0.010	0.272	0.268	0.545	0.536	0.272	0.271
12/26/18	0.000	0.010	0.274	0.270	0.548	0.539	0.274	0.273
12/27/18	0.000	0.010	0.274	0.270	0.549	0.540	0.274	0.273
12/28/18	0.000	0.010	0.274	0.270	0.548	0.540	0.274	0.273
12/29/18	0.000	0.010	0.273	0.270	0.545	0.538	0.273	0.272
12/30/18	0.000	0.010	0.273	0.270	0.545	0.538	0.273	0.272
12/31/18	0.000	0.009	0.273	0.270	0.546	0.539	0.273	0.273

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.156	0.208	0.000	0.204	0.000	0.290	0.345	0.290
1/2/18	0.173	0.203	0.000	0.185	0.000	0.288	0.209	0.290
1/3/18	0.145	0.199	0.000	0.168	0.153	0.284	0.407	0.290
1/4/18	0.187	0.195	0.000	0.153	0.105	0.277	0.193	0.290
1/5/18	0.164	0.194	0.000	0.142	0.181	0.271	0.515	0.290
1/6/18	0.173	0.192	0.000	0.132	0.090	0.265	0.240	0.290
1/7/18	0.193	0.191	0.000	0.124	0.099	0.261	0.232	0.291
1/8/18	0.166	0.191	0.000	0.118	0.214	0.256	0.393	0.291
1/9/18	0.178	0.190	0.000	0.112	0.262	0.252	0.606	0.291
1/10/18	0.218	0.190	0.000	0.107	0.167	0.249	0.416	0.293
1/11/18	0.260	0.194	0.000	0.102	0.104	0.248	0.281	0.297
1/12/18	0.224	0.200	0.000	0.098	0.138	0.247	0.247	0.301
1/13/18	0.175	0.201	0.000	0.095	0.240	0.244	0.569	0.302
1/14/18	0.203	0.199	0.000	0.091	0.132	0.242	0.295	0.303
1/15/18	0.260	0.200	0.000	0.088	0.139	0.240	0.445	0.305
1/16/18	0.249	0.205	0.000	0.086	0.210	0.239	0.597	0.307
1/17/18	0.155	0.207	0.000	0.083	0.186	0.237	0.164	0.310
1/18/18	0.180	0.202	0.000	0.081	0.190	0.236	0.233	0.313
1/19/18	0.158	0.198	0.000	0.079	0.263	0.235	0.427	0.313
1/20/18	0.164	0.194	0.000	0.077	0.215	0.234	0.283	0.312
1/21/18	0.175	0.192	0.000	0.075	0.235	0.235	0.405	0.312
1/22/18	0.098	0.188	0.000	0.073	0.200	0.235	0.000	0.311
1/23/18	0.170	0.182	0.000	0.072	0.218	0.236	0.404	0.310
1/24/18	0.172	0.181	0.000	0.070	0.245	0.236	0.475	0.307
1/25/18	0.169	0.182	0.000	0.069	0.221	0.236	0.339	0.305
1/26/18	0.139	0.181	0.000	0.067	0.263	0.237	0.368	0.306
1/27/18	0.141	0.178	0.000	0.066	0.215	0.237	0.195	0.307
1/28/18	0.161	0.176	0.000	0.065	0.235	0.238	0.368	0.307
1/29/18	0.173	0.176	0.000	0.064	0.201	0.238	0.223	0.306
1/30/18	0.161	0.176	0.000	0.062	0.224	0.239	0.264	0.305
1/31/18	0.169	0.176	0.000	0.061	0.243	0.238	0.428	0.304
2/1/18	0.138	0.176	0.000	0.060	0.206	0.238	0.164	0.302
2/2/18	0.155	0.174	0.000	0.059	0.184	0.239	0.051	0.302
2/3/18	0.091	0.171	0.000	0.059	0.223	0.238	0.025	0.299
2/4/18	0.135	0.166	0.000	0.058	0.279	0.238	0.479	0.294
2/5/18	0.197	0.165	0.027	0.057	0.279	0.238	0.610	0.288
2/6/18	0.161	0.169	0.000	0.058	0.206	0.238	0.209	0.287
2/7/18	0.136	0.169	0.000	0.057	0.214	0.239	0.134	0.290
2/8/18	0.169	0.168	0.000	0.056	0.184	0.239	0.278	0.291
2/9/18	0.260	0.171	0.221	0.061	0.277	0.239	0.610	0.290
2/10/18	0.170	0.178	0.000	0.073	0.186	0.239	0.224	0.290
2/11/18	0.147	0.178	0.000	0.071	0.186	0.239	0.116	0.292
2/12/18	0.145	0.175	0.000	0.067	0.180	0.238	0.156	0.293
2/13/18	0.189	0.173	0.000	0.064	0.249	0.237	0.571	0.290
2/14/18	0.175	0.175	0.000	0.061	0.227	0.236	0.391	0.288
2/15/18	0.161	0.175	0.000	0.058	0.178	0.236	0.131	0.290
2/16/18	0.172	0.174	0.000	0.057	0.279	0.236	0.561	0.291
2/17/18	0.142	0.174	0.000	0.055	0.081	0.235	0.000	0.292
2/18/18	0.223	0.173	0.151	0.057	0.279	0.235	0.610	0.293
2/19/18	0.161	0.177	0.000	0.066	0.279	0.234	0.512	0.293
2/20/18	0.145	0.176	0.000	0.064	0.241	0.233	0.329	0.295

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.169	0.174	0.000	0.061	0.193	0.234	0.266	0.299
2/22/18	0.128	0.172	0.000	0.058	0.218	0.235	0.156	0.302
2/23/18	0.178	0.170	0.000	0.056	0.210	0.235	0.345	0.302
2/24/18	0.163	0.171	0.000	0.054	0.195	0.235	0.209	0.300
2/25/18	0.193	0.171	0.000	0.052	0.170	0.234	0.275	0.298
2/26/18	0.201	0.174	0.000	0.051	0.184	0.233	0.405	0.296
2/27/18	0.183	0.177	0.000	0.050	0.144	0.232	0.164	0.295
2/28/18	0.139	0.177	0.000	0.049	0.207	0.231	0.158	0.294
3/1/18	0.175	0.174	0.000	0.048	0.195	0.229	0.311	0.292
3/2/18	0.180	0.174	0.000	0.047	0.254	0.228	0.546	0.290
3/3/18	0.184	0.175	0.000	0.046	0.187	0.228	0.278	0.289
3/4/18	0.133	0.175	0.000	0.046	0.180	0.227	0.000	0.291
3/5/18	0.204	0.173	0.012	0.045	0.254	0.227	0.610	0.291
3/6/18	0.145	0.174	0.000	0.045	0.215	0.227	0.181	0.289
3/7/18	0.163	0.173	0.000	0.045	0.229	0.227	0.297	0.290
3/8/18	0.190	0.173	0.000	0.044	0.147	0.227	0.021	0.290
3/9/18	0.180	0.174	0.000	0.043	0.203	0.227	0.120	0.289
3/10/18	0.175	0.175	0.000	0.043	0.203	0.227	0.068	0.285
3/11/18	0.218	0.176	0.000	0.042	0.292	0.226	0.540	0.279
3/12/18	0.128	0.178	0.000	0.042	0.303	0.226	0.351	0.275
3/13/18	0.087	0.173	0.000	0.041	0.266	0.227	0.114	0.275
3/14/18	0.158	0.166	0.000	0.041	0.245	0.229	0.571	0.276
3/15/18	0.107	0.164	0.000	0.040	0.254	0.230	0.258	0.276
3/16/18	0.139	0.161	0.000	0.040	0.292	0.232	0.442	0.279
3/17/18	0.107	0.159	0.000	0.040	0.303	0.233	0.020	0.281
3/18/18	0.132	0.156	0.000	0.039	0.245	0.235	0.506	0.283
3/19/18	0.147	0.155	0.026	0.040	0.254	0.236	0.610	0.283
3/20/18	0.163	0.156	0.000	0.041	0.245	0.238	0.153	0.285
3/21/18	0.190	0.159	0.000	0.040	0.170	0.239	0.428	0.289
3/22/18	0.107	0.161	0.000	0.040	0.243	0.239	0.435	0.291
3/23/18	0.124	0.158	0.000	0.039	0.243	0.238	0.184	0.293
3/24/18	0.111	0.155	0.000	0.038	0.241	0.238	0.408	0.295
3/25/18	0.159	0.153	0.000	0.038	0.241	0.238	0.416	0.296
3/26/18	0.158	0.154	0.000	0.037	0.189	0.238	0.286	0.297
3/27/18	0.098	0.155	0.000	0.037	0.178	0.237	0.021	0.299
3/28/18	0.169	0.152	0.000	0.037	0.178	0.237	0.332	0.298
3/29/18	0.127	0.154	0.000	0.036	0.245	0.235	0.510	0.295
3/30/18	0.122	0.152	0.000	0.036	0.254	0.234	0.506	0.293
3/31/18	0.113	0.150	0.000	0.036	0.254	0.233	0.249	0.295
4/1/18	0.110	0.148	0.000	0.035	0.227	0.233	0.249	0.298
4/2/18	0.172	0.147	0.000	0.035	0.227	0.234	0.376	0.299
4/3/18	0.243	0.152	0.000	0.035	0.209	0.234	0.391	0.299
4/4/18	0.336	0.164	0.187	0.039	0.266	0.234	0.610	0.300
4/5/18	0.350	0.181	0.000	0.051	0.277	0.234	0.492	0.302
4/6/18	0.416	0.199	0.000	0.049	0.170	0.234	0.110	0.307
4/7/18	0.410	0.217	0.000	0.046	0.195	0.235	0.565	0.310
4/8/18	0.348	0.231	0.000	0.044	0.204	0.234	0.467	0.311
4/9/18	0.351	0.238	0.000	0.042	0.184	0.234	0.521	0.314
4/10/18	0.334	0.243	0.000	0.040	0.180	0.233	0.527	0.317
4/11/18	0.243	0.244	0.000	0.039	0.169	0.231	0.175	0.322
4/12/18	0.350	0.242	0.402	0.048	0.268	0.230	0.610	0.325

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.361	0.247	0.000	0.072	0.277	0.229	0.595	0.327
4/14/18	0.333	0.252	0.000	0.069	0.138	0.229	0.280	0.330
4/15/18	0.289	0.254	0.000	0.062	0.201	0.229	0.469	0.334
4/16/18	0.193	0.251	0.000	0.057	0.210	0.228	0.000	0.336
4/17/18	0.345	0.245	0.109	0.055	0.195	0.228	0.610	0.335
4/18/18	0.176	0.245	0.000	0.058	0.220	0.227	0.212	0.333
4/19/18	0.197	0.236	0.000	0.055	0.231	0.226	0.396	0.332
4/20/18	0.314	0.232	0.000	0.051	0.241	0.226	0.393	0.330
4/21/18	0.337	0.237	0.069	0.050	0.207	0.226	0.610	0.329
4/22/18	0.327	0.244	0.000	0.052	0.207	0.226	0.334	0.330
4/23/18	0.393	0.251	0.000	0.049	0.135	0.227	0.448	0.332
4/24/18	0.305	0.259	0.315	0.054	0.246	0.226	0.610	0.334
4/25/18	0.314	0.260	0.085	0.074	0.246	0.225	0.610	0.337
4/26/18	0.296	0.261	0.000	0.076	0.193	0.225	0.565	0.341
4/27/18	0.254	0.259	0.000	0.069	0.200	0.225	0.317	0.347
4/28/18	0.347	0.257	0.000	0.062	0.152	0.225	0.376	0.351
4/29/18	0.224	0.258	0.000	0.057	0.156	0.224	0.168	0.353
4/30/18	0.303	0.254	0.301	0.060	0.262	0.223	0.610	0.352
5/1/18	0.311	0.255	0.123	0.079	0.262	0.222	0.610	0.350
5/2/18	0.359	0.259	0.392	0.093	0.226	0.222	0.610	0.351
5/3/18	0.387	0.266	0.106	0.112	0.226	0.222	0.610	0.355
5/4/18	0.391	0.274	0.000	0.109	0.138	0.223	0.609	0.360
5/5/18	0.410	0.282	0.160	0.101	0.152	0.223	0.610	0.366
5/6/18	0.474	0.291	0.236	0.105	0.152	0.222	0.610	0.372
5/7/18	0.421	0.302	0.567	0.124	0.231	0.221	0.610	0.377
5/8/18	0.370	0.307	0.176	0.154	0.231	0.219	0.610	0.383
5/9/18	0.398	0.307	0.211	0.156	0.238	0.219	0.610	0.388
5/10/18	0.520	0.312	0.648	0.166	0.263	0.219	0.610	0.393
5/11/18	0.374	0.322	0.482	0.201	0.277	0.220	0.610	0.397
5/12/18	0.232	0.318	0.000	0.211	0.251	0.221	0.438	0.401
5/13/18	0.370	0.307	0.473	0.197	0.254	0.222	0.610	0.405
5/14/18	0.325	0.305	0.481	0.213	0.292	0.224	0.610	0.406
5/15/18	0.286	0.301	0.205	0.225	0.306	0.225	0.610	0.408
5/16/18	0.385	0.298	0.168	0.216	0.243	0.227	0.610	0.411
5/17/18	0.521	0.305	0.648	0.215	0.224	0.229	0.610	0.414
5/18/18	0.376	0.317	0.205	0.236	0.231	0.230	0.610	0.417
5/19/18	0.313	0.318	0.204	0.230	0.248	0.231	0.610	0.420
5/20/18	0.333	0.312	0.352	0.223	0.248	0.231	0.610	0.423
5/21/18	0.368	0.310	0.360	0.228	0.252	0.232	0.610	0.426
5/22/18	0.370	0.310	0.304	0.233	0.266	0.232	0.610	0.429
5/23/18	0.439	0.313	0.648	0.243	0.311	0.233	0.610	0.431
5/24/18	0.387	0.319	0.560	0.271	0.319	0.233	0.610	0.434
5/25/18	0.387	0.322	0.648	0.294	0.302	0.235	0.610	0.436
5/26/18	0.402	0.323	0.648	0.318	0.317	0.237	0.610	0.438
5/27/18	0.368	0.325	0.566	0.337	0.313	0.239	0.610	0.440
5/28/18	0.317	0.323	0.491	0.345	0.291	0.241	0.610	0.442
5/29/18	0.379	0.319	0.648	0.350	0.297	0.243	0.610	0.444
5/30/18	0.384	0.320	0.648	0.364	0.345	0.245	0.610	0.446
5/31/18	0.376	0.321	0.648	0.379	0.362	0.246	0.610	0.448
6/1/18	0.401	0.323	0.648	0.391	0.373	0.249	0.610	0.450
6/2/18	0.409	0.326	0.648	0.401	0.449	0.251	0.610	0.451

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.495	0.331	0.648	0.410	0.464	0.255	0.610	0.453
6/4/18	0.328	0.338	0.631	0.418	0.345	0.259	0.610	0.455
6/5/18	0.337	0.333	0.597	0.423	0.320	0.263	0.610	0.456
6/6/18	0.333	0.328	0.348	0.419	0.320	0.267	0.610	0.458
6/7/18	0.504	0.328	0.648	0.406	0.344	0.269	0.610	0.459
6/8/18	0.374	0.336	0.648	0.414	0.361	0.270	0.610	0.460
6/9/18	0.401	0.337	0.648	0.425	0.357	0.272	0.610	0.462
6/10/18	0.520	0.341	0.648	0.434	0.480	0.273	0.610	0.463
6/11/18	0.521	0.352	0.648	0.441	0.498	0.275	0.610	0.464
6/12/18	0.441	0.361	0.648	0.448	0.436	0.279	0.610	0.465
6/13/18	0.520	0.365	0.648	0.454	0.424	0.283	0.610	0.466
6/14/18	0.446	0.371	0.648	0.459	0.424	0.287	0.610	0.468
6/15/18	0.382	0.370	0.648	0.463	0.444	0.291	0.610	0.469
6/16/18	0.449	0.366	0.648	0.467	0.444	0.294	0.610	0.470
6/17/18	0.460	0.367	0.648	0.471	0.549	0.297	0.610	0.471
6/18/18	0.456	0.370	0.648	0.474	0.574	0.301	0.610	0.472
6/19/18	0.241	0.367	0.648	0.478	0.498	0.306	0.610	0.473
6/20/18	0.517	0.357	0.648	0.481	0.470	0.311	0.610	0.474
6/21/18	0.422	0.363	0.648	0.483	0.497	0.316	0.610	0.475
6/22/18	0.460	0.365	0.648	0.486	0.483	0.320	0.610	0.476
6/23/18	0.283	0.364	0.604	0.488	0.396	0.324	0.610	0.477
6/24/18	0.415	0.356	0.648	0.487	0.486	0.327	0.610	0.477
6/25/18	0.249	0.351	0.648	0.490	0.486	0.329	0.610	0.478
6/26/18	0.404	0.342	0.648	0.493	0.396	0.331	0.610	0.479
6/27/18	0.460	0.345	0.648	0.495	0.415	0.333	0.610	0.480
6/28/18	0.238	0.347	0.272	0.488	0.415	0.334	0.610	0.481
6/29/18	0.521	0.341	0.648	0.467	0.257	0.334	0.610	0.481
6/30/18	0.334	0.348	0.648	0.471	0.421	0.334	0.610	0.482
7/1/18	0.521	0.350	0.648	0.479	0.614	0.332	0.610	0.483
7/2/18	0.388	0.358	0.648	0.486	0.619	0.332	0.610	0.484
7/3/18	0.512	0.361	0.648	0.491	0.520	0.335	0.610	0.484
7/4/18	0.317	0.365	0.648	0.495	0.546	0.339	0.610	0.485
7/5/18	0.447	0.360	0.648	0.499	0.526	0.344	0.610	0.486
7/6/18	0.263	0.358	0.648	0.502	0.508	0.348	0.610	0.487
7/7/18	0.340	0.347	0.648	0.505	0.579	0.352	0.610	0.487
7/8/18	0.439	0.344	0.648	0.507	0.591	0.355	0.610	0.488
7/9/18	0.354	0.347	0.648	0.510	0.596	0.359	0.610	0.488
7/10/18	0.521	0.350	0.648	0.512	0.610	0.364	0.610	0.489
7/11/18	0.328	0.357	0.648	0.514	0.477	0.368	0.610	0.490
7/12/18	0.430	0.354	0.648	0.515	0.596	0.372	0.610	0.490
7/13/18	0.385	0.356	0.648	0.517	0.622	0.376	0.610	0.491
7/14/18	0.474	0.357	0.648	0.519	0.552	0.379	0.610	0.492
7/15/18	0.288	0.359	0.648	0.520	0.565	0.383	0.610	0.492
7/16/18	0.362	0.351	0.648	0.522	0.455	0.386	0.610	0.493
7/17/18	0.390	0.348	0.648	0.523	0.511	0.388	0.610	0.493
7/18/18	0.156	0.343	0.487	0.520	0.535	0.389	0.610	0.494
7/19/18	0.337	0.328	0.648	0.511	0.441	0.390	0.610	0.494
7/20/18	0.351	0.325	0.648	0.513	0.509	0.391	0.610	0.495
7/21/18	0.282	0.324	0.648	0.517	0.514	0.391	0.610	0.495
7/22/18	0.272	0.319	0.648	0.520	0.515	0.391	0.610	0.496
7/23/18	0.121	0.310	0.289	0.514	0.464	0.391	0.610	0.496

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.313	0.296	0.648	0.494	0.334	0.392	0.610	0.497
7/25/18	0.285	0.296	0.648	0.497	0.549	0.391	0.610	0.497
7/26/18	0.136	0.292	0.502	0.501	0.574	0.390	0.610	0.498
7/27/18	0.200	0.280	0.648	0.498	0.464	0.390	0.610	0.498
7/28/18	0.221	0.273	0.592	0.502	0.487	0.391	0.610	0.499
7/29/18	0.306	0.271	0.648	0.505	0.491	0.391	0.610	0.499
7/30/18	0.262	0.275	0.648	0.510	0.636	0.392	0.610	0.500
7/31/18	0.265	0.275	0.648	0.515	0.659	0.393	0.610	0.500
8/1/18	0.300	0.276	0.648	0.519	0.664	0.396	0.610	0.501
8/2/18	0.266	0.278	0.648	0.522	0.622	0.400	0.610	0.501
8/3/18	0.218	0.276	0.648	0.525	0.464	0.405	0.610	0.501
8/4/18	0.246	0.272	0.648	0.528	0.418	0.409	0.610	0.502
8/5/18	0.221	0.269	0.648	0.530	0.497	0.410	0.610	0.502
8/6/18	0.204	0.264	0.648	0.532	0.520	0.410	0.610	0.503
8/7/18	0.404	0.264	0.648	0.533	0.407	0.410	0.610	0.503
8/8/18	0.367	0.276	0.648	0.535	0.407	0.409	0.610	0.504
8/9/18	0.173	0.281	0.522	0.533	0.402	0.407	0.610	0.504
8/10/18	0.339	0.276	0.648	0.526	0.491	0.405	0.610	0.504
8/11/18	0.238	0.277	0.648	0.528	0.491	0.403	0.610	0.505
8/12/18	0.161	0.272	0.598	0.530	0.368	0.401	0.610	0.505
8/13/18	0.115	0.260	0.262	0.520	0.393	0.400	0.610	0.505
8/14/18	0.215	0.249	0.648	0.498	0.401	0.398	0.610	0.506
8/15/18	0.195	0.245	0.496	0.499	0.401	0.396	0.610	0.506
8/16/18	0.155	0.241	0.264	0.489	0.365	0.394	0.610	0.507
8/17/18	0.145	0.235	0.618	0.471	0.407	0.391	0.610	0.507
8/18/18	0.000	0.225	0.648	0.479	0.407	0.389	0.610	0.507
8/19/18	0.000	0.206	0.000	0.476	0.412	0.387	0.074	0.508
8/20/18	0.000	0.190	0.648	0.445	0.498	0.385	0.610	0.506
8/21/18	0.000	0.176	0.140	0.444	0.498	0.384	0.610	0.500
8/22/18	0.000	0.165	0.648	0.429	0.549	0.384	0.610	0.496
8/23/18	0.000	0.155	0.560	0.442	0.574	0.385	0.610	0.494
8/24/18	0.000	0.147	0.648	0.455	0.405	0.387	0.610	0.494
8/25/18	0.000	0.140	0.000	0.454	0.331	0.390	0.546	0.495
8/26/18	0.000	0.134	0.648	0.427	0.504	0.391	0.610	0.495
8/27/18	0.000	0.129	0.648	0.440	0.526	0.390	0.610	0.496
8/28/18	0.000	0.124	0.648	0.458	0.526	0.390	0.610	0.497
8/29/18	0.000	0.119	0.648	0.473	0.512	0.391	0.610	0.497
8/30/18	0.000	0.115	0.648	0.485	0.367	0.393	0.610	0.498
8/31/18	0.000	0.112	0.324	0.486	0.388	0.394	0.610	0.500
9/1/18	0.000	0.108	0.648	0.474	0.491	0.394	0.610	0.501
9/2/18	0.000	0.105	0.648	0.481	0.525	0.393	0.610	0.502
9/3/18	0.000	0.103	0.648	0.492	0.548	0.393	0.610	0.503
9/4/18	0.000	0.100	0.648	0.500	0.548	0.394	0.610	0.503
9/5/18	0.000	0.097	0.648	0.507	0.548	0.396	0.610	0.504
9/6/18	0.000	0.095	0.648	0.513	0.506	0.398	0.610	0.505
9/7/18	0.000	0.093	0.648	0.518	0.461	0.400	0.610	0.506
9/8/18	0.000	0.091	0.648	0.522	0.436	0.402	0.610	0.506
9/9/18	0.000	0.089	0.648	0.525	0.436	0.403	0.610	0.507
9/10/18	0.000	0.087	0.648	0.528	0.525	0.403	0.610	0.508
9/11/18	0.000	0.085	0.493	0.527	0.543	0.402	0.610	0.508
9/12/18	0.000	0.084	0.389	0.513	0.393	0.403	0.610	0.509

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.000	0.082	0.067	0.486	0.416	0.404	0.610	0.509
9/14/18	0.000	0.080	0.553	0.453	0.466	0.403	0.610	0.510
9/15/18	0.000	0.079	0.648	0.458	0.466	0.402	0.610	0.510
9/16/18	0.000	0.078	0.648	0.474	0.433	0.401	0.610	0.511
9/17/18	0.000	0.076	0.648	0.488	0.433	0.401	0.610	0.511
9/18/18	0.000	0.075	0.000	0.483	0.438	0.400	0.513	0.512
9/19/18	0.000	0.074	0.648	0.451	0.480	0.399	0.610	0.512
9/20/18	0.000	0.073	0.422	0.455	0.503	0.399	0.610	0.511
9/21/18	0.000	0.071	0.648	0.457	0.446	0.399	0.610	0.511
9/22/18	0.000	0.070	0.047	0.456	0.469	0.399	0.610	0.511
9/23/18	0.000	0.069	0.648	0.432	0.497	0.399	0.610	0.511
9/24/18	0.000	0.068	0.648	0.446	0.497	0.400	0.610	0.512
9/25/18	0.000	0.067	0.196	0.453	0.441	0.400	0.610	0.512
9/26/18	0.051	0.068	0.573	0.437	0.396	0.401	0.610	0.513
9/27/18	0.033	0.071	0.000	0.431	0.421	0.401	0.569	0.513
9/28/18	0.088	0.074	0.648	0.406	0.475	0.400	0.610	0.513
9/29/18	0.053	0.079	0.208	0.413	0.475	0.399	0.610	0.513
9/30/18	0.108	0.082	0.648	0.407	0.367	0.399	0.610	0.514
10/1/18	0.002	0.086	0.000	0.411	0.351	0.398	0.521	0.514
10/2/18	0.102	0.085	0.000	0.375	0.200	0.397	0.606	0.514
10/3/18	0.147	0.090	0.648	0.354	0.426	0.394	0.610	0.513
10/4/18	0.091	0.097	0.000	0.365	0.446	0.390	0.609	0.513
10/5/18	0.090	0.100	0.399	0.347	0.376	0.387	0.610	0.513
10/6/18	0.104	0.102	0.000	0.342	0.398	0.385	0.291	0.513
10/7/18	0.079	0.103	0.648	0.330	0.450	0.384	0.610	0.512
10/8/18	0.127	0.104	0.000	0.344	0.450	0.383	0.523	0.509
10/9/18	0.119	0.108	0.211	0.324	0.317	0.383	0.610	0.507
10/10/18	0.149	0.112	0.580	0.323	0.317	0.382	0.610	0.505
10/11/18	0.220	0.119	0.000	0.335	0.328	0.381	0.323	0.505
10/12/18	0.124	0.127	0.411	0.319	0.316	0.379	0.610	0.504
10/13/18	0.173	0.129	0.010	0.318	0.331	0.376	0.610	0.501
10/14/18	0.164	0.133	0.109	0.296	0.221	0.373	0.610	0.500
10/15/18	0.223	0.138	0.157	0.282	0.221	0.370	0.610	0.500
10/16/18	0.203	0.145	0.000	0.270	0.197	0.366	0.430	0.501
10/17/18	0.200	0.151	0.128	0.254	0.231	0.361	0.610	0.501
10/18/18	0.189	0.154	0.000	0.244	0.246	0.355	0.428	0.500
10/19/18	0.150	0.156	0.000	0.228	0.238	0.350	0.435	0.499
10/20/18	0.149	0.154	0.072	0.215	0.238	0.345	0.610	0.497
10/21/18	0.192	0.154	0.000	0.207	0.203	0.341	0.388	0.495
10/22/18	0.204	0.157	0.061	0.198	0.203	0.337	0.610	0.493
10/23/18	0.217	0.161	0.000	0.192	0.203	0.333	0.000	0.491
10/24/18	0.144	0.164	0.180	0.187	0.260	0.329	0.610	0.488
10/25/18	0.172	0.162	0.033	0.191	0.260	0.325	0.610	0.482
10/26/18	0.201	0.162	0.000	0.184	0.164	0.322	0.260	0.478
10/27/18	0.183	0.165	0.000	0.175	0.152	0.319	0.000	0.476
10/28/18	0.193	0.166	0.000	0.166	0.139	0.316	0.382	0.471
10/29/18	0.227	0.169	0.050	0.160	0.159	0.312	0.610	0.462
10/30/18	0.235	0.173	0.000	0.156	0.159	0.307	0.261	0.456
10/31/18	0.204	0.178	0.000	0.150	0.144	0.302	0.411	0.453
11/1/18	0.206	0.179	0.000	0.145	0.215	0.298	0.453	0.449
11/2/18	0.164	0.179	0.000	0.139	0.215	0.294	0.464	0.446

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.197	0.177	0.000	0.135	0.201	0.291	0.161	0.445
11/4/18	0.249	0.179	0.013	0.131	0.206	0.289	0.610	0.443
11/5/18	0.125	0.181	0.000	0.128	0.153	0.287	0.141	0.439
11/6/18	0.178	0.177	0.241	0.131	0.300	0.285	0.610	0.437
11/7/18	0.187	0.175	0.000	0.142	0.130	0.283	0.264	0.434
11/8/18	0.240	0.177	0.000	0.138	0.203	0.282	0.602	0.433
11/9/18	0.204	0.181	0.000	0.131	0.132	0.280	0.249	0.431
11/10/18	0.257	0.184	0.000	0.126	0.043	0.278	0.320	0.431
11/11/18	0.204	0.188	0.000	0.121	0.161	0.275	0.326	0.429
11/12/18	0.229	0.190	0.000	0.117	0.119	0.271	0.216	0.426
11/13/18	0.152	0.190	0.000	0.113	0.186	0.267	0.315	0.422
11/14/18	0.183	0.186	0.083	0.112	0.272	0.264	0.610	0.417
11/15/18	0.184	0.184	0.000	0.114	0.077	0.261	0.000	0.414
11/16/18	0.110	0.181	0.000	0.111	0.245	0.260	0.258	0.412
11/17/18	0.192	0.176	0.174	0.112	0.320	0.259	0.610	0.408
11/18/18	0.124	0.175	0.000	0.120	0.101	0.258	0.000	0.404
11/19/18	0.214	0.173	0.159	0.120	0.272	0.258	0.610	0.401
11/20/18	0.128	0.174	0.000	0.125	0.145	0.258	0.038	0.398
11/21/18	0.203	0.172	0.000	0.119	0.240	0.258	0.524	0.396
11/22/18	0.156	0.173	0.000	0.113	0.265	0.257	0.459	0.393
11/23/18	0.012	0.169	0.000	0.108	0.328	0.257	0.189	0.392
11/24/18	0.195	0.159	0.000	0.104	0.232	0.258	0.549	0.392
11/25/18	0.183	0.162	0.000	0.100	0.226	0.259	0.551	0.391
11/26/18	0.167	0.165	0.000	0.097	0.193	0.260	0.218	0.393
11/27/18	0.173	0.166	0.000	0.094	0.248	0.261	0.561	0.395
11/28/18	0.201	0.168	0.000	0.092	0.156	0.261	0.238	0.395
11/29/18	0.192	0.171	0.000	0.090	0.189	0.260	0.537	0.396
11/30/18	0.104	0.171	0.000	0.088	0.145	0.259	0.000	0.396
12/1/18	0.193	0.167	0.255	0.092	0.283	0.257	0.610	0.395
12/2/18	0.217	0.170	0.000	0.107	0.094	0.256	0.082	0.393
12/3/18	0.193	0.174	0.013	0.104	0.241	0.255	0.610	0.391
12/4/18	0.172	0.175	0.000	0.100	0.150	0.253	0.029	0.389
12/5/18	0.167	0.175	0.000	0.095	0.243	0.252	0.487	0.387
12/6/18	0.107	0.172	0.000	0.091	0.170	0.251	0.000	0.384
12/7/18	0.183	0.168	0.253	0.094	0.353	0.250	0.610	0.381
12/8/18	0.161	0.168	0.000	0.107	0.159	0.250	0.110	0.377
12/9/18	0.223	0.170	0.000	0.104	0.176	0.250	0.407	0.376
12/10/18	0.183	0.174	0.000	0.098	0.260	0.250	0.462	0.373
12/11/18	0.178	0.175	0.000	0.093	0.180	0.250	0.199	0.372
12/12/18	0.204	0.175	0.000	0.089	0.235	0.249	0.404	0.372
12/13/18	0.169	0.177	0.000	0.085	0.269	0.249	0.503	0.371
12/14/18	0.180	0.176	0.000	0.083	0.149	0.249	0.090	0.371
12/15/18	0.144	0.175	0.000	0.080	0.204	0.249	0.113	0.372
12/16/18	0.161	0.172	0.000	0.078	0.280	0.249	0.402	0.369
12/17/18	0.193	0.172	0.000	0.076	0.306	0.248	0.555	0.364
12/18/18	0.198	0.174	0.000	0.075	0.172	0.249	0.116	0.363
12/19/18	0.217	0.177	0.030	0.074	0.309	0.250	0.610	0.363
12/20/18	0.210	0.180	0.000	0.075	0.145	0.250	0.026	0.363
12/21/18	0.197	0.182	0.000	0.073	0.121	0.251	0.000	0.363
12/22/18	0.193	0.183	0.276	0.078	0.405	0.250	0.610	0.360
12/23/18	0.218	0.184	0.000	0.094	0.127	0.249	0.117	0.355

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Cote 07				Country 19			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.262	0.187	0.143	0.095	0.279	0.249	0.610	0.353
12/25/18	0.232	0.193	0.000	0.099	0.141	0.249	0.170	0.352
12/26/18	0.220	0.195	0.000	0.093	0.164	0.249	0.161	0.353
12/27/18	0.283	0.198	0.000	0.087	0.156	0.248	0.371	0.352
12/28/18	0.258	0.203	0.000	0.083	0.223	0.246	0.478	0.349
12/29/18	0.193	0.205	0.000	0.079	0.214	0.244	0.192	0.349
12/30/18	0.246	0.204	0.000	0.076	0.132	0.243	0.103	0.349
12/31/18	0.193	0.204	0.000	0.073	0.218	0.242	0.173	0.348

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.345	0.183	0.720	0.183	0.215	0.272	0.000	0.189
1/2/18	0.288	0.184	0.720	0.184	0.164	0.237	0.000	0.140
1/3/18	0.368	0.184	0.720	0.186	0.227	0.246	0.000	0.116
1/4/18	0.354	0.185	0.720	0.191	0.118	0.205	0.000	0.101
1/5/18	0.330	0.187	0.720	0.199	0.229	0.230	0.000	0.091
1/6/18	0.407	0.190	0.720	0.208	0.076	0.178	0.000	0.083
1/7/18	0.234	0.193	0.720	0.218	0.130	0.178	0.000	0.077
1/8/18	0.260	0.196	0.720	0.228	0.286	0.236	0.000	0.072
1/9/18	0.313	0.198	0.720	0.238	0.344	0.279	0.000	0.068
1/10/18	0.365	0.201	0.720	0.248	0.220	0.249	0.000	0.064
1/11/18	0.340	0.202	0.720	0.258	0.136	0.207	0.000	0.061
1/12/18	0.243	0.204	0.720	0.267	0.183	0.209	0.000	0.058
1/13/18	0.299	0.206	0.720	0.276	0.320	0.261	0.000	0.056
1/14/18	0.378	0.208	0.720	0.285	0.172	0.223	0.000	0.054
1/15/18	0.362	0.210	0.720	0.293	0.144	0.199	0.000	0.052
1/16/18	0.212	0.211	0.720	0.301	0.280	0.241	0.000	0.050
1/17/18	0.251	0.213	0.720	0.308	0.243	0.242	0.000	0.049
1/18/18	0.229	0.215	0.720	0.315	0.252	0.247	0.000	0.047
1/19/18	0.227	0.216	0.720	0.322	0.345	0.285	0.000	0.046
1/20/18	0.252	0.216	0.720	0.328	0.288	0.279	0.000	0.045
1/21/18	0.147	0.216	0.720	0.334	0.311	0.287	0.000	0.043
1/22/18	0.231	0.216	0.622	0.340	0.198	0.247	0.000	0.042
1/23/18	0.245	0.215	0.720	0.346	0.292	0.269	0.000	0.041
1/24/18	0.237	0.214	0.720	0.351	0.322	0.288	0.000	0.040
1/25/18	0.210	0.214	0.720	0.355	0.296	0.286	0.000	0.040
1/26/18	0.197	0.213	0.720	0.360	0.347	0.306	0.000	0.039
1/27/18	0.207	0.212	0.720	0.364	0.285	0.290	0.000	0.038
1/28/18	0.235	0.212	0.720	0.369	0.314	0.297	0.000	0.037
1/29/18	0.215	0.211	0.720	0.373	0.212	0.260	0.000	0.036
1/30/18	0.237	0.210	0.720	0.378	0.221	0.249	0.000	0.036
1/31/18	0.209	0.210	0.720	0.382	0.241	0.252	0.000	0.035
2/1/18	0.215	0.209	0.720	0.386	0.204	0.237	0.000	0.035
2/2/18	0.118	0.209	0.720	0.390	0.184	0.223	0.000	0.034
2/3/18	0.187	0.208	0.720	0.393	0.223	0.231	0.000	0.033
2/4/18	0.271	0.207	0.720	0.397	0.277	0.254	0.000	0.033
2/5/18	0.218	0.206	0.720	0.400	0.279	0.263	0.000	0.032
2/6/18	0.198	0.205	0.720	0.404	0.206	0.239	0.000	0.032
2/7/18	0.209	0.205	0.720	0.407	0.212	0.233	0.000	0.031
2/8/18	0.339	0.204	0.720	0.410	0.184	0.219	0.000	0.031
2/9/18	0.249	0.204	0.720	0.413	0.277	0.249	0.000	0.031
2/10/18	0.206	0.204	0.720	0.416	0.186	0.224	0.000	0.030
2/11/18	0.186	0.205	0.720	0.419	0.184	0.214	0.000	0.030
2/12/18	0.258	0.205	0.720	0.422	0.180	0.208	0.000	0.029
2/13/18	0.258	0.205	0.720	0.425	0.249	0.231	0.000	0.029
2/14/18	0.221	0.205	0.720	0.428	0.227	0.231	0.000	0.029
2/15/18	0.215	0.205	0.720	0.430	0.178	0.212	0.000	0.028
2/16/18	0.227	0.205	0.720	0.433	0.280	0.245	0.000	0.028
2/17/18	0.186	0.205	0.352	0.435	0.062	0.172	0.000	0.028
2/18/18	0.285	0.205	0.720	0.437	0.279	0.228	0.000	0.027
2/19/18	0.197	0.205	0.720	0.438	0.279	0.248	0.000	0.027
2/20/18	0.198	0.205	0.720	0.439	0.241	0.242	0.000	0.027

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.227	0.205	0.720	0.439	0.193	0.223	0.000	0.026
2/22/18	0.173	0.205	0.720	0.440	0.218	0.225	0.000	0.026
2/23/18	0.237	0.205	0.720	0.442	0.209	0.222	0.000	0.026
2/24/18	0.212	0.204	0.720	0.444	0.195	0.215	0.000	0.026
2/25/18	0.254	0.204	0.720	0.446	0.170	0.202	0.000	0.025
2/26/18	0.269	0.204	0.720	0.448	0.183	0.201	0.000	0.025
2/27/18	0.243	0.204	0.720	0.450	0.149	0.187	0.000	0.025
2/28/18	0.184	0.204	0.720	0.452	0.206	0.203	0.000	0.025
3/1/18	0.229	0.204	0.720	0.454	0.217	0.212	0.000	0.024
3/2/18	0.232	0.204	0.720	0.456	0.279	0.240	0.000	0.024
3/3/18	0.235	0.204	0.720	0.458	0.204	0.223	0.000	0.024
3/4/18	0.169	0.204	0.711	0.460	0.198	0.215	0.000	0.024
3/5/18	0.254	0.204	0.720	0.462	0.279	0.243	0.000	0.023
3/6/18	0.181	0.204	0.720	0.464	0.237	0.237	0.000	0.023
3/7/18	0.200	0.204	0.720	0.466	0.251	0.242	0.000	0.023
3/8/18	0.252	0.204	0.720	0.468	0.164	0.210	0.000	0.023
3/9/18	0.240	0.203	0.720	0.469	0.220	0.220	0.000	0.023
3/10/18	0.227	0.203	0.720	0.471	0.224	0.224	0.000	0.022
3/11/18	0.285	0.203	0.720	0.473	0.320	0.263	0.000	0.022
3/12/18	0.164	0.203	0.720	0.474	0.305	0.272	0.000	0.022
3/13/18	0.111	0.204	0.720	0.476	0.232	0.249	0.000	0.022
3/14/18	0.187	0.204	0.720	0.477	0.279	0.260	0.000	0.022
3/15/18	0.138	0.203	0.720	0.479	0.223	0.242	0.000	0.022
3/16/18	0.181	0.202	0.720	0.480	0.193	0.225	0.000	0.021
3/17/18	0.136	0.201	0.720	0.482	0.139	0.196	0.000	0.021
3/18/18	0.155	0.200	0.720	0.483	0.279	0.238	0.000	0.021
3/19/18	0.190	0.199	0.720	0.485	0.231	0.234	0.000	0.021
3/20/18	0.204	0.197	0.720	0.486	0.108	0.186	0.000	0.021
3/21/18	0.231	0.196	0.720	0.488	0.150	0.183	0.000	0.021
3/22/18	0.127	0.195	0.720	0.489	0.275	0.229	0.000	0.021
3/23/18	0.156	0.195	0.720	0.490	0.186	0.210	0.000	0.020
3/24/18	0.128	0.194	0.720	0.491	0.237	0.224	0.000	0.020
3/25/18	0.200	0.193	0.720	0.493	0.197	0.214	0.000	0.020
3/26/18	0.195	0.192	0.720	0.494	0.152	0.192	0.000	0.020
3/27/18	0.107	0.191	0.720	0.495	0.206	0.205	0.000	0.020
3/28/18	0.206	0.191	0.720	0.496	0.189	0.202	0.000	0.020
3/29/18	0.147	0.190	0.720	0.497	0.240	0.221	0.000	0.020
3/30/18	0.155	0.189	0.720	0.499	0.262	0.236	0.000	0.019
3/31/18	0.142	0.188	0.720	0.500	0.187	0.214	0.000	0.019
4/1/18	0.136	0.188	0.720	0.501	0.238	0.226	0.000	0.019
4/2/18	0.210	0.187	0.720	0.502	0.152	0.197	0.000	0.019
4/3/18	0.161	0.186	0.720	0.503	0.218	0.212	0.000	0.019
4/4/18	0.204	0.185	0.720	0.504	0.241	0.226	0.000	0.019
4/5/18	0.197	0.184	0.720	0.505	0.180	0.207	0.000	0.019
4/6/18	0.234	0.184	0.720	0.506	0.053	0.151	0.000	0.019
4/7/18	0.227	0.184	0.720	0.507	0.158	0.169	0.000	0.018
4/8/18	0.190	0.184	0.720	0.508	0.195	0.188	0.000	0.018
4/9/18	0.193	0.184	0.720	0.509	0.180	0.188	0.000	0.018
4/10/18	0.200	0.185	0.720	0.510	0.122	0.167	0.000	0.018
4/11/18	0.132	0.185	0.720	0.511	0.158	0.172	0.000	0.018
4/12/18	0.203	0.186	0.720	0.512	0.251	0.209	0.000	0.018

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.192	0.186	0.720	0.513	0.135	0.178	0.000	0.018
4/14/18	0.173	0.185	0.720	0.514	0.135	0.167	0.000	0.018
4/15/18	0.169	0.185	0.720	0.515	0.164	0.174	0.000	0.018
4/16/18	0.113	0.185	0.698	0.515	0.127	0.161	0.000	0.018
4/17/18	0.200	0.185	0.720	0.516	0.197	0.183	0.000	0.017
4/18/18	0.099	0.184	0.720	0.517	0.183	0.185	0.000	0.017
4/19/18	0.110	0.184	0.720	0.518	0.200	0.193	0.000	0.017
4/20/18	0.173	0.183	0.720	0.518	0.127	0.168	0.000	0.017
4/21/18	0.183	0.182	0.720	0.519	0.167	0.174	0.000	0.017
4/22/18	0.170	0.181	0.720	0.520	0.122	0.159	0.000	0.017
4/23/18	0.260	0.180	0.720	0.521	0.102	0.145	0.000	0.017
4/24/18	0.251	0.179	0.720	0.522	0.215	0.182	0.000	0.017
4/25/18	0.258	0.179	0.720	0.522	0.181	0.182	0.000	0.017
4/26/18	0.241	0.180	0.720	0.523	0.153	0.172	0.000	0.017
4/27/18	0.206	0.181	0.720	0.524	0.158	0.171	0.000	0.017
4/28/18	0.279	0.182	0.720	0.525	0.111	0.152	0.000	0.016
4/29/18	0.186	0.183	0.720	0.525	0.156	0.162	0.000	0.016
4/30/18	0.249	0.184	0.720	0.526	0.220	0.189	0.000	0.016
5/1/18	0.248	0.185	0.720	0.527	0.207	0.195	0.000	0.016
5/2/18	0.291	0.186	0.720	0.528	0.181	0.188	0.000	0.016
5/3/18	0.299	0.187	0.720	0.528	0.138	0.170	0.000	0.016
5/4/18	0.300	0.188	0.720	0.529	0.118	0.155	0.000	0.016
5/5/18	0.311	0.190	0.720	0.530	0.153	0.162	0.000	0.016
5/6/18	0.356	0.192	0.720	0.530	0.135	0.157	0.000	0.016
5/7/18	0.320	0.194	0.720	0.531	0.232	0.192	0.000	0.016
5/8/18	0.046	0.196	0.720	0.532	0.226	0.203	0.000	0.016
5/9/18	0.000	0.198	0.720	0.532	0.201	0.199	0.000	0.016
5/10/18	0.255	0.199	0.720	0.533	0.265	0.223	0.000	0.015
5/11/18	0.272	0.199	0.720	0.534	0.266	0.234	0.000	0.015
5/12/18	0.178	0.198	0.720	0.534	0.240	0.229	0.000	0.015
5/13/18	0.294	0.197	0.720	0.535	0.232	0.226	0.000	0.015
5/14/18	0.249	0.197	0.720	0.536	0.308	0.255	0.000	0.015
5/15/18	0.215	0.197	0.720	0.536	0.243	0.241	0.000	0.015
5/16/18	0.289	0.197	0.720	0.537	0.187	0.216	0.000	0.015
5/17/18	0.391	0.197	0.720	0.538	0.224	0.221	0.000	0.015
5/18/18	0.292	0.198	0.720	0.538	0.164	0.199	0.000	0.015
5/19/18	0.237	0.199	0.720	0.539	0.251	0.223	0.000	0.015
5/20/18	0.262	0.201	0.720	0.539	0.237	0.227	0.000	0.015
5/21/18	0.266	0.203	0.720	0.540	0.252	0.234	0.000	0.015
5/22/18	0.258	0.204	0.720	0.540	0.214	0.223	0.000	0.015
5/23/18	0.313	0.205	0.720	0.541	0.320	0.260	0.000	0.015
5/24/18	0.280	0.206	0.720	0.542	0.252	0.249	0.000	0.015
5/25/18	0.271	0.207	0.720	0.542	0.316	0.270	0.000	0.014
5/26/18	0.282	0.208	0.720	0.543	0.347	0.291	0.000	0.014
5/27/18	0.258	0.209	0.720	0.543	0.291	0.279	0.000	0.014
5/28/18	0.220	0.210	0.720	0.544	0.317	0.287	0.000	0.014
5/29/18	0.268	0.211	0.720	0.544	0.319	0.291	0.000	0.014
5/30/18	0.266	0.211	0.720	0.545	0.410	0.329	0.000	0.014
5/31/18	0.251	0.212	0.720	0.545	0.435	0.354	0.000	0.014
6/1/18	0.255	0.212	0.720	0.546	0.376	0.343	0.000	0.014
6/2/18	0.262	0.213	0.720	0.546	0.556	0.411	0.000	0.014

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.339	0.213	0.720	0.547	0.412	0.384	0.000	0.014
6/4/18	0.212	0.213	0.720	0.547	0.402	0.373	0.000	0.014
6/5/18	0.223	0.214	0.720	0.548	0.381	0.362	0.000	0.014
6/6/18	0.212	0.214	0.720	0.548	0.266	0.314	0.000	0.014
6/7/18	0.390	0.215	0.720	0.549	0.427	0.357	0.000	0.014
6/8/18	0.330	0.215	0.720	0.549	0.449	0.381	0.000	0.014
6/9/18	0.328	0.215	0.720	0.550	0.461	0.396	0.000	0.014
6/10/18	0.430	0.216	0.720	0.550	0.625	0.468	0.181	0.084
6/11/18	0.439	0.217	0.720	0.551	0.569	0.476	0.125	0.090
6/12/18	0.385	0.219	0.720	0.551	0.455	0.439	0.000	0.047
6/13/18	0.491	0.222	0.720	0.552	0.687	0.518	0.506	0.228
6/14/18	0.410	0.225	0.720	0.552	0.531	0.489	0.000	0.103
6/15/18	0.379	0.228	0.720	0.553	0.656	0.530	0.000	0.061
6/16/18	0.407	0.232	0.720	0.553	0.526	0.498	0.000	0.044
6/17/18	0.481	0.235	0.720	0.554	0.780	0.586	0.690	0.303
6/18/18	0.413	0.238	0.720	0.554	0.704	0.592	0.442	0.308
6/19/18	0.292	0.242	0.720	0.554	0.416	0.488	0.000	0.148
6/20/18	0.474	0.245	0.720	0.555	0.644	0.538	0.487	0.280
6/21/18	0.376	0.247	0.720	0.555	0.659	0.562	0.086	0.175
6/22/18	0.480	0.250	0.720	0.556	0.597	0.548	0.342	0.236
6/23/18	0.245	0.252	0.720	0.556	0.362	0.454	0.000	0.127
6/24/18	0.443	0.254	0.720	0.557	0.670	0.536	0.326	0.212
6/25/18	0.231	0.256	0.720	0.557	0.374	0.452	0.000	0.116
6/26/18	0.353	0.258	0.720	0.557	0.453	0.450	0.000	0.080
6/27/18	0.399	0.259	0.720	0.558	0.588	0.499	0.301	0.180
6/28/18	0.198	0.259	0.720	0.558	0.292	0.402	0.000	0.099
6/29/18	0.390	0.260	0.720	0.559	0.348	0.387	0.000	0.069
6/30/18	0.282	0.260	0.720	0.559	0.511	0.440	0.000	0.055
7/1/18	0.382	0.260	0.720	0.559	0.848	0.590	0.690	0.315
7/2/18	0.302	0.260	0.720	0.560	0.579	0.545	0.048	0.166
7/3/18	0.271	0.260	0.720	0.560	0.709	0.584	0.690	0.366
7/4/18	0.286	0.260	0.720	0.561	0.746	0.616	0.134	0.229
7/5/18	0.390	0.259	0.720	0.561	0.664	0.600	0.569	0.352
7/6/18	0.170	0.259	0.720	0.561	0.455	0.516	0.000	0.180
7/7/18	0.292	0.259	0.720	0.562	0.732	0.593	0.267	0.220
7/8/18	0.340	0.258	0.720	0.562	0.568	0.557	0.380	0.277
7/9/18	0.289	0.258	0.720	0.563	0.780	0.627	0.414	0.311
7/10/18	0.382	0.257	0.720	0.563	0.543	0.563	0.631	0.411
7/11/18	0.266	0.257	0.720	0.563	0.651	0.583	0.000	0.209
7/12/18	0.320	0.256	0.720	0.564	0.780	0.640	0.690	0.403
7/13/18	0.320	0.256	0.720	0.564	0.594	0.591	0.153	0.268
7/14/18	0.357	0.256	0.720	0.564	0.641	0.592	0.690	0.428
7/15/18	0.234	0.256	0.720	0.565	0.444	0.517	0.000	0.222
7/16/18	0.291	0.257	0.720	0.565	0.583	0.541	0.000	0.145
7/17/18	0.280	0.257	0.720	0.565	0.639	0.569	0.201	0.189
7/18/18	0.135	0.256	0.720	0.566	0.412	0.491	0.000	0.122
7/19/18	0.215	0.256	0.720	0.566	0.508	0.499	0.000	0.093
7/20/18	0.286	0.255	0.720	0.566	0.661	0.558	0.086	0.111
7/21/18	0.240	0.253	0.720	0.567	0.726	0.606	0.000	0.081
7/22/18	0.180	0.252	0.720	0.567	0.542	0.554	0.000	0.067
7/23/18	0.104	0.250	0.720	0.567	0.426	0.492	0.000	0.059

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.266	0.249	0.720	0.568	0.463	0.482	0.000	0.053
7/25/18	0.186	0.247	0.720	0.568	0.702	0.568	0.000	0.049
7/26/18	0.118	0.245	0.720	0.568	0.439	0.498	0.000	0.045
7/27/18	0.170	0.243	0.720	0.569	0.603	0.536	0.000	0.042
7/28/18	0.183	0.240	0.720	0.569	0.331	0.444	0.000	0.040
7/29/18	0.207	0.238	0.720	0.569	0.634	0.526	0.000	0.038
7/30/18	0.221	0.236	0.720	0.570	0.721	0.589	0.000	0.036
7/31/18	0.218	0.233	0.720	0.570	0.724	0.616	0.000	0.034
8/1/18	0.200	0.232	0.720	0.570	0.724	0.630	0.000	0.033
8/2/18	0.224	0.230	0.720	0.571	0.631	0.603	0.000	0.032
8/3/18	0.178	0.229	0.720	0.571	0.529	0.555	0.000	0.030
8/4/18	0.150	0.228	0.720	0.571	0.395	0.485	0.000	0.029
8/5/18	0.187	0.227	0.720	0.572	0.638	0.550	0.000	0.028
8/6/18	0.169	0.226	0.720	0.572	0.517	0.525	0.000	0.028
8/7/18	0.257	0.224	0.720	0.572	0.542	0.525	0.000	0.027
8/8/18	0.306	0.223	0.720	0.573	0.511	0.513	0.000	0.026
8/9/18	0.124	0.222	0.720	0.573	0.472	0.492	0.000	0.025
8/10/18	0.221	0.221	0.720	0.573	0.633	0.546	0.000	0.025
8/11/18	0.197	0.221	0.720	0.573	0.424	0.484	0.000	0.024
8/12/18	0.130	0.220	0.720	0.574	0.501	0.491	0.000	0.023
8/13/18	0.090	0.219	0.720	0.574	0.460	0.476	0.000	0.023
8/14/18	0.119	0.218	0.720	0.574	0.430	0.458	0.000	0.022
8/15/18	0.161	0.217	0.720	0.575	0.305	0.401	0.000	0.022
8/16/18	0.107	0.215	0.720	0.575	0.347	0.393	0.000	0.022
8/17/18	0.113	0.213	0.720	0.575	0.438	0.422	0.000	0.021
8/18/18	0.172	0.211	0.720	0.575	0.309	0.381	0.000	0.021
8/19/18	0.037	0.209	0.720	0.576	0.252	0.341	0.000	0.020
8/20/18	0.161	0.207	0.720	0.576	0.511	0.424	0.000	0.020
8/21/18	0.104	0.204	0.720	0.576	0.323	0.381	0.000	0.020
8/22/18	0.169	0.202	0.720	0.577	0.545	0.451	0.000	0.019
8/23/18	0.108	0.200	0.720	0.577	0.453	0.442	0.000	0.019
8/24/18	0.186	0.198	0.720	0.577	0.359	0.404	0.000	0.019
8/25/18	0.121	0.197	0.720	0.577	0.296	0.365	0.000	0.019
8/26/18	0.232	0.196	0.720	0.578	0.557	0.450	0.000	0.018
8/27/18	0.195	0.194	0.720	0.578	0.557	0.481	0.000	0.018
8/28/18	0.272	0.194	0.720	0.578	0.557	0.495	0.000	0.018
8/29/18	0.322	0.193	0.720	0.578	0.395	0.441	0.000	0.018
8/30/18	0.265	0.193	0.720	0.579	0.410	0.427	0.000	0.017
8/31/18	0.159	0.194	0.720	0.579	0.339	0.393	0.000	0.017
9/1/18	0.275	0.196	0.720	0.579	0.508	0.444	0.000	0.017
9/2/18	0.142	0.197	0.720	0.579	0.557	0.481	0.000	0.017
9/3/18	0.217	0.198	0.720	0.580	0.557	0.497	0.000	0.017
9/4/18	0.322	0.199	0.720	0.580	0.557	0.505	0.076	0.046
9/5/18	0.231	0.199	0.720	0.580	0.520	0.496	0.000	0.028
9/6/18	0.302	0.200	0.720	0.581	0.484	0.480	0.000	0.022
9/7/18	0.200	0.201	0.720	0.581	0.391	0.439	0.000	0.020
9/8/18	0.184	0.202	0.720	0.581	0.480	0.456	0.000	0.018
9/9/18	0.223	0.203	0.720	0.581	0.418	0.437	0.000	0.018
9/10/18	0.149	0.204	0.720	0.582	0.557	0.484	0.000	0.017
9/11/18	0.130	0.204	0.720	0.582	0.391	0.437	0.000	0.017
9/12/18	0.077	0.204	0.720	0.582	0.441	0.439	0.000	0.016

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.119	0.203	0.720	0.582	0.300	0.384	0.000	0.016
9/14/18	0.093	0.202	0.720	0.582	0.506	0.441	0.000	0.016
9/15/18	0.166	0.200	0.720	0.583	0.416	0.426	0.000	0.016
9/16/18	0.094	0.198	0.720	0.583	0.477	0.444	0.000	0.015
9/17/18	0.218	0.196	0.720	0.583	0.439	0.437	0.000	0.015
9/18/18	0.042	0.195	0.720	0.583	0.395	0.417	0.000	0.015
9/19/18	0.111	0.193	0.720	0.584	0.498	0.449	0.000	0.015
9/20/18	0.098	0.192	0.720	0.584	0.373	0.413	0.000	0.015
9/21/18	0.142	0.190	0.720	0.584	0.467	0.436	0.000	0.015
9/22/18	0.091	0.188	0.720	0.584	0.330	0.390	0.000	0.014
9/23/18	0.163	0.186	0.720	0.585	0.557	0.461	0.000	0.014
9/24/18	0.121	0.185	0.720	0.585	0.494	0.462	0.000	0.014
9/25/18	0.077	0.183	0.720	0.585	0.381	0.421	0.000	0.014
9/26/18	0.116	0.182	0.720	0.585	0.424	0.422	0.000	0.014
9/27/18	0.034	0.180	0.720	0.585	0.381	0.405	0.000	0.014
9/28/18	0.087	0.179	0.720	0.586	0.492	0.441	0.000	0.014
9/29/18	0.050	0.177	0.720	0.586	0.378	0.410	0.000	0.014
9/30/18	0.084	0.175	0.720	0.586	0.407	0.410	0.000	0.014
10/1/18	0.067	0.173	0.720	0.586	0.285	0.361	0.000	0.013
10/2/18	0.101	0.171	0.720	0.587	0.237	0.323	0.000	0.013
10/3/18	0.060	0.169	0.720	0.587	0.475	0.398	0.000	0.013
10/4/18	0.034	0.168	0.720	0.587	0.302	0.357	0.000	0.013
10/5/18	0.076	0.166	0.720	0.587	0.429	0.391	0.000	0.013
10/6/18	0.056	0.164	0.720	0.587	0.232	0.327	0.000	0.013
10/7/18	0.087	0.162	0.720	0.588	0.557	0.429	0.000	0.013
10/8/18	0.076	0.160	0.720	0.588	0.203	0.329	0.000	0.013
10/9/18	0.110	0.159	0.720	0.588	0.373	0.358	0.000	0.013
10/10/18	0.155	0.157	0.720	0.588	0.384	0.371	0.000	0.013
10/11/18	0.070	0.156	0.720	0.588	0.224	0.314	0.000	0.013
10/12/18	0.138	0.155	0.720	0.589	0.387	0.355	0.000	0.013
10/13/18	0.127	0.154	0.720	0.589	0.243	0.313	0.000	0.012
10/14/18	0.170	0.154	0.720	0.589	0.227	0.290	0.000	0.012
10/15/18	0.149	0.154	0.720	0.589	0.265	0.294	0.000	0.012
10/16/18	0.144	0.154	0.720	0.590	0.175	0.259	0.000	0.012
10/17/18	0.105	0.154	0.720	0.590	0.299	0.291	0.000	0.012
10/18/18	0.116	0.154	0.720	0.590	0.229	0.275	0.000	0.012
10/19/18	0.116	0.154	0.720	0.590	0.246	0.274	0.000	0.012
10/20/18	0.145	0.154	0.720	0.590	0.269	0.282	0.000	0.012
10/21/18	0.150	0.154	0.720	0.591	0.153	0.239	0.000	0.012
10/22/18	0.132	0.154	0.720	0.591	0.269	0.267	0.000	0.012
10/23/18	0.099	0.154	0.678	0.591	0.111	0.215	0.000	0.012
10/24/18	0.133	0.154	0.720	0.591	0.330	0.278	0.000	0.012
10/25/18	0.150	0.154	0.720	0.591	0.231	0.263	0.000	0.012
10/26/18	0.132	0.154	0.720	0.591	0.156	0.228	0.000	0.012
10/27/18	0.121	0.154	0.570	0.591	0.053	0.175	0.000	0.012
10/28/18	0.178	0.154	0.720	0.591	0.142	0.186	0.000	0.012
10/29/18	0.169	0.154	0.720	0.591	0.226	0.220	0.000	0.012
10/30/18	0.150	0.154	0.720	0.590	0.111	0.187	0.000	0.011
10/31/18	0.138	0.154	0.720	0.589	0.207	0.211	0.000	0.011
11/1/18	0.115	0.155	0.720	0.589	0.195	0.215	0.000	0.011
11/2/18	0.115	0.155	0.720	0.589	0.240	0.233	0.000	0.011

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.147	0.155	0.720	0.589	0.074	0.176	0.000	0.011
11/4/18	0.062	0.155	0.720	0.590	0.184	0.197	0.000	0.011
11/5/18	0.138	0.155	0.720	0.590	0.200	0.209	0.000	0.011
11/6/18	0.138	0.155	0.720	0.590	0.300	0.252	0.000	0.011
11/7/18	0.169	0.154	0.720	0.590	0.147	0.210	0.000	0.011
11/8/18	0.122	0.154	0.720	0.591	0.183	0.209	0.000	0.011
11/9/18	0.192	0.153	0.720	0.591	0.119	0.183	0.000	0.011
11/10/18	0.145	0.153	0.720	0.591	0.099	0.165	0.000	0.011
11/11/18	0.135	0.154	0.720	0.592	0.145	0.174	0.000	0.011
11/12/18	0.115	0.154	0.720	0.592	0.107	0.161	0.000	0.011
11/13/18	0.132	0.154	0.720	0.592	0.229	0.202	0.000	0.011
11/14/18	0.128	0.154	0.720	0.593	0.266	0.231	0.000	0.011
11/15/18	0.076	0.154	0.584	0.593	0.073	0.169	0.000	0.011
11/16/18	0.107	0.154	0.720	0.593	0.279	0.226	0.000	0.011
11/17/18	0.093	0.153	0.720	0.593	0.289	0.251	0.000	0.011
11/18/18	0.155	0.153	0.585	0.592	0.139	0.204	0.000	0.011
11/19/18	0.091	0.152	0.720	0.592	0.258	0.233	0.000	0.011
11/20/18	0.139	0.151	0.720	0.591	0.190	0.218	0.000	0.011
11/21/18	0.088	0.151	0.720	0.590	0.215	0.222	0.000	0.010
11/22/18	0.008	0.150	0.720	0.590	0.288	0.251	0.000	0.010
11/23/18	0.142	0.150	0.720	0.590	0.362	0.292	0.000	0.010
11/24/18	0.125	0.149	0.720	0.590	0.214	0.252	0.000	0.010
11/25/18	0.111	0.148	0.720	0.590	0.265	0.258	0.000	0.010
11/26/18	0.111	0.147	0.720	0.591	0.175	0.226	0.000	0.010
11/27/18	0.107	0.146	0.720	0.591	0.283	0.255	0.000	0.010
11/28/18	0.139	0.146	0.720	0.591	0.141	0.210	0.000	0.010
11/29/18	0.076	0.145	0.720	0.592	0.241	0.232	0.000	0.010
11/30/18	0.130	0.145	0.547	0.592	0.132	0.197	0.000	0.010
12/1/18	0.144	0.145	0.720	0.592	0.292	0.245	0.000	0.010
12/2/18	0.127	0.144	0.720	0.592	0.077	0.179	0.000	0.010
12/3/18	0.108	0.144	0.720	0.592	0.258	0.224	0.000	0.010
12/4/18	0.082	0.144	0.720	0.591	0.124	0.188	0.000	0.010
12/5/18	0.077	0.144	0.720	0.591	0.258	0.226	0.000	0.010
12/6/18	0.130	0.144	0.598	0.591	0.141	0.194	0.000	0.010
12/7/18	0.108	0.143	0.720	0.591	0.297	0.243	0.000	0.010
12/8/18	0.147	0.143	0.720	0.591	0.133	0.198	0.000	0.010
12/9/18	0.119	0.142	0.720	0.591	0.149	0.187	0.000	0.010
12/10/18	0.113	0.142	0.720	0.591	0.218	0.209	0.000	0.010
12/11/18	0.127	0.142	0.720	0.591	0.150	0.190	0.000	0.010
12/12/18	0.085	0.142	0.720	0.591	0.197	0.201	0.000	0.010
12/13/18	0.125	0.142	0.720	0.591	0.226	0.216	0.000	0.010
12/14/18	0.101	0.141	0.720	0.592	0.125	0.183	0.000	0.010
12/15/18	0.110	0.141	0.720	0.592	0.172	0.188	0.000	0.010
12/16/18	0.000	0.141	0.720	0.593	0.235	0.214	0.000	0.010
12/17/18	0.000	0.140	0.720	0.593	0.258	0.232	0.000	0.010
12/18/18	0.000	0.140	0.720	0.593	0.142	0.195	0.000	0.010
12/19/18	0.000	0.138	0.720	0.594	0.262	0.228	0.000	0.010
12/20/18	0.000	0.136	0.720	0.594	0.119	0.185	0.000	0.010
12/21/18	0.000	0.134	0.593	0.595	0.101	0.162	0.000	0.010
12/22/18	0.000	0.132	0.720	0.595	0.344	0.246	0.000	0.009
12/23/18	0.000	0.129	0.720	0.595	0.145	0.200	0.000	0.009

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Depot 03				Fletcher 08			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.000	0.127	0.720	0.595	0.232	0.218	0.000	0.009
12/25/18	0.000	0.125	0.720	0.594	0.119	0.181	0.000	0.009
12/26/18	0.000	0.122	0.720	0.594	0.138	0.174	0.000	0.009
12/27/18	0.000	0.120	0.720	0.594	0.132	0.167	0.000	0.009
12/28/18	0.000	0.118	0.720	0.595	0.187	0.185	0.000	0.009
12/29/18	0.000	0.116	0.720	0.595	0.176	0.187	0.000	0.009
12/30/18	0.000	0.114	0.720	0.595	0.111	0.162	0.000	0.009
12/31/18	0.000	0.112	0.720	0.596	0.186	0.182	0.000	0.009

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.000	0.224	0.000	0.224	0.127	0.132	0.000	0.122
1/2/18	0.000	0.179	0.000	0.179	0.096	0.128	0.000	0.103
1/3/18	0.000	0.152	0.000	0.152	0.152	0.128	0.000	0.090
1/4/18	0.000	0.134	0.000	0.134	0.093	0.127	0.000	0.081
1/5/18	0.000	0.121	0.000	0.121	0.141	0.126	0.000	0.074
1/6/18	0.000	0.111	0.000	0.111	0.074	0.123	0.000	0.068
1/7/18	0.000	0.103	0.000	0.103	0.076	0.116	0.000	0.064
1/8/18	0.000	0.097	0.000	0.097	0.170	0.119	0.000	0.060
1/9/18	0.000	0.091	0.000	0.091	0.198	0.130	0.000	0.057
1/10/18	0.000	0.087	0.000	0.087	0.125	0.134	0.000	0.054
1/11/18	0.000	0.083	0.000	0.083	0.099	0.130	0.000	0.052
1/12/18	0.000	0.079	0.000	0.079	0.108	0.125	0.000	0.049
1/13/18	0.000	0.076	0.000	0.076	0.184	0.128	0.000	0.048
1/14/18	0.000	0.073	0.000	0.073	0.096	0.130	0.000	0.046
1/15/18	0.000	0.071	0.000	0.071	0.098	0.124	0.000	0.044
1/16/18	0.000	0.068	0.000	0.068	0.169	0.126	0.000	0.043
1/17/18	0.000	0.066	0.000	0.066	0.141	0.130	0.000	0.042
1/18/18	0.000	0.064	0.000	0.064	0.144	0.132	0.000	0.040
1/19/18	0.000	0.063	0.000	0.063	0.206	0.138	0.000	0.039
1/20/18	0.000	0.061	0.000	0.061	0.161	0.143	0.000	0.038
1/21/18	0.000	0.059	0.000	0.059	0.181	0.146	0.000	0.037
1/22/18	0.000	0.058	0.000	0.058	0.132	0.145	0.000	0.036
1/23/18	0.000	0.057	0.000	0.057	0.169	0.144	0.000	0.036
1/24/18	0.000	0.055	0.000	0.055	0.190	0.148	0.000	0.035
1/25/18	0.000	0.054	0.000	0.054	0.164	0.150	0.000	0.034
1/26/18	0.000	0.053	0.000	0.053	0.204	0.153	0.000	0.033
1/27/18	0.000	0.052	0.000	0.052	0.161	0.155	0.000	0.033
1/28/18	0.000	0.051	0.000	0.051	0.173	0.154	0.000	0.032
1/29/18	0.000	0.050	0.000	0.050	0.189	0.156	0.000	0.032
1/30/18	0.000	0.049	0.000	0.049	0.207	0.160	0.000	0.031
1/31/18	0.000	0.048	0.000	0.048	0.238	0.167	0.000	0.030
2/1/18	0.000	0.047	0.000	0.047	0.192	0.171	0.000	0.030
2/2/18	0.000	0.047	0.000	0.047	0.158	0.167	0.000	0.029
2/3/18	0.000	0.046	0.000	0.046	0.204	0.166	0.000	0.029
2/4/18	0.000	0.045	0.000	0.045	0.268	0.174	0.000	0.029
2/5/18	0.000	0.045	0.000	0.045	0.257	0.185	0.000	0.028
2/6/18	0.000	0.044	0.000	0.044	0.201	0.186	0.000	0.028
2/7/18	0.000	0.043	0.000	0.043	0.195	0.183	0.000	0.027
2/8/18	0.000	0.043	0.000	0.043	0.172	0.179	0.000	0.027
2/9/18	0.000	0.042	0.000	0.042	0.262	0.181	0.000	0.027
2/10/18	0.000	0.041	0.000	0.041	0.173	0.183	0.000	0.026
2/11/18	0.000	0.041	0.000	0.041	0.180	0.178	0.000	0.026
2/12/18	0.000	0.040	0.000	0.040	0.170	0.175	0.000	0.026
2/13/18	0.000	0.040	0.000	0.040	0.237	0.177	0.000	0.025
2/14/18	0.000	0.039	0.000	0.039	0.220	0.182	0.000	0.025
2/15/18	0.000	0.039	0.000	0.039	0.164	0.181	0.000	0.025
2/16/18	0.000	0.038	0.000	0.038	0.268	0.183	0.000	0.024
2/17/18	0.000	0.038	0.000	0.038	0.076	0.178	0.000	0.024
2/18/18	0.000	0.038	0.000	0.038	0.255	0.173	0.000	0.024
2/19/18	0.000	0.037	0.000	0.037	0.269	0.186	0.000	0.023
2/20/18	0.000	0.037	0.000	0.037	0.223	0.192	0.000	0.023

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.000	0.036	0.000	0.036	0.186	0.189	0.000	0.023
2/22/18	0.000	0.036	0.000	0.036	0.209	0.187	0.000	0.023
2/23/18	0.000	0.036	0.000	0.036	0.192	0.186	0.000	0.022
2/24/18	0.000	0.035	0.000	0.035	0.189	0.183	0.000	0.022
2/25/18	0.000	0.035	0.000	0.035	0.164	0.180	0.000	0.022
2/26/18	0.000	0.035	0.000	0.035	0.169	0.175	0.000	0.022
2/27/18	0.000	0.034	0.000	0.034	0.139	0.171	0.000	0.022
2/28/18	0.000	0.034	0.000	0.034	0.200	0.170	0.000	0.021
3/1/18	0.000	0.034	0.000	0.034	0.203	0.174	0.000	0.021
3/2/18	0.000	0.033	0.000	0.033	0.265	0.182	0.000	0.021
3/3/18	0.000	0.033	0.000	0.033	0.195	0.187	0.000	0.021
3/4/18	0.000	0.033	0.000	0.033	0.184	0.184	0.000	0.021
3/5/18	0.000	0.032	0.000	0.032	0.269	0.188	0.000	0.020
3/6/18	0.000	0.032	0.000	0.032	0.220	0.193	0.000	0.020
3/7/18	0.000	0.032	0.000	0.032	0.241	0.196	0.000	0.020
3/8/18	0.000	0.031	0.000	0.031	0.000	0.179	0.000	0.020
3/9/18	0.000	0.031	0.000	0.031	0.000	0.149	0.000	0.020
3/10/18	0.000	0.031	0.000	0.031	0.000	0.128	0.000	0.020
3/11/18	0.000	0.031	0.000	0.031	0.000	0.113	0.000	0.019
3/12/18	0.111	0.051	0.000	0.030	0.163	0.114	0.000	0.019
3/13/18	0.187	0.082	0.000	0.030	0.209	0.131	0.000	0.019
3/14/18	0.224	0.112	0.000	0.030	0.249	0.150	0.000	0.019
3/15/18	0.189	0.126	0.000	0.030	0.204	0.161	0.000	0.019
3/16/18	0.181	0.132	0.000	0.030	0.203	0.166	0.000	0.019
3/17/18	0.127	0.127	0.000	0.029	0.132	0.163	0.000	0.019
3/18/18	0.218	0.139	0.000	0.029	0.246	0.165	0.000	0.018
3/19/18	0.241	0.156	0.000	0.029	0.252	0.177	0.000	0.018
3/20/18	0.090	0.141	0.000	0.029	0.098	0.173	0.000	0.018
3/21/18	0.152	0.136	0.000	0.028	0.167	0.164	0.000	0.018
3/22/18	0.251	0.155	0.000	0.028	0.258	0.170	0.000	0.018
3/23/18	0.144	0.153	0.000	0.028	0.163	0.175	0.000	0.018
3/24/18	0.248	0.165	0.000	0.028	0.257	0.178	0.000	0.018
3/25/18	0.156	0.162	0.000	0.028	0.175	0.181	0.000	0.018
3/26/18	0.158	0.156	0.000	0.027	0.172	0.176	0.000	0.017
3/27/18	0.178	0.157	0.000	0.027	0.189	0.174	0.000	0.017
3/28/18	0.142	0.153	0.000	0.027	0.166	0.173	0.000	0.017
3/29/18	0.249	0.168	0.000	0.027	0.258	0.177	0.000	0.017
3/30/18	0.209	0.176	0.000	0.027	0.243	0.187	0.000	0.017
3/31/18	0.189	0.174	0.000	0.027	0.193	0.188	0.000	0.017
4/1/18	0.178	0.171	0.000	0.026	0.209	0.187	0.000	0.017
4/2/18	0.166	0.167	0.000	0.026	0.175	0.184	0.000	0.017
4/3/18	0.181	0.167	0.000	0.026	0.198	0.182	0.000	0.017
4/4/18	0.226	0.176	0.000	0.026	0.251	0.186	0.000	0.016
4/5/18	0.155	0.172	0.000	0.026	0.166	0.187	0.000	0.016
4/6/18	0.043	0.145	0.000	0.026	0.046	0.171	0.000	0.016
4/7/18	0.158	0.144	0.000	0.025	0.176	0.161	0.000	0.016
4/8/18	0.176	0.153	0.000	0.025	0.183	0.165	0.000	0.016
4/9/18	0.139	0.152	0.000	0.025	0.159	0.166	0.000	0.016
4/10/18	0.138	0.149	0.000	0.025	0.149	0.163	0.000	0.016
4/11/18	0.138	0.147	0.000	0.025	0.145	0.161	0.000	0.016
4/12/18	0.210	0.159	0.000	0.025	0.243	0.166	0.000	0.016

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.138	0.157	0.000	0.025	0.141	0.169	0.000	0.016
4/14/18	0.116	0.147	0.000	0.024	0.124	0.162	0.000	0.015
4/15/18	0.161	0.149	0.000	0.024	0.181	0.160	0.000	0.015
4/16/18	0.118	0.145	0.000	0.024	0.119	0.158	0.000	0.015
4/17/18	0.164	0.148	0.000	0.024	0.180	0.157	0.000	0.015
4/18/18	0.198	0.159	0.000	0.024	0.206	0.163	0.000	0.015
4/19/18	0.282	0.182	0.000	0.024	0.200	0.168	0.000	0.015
4/20/18	0.158	0.178	0.000	0.024	0.101	0.164	0.000	0.015
4/21/18	0.255	0.187	0.000	0.023	0.166	0.158	0.000	0.015
4/22/18	0.156	0.180	0.000	0.023	0.099	0.154	0.000	0.015
4/23/18	0.124	0.165	0.000	0.023	0.081	0.144	0.000	0.015
4/24/18	0.316	0.190	0.000	0.023	0.201	0.145	0.000	0.015
4/25/18	0.223	0.199	0.000	0.023	0.144	0.151	0.000	0.015
4/26/18	0.237	0.201	0.000	0.023	0.152	0.151	0.000	0.014
4/27/18	0.198	0.197	0.000	0.023	0.128	0.149	0.000	0.014
4/28/18	0.136	0.182	0.000	0.023	0.087	0.143	0.000	0.014
4/29/18	0.187	0.179	0.000	0.022	0.119	0.137	0.000	0.014
4/30/18	0.325	0.206	0.000	0.022	0.201	0.143	0.000	0.014
5/1/18	0.237	0.213	0.000	0.022	0.152	0.149	0.000	0.014
5/2/18	0.303	0.224	0.000	0.022	0.155	0.149	0.000	0.014
5/3/18	0.176	0.212	0.000	0.022	0.053	0.142	0.000	0.014
5/4/18	0.150	0.194	0.000	0.022	0.071	0.130	0.000	0.014
5/5/18	0.189	0.190	0.000	0.022	0.087	0.124	0.000	0.014
5/6/18	0.170	0.186	0.000	0.022	0.046	0.118	0.000	0.014
5/7/18	0.289	0.204	0.000	0.022	0.145	0.118	0.000	0.014
5/8/18	0.217	0.208	0.000	0.022	0.110	0.122	0.000	0.014
5/9/18	0.234	0.208	0.000	0.021	0.128	0.124	0.000	0.014
5/10/18	0.223	0.209	0.000	0.021	0.113	0.125	0.000	0.014
5/11/18	0.306	0.224	0.000	0.021	0.164	0.129	0.000	0.013
5/12/18	0.231	0.224	0.000	0.021	0.115	0.131	0.000	0.013
5/13/18	0.289	0.230	0.000	0.021	0.149	0.132	0.000	0.013
5/14/18	0.314	0.243	0.000	0.021	0.159	0.136	0.000	0.013
5/15/18	0.299	0.249	0.000	0.021	0.155	0.139	0.000	0.013
5/16/18	0.163	0.228	0.000	0.021	0.079	0.135	0.000	0.013
5/17/18	0.283	0.230	0.000	0.021	0.145	0.131	0.000	0.013
5/18/18	0.193	0.223	0.000	0.021	0.101	0.130	0.000	0.013
5/19/18	0.243	0.222	0.000	0.020	0.125	0.128	0.000	0.013
5/20/18	0.294	0.234	0.000	0.020	0.149	0.131	0.000	0.013
5/21/18	0.248	0.235	0.000	0.020	0.127	0.132	0.000	0.013
5/22/18	0.265	0.236	0.000	0.020	0.135	0.132	0.000	0.013
5/23/18	0.303	0.245	0.000	0.020	0.155	0.135	0.000	0.013
5/24/18	0.207	0.236	0.000	0.020	0.102	0.133	0.000	0.013
5/25/18	0.322	0.245	0.000	0.020	0.163	0.133	0.000	0.013
5/26/18	0.288	0.252	0.000	0.020	0.145	0.137	0.000	0.013
5/27/18	0.231	0.244	0.000	0.020	0.115	0.135	0.000	0.013
5/28/18	0.320	0.252	0.000	0.020	0.159	0.135	0.000	0.013
5/29/18	0.255	0.251	0.000	0.020	0.130	0.137	0.000	0.012
5/30/18	0.325	0.259	0.000	0.020	0.159	0.138	0.000	0.012
5/31/18	0.337	0.271	0.000	0.019	0.167	0.141	0.000	0.012
6/1/18	0.260	0.264	0.000	0.019	0.130	0.142	0.000	0.012
6/2/18	0.399	0.282	0.351	0.083	0.198	0.144	0.000	0.012

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.275	0.278	0.388	0.147	0.136	0.147	0.000	0.012
6/4/18	0.342	0.281	0.000	0.116	0.065	0.138	0.000	0.012
6/5/18	0.255	0.272	0.000	0.079	0.101	0.129	0.000	0.012
6/6/18	0.220	0.256	0.000	0.060	0.108	0.126	0.000	0.012
6/7/18	0.257	0.251	0.387	0.119	0.127	0.126	0.000	0.012
6/8/18	0.296	0.258	0.060	0.116	0.150	0.130	0.000	0.012
6/9/18	0.311	0.266	0.083	0.100	0.159	0.134	0.000	0.012
6/10/18	0.441	0.295	0.590	0.185	0.226	0.143	0.340	0.039
6/11/18	0.398	0.312	0.590	0.265	0.204	0.153	0.340	0.085
6/12/18	0.314	0.304	0.390	0.275	0.130	0.153	0.000	0.091
6/13/18	0.535	0.337	0.590	0.310	0.183	0.151	0.340	0.095
6/14/18	0.424	0.349	0.590	0.346	0.118	0.149	0.072	0.105
6/15/18	0.521	0.368	0.590	0.370	0.161	0.146	0.326	0.112
6/16/18	0.418	0.368	0.590	0.388	0.119	0.144	0.187	0.127
6/17/18	0.613	0.398	0.590	0.401	0.192	0.145	0.340	0.139
6/18/18	0.538	0.416	0.590	0.412	0.163	0.150	0.340	0.161
6/19/18	0.306	0.380	0.000	0.315	0.108	0.146	0.000	0.150
6/20/18	0.478	0.380	0.590	0.334	0.141	0.142	0.340	0.143
6/21/18	0.487	0.392	0.590	0.380	0.142	0.141	0.340	0.166
6/22/18	0.436	0.391	0.590	0.406	0.125	0.140	0.340	0.183
6/23/18	0.262	0.356	0.000	0.315	0.091	0.135	0.000	0.169
6/24/18	0.491	0.368	0.590	0.337	0.144	0.133	0.340	0.159
6/25/18	0.306	0.355	0.000	0.278	0.065	0.129	0.000	0.153
6/26/18	0.384	0.350	0.436	0.287	0.127	0.125	0.000	0.122
6/27/18	0.489	0.371	0.590	0.346	0.125	0.127	0.340	0.128
6/28/18	0.240	0.343	0.000	0.280	0.077	0.124	0.000	0.132
6/29/18	0.291	0.322	0.540	0.305	0.060	0.116	0.000	0.108
6/30/18	0.419	0.337	0.356	0.320	0.133	0.116	0.000	0.090
7/1/18	0.695	0.401	0.590	0.358	0.190	0.125	0.340	0.105
7/2/18	0.478	0.415	0.590	0.395	0.124	0.131	0.340	0.142
7/3/18	0.582	0.430	0.590	0.417	0.156	0.132	0.340	0.168
7/4/18	0.611	0.452	0.590	0.432	0.163	0.136	0.340	0.186
7/5/18	0.543	0.456	0.590	0.443	0.144	0.138	0.340	0.199
7/6/18	0.378	0.426	0.000	0.344	0.121	0.136	0.000	0.182
7/7/18	0.656	0.451	0.590	0.362	0.184	0.138	0.340	0.171
7/8/18	0.506	0.455	0.590	0.407	0.136	0.141	0.340	0.191
7/9/18	0.695	0.483	0.590	0.431	0.197	0.144	0.340	0.206
7/10/18	0.484	0.474	0.590	0.446	0.127	0.145	0.340	0.217
7/11/18	0.580	0.475	0.590	0.456	0.158	0.143	0.162	0.210
7/12/18	0.693	0.503	0.590	0.464	0.200	0.148	0.340	0.207
7/13/18	0.537	0.498	0.590	0.470	0.144	0.150	0.340	0.219
7/14/18	0.614	0.501	0.590	0.475	0.178	0.150	0.340	0.228
7/15/18	0.426	0.474	0.172	0.403	0.141	0.149	0.000	0.208
7/16/18	0.562	0.473	0.590	0.414	0.156	0.148	0.194	0.182
7/17/18	0.613	0.491	0.590	0.446	0.178	0.150	0.340	0.192
7/18/18	0.395	0.464	0.000	0.355	0.098	0.146	0.000	0.183
7/19/18	0.484	0.452	0.365	0.335	0.164	0.143	0.000	0.150
7/20/18	0.631	0.478	0.590	0.386	0.180	0.147	0.340	0.154
7/21/18	0.696	0.512	0.590	0.425	0.181	0.151	0.309	0.181
7/22/18	0.517	0.503	0.294	0.393	0.163	0.153	0.000	0.172
7/23/18	0.412	0.469	0.000	0.305	0.115	0.149	0.000	0.141

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.446	0.452	0.164	0.268	0.119	0.143	0.000	0.119
7/25/18	0.672	0.484	0.590	0.332	0.197	0.145	0.217	0.121
7/26/18	0.421	0.470	0.000	0.284	0.110	0.146	0.000	0.121
7/27/18	0.577	0.475	0.103	0.238	0.164	0.144	0.000	0.104
7/28/18	0.316	0.441	0.000	0.199	0.108	0.142	0.000	0.091
7/29/18	0.460	0.431	0.557	0.269	0.184	0.142	0.000	0.081
7/30/18	0.000	0.351	0.285	0.290	0.240	0.153	0.000	0.074
7/31/18	0.000	0.276	0.312	0.289	0.245	0.166	0.000	0.068
8/1/18	0.447	0.313	0.590	0.342	0.215	0.172	0.256	0.084
8/2/18	0.625	0.389	0.590	0.389	0.172	0.171	0.118	0.104
8/3/18	0.525	0.420	0.000	0.310	0.138	0.165	0.000	0.097
8/4/18	0.391	0.409	0.000	0.232	0.098	0.155	0.000	0.082
8/5/18	0.633	0.440	0.371	0.256	0.173	0.151	0.000	0.072
8/6/18	0.511	0.451	0.000	0.222	0.135	0.151	0.000	0.065
8/7/18	0.537	0.455	0.590	0.285	0.144	0.149	0.162	0.072
8/8/18	0.506	0.455	0.590	0.355	0.133	0.147	0.118	0.086
8/9/18	0.464	0.447	0.000	0.287	0.119	0.143	0.000	0.083
8/10/18	0.625	0.470	0.590	0.322	0.170	0.144	0.261	0.092
8/11/18	0.422	0.456	0.000	0.272	0.105	0.143	0.000	0.098
8/12/18	0.495	0.450	0.000	0.207	0.130	0.139	0.000	0.082
8/13/18	0.456	0.444	0.000	0.171	0.116	0.137	0.000	0.070
8/14/18	0.534	0.453	0.000	0.148	0.144	0.137	0.000	0.062
8/15/18	0.395	0.437	0.000	0.131	0.132	0.137	0.000	0.057
8/16/18	0.453	0.431	0.000	0.119	0.121	0.136	0.000	0.052
8/17/18	0.566	0.451	0.000	0.109	0.156	0.137	0.000	0.049
8/18/18	0.525	0.461	0.000	0.102	0.147	0.139	0.000	0.046
8/19/18	0.325	0.428	0.000	0.095	0.108	0.137	0.000	0.043
8/20/18	0.661	0.459	0.000	0.089	0.180	0.139	0.000	0.041
8/21/18	0.422	0.454	0.000	0.085	0.118	0.140	0.000	0.039
8/22/18	0.704	0.487	0.195	0.116	0.201	0.143	0.000	0.038
8/23/18	0.594	0.504	0.000	0.108	0.175	0.149	0.000	0.036
8/24/18	0.470	0.485	0.000	0.092	0.128	0.148	0.000	0.035
8/25/18	0.382	0.453	0.000	0.083	0.133	0.144	0.000	0.034
8/26/18	0.724	0.492	0.436	0.156	0.215	0.148	0.000	0.033
8/27/18	0.721	0.534	0.271	0.192	0.217	0.158	0.000	0.032
8/28/18	0.721	0.557	0.590	0.261	0.215	0.165	0.279	0.054
8/29/18	0.514	0.535	0.411	0.290	0.144	0.164	0.000	0.068
8/30/18	0.531	0.515	0.216	0.263	0.147	0.158	0.000	0.056
8/31/18	0.436	0.489	0.000	0.201	0.153	0.155	0.000	0.048
9/1/18	0.656	0.508	0.527	0.250	0.192	0.156	0.000	0.043
9/2/18	0.718	0.543	0.158	0.243	0.214	0.162	0.000	0.039
9/3/18	0.715	0.566	0.422	0.264	0.212	0.168	0.000	0.036
9/4/18	0.715	0.580	0.590	0.323	0.214	0.172	0.340	0.061
9/5/18	0.667	0.581	0.549	0.360	0.195	0.174	0.000	0.078
9/6/18	0.622	0.572	0.590	0.389	0.181	0.173	0.006	0.064
9/7/18	0.503	0.544	0.000	0.304	0.139	0.168	0.000	0.054
9/8/18	0.616	0.542	0.068	0.235	0.178	0.164	0.000	0.047
9/9/18	0.538	0.534	0.000	0.189	0.150	0.163	0.000	0.042
9/10/18	0.715	0.556	0.009	0.158	0.214	0.164	0.000	0.039
9/11/18	0.504	0.541	0.000	0.137	0.139	0.165	0.000	0.036
9/12/18	0.566	0.531	0.000	0.121	0.163	0.161	0.000	0.034

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.385	0.497	0.000	0.109	0.135	0.158	0.000	0.032
9/14/18	0.647	0.514	0.000	0.100	0.187	0.158	0.000	0.031
9/15/18	0.537	0.518	0.000	0.092	0.152	0.159	0.000	0.029
9/16/18	0.610	0.526	0.000	0.086	0.176	0.159	0.000	0.028
9/17/18	0.566	0.527	0.025	0.085	0.161	0.159	0.000	0.027
9/18/18	0.506	0.515	0.000	0.080	0.141	0.157	0.000	0.026
9/19/18	0.639	0.528	0.000	0.075	0.189	0.157	0.000	0.026
9/20/18	0.480	0.515	0.000	0.071	0.133	0.157	0.000	0.025
9/21/18	0.602	0.520	0.000	0.067	0.176	0.156	0.000	0.024
9/22/18	0.426	0.498	0.000	0.064	0.115	0.153	0.000	0.024
9/23/18	0.713	0.527	0.119	0.083	0.203	0.154	0.000	0.023
9/24/18	0.670	0.553	0.000	0.079	0.176	0.159	0.000	0.023
9/25/18	0.512	0.536	0.000	0.069	0.136	0.157	0.000	0.022
9/26/18	0.574	0.530	0.000	0.063	0.159	0.155	0.000	0.022
9/27/18	0.511	0.519	0.000	0.059	0.136	0.153	0.000	0.022
9/28/18	0.664	0.537	0.000	0.057	0.190	0.154	0.000	0.021
9/29/18	0.511	0.528	0.000	0.054	0.138	0.155	0.000	0.021
9/30/18	0.549	0.521	0.000	0.052	0.150	0.153	0.000	0.020
10/1/18	0.384	0.489	0.000	0.051	0.094	0.147	0.000	0.020
10/2/18	0.322	0.450	0.000	0.049	0.071	0.137	0.000	0.020
10/3/18	0.641	0.481	0.000	0.048	0.184	0.137	0.000	0.020
10/4/18	0.407	0.474	0.000	0.046	0.102	0.139	0.000	0.019
10/5/18	0.508	0.473	0.000	0.045	0.107	0.135	0.000	0.019
10/6/18	0.314	0.443	0.000	0.044	0.000	0.123	0.000	0.019
10/7/18	0.750	0.493	0.000	0.043	0.000	0.106	0.000	0.018
10/8/18	0.277	0.461	0.000	0.042	0.000	0.094	0.000	0.018
10/9/18	0.517	0.457	0.000	0.042	0.000	0.085	0.000	0.018
10/10/18	0.537	0.474	0.000	0.041	0.000	0.078	0.000	0.018
10/11/18	0.311	0.442	0.000	0.040	0.000	0.073	0.000	0.018
10/12/18	0.538	0.452	0.000	0.039	0.000	0.068	0.000	0.017
10/13/18	0.339	0.435	0.000	0.039	0.000	0.064	0.000	0.017
10/14/18	0.317	0.408	0.000	0.038	0.000	0.061	0.000	0.017
10/15/18	0.368	0.400	0.000	0.037	0.000	0.058	0.000	0.017
10/16/18	0.243	0.375	0.000	0.037	0.000	0.056	0.000	0.017
10/17/18	0.413	0.382	0.000	0.036	0.000	0.054	0.000	0.017
10/18/18	0.316	0.378	0.000	0.036	0.000	0.052	0.000	0.016
10/19/18	0.340	0.372	0.000	0.035	0.000	0.050	0.000	0.016
10/20/18	0.371	0.375	0.000	0.035	0.000	0.048	0.000	0.016
10/21/18	0.209	0.349	0.000	0.034	0.000	0.047	0.000	0.016
10/22/18	0.371	0.352	0.000	0.034	0.000	0.045	0.000	0.016
10/23/18	0.152	0.324	0.000	0.033	0.000	0.044	0.000	0.016
10/24/18	0.452	0.347	0.000	0.033	0.000	0.043	0.000	0.015
10/25/18	0.316	0.353	0.000	0.032	0.000	0.042	0.000	0.015
10/26/18	0.214	0.328	0.000	0.032	0.000	0.041	0.000	0.015
10/27/18	0.074	0.283	0.000	0.031	0.000	0.040	0.000	0.015
10/28/18	0.195	0.270	0.000	0.031	0.000	0.039	0.000	0.015
10/29/18	0.308	0.288	0.000	0.031	0.000	0.038	0.000	0.015
10/30/18	0.152	0.275	0.000	0.030	0.000	0.037	0.000	0.015
10/31/18	0.283	0.280	0.000	0.030	0.000	0.037	0.000	0.015
11/1/18	0.263	0.287	0.000	0.030	0.105	0.044	0.000	0.014
11/2/18	0.323	0.299	0.000	0.029	0.113	0.059	0.000	0.014

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.101	0.269	0.000	0.029	0.046	0.064	0.000	0.014
11/4/18	0.245	0.265	0.000	0.029	0.113	0.068	0.000	0.014
11/5/18	0.272	0.275	0.000	0.028	0.090	0.074	0.000	0.014
11/6/18	0.334	0.293	0.000	0.028	0.145	0.081	0.000	0.014
11/7/18	0.159	0.274	0.000	0.028	0.067	0.085	0.000	0.014
11/8/18	0.192	0.259	0.000	0.028	0.096	0.083	0.000	0.014
11/9/18	0.122	0.240	0.000	0.027	0.060	0.082	0.000	0.014
11/10/18	0.107	0.221	0.000	0.027	0.019	0.076	0.000	0.014
11/11/18	0.153	0.217	0.000	0.027	0.079	0.073	0.000	0.013
11/12/18	0.113	0.208	0.000	0.027	0.056	0.073	0.000	0.013
11/13/18	0.240	0.222	0.000	0.026	0.085	0.075	0.000	0.013
11/14/18	0.282	0.244	0.000	0.026	0.133	0.082	0.000	0.013
11/15/18	0.077	0.221	0.000	0.026	0.039	0.083	0.000	0.013
11/16/18	0.292	0.235	0.000	0.026	0.113	0.082	0.000	0.013
11/17/18	0.302	0.258	0.000	0.025	0.153	0.091	0.000	0.013
11/18/18	0.145	0.242	0.000	0.025	0.043	0.091	0.000	0.013
11/19/18	0.274	0.247	0.000	0.025	0.130	0.090	0.000	0.013
11/20/18	0.198	0.245	0.000	0.025	0.065	0.091	0.000	0.013
11/21/18	0.226	0.243	0.000	0.025	0.118	0.091	0.000	0.013
11/22/18	0.296	0.257	0.000	0.024	0.119	0.095	0.000	0.013
11/23/18	0.378	0.284	0.000	0.024	0.156	0.102	0.000	0.012
11/24/18	0.220	0.275	0.000	0.024	0.108	0.105	0.000	0.012
11/25/18	0.274	0.271	0.000	0.024	0.105	0.104	0.000	0.012
11/26/18	0.178	0.256	0.000	0.024	0.091	0.102	0.000	0.012
11/27/18	0.291	0.262	0.000	0.024	0.113	0.101	0.000	0.012
11/28/18	0.145	0.246	0.000	0.023	0.074	0.099	0.000	0.012
11/29/18	0.283	0.252	0.000	0.023	0.102	0.097	0.000	0.012
11/30/18	0.155	0.240	0.000	0.023	0.081	0.097	0.000	0.012
12/1/18	0.350	0.261	0.000	0.023	0.149	0.100	0.000	0.012
12/2/18	0.091	0.237	0.000	0.023	0.050	0.099	0.000	0.012
12/3/18	0.308	0.247	0.000	0.023	0.125	0.097	0.000	0.012
12/4/18	0.149	0.237	0.000	0.022	0.081	0.098	0.000	0.012
12/5/18	0.308	0.250	0.000	0.022	0.127	0.099	0.000	0.012
12/6/18	0.167	0.241	0.000	0.022	0.091	0.101	0.000	0.012
12/7/18	0.350	0.261	0.000	0.022	0.152	0.104	0.000	0.012
12/8/18	0.158	0.248	0.000	0.022	0.084	0.106	0.000	0.011
12/9/18	0.172	0.232	0.000	0.022	0.091	0.102	0.000	0.011
12/10/18	0.258	0.239	0.000	0.022	0.104	0.101	0.000	0.011
12/11/18	0.176	0.233	0.000	0.021	0.093	0.101	0.000	0.011
12/12/18	0.231	0.234	0.000	0.021	0.087	0.099	0.000	0.011
12/13/18	0.266	0.244	0.000	0.021	0.144	0.102	0.000	0.011
12/14/18	0.144	0.230	0.000	0.021	0.076	0.103	0.000	0.011
12/15/18	0.200	0.224	0.000	0.021	0.073	0.098	0.000	0.011
12/16/18	0.274	0.238	0.000	0.021	0.147	0.101	0.000	0.011
12/17/18	0.302	0.254	0.000	0.021	0.127	0.107	0.000	0.011
12/18/18	0.164	0.240	0.000	0.021	0.088	0.106	0.000	0.011
12/19/18	0.305	0.250	0.000	0.020	0.132	0.106	0.000	0.011
12/20/18	0.139	0.234	0.000	0.020	0.074	0.105	0.000	0.011
12/21/18	0.115	0.211	0.000	0.020	0.060	0.099	0.000	0.011
12/22/18	0.398	0.247	0.000	0.020	0.181	0.103	0.000	0.011
12/23/18	0.167	0.243	0.000	0.020	0.090	0.108	0.000	0.011

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Forge 05				Forge 01, 09, 10, 11, 12			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.271	0.244	0.000	0.020	0.113	0.106	0.000	0.011
12/25/18	0.138	0.228	0.000	0.020	0.074	0.104	0.000	0.011
12/26/18	0.156	0.214	0.000	0.020	0.084	0.100	0.000	0.011
12/27/18	0.128	0.202	0.000	0.020	0.090	0.098	0.000	0.011
12/28/18	0.198	0.206	0.000	0.019	0.110	0.099	0.000	0.010
12/29/18	0.183	0.208	0.000	0.019	0.128	0.103	0.000	0.010
12/30/18	0.110	0.195	0.000	0.019	0.077	0.103	0.000	0.010
12/31/18	0.184	0.196	0.000	0.019	0.102	0.101	0.000	0.010

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.215	0.165	0.000	0.160	0.531	0.534	0.000	0.111
1/2/18	0.166	0.168	0.000	0.146	0.554	0.551	0.000	0.078
1/3/18	0.166	0.167	0.000	0.133	0.449	0.468	0.000	0.064
1/4/18	0.084	0.165	0.000	0.121	0.474	0.482	0.000	0.055
1/5/18	0.150	0.158	0.000	0.112	0.560	0.550	0.000	0.049
1/6/18	0.046	0.154	0.000	0.105	0.605	0.589	0.000	0.045
1/7/18	0.082	0.146	0.000	0.099	0.636	0.618	0.000	0.041
1/8/18	0.178	0.142	0.000	0.093	0.356	0.399	0.000	0.038
1/9/18	0.215	0.147	0.000	0.089	0.327	0.361	0.000	0.036
1/10/18	0.138	0.152	0.000	0.085	0.379	0.395	0.000	0.034
1/11/18	0.085	0.151	0.000	0.081	0.422	0.429	0.000	0.033
1/12/18	0.115	0.146	0.000	0.078	0.429	0.435	0.000	0.031
1/13/18	0.201	0.145	0.000	0.075	0.381	0.397	0.000	0.030
1/14/18	0.107	0.148	0.000	0.073	0.419	0.425	0.000	0.029
1/15/18	0.090	0.145	0.000	0.070	0.518	0.504	0.000	0.028
1/16/18	0.176	0.143	0.000	0.068	0.474	0.474	0.000	0.027
1/17/18	0.152	0.145	0.000	0.066	0.286	0.325	0.000	0.026
1/18/18	0.156	0.147	0.000	0.064	0.309	0.333	0.000	0.025
1/19/18	0.217	0.149	0.000	0.063	0.255	0.286	0.000	0.024
1/20/18	0.180	0.155	0.000	0.061	0.263	0.287	0.000	0.024
1/21/18	0.195	0.157	0.000	0.060	0.391	0.387	0.000	0.023
1/22/18	0.125	0.159	0.000	0.058	0.212	0.249	0.000	0.022
1/23/18	0.181	0.157	0.000	0.057	0.364	0.361	0.000	0.022
1/24/18	0.201	0.158	0.000	0.056	0.344	0.351	0.000	0.021
1/25/18	0.186	0.161	0.000	0.055	0.330	0.340	0.000	0.021
1/26/18	0.217	0.164	0.000	0.054	0.260	0.284	0.000	0.021
1/27/18	0.178	0.167	0.000	0.053	0.266	0.284	0.000	0.020
1/28/18	0.197	0.167	0.000	0.052	0.294	0.305	0.000	0.020
1/29/18	0.172	0.168	0.000	0.051	0.292	0.304	0.000	0.019
1/30/18	0.195	0.168	0.000	0.050	0.260	0.278	0.000	0.019
1/31/18	0.214	0.170	0.000	0.049	0.350	0.347	0.000	0.019
2/1/18	0.178	0.172	0.000	0.048	0.292	0.305	0.000	0.018
2/2/18	0.163	0.171	0.000	0.047	0.336	0.338	0.000	0.018
2/3/18	0.197	0.170	0.000	0.047	0.195	0.228	0.000	0.018
2/4/18	0.245	0.172	0.000	0.046	0.268	0.278	0.000	0.017
2/5/18	0.245	0.177	0.000	0.045	0.379	0.368	0.000	0.017
2/6/18	0.181	0.181	0.000	0.045	0.297	0.309	0.000	0.017
2/7/18	0.187	0.180	0.000	0.044	0.243	0.263	0.000	0.017
2/8/18	0.163	0.178	0.000	0.043	0.303	0.308	0.000	0.016
2/9/18	0.245	0.177	0.000	0.043	0.426	0.407	0.000	0.016
2/10/18	0.164	0.179	0.000	0.042	0.374	0.374	0.000	0.016
2/11/18	0.161	0.177	0.000	0.042	0.325	0.335	0.000	0.016
2/12/18	0.159	0.174	0.000	0.041	0.317	0.326	0.000	0.016
2/13/18	0.218	0.173	0.000	0.041	0.390	0.383	0.000	0.015
2/14/18	0.200	0.175	0.000	0.040	0.351	0.356	0.000	0.015
2/15/18	0.156	0.176	0.000	0.040	0.320	0.330	0.000	0.015
2/16/18	0.248	0.175	0.000	0.039	0.320	0.328	0.000	0.015
2/17/18	0.084	0.177	0.000	0.039	0.258	0.278	0.000	0.015
2/18/18	0.245	0.172	0.000	0.038	0.390	0.379	0.000	0.014
2/19/18	0.246	0.176	0.000	0.038	0.323	0.332	0.000	0.014
2/20/18	0.204	0.181	0.000	0.038	0.330	0.335	0.000	0.014

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.169	0.182	0.000	0.037	0.365	0.363	0.000	0.014
2/22/18	0.193	0.180	0.000	0.037	0.282	0.298	0.000	0.014
2/23/18	0.183	0.179	0.000	0.036	0.365	0.361	0.000	0.014
2/24/18	0.173	0.178	0.000	0.036	0.323	0.331	0.000	0.014
2/25/18	0.150	0.176	0.000	0.036	0.390	0.383	0.000	0.013
2/26/18	0.161	0.173	0.000	0.035	0.449	0.433	0.000	0.013
2/27/18	0.132	0.170	0.000	0.035	0.401	0.400	0.000	0.013
2/28/18	0.183	0.168	0.000	0.035	0.297	0.317	0.000	0.013
3/1/18	0.190	0.168	0.000	0.034	0.376	0.374	0.000	0.013
3/2/18	0.245	0.171	0.000	0.034	0.362	0.365	0.000	0.013
3/3/18	0.181	0.176	0.000	0.034	0.361	0.363	0.000	0.013
3/4/18	0.173	0.176	0.000	0.033	0.251	0.276	0.000	0.013
3/5/18	0.245	0.177	0.000	0.033	0.374	0.368	0.000	0.012
3/6/18	0.209	0.181	0.000	0.033	0.268	0.287	0.000	0.012
3/7/18	0.221	0.183	0.000	0.033	0.274	0.287	0.000	0.012
3/8/18	0.121	0.183	0.000	0.032	0.412	0.395	0.000	0.012
3/9/18	0.161	0.177	0.000	0.032	0.385	0.381	0.000	0.012
3/10/18	0.166	0.174	0.000	0.032	0.350	0.354	0.000	0.012
3/11/18	0.235	0.174	0.000	0.032	0.439	0.425	0.000	0.012
3/12/18	0.232	0.178	0.000	0.031	0.245	0.274	0.000	0.012
3/13/18	0.186	0.182	0.000	0.031	0.158	0.196	0.000	0.012
3/14/18	0.223	0.182	0.000	0.031	0.280	0.285	0.000	0.012
3/15/18	0.180	0.183	0.000	0.031	0.227	0.245	0.000	0.011
3/16/18	0.176	0.182	0.000	0.030	0.291	0.293	0.000	0.011
3/17/18	0.111	0.179	0.000	0.030	0.215	0.235	0.000	0.011
3/18/18	0.223	0.174	0.000	0.030	0.232	0.245	0.000	0.011
3/19/18	0.217	0.177	0.000	0.030	0.311	0.307	0.000	0.011
3/20/18	0.087	0.177	0.000	0.029	0.345	0.338	0.000	0.011
3/21/18	0.149	0.171	0.000	0.029	0.376	0.366	0.000	0.011
3/22/18	0.223	0.169	0.000	0.029	0.207	0.235	0.000	0.011
3/23/18	0.147	0.171	0.000	0.029	0.252	0.263	0.000	0.011
3/24/18	0.221	0.171	0.000	0.029	0.209	0.228	0.000	0.011
3/25/18	0.156	0.174	0.000	0.028	0.323	0.316	0.000	0.011
3/26/18	0.152	0.172	0.000	0.028	0.309	0.310	0.000	0.011
3/27/18	0.166	0.170	0.000	0.028	0.161	0.193	0.000	0.010
3/28/18	0.150	0.168	0.000	0.028	0.317	0.309	0.000	0.010
3/29/18	0.223	0.168	0.000	0.028	0.248	0.259	0.000	0.010
3/30/18	0.223	0.172	0.000	0.027	0.272	0.277	0.000	0.010
3/31/18	0.167	0.176	0.000	0.027	0.246	0.257	0.000	0.010
4/1/18	0.190	0.175	0.000	0.027	0.238	0.249	0.000	0.010
4/2/18	0.152	0.175	0.000	0.027	0.351	0.338	0.000	0.010
4/3/18	0.175	0.172	0.000	0.027	0.258	0.270	0.000	0.010
4/4/18	0.223	0.173	0.000	0.027	0.418	0.394	0.000	0.010
4/5/18	0.145	0.175	0.000	0.026	0.391	0.382	0.000	0.010
4/6/18	0.042	0.170	0.000	0.026	0.470	0.447	0.000	0.010
4/7/18	0.156	0.160	0.000	0.026	0.452	0.438	0.000	0.010
4/8/18	0.156	0.159	0.000	0.026	0.382	0.384	0.000	0.010
4/9/18	0.144	0.159	0.000	0.026	0.374	0.376	0.000	0.010
4/10/18	0.128	0.158	0.000	0.026	0.432	0.420	0.000	0.010
4/11/18	0.125	0.156	0.000	0.026	0.280	0.302	0.000	0.010
4/12/18	0.221	0.155	0.000	0.025	0.422	0.408	0.000	0.009

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.119	0.159	0.000	0.025	0.388	0.386	0.000	0.009
4/14/18	0.107	0.156	0.000	0.025	0.328	0.338	0.000	0.009
4/15/18	0.163	0.153	0.000	0.025	0.365	0.365	0.000	0.009
4/16/18	0.101	0.153	0.000	0.025	0.245	0.269	0.000	0.009
4/17/18	0.158	0.150	0.000	0.025	0.438	0.417	0.000	0.009
4/18/18	0.176	0.151	0.000	0.025	0.215	0.247	0.000	0.009
4/19/18	0.198	0.155	0.000	0.024	0.232	0.251	0.000	0.009
4/20/18	0.104	0.157	0.000	0.024	0.361	0.350	0.000	0.009
4/21/18	0.172	0.154	0.000	0.024	0.368	0.362	0.000	0.009
4/22/18	0.101	0.154	0.000	0.024	0.339	0.341	0.000	0.009
4/23/18	0.084	0.149	0.000	0.024	0.443	0.423	0.000	0.009
4/24/18	0.212	0.146	0.000	0.024	0.368	0.370	0.000	0.009
4/25/18	0.149	0.151	0.000	0.024	0.365	0.366	0.000	0.009
4/26/18	0.159	0.152	0.000	0.024	0.330	0.337	0.000	0.009
4/27/18	0.130	0.152	0.000	0.023	0.269	0.287	0.000	0.009
4/28/18	0.091	0.150	0.000	0.023	0.353	0.349	0.000	0.009
4/29/18	0.128	0.146	0.000	0.023	0.260	0.278	0.000	0.009
4/30/18	0.217	0.146	0.000	0.023	0.334	0.333	0.000	0.009
5/1/18	0.170	0.151	0.000	0.023	0.364	0.358	0.000	0.009
5/2/18	0.186	0.154	0.000	0.023	0.517	0.483	0.000	0.009
5/3/18	0.076	0.155	0.000	0.023	0.526	0.500	0.000	0.008
5/4/18	0.088	0.148	0.000	0.023	0.518	0.499	0.000	0.008
5/5/18	0.113	0.143	0.000	0.023	0.525	0.507	0.000	0.008
5/6/18	0.074	0.140	0.000	0.022	0.586	0.558	0.000	0.008
5/7/18	0.173	0.137	0.000	0.022	0.559	0.541	0.000	0.008
5/8/18	0.167	0.140	0.000	0.022	0.593	0.570	0.000	0.008
5/9/18	0.150	0.144	0.000	0.022	0.636	0.608	0.000	0.008
5/10/18	0.197	0.146	0.192	0.026	0.735	0.691	0.000	0.008
5/11/18	0.198	0.151	0.000	0.038	0.436	0.461	0.000	0.008
5/12/18	0.180	0.155	0.000	0.037	0.297	0.337	0.000	0.008
5/13/18	0.172	0.157	0.000	0.034	0.508	0.492	0.000	0.008
5/14/18	0.229	0.159	0.000	0.032	0.421	0.429	0.000	0.008
5/15/18	0.181	0.163	0.000	0.030	0.362	0.379	0.000	0.008
5/16/18	0.138	0.164	0.000	0.028	0.484	0.471	0.000	0.008
5/17/18	0.169	0.161	0.212	0.032	0.670	0.624	0.000	0.008
5/18/18	0.121	0.159	0.000	0.044	0.518	0.516	0.000	0.008
5/19/18	0.186	0.157	0.000	0.043	0.426	0.439	0.000	0.008
5/20/18	0.176	0.158	0.000	0.039	0.477	0.473	0.000	0.008
5/21/18	0.189	0.160	0.000	0.036	0.466	0.465	0.000	0.008
5/22/18	0.158	0.161	0.000	0.033	0.452	0.453	0.000	0.008
5/23/18	0.229	0.162	0.229	0.036	0.613	0.581	0.000	0.008
5/24/18	0.172	0.166	0.000	0.049	0.638	0.609	0.000	0.008
5/25/18	0.204	0.167	0.154	0.051	0.647	0.622	0.000	0.008
5/26/18	0.223	0.170	0.233	0.061	0.685	0.656	0.000	0.008
5/27/18	0.187	0.172	0.000	0.071	0.631	0.617	0.000	0.008
5/28/18	0.204	0.173	0.000	0.065	0.540	0.544	0.000	0.008
5/29/18	0.203	0.175	0.034	0.058	0.636	0.616	0.000	0.008
5/30/18	0.243	0.177	0.318	0.061	0.644	0.626	0.000	0.008
5/31/18	0.254	0.181	0.363	0.084	0.650	0.633	0.000	0.007
6/1/18	0.215	0.185	0.230	0.106	0.684	0.661	0.000	0.007
6/2/18	0.313	0.189	0.430	0.121	0.682	0.663	0.000	0.007

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.231	0.195	0.430	0.144	0.876	0.819	0.000	0.007
6/4/18	0.224	0.197	0.000	0.156	0.551	0.572	0.000	0.007
6/5/18	0.214	0.196	0.000	0.138	0.608	0.605	0.000	0.007
6/6/18	0.149	0.194	0.000	0.119	0.590	0.589	0.000	0.007
6/7/18	0.243	0.190	0.430	0.112	0.947	0.871	0.000	0.007
6/8/18	0.257	0.192	0.430	0.136	0.774	0.753	0.000	0.007
6/9/18	0.265	0.196	0.430	0.161	0.771	0.749	0.000	0.007
6/10/18	0.356	0.203	0.430	0.181	0.992	0.926	0.000	0.007
6/11/18	0.327	0.213	0.430	0.198	1.020	0.962	0.000	0.007
6/12/18	0.248	0.219	0.430	0.212	0.904	0.878	0.000	0.007
6/13/18	0.339	0.221	0.430	0.224	1.148	1.071	0.000	0.007
6/14/18	0.249	0.225	0.430	0.234	0.956	0.933	0.000	0.007
6/15/18	0.309	0.226	0.430	0.242	0.990	0.956	0.000	0.007
6/16/18	0.251	0.228	0.430	0.250	1.058	1.012	0.000	0.007
6/17/18	0.371	0.229	0.430	0.257	1.264	1.181	0.199	0.166
6/18/18	0.319	0.236	0.430	0.263	1.097	1.063	0.000	0.019
6/19/18	0.183	0.238	0.325	0.266	0.819	0.839	0.000	0.012
6/20/18	0.282	0.231	0.430	0.264	1.283	1.193	0.000	0.010
6/21/18	0.288	0.231	0.430	0.269	1.055	1.032	0.000	0.009
6/22/18	0.258	0.232	0.430	0.275	1.307	1.229	0.000	0.008
6/23/18	0.155	0.229	0.000	0.270	0.681	0.743	0.000	0.008
6/24/18	0.288	0.223	0.430	0.249	1.216	1.140	0.000	0.008
6/25/18	0.155	0.222	0.034	0.245	0.695	0.744	0.000	0.008
6/26/18	0.197	0.215	0.430	0.231	1.023	0.982	0.000	0.007
6/27/18	0.249	0.212	0.430	0.240	1.371	1.269	0.000	0.007
6/28/18	0.121	0.211	0.000	0.244	0.574	0.658	0.000	0.007
6/29/18	0.147	0.202	0.430	0.228	1.355	1.245	0.000	0.007
6/30/18	0.212	0.197	0.430	0.238	0.837	0.863	0.000	0.007
7/1/18	0.351	0.200	0.430	0.252	1.338	1.245	0.622	0.503
7/2/18	0.241	0.211	0.430	0.263	0.990	0.990	0.000	0.043
7/3/18	0.291	0.214	0.430	0.272	1.318	1.241	0.065	0.075
7/4/18	0.305	0.220	0.430	0.280	0.890	0.915	0.000	0.020
7/5/18	0.272	0.225	0.430	0.286	1.221	1.161	0.000	0.015
7/6/18	0.184	0.225	0.325	0.289	0.712	0.768	0.000	0.013
7/7/18	0.314	0.222	0.430	0.287	0.885	0.881	0.000	0.011
7/8/18	0.243	0.225	0.430	0.291	1.241	1.165	0.000	0.010
7/9/18	0.334	0.227	0.430	0.297	0.877	0.894	0.000	0.010
7/10/18	0.234	0.231	0.430	0.301	1.351	1.259	0.000	0.009
7/11/18	0.277	0.230	0.430	0.305	0.808	0.849	0.000	0.009
7/12/18	0.333	0.233	0.430	0.308	1.193	1.134	0.159	0.135
7/13/18	0.254	0.237	0.430	0.311	0.969	0.969	0.000	0.018
7/14/18	0.294	0.237	0.430	0.314	1.297	1.223	0.055	0.056
7/15/18	0.201	0.237	0.430	0.317	0.699	0.763	0.000	0.014
7/16/18	0.262	0.232	0.430	0.319	0.884	0.882	0.000	0.011
7/17/18	0.288	0.232	0.430	0.321	1.024	0.994	0.000	0.010
7/18/18	0.186	0.232	0.000	0.314	0.429	0.526	0.000	0.009
7/19/18	0.231	0.227	0.430	0.289	0.828	0.812	0.000	0.009
7/20/18	0.300	0.226	0.430	0.292	0.870	0.854	0.000	0.008
7/21/18	0.330	0.231	0.430	0.300	0.764	0.774	0.000	0.008
7/22/18	0.243	0.236	0.430	0.307	0.750	0.759	0.000	0.008
7/23/18	0.193	0.234	0.000	0.303	0.334	0.424	0.000	0.008

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.206	0.228	0.430	0.281	0.823	0.788	0.000	0.007
7/25/18	0.316	0.226	0.430	0.286	0.778	0.768	0.000	0.007
7/26/18	0.195	0.229	0.000	0.286	0.376	0.450	0.000	0.007
7/27/18	0.272	0.227	0.430	0.267	0.548	0.565	0.000	0.007
7/28/18	0.149	0.226	0.000	0.266	0.599	0.606	0.000	0.007
7/29/18	0.288	0.221	0.430	0.251	0.845	0.803	0.000	0.007
7/30/18	0.333	0.225	0.430	0.261	0.716	0.715	0.000	0.007
7/31/18	0.334	0.233	0.430	0.275	0.713	0.711	0.000	0.007
8/1/18	0.330	0.241	0.430	0.287	0.829	0.803	0.000	0.007
8/2/18	0.280	0.246	0.430	0.296	0.730	0.731	0.000	0.007
8/3/18	0.238	0.245	0.427	0.303	0.590	0.616	0.000	0.007
8/4/18	0.178	0.240	0.072	0.301	0.675	0.675	0.000	0.007
8/5/18	0.288	0.234	0.430	0.284	0.611	0.625	0.000	0.007
8/6/18	0.232	0.234	0.382	0.288	0.560	0.581	0.000	0.007
8/7/18	0.243	0.233	0.430	0.294	1.001	0.927	0.000	0.006
8/8/18	0.231	0.231	0.430	0.301	1.009	0.957	0.000	0.006
8/9/18	0.212	0.229	0.000	0.299	0.395	0.477	0.000	0.006
8/10/18	0.285	0.227	0.430	0.278	0.922	0.868	0.000	0.006
8/11/18	0.193	0.229	0.291	0.281	0.655	0.673	0.000	0.006
8/12/18	0.226	0.225	0.000	0.273	0.436	0.490	0.000	0.006
8/13/18	0.210	0.223	0.000	0.247	0.309	0.373	0.000	0.006
8/14/18	0.245	0.221	0.170	0.225	0.588	0.580	0.000	0.006
8/15/18	0.184	0.221	0.000	0.214	0.545	0.554	0.000	0.006
8/16/18	0.207	0.217	0.000	0.197	0.361	0.407	0.000	0.006
8/17/18	0.263	0.216	0.000	0.180	0.393	0.421	0.000	0.006
8/18/18	0.240	0.219	0.142	0.169	0.795	0.739	0.000	0.006
8/19/18	0.152	0.218	0.000	0.166	0.122	0.223	0.000	0.006
8/20/18	0.306	0.215	0.407	0.165	0.557	0.539	0.000	0.006
8/21/18	0.193	0.219	0.000	0.179	0.357	0.392	0.000	0.006
8/22/18	0.328	0.219	0.430	0.178	0.588	0.568	0.000	0.006
8/23/18	0.152	0.223	0.000	0.191	0.376	0.409	0.000	0.006
8/24/18	0.144	0.217	0.079	0.180	0.828	0.761	0.000	0.006
8/25/18	0.118	0.208	0.000	0.168	0.416	0.455	0.000	0.006
8/26/18	0.223	0.201	0.430	0.164	0.809	0.754	0.000	0.006
8/27/18	0.223	0.202	0.430	0.188	0.696	0.682	0.000	0.006
8/28/18	0.223	0.204	0.430	0.212	1.145	1.041	0.000	0.006
8/29/18	0.158	0.205	0.430	0.232	1.092	1.026	0.000	0.006
8/30/18	0.166	0.201	0.430	0.248	1.130	1.066	0.000	0.006
8/31/18	0.135	0.196	0.000	0.252	0.520	0.589	0.000	0.006
9/1/18	0.203	0.192	0.430	0.236	0.975	0.921	0.000	0.006
9/2/18	0.223	0.193	0.430	0.246	0.689	0.708	0.000	0.006
9/3/18	0.223	0.197	0.430	0.259	0.780	0.769	0.000	0.006
9/4/18	0.223	0.199	0.430	0.271	1.153	1.068	0.000	0.006
9/5/18	0.209	0.201	0.430	0.281	0.979	0.952	0.000	0.006
9/6/18	0.193	0.201	0.430	0.289	1.035	0.996	0.000	0.006
9/7/18	0.156	0.199	0.145	0.290	0.718	0.747	0.000	0.006
9/8/18	0.192	0.196	0.430	0.278	0.848	0.835	0.000	0.006
9/9/18	0.167	0.194	0.343	0.282	0.808	0.805	0.000	0.006
9/10/18	0.223	0.193	0.430	0.285	0.534	0.584	0.000	0.006
9/11/18	0.156	0.194	0.000	0.283	0.474	0.519	0.000	0.006
9/12/18	0.176	0.191	0.000	0.255	0.470	0.505	0.000	0.006

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.121	0.188	0.000	0.227	0.447	0.480	0.000	0.006
9/14/18	0.201	0.184	0.000	0.203	0.316	0.369	0.000	0.006
9/15/18	0.167	0.185	0.083	0.187	0.630	0.608	0.000	0.006
9/16/18	0.190	0.184	0.000	0.177	0.546	0.554	0.000	0.005
9/17/18	0.176	0.185	0.430	0.173	0.851	0.796	0.000	0.005
9/18/18	0.158	0.184	0.000	0.188	0.159	0.263	0.000	0.005
9/19/18	0.200	0.183	0.052	0.178	0.441	0.454	0.000	0.005
9/20/18	0.149	0.183	0.000	0.166	0.562	0.553	0.000	0.005
9/21/18	0.187	0.182	0.139	0.156	0.583	0.577	0.000	0.005
9/22/18	0.132	0.181	0.000	0.154	0.367	0.408	0.000	0.005
9/23/18	0.223	0.179	0.430	0.153	0.620	0.599	0.000	0.005
9/24/18	0.186	0.182	0.329	0.177	0.673	0.651	0.000	0.005
9/25/18	0.152	0.182	0.000	0.187	0.371	0.417	0.000	0.005
9/26/18	0.170	0.180	0.000	0.173	0.559	0.552	0.000	0.005
9/27/18	0.152	0.179	0.000	0.157	0.210	0.279	0.000	0.005
9/28/18	0.198	0.178	0.281	0.149	0.556	0.536	0.000	0.005
9/29/18	0.150	0.178	0.000	0.156	0.337	0.373	0.000	0.005
9/30/18	0.163	0.177	0.057	0.147	0.704	0.657	0.000	0.005
10/1/18	0.115	0.175	0.000	0.139	0.470	0.488	0.000	0.005
10/2/18	0.094	0.169	0.000	0.129	0.667	0.638	0.000	0.005
10/3/18	0.190	0.165	0.018	0.121	0.410	0.443	0.000	0.005
10/4/18	0.121	0.166	0.000	0.114	0.412	0.433	0.000	0.005
10/5/18	0.172	0.165	0.000	0.108	0.487	0.489	0.000	0.005
10/6/18	0.093	0.164	0.000	0.103	0.364	0.393	0.000	0.005
10/7/18	0.223	0.162	0.255	0.103	0.579	0.557	0.000	0.005
10/8/18	0.081	0.165	0.000	0.115	0.534	0.531	0.000	0.005
10/9/18	0.170	0.161	0.000	0.110	0.483	0.491	0.000	0.005
10/10/18	0.192	0.162	0.000	0.103	0.690	0.654	0.000	0.005
10/11/18	0.111	0.164	0.000	0.097	0.348	0.393	0.000	0.005
10/12/18	0.183	0.162	0.000	0.092	0.580	0.563	0.000	0.005
10/13/18	0.121	0.163	0.000	0.088	0.540	0.539	0.000	0.005
10/14/18	0.115	0.160	0.000	0.084	0.726	0.687	0.000	0.005
10/15/18	0.132	0.157	0.000	0.081	0.650	0.638	0.000	0.005
10/16/18	0.088	0.154	0.000	0.078	0.627	0.620	0.000	0.005
10/17/18	0.149	0.151	0.000	0.075	0.616	0.611	0.000	0.005
10/18/18	0.115	0.151	0.000	0.073	0.483	0.505	0.000	0.005
10/19/18	0.124	0.149	0.000	0.071	0.489	0.502	0.000	0.005
10/20/18	0.135	0.148	0.000	0.069	0.619	0.602	0.000	0.005
10/21/18	0.076	0.147	0.000	0.067	0.650	0.633	0.000	0.005
10/22/18	0.136	0.144	0.000	0.065	0.610	0.605	0.000	0.005
10/23/18	0.054	0.142	0.000	0.064	0.407	0.443	0.000	0.005
10/24/18	0.166	0.139	0.000	0.062	0.563	0.556	0.000	0.005
10/25/18	0.115	0.141	0.000	0.061	0.645	0.626	0.000	0.005
10/26/18	0.079	0.140	0.000	0.060	0.577	0.577	0.000	0.005
10/27/18	0.005	0.134	0.000	0.059	0.532	0.540	0.000	0.005
10/28/18	0.000	0.124	0.000	0.057	0.755	0.715	0.000	0.005
10/29/18	0.099	0.117	0.000	0.056	0.693	0.677	0.000	0.005
10/30/18	0.054	0.116	0.000	0.055	0.650	0.644	0.000	0.005
10/31/18	0.105	0.115	0.000	0.054	0.585	0.591	0.000	0.005
11/1/18	0.011	0.115	0.000	0.053	0.605	0.603	0.000	0.005
11/2/18	0.079	0.111	0.000	0.053	0.472	0.497	0.000	0.005

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.026	0.109	0.000	0.052	0.610	0.599	0.000	0.005
11/4/18	0.070	0.106	0.000	0.051	0.724	0.694	0.000	0.005
11/5/18	0.074	0.105	0.000	0.050	0.399	0.444	0.000	0.005
11/6/18	0.113	0.106	0.000	0.049	0.597	0.586	0.000	0.005
11/7/18	0.056	0.108	0.000	0.049	0.608	0.600	0.000	0.005
11/8/18	0.068	0.107	0.000	0.048	0.733	0.702	0.000	0.005
11/9/18	0.045	0.105	0.000	0.047	0.645	0.640	0.000	0.005
11/10/18	0.037	0.102	0.000	0.046	0.817	0.776	0.000	0.005
11/11/18	0.053	0.099	0.000	0.046	0.655	0.656	0.000	0.005
11/12/18	0.040	0.097	0.000	0.045	0.706	0.692	0.000	0.005
11/13/18	0.087	0.096	0.000	0.045	0.474	0.509	0.000	0.005
11/14/18	0.099	0.098	0.000	0.044	0.594	0.592	0.000	0.005
11/15/18	0.028	0.099	0.000	0.043	0.588	0.589	0.000	0.005
11/16/18	0.104	0.098	0.000	0.043	0.317	0.373	0.000	0.005
11/17/18	0.108	0.100	0.000	0.042	0.614	0.593	0.000	0.005
11/18/18	0.053	0.102	0.000	0.042	0.410	0.440	0.000	0.005
11/19/18	0.096	0.101	0.000	0.041	0.672	0.640	0.000	0.005
11/20/18	0.067	0.102	0.000	0.041	0.413	0.446	0.000	0.005
11/21/18	0.081	0.101	0.000	0.040	0.617	0.598	0.000	0.005
11/22/18	0.108	0.102	0.000	0.040	0.518	0.527	0.000	0.005
11/23/18	0.135	0.105	0.000	0.040	0.037	0.140	0.000	0.005
11/24/18	0.081	0.108	0.000	0.039	0.644	0.594	0.000	0.005
11/25/18	0.099	0.108	0.000	0.039	0.556	0.546	0.000	0.005
11/26/18	0.065	0.107	0.000	0.038	0.526	0.526	0.000	0.005
11/27/18	0.107	0.106	0.000	0.038	0.532	0.531	0.000	0.005
11/28/18	0.054	0.106	0.000	0.037	0.625	0.605	0.000	0.005
11/29/18	0.101	0.104	0.000	0.037	0.619	0.606	0.000	0.005
11/30/18	0.056	0.104	0.000	0.037	0.340	0.387	0.000	0.005
12/1/18	0.125	0.103	0.000	0.036	0.614	0.590	0.000	0.005
12/2/18	0.033	0.104	0.000	0.036	0.682	0.654	0.000	0.005
12/3/18	0.110	0.101	0.000	0.036	0.574	0.575	0.000	0.005
12/4/18	0.054	0.102	0.000	0.035	0.525	0.533	0.000	0.005
12/5/18	0.110	0.101	0.000	0.035	0.521	0.527	0.000	0.005
12/6/18	0.060	0.102	0.000	0.035	0.323	0.368	0.000	0.004
12/7/18	0.111	0.101	0.000	0.034	0.599	0.575	0.000	0.004
12/8/18	0.057	0.102	0.000	0.034	0.514	0.517	0.000	0.004
12/9/18	0.063	0.100	0.000	0.034	0.702	0.666	0.000	0.004
12/10/18	0.079	0.099	0.000	0.033	0.545	0.551	0.000	0.004
12/11/18	0.063	0.098	0.000	0.033	0.545	0.547	0.000	0.004
12/12/18	0.070	0.097	0.000	0.033	0.597	0.588	0.000	0.004
12/13/18	0.098	0.096	0.000	0.033	0.531	0.537	0.000	0.004
12/14/18	0.053	0.097	0.000	0.032	0.559	0.556	0.000	0.004
12/15/18	0.059	0.095	0.000	0.032	0.467	0.484	0.000	0.004
12/16/18	0.101	0.094	0.000	0.032	0.517	0.518	0.000	0.004
12/17/18	0.096	0.096	0.000	0.032	0.559	0.552	0.000	0.004
12/18/18	0.060	0.097	0.000	0.031	0.571	0.565	0.000	0.004
12/19/18	0.096	0.097	0.000	0.031	0.594	0.585	0.000	0.004
12/20/18	0.051	0.097	0.000	0.031	0.568	0.566	0.000	0.004
12/21/18	0.043	0.094	0.000	0.031	0.521	0.528	0.000	0.004
12/22/18	0.132	0.093	0.000	0.030	0.535	0.537	0.000	0.004
12/23/18	0.062	0.096	0.000	0.030	0.607	0.593	0.000	0.004

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Howard 06G, 13G, 14G, 15G, 16G				Stepinski 20			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.085	0.096	0.000	0.030	0.761	0.720	0.000	0.004
12/25/18	0.051	0.095	0.000	0.030	0.693	0.677	0.000	0.004
12/26/18	0.059	0.093	0.000	0.029	0.622	0.621	0.000	0.004
12/27/18	0.053	0.091	0.000	0.029	0.794	0.755	0.000	0.004
12/28/18	0.065	0.090	0.000	0.029	0.712	0.699	0.000	0.004
12/29/18	0.071	0.089	0.000	0.029	0.521	0.547	0.000	0.004
12/30/18	0.043	0.089	0.000	0.029	0.656	0.643	0.000	0.004
12/31/18	0.063	0.087	0.000	0.028	0.545	0.558	0.000	0.004

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
1/1/18	0.081	0.064	0.648	0.064	0.043	0.061	0.000	0.061
1/2/18	0.088	0.064	0.648	0.064	0.048	0.061	0.000	0.061
1/3/18	0.074	0.064	0.648	0.064	0.040	0.061	0.000	0.061
1/4/18	0.096	0.064	0.648	0.064	0.051	0.061	0.000	0.061
1/5/18	0.084	0.064	0.648	0.064	0.045	0.061	0.000	0.061
1/6/18	0.088	0.064	0.648	0.065	0.048	0.061	0.000	0.061
1/7/18	0.098	0.064	0.648	0.065	0.053	0.061	0.000	0.061
1/8/18	0.085	0.064	0.648	0.065	0.046	0.061	0.000	0.061
1/9/18	0.090	0.064	0.648	0.065	0.050	0.061	0.000	0.061
1/10/18	0.111	0.064	0.648	0.066	0.060	0.061	0.000	0.061
1/11/18	0.132	0.065	0.648	0.066	0.071	0.061	0.000	0.061
1/12/18	0.115	0.065	0.648	0.067	0.062	0.061	0.000	0.061
1/13/18	0.090	0.065	0.648	0.068	0.048	0.061	0.000	0.060
1/14/18	0.102	0.065	0.648	0.069	0.056	0.061	0.000	0.060
1/15/18	0.132	0.065	0.648	0.071	0.071	0.061	0.000	0.060
1/16/18	0.127	0.065	0.648	0.072	0.068	0.061	0.000	0.060
1/17/18	0.077	0.065	0.648	0.074	0.042	0.060	0.000	0.060
1/18/18	0.091	0.065	0.648	0.076	0.050	0.060	0.000	0.060
1/19/18	0.081	0.065	0.648	0.078	0.043	0.060	0.000	0.059
1/20/18	0.084	0.065	0.648	0.080	0.045	0.060	0.000	0.059
1/21/18	0.090	0.065	0.648	0.083	0.048	0.060	0.000	0.059
1/22/18	0.050	0.065	0.648	0.085	0.026	0.060	0.000	0.059
1/23/18	0.087	0.065	0.648	0.087	0.046	0.060	0.000	0.058
1/24/18	0.087	0.065	0.648	0.090	0.046	0.060	0.000	0.058
1/25/18	0.085	0.065	0.648	0.092	0.046	0.060	0.000	0.058
1/26/18	0.071	0.066	0.648	0.095	0.039	0.060	0.000	0.057
1/27/18	0.071	0.066	0.648	0.098	0.039	0.060	0.000	0.057
1/28/18	0.082	0.066	0.648	0.100	0.045	0.060	0.000	0.057
1/29/18	0.088	0.066	0.648	0.103	0.048	0.060	0.000	0.056
1/30/18	0.082	0.066	0.648	0.106	0.045	0.060	0.000	0.056
1/31/18	0.087	0.066	0.648	0.109	0.046	0.060	0.000	0.056
2/1/18	0.071	0.066	0.000	0.111	0.036	0.059	0.648	0.056
2/2/18	0.082	0.066	0.000	0.114	0.040	0.059	0.648	0.055
2/3/18	0.048	0.066	0.000	0.117	0.025	0.059	0.648	0.055
2/4/18	0.071	0.066	0.000	0.119	0.036	0.059	0.648	0.055
2/5/18	0.102	0.066	0.000	0.122	0.051	0.059	0.648	0.054
2/6/18	0.085	0.067	0.000	0.125	0.042	0.059	0.648	0.054
2/7/18	0.071	0.067	0.000	0.127	0.036	0.059	0.648	0.054
2/8/18	0.088	0.067	0.000	0.130	0.045	0.059	0.648	0.054
2/9/18	0.136	0.067	0.000	0.132	0.068	0.059	0.648	0.054
2/10/18	0.088	0.067	0.000	0.134	0.045	0.058	0.648	0.054
2/11/18	0.077	0.067	0.000	0.136	0.039	0.058	0.648	0.054
2/12/18	0.076	0.067	0.000	0.138	0.039	0.058	0.648	0.054
2/13/18	0.099	0.067	0.000	0.139	0.050	0.058	0.648	0.055
2/14/18	0.091	0.067	0.000	0.140	0.046	0.058	0.648	0.056
2/15/18	0.085	0.067	0.000	0.141	0.042	0.058	0.648	0.057
2/16/18	0.091	0.067	0.000	0.142	0.045	0.058	0.648	0.059
2/17/18	0.074	0.067	0.000	0.143	0.037	0.058	0.648	0.060
2/18/18	0.116	0.067	0.000	0.143	0.059	0.058	0.648	0.062
2/19/18	0.085	0.067	0.000	0.143	0.042	0.057	0.648	0.064
2/20/18	0.076	0.067	0.000	0.143	0.039	0.057	0.648	0.066

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
2/21/18	0.088	0.067	0.000	0.143	0.043	0.057	0.648	0.068
2/22/18	0.068	0.067	0.000	0.142	0.034	0.057	0.648	0.070
2/23/18	0.093	0.067	0.000	0.142	0.046	0.057	0.648	0.072
2/24/18	0.085	0.067	0.000	0.141	0.042	0.057	0.648	0.075
2/25/18	0.101	0.067	0.000	0.141	0.051	0.057	0.648	0.077
2/26/18	0.105	0.067	0.000	0.140	0.053	0.057	0.648	0.080
2/27/18	0.094	0.067	0.000	0.139	0.048	0.057	0.648	0.082
2/28/18	0.073	0.067	0.000	0.139	0.037	0.056	0.648	0.085
3/1/18	0.046	0.067	0.648	0.138	0.048	0.056	0.000	0.088
3/2/18	0.050	0.067	0.648	0.137	0.050	0.056	0.000	0.090
3/3/18	0.048	0.068	0.648	0.136	0.051	0.056	0.000	0.093
3/4/18	0.034	0.068	0.648	0.135	0.037	0.056	0.000	0.096
3/5/18	0.054	0.068	0.648	0.134	0.057	0.056	0.000	0.098
3/6/18	0.034	0.068	0.648	0.133	0.040	0.056	0.000	0.101
3/7/18	0.042	0.068	0.648	0.132	0.045	0.056	0.000	0.104
3/8/18	0.051	0.068	0.648	0.131	0.053	0.056	0.000	0.106
3/9/18	0.051	0.068	0.648	0.130	0.050	0.056	0.000	0.109
3/10/18	0.042	0.068	0.648	0.130	0.050	0.055	0.000	0.111
3/11/18	0.057	0.068	0.648	0.129	0.060	0.055	0.000	0.113
3/12/18	0.033	0.068	0.648	0.129	0.036	0.055	0.000	0.115
3/13/18	0.022	0.068	0.648	0.129	0.025	0.055	0.000	0.117
3/14/18	0.051	0.068	0.648	0.130	0.043	0.055	0.000	0.118
3/15/18	0.076	0.068	0.648	0.130	0.029	0.055	0.000	0.119
3/16/18	0.115	0.068	0.648	0.131	0.039	0.055	0.000	0.120
3/17/18	0.087	0.067	0.648	0.132	0.031	0.055	0.000	0.121
3/18/18	0.108	0.067	0.648	0.133	0.037	0.055	0.000	0.122
3/19/18	0.121	0.067	0.648	0.134	0.040	0.055	0.000	0.122
3/20/18	0.136	0.067	0.648	0.136	0.046	0.055	0.000	0.122
3/21/18	0.159	0.067	0.648	0.137	0.053	0.055	0.000	0.122
3/22/18	0.082	0.067	0.648	0.139	0.029	0.055	0.000	0.122
3/23/18	0.104	0.067	0.648	0.141	0.034	0.054	0.000	0.122
3/24/18	0.093	0.067	0.648	0.142	0.031	0.054	0.000	0.122
3/25/18	0.132	0.067	0.648	0.144	0.045	0.054	0.000	0.122
3/26/18	0.127	0.067	0.648	0.146	0.043	0.054	0.000	0.121
3/27/18	0.081	0.066	0.648	0.148	0.028	0.054	0.000	0.121
3/28/18	0.138	0.066	0.648	0.150	0.046	0.054	0.000	0.120
3/29/18	0.107	0.066	0.648	0.152	0.036	0.054	0.000	0.120
3/30/18	0.102	0.066	0.648	0.154	0.033	0.054	0.000	0.119
3/31/18	0.094	0.066	0.648	0.157	0.031	0.054	0.000	0.118
4/1/18	0.090	0.067	0.000	0.159	0.000	0.054	0.648	0.118
4/2/18	0.139	0.067	0.000	0.161	0.000	0.054	0.648	0.117
4/3/18	0.116	0.067	0.000	0.163	0.000	0.054	0.648	0.116
4/4/18	0.000	0.067	0.000	0.165	0.000	0.053	0.648	0.115
4/5/18	0.000	0.067	0.000	0.168	0.000	0.053	0.648	0.114
4/6/18	0.000	0.067	0.000	0.170	0.003	0.053	0.648	0.114
4/7/18	0.000	0.067	0.000	0.172	0.000	0.053	0.648	0.113
4/8/18	0.000	0.067	0.000	0.174	0.000	0.053	0.648	0.112
4/9/18	0.081	0.067	0.000	0.176	0.084	0.053	0.648	0.112
4/10/18	0.091	0.067	0.000	0.177	0.122	0.053	0.648	0.111
4/11/18	0.059	0.068	0.000	0.179	0.094	0.053	0.648	0.111
4/12/18	0.077	0.068	0.000	0.180	0.135	0.053	0.648	0.111

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
4/13/18	0.077	0.068	0.000	0.181	0.136	0.052	0.648	0.111
4/14/18	0.071	0.068	0.000	0.182	0.124	0.052	0.648	0.111
4/15/18	0.053	0.068	0.000	0.182	0.091	0.052	0.648	0.112
4/16/18	0.045	0.068	0.000	0.182	0.076	0.052	0.648	0.113
4/17/18	0.077	0.068	0.000	0.182	0.135	0.052	0.648	0.114
4/18/18	0.039	0.068	0.000	0.182	0.068	0.052	0.648	0.115
4/19/18	0.042	0.068	0.000	0.182	0.074	0.051	0.648	0.116
4/20/18	0.067	0.068	0.000	0.181	0.116	0.051	0.648	0.117
4/21/18	0.071	0.067	0.000	0.181	0.121	0.051	0.648	0.119
4/22/18	0.068	0.067	0.000	0.180	0.113	0.051	0.648	0.121
4/23/18	0.071	0.067	0.000	0.179	0.125	0.051	0.648	0.122
4/24/18	0.065	0.067	0.000	0.178	0.115	0.051	0.648	0.124
4/25/18	0.067	0.067	0.000	0.177	0.116	0.051	0.648	0.126
4/26/18	0.063	0.067	0.000	0.176	0.108	0.052	0.648	0.128
4/27/18	0.053	0.067	0.000	0.175	0.090	0.052	0.648	0.130
4/28/18	0.070	0.067	0.000	0.174	0.119	0.052	0.648	0.132
4/29/18	0.043	0.067	0.000	0.173	0.076	0.052	0.648	0.134
4/30/18	0.062	0.067	0.000	0.172	0.107	0.052	0.648	0.137
5/1/18	0.060	0.067	0.648	0.170	0.091	0.052	0.000	0.139
5/2/18	0.062	0.067	0.648	0.169	0.091	0.052	0.000	0.141
5/3/18	0.082	0.066	0.648	0.168	0.122	0.053	0.000	0.143
5/4/18	0.084	0.066	0.648	0.166	0.119	0.053	0.000	0.145
5/5/18	0.082	0.066	0.648	0.165	0.118	0.053	0.000	0.148
5/6/18	0.093	0.066	0.648	0.164	0.128	0.053	0.000	0.150
5/7/18	0.071	0.066	0.648	0.162	0.104	0.053	0.000	0.152
5/8/18	0.079	0.066	0.648	0.161	0.116	0.054	0.000	0.154
5/9/18	0.082	0.066	0.648	0.160	0.122	0.054	0.000	0.156
5/10/18	0.101	0.066	0.648	0.159	0.147	0.054	0.000	0.158
5/11/18	0.068	0.066	0.648	0.159	0.098	0.054	0.000	0.160
5/12/18	0.034	0.066	0.648	0.158	0.050	0.055	0.000	0.161
5/13/18	0.073	0.066	0.648	0.158	0.111	0.055	0.000	0.162
5/14/18	0.063	0.066	0.648	0.158	0.098	0.055	0.000	0.163
5/15/18	0.054	0.066	0.648	0.158	0.082	0.055	0.000	0.164
5/16/18	0.071	0.066	0.648	0.159	0.107	0.056	0.000	0.164
5/17/18	0.084	0.065	0.648	0.160	0.125	0.056	0.000	0.165
5/18/18	0.073	0.065	0.648	0.160	0.115	0.056	0.000	0.165
5/19/18	0.060	0.065	0.648	0.161	0.094	0.057	0.000	0.165
5/20/18	0.060	0.065	0.648	0.163	0.096	0.057	0.000	0.165
5/21/18	0.067	0.065	0.648	0.164	0.104	0.057	0.000	0.164
5/22/18	0.065	0.065	0.648	0.165	0.101	0.057	0.000	0.164
5/23/18	0.070	0.065	0.648	0.167	0.102	0.058	0.000	0.163
5/24/18	0.085	0.065	0.648	0.168	0.096	0.058	0.000	0.163
5/25/18	0.084	0.065	0.648	0.170	0.087	0.058	0.000	0.162
5/26/18	0.087	0.065	0.648	0.172	0.084	0.058	0.000	0.161
5/27/18	0.079	0.065	0.648	0.174	0.071	0.058	0.000	0.160
5/28/18	0.054	0.065	0.648	0.175	0.046	0.059	0.000	0.159
5/29/18	0.084	0.065	0.648	0.177	0.090	0.059	0.000	0.158
5/30/18	0.082	0.065	0.648	0.179	0.087	0.059	0.000	0.157
5/31/18	0.081	0.065	0.648	0.181	0.077	0.059	0.000	0.156
6/1/18	0.087	0.065	0.000	0.183	0.076	0.060	0.648	0.155
6/2/18	0.074	0.065	0.000	0.185	0.067	0.060	0.648	0.154

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
6/3/18	0.107	0.065	0.000	0.187	0.110	0.060	0.648	0.153
6/4/18	0.071	0.065	0.000	0.189	0.068	0.060	0.648	0.152
6/5/18	0.073	0.065	0.000	0.191	0.063	0.060	0.648	0.150
6/6/18	0.070	0.065	0.000	0.193	0.059	0.060	0.648	0.149
6/7/18	0.119	0.065	0.000	0.195	0.085	0.061	0.648	0.148
6/8/18	0.051	0.065	0.000	0.197	0.076	0.061	0.648	0.147
6/9/18	0.000	0.065	0.000	0.199	0.087	0.061	0.648	0.146
6/10/18	0.000	0.065	0.000	0.200	0.098	0.061	0.648	0.145
6/11/18	0.000	0.065	0.000	0.201	0.135	0.061	0.648	0.145
6/12/18	0.000	0.065	0.000	0.202	0.133	0.061	0.648	0.144
6/13/18	0.000	0.065	0.000	0.203	0.166	0.061	0.648	0.144
6/14/18	0.000	0.065	0.000	0.204	0.161	0.061	0.648	0.144
6/15/18	0.000	0.065	0.000	0.204	0.128	0.061	0.648	0.145
6/16/18	0.000	0.065	0.000	0.204	0.161	0.061	0.648	0.145
6/17/18	0.000	0.065	0.000	0.204	0.166	0.062	0.648	0.146
6/18/18	0.000	0.065	0.000	0.204	0.164	0.062	0.648	0.147
6/19/18	0.000	0.065	0.000	0.203	0.087	0.062	0.648	0.148
6/20/18	0.000	0.065	0.000	0.203	0.186	0.062	0.648	0.149
6/21/18	0.000	0.065	0.000	0.202	0.145	0.062	0.648	0.150
6/22/18	0.000	0.065	0.000	0.201	0.181	0.062	0.648	0.151
6/23/18	0.000	0.064	0.000	0.200	0.108	0.062	0.648	0.153
6/24/18	0.000	0.064	0.000	0.199	0.161	0.062	0.648	0.154
6/25/18	0.000	0.064	0.000	0.198	0.099	0.063	0.648	0.156
6/26/18	0.000	0.064	0.000	0.197	0.156	0.063	0.648	0.158
6/27/18	0.000	0.064	0.000	0.196	0.192	0.063	0.648	0.160
6/28/18	0.000	0.063	0.000	0.194	0.094	0.063	0.648	0.161
6/29/18	0.087	0.063	0.000	0.193	0.139	0.064	0.648	0.163
6/30/18	0.136	0.063	0.000	0.191	0.127	0.064	0.648	0.165
7/1/18	0.187	0.062	0.648	0.190	0.170	0.064	0.000	0.167
7/2/18	0.159	0.062	0.648	0.189	0.153	0.064	0.000	0.169
7/3/18	0.198	0.062	0.648	0.187	0.184	0.065	0.000	0.171
7/4/18	0.132	0.061	0.648	0.186	0.125	0.065	0.000	0.173
7/5/18	0.181	0.061	0.648	0.184	0.167	0.065	0.000	0.175
7/6/18	0.084	0.061	0.648	0.183	0.077	0.066	0.000	0.177
7/7/18	0.139	0.060	0.648	0.181	0.132	0.066	0.000	0.179
7/8/18	0.155	0.060	0.648	0.180	0.147	0.066	0.000	0.181
7/9/18	0.144	0.060	0.648	0.179	0.135	0.067	0.000	0.183
7/10/18	0.187	0.060	0.648	0.178	0.178	0.067	0.000	0.184
7/11/18	0.135	0.060	0.648	0.177	0.128	0.067	0.000	0.186
7/12/18	0.150	0.060	0.648	0.177	0.141	0.068	0.000	0.187
7/13/18	0.159	0.060	0.648	0.176	0.155	0.068	0.000	0.188
7/14/18	0.167	0.060	0.648	0.176	0.158	0.068	0.000	0.188
7/15/18	0.118	0.060	0.648	0.176	0.113	0.069	0.000	0.189
7/16/18	0.149	0.060	0.648	0.177	0.138	0.069	0.000	0.189
7/17/18	0.135	0.060	0.648	0.177	0.130	0.069	0.000	0.189
7/18/18	0.062	0.061	0.648	0.178	0.059	0.070	0.000	0.189
7/19/18	0.111	0.061	0.648	0.179	0.102	0.070	0.000	0.189
7/20/18	0.144	0.061	0.648	0.180	0.141	0.070	0.000	0.189
7/21/18	0.115	0.061	0.648	0.181	0.108	0.071	0.000	0.188
7/22/18	0.087	0.062	0.648	0.183	0.082	0.071	0.000	0.188
7/23/18	0.050	0.062	0.648	0.184	0.050	0.071	0.000	0.187

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
7/24/18	0.127	0.062	0.648	0.185	0.124	0.071	0.000	0.186
7/25/18	0.091	0.063	0.648	0.187	0.088	0.072	0.000	0.185
7/26/18	0.056	0.063	0.648	0.189	0.056	0.072	0.000	0.184
7/27/18	0.081	0.063	0.648	0.190	0.081	0.072	0.000	0.183
7/28/18	0.090	0.064	0.648	0.192	0.087	0.072	0.000	0.182
7/29/18	0.099	0.064	0.648	0.194	0.099	0.073	0.000	0.181
7/30/18	0.107	0.064	0.648	0.196	0.105	0.073	0.000	0.180
7/31/18	0.107	0.065	0.648	0.198	0.104	0.073	0.000	0.178
8/1/18	0.098	0.065	0.000	0.199	0.096	0.073	0.648	0.177
8/2/18	0.108	0.065	0.000	0.201	0.105	0.073	0.648	0.176
8/3/18	0.088	0.065	0.000	0.203	0.085	0.073	0.648	0.174
8/4/18	0.076	0.066	0.000	0.205	0.073	0.074	0.648	0.173
8/5/18	0.090	0.066	0.000	0.207	0.090	0.074	0.648	0.172
8/6/18	0.082	0.066	0.000	0.209	0.079	0.074	0.648	0.171
8/7/18	0.141	0.066	0.000	0.211	0.133	0.074	0.648	0.169
8/8/18	0.149	0.066	0.000	0.213	0.147	0.074	0.648	0.168
8/9/18	0.071	0.067	0.000	0.214	0.068	0.074	0.648	0.167
8/10/18	0.113	0.067	0.000	0.215	0.108	0.074	0.648	0.166
8/11/18	0.096	0.067	0.000	0.217	0.096	0.074	0.648	0.165
8/12/18	0.065	0.067	0.000	0.218	0.063	0.074	0.648	0.165
8/13/18	0.046	0.067	0.000	0.218	0.045	0.074	0.648	0.164
8/14/18	0.062	0.067	0.000	0.219	0.059	0.074	0.648	0.164
8/15/18	0.079	0.067	0.000	0.219	0.079	0.074	0.648	0.165
8/16/18	0.063	0.068	0.000	0.219	0.063	0.074	0.648	0.165
8/17/18	0.057	0.068	0.000	0.219	0.057	0.074	0.648	0.165
8/18/18	0.087	0.068	0.000	0.218	0.087	0.074	0.648	0.166
8/19/18	0.017	0.068	0.000	0.218	0.017	0.074	0.648	0.167
8/20/18	0.079	0.068	0.000	0.217	0.081	0.074	0.648	0.168
8/21/18	0.051	0.068	0.000	0.216	0.051	0.074	0.648	0.169
8/22/18	0.084	0.068	0.000	0.215	0.084	0.074	0.648	0.170
8/23/18	0.053	0.068	0.000	0.214	0.053	0.074	0.648	0.172
8/24/18	0.091	0.068	0.000	0.213	0.093	0.074	0.648	0.173
8/25/18	0.059	0.068	0.000	0.212	0.059	0.074	0.648	0.175
8/26/18	0.113	0.068	0.000	0.211	0.115	0.074	0.648	0.176
8/27/18	0.096	0.068	0.000	0.210	0.096	0.074	0.648	0.178
8/28/18	0.132	0.068	0.000	0.208	0.135	0.074	0.648	0.180
8/29/18	0.164	0.068	0.000	0.207	0.167	0.074	0.648	0.181
8/30/18	0.128	0.068	0.000	0.205	0.130	0.074	0.648	0.183
8/31/18	0.084	0.068	0.000	0.204	0.088	0.073	0.648	0.185
9/1/18	0.141	0.068	0.648	0.202	0.144	0.073	0.000	0.187
9/2/18	0.073	0.068	0.648	0.201	0.074	0.073	0.000	0.189
9/3/18	0.113	0.068	0.648	0.199	0.115	0.073	0.000	0.191
9/4/18	0.164	0.068	0.648	0.198	0.167	0.073	0.000	0.193
9/5/18	0.127	0.068	0.648	0.196	0.130	0.073	0.000	0.194
9/6/18	0.161	0.068	0.648	0.194	0.167	0.073	0.000	0.196
9/7/18	0.101	0.068	0.648	0.193	0.102	0.073	0.000	0.198
9/8/18	0.094	0.068	0.648	0.192	0.096	0.073	0.000	0.200
9/9/18	0.113	0.069	0.648	0.190	0.116	0.073	0.000	0.202
9/10/18	0.074	0.069	0.648	0.189	0.076	0.073	0.000	0.203
9/11/18	0.067	0.069	0.648	0.189	0.067	0.073	0.000	0.204
9/12/18	0.040	0.069	0.648	0.188	0.040	0.073	0.000	0.205

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
9/13/18	0.060	0.069	0.648	0.188	0.062	0.073	0.000	0.206
9/14/18	0.057	0.069	0.648	0.187	0.059	0.073	0.000	0.207
9/15/18	0.088	0.069	0.648	0.188	0.088	0.073	0.000	0.207
9/16/18	0.050	0.069	0.648	0.188	0.050	0.073	0.000	0.207
9/17/18	0.116	0.070	0.648	0.188	0.119	0.073	0.000	0.207
9/18/18	0.022	0.070	0.648	0.189	0.022	0.073	0.000	0.207
9/19/18	0.060	0.070	0.648	0.190	0.060	0.073	0.000	0.207
9/20/18	0.051	0.070	0.648	0.191	0.053	0.073	0.000	0.206
9/21/18	0.079	0.070	0.648	0.192	0.082	0.074	0.000	0.206
9/22/18	0.048	0.070	0.648	0.193	0.050	0.074	0.000	0.205
9/23/18	0.099	0.070	0.648	0.195	0.101	0.074	0.000	0.204
9/24/18	0.068	0.070	0.648	0.196	0.071	0.074	0.000	0.203
9/25/18	0.050	0.070	0.648	0.198	0.054	0.074	0.000	0.202
9/26/18	0.050	0.070	0.648	0.199	0.053	0.074	0.000	0.201
9/27/18	0.029	0.070	0.648	0.201	0.031	0.074	0.000	0.200
9/28/18	0.076	0.070	0.648	0.203	0.082	0.073	0.000	0.199
9/29/18	0.046	0.070	0.648	0.204	0.050	0.073	0.000	0.198
9/30/18	0.073	0.070	0.648	0.206	0.079	0.073	0.000	0.196
10/1/18	0.059	0.070	0.000	0.208	0.063	0.073	0.648	0.195
10/2/18	0.088	0.070	0.000	0.210	0.093	0.073	0.648	0.194
10/3/18	0.054	0.070	0.000	0.212	0.057	0.073	0.648	0.192
10/4/18	0.031	0.070	0.000	0.214	0.033	0.073	0.648	0.191
10/5/18	0.065	0.070	0.000	0.216	0.068	0.073	0.648	0.189
10/6/18	0.048	0.070	0.000	0.217	0.051	0.073	0.648	0.188
10/7/18	0.076	0.070	0.000	0.219	0.081	0.073	0.648	0.187
10/8/18	0.070	0.070	0.000	0.221	0.074	0.073	0.648	0.185
10/9/18	0.054	0.069	0.000	0.222	0.046	0.072	0.648	0.184
10/10/18	0.077	0.069	0.000	0.224	0.057	0.072	0.648	0.183
10/11/18	0.033	0.069	0.000	0.225	0.046	0.072	0.648	0.182
10/12/18	0.065	0.069	0.000	0.226	0.059	0.072	0.648	0.182
10/13/18	0.060	0.069	0.000	0.226	0.054	0.072	0.648	0.181
10/14/18	0.079	0.069	0.000	0.227	0.068	0.072	0.648	0.181
10/15/18	0.071	0.069	0.000	0.227	0.057	0.072	0.648	0.181
10/16/18	0.070	0.069	0.000	0.227	0.053	0.071	0.648	0.181
10/17/18	0.053	0.069	0.000	0.227	0.042	0.071	0.648	0.182
10/18/18	0.054	0.068	0.000	0.226	0.050	0.071	0.648	0.182
10/19/18	0.053	0.068	0.000	0.226	0.046	0.071	0.648	0.183
10/20/18	0.068	0.068	0.000	0.225	0.056	0.071	0.648	0.184
10/21/18	0.071	0.068	0.000	0.224	0.053	0.071	0.648	0.185
10/22/18	0.068	0.068	0.000	0.223	0.046	0.071	0.648	0.186
10/23/18	0.043	0.068	0.000	0.222	0.040	0.070	0.648	0.187
10/24/18	0.060	0.068	0.000	0.221	0.051	0.070	0.648	0.189
10/25/18	0.070	0.068	0.000	0.220	0.054	0.070	0.648	0.190
10/26/18	0.060	0.068	0.000	0.219	0.045	0.070	0.648	0.192
10/27/18	0.060	0.068	0.000	0.217	0.039	0.070	0.648	0.193
10/28/18	0.079	0.067	0.000	0.216	0.068	0.070	0.648	0.195
10/29/18	0.081	0.067	0.000	0.215	0.067	0.070	0.648	0.197
10/30/18	0.067	0.067	0.000	0.213	0.051	0.069	0.648	0.198
10/31/18	0.068	0.067	0.000	0.212	0.045	0.069	0.648	0.200
11/1/18	0.062	0.067	0.648	0.210	0.045	0.069	0.000	0.202
11/2/18	0.060	0.067	0.648	0.208	0.051	0.069	0.000	0.204

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
11/3/18	0.071	0.067	0.648	0.207	0.056	0.069	0.000	0.205
11/4/18	0.082	0.067	0.648	0.205	0.057	0.069	0.000	0.207
11/5/18	0.034	0.067	0.648	0.204	0.023	0.068	0.000	0.209
11/6/18	0.062	0.067	0.648	0.202	0.051	0.068	0.000	0.211
11/7/18	0.062	0.067	0.648	0.201	0.048	0.068	0.000	0.213
11/8/18	0.079	0.066	0.648	0.199	0.054	0.068	0.000	0.214
11/9/18	0.057	0.066	0.648	0.198	0.040	0.068	0.000	0.216
11/10/18	0.091	0.066	0.648	0.197	0.073	0.068	0.000	0.217
11/11/18	0.065	0.066	0.648	0.196	0.045	0.067	0.000	0.218
11/12/18	0.063	0.066	0.648	0.196	0.037	0.067	0.000	0.219
11/13/18	0.054	0.066	0.648	0.195	0.046	0.067	0.000	0.220
11/14/18	0.060	0.066	0.648	0.195	0.043	0.067	0.000	0.221
11/15/18	0.056	0.066	0.648	0.195	0.034	0.067	0.000	0.221
11/16/18	0.039	0.066	0.648	0.195	0.022	0.067	0.000	0.221
11/17/18	0.050	0.066	0.648	0.196	0.031	0.066	0.000	0.221
11/18/18	0.036	0.066	0.648	0.197	0.028	0.066	0.000	0.221
11/19/18	0.076	0.066	0.648	0.197	0.054	0.066	0.000	0.220
11/20/18	0.037	0.066	0.648	0.198	0.023	0.066	0.000	0.220
11/21/18	0.067	0.066	0.648	0.200	0.039	0.066	0.000	0.219
11/22/18	0.040	0.066	0.648	0.201	0.029	0.066	0.000	0.218
11/23/18	0.003	0.065	0.648	0.202	0.003	0.065	0.000	0.217
11/24/18	0.060	0.065	0.648	0.204	0.039	0.065	0.000	0.216
11/25/18	0.063	0.065	0.648	0.205	0.037	0.065	0.000	0.215
11/26/18	0.051	0.065	0.648	0.207	0.028	0.065	0.000	0.214
11/27/18	0.051	0.065	0.648	0.208	0.025	0.065	0.000	0.213
11/28/18	0.051	0.065	0.648	0.210	0.019	0.065	0.000	0.212
11/29/18	0.062	0.065	0.648	0.212	0.040	0.064	0.000	0.210
11/30/18	0.034	0.065	0.648	0.214	0.019	0.064	0.000	0.209
12/1/18	0.054	0.065	0.000	0.215	0.028	0.064	0.648	0.207
12/2/18	0.054	0.065	0.000	0.217	0.025	0.064	0.648	0.206
12/3/18	0.053	0.065	0.000	0.219	0.020	0.064	0.648	0.204
12/4/18	0.048	0.064	0.000	0.221	0.014	0.063	0.648	0.203
12/5/18	0.033	0.064	0.000	0.223	0.011	0.063	0.648	0.202
12/6/18	0.036	0.064	0.000	0.225	0.020	0.063	0.648	0.200
12/7/18	0.051	0.064	0.000	0.226	0.028	0.063	0.648	0.199
12/8/18	0.043	0.064	0.000	0.228	0.022	0.062	0.648	0.197
12/9/18	0.056	0.064	0.000	0.229	0.023	0.062	0.648	0.196
12/10/18	0.053	0.064	0.000	0.231	0.019	0.062	0.648	0.195
12/11/18	0.043	0.064	0.000	0.232	0.012	0.062	0.648	0.194
12/12/18	0.054	0.064	0.000	0.233	0.012	0.062	0.648	0.193
12/13/18	0.034	0.063	0.000	0.233	0.009	0.061	0.648	0.193
12/14/18	0.053	0.063	0.000	0.234	0.020	0.061	0.648	0.193
12/15/18	0.039	0.063	0.000	0.234	0.014	0.061	0.648	0.193
12/16/18	0.043	0.063	0.000	0.234	0.012	0.061	0.648	0.193
12/17/18	0.053	0.063	0.000	0.234	0.029	0.060	0.648	0.193
12/18/18	0.056	0.063	0.000	0.233	0.033	0.060	0.648	0.194
12/19/18	0.060	0.063	0.000	0.233	0.034	0.060	0.648	0.194
12/20/18	0.057	0.063	0.000	0.232	0.029	0.060	0.648	0.195
12/21/18	0.057	0.062	0.000	0.231	0.026	0.059	0.648	0.196
12/22/18	0.048	0.062	0.000	0.230	0.019	0.059	0.648	0.197
12/23/18	0.050	0.062	0.000	0.229	0.020	0.059	0.648	0.199

Westford Baseline and Optimization Scenario Pumping and Stream Depletion Rates

	Nutting 17				Nutting 18			
	Baseline		Optimization Scenario		Baseline		Optimization Scenario	
Date	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)	Pumping (cfs)	Depletion (cfs)
12/24/18	0.081	0.062	0.000	0.228	0.039	0.059	0.648	0.200
12/25/18	0.062	0.062	0.000	0.227	0.028	0.059	0.648	0.201
12/26/18	0.062	0.062	0.000	0.226	0.025	0.058	0.648	0.203
12/27/18	0.076	0.062	0.000	0.224	0.028	0.058	0.648	0.204
12/28/18	0.068	0.062	0.000	0.223	0.025	0.058	0.648	0.206
12/29/18	0.051	0.061	0.000	0.221	0.022	0.058	0.648	0.207
12/30/18	0.070	0.061	0.000	0.220	0.026	0.057	0.648	0.209
12/31/18	0.037	0.061	0.000	0.218	0.012	0.057	0.648	0.211