Water Monitoring Program

WASHINGTON CONSERVATION DISTRICT STANDARD OPERATING PROCEDURE (S.O.P.) No. 1

FLOW MONITORING

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Standard Operating Procedure No. 1

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1.0 SCOPE AND APPLICABILITY

.1 Overview of Streamflow Gauging Requirements

An open-channel streamflow gauging station is established by developing a relationship between stage (water level) and discharge at a selected watercourse cross section. The relationship is developed by taking discharge measurements over the expected range of discharge and stage. Each discharge measurement and corresponding water level is plotted and a smooth curve is drawn. The stage-discharge curve is used with a continuous water level record to produce a time series of discharge for the period during which water level has been recorded. Another option to gauge discharge is to use an area-velocity meter. An area-velocity meter can be programmed to log discharge based on a channel of a particular shape (i.e. round pipe, rectangular channel). Once the channel shape is programmed, the area-velocity meter can determine the area of the channel filled by water using the level data. By multiplying the area of water by the velocity, discharge can be calculated. Area-velocity gauging is desirable only in particular scenarios where channels or conduits are a fixed shape or in scenarios where backwater is present from downstream sources.

Summary of Procedure

The streamflow gauging procedure can be summarized as follows:

1. Reconnaissance survey is conducted to gather information on the physical characteristics of the locations where streamflow-gauging sections are to be established.

2. Hydrologic and hydraulic calculations are carried out to estimate the expected range of flow rates and flow depth variations at each gauging site.

3. Continuous water level recorder, staff gauge, and if necessary, a velocity meter is installed at each gauging site.

4. During the course of the monitoring program, a series of stage-discharge measurements are made at each gauging section. Discharge is measured by measuring flow depth and flow velocity at selected points across the gauging cross section. This is done on a number of occasions in order to obtain stage-discharge measurements over the range of flows of interest.

5. For each section a "rating curve" is then developed from the stage-discharge measurements. The rating curve represents the relationship between water level (i.e., stage) at the gauging section and discharge at the section. The rating curve allows a time series of discharge rates to be computed using the data acquired from the station's continuous water-level recorder.

.2 Scope of the S.O.P.

This SOP describes required procedures for establishing streamflow-gauging stations in Twin Cities watersheds. This SOP describes:

- Selection of gauging station location and cross-sections for discharge measurement.
- Methods and procedures for discharge measurement using velocity and depth measurements.
- Computation of discharge from velocity/depth data.
- Installation and maintenance of continuous water level recorder.
- Installation of staff gauge for on-going verification of water-level recorder operation and accuracy.

2.0 DEFINITIONS

Streamflow, discharge or **flowrate** is the volume of water passing through a given cross section of the watercourse during a specific period of time. Typical units are cubic feet per second (cfs).

A **current meter** is an instrument used to measure water velocity at a point. This procedure recommends that vertical-axis bucket-wheel current meters be used; for example, the Price Type AA current meter and the Pygmy type current meter. Another option is to use and electromagnetic current meter such as a Marsh-McBirney current meter.

3.0 EQUIPMENT AND MATERIALS

The following equipment and materials will be required:

- Field log book or electronic field log book
- First-aid kit
- Survey tape measure, survey level and survey rod
- Current meter (i.e. Price Type AA, Pygmy vertical-axis, Marsh McBirney electromagnetic) and associated instrument rod
- Hip or chest waders for personnel wading into the watercourse
- Staff gauge for installation at each gauging site (for visual monitoring of water level)
- Water-level sensor (e.g., pressure-transducer sensor) for providing continuous measurement of water level at each gauging site
- Data logger compatible with velocity sensor
- Data logger compatible with water-level sensor

- Laptop computer to allow for setup of and real-time interrogation of data logger and water level sensor, and data retrieval from the data logger
- Hardware, tools, and miscellaneous materials needed for installation of staff gauge and water level sensor

Specific requirements for hardware and materials needed for staff gauge, water level and velocity sensor/data logger installations will be determined during site reconnaissance survey.

4.0 PROCEDURES

.1 Procedure for Selecting Gauging Locations

The following procedures are to be applied to the process of selecting the specific locations (i.e., stream cross sections) where gauging will be carried out.

.1.1 Reconnaissance Survey

An initial reconnaissance survey will be carried out to establish suitable monitoring locations. This will also provide information on local turbulence and other factors that may affect the flow-gauging program and gauging site selection.

During the reconnaissance survey, proposed gauging site locations will be examined in detail to select specific locations for cross sections at which stage-discharge measurements will be taken and water level recorders and staff gauges installed.

.1.2 Criteria for Gauging Site Selection

The following criteria will be used to select gauging cross sections:

1. The cross section is to be located where stream bed and banks are reasonably straight and uniform for a distance of approximately five times the section's width upstream, and two times the section's width downstream

2. The streambed and banks appear to be stable and not subject to scour (e.g., bank erosion), deposition (e.g., sand bar formation), or debris accumulation.

3. The stream bed cross section is as uniform as possible and free from vegetation growth or any large rocks or protruding obstructions

4. The cross section should be perpendicular to the general direction of flow and should not be subject to highly turbulent conditions that would make point velocity measurements difficult or inaccurate.

5. The cross section should be located such that there is a "control" situated downstream of the cross section that ensures a stable stage-discharge relationship at the cross section. The control is a physical condition in the stream that controls or determines the discharge that passes the cross section for a given upstream water level. It may be a natural phenomenon such as a stretch of rapids, a weir or other artificial structure. In the absence of a prominent feature, it may be a less obvious condition such as convergence of the channel or the resistance to flow through a downstream reach. Care must be taken during selection of properly controlled cross sections for stream gauging. In particular, consideration must be given to the possibility of backwater effects during high-flow conditions that could result from downstream flow restrictions (e.g., culverts or bridges) or incoming tributary flows.

6. The gauging location should be situated where there is a suitable and convenient location for secure installation of a continuous water-level recorder and electronic data logger. As well, there should be a suitable location for installation of a staff gauge that will allow for routine visual checks on water level.

7. The gauging cross section should be located where there are suitable on-shore reference points to assist with repeated measurement of flow velocities at locations across the cross section. As well, on-shore reference points are needed to serve as elevation benchmarks. These horizontal/vertical reference points should be well-defined immovable objects.

.2 Procedure for Stage-Discharge Measurements

Once gauging sites have been selected, discharge measurements will be carried out during the course of the monitoring program, to establish the relationship between water level and discharge at each of the gauging sites. The measurements must be done over a range of flows, so that the rating curve will be valid over the full range of flows encountered during the monitoring period.

.2.1 Required Number of Measurements at Each Gauging Station

The accuracy of the rating curve developed for each flow gauging station will depend in part on the number of stage-discharge measurements made at each location, and the range of those measurements. The minimum requirement is that ten stage-discharge measurements be made at each location, consisting of:

- 3 measurements under relatively low flow conditions (e.g., dry weather)
- 4 measurements under moderate flow conditions (e.g., shortly after a runoff peak, during hydrograph recession)

- 3 measurements under high flow conditions (e.g., during the peak of a significant runoff episode)

The rating curve for each station is developed by plotting the stage-discharge pairs on graph paper or in an appropriate computer program, and then fitting a smooth curve over the range of the data. Visual or mathematical curve fitting techniques can be used.

Once a good rating curve has been established for sites where monitoring is continued over multiple years, gauging during subsequent years can be completed on an as needed basis. This should include at least three new points per year distributed between low, medium and high flows; and additional measurements targeting areas on the rating curve where the uncertainty and variability are highest. However, whenever there is a change in channel cross section occurs near the monitoring site (i.e., from construction, new bridge crossings, erosion, etc.) a completely new rating curve needs to be developed.

.2.2 Discharge Measurement Procedure

The general approach will be to take point velocity readings at evenly spaced stations across the cross section, and at the same time record the water depth at each station. Flow rate can then be computed using the method described below. Paired water level/discharge values can then be used to develop the station's rating curve.

The following procedures will be used to carry out stage-discharge measurements at selected cross sections:

1. The cross section is first divided into a number of vertical subsections or "panels" of equal width. As a general rule, there should be at least 10 panels to properly account for velocity variations across the cross section. Discretion may have to be used to estimate number of panels needed for small channels See Figure SOP3-1.

2. Using an on-shore reference object, the distance to the mid-point of each panel should be measured using a surveyor's tape or other suitably accurate method. Distances should be expressed as distance from the on-shore reference point.

3. A tag line should then be strung across the cross section. The tag line will have markers indicating the locations were depth and flow velocity are to be measured (i.e., the midpoints of each of the panels).

4. The tag line is used to determine where velocity and depth measurements are taken.

5. On each occasion when stage-discharge measurement is made, first make notes on conditions at the gauging site, including information on any scour, deposition, and aquatic vegetation growth or debris accumulation. Make particular note of any apparent changes

since the previous measurement visit. Take photos of the site and stream conditions if necessary.

6. Record the start time and current water level and begin the panel-by-panel depth and velocity measurements.

7. Flow depth at the midpoint of each panel is measured using a suitable rod or weighted cable. The rod or weighted cable is lowered vertically into the water until it reaches the bed or bottom of the creek. Take care that the rod is not pushed into the bed of the creek.

8. Flow velocity is also measured at the midpoint of each panel. Velocity measurements will be taken with a reliable and calibrated velocity probe.

    - If water depth is greater than 30 inches, measure velocity at 20% and 80% of water depth. These measurements are to be made along a vertical line at the mid-point of the panel.
    - If water depth is less than 30 inches, measure velocity at 60% of water depth.
    - When measuring velocity, hold the probe steady for at least 30 seconds to allow a stable reading.
    - Ensure that all velocity readings are within the measurement range of the probe. If low velocities (e.g., less than 0.1 fps) are being encountered, it may be necessary to use a different probe (e.g., a Pygmy meter) to provide accurate velocity measurements.

1. If wading across the section, use a suitable pole or rod to check streambed conditions. Check for any scour holes, boulders, cobbles, or other conditions that could make for unsafe footing.

2. When taking velocity measurements, place the current meter in a position that least affects the flow passing the current meter.

3. Record water depth and velocity readings as they are taken. These can be relayed to on-shore personnel for recording. Use Form SOP3-1 or equivalent.

4. Once all readings have been taken, record the stop time and the water level. Then compute the discharge using the method described below. If any of the individual depth or velocity measurements or the computed discharge appears questionable, take additional readings to confirm the results.

.2.3 Procedure for Computing Discharge from Depth-Velocity Data

The method used to compute discharge makes the following assumptions:

- The measured depth at the mid-point of each panel is considered to be the mean depth for the panel
- The mean velocity at an observation vertical is assumed to be the mean velocity for the respective panel

For each panel, the discharge is the mean depth multiplied by the mean velocity. The panel discharges are then summed to obtain the total discharge through the gauging cross section.

For panels where velocity was measured at 20% and 80% of depth, the mean velocity is computed as the arithmetic average of the two readings: $V_{mean} = (V_{0.2}+V_{0.8})/2$. Where velocity was measured at only 60% of depth, that velocity would be considered the mean velocity.

.3 Methods and Procedures for Continuous Water Level Monitoring

.3.1 Continuous Water-level Sensor and Data Recorder

At each gauging station, a water level sensor and data logger will be installed to provide continuous electronic logging of water levels during the monitoring period.

1. The water level probe will be an ultrasonic, pressure-transducer sensor or bubbler system, capable of measuring water depth to within 2.0% precision. It will be capable of measuring depth over the full range of expected depths. Hydraulic calculations should be made to estimate the range of depths that might be encountered at the gauging site.

2. The water level measurements will be recorded on an electronic data-logger. The data-logger will be of a type and design that allows real-time data access and/or graphical review of stored data using a laptop computer.

3. The water level sensor must be installed in a secure location that ensures that the sensor will not be moved by the flow or any debris carried by the flow. Sensor and data logger must be installed in a location that minimizes risk of vandalism and minimizes the possibility of damage by debris carried by the flow.

4. The water level sensor and data-logger system will be set up to provide water level readings every 15 minutes. This setting can be adjusted if watershed response times and hydrograph recession times prove to be shorter or longer than expected.

5. Water level sensor operation and accuracy shall be verified at least once every seven to fourteen calendar days. At each check, the water level sensor accuracy will be verified by comparing the sensor reading with a water level measurement taken from the gauging site's staff gauge (see below) and/or other water level measurement reference point. The time and results of each of these checks shall be recorded in the field logbook.

6. During each check, data-logger operation will also be verified. The stored data will be accessed and reviewed to determine if there has been any drift or unexplained variation in recorded water levels.

7. If the check reveals that the water-level sensor is in error by more than 5% of water depth at the sensor, then the sensor is to be removed and inspected. Time of sensor removal must be recorded in the field logbook. If no reason for the error can be found, the sensor should be immediately replaced by a calibrated sensor. Time of any such replacement must be recorded in the log book.

.3.2 Staff Gauge and Vertical Reference Benchmark

To assist with routine checks on the accuracy and operation of the water level sensor and data-logger, a staff gauge and/or reference point will be installed at each gauging site. The staff gauge will consist of a vertical weather-resistant staff marked at even depth increments that allow visual measurement of water level within 0.01 feet. The staff gauge will be installed in a secure location and in a manner that ensures that it will not be moved by the flow, debris carried by the flow, wind or other forces that might be expected to act on the staff gauge.

At each gauging station, an on-shore vertical reference benchmark shall be established, and all water levels shall be measured relative to this vertical benchmark. The on-shore benchmark must be an immovable object that is expected to remain above the water level at all times. The staff gauge should be designed and installed such that water levels read from the staff gauge can be readily expressed as distance below the on-shore benchmark. The staff gauge must therefore be installed using proper level surveying techniques.

.4 Data Acquisition, Calculations, and Data Reduction

.4.1 Field Log Book or Electronic Field Log Book

A field logbook or electronic field logbook will be maintained during the course of the streamflow-gauging program. It will contain notes and observations on each visit to each gauging station site. On each visit during which depth-discharge measurements are made, notes will be made regarding

- Flow conditions
- Extent of floating debris carried by the flow
- Streambank and streambed erosion, deposition or debris accumulation
- Weather conditions
- Upstream and downstream conditions

- Condition of staff gauge and water level sensor and datalogger
- Any other pertinent information

Water levels (from staff gauge readings and the water level recorder) and clock times at the start and end of the depth-velocity measurement period should be recorded in the field log book or electronic field log book.

.4.2 Water Depth and Velocity Data for Rating Curve Development

As noted above, water depth and velocity data are to be recorded as they are gathered at individual gauging stations. Form SOP3-1 or similar form(s) should be used to record the data by on-shore personnel as values are measured by personnel wading across the gauging section.

Form SOP3-1 or similar form(s) should include columns for computation of discharge for each vertical sub-section or panel of the gauging section, and for then computing total discharge at the section. These computations and tabulations shall be made in the field immediately after completing the depth and velocity measurements, to allow for immediate assessment of the reasonableness of the results.

.4.3 Rating Curve Development

A rating curve is developed for each gauging station by plotting the stage-discharge measurements on graph paper or in an appropriate computer program, and then fitting a smooth curve to the data.

A variety of techniques can be used to fit a rating curve to observed stage-discharge data, or alternatively, to develop a rating table (i.e., a table that describes the relationship between water level and total discharge at the gauging station). Mathematical techniques or visual curve fitting can be applied if an appropriate computer program is not capable of fitting the curve.

The methods and techniques presented the U.S. Geological Survey manual entitled, "Discharge Ratings at Gauging Stations" (E.J. Kennedy, 1984), should be applied to this task with the assistance of computer-based computations for curve fitting.

.4.4 Continuous Water Level Data

Continuous water level data will be retrieved from the datalogger once every seven to fourteen calendar days, and in no case shall the interval between site visits exceed three weeks. The data will be reviewed by field personnel for any apparent anomalies or water-level sensor malfunctions. If problems are suspected, then the data will be immediately reviewed with the QA personnel. Refer to QA/QC requirements below for more information on data review requirements.

5.0 HEALTH AND SAFETY

If flow velocity and depth measurements are taken by wading across the gauging section, the following safety practices must be followed:

- Stage-discharge measurements must be made by a team of at least two personnel except during low flows when velocities are less than 2 fps and water depth is 1.5 feet or less. During the measurement procedure, only one team member is in the water at any time, with the other assisting by recording data and otherwise assisting and ensuring the safety of the person wading in the stream.
- If flow is high, make an estimate of maximum flow depth and flow velocity before wading into the water. Floating debris can be used to estimate velocity. The staff gauge reading can be used to determine depth. As a general rule, if the product of velocity (in feet per second) and depth in feet is 7 or greater (for example, velocity of 3 fps and depth of 2.5 feet gives a product of 7.5), then wading into the flow is not likely to be safe and should not be attempted.

- When wading across the section, use a rod to check the stream bed conditions when advancing across the section. Check for scour holes, obstructions, or any other conditions that could make for unsafe footing.

- While personnel are wading in the watercourse, all team members should be attentive to flow conditions. In particular, watch for floating debris or other hazards that could damage equipment or cause problems for the in-water personnel.

If flow velocity and depth measurements are taken from a bridge crossing, the following safety practices must be followed:

- Stage-discharge measurements must be made by at least two personnel except where vehicle traffic is low and there is a sidewalk or shoulder area providing a separation distance from traffic.

- Field personnel should use appropriate clothing, including orange reflective vests, while engaged in velocity measurements from a bridge crossing.

- If necessary, traffic cones should be placed curbside to warn approaching traffic.

6.0 PERSONNEL

.1 Field Personnel for Stream Gauging

The team responsible for field activities related to stream gauging will consist of at least two personnel, except during low flows when velocities are less than 2 fps and water depth is 1.5 feet or less.

At least one member of the stream gauging team should be familiar with theory of open-channel hydraulics and should have experience with open-channel flow measurement.

All team members should be physically fit and healthy at the time of stream flow measurement and equipment installation.

.2 Quality Assurance and Approval

Quality assurance requirements (see below), including in-progress review of the stream gauging activity, will be the responsibility of a qualified professional. The professional must have expertise in hydrology, open-channel hydraulics, flow measurement techniques and procedures, and data reduction techniques.

7.0 QUALITY ASSURANCE AND CONTROL (QA/QC)

.1 Data Management and Records Management

Maintenance of the field logbook or electronic field logbook will be the responsibility of the stream gauging field team. The field logbook or electronic field logbook will be routinely reviewed and audited as part of the QA/QC procedures (see below).

Continuous water-level data will be stored in computer data files. All raw data files extracted from the field data logger will be stored in a central office location.

.2 Quality Control for Continuous Water-level Recorder

- Water level sensor operation and accuracy shall be verified at least once every 7 to 14 calendar days. At each check, the water level sensor accuracy will be verified by comparing the sensor reading with a water level measurement taken from the gauging site's staff gauge or reference point. The time and results of each of these checks shall be recorded in the field log book.

- During each check, data-logger operation will also be verified. The stored data will be accessed and reviewed to determine if there has been any drift or unexplained variation in recorded water levels.

- If the check reveals that the water-level sensor is in error by more than 5% of water depth at the sensor, then the sensor is to be removed and inspected. Time of sensor removal must be recorded in the field log book. If no reason for the error can be found, the sensor should be immediately replaced by a calibrated sensor. Time of any such replacement must be recorded in the log book.

.3 Calibration of Current Meter (Water Velocity Meter)

Maintenance and calibration of the current meter will be done by reviewing the company's operations manual for proper calibration and maintenance procedures.

.4 Validation of Rating Curve Data

.4.1 Data Review, Audit and Approval

Immediately after completion of a stage-discharge measurement at a gauging station, results of that measurement will be reviewed to determine the adequacy of each measurement for use in developing the station's rating curve. This will consist of review and audit of the field log book or electronic field log book, data records and data reduction tabulations (i.e., tabulations on Form SOP3-1 or similar form{s}), along with interview with the personnel that undertook the measurement.

If results are judged acceptable, then the data acquisition/reduction form (Form SOP3-1 or similar form{s}) will be approved.

If any deficiencies are found, then they will be reviewed in detail with the personnel that carried out the measurements so that appropriate corrective action is taken to ensure that adequacy of future measurements.

.4.2 Maintaining Approved Rating Curve Data

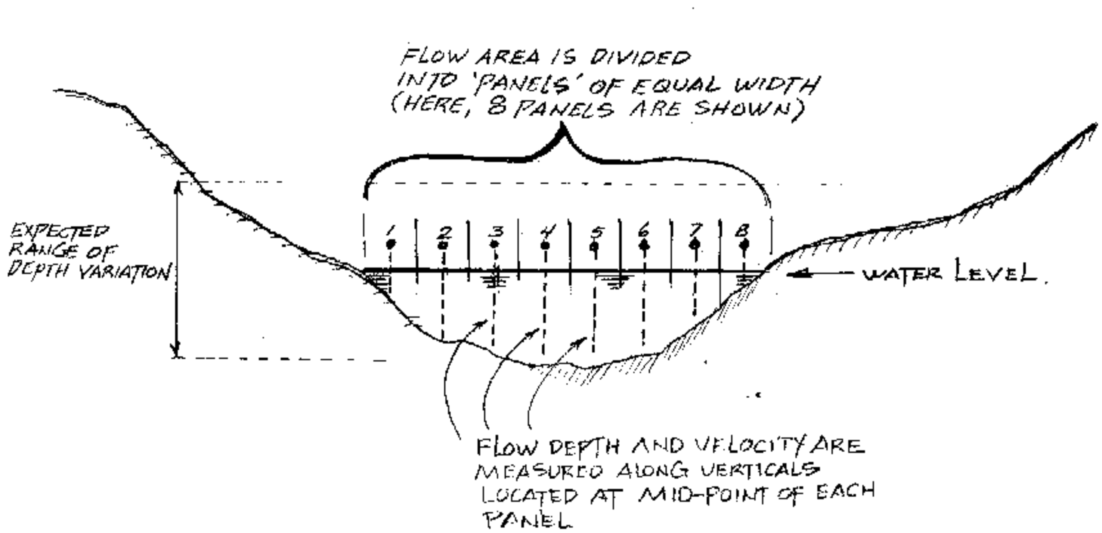
The project engineer will maintain a copy of all approved stage-discharge measurements for all stations, and will be responsible for developing each station's rating curve according to the requirements of this S.O.P.

8.0 REFERENCES

Kennedy, E.J., 1984. "Discharge Ratings at Gauging Stations," published by US Geological Service (Department of the Interior) as part of series entitled “Techniques of Water Resources Investigations of the United States Geological Survey," Book 3, Chapter A10.

9.0 FORMS AND FIGURES

FIGURE SOP3-1:



FORM SOP3-1

WATERSHED MONITORING

FORM SOP3-1

STREAMFLOW GAUGING: STAGE-DISCHARGE MEASUREMENT DATA SHEET

Date of measurement

Crew members

Weather conditions

Stream observations/ flow conditions

DEPTH VELOCITY DATA

Start time		Water level at start time:	
		Level recorder	
		Staff gauge	

Distance from on-shore reference point	Panel number	Panel width	Time	Water depth	Velocity readings			Mean velocity	Panel discharge	Notes
					20% depth	60% depth	80% depth			
feet			hh:mm	feet	fps	fps	fps	fps	cfs	
	1									
	2									
	3									
	4									
	5									
	6									
	7									
	8									
	9									
	10									

Total of panel discharges: ____ cfs

Stop time		Water level at stop time	
		Level recorder	
		Staff gauge	