Flow Monitoring Sample Collection and Processing Standard Operating Procedures (SOP) for Chesapeake and Coastal Bays Trust Fund Projects

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1.0 Introduction

Concurrent with the intensified efforts to reduce sediment and nutrients entering Chesapeake Bay is a need to document whether these efforts are producing the intended results. This often involves the calculation of loads, which in turn requires measuring or estimating stream flow. To provide the highest likelihood of detecting change in a relatively short time period, small watersheds are often the focus of monitoring because in theory they are less likely to see confounding effects and also because a greater percentage of the watershed can be treated. However, the advantages of working in small watersheds also come with a disadvantage—greater difficulty in accurately quantifying flow using standard open channel flow measurement.

The purpose of this Standard Operating Procedure (SOP) is to describe, in detail, the specific procedures that must be followed when collecting and processing flow data in association with Chesapeake and Coastal Bays Trust Fund restoration projects. Strict adherence to these protocols is imperative to ensure that data collected are of known and acceptable quality.

In most cases, the collection flow data at Trust Fund monitoring projects will be for the purpose of calculating and documenting changes in sediment and nutrient loads. With this in mind, it is important to understand practical constraints, the potential magnitude of errors, and potential solutions prior to implementation of a monitoring program for flow. A general discussion of these topics is presented in Appendix A.

Three basic types of data collection are covered under this SOP- measurement of velocity and depth to calculate instantaneous flow (discharge), installation and use of water level recorders, and documentation of channel elevations in the vicinity of continuous water level recorders. In addition, data handling, processing and reporting are also discussed.

2.0 Locational Data and Site Naming

To avoid confusion and facilitate efficient re- use in the future, all sites should have accurate (+/- 10m) latitude/longitude information and be named using a consistent naming protocol. Geographic coordinates should be provided for all sites in the NAD83 state plane coordinate system. The name of each site will be based on an abbreviation of the water body name in three letters and the distance in miles and tenths of miles from the mouth, e.g. station WCK0001 is located on Wheel Creek, approximately 0.1 stream miles from the mouth. To name new sites, Bill Romano at Maryland DNR should be contacted (bill.romano@maryland.gov).

3.0 Field Sampling Considerations & Sampling Frequency

3.1 Field Equipment

Prior to heading out to conduct flow monitoring, the Crew Leaders should verify that all necessary equipment is on hand and in good working order, and that there are extra charged batteries for all battery operated gear. Battery operated gear may include, but not be limited to flowmeters, digital camera, laptop computer and laser planer. The list of equipment for flow monitoring is shown in Table 1.

Table 1. List of equipment for Trust Fund flow monitoring projects.

Sampling manual	Spare crumbled cork in plastic bag
Data Sheets on waterproof paper	Spare batteries for battery operated gear
Pencils	Two 100' tapes
Hand calculator	Small sledge and survey flags
Machete or other clearing tool such as a pruner	Steel rebar (at least 4') and hacksaw
Tripod, laser level, and stadia	Cellular phone
Digital camera	Tool box (keep in vehicle)
Water level sensors (keep spare in the backpack)	Spare stainless hardware
Shuttle device/docking station for sensor operation and download	G.P.S. unit
Flowmeter and staff gage	Disinfectant lotion
Clipboard	Drinking water
Flagging	Road maps
Field-compatible laptop computer	First aid kit
Stopwatch	Foul weather gear
Weir flow capture device	Wader repair kit
7 gal bucket	Chest waders
Yardstick	Life vest
Battery powered electronic scale	Safety rope
Squirt bottle for crest gage resetting	Virkon wader disinfectant powder
	Spray applicator for Virkon
	Hand file for v-notch repairs

After gathering the necessary equipment, the Crew Leader should verify that it is in good working order and that any flow meters to be used as primary or back-up units have been calibrated within the last 12 months. <u>Broken or malfunctioning field equipment can cause significant loss of time as well as irrecoverable loss of data, so treating gear appropriately and having spares is an important part of every field collection effort</u>. As most equipment associated with flow monitoring is highly sensitive to impacts and vibration, extra special care should be taken during transport to secure and pad gear with cushioning, and all field personnel should be made aware of the need for gentle handling. This handling includes never transporting flow monitoring gear in an unsecure manner, stacked on top of other equipment, or in the back of a trailer.

3.2 Landowner Permission

For each sampling location, the Crew Leader should be aware of and comply with any requirements for receiving landowner permission prior to accessing the sampling location. In rare cases site access may require landowner notification every time the site is sampled. In any event, all sampling on private land must respect the wishes of the landowner, and the Crew Leader should make the sampling crew aware of these wishes and ensure that they are followed. The Crew Leader should also keep a record of exactly who gave them permission to use their property for access, when that permission was given, and any conditions for access. This information should be kept with the backpack used for hauling equipment.

3.3 Determination of Sampleability

Safety is a primary concern for flow monitoring data collection/retrieval. To ensure that a site can be safely and effectively sampled, the Crew Leader should always examine the stream prior to the initiation of any entry into the water. Additionally, the field crew should be especially mindful of changes in conditions that may be occurring at the site. Examples of conditions which could deem a site unsampleable include unsafe velocities/depths and movement of large woody debris through the sampling area. Under no circumstances should sampling and/or data retrieval take place under dangerous conditions. The USGS has a rule of thumb that prohibits wading if the product of depth (in ft) and velocity (in ft/s) exceeds 8 anywhere in the cross-section.

During elevated water conditions, or in streams with loose and slippery substrates, wading may be difficult and more hazardous than normal. During these times, the Crew Leader may elect to have the person wading hold a safety line and wear a life vest to provide an added level of safety. In addition, studded wading boots or slip-on chains should be available to increase traction. If wading is attempted and safety is compromised, sampling should be discontinued.

3.4 Unusual Conditions

Any unusual or unique conditions that exist at the site should be documented with one or more digital photographs. Examples of unusual or unique conditions include severely eroded stream banks, filling in of pools with sediment, and obvious evidence of out-of-bank flow. In addition, photographs should be taken of channel changes or debris caught in monitoring weirs that would introduce error into stage recordings. A unique number should be used to label each digital photograph after it is downloaded from the camera. The photograph number shall consist of the seven character station name, the date on which the photograph was taken in mmddyy format, and an alphabetic character to denote the order of the photographs. For example, WCK0001073112a would be the first photograph taken at station WCK0001 on 31 July 2012. This number, along with a descriptive title, should be entered in the appropriate portion of the data sheet. All files should be appropriately backed up.

3.5 Sampling Frequency

To obtain sufficient data to develop a rigorous rating curve for the sampling site, bi-monthly visits should be made to each flow monitoring site so that instantaneous discharge data can be collected along with staff gage height. During these visits, data from water level sensors should also be downloaded and stored, and sensors reset, to continue collecting data. In addition, the site should be inspected on each visit to look for and document problems such as changes in channel morphology or debris caught in the notch of a weir and removed only after a staff gage height measurement is taken. In addition to bi-monthly visits, a minimum of eight flow measurements should be taken during storms to establish the upper end of the rating curve. Although measuring discharge during large events is challenging and should only be conducted when conditions are safe, the data collected at high flows is important because flow prediction is only valid within the values actually measured and gross estimates are restricted to 10% above measured stream stage.

NOTE: Trust Fund sites in urban/suburban settings will tend to be flashy, allowing for the possibility of multiple high flow measurements collected on the same day. However, it is also important to collect discharge data over the course of the year to document whether the rating curve is shifting over time.

4.0 Data Recording & Entry

All data for Trust Fund flow monitoring should be recorded on standardized data sheets (Attachments 1-2), including discharge data collected by personnel who are conducting routine or storm event-based sampling of water quality. After completion of data recording at a site, <u>and prior to leaving</u>, all data sheets should be reviewed by two crew members (one of which may be the person who recorded the data). Completion of this task will help ensure that all necessary data are recorded during each site visit, and reviewers should initial the appropriate box in the upper right hand corner of the data sheet. This will help ensure that all necessary data is collected and recorded in a standardized manner.

In the office, all data sheets should be double-entered by the field crew within 10 days of data collection, and the data analyst should compare and resolve the two entries and compile a data set at least quarterly. Double entering data means to have two individuals enter data from data sheets into the database. A data manager then compares these two entries and corrects any conflicts. Data sets should be well labeled and stored electronically in two different locations, and field data sheets should be filed and stored for a minimum of five years.

5.0 Measurement of Velocity and Depth

Stream discharge (**Q**) is the volume of water passing a point on a stream per unit of time, and for Trust Fund monitoring, discharge is expressed in English units as cubic feet per second (cfs). Discharge is calculated as velocity times cross-sectional area (**Q = V*A**). In open channels such as natural streams, discharge is calculated as the sum of multiple cross-sectional measurements to account for variability in water velocity and depth. Discharge, in conjunction with water level at a staff gage or recording instrument, is used to establish a rating curve—the unique relationship between water level and flow at a site that allows continuous estimation of flows over extended periods of time.

For Trust Fund flow monitoring in small streams, Marsh-McBirney Model 2000 Flo-Mate or Hach Model FH950 Portable Flow Meters are currently being used by the Maryland

Department of Natural Resources. These portable, water-resistant flow meters use an electromagnetic sensor to measure the water velocity. The basic principle of operation is that as a conductor such as water moves through a magnetic field, a voltage proportional to the water velocity is produced (Faraday's law of electromagnetic induction).

5.1 Standard Open Channels

Velocity and depth measurements used to calculate flow (also referred to as instantaneous discharge or merely discharge) are recorded on the Discharge/Download Data Sheet (Attachment 1). The manufacturers instructions and the following procedures should be followed.

Prior to using a flow meter, ensure that it has been calibrated at a laboratory within the past year. ***NOTE: a calibrated spare should also be in the vehicle on all field visits. Meter calibration services are available from Hach, Inc.***

Check battery charge prior to each use.. The Marsh McBirney instrument requires 2 alkaline D size batteries which can be replaced when the instrument indicates low battery voltage. The Hach FH950 operates on a re-chargeable Lithium-Ion battery which is approx. 4.1 volts fully charged, and provides 18 hrs of use. Please fully charge when battery life gauge reads less than 3 bars.

Confirm that the instruments read velocity in feet/sec (f/s) and are set to Fixed Point Averaging (FPA) of 10 sec. This setting may be adjusted later depending on whether you are measuring base flow (40 sec.) or rapidly changing storm flow conditions (10 sec).

When using Marsh McBirney 2000 Flo-mates or Hach FH950 Portable Flow meters, *zero velocity calibration should be checked at the start of each sampling day by a) placing the flow meter sensor in a plastic bucket of still water, keeping it at least 3 inches from the bottom and sides and b) reading the velocity 10-15 minutes after placing the sensor in the bucket. If the zero velocity reading after 10 min. is between -0.05. and 0.05 ft/sec, the unit may be used to collect data. If not, the Flo-mate meter can be zero adjusted by pressing the STO and RCL keys at the same time. When the number 3 is displayed, use the down arrow key to decrease the value to zero. The number 32 will then be displayed and the unit will self decrement to zero and turn off. The Hach FH950 can be also be zero calibrated by following the same procedure and using the same criteria by entering the Setup screen, Velocity Calibration tab, and using the Zero Velocity tab when readings have stabilized for at least 10 min..*

1) Upon arrival at the site, record the staff gage height on the data sheet (prior to commencing velocity and depth measurements). **NOTE:** Measurement of discharge should always take place BEFORE removing the water level sensor so that there is a recorded water level that corresponds with the measured discharge.

2) Locate a transect that is suitable for taking velocity and depth measurement [or if a weir is present, go to to section 5.3]. A suitable transect approximates a "U"

shaped channel with few large rocks or other irregularities to the extent possible, as these features can create backflows and cross flows. Whenever possible, current-meter gaging stations should be located in straight, uniform stretches of channel having smooth banks and beds of permanent nature. ***Note:*** At some Trust Fund monitoring stations, conditions in the stream channel have been altered to create better conditions for discharge measurements, especially under low flow conditions. In small streams, the channel can be constricted and modified to more closely approximate a smooth, "U" shaped channel and provide laminar flow with adequate depth for taking velocity measurements. [*Note: If adjustments to the channel are made at the time of the visit, some time should elapse before measurements are made to allow the water elevation to equilibrate*].

3) When a transect is identified, a measuring tape (marked in 1/10ft increments) should be stretched from river left to river right (facing downstream) and firmly secured so that it is perpendicular to the stream channel and near the water surface. Be sure to account for where the starting point on the tape is at the water's edge. In other words, if the process of tying the tape results in the water's edge being 1ft on the tape, 1 ft will be the first recorded value when doing lateral locations across the stream.

4) The total wetted width should then be determined by subtracting the river left value from the river right one. This number should be divided by 25 (using a calculator) and rounded to the nearest 1/10th foot to derive sampling intervals for depth and velocity. *NOTE: In instances where depths or velocities change by more than 10% between intervals it is suggested to add extra intervals, so that you are taking more measurements in areas where stream conditions are changing rapidly.* The interval should then be used to denote on the Lateral Location portion of the data sheet where velocity and flow measurements should be taken along the measuring tape. *NOTE: For very small streams, the minimum sampling interval is 0.1ft (double check this but I thought we had this conversation with Paul and he agreed that the minimum interval would be 0.2 ft since the width of the sensor was about 0.2 ft - we have been using the 0.2 ft. intervals in the low flow channels . As a result, Streams less than 2.5ft (5 ft.)wide will have fewer than 25 measurements.*

   At each sampling interval, measurement of depth (to the nearest 0.01ft, using a staff gage or a top-setting wading rod marked in 0.01 ft. increments) and velocity (to the nearest 0.01ft/sec) should be recorded. After the depth is measured and recorded at a given sampling interval, a calibrated current meter (Marsh-McBirney Flo-mate 2000 or Hach FH950 Portable Flow Meter) should be used to measure velocity at the same location as each depth measurement. Using a top-setting rod held vertically in the stream and resting firmly on the substrate, velocity measurements should be taken at 0.6 of the distance from the water surface to the bottom (measured from the surface). The top-setting rod allows for convenient depth setting. To set the sensor at 60% of the depth, line up the foot scale on the sliding rod with the tenth scale on the top of the depth gage rod. If, for example, the total depth is 2.7 ft, then line up the 2 on the foot scale with the 7 on the tenth scale.

5) Under normal base flow conditions, the meter should be set to provide a velocity reading averaged over 40 seconds. When the stage height is visibly changing over a short period of time (e.g., 2 minutes), the number of intervals should be reduced to 10 and the averaging duration should be reduced to 10 seconds, If substrate is soft, care should be taken not to push the baseplate or meter stick into the substrate.

   Prior to taking a velocity measurement, be sure to orient the sensor to face upstream and take care to stand well downstream and to the side of the sensor to avoid deflection of flows. To take a reading, the sensor must be completely submerged, facing directly into the current, and free of interference. Additionally, care should be taken so that depth and velocity measurements should be taken at the exact same locations along the transect line. However, when necessary, the rod may be adjusted slightly up or downstream to avoid obstructions.

   NOTE 1: In the unlikely event that depth (d) is greater than 2.5 feet in the transect being measured, take velocity readings at 0.2 and 0.8 times the total depth (e.g., if d is 3 feet, measure at 0.6 ft. and 2.4 ft. from the water surface). Record these readings on the data sheet in the appropriate column. Unless stage height of the stream is rapidly changing, the average of these two readings will provide a more accurate velocity for the subsection. *If stage is obviously changing fast, the Crew Leader may exercise discretion and collect only a single velocity measurement at the 0.6 depth, with the time averaging duration reduced to 10 seconds.*

   NOTE 2: One issue of these flowmeters is that electrical interference can interfere with normal operation. If the unit detects interference, the display will blank and a noise flag is displayed. One circumstance where this could occur is measuring flow under 220kva power lines.

   NOTE 3: Nonconductive coatings such as oil and grease on the sensor can result in noisy readings or conductivity lost errors. If these occur or are suspected, clean the sensor with soap and water and in extreme cases use 600 grit sandpaper or finer to remove build-ups.

6) <u>When velocity and depth measurements have been completed, immediately record the staff gage height on the data sheet, and if necessary record any comments/observations about flow changes noted during flow measurements.</u>

5.2 Float Method (consider possibly dropping this method which we have never used and would probably be a last resort due to unsafe conditions or forgetting all of our equipment. It would also free up some need space on our data sheet.

If flows are so low that the flow meter sensor cannot be fully submerged (and the site does not have a notched weir, flow can be estimated with a small floating object that is not affected by the wind.

1) The stream should be constricted as much as possible into a 3 ft long straight section of uniform width and depth. Some temporary form of marking the beginning and endpoints should be placed along the edge of the channel or small

branches inserted into the stream bed (a yardstick works well for this purpose.) *NOTE: Trust Fund flow monitoring sites without weirs may have alterations made to the channel to semi-permanently constrict the flow and make measurement easier-- it is important to know where such modifications have been made so that they can be used under low flow conditions.*

2) The width and depth of the confined channel should be measured at the upstream end, mid-point and downstream end of the 3ft long test area.

3) The speed of a partially submerged floating object unlikely to be influenced by wind (such as a small piece of twig) should be recorded five times as a substitute for velocity measured with the flow meter. To do this, release the object upstream from the target zone for measuring so that it is at full velocity as it passes the upstream end of the measurement zone. Record on the Discharge/Download Data Sheet the time of travel (5 separate trials) for the floated object. NOTE: Because the channel will normally be only 6 inches wide or less, the release point for the object should be in mid-channel. If the object "catches" on the bottom, the obstruction should be removed if possible or the channel made even narrower. In any case, data from trials where the object did not float freely through the entire measurement zone should not be used or recorded on the data sheet.

5.3 Low Flow Measurement at Compound V-notch weirs

In small headwater streams such as those commonly sampled to document improvements from a specific set of Best Management Practices (BMPs), measurement of discharge during baseflow conditions is often problematic, with issues ranging from depths too shallow for the measuring probe to a substantial part of the total flow at a site moving through the hyporheic zone rather than on the surface. In such cases, strong consideration should be given to installing a weir to force water movement through a uniformly engineered structure. Properly installed, weirs allow for greatly increased accuracy and precision in flow measurements. For weirs installed to monitor Trust Fund projects, the guidelines in Appendix B should be followed during design and construction.

For weirs installed to date, a 90 degree v-notch, compound design has been used. For this design, predicted flows versus water elevation above the notch are shown in Table 2. Values listed for notch heights below 0.20 ft are only estimated because very low flows tend to adhere to the weir face in the process of spilling, making it more difficult to accurately measure. At heights greater than 0.20 ft, the known relationship between stage height and flow provides an accurate estimate of discharge, providing conditions at the weir are close to those used in laboratory testing. Thus, at stage levels less than 0.20 ft, a measurement of discharge is necessary. This can either be accomplished using the float method described in section 5.2, or more preferably, by capturing all water flowing over the weir for a timed interval (Bucket Method), described below. On each visit to a weir:

1) Upon Arrival, the staff gage height should be read and recorded on the Discharge/Download Data Sheet. It should also be recorded after each timed water quantity measurement.

2) A rapid inspection should be conducted. First, examine the structure to determine whether leakage is occurring around the weir structure or through any cleanout plugs that may have been installed. If leakage is detected, the situation should be fully described on the Discharge/Download Data Sheet, and the Project Officer and Quality Assurance Officers should be promptly notified so that remedial action can be taken.

3) Inspect the weir notch itself and note any flow obstructions on the Discharge/Download Data Sheet. If debris is present on the weir, remove it, wait 10 minutes, and then take a new staff gage reading (I believe that we all had this discussion and came to an agreement that we would not remove any obstruction to the weir before doing a flow measurement. As long as it was physically possible, we would read the gage, do a flow measurement and then remove the obstruction allowing the elevation to return to “normal”. Confirm this with Bill and Heather. If all agree, we can change the order of this.) Inspect the beveled edge of the notch to look for nicks or dents and note any damage in the comments section of the Discharge/Download Data Sheet . [even small nicks and dents can reduce the accuracy of an otherwise good weir installation]. Any nicks or dents that do occur should be carefully dressed with a fine-cut file or stone, stroking only in the plane of the upstream face of the weir plates or the plane of the beveled surface of the weir plates. ***Under no circumstances should any attempt be made to completely remove an imperfection, which will result in a change to the shape of the weir opening. Instead, only those portions of the metal that protrude above the normal surfaces should be removed.***

4). Inspect the weir pool. The weir is considered to be non- functional and the pool must be cleared of sediment if it accumulates to within 6 inches of the v-notch. This condition should be prominently noted on the Discharge/Download Data Sheet. If installed, cleanout plugs can be pulled and used, along with manually assisting transport of sediment through the plug, to restore the weir pool to an acceptable depth. NOTE: The start and stop times of flushing and any other pool manipulation should be carefully noted on the comments section of the Discharge/Download Data Sheet so that the data collected during this period are discarded and not used.

5) During visits to capture storm events, approach flow conditions should be evaluated and documented with photographs. In general, the approaching flow should be subcritical. The flow should be fully developed, mild in slope, and free of curves, projections, and waves. Record the stage height and condition of the notch at the weir upon arrival, along with the time [this should be done for all visits to sites with weirs so that water level data quality recorded by the pressure sensor can be assessed]. If the water height is less than the height of the notch, record it as a negative number on the data sheet and carefully inspect the weir and downstream area for evidence that water is leaking around or under the weir. Note your findings and observations on the data sheet and take digital photos as appropriate.

6) When using the bucket method, the data recorder should zero a stopwatch and signal to the water collector that collection can begin.

7) At that instant the water collector begins the collection below the weir, the data recorder starts the stopwatch. When the collector stops the collection after appoximately10-15 seconds, the data recorder stops the stopwatch and reads the elapsed time to the hundredths of a second.. Extreme care should be taken to firmly place the water collecting apparatus such that there is a firm seal against the face of the weir and that the bag is capturing all water spilling through the notch.

7) Just before the collection time has elapsed, the data recorder should say “ready, stop”. At that point the water collector should instantly move the collecting apparatus downstream and in an upward motion away from the notch. If there are problems (spillage, took too long to remove apparatus,etc., the process should simply be started over). *NOTE: If the volume collected in 10 seconds is more than 50lbs, the elapsed time can be reduced. Conversely, if the volume collected is low, the elapsed time should be increased since accuracy increases as elapsed time increases due to human error in starting/stopping the stopwatch at the exact time the collector begins/ends the water collection.* The elapsed time for water collection should be recorded on the Discharge/Download Data Sheet each time water is collected and weighed.

8) The team should then set up the digital scale (0-60 lbs; 0.002lb accuracy) on a level surface and tare the scale with a wet 7 gallon bucket and collection apparatus on it.

9) The bucket should then quickly be removed from the scale and the water from the collecting apparatus gently dumped into the bucket. At the same time, the staff gage height should also be observed and recorded.

10) The bucket should then be moved back on to the scale and the weight observed and recorded on the data sheet.

11) This process should be repeated two additional times and results should be recorded on the data sheet, along with an ending staff gage height.

Table 2. Predicted flows based on water elevation for a 90 degree v-notch weir, computed from the formula *Q*=2.49*h*

Head	**Discharge**	**Head**	**Discharge**	**Head**	**Discharge**	**Head**	**Discharge**
H, ft	Q, ft^3/sec	*H*, ft	Q, ft^3/sec	*H*, ft	Q, ft^3/sec	*H*, ft	Q, ft^3/sec
0.02	0.0002	0.25	0.08	0.5	0.446	0.75	1.22
0.03	0.0004	0.26	0.088	0.51	0.469	0.76	1.26
0.04	0.0008	0.27	0.097	0.52	0.492	0.77	1.3
0.05	0.0015	0.28	0.106	0.53	0.516	0.78	1.34
0.06	0.0023	0.29	0.116	0.54	0.54	0.79	1.39
0.07	0.0034	0.3	0.126	0.55	0.565	0.8	1.43
0.08	0.0047	0.31	0.136	0.56	0.591	0.81	1.48
0.09	0.0063	0.32	0.148	0.57	0.618	0.82	1.52
0.1	0.008	0.33	0.159	0.58	0.645	0.83	1.57
0.11	0.01	0.34	0.172	0.59	0.673	0.84	1.62
0.12	0.013	0.35	0.184	0.6	0.701	0.85	1.66
0.13	0.016	0.36	0.198	0.61	0.731	0.86	1.71
0.14	0.019	0.37	0.212	0.62	0.761	0.87	1.76
0.15	0.023	0.38	0.226	0.63	0.792	0.88	1.81
0.16	0.026	0.39	0.241	0.64	0.823	0.89	1.87
0.17	0.031	0.4	0.257	0.65	0.856	0.9	1.92
0.18	0.035	0.41	0.273	0.66	0.889	0.91	1.97
0.19	0.041	0.42	0.29	0.67	0.922	0.92	2.02
0.2	0.046	0.43	0.307	0.68	0.957	0.93	2.08
0.21	0.052	0.44	0.325	0.69	0.992	0.94	2.14
0.22	0.058	0.45	0.344	0.7	1.03	0.95	2.19
0.23	0.065	0.46	0.363	0.71	1.06	0.96	2.25
0.24	0.072	0.47	0.383	0.72	1.1	0.97	2.31
		0.48	0.403	0.73	1.14	0.98	2.37
		0.49	0.425	0.74	1.18	0.99	2.43
						1	2.49

6.0 Calculating Discharge

As most partnering government agencies use English units for discharge records, flow-related measurements conducted for Trust Fund monitoring will be recorded and reported in English units. To reduce the possibility of math errors, discharge should be calculated in the office using an Excel spreadsheet, and calculations will be independently verified.

For computing discharge from a series of open channel measurements, the mid-section method is currently recommended by the U.S. Geological Survey. This method uses the vertical line of each measurement as the centerline of a rectangular subsection; subsection boundaries fall halfway between the centerlines. Discharge in the triangles at the water's edge, where the water is too shallow to allow a meter reading, are negligible in terms of total discharge. The basic procedure is to multiply the mean velocity for each subsection by the area of the subsection to compute the discharge (**Q_n**) for the subsection. Then, all subsection discharges are added to get the total discharge (**Q**) for the entire cross-section.

Mathematically, this is defined as

Q is the total discharge, a is the area of a rectangular subsection, the product of width (w) and depth (d) for that subsection, and is the mean velocity of the current in a subsection.

1. Using the mid-section method, compute the area (**a_n**) of each subsection, where b is distance along the tape from initial point
2. Next, multiply the subsectional area (a_n) by the mean velocity ($_n$) for the subsection to get the subsection discharge (Q_n). If only one velocity measurement was taken at 0.6 depth, it is the mean velocity ($_n$). If two measurements ($_1$ and $_2$) were taken at 0.2 and 0.8 depth, compute the mean value as below:
3. To compute the discharge for each subsection, use the equation:

$Q_n = a_n{}_n$ where
Q_n = discharge for subsection n,
a_n = area of subsection n, and
$_n$ = mean velocity for subsection n.
The calculation repeats this process for each subsection, as shown below:
$Q_1=a_1{}_1$, Q2=$a_2{}_2$, $Q_3=a_3{}_3$, $Q_4=a_4{}_4$,
and so on. ..

4. The subsection products are then added to get total discharge (Q):

$Q_1 = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$
and so on...
Thus, total discharge (Q) equals the sum of all partial discharges from the individual cells. "Lost" discharge in the triangular areas at the edges is assumed negligible.

When the float method is used to collect discharge data, the average values of multiple trials are used to get the mean surface velocity. Then the mean value is multiplied by a velocity adjustment coefficient of 0.85 to calculate the mean velocity of the entire cross section. Using the measured cross-sectional area, multiply corrected velocity times area (mean of the 3 depth and width measurements) to find discharge (Q = VA).

If the station being sampled has a weir, and the stage height is 0.20 ft or higher than the point of the v-notch, the discharge should be taken from Table 2.

7.0 Installation and Use of Water Level Recorders and Staff Gages

Proper installation, maintenance and use of continuous water level sensors is a critical component of a rigorous flow monitoring program such as the type envisioned to quantify flow at Trust Fund monitoring sites. In addition, proper siting, installation and care of staff gages is also crucial, because staff gage readings allow a moment in time linkage between visually observed water levels and sensors that continuously record stream height. <u>When staff gage readings do not closely agree with sensor readings, problems with the sensor are indicated and should be promptly investigated.</u>

A staff gage is a scale printed on enameled steel that for Trust Fund projects is marked in hundredths of feet. The gage is often mounted in the stream on a vertical wooden or metal post to show the water surface elevation. Calibration is periodically verified by referencing a specific height on the gage to a fixed, surveyed elevation point established at the time of installation. Staff gages are used to establish rating curves- the relationship between water elevation (stage) and discharge for a range of flow conditions. Once the curve is established, the discharge at any time can be estimated by reading gage height alone as long as channel conditions have not changed since the rating curve was developed.

7.1 Procedure for Installing a Staff Gage

1) Select and order a staff gage that is long enough to handle the full range of stream elevations expected at the station. For small streams currently being monitored as part of the Trust Fund program, a gage with 0-3ft or 0-4ft range should suffice.
2) Pick a gage location that is in a stable section of stream, making sure the lower end of the gage will be within the wetted channel at very low flows. Avoid installing the gage in the path of high-velocity currents or floating debris (in small streams this may not be possible), and consider the best location to read the gage from during high flows<u>. If installing a staff gage in conjunction with a weir, the gage should be a minimum of 3 feet upstream from the face of the weir to avoid depression of the height associated with flow over the weir.</u>
3) When possible, conduct the installation during low flow and dewater the section of stream using a small pump.
4) For wooden post installations: Dig a hole that is ideally 2.5 feet or more below the stream bed, and place a pressure treated 4x4 vertically in the hole. Pour quick setting concrete into the hole and use a corner level to ensure that the post is vertical. Alternatively, Drive a steel sign post, pipe, or heavy aluminum angle vertically into the stream bed at least 36” into the stream bed. In stream beds where boulders make these approaches impossible, look for a vertical face on a large boulder, drill holes in the rock, and attach the gage plate (with pressure treated wood or metal angle or pipe as support) with expansion bolts.
5) Use stainless steel hardware to screw or bolt the gage plate to the support at a height where it will show the full range of stages for the reach and be visible even under high water conditions. Annually check the elevation of the staff gage with

known elevation monuments (*benchmarks*, described in section 9.1) to make sure it has not moved.

7.2 Reading a Staff Gage

As described earlier, staff gage height and the time of reading should recorded during every visit to the site. To read the staff gage:

1) Remove any floating debris from the gage, and gently scrub away any debris from the gage surface. **NOTE:** *This should not be attempted if conditions are unsafe to reach the staff gage.*
2) Make sure the water line on the gage is stable, and allow any minor waves or turbulence to subside before making a gage reading. **NOTE**: *During certain high flow conditions, water levels may not stop fluctuating. Under these circumstances, the average reading should be visually estimated.*

7.3 Deploying Water Level Recorders

Water level recorders are currently being housed in a 2 inch PVC pipe with 'windows' and a bottom made from 500 micron mesh, stainless steel screen. The recorder sits on a stainless steel bolt that is part of the attachment of the PVC stilling well to the aluminum staff gage upright. This design ensures that the recorder is well protected but presents a low profile to passing debris, is always at the same elevation, is kept from being surrounded by silt, is easily taken in and out of the unit for downloading data and redeploying, and is always submerged. One advantage of mounting the stilling well to the aluminum angle upright is that the aluminum will transfer heat from the ground during cold weather, reducing the likelihood of the recorder freezing.

Standard procedures for operation of water level recorders include verifying the serial number of the sensor, inspecting and cleaning the screen on the stilling well, and verifying that clocks are operating properly. Clocks should be set to record in Eastern Standard Time and take level logger and barometer readings simultaneously at five minute intervals. Field staff should check that level loggers are fully submerged while deployed, and that no silt or sediment has entered the stilling well. Inspections at regular, short intervals (e.g., 2 weeks) are generally required to keep breaks in data at a minimum. Persons installing and servicing water level recorders should follow manufacturers' recommended instructions for that particular instrument. <u>These instructions should be in the hands of the field crew on all site visits.</u>

7.4 Downloading and Processing Data from Water Level Recorders

Water level recorders should be downloaded approximately every other week to minimize any gaps in data if problems develop. <u>**NOTE: It is important to wait until after discharge measurements are complete to remove the water level recorder for downloading.**</u>

Each time a level senor is retrieved, discharge at the time of retrieval should be measured prior to removing the sensor. The time and date of retrieval should be recorded, along with the serial number. At the time of retrieval, verify that the serial number for the sensor matches the serial number entered on the Discharge/Download Data Sheet. When a sensor is being removed from a station and not being immediately re-deployed It is often useful (and recommended) to attach a flag or piece of tape to the sensor with the site identification, date, and time of retrieval.

Standard procedures for operation of water-stage recorders should include checking that water elevations inside and outside of the stilling well match, inspecting and cleaning the screen on the stilling well, and verifying that clocks are operating properly. Inspections at regular, short intervals (e.g., 2 weeks) are generally required to keep breaks in data at a minimum. Persons installing and servicing water-stage recorders should follow manufacturers' recommended instructions for that particular instrument. These instructions should be in the hands of the field crew on all site visits.

7.5 Crest Gages

A crest gage marks the highest elevation of the water surface so that peak flows can be recorded without being present at the site. In order to have some record of peak water levels during highly intense, rare storm events, a crest gage should be installed at all locations where staff gages are located.

The U.S. Geological Survey recommends 2" galvanized pipe, capped at both ends and vented at the top, with intake holes along the side. For Trust Fund flow monitoring sites, a 3ft tall PVC crest gage with removable end caps should be placed at an elevation such that the bottom overlaps exactly 2 feet with the staff gage, allowing for characterization of peak flows 2 feet higher than the staff gage. An aluminum yardstick is snugly fitted into the pipe and granulated cork is placed inside the pipe after installation. The bottom of the yardstick is notched so that the yardstick always rests on a securing stainless steel bolt which has been surveyed to a known elevation. Readings are made by removing the top cap and withdrawing the yardstick. The crest level is indicated by the highest grains of cork adhering to the yardstick , The yardstick is then held against the staff gage to get a reading to the nearest tenth of a foot. The PVC tube is fixed to the back of the support for the gage plate or to another vertical support, with the marked increments matched for elevation. If the staff gage and crest gage are not in the same location, a level should be used to ensure correct mounting.

1) During each routine site visit to measure discharge or any time there is information that suggests that a very high flow event occurred, uncap the tube, and note where the cork particles are.
2) Place the yardstick from the crest gage against the staff gage to obtain a reading to the closest 1/10th of a foot. Record the reading on the data sheet.
3) Clean out the old wet cork from the end cap and PVC tube
4) Replace the yardstick in the crest gage tube, carefully resting it in the notch over the bolt
5) Add 1-2 tablespoons of fresh dry cork to the lower end cap and replace caps.

8.0 Creating Rating Curves & Estimating Flows

Initial data processing should include plotting compensated level logger data versus date-time by month to scan for potentially erroneous values that may need to be deleted from the final data set (data should never be deleted from the original raw data files). An example of data that may need to be deleted includes level logger readings that are recorded after the instrument is removed from the stilling well and before the data download is initiated. This process can be done using Excel software; however, it may be more efficient to perform initial data processing using a more powerful software package such as SAS®.

Rating curves for each stream gage location will be developed using instantaneous flow measurements and the associated staff plate readings. Flow data and staff plate readings will be entered into an Excel spreadsheet, graphed and a regression model will be developed that predicts discharge based on gage height. The R-square of the model should be noted. Various data transformations (e.g., log-log) may be needed to develop a predictive model with a sufficiently high R-square to explain variability in the data. If, following reasonable data transformations a satisfactory predictive model is not developed, more complicated procedures may be required that include the use of locally weighted regression (LOESS) or perhaps a Generalized Additive Model (GAM).

After data have gone through appropriate quality assurance checks (listed in Section 11) and the rating curve has been developed, it may be necessary to apply offsets to the level logger data if there are differences between the level logger data and the associated staff plate readings, since the flow model is based on gage heights. Any needed offset should be specific to each monitoring site and should be a constant that is added to or subtracted from the level logger data. If there are multiple or non-constant offsets more effort may be required that involves locally weighted regression or some other procedure that supports a SCORE statement, which creates a new data set containing predicted values. This process should result in the conversion of level logger data to gage heights. After level logger data are converted to gage heights they are converted to flows using the stage-discharge curve. If absolutely necessary it may be acceptable to extrapolate predicted flows up to 10% beyond measured values; however, this should be discouraged.

Streamflow measurements, including those made at elevated flows, need to be conducted on a regular basis to either verify the accuracy of the stage-discharge rating curve or to follow changes (shifts) in the rating. Substantial sediment deposition or erosion near the area of a gage location can cause a shift in a stage-discharge rating curve. Shifts in the discharge rating reflect the fact that stage-discharge rating curves are not always permanent but vary from time to time, either gradually or abruptly. According to the USGS, if a streamflow measurement is within 5 percent of the streamflow discharge value indicated by the stage-discharge rating curve, the measurement is considered to verify the rating curve. However, if several consecutive measurements meet the 5-percent criterion, but they all plot on the same side of the defined segment of the stage-discharge rating curve, they may be considered to define a period of shifting control. At this point the QC Officer may choose to initiate a field visit to document whether channel elevations have changed (Section 9.0 below).

9.0 Documentation of Channel Elevations

To characterize discharge in a stream at any given point in time using remotely collected water level data, the relationship between stage height and discharge must be known, and that relationship must remain consistent over time. After a large storm, the volume of the pool where the staff gage and water level sensor are mounted changes for a given staff gage height may change. In this case, a new rating curve for the station must be constructed to account for the altered relationship. To document whether calculation of a new rating curve is necessary, periodic examination of the stream channel is necessary. [**NOTE**: *At Trust Fund sites where a 90 degree v-notch weir has been installed. the relationship that has been empirically derived in a laboratory will work so long as there is smooth, laminar flow moving over the weir. Thus, there is no need to do an extensive characterization and ongoing monitoring of the channel beyond documenting the elevation of the weir notch relative to the staff gage and two points of unchanging elevation (benchmarks,described below).*

9.1 Two-peg Test The calibration and proper functioning of the instrument that is used for collecting elevation data must be verified prior to each use by performing the two-peg test. To save field crew time in the event the instrument fails, this test should be performed in an outside area near the lab or office. When complete, the results of this test should be entered on the Channel Elevation Data Sheet (Attachment 2).

1) Drive two stakes (“A & “B”) near ground level 250 feet apart with a clear line of sight.
2) Set up the surveyors level or laser level halfway between the two points. Ensure that it is level (Steps 2-4 in section 9.3 below)
3) Take a stadia or laser level reading (“a”) from the top of stake A, and a second reading (“b”) that corresponds to the top of stake B. Record these readings to the nearest $1/100^{th}$ foot and record the elevation difference (“a - b”).
4) Now move the level to within 10ft of stake A.
5) Take a new stadia or laser level reading (“c”) on Stake A and a second reading (“d”) on Stake B. If the instrument is in adjustment, (c - d) will equal (a - b). If the difference between the two readings is in excess of the stated accuracy of the device (0.05 ft), the instrument is out of adjustment and should not be used.

9.2 Benchmarks

Prior to conducting channel elevation survey work, benchmarks need to be located or established. The benchmark is the initial reference (or starting) point of the survey and a reference point that should not change in elevation over time. Because Trust Fund monitoring sites may be sampled over an extended number of years, two benchmarks should be established for each site as an insurance against losing one, also to provide a means to check for changes over time. If there is an existing monument (benchmark) near the survey area and it is in good condition, use it. More often, a new benchmark will need to be established. The elevation of this benchmark may be assumed (100 ft is normally used) or tied into a project datum or mean sea level. In any case, the description of the reference on the survey data sheet should include this information.

To install a new benchmark, choose a location outside the stream channel (and floodplain, if possible) yet near enough to be clearly visible. The best placement is on a permanent feature of the site such as a bedrock outcrop, or a distinctive point on a large boulder. If this type of feature is used, drill a hole using a concrete bit and use epoxy or similar material to cement a stainless steel carriage bolt to the feature. A semi-permanent feature such as a large, healthy tree can also be used, by driving in a galvanized 40-80 penny spike into its base such that a level can be set on its head and be clearly visible from the stream channel where channel elevations will be made. **NOTE:** *Tree selection should consider the possibility for windthrow or loss from bank erosion during storms. In addition, trees perched on streambanks may slowly 'slide' downward in elevation, so these should be avoided as well.*

Another alternative is to dig a 9 inch diameter circular hole 18 inches to 2 feet deep in a terrace of the stream. A bag of concrete is then mixed, and the hole is filled with it level to the existing elevation around the hole. Before the concrete sets up, a 6" zinc-coated carriage bolt is placed into the center, flush with the concrete. A final alternative is a rebar monument. This type of benchmark is created by driving a 4ft long piece of rebar (1/2" diameter or larger) within ½ inch of the ground level, and then cover the end with a plastic cap. In all cases, an aluminum or plastic survey marker tag should be used to label the benchmark to avoid confusion on subsequent surveys.

If the benchmark may be difficult to find on return visits, permanent markings should be considered. These should not be obtrusive, but need to be visible in fture years. In any case, location should be well described and photographed.. Remove temporary flagging, stationing stakes, and other marks when the survey is complete.

9.3 Setting up the Laser Level or Surveyors Level

Collection of elevation data for Trust Fund monitoring sites will primarily use a calibrated laser level. This instrument is delicate and should be stored in a cool, dry place and transported with great care. Because elevation data will only be collected infrequently, a two-peg test should be conducted just prior to each use to ensure that the unit is within calibration specifications. <u>Only levels that have passed the two-peg test prior to use should be used to collect elevation data on Trust Fund projects.</u>

1) Set up the level so that the two benchmarks and all or most of the site to be surveyed is visible. The best locations are usually on the low stream terrace, because it is stable and close enough to the water surface that staff extensions are minimized. **NOTE:** *Consider setting up in the stream channel if visibility is limited and if the depth and bottom conditions make this feasible (the stream bottom should be stable and the level must not get wet). Having to move the instrument adds time and complexity to the survey, so choosing a good location for the level is important.*
2) Screw the level snugly to the head of the tripod. "Snug" means fingertight. **NOTE:** *Overtightening can cause warping of the tripod plate or instrument, which will result in inaccurate measurement*.
3) Spread the tripod legs 3 or 4 feet apart, adjust the legs to roughly level the tripod. Push the legs firmly into the ground.
4) Move the leveling screws one at a time or in pairs to bring the bubble into the target circle on the leveling bubble. Rotate the scope 90° and re-level. Start by leveling across two of the screws and finish with the third screw after making the 90° degree turn. Repeat until the bubble stays level throughout a 180° rotation. **NOTE:** *with a self-leveling instrument such as a laser planer, this procedure*

brings the instrument into the range where the leveling pendulum prism can operate.

9.4 Establishing Pool Cross-Section Measuring Points

To document pool stability over time at sites where a weir is not installed, an initial set of channel elevation data should be collected at the time that the site is established (or re-established after a disturbance such as channel reconfiguration). Using the same longitudinal locations and two fixed reference points (such as known elevation monuments installed during stream channel reconfiguration), this survey should be repeated annually and after obvious changes, using identical methods and gear whenever possible.

The basic idea of surveying the channel is to characterize the pool where the staff gage and pressure sensor are located well enough to know whether there have been meaningful changes in volume at each elevation within the stream channel. To accomplish this, the following procedure should be used:

1) For efficiency and safety, the channel elevation survey should be completed under non-storm conditions.
2) First, set up the level on a terrace within the monitoring pool in a location that offers good visibility up and downstream [Level set-up described below].
3) Then, visually delineate the downstream extent of the pool at normal flows. Use a pin flag to mark this location.
4) Walk to the upstream end of the low flow pool. At that location, use the surveyors level to determine the elevation of the lowest terrace. Now, use the level to find this elevation in the stream bed by walking upstream. At this point use a pin flag to mark the upper boundary of the staff gage pool.
5) Use a measuring tape to determine the length of the staff gage pool. **Note***: the tape should be laid out along the thalweg of the stream rather than taking the straight line distance between the pin flags*. Leave the measuring tape along the stream.
6) Divide the total length by 10 and use this distance to put 9 additional pin flags at equal distances from each other along the measuring tape—these 11 points will be used for cross-section measurements.
7) At each measurement point, choose a location along a line that is perpendicular to stream flow that is at the beginning of the terrace on river left (on the left bank facing downstream), and drive a 3ft-long rebar into the terrace to within ½ inch of the ground at that point. Place a cap on the protruding rebar. Use a plastic or aluminum tag to label the transects from 0 (most upstream) to 10 (most downstream). Repeat this process for the other 10 cross-sections to be monitored.

9.5 Measuring Cross-section Elevations

After the 11 cross-section stations have been established, characterization of the staff gage pool volume at different elevations can be competed. This procedure is based on differential leveling, that is, elevations are determined in relation to a fixed reference point of known (or more likely, assumed) elevation. The standard instrument for surveying channel elevations at Trust Fund monitoring sites is a laser level. Laser levels project a beam in a circular plane through a rotating prism. A special leveling rod with a detector is moved up or down until the beam intersects it. The use of laser levels is relatively easy and allows one person to collect elevation data.

SIDEBAR: NOTES ON CARE OF THE LEVEL
• Place the level on a firm base in a vehicle rather than on top of other equipment.
• Store the lens cap and tripod cap in the level case while the level is in use.
• Keep the case closed while the instrument is in use.
• Don't run while carrying the level, don't drop it, and *never* fall with it. If you do, the level may need repair and recalibration. (See Two-Peg Test)
• Never force screws or parts when adjusting or maintaining your level.
• Use the sunshade to protect the lenses.
• Clean the lenses only with compressed air or special lens cloth, not with fingers, sleeves, kerchiefs, etc.

1) The level should be placed in a location where all survey points are clearly visible, or such that a minimum number of moves will be necessary to collect all elevation data. The instrument should then be leveled.
2) Using a rod outfitted with a laser detector, [or if using a surveyors level, a stadia marked in 1/100ft increments], the rod/stadia holder should move to a benchmark and read off the benchmark number on the tag or label. The number should be recorded on the data sheet. The rod holder should then hold the rod upright and move the laser detector up or down until an audible beep indicates that the laser plane has been crossed. The height of the rod should then be recorded on the data sheet. **Note:** *If using a surveyors level, the stadia holder should hold the stadia in a vertical position and the instrument reader should look through the telescope and record the stadia reading associated with the horizontal cross hair on the instrument.*
3) The process should be repeated for the second benchmark and the relative difference in height compared against the historical difference in elevation between the two benchmarks.
4) After the benchmark elevations have been recorded and determined not to have changed, attach the zero end of the 100ft measuring tape to a stake placed in the ground at the upstream cross-section (0). Stretch the tape tight and level above the water perpendicular to the stream channel and anchor it on the other bank. **NOTE***: If the stream is so wide that the tape sags excessively, use a rope that can be stretched straight. Record the total distance between endpoints on the Channel Elevation data sheet.*
5) Starting with the left endpoint stake facing downstream as zero, begin collecting and recording elevation data at 0.5ft intervals across the channel cross-section until the terrace is reached. **NOTE:** *In areas such as floodplains or sections of stream with little topographic relief, fewer measurements may be taken at the discretion of the Crew Leader.*
6) When one cross-section is completed, move downstream to the next cross-section and repeat the process until all 11 cross-sections have been completed.
7) CLOSE THE SURVEY. Close the survey loop by moving the level to a new location at least one channel width away from the initial level location. After the instrument is level, re-shoot the final location on the 11th cross section, and then re-shoot the initial benchmark. **NOTE:** *Shooting directly back to the benchmark without moving the instrument only detects movement of the level, but not instrument error.*

8) ***While still at the site***, calculate closure by comparing the difference between the first benchmark reading and last shot on cross-section 11 and the second shot of the benchmark. **NOTE:** *If the difference between the two readings has changed by more than the instrument error (0.1ft),the entire process should be repeated.*

10.0 Photodocumentation

To allow visual documentation of changes in the site over time, periodic site photographs taken from a fixed location and gear set-up method are necessary. For Trust Fund monitoring sites, photographs should be taken each time channel elevations are measured- annually and as necessary after major storm events.

1) Choose two fixed points to capture the view of the staff gage pool from upstream and downstream. Drive a 2ft-long rebar within ½ inch of the ground and place a cap and label on it.
2) Record the camera model and lens focal length on the channel elevation data sheet.
3) Attach the camera to a tripod set so that the camera is 48" above the photoreference point.
4) Use the zoom function to move the lens to the full out position (maximum view).
5) Take the photo and then record the photo number and location on the Channel Elevation data sheet.
6) Repeat the process for the other photo reference point at the site.

11.0 Quality Assurance

The procedures outlined in this section are intended to ensure that flow monitoring data from Trust Fund monitoring projects are of known and acceptable quality.

1) A Quality Assurance Officer should be designated, with ultimate responsibility for data quality on Trust Fund flow monitoring projects conduct by DNR staff and other Trust Fund partners.
2) All activities of field crew data collection activities should follow the procedures outlined in the SOP, and the QA Officer should be promptly notified of any deviations, unusual conditions, etc.
3) The QA Officer should observe and document activities of the field crew two to three times per year.
4) All field personnel participating in Trust Fund flow monitoring should attend annual training and pass a 20 question test with a score of 90% or higher to demonstrate familiarity with data collection and recording requirements established in the Standard Operating Procedures (SOP) manual (this document).
5) All numerical data collected for Trust Fund flow monitoring should be double entered, compared electronically for consistency, and any discrepancies noted and resolved.

6) A calibration logbook shall be maintained for all equipment and instrumentation used for Trust Fund monitoring, and calibration should be checked or completed as specified in the SOP.
7) Data sheets should be stored and maintained for a total of 5 years minimum, and 2 electronic copies of the data should be maintained in separate locations.

Appendix A

Measurement Accuracy

Accurate application of water measuring devices generally depends upon standard designs or careful selection of devices, care of fabrication and installation, good calibration data and analyses, and proper user operation with sufficiently frequent inspection and maintenance procedures. In operations, accuracy requires continual verification that the measuring system, including the operator, is functioning properly. Thus, good training and supervision is required to attain measurements within prescribed accuracy bounds. **Accuracy** is the degree of conformance of a measurement to a standard or true value. The standards are set by users, providers, governments, or compacts between these entities. Accuracy is usually stated in terms of deviation of discharge discussed subsequently. All parts of a measuring system, including the user, need to be considered in assessing the system's total accuracy. A measurement system usually consists of a **primary element**, which is that part of the system that creates what is sensed, and is measured by a **secondary element**. For example, weirs and flumes are primary elements. A staff gage is the secondary element.

Flow mate accuracy is +-2% plus zero stability

Accuracy standard set by the USGS Office of Surface Water (OSW) for the measurement of stage for most applications, which is ±0.01 foot (ft) or 0.2 percent of the effective stage

CONTRIBUTION OF INSTRUMENT ERROR TO DISCHARGE-MEASUREMENT ERROR

Instrument error is only one of several significant errors that may contribute to the overall error of a discharge measurement. Sauer and Meyer (1992) found that most measurements of discharge by current meters will have standard errors ranging from 3 to 6 percent. Poor measuring conditions (such as very slow water velocities or shallow depths) or improper procedures of meter use, however, can result in much larger errors. They cited important sources of error--other than the error contributed by the current meter--such as the measurement of depth, the pulsation of flow, the vertical distribution of velocities, the measurement of horizontal angles, and the computations involving the horizontal distribution of velocity and depth (insufficient number of or inadequate measuring subsections).

Sauer and Meyer estimated the total error of discharge measurements by taking the square root of the sum of the squares of the individual errors contributed by the various sources of error. The error associated with the current meter, which Sauer and Meyer termed "instrument error", was relatively small (0.3 percent) for AA meters (commonly known as Price-type current meters) used under ideal measuring conditions and following the recommended field procedures. For pygmy meters, the instrument error they used was still relatively small at 0.8 percent for a wading measurement with good field conditions. Their analysis properly used the standard error of estimate, which is 1 standard deviation of the calibration data used to develop the standard rating. Sauer and Meyer did not consider the case of a meter whose difference from the standard rating is near to or falls outside of the accuracy criteria, which is 2 standard deviations. Such a meter could contribute an instrument error up to about twice as large as they used.

In poorer field conditions where the velocity is slow, Sauer and Meyer found meter error to be a large source of error with respect to the other sources. Here again, they used the standard error of 1, not 2, standard deviations as the instrument error.

The errors associated with individual discharge measurements contribute to the error of the rating curve, which is the graphical relationship between stage and discharge for a streamflow gaging station. The rating-curve error is incorporated directly in the discharges that are computed and published for a station.

If several meters were employed in the development of the rating curve, instrument errors might off-set each other. This does not always happen in practice, however. Sometimes long periods go by when one meter is predominately used to define the rating curve. Thus, any error in velocity data that is introduced by a current meter would be of concern.

Definitions of Terms Related to Accuracy

Precision is the ability to produce the same value within given accuracy bounds when successive readings of a specific quantity are measured. Precision represents the maximum departure of all readings from the mean value of the readings. Thus, a measurement cannot be more accurate than the inherent precision of the combined primary and secondary precision. **Error** is the deviation of a measurement, observation, or calculation from the truth. The deviation can be small and inherent in the structure and functioning of the system and be within the bounds or limits specified. Lack of care and mistakes during fabrication, installation, and use can often cause large errors well outside expected performance bounds. Since the true value is seldom known, some investigators prefer to use the term **Uncertainty**. Uncertainty describes the possible error or range of error which may exist. Investigators often classify errors and uncertainties into spurious, systematic, and random types.

Spurious errors are commonly caused by accident, resulting in false data. Misreading and intermittent mechanical malfunction can cause discharge readings well outside of expected random statistical distribution about the mean. A hurried operator might incorrectly estimate discharge. Spurious errors can be minimized by good supervision, maintenance, inspection, and training. Experienced, well-trained operators are more likely to recognize readings that are significantly out of the expected range of deviation. Unexpected spiral flow and blockages of flow in the approach or in the device itself can cause spurious errors. Repeating measurements does not provide any information on spurious error unless repetitions occur before and after the introduction of the error. On a statistical basis, spurious errors confound evaluation of accuracy performance.

Systematic errors are errors that persist and cannot be considered entirely random. Systematic errors are caused by deviations from standard device dimensions. Systematic errors cannot be detected by repeated measurements. They usually cause persistent error on one side of the true value. For example, error in determining the crest elevation for setting staff or recorder chart gage zeros relative to actual elevation of a weir crest causes systematic error. The error for this case can be corrected when discovered by adjusting to accurate dimensional measurements. Worn, broken, and defective flowmeter parts, such as a permanently deformed, over-stretched spring, can cause systematic errors. This kind of systematic error is corrected by maintenance or replacement of parts or the entire meter. Fabrication error comes from dimensional deviation of fabrication or construction allowed because of limited ability to exactly reproduce important standard dimensions that govern pressure or heads in measuring devices. Allowable tolerances produce small systematic errors which should be specified.

Calibration equations can have systematic errors, depending on the quality of their derivation and selection of form. Equation errors are introduced by selection of equation forms that usually only approximate calibration data. These errors can be reduced by finding better equations or by using more than one equation to cover specific ranges of measurement. In some cases, tables and plotted curves are the only way to present calibration data.

Random errors are caused by such things as the estimating required between the smallest division on a head measurement device and water surface waves at a head measuring device. Loose linkages between parts of flowmeters provide room for random movement of parts relative to each other, causing subsequent random output errors. Repeating readings decreases average random error by a factor of the square root of the number of readings.

Total error of a measurement is the result of systematic and random errors caused by component parts and factors related to the entire system. Sometimes, error limits of all component factors are well known. In this case, total limits of simpler systems can be determined by computation (Bos et al., 1991). In more complicated cases, different investigators may not agree on how to combine the limits. In this case, only a thorough calibration of the entire system as a unit will resolve the difference. In any case, it is better to do error analysis with data where entire system parts are operating simultaneously and compare discharge measurement against an adequate discharge comparison standard.

Calibration is the process used to check or adjust the output of a measuring device in convenient units of gradations. During calibration, manufacturers also determine robustness of equation forms and coefficients and collect sufficient data to statistically define accuracy performance limits. In the case of long-throated flumes and weirs, calibration can be done by computers using hydraulic theory. Users often do less rigorous calibration of devices in the field to check and help correct for problems of incorrect use and installation of devices or structural settlement. A calibration is no better than the comparison standards used during calibration.

Comparison standards for water measurement are systems or devices capable of measuring discharge to within limits at least equal to the desired limits for the device being calibrated. Outside of the functioning capability of the primary and secondary elements, the quality of the comparison standard governs the quality of calibration.

Discrepancy is simply the difference of two measurements of the same quantity. Even if measured in two different ways, discrepancy does not indicate error with any confidence unless the accuracy capability of one of the measurement techniques is fully known and can be considered a working standard or better. Statistical **deviation** is the difference or departure of a set of measured values from the arithmetic mean.

Standard Deviation Estimate is the measure of dispersion of a set of data in its distribution about the mean of the set. Arithmetically, it is the square root of the mean of the square of deviations, but sometimes it is called the root mean square deviation.

Capability Terms

The term **linearity** usually means the maximum deviation in tracking a linearly varying quantity, such as measuring head, and is generally expressed as percent of full scale. **Discrimination** is the number of decimals to which the measuring system can be read. **Repeatability** is the ability to reproduce the same reading for the same quantities. **Sensitivity** is the ratio of the change of measuring head to the corresponding change of discharge. **Range** is fully defined by the lowest and highest value that the device can measure without damage and comply with a specified accuracy. The upper and lower range bounds may be the result of mechanical limitations, such as friction at the lower end of the range and possible overdriving damage at the higher end of the range. Range can be designated in other ways: (1) as a simple difference between maximum discharge (Q_{max}) and minimum discharge (Q_{min}), (2) as the ratio (Q_{max}/Q_{min}), called **rangeability**, and (3) as a ratio expressed as 1:(Q_{min}/Q_{max}). Neither the difference nor the ratios fully define range without knowledge of either the minimum or maximum discharge.

Additional terms are related more to dynamic variability and might be important when continuous records are needed or if the measurements are being sensed for automatic control of canals and irrigation. **Hysteresis** is the maximum difference between measurement readings of a quantity established by the same mechanical set point when set from a value above and reset from a value below. Hysteresis can continually get worse as wear of parts increases friction or as linkage freedom increases. **Response** has several definitions in the instrumentation and measurement fields. For water measurement, one definition for response is the smallest change that can be sensed and displayed as a significant measurement. **Lag** is the time difference of an output reading when tracking a continuously changing quantity. **Rise time** is often expressed in the form of the **time constant**, defined as the time for an output of the secondary element to achieve 63 percent of a step change of the input quantity of the primary element.

The main factors which influence the selection of a measuring device include:

- Accuracy requirements
- Cost
- Legal constraints
- Range of flow rates
- Head loss
- Adaptability to site conditions
- Adaptability to variable operating conditions
- Type of measurements and records needed
- Operating requirements
- Ability to pass sediment and debris
- Longevity of device for given environment
- Maintenance requirements
- Construction and installation requirements
- Device standardization and calibration
- Field verification, troubleshooting, and repair
- User acceptance of new methods
- Vandalism potential
- Impact on environment

(a) Accuracy

The target or desired accuracy of the measurement system is an important consideration in measurement method selection. Most water measurement devices can produce accuracies of ±5 percent. Some devices are capable of ±1 percent under laboratory settings. However, in the field, maintaining such accuracies usually requires considerable expense or effort (e.g., special construction, recalibration, maintenance, etc.). Selecting a device that is not appropriate for the site conditions can result in a nonstandard installation of reduced accuracy, sometimes greater than ±10 percent.

Accuracies are usually reported for the primary measurement method or device. However, many methods rely on a secondary measurement, which typically adds error to the overall measurement. For example, the primary calibration for a weir is the relationship between head and discharge; this relationship typically contains a small error. However, the head must be measured, which potentially introduces additional error.

Deviation from a normal transverse or vertical flow distribution, or the presence of watersurface boils, eddies, or local fast currents, is reason to suspect the accuracy of the measuring device. Errors of 20 percent are common, and errors as large as 50 percent or more may occur if the approach flow conditions are very poor.

The approach velocity toward weirs should be less than 0.5 foot per second (ft/s). This velocity value is equivalent to a head error of 0.005 ft. Velocity of approach can be estimated by dividing the maximum discharge by the area at a point 4 to 6 measuring heads upstream from the blade.

INSPECTION OF WATER MEASUREMENT SYSTEMS

Turbulence

Turbulence results from relatively small parcels of water spinning in a random pattern within the bulk flow while moving downstream. Turbulence may be recognized as water surface boils or three dimensional eddies which appear and disappear haphazardly. Because of this local motion within the general motion of the bulk flow, any particle of water may, at any given instant, move forward, sideways, vertically, or even backward. In effect, the water is passing a given point with accelerating and decelerating motion superimposed upon the main flow rather than with a uniform, ideal velocity. Thus, more or less water may pass a given point over a short length for short time periods, depending on the observation point chosen.

Excessive turbulence will adversely affect the accuracy of any measuring device but is particularly objectionable when using current meters or propeller meters of any kind. Turbulence can be objectionable even without air entrainment or the "white water" often associated with turbulence. Turbulence is commonly caused by stilling basins or other energy dissipators, by a sudden drop in water surface, or by obstructions in the flow area such as turnouts-- operating or not--that have projections or indentations from the supply canal. Shallow flow passing over a rough or steep bottom can also cause turbulence. Weeds or riprap slumped into the flow area or along the banks, or sediment deposits upstream from the measuring device, also can cause excessive turbulence.

Excessive turbulence can cause measuring errors of 10 percent or more. Therefore, the flow approaching a measuring structure or device should be modified to resemble tranquil canal flow.

Velocity Head in Approach

As flow approaches a weir, the water surface becomes lower due to acceleration of the flow by the force of gravity.

A drop in water surface of 0.1 ft is common just upstream from a weir and represents an increase in velocity of 0.8 ft/s. If the head on the weir is measured too close to the weir, the head measurement can be up to 0.1 ft too small. For a weir 6 ft long, with a head of 0.45 ft, a discharge of 7 ft^3/s is indicated. If you measured the head too close to the weir, such that the head was reduced by 0.1 ft, a discharge of 5 ft^3/s would be indicated. This difference amounts to an error of about 35 percent based on the reported discharge.

Standard weir tables are based on the measured head of the weir (velocity head is negligible) and do not compensate for excessive velocity head. Any increase in velocity above standard conditions, therefore, will result in measuring less than the true head on the weir. Therefore, more water will be delivered than is measured. Causes of excessive velocity head include inadequate pool depth upstream from the weir, deposits in the upstream pool, and poor lateral velocity distribution upstream from the weir.

Exit Flow Conditions

Exit flow conditions can cause as much flow measurement error as approach flow problems. However, these conditions are not encountered as often in practice. In general, ensuring that backwater does not submerge or drown out a device designed for free flow is sufficient. Occasionally, a flume is set too low, and backwater submerges the throat excessively, which can introduce extremely large errors in discharge measurement. The only remedy is to raise the flume, unless some local obstruction downstream can be removed to reduce the backwater. Sharp-crested weirs should discharge freely rather than submerged, although a slight submergence (the backwater may rise above the crest up to 10 percent of the head) reduces the discharge a negligible amount (less than 1 percent). However, a weir operated near submergence may not affect the discharge as much as the possible lack of nappe ventilation resulting from high downstream depth or intermittent waves lapping the underside of the nappe.

The underside of weir nappes should be ventilated sufficiently to provide near atmospheric pressure beneath the nappe, between the under-nappe surface, and the downstream face of the weir. The height of pull-up behind the nappe depends upon the drop, discharge, and crest length. The height that the water raises behind the nappe is a measure of the discharge error. For example, if the measuring head on a 3-ft suppressed weir is 1 ft and the water behind the nappe pulls up 0.3 ft, the error of discharge measurement would be about +6.5 percent. If the water was only pulled up 0.1 ft, the error for the same weir and measuring head would be +2.5 percent.

If the head upstream from the weir is pulled down a significant amount, then the weir is not sufficiently ventilated. An easy test for sufficient ventilation is to part the nappe downstream from the blade for a moment with a hand or a shovel to allow a full supply of air to enter beneath the nappe. After removing the hand or shovel, the nappe should not gradually become depressed (over a period of several or more minutes) toward the weir blade. If the upper nappe profile remains the same as it was while fully ventilated, the weir has sufficient ventilation.

If the nappe clings to the downstream side of the weir and does not spring clear, the weir may discharge up to 25 percent more water than the head reading indicates. This problem is generally a low flow problem with heads near and less than 0.2 ft and occurs more frequently with V-notch weirs. Good practice would involve checking the nappe before and after readings.

Weathered and Worn Equipment

Sharp-crested weir blades on older water measuring devices are often in bad condition. Weir blades are seen with dull and dented edges, discontinuous with bulkheads, pitted and covered with rust tubercles, and not vertical. Weir blades have sagged and are no longer level. Staff gages are worn and difficult to read. Stilling well intakes are buried in sediment or partly blocked by weeds or debris. Broad-crested weirs and flumes are frost heaved and out of level. Meter gates are partly clogged with sand or debris, and gate leaves are cracked and warped. These and other forms of deterioration often cause serious errors in discharge measurements. This type of deficiency is difficult to detect because, as mentioned before, deterioration occurs slowly. Therefore, the person responsible for measuring devices must inspect them with a critical eye. The attitude should be: "I am looking for trouble."

Out of plumb or skewed weir blades will show flow measurement inaccuracies of measurable magnitude if the weir is out of alignment by more than a few degrees. Rusted or pitted weir blades or those having projecting bolts or offsets on the upstream side can cause errors of 2 percent or more depending on severity of the roughness. Any roughness will cause the weir to discharge more water than indicated. Rounding of the sharp edge of a weir or reversing the face of the blade also tends to increase the discharge. A well rounded edge can cause a 15- to 25-percent or more increase in discharge.

Measuring Techniques Reducing Accuracy of Measurement

Regularly maintained equipment, properly installed in an ideal location, will still give inaccurate discharge measurements if the operator uses poor measuring techniques.

(a) Faulty Head Measurement

Measurement of the head on a sharp-crested weir, a seemingly simple matter, can be difficult under all but ideal conditions. The head is the height of water above the blade edge or the bottom of the V notch, measured at a point where the velocity head (or approach velocity) is negligible. In practice, this point is located four to six times the measuring head upstream from the center of the weir blade. If the head is measured too far upstream, a head not related to the water surface profile at the weir can be measured. If the head is measured closer to the weir blade, some drawdown (caused by increased velocity near the weir) may occur and less than the true head will be measured.

(b) Number of Significant Figures in Computations

As a rule, in any computation involving multiplication or division in which one or more of the numbers is the result of observation, the answer should contain the same number of significant figures as is contained in the observed quantity having the fewest significant figures. In applying this rule, it should be understood that the last significant figure in the answer is not necessarily correct, but represents merely the most probable value.

APPENDIX B

Design concepts and construction of compound v-notch weirs at Trust Fund monitoring sites

General Design Criteria for Trust Fund Site Weir Installations

Safety and Regulations

1. All permitting regulations must be followed. Coordination through the county project engineer (DPW) and MDE is mandatory. Permits must be on-hand or posted per local regulations and guidance.
2. In all cases, call Miss Utility to mark the sites 48-96 hours prior to digging. Someone will need to be onsite to show the Miss Utility subcontractors exactly where the digging will occur.
3. Refueling, painting, wood treatment, etc. should be performed in a safe and containable environment. Should spills occur, immediately contain and clean in accordance with applicable policies. Spill kits must be on hand and available at all times.
4. In most cases, installations will be on public lands or lands accessible by the public. All potential hazards will be eliminated as best as possible. Specifically, vertically oriented rebar, metal edges, stakes, etc should be removed and cleaned from the site everyday. Pooling of water, which is inherent with the project, should be minimized and safety of all should be maximized. During construction, hazards must be identified with bright orange paint or orange surveyor’s tape.
5. Sandbagging the stream and bypass pumping around the installation site is required.

Materials

1. Class I rip-rap is angular stone of 2” to 15” diameter. Twenty percent by weight shall be at least 4” in size.
2. Geotextile must be a woven stabilization product similar to US Fabrics US200 product or Propex GeoTex 200ST. Note that a majority of this material will degrade with UV exposure. It should be covered during storage, and when installed, it will be covered with a minimum of 0.5 feet of material.
3. Waterproof layer will be either reinforced polypropylene (>30 mil) or EPDM rubber. Both of these products are UV stable and are resistant to tearing/punctures. Care should be taken when placing material onto the liner or when walking on the liner. The liner should be installed as one piece.
4. Pressure Treated Lumber will be rated for ground contact. Typically, this will be 0.40 pcf for ACQ, CCA-C, MCQ treated lumber.
5. Self-Adhesive waterproof membrane can be found throughout the roofing industry as a replacement for roofing felt especially in areas where ice damming is a concern. It is a self-adhesive rubberized asphalt and reinforced polyethylene product. A UV-stable product will be selected. A recommended product is Grace Ice and Water Shield HT.
6. Sodium Bentonite is commonly referred to as driller’s mud. It typically ships in 50 lb bags. A local well drilling company can provide this material.
7. Concrete used in this project is for setting uprights similar to fence post construction. A product similar to Sakrete Fence Post Concrete is recommended as it can be poured in the hole dry, water is then added to it, and then the hole can be backfilled immediately. The product sets in 30-60 minutes allowing for work to continue.

8. Starboard plastic is a marine-grade polymer building sheet manufactured by King Plastics. A local supplier who will provide and cut the material as well as perform on-site welding is Maritime Plastics in Eastport. The contact person is Keith Manuel.
9. Extruded aluminum horizontal structure – This is a 12" wide extruded 6036T6 alloy aluminum panel known as part#5432 manufactured by Rocal, Inc. This material is utilized by State Highways as sign mounting structural material. It has an ultimate strength of 36000 psi and a yield strength of 33,100 psi with a maximum of 11% elongation.
10. Staff gage – recommended type is Stevens Style C due to its dimensions and readability. http://www.stevenswater.com/catalog/Style-C-P182C32.aspx

Supportive Structure

1. The supportive structure must be securely installed into the stream channel by no less than 1 feet of subsurface material. The horizontal supports must be installed a minimum of three feet into the channel banks to prevent end around erosion. When digging the trench to install the weir, the downstream face of the weir should be as undisturbed as possible. Dig from the upstream side of the weir. In all locations, disturbance should be minimized through proper planning (laying out of survey stakes and lines), tool selection (trenching shovels vs. general spade shovels), and stream diversion.
2. The supportive structure will be made from 6x6 pressure treated lumber for uprights and 4x6 pressure treated lumber for crossmembers as needed. Cut ends will be coated with additional treatment material to prolong the life of the material (copper naphthenate or IPBC (3-iodo 2-propynyl butyl carbamate)). Factory cut ends should be installed in the earth with field-cut ends facing upwards. All exposed joining hardware will be galvanized steel or stainless steel. Any subsurface (soil or water) will be stainless steel hardware*. If aluminum horizontal supports or aluminum faceplate is used, all joining hardware will be stainless steel.* Appropriate length and diameter hardware will be used. Flat washers will be used in all cases for load/force distribution as possible.
3. Uprights will be installed on both sides of the upper portions of the notch (v or rectangular [nominally 2 foot spacing in center of stream channel]) and every three feet or portion of three foot increments between the weir uprights and channel bank. When the distance between an upright and the channel is less than three feet, the upright should be installed at a distance which splits the distance equally. The uprights should not impede the flow of water through the weir, but they should be cut to the maximum height to provide as much support to the weir as possible. A minimum of four uprights will be emplaced.
4. Uprights will be installed at a minimum depth of three feet below load supportive grade (does not include loose bedding material). Additional install depth should follow the guidelines below. Depths are for consolidated clays which are expected in the Trust Fund sites. Should the sub-grade material transition to sand, additional depth will be needed. Uprights will be plumb and inline with faces square to the weir faceplate. Uprights will be cemented in place using concrete (Sakrete Fence Post concrete, Sakrete Fast Setting High-Strength Concrete or similar) and backfilled using existing material. All backfill will be tamped and compacted in 3" lifts.

Height above channel bottom (Feet)	Sub-Surface Installed Depth (Feet)
1	3
2	3
3	3.5
4	4
5	4.5
>5	Need to change structure design

5. Horizontal supporting structures will be made from 2x6 (or larger dimensions) pressure treated lumber or 12" extruded aluminum highway sign material. Cross-members will be placed to a depth of at least 12" below finished grade (both upstream and downstream). They will be continuous from bank foundation to bank foundation in as much as possible. The horizontal support structure will be installed no closer than 3.5" (nominal 5") below the bottom elevation of the notch so as to not interfere with the weir spillway. Additional horizontal supports will continue upward between the bank and the uprights with the intent of providing support for the faceplate while not interfering with the weir spillways.
6. If aluminum structural members are utilized, contact between the aluminum member and the pressure treated wood will be isolated using a rubber membrane such as a self-adhesive ice and water roofing membrane.
7. The distance between horizontal supporting structures is dependent on the faceplate material. If the faceplate is <1/4" aluminum sheet (regardless of ply unless they are bonded), the horizontal supports will be installed with no more than ½" gap; preferably, they will be installed with 1/8" gap. If the faceplate is 3/4" Starboard plastic, the horizontal supports will be installed with no more than a 12" gap; preferably, they will be installed with no greater than a 6" gap. Any other materials will need to be submitted for approval and design modifications.
8. Horizontal supports joints and faceplate joints will be minimized. Where the joints are necessary, they will be placed at an upright support location. Additional upright supports may need to be added or slightly adjusted to support the joints.

Weir Faceplate and Notch

1. The weir faceplate must be securely installed into the stream channel by no less than 2 feet of subsurface material. The faceplate must be installed a minimum of three feet into the channel banks to prevent end around erosion. When digging the trench to install the weir, the downstream face of the weir should be as undisturbed as possible. Dig from the upstream side of the weir. In all locations,

disturbance should be minimized through proper planning (laying out of survey stakes and lines), tool selection (trenching shovels vs. general spade shovels), and stream diversion.

2. The faceplate is the water barrier forcing all water to go through the notch. This barrier should be seamless. If seams are necessary, they should be welded if possible or sealed with appropriate sealant for the water head forces.
3. The faceplate will be secured to the structure using lag bolts (3/8 inch), fender washers, lock washers, and nuts. All penetrations of the faceplate will be sealed with 3M Marine Silicon sealant or equivalent. Care will be used to minimize the size of the openings on the upstream side and sealing of those openings.
4. Notch elevation and level is critical. The faceplate will consist of a V-shaped notch and likely a rectangular notch above it (compound weir). The point of the V-shaped notch is the fix point for the elevation of the weir. All weirs will be different; however, this point will generally be between 0.75 and 1.5 feet above the finished grade of the upstream channel. See site specific details for this elevation. The level of the weir is critical for the flow across the upper rectangular shaped portion of the weir. Appropriate construction techniques will be used to ensure the level of the weir.
5. The notch of the weir will be sharp-crested with the upstream side of the notch being of a thickness between 1mm-1.5mm. If the material is thicker than 1.5 mm, it will be chamfered at an angle between 50-70 degrees (nominal 60 degrees) to obtain the 1-1.5mm desired thickness.
6. The backfill of the weir faceplate will be performed with sodium bentonite (Driller's mud) to a depth of not less than 1 foot. The remainder of the backfill can be excavated material.

Weir Approach Pond

1. The approach pond will be covered in Geotextile (Woven Stabilization Fabric) and covered with Class I rip-rap or natural existing stone of that size to a minimum depth of 0.5 feet. In areas where the stream channel can not be elevated by that amount, the stream will be excavated by 0.5 feet to allow the Geotextile and stone armament.
2. The armament will extend from bank to bank and to a height of the weir. It will extend from the face of the weir upstream to a distance of 10' or the edge of the pond.
3. The Geotextile fabric will be locked in to the sides of the channel to a minimal depth of 1 foot. The fabric will be locked in at the upper and lower parts of the channel by digging trenches to a minimal depth of 1 foot, wrapping the Geotextile into the trench, and backfilling with Class I rip-rap or similar natural material.
4. In areas of highly permeable but stable substrate, a waterproof liner will be installed on top of the Geotextile. It shall encompass the same area as the Geotextile and be locked into place using the same key trenches and material as the Geotextile fabric. Additionally, the waterproof liner will extend to -0.5 feet upstream elevation on the faceplate and be attached to the faceplate using appropriate sealing tape (Gorilla Tape). A self-adhesive roofing membrane such as ice and water roofing membrane will be adhered to the liner and front face of the weir. An additional layer of Geotextile will be placed on top of the waterproof liner for protection.

Weir Splashblock and Downstream Channel Armament

1. Splashblocks will be installed to eliminate erosion of the channel bed from the water spilling out of the weir.
2. Splashblocks will begin at the base of the weir and extend downstream for a distance of three feet plus the height of the weir above the channel bed.
3. The location of the splashblock will be excavated to -0.5 feet of finished grade, lined with geotextile (Woven Stabilization Fabric) and covered with 0.5 feet of rock (see below) or class I Rip-Rap.
4. Natural rocks of various sizes will be used with foundation rocks of the 20-30 pound size (preferably flat and wide). An alternative is a poured concrete splashblock or artificial material which is anchored in place.
5. Splashblocks will not infringe upon the freefall of water over the weir.
6. Armament of the downstream banks will be performed. Geotextile (Woven Stabilization Fabric) will be used to line the banks from the weir to a minimal distance of +5 feet downstream. Class I Rip-rap or naturally occurring rocks of that size will be used to line the channel. At a site where an engineered channel preexists which meets this specification, it is not necessary to reconstruct this protection. The Armament should be installed to the top of the weir.

Instrumentation

1. The instrumentation site will be located on an installed 4"x4" Pressure-treated post generally located between ½ and 2/3 the distance upstream in the weir approach pond. The ideal location is at a site which is four times the distance upstream of the weir as the expected high flow notch head height, and at a depth of two times this height. It is unlikely that ideal conditions will be met; however, the general guidelines of selecting a location in the pool which is still, fairly deep, and not part of the drawdown or eddies associated with the weir should be followed. Where possible, this mounting post will be located near a bank to allow convenient downloading of data and maintenance of the recording instrument.

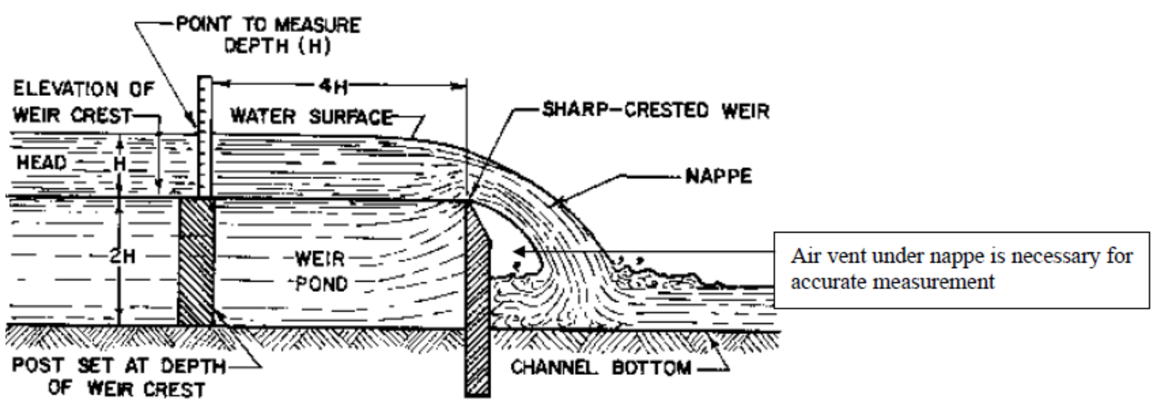

Figure 1. General Location and dimensions of measuring point.

2. The 4x4 post will be placed 3 feet below grade, anchored with concrete (Sakrete Fence Post Concrete or similar), and plumbed. Backfill with excavated material, tamping and compacting in 3" lifts. The post faces will be square with the weir face. The 4x4 post will extend to an elevation of +4 feet above the top of the weir notch.
3. The elevation of the bottom of the weir notch will be transferred to the upright. A stainless steel screw will be driven into the corner of the post with ½"remaining exposed for future survey checks. Additionally, another survey screw will be placed at +2.00' above that screw (with 1/2" exposed) for future survey checks.
4. A staff gage will be installed on the upright on the downstream side. It will be placed so that the 0.00 reading is at the elevation of the notch bottom. A staff gage similar to a Stevens Style C ranging from 0.00 to 3.06 feet will be installed. This staff gage is 2.5 inches wide and is marked similar to a stadia rod. The gage will be mounted to the upright using stainless steel screws/fasteners at a minimum of every foot. Care will be taken to avoid obscuring measurements.

Figure 2. Stephens Style C staff gage

5. A stilling well will be constructed of 2" Schedule 80 PVC. This well will be used to hold the water leveling instrument. The bottom of the stilling well will have a 2" cleanout fitting glued to the pipe with an installed threaded plug (not glued). This plug will be secured only hand tight as it will be regularly taken off for sediment removal. Four 1/8" holes will be drilled into the bottom of the pipe ¼" above the cleanout fitting joint. These holes will be spaced equally around the pipe at 0, 90, 180, and 270 degrees. One 3/16" hole will be drilled into the center of the cleanout plug. Pipe cradles (1" standoff) will be made from 1" Starboard plastic (or similar) and a 2 3/8" hole saw. The cradles will be predrilled and secured to the post using stainless steel screws at one foot intervals. The well will be secured to the post and cradles using silicone sealant on the cradles and polypropylene pipe hanger strap secured with stainless/galvanized screws and fender washers. Note that this strapping is subject to UV degradation, and it will need to be maintained. The stilling well should be secured at an elevation where the cleanout is at 8 inches below the weir notch. Alignment marks will be made on the pipe, the standoff, and the post using permanent marker for easy identification of movement.
6. The top of the pipe will be cut at a level so that the levelogger well cap will be 1" below the top of the post after. The top of the stilling well will have the levelogger well cap installed and secured.

7. OPTIONAL: Coordination with other monitoring agencies will be made to determine if the coexistence of their samplers is possible. If so, an appropriate PVC housing similar in construction of the stilling well will be made and secured to the upstream side of the post.
8. The post will be armored with class I rip-rap or similar natural material within a foot radius around the pole to eliminate erosion due to induced eddies. Access to the cleanout plug will be maintained.
9. Barometer Installation (at selected sites) – The intent of this installation is to maintain the barometer at a temperature similar to that of the stream, and to avoid any significant temperature changes caused by sunlight or high/low ambient temperatures. A two foot deep pit will be dug at a selected location above the flood plain, but still within the general area (1/2 mile radius) of the instrumentation. The pit shall be made to have drainage and not to flood. A minimum of one foot of drainage rock shall be placed in the bottom of the pit. A 2" PVC pipe with a cleanout fitting and plug will be placed in the pit and backfilled so that the majority of the pipe is buried. Two ¼" holes will be drilled in the cleanout cap and the barometer will be tied to the cap. The barometer will be placed into the buried PVC pipe and the cleanout plug screwed onto the pipe. The ¼" holes should remain open so that the barometer can read the atmospheric pressure. A rock can be placed on top of the pipe for camouflage as long as the holes remain open.

Final Survey

1. A known benchmark (existing benchmark, installed benchmark, or existing relatively stable object (storm drain, bridge abutment, foundation, etc.) within 50 feet of the installed site but outside of the stream and floodplain area should be used as a reference in all surveys. If installation of a mark is necessary, further guidance can be provided.
2. Cross-Section surveys will be performed at a minimum of seven places post-construction of the weir. Three cross sections will be surveyed within the approach pond (just behind the weir faceplate, halfway upstream in the pond, upstream top of pond). Two additional cross sections will be performed upstream of the pond at intervals equal to 1 and 2 times the length of the approach pond. Two additional cross sections will be performed downstream of the weir at +2 feet downstream of the weir faceplate and at a distance equal to four times the width of the original stream channel or 10 feet, whichever is greater.
3. Longitudinal surveys will be performed through the thalweg of the stream beginning at – 100 feet from the weir faceplate and ending at +100 feet from the weir faceplate. Elevations will be recorded at a maximum interval of every 10 feet outside of the weir pond. Elevations will be recorded at a maximum interval of every 2 feet within 10 feet of the weir (upstream and downstream).
4. These surveys will be repeated once a month for the first three months post-installation and after the first large storm to verify the stability of the channels and weir.

Weir Calibration

1. Notch weirs are designed using theoretical levels vs. expected flow rates. This level vs. flow rate relationship needs to be calibrated in the field at various levels and flow rates to develop the stage-discharge curve for the weir. Additionally, once this curve is developed, it is necessary to verify as time continues due to biologic buildup, physical changes of the site, and various other field conditions which are unpredicted.
2. When possible a known volume collection bucket under the weir spillway and a stopwatch is a quick, easy, and accurate method to determine the flow rate. All flowrate measurements will include an error range.
3. During flow rate measurement, the weir pond level should be noted using the installed staff gage at the beginning and end of the measurement process. The time will be noted for comparison with the downloaded water level recorder measurements.

Installation Guideline: Riprap

Geotextile Placement

Place the geotextile without wrinkles or folds on a smooth graded surface approved by the project engineer.

Orient the geotextile with the machine direction parallel to the direction of water flow. This is normally parallel to the slope for erosion control runoff and wave action and parallel to the stream or channel for stream bank and channel protection.

Use key trenches or aprons at the crest and toe of the slope to anchor the ends of the geotextile. 18" anchoring pins may be an acceptable option to expedite construction.

Joining Adjacent Sheets

Successive sheets of the geotextile can be overlapped upstream over downstream and/or over down slope in a "shingle effect."

Overlap adjacent rolls a minimum of 12" in all instances except when placed under water. Overlaps under water should be a minimum of 3'.

In cases where wave action or multidirectional flow is anticipated, all adjoining sheets perpendicular to the direction of flow should be sewn.

Soil CBR (California Bearing Ratio) will determine if overlapping or sewing is the correct option. AASHTO (American Association of State Highway and Transportation Officials) offers these general guidelines for sewing versus overlapping:
Soil CBR > 3 Minimum overlaps of 0.3 - 0.45 meters
Soil CBR 1-3 Minimum overlaps of 0.6 - 1.00 meters
Soil CBR < 0.5 Must be sewn

Riprap Placement

Begin the riprap placement at the toe and proceed up the slope.

Avoid stretching and tearing the geotextile. Do not drop heavy riprap from a height of more than 12". Do not drop smaller sizes of riprap from a height exceeding 3' unless it can be demonstrated that the placement procedures will not damage the geotextile. Do not allow riprap with a mass of more than 225 lbs to roll down the slope.

Field monitoring should be performed to verify that the riprap placement does not damage the geotextile.

Backfill all voids in the riprap with smaller stone to ensure full coverage.

For underwater applications, place the geotextile and backfill material on the same day.

After placement of the riprap, avoid any grading above the geotextile that results in movement of the riprap.

Repair

In lieu of specific project guidelines, overlap the damaged geotextile by a minimum of 36" in all directions with the replacement geotextile.

Storage

Geotextile rolls are wrapped in a UV protective cover.

Contractor should ensure rolls are adequately protected from moisture.

If stored outdoors, the geotextile should be elevated from the ground and covered with a tarpaulin or opaque plastic.

Generalized weir construction steps

1) Post or have on hand construction permit
2) Ensure all supplies and materials are on hand, including surveying gear
3) Pump around in place and working so that construction area is dewatered
4) Mark the site with pin flags- trench location, upstream and downstream boundaries for geofabric, downstream bank armoring boundary
5) Determine and note the final desired elevation of the notch, 6 inches above the final upstream stream bed elevation at the weir
6) String line for weir so that top of weir on line results in desired height at notch
7) Cut existing geofab liner 1 ft below and 2ft above weir location (if necessary), hand pick rip rap out of trench

8) In a warm location, attach pond liner to 6x6 supports on all 4 sides using adhesive as well as stainless steel screws, set aside to thoroughly cure
9) Use power auger to dig holes for 6x6's- 3 feet into solid, load supporting material
10) Set 6x6's in place, level and plumb with weir line
11) Do not disturb immediate area for 60+ min
12) Begin removing 1 ft of substrate (or to geofab layer, whichever is first) from the area 8ft upstream from the weir down to the weir, working downstream to give post concrete maximum time to set up
13) Cut a one foot wide section of the existing geofabric layer from 7 to 8 ft above the weir, then dig a 1ft deep key trench to anchor the new geofab installation
14) Excavate from the upstream side of the weir location an 18 inch wide by 32 inch deep trench that extends across the stream channel. When the bank is reached, the trench can be narrowed to approximately 12 inches wide. This trench must extend into each bank a minimum of 3 ft at the highest elevation, and the total width needs to accommodate the weir as constructed
15) Cut the new geofabric and waterproof pond liner to the desired dimensions
16) Carefully maneuver the weir into position, laying it horizontally across the stream just above its ultimate destination (flat side facing up) using four people, taking special care not to slam the weir into the 6x6 supports and leaving the bottom
17) Attach the new geofabric and pond liner to the very bottom of the weir using adhesive, stainless steel screws, and a 1.5 inch wide aluminum strip as a 'washer' to maintain a good seal. Let the fabric loosely dangle, with enough slack to allow the weir to be moved into final position without dragging the material
18) Using a team of four, rotate the weir to an upright position and gently place it into the slit trench
19) Adjust the weir height so that the notch elevation is 6 inches above the final upstream elevation (as determined prior to disturbing the site) and the weir is plumb.
20) Use sodium bentonite as a fill on the upstream side of the weir.

APPENDIX C

Deploying and downloading data procedures for Solinst Levelloggers, intended for Maryland DNR staff

Downloading Data from Barologgers Level Loggers

1a) The submerged level loggers within a watershed should always be downloaded first, followed by the barologger. There is one barometric pressure level logger per watershed, and it is installed in a PVC pipe sunk into the ground above the high water zone. This logger is tied by a string and can easily be removed.

1b) For submerged level loggers, a discharge measurement should be completed prior to taking the logger off-line.

2) Remove the stilling well from the support post by unfastening the two stainless steel wing nuts and bolts and placing them in a secure place. Take the bottom cap (screened end) off of the stilling well and remove the level logger.

3) Power up the Toughbook laptop computer.

4) Verify that the laptop time is correct and set to EST using time from a cellphone or similar device with automatic time updates. To set the laptop to display EST, right click the Time icon at bottom right of laptop screen, unclick “auto adjust for daylight savings time”.

5) Plug the sensor docking station into the laptop and place the sensor into the docking station.

6) Open the Solinst software (*Level logger icon on desktop*).

7) When prompted, choose the USB Serial Port (COM24) (*in com port dropdown list*).

8) Click the Level Logger Settings tab.

9) Click the connect button (*on left, blue icon with sensor and green arrow*).

10) Confirm that serial number on sensor matches the serial number in the window.

11) Click the “Data Control” tab.

12) Click the icon containing the red downward arrow to download data.

13) Choose “All Data”. When progress bar completes, data will be displayed. Review the data to ensure that levels look reasonable.

15) Save as a Solinst file

Click File-Save As-Data-Brampton/Wheel

Create a new date subfolder in the Brampton or Wheel folder- mmddyy

The file name will automatically populate in the format “station code_yyyy_mm_dd”. *NOTE: The barometer file name will automatically populate in the format “station code_baro_yyyy_mm_dd”*

16) Export and save the data as an excel csv file-

-File-Export-Data-Brampton/Wheel-

save file name in format “station code_yyyy_mm_dd”. *NOTE: Save barometer file as file name “station code_baro_yyyy_mm_dd”*

17) Remove the levellogger from the docking station.

18) Repeat the process for other level loggers and barologger.

Data Compensation

Each level logger file must be compensated to subtract out the barometric pressure. To do this:

1) Click data compensation button (*located next to download button*).

2) Select “Submerged level logger file”.

3) Click “next”, then “next” again

4) Select the correct barometer file by opening the correct “mmddyy” folder and clicking on the barometer file that was saved earlier.

5) The program will ask you to “save as”, asking you to choose a file name.

The filemame should automatically populate in the format “station code_yyyy_mm_dd_compensated”

6) After clicking “save” the program will automatically compensate the level file.

7) Close out all tabs and then open the compensated file that was just created.

8) Review the data to ensure levels look reasonable.

9) Export and save the compensated file as an Excel csv file-

-File-Export-Data-Brampton/Wheel-

save file name in format “station code_yyyy_mm_dd_compensated”.

10) Before deleting files from the level logger and re-deploying, open the date folder and ensure that there are two Solinst (.lev) files and two excel files

for each station, [the barologger should have one Solinst ".lev" file and one excel file].

Deployment and re-deployment of barologgers and leveloggers

The following instructions are for Solinst Levelloggers and the Toughbook laptop computer currently used on several Trust Fund monitoring projects.

1) Power on the Toughbook laptop computer

2) Verify laptop time is correct and set to EST using time from a cellphone or similar device with automatic time updates. To set the laptop to display EST, right click the Time icon at bottom right of laptop screen, unclick "auto adjust for daylight savings time"

3) Plug the sensor docking station into the laptop and place the sensor into the docking station.

4) Open the Solinst software (*Level logger icon on desktop*)

5) When prompted, choose the USB Serial Port (COM24) (*in com port dropdown list*)

6) Click the Level Logger Settings tab

7) Click the connect button (*on left, blue icon with sensor and green arrow*).

8) If deploying sensors for the first time at a new location-

Fill in Project ID (*for example "Wheel Creek")*, Location (for example "Upper (or Lower)", Altitude (in meters), *(To get altitude, use Google Earth- Scroll to the general location of the site, then move cursor around until you get the lowest reading (this should be in the stream bed). Goggle earth defaults to "feet" so don't forget to convert 1 foot = 0.3048 meters).*

10) Click the red stop sign icon, then choose "stop logging"; Click the green arrow icon. When prompted with "All data will be erased?" Click "yes"

9) When prompted for Time Synchronization- click enable.

11) Choose to start the logger at a future time, at some five minute interval, for example 10:15:00, by changing the time in the window. Choose a time far enough in the future to ensure you will be able to re-install sensors before the time you choose. Window should now say "future start @ hh:mm:ss". [Don't be alarmed by "time span error" if displayed].

12) To deploy the water level recorder, first remove the two 1/4 inch diameter stainless steel bolts that secure the PVC stilling well to the staff gage

support (4x4 wood post or heavy aluminum angle). Remove the bottom cap of the stilling well (the end with the screen).

13) Insert the water level recorder into the bottom of the stilling well and replace the cap. Align the holes of the stilling well and cap.

14) Carefully holding the assembly together, align the stilling well with the holes on the staff gage support and reinsert the two stainless steel bolts through the support. Fasten finger tight with wing nuts.

15) Note the time when level logging will start on the *Trust Fund Discharge/Download Data Sheet*.