

Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedure for Measuring and Calculating Stream Discharge

Version 1.1

Author – James R. Shedd

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Reviewer – Chuck Springer

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QA Approval - William R. Kammin, Ecology Quality Assurance Officer

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Signatures on File

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## Environmental Assessment Program

### Standard Operating Procedure for Measuring and Calculating Stream Discharge

#### **1.0 Purpose and Scope**

- 1.1 This standard operating procedure describes the techniques and methods used to measure and calculate stream discharge in a variety of measurement conditions.

#### **2.0 Applicability**

- 2.1 The procedures presented in this document apply primarily to stream discharges measured with mechanical instruments and acoustic velocimeters. However, some sections including but not limited to; Cross Section Selection, Measurement Rating Guidelines, and Assessing the Control also apply to discharges measured with acoustic profilers.

#### **3.0 Definitions**

- 3.1 Midsection Method – A widely used technique for calculating stream discharge, the midsection method involves the calculation of discharge in individual measurement cells in a cross section.
- 3.2 Cross Section – The measurement cross section is a vertical plane extending from either stream edge, up from the stream bottom to the surface. Depth measurements and velocity samples are taken at about 30 predetermined verticals across the cross section.
- 3.3 Vertical – The vertical is one of a series of measurement points through the cross section where depth and velocity are measured.
- 3.4 Primary Gage Index – The primary gage index is the base gage for the station and is directly referenced to the recording gage. The primary gage index is the most stable and reliable gage at a site. All other gages at a station are considered secondary.
- 3.5 Control – The physical features of a stream that controls the relationship between stage and discharge at a gage site.
- 3.6 Point of Zero Flow – The point of zero flow is the elevation of the lowest point of a control structure. Flow stops when stage reaches the point of zero flow elevation.

## **4.0 Personnel Qualifications/Responsibilities**

- 4.1 Personnel using this document will have the training necessary to operate current meters and related equipment. Staff will have knowledge of field and safety procedures associated with the collection of stream flow information.
- 4.2 Users of this document will typically work in the Environmental Specialist or Hydrogeologist job classifications.
- 4.3 No special certifications are required.

## **5.0 Equipment, Reagents, and Supplies**

- 5.1 A standard English four foot, top set [wading rod](#) measures vertical depths in streams shallow enough for wading. A velocity meter attached to the top set wading rod measures current speed. The rod is designed to set the current meter at 0.2, 0.6, and 0.8 of the total stream depth.
- 5.2 The Sontek® FlowTracker® Acoustic Doppler Velocimeter® is used in the majority of wading measurements. The basic components of the FlowTracker® include the under water probe containing the acoustic elements, the probe cable, keypad and controller (Burks, 2009). All of these components attach to a wading rod.
- 5.3 The primary mechanical current meter used in wading measurement applications is the Swoffer®, Inc. Model 2100® flow meter kit. The flow meter kit consists of a model 2100® digital indicator, sensor cable, and a two inch rotor assembly (Holt, 2009).
- 5.4 In the case of measurements from a bridge using mechanical equipment, a bridge board or bridge crane is used. Three types of sounding reels are available; USGS Type A and B reels, and a Hydrological Services® Pty Ltd San Winch®. The Swoffer® flow meter kit and the Hydrological Services® OSS-B® current meter are the mechanical instruments used in bridge measurements. The Hydromate® counter registers velocities for the OSS-B1 current meter (Holt, 2009).



**Figure 1 Bridge board equipped with a USGS Type A reel. (Photo by Washington Dept. of Ecology)**



**Figure 2 Bridge crane equipped with a USGS Type B reel. (Photo by Washington Dept. of Ecology)**

- 5.5 Shore operated cableway discharge measurements require the use of a removable sounding reel, permanently installed bearing posts, main tow cable, pulleys, trolley, and related hardware.

- 5.6 Discharges measured from a boat require specially made equipment. This equipment includes a crosspiece, retractable boom, and a nose piece. A Kevlar® tag line maintains the position of the boat along a cross section.



**Figure 3 A boat measurement conducted with necessary equipment attached to a Kevlar® tag line. (Photo by Washington Dept. of Ecology)**

- 5.7 Columbus sounding weights, ranging from 15 to 100 pounds are attached to the cable of the sounding reels in bridge, cableway, and boat measurements.
- 5.8 Copies of form number 040-56 ([Appendix A](#)) for recording discharge notes are kept in a suitable field notebook. These forms are printed on Rite in the Rain™ paper for outdoor durability.
- 5.9 A fiberglass measuring tape or marked cable is stretched across the measurement cross section or bridge span.
- 5.10 Good quality hip or chest waders are worn by staff conducting discharge measurements by wading.
- 5.11 As mandated by the Environmental Assessment Program's Safety Manual (EAP, 2010) an approved personal flotation device must be worn when working in areas where the danger of drowning exists, such as on the water, over the water, or alongside the water.

## **6.0 Summary of Procedure**

### **6.1 Preparation**

- 6.1.1 Prior to departure complete a [Field Work Plan](#).
- 6.1.2 Review the equipment checklist ([Appendix B](#)) and ensure all field and safety equipment are in the vehicle. Make sure all station information, instructions, and

field forms are on hand. Test all stream discharge measuring equipment for proper operation.

- 6.1.3 Ensure vehicle is equipped to handle the driving conditions you may encounter. Make sure vehicle operates properly before leaving. Check oil level, fluid levels and tire pressure.

## 6.2 Measurement Notes

- 6.2.1 It is important that field staff record clear, detailed notes prior to, during, and after the measurement. Future evaluations of a measurement depend on complete and thorough notes. Record the following information at each discharge measurement:

- 6.2.1.1 Name of station and station number.

- 6.2.1.2 Party (person conducting measurement listed first, person recording notes listed second).

- 6.2.1.3 Date and time measurement started and ended using 24 hr clock in Pacific Standard Time.

- 6.2.1.4 Note the start and end time along with REW (right edge of water) or LEW (left edge of water). Right and left edges of water are oriented looking downstream.

- 6.2.1.5 Identify the type of instrument and record the instrument number. If using mechanical equipment, note the propeller or fan number.

- 6.2.1.6 Record pre and post calibration readings if applicable (Holt, 2009).

- 6.2.1.7 Record the gage height from the primary and secondary gage indices at the beginning and end of the measurement. Additionally, observe and note the gage height at least once during the course of the measurement to determine if stage is changing.

- 6.2.1.8 Record the variability in gage height observations, i.e. the range of water level bounce i.e. +/- n hundredths of a foot of variability.

- 6.2.1.9 At stations equipped with continuously recording data loggers, record the time beside the corresponding vertical in the notes every 15 minutes. These time observations are important in determining the mean gage height if the [stage is changing significantly](#) during the measurement. In the case of stations without a continuous recorder the gage height is manually observed and noted when stage is changing rapidly.

- 6.2.1.10 Record the water temperature particularly when using acoustic instruments.

- 6.2.1.11 At the end of the measurement indicate the [rating of the measurement](#) in the space provided on the note sheet.
- 6.2.1.12 When measurement statistics are available in electronic form, record the width, area, average velocity, and maximum depth. Also include the number of verticals, wetted perimeter and discharge.
- 6.2.1.13 Record velocity uncertainty, depth uncertainty, and overall uncertainty in the space provided on the note sheet when these statistics are available.
- 6.2.1.14 Thoroughly describe channel and [control](#) conditions.
- 6.2.1.15 Describe any situation which might affect the accuracy of the measurement or affect the stage and discharge relationship.
- 6.2.1.16 Measure and record the [point of zero flow](#) if possible.
- 6.2.1.17 Prior to submittal of notes for review, the measurement number, and initials of person compiling notes are entered in the space provided on the note form.
- 6.2.1.18 The person reviewing the measurement enters their initials in the space provided on the note form.
- 6.2.1.19 Record vertical locations, depths, and velocities on the back side of the measurement note form. It is important to record velocities in the proper two tenths, six tenths, or eight-tenths column.
- 6.3 Selecting the Correct Instrument to Conduct a Discharge Measurement
- 6.3.1 Not all available measurement equipment is designed for use in all measurement situations.
- 6.3.2 Acoustic Doppler Current Profilers (ADCP) makes an attractive instrument choice because of their convenience and relative ease of deployment. If used appropriately ADCPs provide a more complete and accurate measurement.
- 6.3.3 However, they are not used in every situation. The following are circumstances in which an ADCP may not be an appropriate instrument choice:
  - 6.3.3.1 Poor depth distribution.
  - 6.3.3.2 High Turbulence.
  - 6.3.3.3 Aerated water.
  - 6.3.3.4 Soft or vegetal covered substrate.

- 6.3.3.5 Moving bed situations.
- 6.3.3.6 Debris or fish in the water.
- 6.3.3.7 Extremely clear water with very little or no turbidity or entrained material.
- 6.3.4 As a matter of practice, field staff should review the quality of past ADCP measurements at a site. Consider using another type of instrument or changing measurement locations if there were problems with past measurements.
- 6.3.5 Refer to The Teledyne RD Instruments® (TRDI) StreamPro® Standard Operating Procedure (Shedd, et al, 2008) or the WinRiver II Quick Start Guide (TRDI, 2007) for detailed information regarding the proper use of current profilers.
- 6.3.6 In circumstances where use of an ADCP is inappropriate, use either an acoustic velocimeter or a mechanical instrument.
- 6.3.7 FlowTracker® velocimeters are preferred over mechanical equipment because of their accuracy, automatic discharge calculation capabilities, statistical presentation of data quality parameters, and lack of moving mechanical parts. The acoustic velocimeter is versatile and can be used in most wading measurement applications. However like the ADCP, the velocimeter will not work in all measurement situations.
- 6.3.8 Boulders, logs or other large structures collectively referred to as boundaries cause interference with acoustic signals. This interference precludes velocity measurements with velocimeters. Avoid cross sections with significant boundary structures.
- 6.3.9 Very clear water with very little or no turbidity is another condition in which velocities cannot be measured with these instruments.
- 6.3.10 Highly turbulent or aerated water can also prohibit the use of the velocimeter.
- 6.3.11 Mechanical equipment will perform in almost all situations except in velocities less than about 0.10 feet per second. Mechanical instruments will register a velocity in situations where an acoustic instrument may not. However, the same factors that preclude the use of acoustic instruments may also limit the reliability of mechanical equipment.
- 6.3.12 If a velocimeter cannot be used because of channel and flow conditions, attempt to find a more favorable measurement location. Use mechanical equipment only when circumstances preclude the use of acoustic equipment.

## 6.4 Selecting a Cross Section

- 6.4.1 Prior to conducting a stream discharge measurement field staff make considerable efforts to locate the best available measurement cross section. If the stream cannot be waded and an Acoustic Doppler Current Profiler (ADCP) cannot be used, the measurement must be made either from a bridge, cableway, or a boat.
- 6.4.2 In the case of ADCP and wading measurements the selection of a suitable cross section cannot be over emphasized. The quality of equipment or the ability of the individuals conducting the measurement cannot overcome the limitations in measurement quality caused by a poor cross section. The choice of cross sections is obviously limited when measuring from a bridge, cableway, or boat.
- 6.4.3 Field staff look for the following characteristics in an ideal measurement cross section (Rantz, 1982):
- 6.4.3.1 A stream channel relatively straight with parallel edges upstream and downstream of the cross section.
  - 6.4.3.2 Defined edges on both sides of the cross section.
  - 6.4.3.3 A channel of uniform shape.
  - 6.4.3.4 A channel free of vegetative growth, large cobbles, and boulders.
  - 6.4.3.5 A cross section free of eddies, slack water, and turbulence.
  - 6.4.3.6 A cross section with depths greater than 0.5 feet.
  - 6.4.3.7 Velocities greater than 0.5 feet per second and distributed evenly through the cross section.
  - 6.4.3.8 A cross section relatively close to the gaging station control to avoid the inflow of tributaries and differences in relative flow between the control and cross section during periods of changing stage.
- 6.4.4 Meeting all of the selection criteria is often not possible. Field staff should choose the best available cross section based on these characteristics.

## 6.5 Dividing the Stream Channel into Segments

- 6.5.1 After locating a satisfactory cross-section, stretch a measuring tape or marked tag line across the measurement cross section. The tape or tag line extends across the channel perpendicular or normal to the direction of flow. Limit the number of cells with [oblique flow angles](#), i.e. cells with current angles not perpendicular to the cross section.

- 6.5.2 Note the width of the stream channel at the cross section and divide into measurable segments or cells. Divide the cells such that approximately five percent and no more than ten percent of the total flow is within any one segment. In most cases divide the cross section into approximately 30 segments. Position verticals closer together where flow is more concentrated and velocity variation or bottom irregularities are greatest.
- 6.5.3 The width of a measurement segment should not be less than three tenths of a foot.
- 6.6 Measuring Velocity
- 6.6.1 Measure velocity at each pre-determined vertical across the stream. Although velocity is evenly distributed in ideal cross sections, there can be significant variability in stream velocity throughout a less than ideal cross section. Velocity varies horizontally across the cross section and vertically through the water column. Velocity also naturally pulses in streams at any single location over short periods of time.
- 6.6.2 *Horizontal Velocity Variation*
- 6.6.2.1 Channel geometry, substrate, and other stream features cause horizontal variability between stream segments. Field staff can minimize measurement uncertainty due to horizontal velocity variation by applying these guidelines:
- 6.6.2.1.1 Divide the stream cross-section into about 30 segments. If previous measurements show uniformity of the cross section and an even velocity distribution, fewer verticals may be used (Rantz, 1982).
- 6.6.2.1.2 Concentrate the distribution of segments where discharge is highest and in areas where significant velocity variation can be identified.
- 6.6.2.1.3 Increase the number of verticals in vicinity of bridge piers.
- 6.6.3 *Vertical Velocity Variation*
- 6.6.3.1 In most natural stream conditions, a logarithmic relationship exists between velocities through the water column. Typically velocity increases in the upper portion of the water column and decreases near the bottom. Address vertical velocity variability within a segment using one of the following methods, depending on measurement conditions.
- 6.6.3.1.1 Six tenths method: Sample velocities at sixth tenths of the depth from the water surface. Assume velocity samples at six tenths of depth represent the average velocity through the water column up to 1.5 feet. Use the six tenths method in stream segments less than 1.5 feet in depth. Use the six tenths method at all depths when stage is fluctuating rapidly and the measurement must be made quickly.

- 6.6.3.1.2 Two point method: Employ the two point method in streams with depths greater than 1.5 feet. Velocities are sampled at two tenths and eight tenths of the depth, and the results are averaged.
- 6.6.3.1.2.1 When measuring from a bridge, cableway, or boat, the two point method is used in depths greater than 2.5 feet.
- 6.6.3.1.3 Three point method: When a logarithmic relationship does not exist between strata of velocities through the water column, use the three point method.
- 6.6.3.1.3.1 Presume a non logarithmic relationship exists when the two tenths velocity is less than the eight tenths velocity or the two tenths velocity is greater than two times the eight tenths velocity.
- 6.6.3.1.3.2 The three point method consists of velocity samples at two tenths, six tenths, and eight tenths of depth. Average the six tenths sample against the mean of the eight tenths and two tenths velocity samples, thus weighting the six tenths sample as half of the calculated velocity for the segment.

#### 6.6.4 *Single-Point Velocity Variation*

- 6.6.4.1 Stream velocities in natural conditions tend to pulse over time at the same stage. These fluctuations compound the effects of horizontal and vertical velocity variability at fixed locations in the stream. Apply the following guidelines to address single point velocity variability:
  - 6.6.4.1.1 Take 40 second velocity samples to address variations in velocity over time at a single measurement point.
  - 6.6.4.1.2 Measure 40 second velocity samples at each measurement point except when stage is rapidly fluctuating, or when velocities less than 0.5 feet per second exist when measuring with mechanical instruments.
  - 6.6.4.1.3 In circumstances when [stage is fluctuating](#), take single 20 second velocity samples to complete the discharge measurement quickly.
  - 6.6.4.1.4 When using mechanical equipment, increase the sample time to 60 seconds when velocity is less than 0.5 feet per second.

#### 6.7 Adjusting Velocities of Oblique Flow Angles

- 6.7.1 Pay close attention to the direction of flow when using mechanical current meters. The velocity of the current normal or perpendicular to the cross section must be determined to calculate discharge correctly.
- 6.7.2 The following procedure does not apply to SonTek® velocimeters as they are always pointed perpendicular to the cross section. SonTek® velocimeters automatically calculate and report velocity as normal to the cross section (Burks, 2009).

- 6.7.3 Ecology's Freshwater Monitoring Unit's mechanical instruments consist of horizontal axis type current meters. In wading measurements mechanical meters should be pointed into the current when the angle of the current, relative to the perpendicular of the cross section is greater than 15 degrees. When the meter is suspended by a cable the meter will automatically point into the current.
- 6.7.4 At any measurement vertical, when a mechanical meter is pointed into an oblique current greater than 15 degrees from the perpendicular of the cross section, multiply the registered velocity by the cosine of the angle. This calculation yields velocity normal to the cross section. An approximate 3.5 percent difference exists between registered velocity at a 15 degree current angle and the calculated velocity normal to the cross section. A 20 degree angle results in a greater than 6 percent difference between registered and calculated velocity normal to the cross section.
- 6.7.5 Determine the cosine in the field with the use of the Ecology Discharge Measurement Note sheet number [040-56](#). On the back side of the form locate the dot in the center of the left margin. Cosine values are on the right side of the page as well as the top and bottom.
- 6.7.6 Hold the note sheet horizontally with the dot over the measuring tape if wading, or the edge of a bridge rail if conducting a bridge measurement. Position the note sheet such that the long edge of the sheet is parallel to the direction of the current. The measuring tape or bridge rail edge will intersect the cosine value on the right edge, top, or bottom of the sheet. Multiply the cosine value times the registered velocity to obtain the velocity normal to the cross section.
- 6.7.7 Oblique angles should be measured and velocities adjusted at all verticals where current angles are greater than 15 degrees.
- 6.7.8 In many instances when measuring discharge from a bridge, the entire stream channel is at an oblique angle to the cross section defined by the bridge. In this case multiply the raw average velocity of the measurement by the cosine of the angle between current direction and the cross section.
- 6.8 Measuring Discharge When Stage Is Fluctuating Rapidly
- 6.8.1 Field staff should streamline measurement methods to obtain a more representative gage height when stage changes rapidly. Some accuracy in the measurement is sacrificed. However the error caused by changing flow patterns in rapidly changing stage situations is greater than the loss of accuracy in a streamlined discharge measurement (Buchanan and Somers, 1969).

- 6.8.2 Generally, stage is considered rapidly changing when stage changes at a rate greater than 0.1 feet per hour. Be aware that measurements conducted during or after storm events, impoundment or diversion activities, or seasonal snow melt periods are the most likely times to encounter rapidly changing stage conditions.
- 6.8.2.1 Measure velocities using the [six-tenths](#) method regardless of depth.
- 6.8.2.2 If the six tenths method is not possible, use either the [two tenths method](#), [subsurface method](#), or the [surface](#) method.
- 6.8.2.3 Reduce velocity sampling time to 20 seconds.
- 6.8.2.4 Reduce the number of verticals to 15 or 20.
- 6.8.2.5 At sites with continuous stage height recorders, record the time every 15 minutes on the note sheet corresponding to the vertical measured at that time.
- 6.8.2.6 In the case of non-recoding stations, manually read and note gage heights. Observation times are recorded on the note sheet next to the corresponding vertical.
- 6.8.2.7 This record of stage and corresponding observation times are used in the calculation of a weighted mean gage height.
- 6.9 Calculating Mean Gage Height When Stage Is Fluctuating Rapidly
- 6.9.1 The mean gage height of a discharge measurement and the discharge value itself comprise the two plotted coordinates used to establish a rating. An accurate determination of mean gage height is as important as the accuracy of a discharge measurement.
- 6.9.2 At continuously recording stations the stage record during the time of the measurement is checked against the recorded times on the measurement sheet. Check the record for the amount of fluctuation in stage during the measurement.
- 6.9.3 If changes in stage occurred during the measurement and the changes are uniform and less than about 0.1 feet, mean gage height is determined by calculating the average of the beginning and ending gage height readings (Buchanan and Somers, 1969). Use judgment in determining the allowable change in gage height where a simple mean gage height is calculated. Consider the percentage of discharge the change in stage represents at smaller streams.
- 6.9.4 If the change in stage is greater than 0.1 feet or the change is not uniform a weighted mean gage height for the measurement is calculated. Two methods are used to obtain a weighted mean gage height. The first, called Partial Discharge Weighting is only appropriate for use with discharges measured with mechanical equipment or acoustic velocimeters. The second method, Time Weighting, is

used with all measurement equipment including Acoustic Doppler Current Profilers. When mechanical equipment or acoustic velocimeters are used both methods are employed and the separate results averaged to obtain a weighted mean gage height.

6.9.4.1 With the Partial Discharge Weighting method, the discharge between recorded times during the measurement, the mean gage height for the corresponding time periods, and the total measured discharge are used to compute a mean gage height. The Partial Discharge Weighting formula is

$$H = \frac{q_1 h_1 + q_2 h_2 + q_3 h_3 \dots + q_n h_n}{Q}$$

where

H = mean gage height

Q = total discharge =  $q_1 + q_2 + q_3 \dots + q_n$

where  $q_1 + q_2 + q_3 \dots + q_n$  = discharge measured during time interval 1, 2, 3, ...n and

$h_1 + h_2 + h_3 \dots + h_n$  = average gage height during time interval 1, 2, 3, ...n.

6.9.4.1.1 In figure 4 an example of a partial discharge weighting calculation is presented. The gage height (h) is recorded every 15 minutes from 13:30 to 14:30. The average gage height (Avg h) is calculated between each 15 minute interval. The sum of the discharges of each cell (q) measured in the 15 minute interval is computed. Each of these discharges are summed to give Sum Q = 76.37. The product of each Avg. h and q is calculated and the products summed to give Sum (avg. gh) \* (q) = 135.43. To calculate the mean gage height H, divide (avg. gh) \* (q) by sum Q in the form  $\frac{135.43}{76.37}$  to give a mean gage height of 1.77 feet.

Example:

Time	h	Avg. h q	(Avg. h) X (q)	
13:30	1.94	<b>1.92</b>	<b>16.1</b>	<b>30.91</b>
13:45	1.90	<b>1.70</b>	<b>24.31</b>	<b>41.33</b>
14:00	1.49	<b>1.67</b>	<b>20.99</b>	<b>35.05</b>
14:15	1.85	<b>1.88</b>	<b>14.97</b>	<b>28.14</b>
14:30	1.92			
<b>Sum q = 76.37</b>		<b>Sum (avg. gh) * (q) = 135.43</b>		

$$H = \frac{135.43}{76.37} = 1.77 \text{ feet}$$

**Figure 4 Example of partial discharge weighting calculation method.**

6.9.4.2 The Time Weighting method uses the mean gage heights between the noted times, the duration of those times, and the total time of the measurement. The Time Weighting formula is

$$H = \frac{t_1 h_1 + t_2 h_2 + t_3 h_3 \dots + t_n h_n}{T}$$

where

H = mean gage height

T = total time for the measurement, in minutes =  $t_1 + t_2 + t_3 \dots t_n$ ,

$t_1, t_2, t_3 \dots t_n$  = duration of time intervals between GH observations, and

$h_1, h_2, h_3 \dots h_n$  = average height during time interval 1, 2, 3, ....n.

6.9.4.2.1 In the example below the average gage heights (Referred to as Avg. (h)) from the discharge weighting example are used. The product of each time interval of 15 minutes Time interval (t) and Avg, (h) are calculated to give  $h * t$ . The four 15 minute time intervals in the example are added to give a total of 60 minutes. Each product of  $h * t$  are summed to give a total of 107.55. The summed products of  $h * t$  are divided by the total time in the form  $\frac{107.55}{60}$  to give a mean gage height of 1.79 feet.

Example:

Avg. (h)	Time interval (t)	$h * t$
1.92	15	28.80
1.70	15	25.50
1.67	15	25.05
1.88	15	28.20
Total	60	107.55

$$H = \frac{107.55}{60} = 1.79 \text{ feet}$$

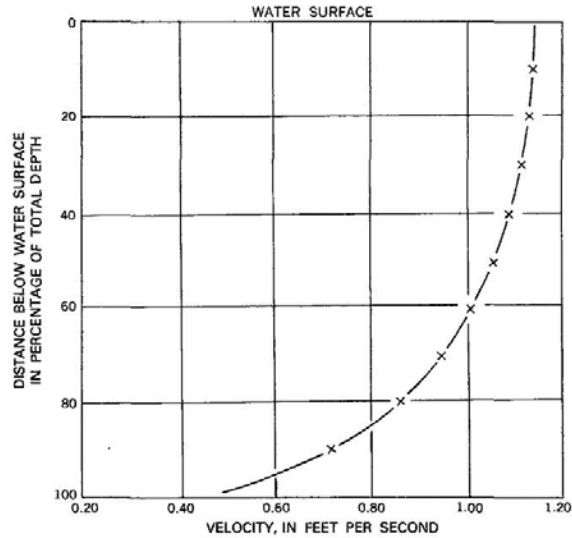
**Figure 5 Example of time weighted calculation method.**

6.9.5 Studies by the United States Geological Survey indicate the Partial Discharge method tends to overestimate the mean gage height and the Time Weighted method underestimates the mean gage height. For that reason it is recommended that both methods are computed and the two results averaged (Rantz, 1982). Keep in mind both methods are only applied to measurements where mechanical instruments or acoustic velocimeters were used. In the above examples the mean stage for the measurement using the results of both methods is 1.78 feet.

- 6.10 Measurement and Calculation Techniques When High Velocities Preclude Depth Soundings or Conventional Velocity Observations
- 6.10.1 If velocity is too great to make depth soundings or obtain conventional velocity samples, three alternative methods make discharge estimations possible. These are the two tenths method, the subsurface velocity method, and the surface velocity method.
- 6.10.2 *Two Tenths Velocity Method*
- 6.10.2.1 Calculation of velocity using the two tenths depth method involves sampling velocity at 0.2 of the depth from the surface and applying a coefficient derived from the point to mean velocity ratio. The point to mean velocity ratio refers to the calculated or estimated ratio between the measured velocity at two tenths depth, and the mean velocity of the entire water column.
- 6.10.2.2 In circumstances where depths can be reliably sounded but velocity cannot be sampled at 0.6 or 0.8 of depth because of drift debris or other reasons, sample velocity at 0.2 of the measured depth.
- 6.10.2.3 In situations where soundings are not possible, depths can be estimated when a reliable standard cross section or some knowledge of the bottom contour is available (Buchanan, Somers, 1969).
- 6.10.2.4 Coefficients applied to two tenths depth velocities are most reliable when derived from velocity curves from the specific location as opposed to published velocity curves. Develop a velocity curve between two tenths velocities and true mean velocities by recalculating past measurements. Recalculate complete measurements or measurement segments where 0.8 and 0.2 depth velocity samples were measured, using only the 0.2 velocity in the calculation. By plotting the true mean velocities versus the two tenths velocities for each measurement a mathematical relationship can be derived.
- 6.10.2.5 Studies conducted by USGS indicate that for a given cross section the relationship between the two tenths and true mean velocities remains constant or varies uniformly with stage (Rantz, 1982).
- 6.10.2.6 USGS Water Supply Paper 2175 (Rantz, 1982) provides a vertical velocity graph and table of point to mean velocity ratios. This graph and table were developed through intensive study of vertical velocity curves. If an insufficient number of measurements have been conducted to derive a reliable relationship at a specific site, the replicated graph (figure 6) and table 1 may be used to calculate point velocities. The point velocity is derived from the table by dividing the measured velocity by the ratio of point velocity to mean velocity. For example the ratio applied to a velocity measured at 0.2 of depth is calculated in the form  $\frac{V}{1.149}$

1.149

where  $v$  is the measured velocity and the denominator of 1.149 is the ratio of point velocity to mean velocity at 0.2 of depth found on table 1.



**Figure 6 Graphical representation of standard vertical velocity curve developed by USGS. (Illustration from USGS Water Supply Paper 2175, pg. 133.)**

**Table 1 Point to mean velocity ratios for standard vertical velocity curve. (Table from USGS Water Supply Paper 2175, pg. 133.)**

Ratio of observation depth to depth of water	Ratio of point velocity to mean velocity in the vertical
0.05	1.160
.1	1.160
.2	1.149
.3	1.130
.4	1.108
.5	1.067
.6	1.020
.7	.953
.8	.871
.9	.746
.95	.648

6.10.3 *Subsurface Velocity Method*

6.10.3.1 Use the subsurface velocity method if measuring or estimating depth is not possible or practical.

6.10.3.2 Sample velocities at an arbitrary depth at least two feet below the surface.

- 6.10.3.3 Determine depths by soundings made at a later measurement when the flow has receded. Calculate the difference between the gage heights of the two measurements to estimate depths and meter elevations at the time of the subsurface velocity measurement. Compare cross sections of previous measurements with the cross section of the latest measurement to determine if the cross section has shifted (Buchanan, Somers, 1969).
- 6.10.3.4 With the known depths of the current meter, the ratio of point of velocity observation to vertical depth is computed.
- 6.10.3.5 As previously described, point velocity to mean velocity ratios can be obtained from velocity curves developed for the specific site. Use the graph in figure 6 and table 1 if a velocity curve specific to the site is not available.
- 6.10.3.6 A simple example of this application follows: Based on soundings subsequent to a subsurface velocity sample at a certain vertical, the depth at the time of the sample is calculated at 10 feet. Velocities were sampled at 3 feet below the surface. The ratio of point of velocity observation to vertical depth is  $\frac{3\text{feet}}{10\text{feet}} = 0.3$ . Table 1 shows the ratio of point velocity to mean velocity in the vertical at 0.3 of depth is 1.13. Calculate the adjusted velocity at 0.3 of depth in the form  $\frac{v}{1.13}$  where v is the measured velocity and the denominator 1.13 is the ratio of point velocity to mean velocity.
- 6.10.4 *Surface Velocity Method*
- 6.10.4.1 If obtaining velocities below the surface is not practical or possible, the surface velocity method may be used. Lower the meter to the water surface to sample the velocity. The coefficient used to calculate mean velocity is 0.85 (Rantz, 1982). Alternatively the sampled velocity can be divided by 1.18.
- 6.11 Rating a Measurement
- 6.11.1 At the conclusion of each measurement, field staff apply a rating of the measurement on a scale from excellent to poor. This field rating forms the basis of the final quality code assigned to the measurement by the station's principle investigator.
- 6.11.2 Field staff base the measurement rating on observed conditions as well as quality analysis statistics available in the field. Acoustic velocimeters' and current profilers' operating systems offer comprehensive analytical packages.
- 6.11.3 The desirable [characteristics](#) of a measurement location serves as the basis for rating the physical conditions of the channel and cross section. Field staff observe the degree in which each of these characteristics influence the quality of the measurement.

- 6.11.4 Take into account factors such as the proximity of bridges and other structures to the cross section. These structures can effect velocity distribution and uniformity of depth (Rantz, 1982).
- 6.11.5 Consider the number of and the degree in which velocities are corrected because of oblique current angles. Keep in mind the assumption that the angle observed at the surface prevails through the entire vertical may be incorrect. Numerous angles of flow approaching the cross section from various directions may indicate turbulence resulting in non representative velocity samples.
- 6.11.6 Take notice of the condition of the equipment. Rate the measurement accordingly if problems with equipment occurred during the measurement.
- 6.11.7 Look at the role of the weather in the measurement. Wind over the water surface can obscure the direction of flow. Cold weather may cause ice or slush to form in the cross section. Ice or slush can adversely affect the operation of mechanical current meters and the ability to measure depth accurately.
- 6.11.8 Water level bounce and velocity pile up on wading rods and stadia rods adds uncertainty to depth determinations. Take into account these factors when rating a measurement.
- 6.11.9 Not all of the variables affecting the quality of a discharge measurement can be described here. Field staff must consider all the conditions and use professional judgment in rating a measurement.
- 6.11.10 The principle investigator or basin lead thoroughly reviews all of the components of the field rating and renders the final decision in all quality code assignments. It is extremely important field notes are thorough and complete.
- 6.11.11 Measurements are rated as excellent, good, fair, or poor on the discharge note form. An excellent measurement indicates the measured discharge value is within 2 percent of the actual flow value. A rating of good means the measured value is within 5 percent. A fair rating of a measurement indicates the measured value is within 8 percent. Poor means the error in the measured flow is within 13 percent of the actual discharge.
- 6.11.12 Field staff do not consider the level of difficulty in obtaining gage height observations in the measurement rating. Base the rating solely on measurement conditions. However, field staff should focus particular attention in field notes on the circumstances and degree of difficulty in obtaining an accurate gage height observation. Consider water level bounce and velocity pile up on staff gages or stadia rods. Wind can cause wave action that may make it difficult to locate the water surface with sounding weights. The principle investigator considers carefully these factors in formulating the final rating.

6.11.13 Principle investigators should keep in mind that in situations when stage changes rapidly the measurement is purposefully accelerated and some accuracy is lost. Stage determinations in these circumstances are often calculated rather than directly observed. Rate the measurement appropriately in these circumstances.

6.12 Assessing the Control

6.12.1 The physical features of a stream that regulates the relationship between stage and discharge at a gauge site is the control.

6.12.2 There are three basic types of controls; section control, channel control, and flood plain control.

6.12.3 The following discussion focuses on section and channel controls.

6.12.4 *Section Control*

6.12.4.1 A section control governs the stage and discharge relationship in a localized reach of the stream, downstream from the gage. The section control can be a natural or artificial structure, a channel constriction, or a downward break in slope in the stream bed.

6.12.4.2 Common section control structures include the buildup of rocks and boulders, or woody debris stretched across the channel. Manmade dams, weirs, or water diversion structures often serve as section controls. Channel constrictions can include rock outcrops or gravel bars. Bridges where the waterway opening is narrower than the natural channel is a common section control caused by channel constriction. Downward breaks in the slope of a streambed include heads of riffles, cascades or the brink of a falls.



**Figure 7 This section control is defined by the downward break in slope at the head of the riffle. (Photo by Washington Dept. of Ecology)**

6.12.4.3 At some stations more than one section control may be present. In these instances an upstream section control is in effect at lower stages. At higher stages another downstream section control becomes effective.

6.12.5 *Channel Control*

6.12.5.1 Channel control exists when the physical attributes of a long reach of the channel controls the relationship between stage and discharge. These physical attributes include shape, length, width, slope, sinuosity, and roughness of the channel. The length of the channel as an effective control increases as discharge increases (Rantz, 1982).



**Figure 8 An example of channel control at the same location as figure 7. (Photo by Washington Dept. of Ecology)**

6.12.6 *Control Dynamics*

6.12.6.1 Typically, section control is effective at lower stages and channel control effective at higher stages. An intermediate range of flows are subject to partial control. Partial control occurs when the relationship between stage and discharge is governed by both section and channel controls or by two separate section controls. As flows increase, section control is progressively drowned out by channel control. Partial control occurs between two section controls when stage increases such that the downstream control becomes increasingly effective.

6.12.6.2 The propensity of the channel to change over time determines the stability of the station controls. If high flow events frequently cause scour or filling of a channel, the controls are unstable. If a control changes frequently, the stage and discharge relation changes frequently. If controls are stable, the stage and discharge relationship remains stable.

6.12.6.3 Ideally all stations would have stable controls. Unfortunately this is not the case in the natural environment. Stations with unstable controls require frequent adjustment of rating curves. Additional measurements are required to establish new ratings rather than further define and reaffirm existing ones. More time is needed to manage records when ratings need frequent adjustment. This increases the costs to operate a station and can reduce the timeliness, and reliability of discharge records.

#### 6.12.7 *Documenting the Condition of Controls*

6.12.7.1 Because controls may change over time, field staff must monitor and document the condition of controls at each discharge measurement. The station's principle investigator will need detailed information about the control if a change in rating occurs.

6.12.7.2 Field staff should identify the effective control or if there is a partial control situation. If section control is in effect, note the location of the control relative to the gage. Note the type of section control i.e., the control is a structure in the stream, or the control constricts flow like a gravel bar or outcrop. Note the materials making up the section control. Have copies of past notes or photos on hand to document changes in the control relative to previous visits.

6.12.7.3 It is important to note any forms of seasonal vegetal growth or ice on or around the control, and on the bed and banks. Aquatic vegetation and ice on the control or in the channel alters the stage and discharge relationship by reducing velocity and the effective waterway area (Rantz, 1982).

6.12.7.4 In autumn the accumulation of leaves can temporarily change the stage and discharge relationship. Note the extent of accumulation of leaves on the control or in the channel where the stage and discharge relation may be impacted.

#### 6.13 Measuring the Point of Zero Flow

6.13.1 The point of zero flow (PZF) is the lowest point on a control and the stage at which flow ceases.

6.13.2 A PZF should be identified and measured whenever possible. A determination of the PZF is important because it helps define the lower end of a rating and serves as a first estimate of the off-set of a rating.

6.13.3 A change in PZF elevation or location indicates alteration of the control. A measurable alteration in the control can signify a shift in the rating.

6.13.4 Attempt to measure a PZF only when it is safe to do so. Follow these steps to identify and determine a PZF.

- 6.13.4.1 Locate the section control.
- 6.13.4.2 Take depth soundings across the control with a wading rod.
- 6.13.4.3 Locate and measure the depth of the PZF, the deepest point of the control.
- 6.13.4.4 Include in the depth reading the pile up of water on the wading rod.
- 6.13.4.5 Note the depth of the PZF to the nearest one-tenth of a foot.
- 6.13.4.6 Note the locations of the control and the PZF.
- 6.13.4.7 Take photographs of the control if the control is altered.
- 6.13.5 A record of PZF soundings and locations are kept in station notes.
- 6.14 Calculating Stream Flow Using the Midsection Method
- 6.14.1 Ecology's Freshwater Monitoring Unit uses the midsection method to calculate stream flows measured with mechanical current meters or acoustic velocimeters.
- 6.14.2 The equations comprising the midsection method are written into a variety of computer programs. The Freshwater Monitoring Unit uses Ecology's proprietary discharge calculation program, QWin to compute discharge. The SonTek® FlowTracker® contains a built in midsection calculation program to calculate discharge (Burks, 2009).
- 6.14.3 Although computation of discharge by hand is virtually unnecessary, an understanding of the midsection calculation method can influence strategies and decisions while conducting discharge measurements.
- 6.14.4 The midsection calculation method involves summing the discharges of the individual cells comprising the cross section. This is expressed in the following equation,  $Q = \sum(a v)$  where  
 Q = total measured discharge  
 a = area  
 v = velocity.
- 6.14.5 The discharge of an individual cell is the product of its area and velocity normal to the cross section.
- 6.14.6 The area of the cell extends laterally half the distance from the previous vertical to half the distance to the next. The area also extends vertically from the water surface to the sounded depth. Evenly spaced verticals are not necessary. The mean velocity sampled at the vertical represents the velocity through the entire cell.

6.14.7 The discharge of any cell at vertical x is represented in the equation,

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

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

where

$q_x$  = discharge through cell x,

$v_x$  = mean velocity at cell x,

$b_x$  = distance from initial point to vertical x,

$b_{(x-1)}$  = distance from initial point to preceding vertical,

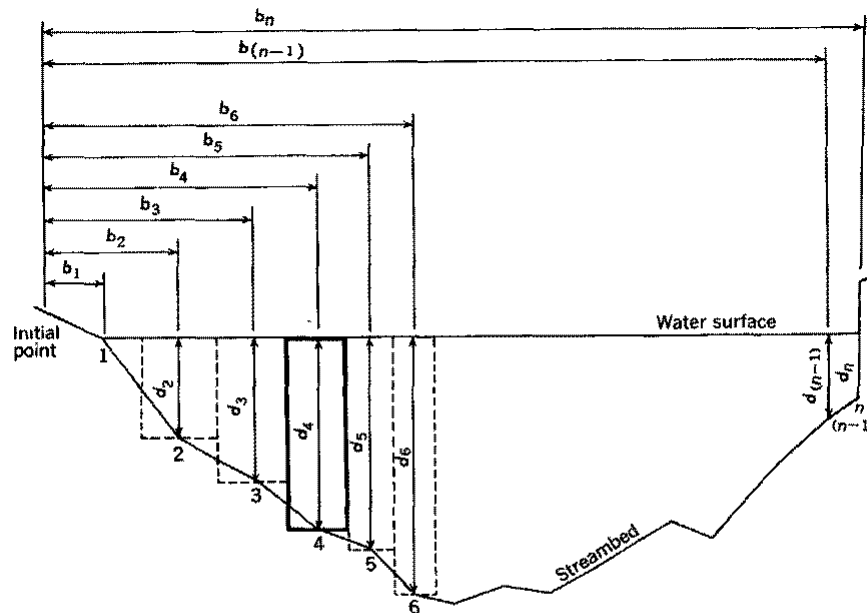
$b_{(x+1)}$  = distance from initial point to next vertical, and

$d_x$  = depth of water at vertical x.

6.14.8 For example, the discharge in highlighted cell 4 in figure 9 is expressed as

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

6.14.9 The total discharge of the stream is equal to the sum of the discharges of each cell.



**EXPLANATION**

1, 2, 3 ..... n	Observation verticals
$b_1, b_2, b_3, \dots, b_n$	Distance, in feet or meters, from the initial point to the observation vertical
$d_1, d_2, d_3, \dots, d_n$	Depth of water, in feet or meters, at the observation vertical

**Figure 9 Cross section sketch illustrates depth and distance between verticals that define the area of measurement cells. Velocities measured at these verticals represent the velocity of the cell. (Illustration from USGS Water Supply Paper 2175, pg. 81.)**

- 6.14.10 Observe in figure 9 the discharge of  $q_1$  is zero. This is because the depth of observation point 1 is zero. There may or may not be actual discharge in this half cell on the edge of the cross section. Typically the amount of actual flow here is inconsequential. However the first and last vertical should be placed close to the edge when the depth at the edge is zero. This insures any residual, uncounted flow remains insignificant.
- 6.14.11 Now observe vertical  $n$  at right edge of figure 9. Here the edge is a vertical boundary where the depth is not zero and the velocity may or may not be zero.
- 6.14.12 Because velocity cannot be measured accurately at a vertical boundary, the velocity at the boundary can be estimated by measuring the mean velocity at a distance from the boundary equal to the depth at the boundary (Rantz, 1982).
- 6.15 Use of a Wading Rod
- 6.15.1 Ecology's Fresh Water Monitoring Unit uses a standard four foot top setting wading rod in graduated English units. Top setting wading rods have a 1/2-inch hexagonal rod to measure depth. The hexagonal rod is marked by single lines scored in one-tenth foot graduations up the length of the rod. Every one half foot is marked with double lines. At every one foot increment a group of three lines are scored. The top of the hexagonal rod at the base of the rod handle is 4 feet from the base of the rod.
- 6.15.2 The wading rod is placed in the stream such that the round base sits on the streambed. The depth of the water is read on the hexagonal rod. Care should be taken to make sure the depth is read consistent with the incremental marks on the rod as these markings are not numbered. Make sure the correct foot, half-foot, and tenth-foot marks are referenced.
- 6.15.3 Velocity head or pile up will occur to varying degrees depending on the velocity. If the pile up on the rod is low a depth reading is somewhat easy. In higher velocities pile-up and surface bounce will make the depth reading more difficult. Attempt to read the surface by eyeballing the water surface around the rod and estimate where it intersects the rod. To account for bounce try to estimate the average between the top and bottom of the bounce. Depending on the severity of these conditions the depth should be read to the nearest 0.1 or 0.05 depth.
- 6.15.4 A 3/8-inch diameter round rod is used for setting the position of the current meter to the desired measurement depth of two tenths, six tenths, or eight tenths of total depth at the measurement vertical.
- 6.15.5 The round rod is engraved with numbered lines extending around the circumference of the rod. The numbered lines correspond to the whole foot increment of the measured depth, for example 1.7 feet.

- 6.15.6 On the wading rod handle, the numbers 0 through 10 are pressed with corresponding hash marks. These numbers correspond to the tenths of feet measured in addition to the whole feet, for example 1.7 feet. The current meter is set by aligning the numbered lines corresponding to whole feet of the round rod with the appropriate tenths number pressed into the rod handle.
- 6.15.7 For example if a depth of 1.7 feet was observed, set the meter at six tenths of depth by aligning the 1 foot line on the round rod with the seven tenths mark on the rod handle. If the depth can be read to increments less than one tenth of a foot, set the round rod appropriately.



**Figure 10 Wading rod with meter set at six tenths of a depth of 1.7 feet. (Photo by Washington Dept. of Ecology)**

- 6.15.8 Meter settings at two tenths, eight tenths, and six tenths of depth means the meter is positioned in the water column at the respective depth setting measured from the surface of the water. The top setting rod is designed to automatically set the meter at six tenths of depth from the water surface.
- 6.15.9 Described alternatively, when the meter is set at six tenths from the water surface it is also set at four tenths of depth from the streambed. This point is important in understanding how to set the rod to measure velocities at two tenths and eight tenths of depth. By dividing the depth by 2 and setting the meter at that corresponding value, the meter is now set at two tenths depth from the bottom or eight tenths from the water surface. The current meter set at this depth is referred to as an eight tenths velocity sample because the meter is set at eight tenths of the depth from the water surface.

6.15.10 Conversely, if the observed depth is multiplied times 2, the meter is set at eight tenths from the bottom and two tenths from the water surface. This current meter setting is referred to as a two tenths velocity sample because the meter is set at two tenths of the depth from the water surface.

## **7.0 Records Management**

### **7.1 Field Note Forms Archives**

7.1.1 All original field discharge measurement notes are stored in central locations at Ecology Headquarters, Regional, and Field Offices.

### **7.2 Discharge Records in Hydstra Database**

7.2.1 All discharge measurement details are recorded and stored electronically to the Hydstra Gauging and Sections databases.

7.2.2 Measurement details stored in the Gaugings database include the stage, discharge, date and time of the measurement. Other details stored in the Gaugings database include average velocity, area, maximum depth and velocity, width, and wetted perimeter.

7.2.3 Cross section details such as vertical locations and bed elevations are stored in the Sections database.

## **8.0 Safety**

8.1 All EAP safety policies are followed and safety is always the top priority when conducting stream discharge measurements. Refer to the EAP Safety Manual, pages 36-37 and 54-59 (EAP, 2010) for further information about working in and around streams.

8.2 In all measurement situations unsafe deployments that may result in injury to staff, loss or damage to equipment are not attempted.

8.3 Always consider the safety and traffic situations when measuring from a bridge and take appropriate actions including suspending the measurement if unsafe conditions exist. Consult the EAP Safety Manual, page 59-60 (EAP, 2010) for further guidance regarding bridge measurement safety.

8.4 Crossing the stream is done safely and in accordance with the guidelines for working in and around streams established in the EAP Safety Manual, pages 36-37 and 54-56 (EAP, 2010).

## 9.0 References

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## Appendix B (Equipment Checklist)

### Vehicle and Equipment Checklist

#### Standard Vehicle Equipment:

*This equipment should be present anytime the vehicle is used.*

- Cell Phone and Charger

#### Vehicle Folder containing

- Mileage Logs
- Emergency Information
- Fuel Card
- Maps

#### Safety Equipment

- First Aid Kit
- MUTCD compliant Safety Vests (2)
- CG Approved PFD (1 per person)
- PFD CO<sub>2</sub> Refill
- Road Cones
- Signs
- Hard Hats (2)
- Orange Strobe

#### Tools / Other

- Mechanic's Toolbox
- Shovel
- Loppers/Clippers/Machete
- Tire Chains
- 2- 150 ft. Ropes
- Spare Key
- Jack, jack handle, adequate spare
- Flashlight
- Lighter
- Electrical Tool Box
- Pens
- Pencils
- Note Paper
- Flagging Tape
- Orange Spray Paint
- Spare Bucket

#### Standard Flow Gear

##### Flow Box:

- Weighted Tape for Tape Down
- Tag Line
- 300 ft. Transect Tape
- Line Clamps
- Swoffer Kit w/ Cables and Fans
- Swoffer Meter
- Bridge Depth Sounding Correction Sheets (2/10, 6/10, 8/10's)
- Survey Pins and Hammer
- Flow Tracker
- Wading rod
- Laser Level
- Stadia Rod

- Thermistor
- Spare Batteries for All Devices
- Battery Chargers
- Discharge Measurement Sheets

#### Station Visit

- Station Visit Data Flash Card
- Multi-meter
- Logger Menu Flow Chart
- Desiccant
- Station Key
- USGS key
- Other Keys as needed
- Appropriate DCP Batteries

#### ADCP Gear

- ADCP Unit
- PDA (CHECK BATTERY STATUS )
- SD card for PDA
- Tow Ropes and Carabiners
- ADCP Data Sheet

#### Bridge Gear (If Needed)

- Lead Flow Weights, all sizes
- Bridge Board
- T-bar
- Reel w/ Swoffer Cable

#### 3-Wheel Crane

- Reel
- Crane Assembly

#### 4-Wheel Crane

- HS Meter Box
- Props
- Meter Body w/Fiber-Fin
- Cleaning Soln.
- Lubricant
- Reel
- Crane Assembly/Boom
- Counterweights
- Wheel Chocks

#### Personal Equipment

- Water
- Food
- Dry Clothes
- Rain Gear
- Sunscreen
- Gloves
- Waders/Hip Boots
- Up to Date Ratings Sheets
- Maps/Station Directions
- Notebook w/ Extra Data Sheets