Standard Operating Procedure

Measuring Stream Discharge

Kentucky Energy and Environment Cabinet
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Division of Water

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4.1 Scope and Applicability

This standard operating procedure (SOP) outlines the general protocols used by the Kentucky Division of Water (KDOW) to measure discharge using flow meters and to estimate stream discharge using floats in wadeable surface waters of Kentucky. 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.

4.2 Health & Safety Assertion

Field staff working in and around potentially contaminated surface waters should receive immunization shots for Hepatitis A, Hepatitis B, and Tetanus to prevent contracting these pathogens. At a minimum, staff should receive annual OSHA training and annual medical monitoring.

Personal protective equipment (PPE) must be worn when sampling in known waters where the potential for adverse health effects exists, or in unknown waters that have been determined impaired but the pollutants have not been identified. Examples of PPE worn are: nitrile or latex gloves, chest waders, wading boots, personal floatation devices and protective eyewear.

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

4.3 Cautions

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.
- Do not over tighten the thumbscrew on Marsh-McBirney sensors, as excessive force on the screw could damage the sensor.
- Remove batteries from flow meter units prior to long term storage.

4.4 Interferences

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.

4.5 Personnel Qualifications / Responsibilities

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.

4.6 Equipment

A list of equipment currently used by KDOW to measure stream discharge can be found in Table 4.6.

Table 4.6. KDOW Equipment for Measuring Stream Discharge

Equipment	User Manual
SonTek FlowTracker	SonTek® FlowTracker Handheld ADV® Technical Manual (SonTek/YSI 2007)
Marsh-McBirney Flo-Mate	Marsh-McBirney, Inc. Flo-Mate Model 2000 Portable Flowmeter Instruction Manual (Marsh-McBirney, 1990)
Marsh-McBirney Flow Meter	Marsh-McBirney, Inc. Model 201 Portable Water Flow Meter Instruction Manual (Marsh-McBirney, n.d.)
Top-setting Wading Rod	n/a
100’-200’ Tape Measure (marked in 1/10’ increments)	n/a
Stakes (to anchor tape)	n/a
Field Data Sheets and clipboard	n/a
Stopwatch (capable of 0.1 sec measurements)	n/a

4.7 Measuring Discharge Using Flow Meters

4.7.1 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, or other obstructions in order to construct a desirable cross-section free of turbulence. Additionally, one can place rocks or other obstructions 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.

4.7.2 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.

Identify the starting edge as either left edge of water (LEW) or right edge of water (REW) when facing downstream. Determine the approximate width of the stream with active stream flow, being sure not to include slack water areas. Hence, the edge of slack water areas should be considered the edge of the stream.

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, 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.

4.7.3 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. 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. It is advisable to permanently mark these increments on the wading rod to increase the accuracy of depth measurements.

4.7.4 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 is dependant upon the depth of the stream. Follow these guidelines when determining the number of measurements to make:

<u>Depths of ≤ 2.5 feet</u>

When water depth is ≤ 2.5 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 (Rantz et al., 1982). A standard top-setting wading rod will automatically adjust the probe to the 0.4-depth position up from the streambed.

<u>Depths of ≥ 2.5 feet</u>

When water depth is ≥ 2.5 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 (Rantz et al., 1982). 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 half the water depth.
- To set the rod at the 0.8-depth, position the setting rod at twice the water depth.

The wading rod should be held perpendicular to the water's surface and the instrument should be parallel to the stream flow. The individual making the measurements should stand at least 1.5 feet away from the wading rod and 3 inches downstream of the tagline in a way that alters 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.

Record the location of the starting edge on the field data sheet (LEW or REW). If the starting edge has a water depth, record this. No velocity measurements should be made at the starting or ending edges. Facing upstream, place the wading rod behind the tape measure at the first vertical and record 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. two-point method). Continue until you have reached the end of the cross-section. Record the location and depth of the ending edge.

Some instruments, such as the SonTek FlowTracker, 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. Other instruments, such as the Marsh-McBirney Flo-Mate, do not record information or calculate discharge, and therefore depth and velocity measurements must be manually recorded on a field data sheet. The procedure for manually entering data is described in the following steps, and an example field data sheet can be found in Appendix A. Total discharge calculations should be done in the office using the mid section equation in Section 4.10.2.

1. Record the starting edge (LEW or REW) in the first cell under the "Station" column. The actual location of the edge in relation to the tagline should be recorded. For example, if the starting edge occurs at 2.5' on the tagline, the starting edge will be recorded as 2.5.
2. Record the starting edge depth in the first cell under the "Depth" column and the velocity in the first cell under the "Velocity", if these exist at the starting edge. If there are no depth and velocity, record a 0 in these cells.
3. Proceed to the first vertical at which velocity will be measured. Record the depth and the velocity.
4. If using the 0.6 method, fill out only one row per vertical. If using the two-point method, fill out two rows for each station and designate the measurement point in parenthesis next to the station. For example, if the two-point method was used at station 5, one row would contain the station name of "5 (0.2)" and the next row would contain the station name of "5 (0.8)". Record the depth and velocity for both points in the appropriate cells.
5. Continue until you have completed the final velocity measurement. Record the ending edge (LEW or REW) as well as the depth and velocity, if these exist.

4.8 Estimating Discharge using Floats

If the stream cannot be safely waded or if a flow meter is not accessible, floats can be used to estimate stream discharge. All measurements using this procedure should be flagged as estimated on field data sheets and on final data reports. An example of how to fill out a field data sheet for this type of measurement for a 20' wide stream can be found in Figure 4.8.

The procedure is as follows (adapted from Rantz et al., 1982):

1. Find a long, relatively straight section of stream that allows a travel time of 20 seconds. A shorter time can be used if these conditions cannot be met.
2. Select two cross sections along the reach; one at the top and one at the bottom.
3. Measure the width of the stream at the cross sections and in a few areas between the cross sections to obtain an average width. If the stream is not wadeable, estimate the width. Record the width on the field data sheet (Figure 4.8).
4. Estimate how far an object will float in 20 seconds and stretch a tagline along the stream bank to account for that distance. A distance of 30-50 feet is ideal. A shorter run length may be used if these conditions cannot be met.
5. Based on the width, divide the stream into 2-3 longitudinal profiles. Measure or estimate the depths at these profiles. On the field data sheet record the nearest bank (REW/LEW) as 0. Record the farthest bank as the total width of the stream.
6. Have one person stand at the starting point on the tagline and a second person stand at the point designated as the end of the run. The person at the end of the run should use a stopwatch that can measure to tenths of a second.
7. The person at the starting point will throw a floating object (large stick, orange, hedge apple, etc.) just upstream of the top cross section within the first longitudinal profile area. When the object crosses the upstream cross section, the person will yell out "start" and the person at the end of the run will start the timer.
8. When the object crosses the downstream cross section, the person with the timer will stop the timer.
9. Record the distance the object traveled and the number of seconds, to the tenths of a second, the object took to travel that distance (see Figure 4.8).
10. Repeat Steps 6-9 for the remaining profiles.
11. Total discharge should be calculated using the mid section equation in Section 4.10.2.

Field Data Sheet							
Station	**Profile Width (ft)**	**Depth (ft)**	**Area (ft^2)** (width x depth)	**Run Length (ft)**	**Secs**	**Velocity (ft/s)**	**Discharge (ft^3/s)** (Area x Velocity)
0 (LEW)	2.5	0	0	0	0	0	0
5	5	3	15	40’	50.3	0.80	12.0
10	5	5	25	40’	35.8	1.12	28.0
15	5	3	15	40’	60.9	0.66	9.9
20 (REW)	2.5	0	0	0	0	0	0
	Total = 20’						**Total = 49.9 cfs**

Figure 4.8. Field Data Sheet Showing Discharge Measurements using the Float Method

4.9 Troubleshooting

For information on troubleshooting flow meter errors, refer to the appropriate user manual.

4.10 Data Acquisition & Calculations

4.10.1 Data Acquisition

Discharge measurements that are obtained using flow meters that cannot store measurements or by the float method must manually be recorded in a bound field book, or on other appropriate field data sheets, using indelible, waterproof ink and waterproof paper. An example of such documentation can be found in Appendix A.

Some flow meters have the capability of storing all measurements electronically. These discharge files should be downloaded and stored in electronic project records. Please refer to user manuals for instructions on how to download such data. It is advisable to record the final calculated discharge measurement obtained using these types of meters on a field data sheet.

4.10.2 Calculations

Stream discharge values shall be calculated using the mid section discharge equation described in Rantz et al. (1982). The basic equation for calculating discharge is:

$$Q = \Sigma (a \nu)$$

Where:

Q = total discharge

a = the individual area of a rectangular subsection, the product of width (w) and depth (d) for that subsection

ν = velocity of the current in a subsection

The mid section method assumes that the velocity sample at each point represents the mean velocity in a rectangular subsection (Rantz et al., 1982). Subsection discharge is calculated using the following equation (Rantz et al., 1982):

$$q_x = v_x \left[\frac{(b_x - b_{(x-1)})}{2} + \frac{(b_{(x+1)} - b_x)}{2}\right] d_x$$

$$= v_x \left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right] d_x$$

Where:

q_x = discharge through subsection x,
v_x = mean velocity at vertical x,
b_x = distance from initial point to vertical x,
$b_{(x-1)}$ = distance from initial point to preceding vertical
$b_{(x+1)}$ = distance from initial point to next vertical, and
d_x = depth of water at vertical x

The discharge calculation for subsection 4 (darkened, solid box) in Figure 4.10 would look like the following (Rantz et al., 1982):

$$q_4 = v_4 \left[\frac{b_5 - b_3}{2}\right] d_4$$

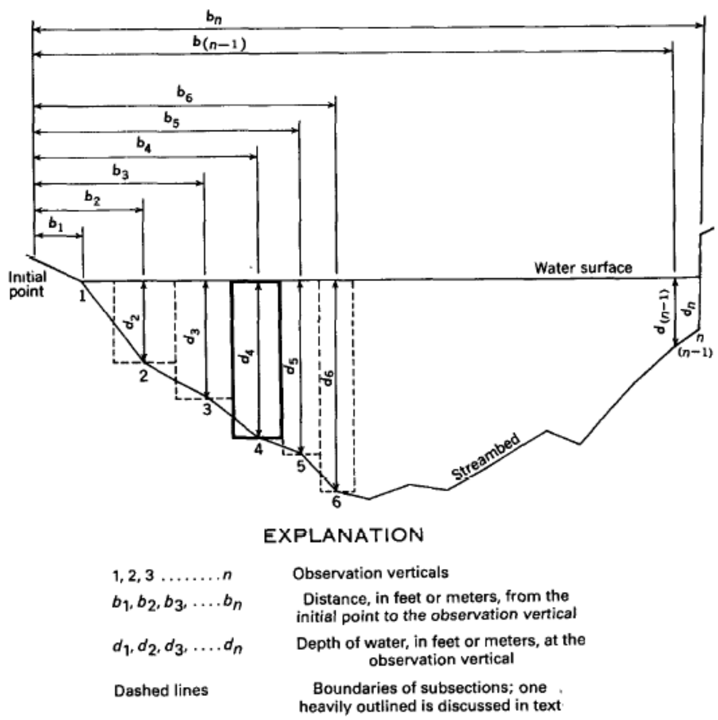

Figure 4.10. Mid Section Discharge Definition Sketch (from Rantz et al., 1982)

The preceding equation has been summarized in the following steps. Refer to Appendix A for an example field data sheet with completed measurements and calculations.

1. Calculate the average velocity for any multiple depth measurements.
2. Calculate the width of the verticals. The first station width is equal to ½ the difference between the first station and the second station. The second station width is equal to ½ the difference between the first station and the third station. The last station width is equal to ½ the difference between the last station and the preceding station.
3. Sum all the widths to ensure that this value is equal to the distance between the LEW and REW.
4. Multiply the width by the depth of each vertical to determine the area.
5. Multiply the area by the velocity of each vertical to determine the discharge for each vertical.
6. Sum all discharges for the total discharge of the measurement.

4.11 Data and Records Management

Hardcopy discharge records, including all related quality control documentation, must be maintained in permanent project files. It is desirable to scan these documents for electronic storage, as well. All records relating to discharge measurements, including hardcopy and electronic files, that are collected by KDOW staff or that are collected for the explicit use by KDOW must be kept according to DEP record retention policy (KDLA 2006).

5. 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, discharge measurements and discharge calculations.

5.1 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 Factory Calibration
- Routine In-House Calibration

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 KDOW.

Table 5.1. QA/QC Suggestions for Flow Meters

Flow Meter QA/QC Manufacturers' Suggestions								
Meter	**Routine Maintenance**	**Frequency**	**Factory Calibration**	**Frequency**	**In-House Calibration**	**Frequency**	**In-Field Diagnostics**	**Frequency**
SonTek FlowTracker Handheld ADV	•Clean sensor with mild soap and water •Check battery power	•Weekly •Weekly	Not Required	N/A	Beam Check	Weekly	Auto QC Test	First station of every day of use
Marsh-McBirney FloMate 2000	•Clean sensor with mild soap and water •Check battery power	•Weekly •Weekly	Required	Annually	Zero Check	Weekly	N/A	N/A
Marsh-McBirney Flow Meter 201	•Clean sensor with mild soap and water •Check battery power	•Weekly •Weekly	Required	Annually	Zero Check	Weekly	CAL Test	First station of every day of use

5.2 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.

5.3 Discharge Calculations Quality Control and Quality Assurance

To ensure that discharge calculations are correct, a minimum of 10% of all manual measurements should be recalculated by an individual other than the one who made the initial calculations. This includes manual flow meter calculations and estimated discharge measurements made using the float method.

5.4 Flow Meter Manufacturer Specifications

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

Table 5.4. Flow Meter Manufacturer Specifications

	FlowTracker Handheld ADV	**Marsh-McBirney Model 2000**	**Marsh-McBirney Model 201**
Method	Acoustic doppler	Electromagnetic (Faraday principle)	Electromagnetic (Faraday principle)
Range	±0.003 to 13 ft/s	-0.5 to 19.99 ft/s	-0.5 to 10 ft/s
Accuracy	±1% of measured velocity	±2% of measured velocity	±2% of measured velocity
Operating temperature	-20°C to 50°C	0°C to 72°C	0°C to 65°C
Storage temperature	-20°C to 50°C	0°C to 50°C	-1°C to 40°C

6. Reference Section

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.

Marsh-McBirney, Inc. n.d. Model 201 Portable Water Flow Meter Instruction Manual. Marsh-McBirney, Inc., Frederick, MD. www.marsh-mcbirney.com

Marsh-McBirney, Inc. 1990. Flo-Mate™ Model 2000 Portable Flowmeter Instruction Manual. Marsh-McBirney, Inc., Frederick, MD. www.marsh-mcbirney.com

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

7. Appendix A – Field Data Sheet for Discharge Measurements

Stream Discharge Measurement Sheet

Site ID #: ____

Name and Location: ______________________________________

Date:______________ Crew: _________________________

County: _______________________

Weather: ____

Cross-section Location: ___________________________________

Meter: ____________________________

Station	Width	Depth	Area (Width x Depth)	Run Length	Secs	Velocity (cfs)	Average Velocity Use with 2pt method (0.2+0.8)/2	Discharge (Area x Velocity)
2 (LEW)	0.5	0	0			0		0
3	1.0	1.0	1.0			0.2		0.20
4	1.0	1.0	1.0			0.2		0.20
5 (0.2)	1.0	2.5 (2)	2.5			0.15	0.175	0.4375
5 (0.8)		2.5 (0.5)				0.20		
6 (0.2)	1.0	2.8 (2.24)	2.8			0.20	0.225	0.63
6 (0.8)		2.8 (0.56)				0.25		
7	1.0	2.0	2			0.25		0.50
8	1.0	2.0	2			0.25		0.50
9	1.0	1.8	1.8			0.30		0.54
10	1.0	1.8	1.8			0.30		0.54
11	1.0	1.5	1.5			0.20		0.30
12	1.0	1.5	1.5			0.20		0.30
13	1.0	1.0	1.0			0.18		0.18
14	1.0	1.0	1.0			0.18		0.18
15	1.0	1.0	1.0			0.10		0.10
16	1.0	1.0	1.0			0.05		0.05
17	0.5	0	0			0		0
15’	15’							**4.658 cfs**

Total Discharge: 4.658 CFS (oMeasured, o Estimated)

Comments: