Standard Operating Procedure

Measuring Stream Discharge

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2/1/2020	all	Major updates include removal of float method, manual calculations, and Marsh-McBirney information. Also, changed depth for requiring 2-point method from >2.5 foot depths to >1.5 foot depths, per USGS guidance (Turnipseed and Sauer, 2010).	James Mullins

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1.0 SCOPE AND APPLICABILITY

This standard operating procedure (SOP) outlines the general protocols used by the Kentucky Division of Water (DOW) to measure discharge using flow meters. The procedures presented in this SOP have largely been adapted from the protocols established by the United States Geological Survey (Rantz et al., 1982).

All discharge measurements and estimates must use the described methodology to ensure accurate and uniform results. A working knowledge of flow meter operation, as well as the limitations of operation, must be attained prior to the use of this type of equipment. The operation of these meters must follow the instructions provided by the manufacturer in the user manual. Water Quality Branch equipment manuals for FlowTracker and FlowTracker2 are located at: V:\DOWWQB\Equipment user Manuals and maintenance log\Stream Current Meters\Flow Tracker.

2.0 SUMMARY OF METHOD

In order to measure stream discharge a cross-section of the stream representing the most uniform laminar flow should be located. At this location, a tagline is placed perpendicular to the stream flow and the wetted-width of the stream is determined. This width is divided by the appropriate number of desired vertical measurement stations. At each vertical station along the tagline, the station location and water depth are determined and used to measure mean velocity with a Sontek handheld Acoustic Doppler Velocimeter unit. Upon completion of data collection, these units automatically calculate final discharge (cfs) and an estimate of calculation uncertainty.

3.0 DEFINITIONS AND ACRONYMS

cfs or ft/s^3 – Cubic feet per second
DEP – Kentucky Department of Environmental Protection
Discharge – volumetric flow rate of water that is transported through a given cross-sectional area, measured in cfs.
DOW – Kentucky Division of Water
fps or ft/s – Feet per second
KDLA – Kentucky Department for Libraries and Archives
LEW – the left edge of water when facing downstream
PPE – Personal Protective Equipment
QA – Quality Assurance
QC – Quality Control
REW – the right edge of water when facing downstream
SNR – Signal to Noise Ratio – a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the FlowTracker

Velocity – the speed at which the water is moving in feet per second
σV – Standard Error of Velocity

4.0 HEALTH & SAFETY STATEMENT

All field staff should review *Worksite Hazard Assessment Guidance Document* (DOW, 2017). In addition, each employee will be individually trained by his/her supervisor, or designee, to perform assigned job tasks safely, prior to his/her performing the task.

Field staff working in and around potentially contaminated surface waters should receive immunization shot for Hepatitis A in accordance with DEP Policy SSE-708. In addition, staff should receive immunization for Hepatitis B and tetanus, to aid in the prevention of contracting those pathogens. All field staff should also be trained in CPR, First Aid, and Blood Borne Pathogens in accordance with DEP Policy SSE-711.

The use of personal protective equipment (PPE) should be used when sampling including, but not limited to: site-appropriate wading boots, personal floatation device, latex or nitrile gloves, and cold weather clothing.

Monitoring may include field activities during all stages of the hydrologic cycle, including high discharge/flood stage conditions. It is recommended that field staff use the buddy system and personal floatation devices when collecting samples during high flow conditions. If high discharge conditions are determined unsafe by any Field Activities Staff, do not sample during that time.

5.0 CAUTIONS AND INTERFERENCES

Specific cautions exist for flow meter equipment. It is important to read the manufacturer's user manual and to become familiar with the specific cautions of each piece of equipment prior to its use. The following are general cautions one should be aware of prior to making instream discharge measurements.

- It is not always possible to find a cross section that meets all of the desirable characteristics for measuring discharge. In this case, a cross section should be chosen using best professional judgment.
- An attempt should be made to measure discharge at the same cross-section during each sampling event. However, it may be necessary to change the cross-section location due to instream physical changes.
- The vertical spacing width should never be less than 0.2 feet.
- Velocity readings should be averaged over a time period of 25s – 45s, depending on in-stream conditions.
- If multiple channels exist in the cross-section, all islands must be accounted for in the discharge calculation. Island edges should be treated like river edges;

however, there should not be velocity data for any area between the edges of the same island.

- Flow meters can be influenced by interference from underwater objects. Reflections can occur from the bottom, the water surface, or from submerged obstacles such as rocks or logs. If the sampling volume is downstream of an underwater object, velocity data will be altered. When working in very shallow water or when underwater obstacles are ≤15 cm (6 in) away from the sampling volume, reflections can potentially affect velocity data.
- Pressure can build up inside the FlowTracker unit over time. Vent the unit frequently by loosening the dummy cap on the external communication connector a few turns. Wait a few seconds and then tighten the dummy cap. Leave the dummy cap loose when storing.
- Remove batteries from flow meter units prior to long term storage.

6.0 PERSONNEL QUALIFICATIONS

All Field Activities Staff will meet the minimum qualifications for their job classification. In addition, field staff will be trained by experienced field personnel in the proper calibration and use of monitoring equipment. Training will continue on-the-job and as formal educational opportunities become available.

7.0 EQUIPMENT AND SUPPLIES

A list of equipment currently used by DOW to measure stream discharge can be found in Table 1.

Table 1. DOW Equipment for Measuring Stream Discharge

Equipment	User Manual
SonTek FlowTracker	SonTek® FlowTracker Handheld ADV® Technical Manual (SonTek/YSI, 2007)
SonTek FlowTracker2	SonTek® FlowTracker2 Handheld ADV® Technical Manual (SonTek/YSI, 2018)
Top-setting Wading Rod	n/a
100’-200’ Tape Measure (marked in 1/10’ increments)	n/a
Stakes (to anchor tape)	n/a
Field Observation Forms and clipboard	n/a
AA batteries	n/a

8.0 STEP-BY-STEP PROCEDURE

8.1 Selecting a Cross-Section

The following site characteristics for cross-section locations are critical for accurate discharge measurements (from Rantz et al., 1982 unless otherwise cited):

- The site lies within a straight reach of stream and flowlines are parallel to each other. Avoid sites directly below sharp bends.
- Flow is relatively uniform and free from eddies, slack water, and excessive turbulence.
- The streambed is free from large obstructions, such as boulders and aquatic vegetation.
- Water velocity is >0.5 ft/s.
- Water depths >0.5 ft are preferred but a minimum depth of >0.1 ft is required.
- The flow is perpendicular to the tagline at all points (SonTek/YSI, Inc., 2007).

Finding a cross-section that achieves all of the above criteria in the natural environment is difficult. Therefore, it may be necessary to "engineer" the stream by moving rocks, logs, branches, algae mats, rooted aquatic vegetation, debris, and/or other obstructions in order to construct a desirable cross-section free of turbulence. Additionally, rocks or other obstructions can be placed in the slack water to create an artificial bank such that no or minimal stream flow goes over or through the obstructions (Rantz et al., 1982). If this is necessary, make all adjustments and wait a few minutes for the system to stabilize prior to beginning the stream flow measurements.

8.2 Setting the Tagline and Vertical Spacing

After selecting the best cross-section, set up a tagline by stretching a tape measure across the stream so that it is taut and perpendicular to the stream flow lines. The tagline should be directly above the cross-section to be measured and must not touch the water surface.

Discharge measurements are taken at several verticals, defined as a point along the cross-section where water velocity is measured at a defined depth (or depths). Twelve to twenty verticals should be targeted for streams <20 feet wide, whereas twenty to thirty verticals should be targeted when stream width is >20 feet. To calculate the approximate spacing of verticals, determine the width of the stream and divide the stream width by the number of desired verticals. Importantly, the average velocity in one vertical should not exceed 10% of the total stream discharge (Rantz et al., 1982). Therefore, it may be necessary to space verticals more closely together in areas that are deeper or that have a greater velocity than the majority of the stream. Conversely, the spacing of verticals may be farther apart in areas that are shallower or have lower velocity compared to the majority of the stream. Uniform spacing across the tagline should only be used if the stream is of relative uniform depth and velocity regimes.

Although vertical spacing can vary, verticals should never be spaced less than 0.2 feet apart. As a result of this minimum spacing, small streams with a flowing width of less than 2.2 feet will have less than 12 verticals and can have as few as one vertical during very low stream flow. If less than 12 verticals are measured, it should be noted in the comments section on the field observation sheet with an explanation.

8.3 Measuring Depth

A standard top-setting wading rod should be used to correct for depth when using flow meters. The flow meter probe must be mounted according to the user manual to achieve accurate measurements. The wading rod should be adjusted to the appropriate depth, which is marked in 0.10 foot increments along the rod using hash marks. 0.10 foot increments are denoted by a single groove, whereas 0.5 foot increments are denoted by a double groove, and 1 foot increments are displayed by a triple groove. It is appropriate to further estimate depth to the 0.02' or 0.05' increment level, despite the wading rod not being marked to this level.

8.4 Measuring Velocity

A working knowledge of flow meter operation, as well as the limitations of operation, must be attained prior to the use of this type of equipment. The operation of these meters must follow the instructions provided by the manufacturer in the user manual.

The number of measurements taken at each vertical depends upon the depth of the stream. Follow these guidelines when determining the number of measurements to make:

Depths of ≤ 1.5 feet

When water depth is ≤ 1.5 feet, discharge is measured at 0.6 of the depth below the water's surface at each vertical, referred to as the 0.6-depth method (Turnipseed and Sauer, 2010). A standard top-setting wading rod will automatically adjust the probe to the 0.4-depth position up from the streambed.

Depths of ≥ 1.5 feet

When water depth is ≥ 1.5 feet, discharge is measured at 0.2 and 0.8 of the total depth below the water's surface at each vertical, referred to as the two-point method (Turnipseed and Sauer, 2010). For example, if the stream depth is 3 feet at a particular station, one should take a velocity measurement at 0.6' and another at 2.4'. An average of these two readings will be used as the average velocity for the vertical.

A standard top-setting wading rod can be adapted to this method by following these instructions:

- To set the rod at the 0.2-depth, position the setting rod at twice the water depth.
- To set the rod at the 0.8-depth, position the setting rod at half the water depth.

The wading rod should be set ~3" below the tagline with the probe perpendicular to the tag line and the operator facing upstream. The operator should stand at least an arm's length distance away from the probe side of the rod so that the operator's feet alter the stream flow as little as possible. (Rantz et al., 1982). Rocks, logs, or other obstructions should not be moved during the measurement process as this may cause the stream flow to change in an area of the stream where velocity has already been measured. Once the process of measuring velocity has begun, the stream should not be altered further.

Identify the starting edge as either left edge of water (LEW) or right edge of water (REW) when facing downstream. No velocity measurements should be made at the starting or ending edges. Facing upstream, place the wading rod downstream of the tape measure at the first vertical and enter the location and stream depth. Velocity readings should be averaged over a time period of 25s – 45s, depending on in-stream conditions.

Once the stream velocity has been measured and recorded at the first vertical, continue measuring water velocity at each vertical, making sure that the appropriate number of measurements are being taken based on water depth (0.6-depth method vs. 0.2/0.8 two point method). Continue until you have reached the end of the cross-section. Record the location and depth of the ending edge.

Instruments, such as the SonTek FlowTracker and FlowTracker 2, record depth and velocity information as you progress along the cross-section and then calculate discharge once the ending edge has been reached. If this is the type of instrument being used, be sure to record the final calculated discharge value on a field data sheet

9.0 TROUBLESHOOTING

A list of warnings, their meaning, and suggested action are listed in Table 2. These warnings will automatically be displayed on the FlowTracker/ FlowTracker2 if a certain parameter exceeds its limits.

Table 2. Warnings and Suggested Actions

Warning	QC Criteria	Description	Suggested Action
Low SNR	**None**	SNR < 4 dB	• Improve SNR
Beam SNR	**SNR Threshold**	Difference in SNR for any 2 beams is > **SNR Threshold**	• Look for underwater obstacles; repeat measurement. • Check probe operation
SNR Variation	**None**	One-second SNR data varies more than expected during a measurement. May indicate underwater interference or a highly aerated environment.	• Look for underwater obstacles; repeat measurement. • Look for environmental sources (e.g., aerated water).
SNR Change	**SNR Threshold**	SNR more than SNR Threshold different previous measurements; major change in measurement conditions.	• Look for changes upstream, i.e. someone wading upstream from the tagline. If changes do not affect overall measurement then accept. •If activity upstream is not causing SNR changes, look for underwater obstacles or changing water conditions and repeat measurement if necessary.
High σV	**σV Threshold**	**σV > σV Threshold**; adjusted based on previous data and measured velocity. May indicate interference or a highly turbulent environment.	• Look for underwater obstacles or a change in conditions. • Consider real turbulence levels in stream. •Up averaging time if needed. • Repeat measurement.
Bad Boundary QC	**None**	**Boundary QC** is **FAIR** or **POOR**. Indicates possible interference from underwater obstacles.	• Consider re-locating probe and repeating test. • Measurement can proceed if results are consistent.
High Spikes	**Spike Threshold**	**Spikes > Spike Threshold** percent of samples. May indicate poor measurement conditions.	• Look for underwater obstacles or unusual conditions (e.g., aerated water). • Repeat measurement.
High Angle	**Max Velocity Angle**	**Angle > Max Velocity Angle**. May only indicate non-ideal measurement environment.	• Consider if measured angle is realistic. • Repeat measurement if needed.
High %Q	**Max Section Discharge**	**%Q > Max Section Discharge**. Station contains more than 10% of the total discharge.	• Add more stations, especially between stations with High %Q. •Pay special attention and add stations to area of stream that is deeper and/or has most flow
Suspect Depth Value	**Max Depth Change**	Station depth differs from adjacent stations by more than **Max Depth Change** %. This may indicate a data entry problem.	• Verify station depth value. • Re-enter if needed.
Suspect Location Value	**Max Location Change**	Spacing between stations has changed by more than **Max Location Change** %. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.
Location out of Order/ Location Outside Edge	**None**	Station location out of sequence or outside river edge. This may indicate a data entry problem.	• Verify station location value. • Re-enter if needed.

10.0 DATA AND RECORDS MANAGEMENT

Electronic discharge records, including all related quality control documentation, must be maintained in permanent project files. All records relating to discharge measurements, including hardcopy and electronic files, that are collected by DOW staff or that are collected for the explicit use by DOW must be kept according to DEP record retention policy (KDLA, 2006).

11.0 QUALITY CONTROL AND QUALITY ASSURANCE

The quality control and quality assurance (QA/QC) requirements for various projects must be specified in quality assurance project plans (QAPP). The following sections will outline suggested QA/QC for flow meters and discharge measurements.

11.1 Flow Meter Quality Control and Quality Assurance

Types of QA/QC for flow meters may include:

- Routine maintenance
- Proper installation and mounting of flow meter probes
- Field diagnostics
- Routine in-house beam check

Refer to the appropriate user manual for QA/QC requirements and suggestions for specific flow meters. The following table describes the manufacturers' suggested QA/QC protocols for flow meters used by DOW. Factory calibration is not required for SonTek FlowTracker ADV units.

Table 3. QA/QC Suggestions for Flow Meters

Flow Meter QA/QC Manufacturers' Suggestions						
Meter	**Routine Maintenance**	**Frequency**	**In-House QC**	**Frequency**	**In-Field Diagnostics**	**Frequency**
SonTek FlowTracker Handheld ADV	•Clean sensor with mild soap and water •Check battery power	•Weekly •Weekly	Beam Check	Weekly	Auto QC Test	First station of every day of use
SonTek FlowTracker2 Handheld ADV	•Clean sensor with mild soap and water •Check battery power	•Weekly •Weekly	Beam Check	Weekly	Auto QC Test	First station of every day of use

In addition, the Sontek FlowMeter and FlowMeter2 have a set of built in parameters for Quality Control. The table below outlines and describes these parameters.

Table 4. Device QC Parameters

Parameter	Description	Expected Values
SNR	**SNR** is the most important QC parameter. • It measures the strength of the acoustic reflection from particles in the water. • Without sufficient SNR, the FlowTracker cannot measure velocity	Ideally > 10 dB Minimum ≥ 4 dB
σV	**σV** (standard error of velocity) is a direct measure of the accuracy of velocity data. • It includes the effects of turbulence in the river and instrument uncertainty.	Typically < 0.01m/s (0.03 ft/s). Higher in turbulent environment.
Boundary QC	**Boundary QC** evaluates the measurement environment for interference from underwater obstacles. • **FAIR** or **POOR** results may indicate significant interference from an underwater obstacle.	**BEST** or **GOOD**
Spikes	**Spikes** in FlowTracker velocity data are removed using a spike filter. • Some spikes are common and no cause for concern. • Too many spikes (>3 per station) indicate a problem in the measurement environment (e.g., interference from underwater obstacles or highly aerated water).	Typically < 5% of total samples. Should be < 10% of total samples.
Angle	**Angle** is the direction of the measured velocity relative to the FlowTracker X-axis. • Used for discharge measurements only. • A good site should have small velocity angles. • Large angles may be unavoidable at some sites.	Ideally < 20º
%Q	**%Q** is the percentage of the total discharge in a single measurement station. • Most agencies have criteria for the maximum **%Q**.	Typical criteria: Ideally < 5% Maximum < 10%

11.2 Discharge Measurement Quality Control and Quality Assurance

Replicate discharge measurements may be made to test the accuracy of the individual making the measurements. Replicate measurements should be made by the same individual who made the original measurements. The replicate measurement should be made at the same cross section as the original, but the same verticals (stations) should not be used. For example, if the original cross section had stations at even intervals (2, 4, 6, 8, etc.), the replicate measurement might have stations set at odd intervals (3, 5, 7, 9, etc.).

Duplicate discharge measurements may be made to measure the similarity of measurements made by two separate individuals. Duplicate measurements should be made by an individual other than the individual who made the original measurements.

The duplicate measurement should be made at the same cross section and verticals as the original.

11.3 Flow Meter Manufacturer Specifications

The following table outlines the manufacturers' specifications for the flow meters used by DOW.

Table 5. Flow Meter Manufacturer Specifications

	FlowTracker Handheld ADV	**FlowTracker 2 Handheld ADV**
Method	Acoustic doppler	Acoustic doppler
Range	±0.003 to 13 ft/s	±0.003 to 13 ft/s
Accuracy	±1% of measured velocity	±1% of measured velocity
Operating temperature	-20°C to 50°C	-20°C to 50°C
Storage temperature	-20°C to 50°C	-20°C to 50°C

15.0 REFERENCES

Kentucky Department for Libraries and Archives (KDLA). 2006. State Agency Records Retention Schedule: Department for Environmental Protection. State Archives and Records Commission, Public Records Division, Frankfort, KY.

Kentucky Division of Water (DOW). 2017. Worksite Hazard Assessment Guidance Document, Water Quality Branch. Kentucky Department for Environmental Protection, Division of Water, Frankfort, Kentucky.

Rantz, S. E., and others. 1982. Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge. U.S. Geological Survey Water-Supply Paper 2175.

SonTek/YSI, Inc. 2007. FlowTracker Technical Manual. SonTek/YSI Inc., San Diego, CA. www.sontek.com

SonTek/YSI, Inc. 2018. FlowTracker2 Technical Manual. SonTek/YSI Inc., San Diego, CA. www.sontek.com

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p. (Also available at *http://pubs.usgs.gov/tm/tm3-a8/*.)