MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF ENVIRONMENTAL QUALITY
ENVIRONMENTAL SERVICES PROGRAM
Standard Operating Procedure

SOP#: MDNR-ESP-113 EFFECTIVE DATE: July 2, 2015

SOP TITLE: Flow Measurements in Open Channels

WRITTEN BY: Randy Niemeyer, Carl Wakefield, WQMS, ESP

REVISED BY: Michael D. Irwin, Lynn Milberg and Kenneth B. Lister, WQMS, ESP

APPROVED BY: Original signed by Alan Reinkemeyer, Director, ESP

SUMMARY OF REVISIONS: Changed for minor corrections and to standardize SOP format. Final velocity is recorded when flow stabilizes – changed from average of FPAs (see 7.1.9).

APPLICABILITY: These procedures apply to all ESP personnel who measure flow (discharge) in open channels.

DISTRIBUTION: MDNR Intranet
SOP Coordinator

RECERTIFICATION RECORD:

Date Reviewed:				
Initials:				

1.0 SCOPE AND APPLICABILITY

Field measurements of open channel flow, also known as discharge or Q, may be accomplished by a variety of methods. One method to be utilized by ESP personnel is with the aid of a Marsh-McBirney Model 2000 Flo-Mate™ current meter. This meter uses an electromagnetic probe to measure velocity (V) in a conductive liquid such as water. The probe measures flow using the Faraday law of electromagnetic induction. The law states that as a conductor moves through a magnetic field, a voltage is produced. The magnitude of the voltage is proportional to the velocity of water passing by the probe. The probe is very sensitive and can measure velocity as low as 0.01 feet per second (ft/s). This instrument calculates only velocity, so discharge measurements must be calculated by hand or with the assistance of a personal computer (PC).

A second method used by ESP personnel is with the aid of a SonTek/YSI FlowTracker® Handheld-ADV (Acoustic Doppler Velocimeter). The FlowTracker® uses SonTek's ADV® technology to measure 2-D or 3-D (depending on how the meter is set up) velocities. The Doppler principle says that if a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmitted frequency. The FlowTracker® uses the Doppler shift by measuring the change in frequency of sound that is reflected off particles in the water. The FlowTracker® is operated from a keypad interface, with instructions and real-time data displayed on an LCD screen. The system collects data for a fixed length of time at each location. For each location, a few parameters must be entered to document the data set (e.g., location, water depth, measurement width). For river discharge applications, these parameters are used with velocity data to compute discharge in real-time. All the data are stored on an internal recorder. Later, the data can be downloaded to a PC for additional processing, display, and archiving. The velocity accuracy of the FlowTracker® is as low as 0.003 ft/s and up to 15 ft/s.

2.0 SUMMARY OF METHOD

Stream flow is a measure of the amount of water flowing through a cross-sectional area (A) for a particular duration of time. There are a variety of measurements used to report surface water flow, but it is most commonly expressed in the United States as cubic feet per second (cfs). Flow is a crucial component for calculating pollutant loading and assessing habitat availability. This SOP describes the methods and equipment needed for calculating flow using two different systems/technologies.

3.0 DEFINITIONS AND ABBREVIATIONS

A – area
ADV – Acoustic Doppler Velocimeter
Calc. Disch. – calculate discharge
cfs – cubic feet per second
d – depth
ESP – Environmental Services Program
FPA – fixed point averaging
ft/s – feet per second

FV – following vertical
LEW – left edge water
MDNR – Missouri Department of Natural Resources
m/s – meters per second
PC – personal computer
PV – previous vertical
Q – flow
QC – quality control
RCL – recall
REW – right edge water
SNR – signal-to-noise ratio
SOP – standard operating procedure
STO – store
V – velocity
W_{lb} – left bank of water's edge
W_{rb} – right bank of water's edge
WQMS – Water Quality Monitoring Section

4.0 HEALTH AND SAFETY REQUIREMENTS

Field activities involve the collection of flow measurements at various water levels and weather conditions. Flow should not be measured at extremely high water levels, during thunderstorms, or other conditions that could be dangerous to personnel. Field personnel who could be exposed to wastewater (domestic or animal) should wear protective equipment such as clean, impermeable, disposable gloves; waders, and hands should be washed frequently with soap and water. See DNR policy 3.09, Employee Health and Safety Policy, for additional safety considerations and vaccination information. All recommended safety practices outlined by the manufacturer shall be followed.

5.0 PERSONNEL QUALIFICATIONS

Field personnel shall have, at a minimum, attended the Department-sponsored inspection and enforcement training and received training from an MDNR employee knowledgeable of cross-sectional flow procedures.

6.0 SUPPLIES AND EQUIPMENT

6.1 Equipment for both methods of flow measurement

- Measuring tape or tag line
- Waders
- Hammer and 2 pieces of rebar

6.2 Equipment specific to the Marsh-McBirney Model 2000 Flo-Mate™ method

- Marsh-McBirney Model 2000 Flo-Mate™ current meter
- Top-adjustable wading rod

- Clipboard, pen, discharge measurement forms (see Appendix C for a completely filled out form and Appendix D for a blank form)
- Extra D cell batteries (2 required)

6.3 Equipment specific to the SonTek/YSI FlowTracker® method
- SonTek/YSI FlowTracker®
- FlowTracker® adjustable wading rod
- Extra AA cell batteries (8 required)

7.0 PROCEDURE

7.1 Measurement of Open Channel Flow Using the Marsh-McBirney Model 2000 Flo-Mate

7.1.1 Prior to going out in the field, the meter should be calibrated to zero flow (see section 9.2).

7.1.2 Select a reach of the stream that is straight, uniform, not pooled, not turbulent, and free of obstructions. The streambed may be altered prior to making flow determinations by removing any objects that can affect flow (e.g. rocks, sticks, weeds, etc). The stream bank may also be altered by filling holes, removing logs, etc. Sufficient time must be allowed to pass after making alterations to the stream to allow flow to stabilize. Once measurements have begun, care must be taken not to disturb the streambed in any way.

7.1.3 Place and anchor the measuring tape across the stream perpendicular to the flow with rebar or a stationary object on the stream bank. The measuring tape must be suspended above and not touching the water, stretched as tightly as possible, with the unit markings (0.1-foot increments) clearly visible.

7.1.4 Determine the spacing of the partial cross-section area or vertical for the stream (Appendix A). The midsection method of making current measurements is used, which assumes that the velocity measurement at each location represents the mean velocity in a partial rectangular area. The area extends laterally from half the distance from the preceding meter location to half the distance to the next meter location (see "d_4" in Appendix A). Space the partials so that no one section has more than 10 percent of the total discharge passing through it, usually 1-2 feet. The ideal measurement is one in which no partial section exceeds 5 percent of the total discharge. The width of the partials should be adjusted as the depth and velocity of the stream increases or decreases.

7.1.5 Attach the current meter probe to the wading rod. Set the meter to fixed point averaging mode (FPA), time interval to 15 seconds, and unit measurement to ft/s mode. To set meter in fixed point averaging mode, press the up and down arrow keys at the same time until FPA is displayed on the meter. Time interval between readings can be increased or decreased by pressing the up or down arrow key. Units of measurement can be changed from ft/s to m/s by pressing the ON/C and OFF keys at the same time (see Appendix B for picture of meter). Because the meter's units of measurement can be changed so easily, it is recommended that the user ensure the unit is measuring ft/s before measuring flow at each stream location.

7.1.6 On the discharge recording sheet (Appendix C) record:

- the stream name and the location where the measurements are being recorded
- the date and the analyst(s) name
- the reading on the measuring tape, usually at the left (descending) bank of the water's edge in Column B (see "W_{lb}" in Appendix C)
- any other information that might affect the accuracy of the discharge measurement

7.1.7 The hexagonal part of the wading rod has a single groove at every 0.1 foot, a double groove at every 0.5 foot, and a triple groove at every 1.0 foot for measuring depth. If the depth of the water is less than 2.5 feet, the velocity should be measured using the 60% (0.6) depth method. Set the round sliding rod of the top-adjustable wading rod to the recorded depth and record the value (the meter's default is set to measure at the 60% (0.6) depth method). If a stream vertical is deeper than 2.5 feet and still capable of being measured using the wading rod, the velocity must be measured at 20% (0.2) and 80% (0.8) of total depth. To determine the 0.2 level, multiply the depth value by 2 and set the sliding rod to that depth. To determine the 0.8 level, divide the depth value by 2 and set the sliding rod to that depth. Once the two values for velocity have been determined, average the two readings and enter that value in Column F of Appendix C.

7.1.8 Standing downstream and to the side of the wading rod, hold the rod vertically, ensuring that the probe is parallel and facing into the stream's flow.

7.1.9 Allow the meter to run through at least 2-3 fixed point averaging cycles to allow flow to stabilize. Final velocity is recorded on the discharge measurement form in Column F (Appendix C).

7.1.10 Continue recording the tape readings and velocity measurements for each selected vertical. After the last vertical has been recorded, record the

measuring tape reading at the right bank of water's edge (see "W_{rb}" in Column A of Appendix C).

7.1.11 Upon returning to the office, determine the width for each vertical and record it in Column C (Appendix C). This is accomplished by subtracting the value from the following vertical (FV) from the previous vertical (PV) and dividing the result by 2 (FV-PV/2). The highlighted area around observation point #4 in Appendix A is an example of a vertical width.

7.1.12 Multiply the width of vertical (Column C) times the depth (Column D) for each vertical and record the resulting area in Column E.

7.1.13 Multiply the area (Column E) times the velocity (Column F) for each vertical and record the flow value for each portion of the stream in Column G.

7.1.14 Sum Column E to record the total area in square feet (see H of Appendix C) and sum Column G for the total discharge in cfs (see I of Appendix C).

7.1.15 Total discharge can also be calculated using a Microsoft Access® database located in the Water Quality Monitoring Section (WQMS) instead of calculating discharge by hand. Regardless of calculation method data should be entered into the flow database for record keeping purposes.

7.1.16 Record the calculated discharge value on the chain-of-custody sheet.

7.1.17 All measurement values below 0.1 cfs will be reported as <0.1 cfs.

7.2 Measurement of Open Channel Flow Using the Sontek/YSI FlowTracker®

7.2.1 Select a reach of the stream that is straight, uniform, not pooled, not turbulent, and free of obstructions. The streambed may be altered prior to making flow determinations by removing any objects that can affect flow (e.g. rocks, sticks, weeds, etc). The stream bank may also be altered by filling holes, removing logs, etc. Sufficient time must be allowed to pass after making alterations to the stream to allow flow to stabilize. Once measurements have begun, care must be taken not to disturb the streambed in any way.

7.2.2 Place and anchor the measuring tape across the stream perpendicular to the flow with rebar or stationary object on the stream bank. The measuring tape must be suspended above and not touching the water, stretched as tightly as possible, with the unit markings (0.1-foot increments) clearly visible.

7.2.3 Determine the spacing of the partial cross-section area or vertical for the stream (Appendix A). The midsection method of making current measurements is used, which assumes that the velocity measurement at each location represents the mean velocity in a partial rectangular area. The area extends laterally from half the distance from the preceding meter location to half the distance to the next meter location (see "d4" in Appendix A). Space the partials so that no one section has more than 10 percent of the total discharge passing through it, usually 1-2 feet. The ideal measurement is one in which no partial section exceeds 5 percent of the total discharge. The width of the partials should be less as the depth and velocity of the stream increases or decreases.

7.2.4 Attach the current meter probe to the wading rod. Turn the handheld device on and press ENTER to display the Main Menu (see Appendix E for picture of the meter). From the Main Menu, one can review the current settings (units, mode, discharge equation, averaging time, etc.) and change the settings if needed to meet your requirements. When you are finished with this step, press 0 to return to the Main Menu.

7.2.5 From the Main Menu, press 3 to Start Data Run and enter locational and operator information.

7.2.5.1 Press 1 to specify file name then press Enter. You have the option to enter a file extension (maximum 3 characters). Press 9 to accept the name and to start data collection.

7.2.5.2 Press 1 to specify site information (optional). Press 2 to enter operator information. Press 9 to start.

7.2.5.3 Gauge Height or Staff Height information (optional) may be entered by pressing the QC Menu (8) button at any time. Press ENTER to continue.

7.2.5.4 Run the automatic QC test by pressing 1.

7.2.6 Starting edge information will be displayed. Select the first vertical of measurements and press Set Location to set starting edge location. With the wading rod held vertically and the current meter probe oriented perpendicular to the direction of the flow, read the depth (minimum 0.2 ft.) of the water indicated on the wading rod and press Set Depth to set starting edge water depth. The hexagonal part of the wading rod has a single groove at every 0.1 foot, a double groove at every 0.5 foot, and a triple groove at every 1.0 foot for measuring depth. Specify if the starting edge is at LEW/REW (Left or Right Edge Water). When starting information is complete press Next Station.

7.2.7 Station information will be displayed. Select the vertical measurement location on the measuring tape and press Set Location to enter the location. Read the depth of water indicated on the wading rod and press Set Depth to enter the depth of water at this location. Standing downstream and to the side of the wading rod, hold the rod vertically, ensuring that the probe is perpendicular to the stream's flow with the red band (receiver arm #1) facing downstream, and press Measure to begin measuring velocity at this section. The display will show the measured velocity. On completion of the averaging time, a summary will be displayed. Press 1 to Accept or 2 to Repeat.

7.2.8 The FlowTracker® supports different methods of velocity measurements and can be changed by pressing either the Method + or the Method – button until the desired method is displayed. If the depth of the water is less than 1.5 feet, measure the flow via the 60% method by setting the round sliding rod of the top adjustable wading rod to the recorded depth. If a stream vertical is deeper than 1.5 feet, the velocity must be measured at 20% (0.2) and 80% (0.8) of total depth. To determine the 0.2 level, multiply the depth value by 2 and set the sliding rod to that depth when prompted by the FlowTracker® then take the 0.2 measurement. To determine the 0.8 level, divide the depth value by 2 and set the sliding rod to that depth when prompted by the FlowTracker® then take the 0.8 measurement. Follow the prompted instructions for setting the device to the correct measurement method.

7.2.9 After the first measurement is accepted, the FlowTracker® will display the next station information. Repeat step 4 for each station until ready to end the flow measurement and calculate total discharge. Note: The FlowTracker® will automatically calculate widths based on the distance between the previous 2 stations entered. The location can be changed at any time, or one can continue with the number automatically displayed by the FlowTracker®.

7.2.10 When the last section is complete, press End Section, this will activate the ending edge screen. The device will allow you to scroll through and review any noted QC information (refer to section 9.3.2 for more information) prior to ending the section. Set the location and the depth for the end of the section then press Calc. Disch. to compute total discharge. It is recommended that total discharge be recorded in a field notebook as well as on the chain-of-custody sheet. When complete, press 0 to return the Main Menu. Always return to the Main Menu before turning the system off to ensure all data has been properly saved

7.2.11 Upon returning to the office, download the data files (see section 6.4 in the FlowTracker® Technical Manual) from the FlowTracker. The data files should be saved in the FlowTracker® Flow Data folder on the WQMS P-

Drive. In addition, the data files collected should be deleted off the FlowTracker to keep memory space available for other users. Follow the directions in the Technical Manual (see section 6.4.2 in the FlowTracker® Manual) to format the handheld device and delete the data files.

7.2.12 All measurement values below 0.1 cfs will be reported as <0.1 cfs.

8.0 SPECIAL CONSIDERATIONS

8.1 Check flow meters for sufficient battery life. All data will be lost if FlowTracker® battery life is not sufficient.

8.2 Turn flow meters off between sample locations.

9.0 QUALITY ASSURANCE/QUALITY CONTROL

9.1 All Meters Used to Measure Open Channel Flow

All flow meters should be taken out once a year by the Water Quality Monitoring Section staff so that side-by-side in-stream comparisons of the meters can be made, and quality control (QC) information should be entered in an instrument logbook each time a meter is zeroed and side-by-side in-stream comparisons are made.

9.2 QC Procedures for the Marsh/McBirney Model 2000 Flo-Mate™

Marsh-McBirney Model 2000 Flo-Mate™ Meters should be zeroed prior to each sampling trip. Before zeroing, clean the sensor because a thin film of oil can accumulate on the electrodes and cause noisy readings. The sensor should be cleaned with soap and water or, if problems persist, very fine grit (600) sand paper. To start the zeroing procedure, attach the sensor to the top adjustable wading rod and place in a 5-gallon bucket of water. Allow the meter to take readings for 10-15 minutes to make sure the water has stabilized inside the bucket. If meter readings are within 0.05 ft./sec. of zero flow, zeroing is not necessary. If zeroing is needed, press the recall (RCL) and store (STO) keys on the meter at the same time. The number 3 will appear on the meter display. Decrement to zero with down arrow key. The number 32 will appear on the meter display. The meter will automatically decrement itself to zero and turn off. The meter is now zeroed (See Appendix B for picture of meter).

9.3 QC Procedures for the Sontek/YSI FlowTracker®

9.3.1 No calibration of the unit required. However, it is recommended that personnel run pre-deployment diagnostics before taking the instrument to the field. Simple diagnostic procedures are provided to verify system operation. BeamCheck requires an external computer. Other procedures

(such as checking the available space on the handheld device, checking battery power, and checking accuracy of the temperature and time) require only a few minutes and can be performed in the field from the keypad interface. In addition, the handheld device will prompt personnel to run a QC test instream prior to each data run.

9.3.2 Quality Control Data: The FlowTracker® records QC data with each measurement. QC parameters are automatically reviewed with each measurement and at the completion of a discharge cross section (when the End Section key is pressed). If any value exceeds expected criteria, a warning is given. Table 1-2 of the manufacturer's manual lists QC warning messages and gives guidelines for interpreting these messages. All QC review criteria can be adjusted or disabled.
The following QC parameters are reviewed with each measurement:

- Signal-to-noise ratio (SNR) measures the strength of the acoustic reflection from particles in the water. Without sufficient SNR, the FlowTracker® cannot measure velocity. Stirring up sediment upstream of the point of flow measurement will improve a poor SNR.

- 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. This QC number is usually higher in a turbulent environment

- Boundary QC evaluates the measurement environment for interference from underwater obstacles. FAIR or POOR results may indicate significant interference from an underwater obstacle. The expected value is BEST or GOOD.

- Spikes in FlowTracker® velocity data are unusually high velocity measurements compared to the average and usually the result of large particles or bubbles. A measurement is automatically filtered from the dataset by FlowTracker® if it is identified as a spike. Some spikes are common and no cause for concern. Too many spikes indicate a problem in the measurement environment (e.g., interference from underwater obstacles or highly aerated water). Typically the range of spikes is between 5% and 10% of total samples.

- Angle is the direction of the measured velocity relative to the Flow-Tracker X-axis. It is used for discharge measurements only. A good site should have small velocity angles. Large angles may be unavoidable at some sites.

- %Q is the percentage of the total discharge in a single measurement station. See section 5.4 for criteria for the maximum %Q.

10.0 REFERENCES

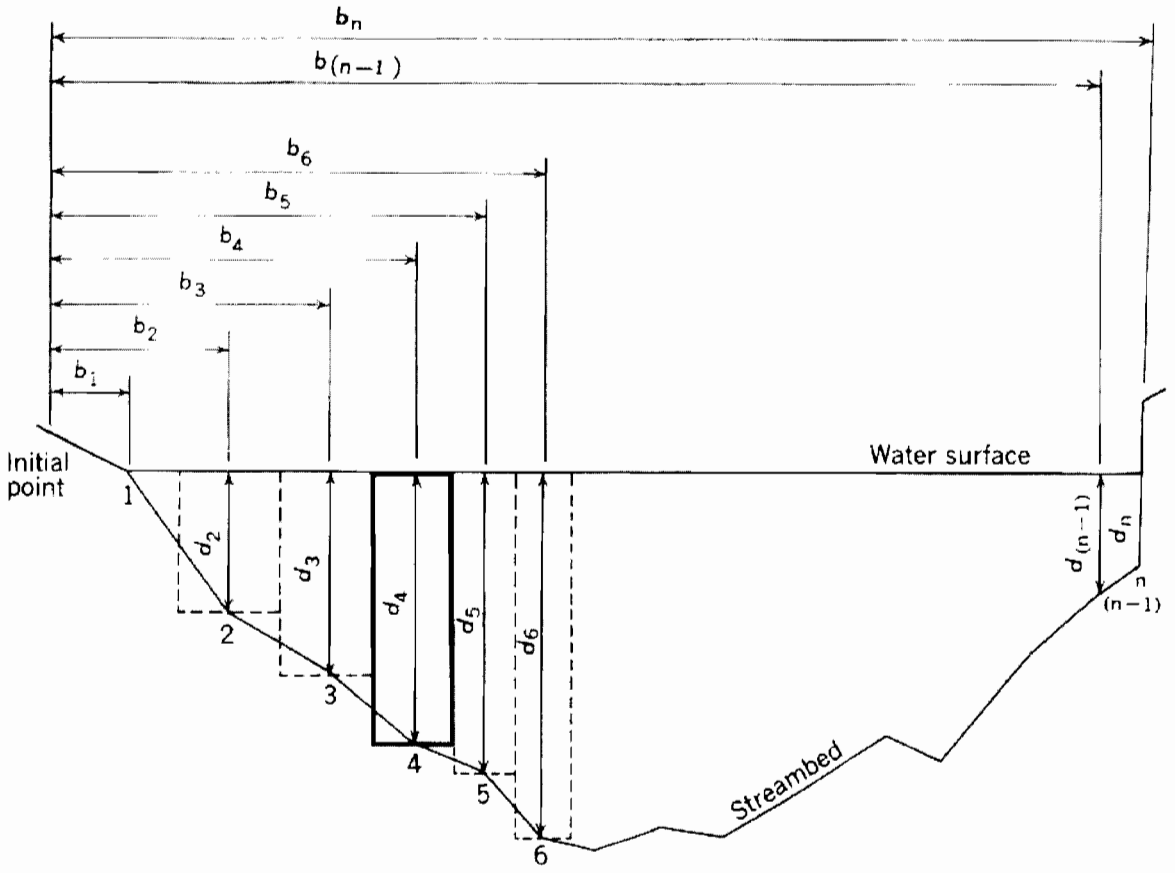
Buchanan, T. J. and W. P. Somers. 1969. Techniques of Water Resources Investigations of the United States Geological Survey; Book 3, Chapter A8, Discharge measurements at gauging stations. 65 pp.

1990. Model 2000 Portable Flowmeter Installation and Operations Manual. Marsh-McBirney, Inc. Frederick, Maryland. 20 pp.

2007. SonTek/YSI FlowTracker® Handheld ADV®, Technical Manual, Firmware Version 3.3, Software Version 2.20.

Appendix A

Illustration: Flow Measurement in Open Channel (cross section)



EXPLANATION

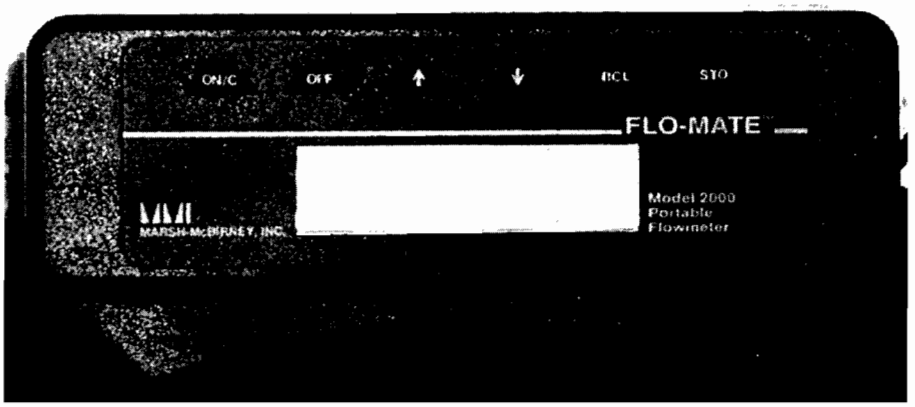
1, 2, 3, ... *n*	Observation points
$b_1, b_2, b_3, \ldots\ldots b_n$	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3, \ldots\ldots d_n$	Depth of water, in feet, at the observation point
Dashed lines	Boundary of partial sections; one heavily outlined discussed in text

From Buchanan, T. J. and W. P. Somers. 1969. Techniques of Water Resources Investigations of the United States Geological Survey; Book 3, Chapter A8, Discharge measurements at gauging stations.

Page 2.

Appendix B

Marsh McBirney Flo-Mate Model 2000 Portable Flowmeter



Appendix C

Example: DISCHARGE MEASUREMENT FORM FOR MARSH-McBIRNEY METER

Date: *4-9-15*	Analyst: *LM*	Station#: *1*	Location: *Doe Creek*

A Vertical	B Tape Reading	C Width of Vertical (FV-PV/2)	D Depth (D)	E Area (A)	F Velocity (V)	G Flow (Q)
W_{lb}	***2***		--		--	
W_1	***4***	*2*	***0.22***	*0.44*	***0.1***	*0.04*
W_2	***6***	*2*	***0.84***	*1.68*	***0.3***	*0.50*
W_3	***8***	*2*	***0.96***	*1.92*	***0.3***	*0.58*
W_4	***10***	*1.5*	***0.92***	*1.38*	***0.45***	*0.62*
W_5	***11***	*1*	***0.83***	*0.83*	***0.5***	*0.42*
W_6	***12***	*1*	***0.91***	*0.91*	***0.9***	*0.82*
W_7	***13***	*1*	***1.03***	*1.03*	***1.2***	*1.24*
W_8	***14***	*0.75*	***0.81***	*0.61*	***1.4***	*0.85*
W_9	***14.5***	*0.5*	***0.56***	*0.28*	***1.3***	*0.36*
W_{10}	***15***	*0.5*	***0.56***	*0.28*	***1.5***	*0.42*
W_{11}	***15.5***	*0.5*	***0.55***	*0.28*	***1.3***	*0.36*
W_{12}	***16***	*0.75*	***0.71***	*0.53*	***1.0***	*0.53*
W_{13}	***17***	*1*	***0.72***	*0.72*	***0.6***	*0.43*
W_{14}	***18***	*1*	***0.61***	*0.61*	***0.3***	*0.18*
W_{15}	***19***	*1*	***0.43***	*0.43*	***0.1***	*0.04*
W_{16}	***20***	*2*	***0.42***	*0.84*	***0.1***	*0.08*
W_{17}	***23***	*2*	***0.39***	*0.78*	***0.13***	*0.10*
W_{18}	***24***	*1*	***0.37***	*0.37*	***0.21***	*0.08*
W_{19}	***25***	*1.5*	***0.36***	*0.54*	***0.08***	*0.04*
W_{20}	***27***	*1.25*	***0.34***	*0.43*	***0.09***	*0.04*
W_{21}	***27.5***	*0.5*	***0.29***	*0.15*	***0.11***	*0.02*
W_{22}	***28***	*0.75*	***0.25***	*0.19*	***0.07***	*0.01*
W_{23}	***29***	*1*	***0.20***	*0.20*	***0.05***	*0.01*
W_{24}	***30***	*1*	***0.17***	*0.17*	***0.04***	*0.007*
W_{25}	***31***	*1*	***0.15***	*0.15*	***0.02***	*0.003*
W_{26}	***32.0***	*0.75*	***0.10***	*0.075*	***0.01***	*0.0008*
W_{rb}	***32.5***		--		--	
				H *15.81*		*I* *7.79*

Bold *= recorded measurements*

Appendix D

DISCHARGE MEASUREMENT FORM FOR MARSH-McBIRNEY METER

Date:	Analyst:	Station#:	Location:

Vertical	Tape Reading	Width of Vertical (W) FV-PV/2	Depth (D)	Area (A) W x D	Velocity(V)	Flow (Q) A x V
W_{lb}						
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Appendix E

SonTek/YSI FlowTracker