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Site Establishment for Large Rivers Water Quality Monitoring: Stage-Discharge Relationships at Selected Sites Within the St. Croix National Scenic Riverway

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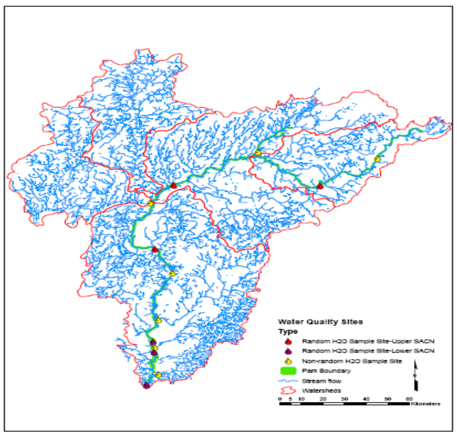

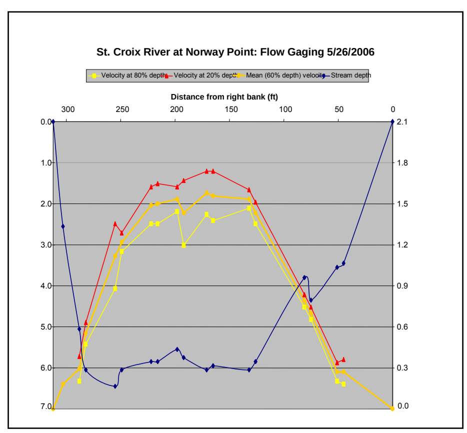

Great Lakes Inventory and Monitoring Network Report GLKN/2008/02 March 2008

On the cover, clockwise from top left: map of the St. Croix River watershed, photo near the mouth of the Kettle River, flow gaging graph of the St. Croix River at Norway Point, photo of author in the Snake River (photo by Brenda Moraska Lafrancois).

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Executive Summary

Long-term monitoring of river water quality requires an understanding and analysis of river discharge. Because water quality concentrations are affected by fluctuations in flow, a record of discharge enables the assessment of flow-corrected concentrations and loading analysis. For example, a suspended sediment concentration of 1000 mg/L at low flow would represent something entirely different than the same value at high or flood flows. For this reason, the qualitative estimate or quantitative measurement of discharge is recommended by the National Park Service – Water Resources Division (NPS-WRD) for all freshwater flowing waterbodies during each sampling event (Penoyer 2003). It is preferable to conduct long-term monitoring at or near a continuous flow gaging station. In the absence of any nearby continuous recording gaging station, discharge can be measured directly or calculated from discharge rating curve relationships. A rating curve is the relationship between stage height and discharge at a particular cross-section of a river.

As follow-up to the development of a protocol for monitoring the water quality of large rivers within the NPS-Great Lakes Network (GLKN) (Magdalene et al. 2007), this project sought to establish stage-discharge rating curves for monitoring sites within the St. Croix National Scenic Riverway (SACN) that do not have nearby USGS flow gages. Preliminary work (summarized in Table 1) identified three monitoring sites that needed additional flow monitoring: on the Namekagon River at Earl, on the St. Croix River at Norway Point, and on the Snake River at the Chengwatana State Forest Campground. The purposes of this project were: 1) to gather concurrent water level (stage) and water flow (discharge) information over a range of flows at these sites during field work conducted May-August 2006, and 2) to analyze the data for stage-discharge rating relationships and develop rating equations.

This document summarizes the tasks of site establishment including quality assurance measures, especially those that focus on developing stage-discharge ratings: measuring stage, measuring discharge, and rating curves. Particular attention is paid to the stage and discharge methods that are most applicable to the range of flow conditions expected for SACN. Average annual river flows within SACN range from 480 cfs (1928-1970, 1988-2006) at Trego (USGS gage #05332500) near the upstream end, to 4,380 cfs (1911-2006) at St. Croix Falls (USGS gage #05340500) toward the downstream end. The three flow monitoring sites required a range of methods depending on flow volumes, from wading to boating to working from a bridgedeck.

The rating curve development process for each of the three monitoring sites is fully documented, and this report includes recommendations for adjustments to the on-going collection of flow data at NPS-GLKN large river sites.

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1 Introduction

A protocol for monitoring water quality of large rivers (Magdalene et al., 2007) was developed for the National Park Service (NPS) to assess long-term trends in the concentrations of selected water quality variables in the two parks of the Great Lakes Network (GLKN) that are centered on large rivers, the St. Croix National Scenic Riverway (SACN) and the Mississippi National River and Recreation Area (MISS). The protocol was not designed to collect sufficient information to estimate annual loads; this requires continuous flow gaging and high frequency water quality sampling at each site, which the current monitoring budget could not afford. However, even when tracking concentrations without loading analysis, the National Park Service – Water Resources Division (NPS-WRD) recommends collecting flow data at the time of water quality sampling to aid in the interpretation of water quality results. For example, a total suspended solids (TSS) concentration of 1000 mg/L measured during low-flow baseflow conditions has significantly different implications than the same concentration measured during high-flow stormflow conditions. Information about flow conditions at the time of sampling is an important factor in the correct interpretation of river health.

The two river parks, MISS and SACN, have very different characteristics with respect to scales of geography and hydrology: MISS is a smaller park unit containing a very large river, while SACN is a larger park unit containing a river that is not as large. MISS encompasses 123 km of the Mississippi River within the urbanized Twin Cities Metropolitan Area. There are four long-term U.S. Geological Survey (USGS) flow gages on this stretch of the Mississippi (about 30 km/gage), and active flow gages on six of the eleven major tributaries that enter on this stretch. Average annual flows range from 8,280 cfs (1932-2007) at Anoka (USGS gage #05288500) near the upstream end, to 18,350 cfs (1929-2007) at Prescott (USGS gage #05344500) near the downstream end. With such large flow volumes, it is not feasible for the NPS to collect accurate flow data independently of the USGS flow gages that measure this short stretch of river.
In contrast, SACN encompasses 420 km of the Namekagon and St. Croix Rivers within a basin that grades from forest and wetland in the north to agriculture and urban land uses in the south. There are four long-term USGS flow gages on the Namekagon and St. Croix mainstems (about 105 km/gage), and active flow gages on eight of the twenty-three major tributaries that enter the mainstem. Average annual flows range from 480 cfs (1928-1970, 1988-2006) at Trego (USGS gage #05332500) near the upstream end, to 4,380 cfs (1911-2006) at St. Croix Falls (USGS gage #05340500) toward the downstream end. At this time, additional information gathered by the NPS about flows at its SACN water quality sampling sites is warranted and recommended.

1.1 Purpose and Scope

The purpose of this project was to gather concurrent water level (stage) and water flow (discharge) information at or near NPS water quality monitoring sites within SACN that did not have nearby flow gages and at which flow measurements were feasible. The information was gathered over a range of flows during field work conducted May-August 2006. The data were analyzed for stage-discharge rating relationships and rating equations were developed. Finally, this report includes recommendations for adjustments to the on-going collection of flow data, in relation to the NPS-GLKN long-term water quality monitoring sites within SACN.

2 Background

2.1 Flow Monitoring Site Selection Process

The water quality monitoring site selection process for SACN, described in detail within the Large Rivers Water Quality Protocol Narrative (Magdalene et al., 2007), resulted in six randomly- and five nonrandomly-selected water quality monitoring sites (Figure 1). Table 1 summarizes the subsequent process for selecting sites at which to monitor flow based on the best available information in 2006, which included: 1) assessment of the distance between water quality monitoring sites and established USGS flow gages, 2) assessment of the ease or difficulty of taking field measurements of flow at each water quality monitoring site, and 3) monitoring priority-level assigned by the interagency St. Croix River Basin Water Resources Planning Team. Table 1 includes the reasons that supported (pro) or disputed (con) the establishment of flow measurement at each water quality monitoring site. In the end, it was decided to establish flow monitoring sites at three of the water quality monitoring sites: Namekagon River at Earl (river mile = 42), St. Croix River at Norway Point (river mile = 102.5), and Snake River at the Chengwatana State Forest Campground (river mile = 0.8).

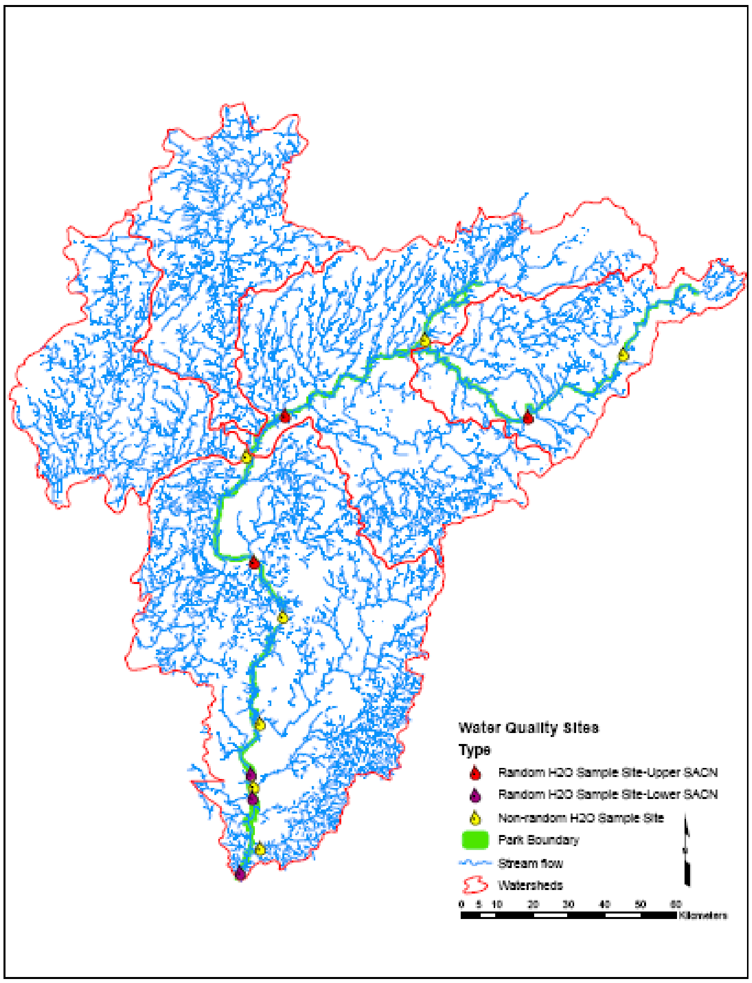


Figure 1. Water quality monitoring sites within the St. Croix National Scenic Riverway (SACN).

Table 1. Selection factors for flow monitoring at NPS-GLKN large rivers water quality monitoring sites, including the pros and cons, as of 2006, for the establishment of flow measurement at each site. Deciding factor (pro or con) is highlighted in bold text.

New WQ Monitoring Sites	PRO	CON
1. Namekagon R. @ Earl (River mile = 42)	**·Closest USGS gages: 40 mi from Leonards, 45 mi from Danbury** **·Easier to gage - nearby bridge**	
2. St. Croix R. @ Norway Point (River mile = 102.5)	**·Closest USGS gages: 25 mi from Danbury, 50 miles from St. Croix Falls** **·Selected by Basin Team as high priority mainstem monitoring site**	
3. Snake R. @ mouth (River mile = 0.8)	**· Selected by Basin Team as high priority tributary monitoring site** **·Easier to gage - narrow channel** **·Large discharge range reported**	·Nearby USGS gage: 10 mi from Pine City
4. St. Croix R. nr Trade R. (River mile = 65)		**·Nearby USGS gage: 15 mi from St. Croix Falls** **·Difficult to gage - wider channel**
5. St. Croix R. @ St. Croix Falls (River mile = 52)	·Selected by Basin Team as high priority mainstem monitoring site	**·Existing USGS gage at this location**
6. Apple R. @ mouth (River mile = 2.7)	· Selected by Basin Team as high priority tributary monitoring site	**·Nearby USGS gage: 5+ mi from Somerset, WI**
7. St. Croix R. @ Bayport Pool (River mile = 20)	·Closest USGS gage: 32 mi from St. Croix Falls ·Selected by Basin Team as high priority mainstem-lake monitoring site	**·Location too wide (~0.6 mi) to gage accurately**
8. Willow R. @ mouth (River mile = 0.4)	· Selected by Basin Team as high priority tributary monitoring site	**·Nearby USGS gage: 2 mi from Willow R. State Park**
9. St. Croix R. @ Troy Beach Pool (River mile = 12)	· Closest USGS gage: 40 mi from St. Croix Falls ·Selected by Basin Team as high priority mainstem-lake monitoring site	**·Location too wide (~0.9 mi) to gage accurately**
10. Kinnickinnic R. @ mouth (River mile = 2.3)	· Selected by Basin Team as high priority tributary monitoring site	**·Nearby USGS gage: 2 mi from County Road F**
11. St. Croix R. @ Kinnickinnic Pool (River mile = 2)	· Closest USGS gage: 50 mi from St. Croix Falls ·Selected by Basin Team as high priority mainstem-lake monitoring site	**·Location too wide (~0.4 mi) to gage accurately**

3 Methods

3.1 Location Reconnaissance and Assessment

Once a potential monitoring station has been selected and its GPS location verified on a map, the site should be visited to assess whether it is an appropriate monitoring location. It should be noted that the water quality monitoring site and the flow monitoring site for a given monitoring station do not need to be at the exactly same location, but they should be within one mile of each other and represent the same flow conditions (no sinks or sources between the two sites). Key concerns are accessibility, representativeness, and stability.

3.1.1 Accessibility

Bridge crossings provide safe access to large rivers during high flows, but can be the source of road contaminants (volatile organic compounds and especially road salts), and rarely cross at randomly-selected locations. Therefore it is preferable to sample from boats. Identify the nearest public access boat landing. The landing should be located within a few miles (<10 miles) of proposed monitoring site. Visit the site using the boat that is planned for field work, to verify that average flow conditions are passable using that boat and route is not blocked by riffles or rapids. Select monitoring locations that allow safe sampling during high flow with minimal risk to sampling personnel.

3.1.2 Representative of average flow and water quality of river reach

At the proposed monitoring location, river discharge should be free-flowing, not stagnant, but not overly aerated or churned. The flow conditions should represent well-mixed but laminar flow. As part of the reconnaissance, verify that the proposed site is not immediately downstream of a pollution point source. If the site has been selected randomly to represent the average conditions of the St. Croix River, then it should be located at least five stream-widths downstream from a tributary, to ensure complete mixing of waters (Stednick and Gilbert 1998). During reconnaissance of a potential site, verify vertical and lateral mixing, as measured by core suite readings of the stream cross-section (see section 3.2 below).

3.1.3 Stable setting for long-term monitoring

The proposed monitoring site should be located along a straight portion of the river channel; avoid meander bends or side channels that may experience changes in the streambed morphology. It is best if the site is entrenched between stable river banks; avoid low banks or levees on one or both sides of the river that are prone to overbank flow, unless this is representative of the average conditions for this reach. For discharge measurements, it is preferable that the selected location is confined between bedrock or high clay banks; avoid sandy streambeds.

3.2 Cross-Sectional Profile of Field Water Quality Variables

Before site establishment can be finalized, mixing must be verified by less than 10% variance of the core suite variables (pH, temperature, specific conductivity, and dissolved oxygen) when measured in cross-sectional profile.

To establish a profile of field measurements:

- Establish a cross-sectional profile of stream discharge.

- Check the cross-sectional profile data of the stream site to determine the variability of discharge per unit width of the stream.
- Determine the location within the cross-section at which discharge is approximately equal on both sides of that point (the discharge between that point and the right bank is equal to the discharge between that point and the left bank); this is the centroid of flow and the point at which water quality samples should be obtained.
- Make individual measurements of required field parameters (temperature, dissolved oxygen, pH and conductivity) at a number of equally spaced locations along the cross-section and at multiple depths at each location.
- Check the cross-sectional profile data to determine the variability of required field variables per unit width of the stream.
- The variability within field measurement profiles are needed for a range of low- and high-flow conditions and should be verified at least every two years.
- Record the information collected in the above steps and include it in the field folders for each station.

If the cross-sectional profile of stream discharge and field measurements indicates that the section is not homogeneous, then repeat the procedure at additional nearby locations until a suitable site has been identified. If sampling must be conducted at a highly-desirable site that is poorly mixed, then field personnel should follow the instructions for the collection of isokinetic, depth-integrated samples (USGS 2006), which entails collecting multiple samples within the cross-section.

3.3 Measuring River Stage and Discharge

Long-term monitoring of river water quality requires an understanding and analysis of river discharge. Because water quality concentrations are affected by fluctuations in flow, a record of discharge enables the assessment of flow-corrected concentrations and loading analysis. Therefore, the qualitative estimate or quantitative measurement of discharge is recommended for all freshwater flowing waterbodies (Penoyer 2003) during each sampling event.

It is preferable to conduct long-term monitoring at or near a continuous flow gaging station. The readings from the nearby gaging station may be used as the proxy for on-site discharge measurements after a minimum of 10 measurements have been used to develop a scaling factor, defined as the ratio between discharge at the monitoring site and discharge at the nearby gaging station. In addition, occasional validation of the proxy data and scaling factor should be conducted by comparison with discharge measurements at the monitoring site (2-3x/year).

In the absence of any nearby continuous recording gaging station, discharge can be measured directly or calculated from discharge rating curve relationships. Direct measurement of the discharge of very small flows can be accomplished by placing a weir at a cross-section of a small stream or ditch. However, this method is difficult and impractical for large rivers; discharge rating curves are a practical solution. A rating curve is the relationship between stage height and discharge at a particular cross-section of a river. This relationship is usually controlled by a section or reach of channel below the gage, called the station control, which eliminates the effect of all other downstream locations on the velocity of flow at the gage. Flow controls can be either natural or constructed and may consist of a ledge of rock across the channel, a boulder-covered riffle, an overflow dam, or any other physical feature capable of maintaining a stable relation between stage and discharge. Depending on channel features (e.g., slope, roughness, shape, constrictions and expansions), one flow control may be effective at low discharges and another control could be effective at medium and high discharges.

To develop a discharge rating curve, a hydrologist makes a series of discharge measurements, conventionally using a current meter. These measurements are made over a period of time, over a range of discharge from low flow to high flow. The stage height is recorded at the same time as the discharge measurement. By relating the depth of flow to the volume of flow, a rating curve accounts for the shape and cross-sectional area of the river channel at the measurement location. Therefore, each rating curve applies to one measurement location, and each measurement location requires its own rating curve. If the cross-section of a river channel is changed due to flooding or human-induced alterations, the rating curve must be updated (Kennedy 1984).

Rantz et al. (1982) give the criteria for an ideal discharge-gaging site:

1. The general course of the stream is straight for about 300 ft (approx. 100 m) upstream and downstream from the gage site.
2. The total flow is confined to one channel at all stages, and no flow bypasses the site as subsurface flow.
3. The streambed is not subject to scour and fill and is free of aquatic growth.
4. Banks are permanent, high enough to contain floods, and are free of brush.
5. Unchanging natural controls are present in the form of a bedrock outcrop or other stable riffle for low flow, and a channel constriction for high flow, or a falls or cascade that is unsubmerged at all stages.
6. The gage site is located at the downstream end of a pool, to ensure recording of stage at extremely low flow and to avoid high velocities at the upstream end of gaging-station intakes during periods of high flow.
7. The gage site is far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gage site.
8. A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gage site. (It is not necessary that low and high flows be measured at the same stream cross section.)
9. The site is readily accessible for ease in installation and operation of the gaging station.

The basic method for discharge measurement has not changed in several decades and is best detailed by the USGS (Buchanan and Somers 1969). After selecting a straight reach of river with low turbulence and stable banks, a river cross-section is identified and marked. Stage height is measured from a permanent gage. The hydrologist divides the cross-section into several partial sections, usually 25 or more. At the midpoint of each partial section, the flow depth and average flow velocity are measured using a current meter with a top-setting wading rod or sounding weight attached to a cable. The average flow velocity of each partial section is measured and recorded. Discharge is the product of flow velocity and cross-sectional area, so the total discharge of a river cross-section is calculated as the sum of the product of the velocity and the area measured at each partial section (Figure 2). Dimensions are traditionally measured and reported in English (not metric) units of feet and seconds. Each of these steps is described in greater detail in the following sections.

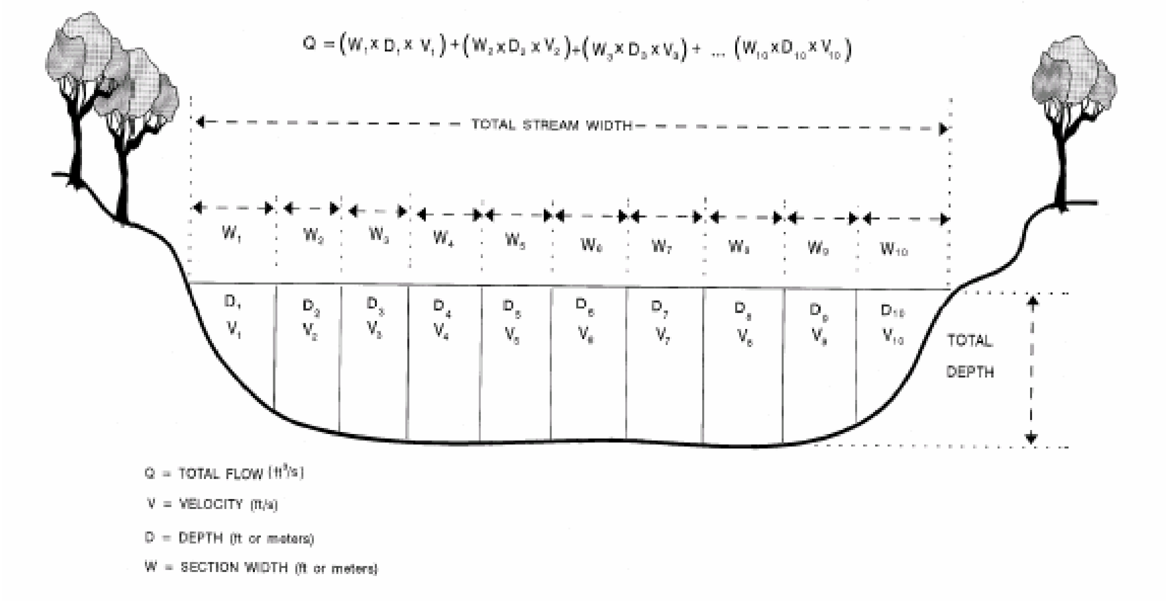


Figure 2. Schematic diagram of discharge measurement procedure in cross-section.

3.3.1 Methods for measuring river stage

River stage is defined as the water surface elevation relative to an arbitrary zero datum. To measure river stage for the development of discharge rating curves, it is usually best to install a staff gage (Penoyer 2003). A staff gage is a scale bar (usually enameled steel) placed in a stream to show the elevation of the water surface. The staff gage should be located in an area that will provide some degree of protection from floating debris, etc. Mounted on a post and anchored in the stream bed (or mounted on a bridge), the gage will consist of a vertical scale that is permanently marked in increments of 0.01 ft and the stage is read directly from these markings to the nearest 0.01 ft. The staff gage is mounted at the time of installation to enable gage readings across the expected range of low- to high-flows. As an alternative to a staff gage, stage height can be measured from a permanent and stable benchmark, such as a bridge railing or a bedrock ledge. In these cases, a tape measure is used to record the water level as the distance below the benchmark datum.

Regardless of the type of gage (staff gage or benchmark), the gage height at zero flow (GZF) should be calculated for each gage. For most river cross-sections, GZF is equivalent to the lowest elevation of the stream bed, or the measured water elevation minus the deepest partial section. If desired, the gage height can be calibrated to the global coordinate system by referencing a datum on the gage to the surveyed elevation of the water surface, preferably at the time of installation.

3.3.2 Range of equipment choices

Depending on the rate and volume of flow at the time of measurement, a variety of measurement tools will be required for this project (see next section for specific guidelines). Current meters fall into two categories, those with vertical-axis rotation and those with horizontal-axis rotation.

Vertical-axis current meters are better able to measure lower flow rates (Buchanan and Somers 1969), but horizontal-axis current meters can measure lower flow volumes due to their streamlined profile (Fulford et al. 1994). Horizontal-axis meters tend to function better under turbulent flow (Fulford et al. 1994), but their difficult maintenance and repair in the field makes vertical-axis meters the common choice of USGS hydrologists. Among vertical-axis current meters, the most commonly used are the Type AA meter and the Pygmy meter. Type AA meters have lower variability and higher reliability than Pygmy meters (Hubbard et al. 1999), but Pygmy meters, at two-fifths scale of the Type AA, can be used in low flow volumes.

Current meters are used in conjunction with equipment that measures flow depth; the choice of equipment may vary depending on flow depth. Top-setting wading rods are available in lengths up to 10 feet, and can be used while wading or from a boat deck. For greater depths, the current meter is suspended on a cable attached to a sounding weight, and operated from the deck of a boat or bridge.

The method or instrument used to measure flow must be recorded on the discharge field form. Equipment used to measure discharge or flow should be tested and calibrated (e.g., spin tests for current meters, calibrated depth markings on sounding weight cables) prior to mobilization to the field. Consult the manufacturer's manual for specific calibration methods and appropriate applications for selected current meter and other devices used in the flow/discharge determinations.

3.3.3 Equipment and method depend on flow depth

The choices in equipment and measurement method both depend on the river flow depth at the time of measurement (Table 2). The Pygmy current meter is designed to measure low flow volumes, but cannot be used when flow is less than 0.3 ft deep. Do not use the Pygmy meter in velocities less than 0.2 ft/s unless absolutely necessary (Buchanan and Somers 1969); instead, estimate flow by timing a float or use the volumetric method. (At a nearby falls or drop-off, or at a weir plate placed across the streamflow, measure the amount of time that it takes to fill a container of known volume.) If the majority of the river cross-section is more than 1.5 ft deep, then use the Type AA current meter. The Type AA meter is not recommended for flow depths less than 1.0 ft or flow velocities less than 2.5 ft/s.

Whether to use a wading rod, or a cable system from a boat, depends on safety. From the boat, take a preliminary flow velocity measurement at the deepest point: if the product of the velocity and the flow depth is greater than 10 ft^2/sec, do not wade into the river. For example, water depth of 2 ft and flow of >5 ft/s may constitute unsafe conditions. Always wear a life jacket, whether wading or measuring from a boat.

The method used to measure flow also depends on depth. From theory and practice, it is well known that velocity decreases exponentially with depth due to frictional drag on the streambed. The average flow velocity is located at 60% of the total flow depth (40% above the streambed). When flow is measured only at the 60% depth, it is called the one-point measurement method. However, if flow is deep enough, a better method is to take the average of velocity measurements at two depths (20 and 80% of total flow depth), called the two-point method. This is not recommended for shallow flows because the current meter rotors do not work well when very close to the bed or water surface. Refer to Table 2 to select the appropriate equipment and measurement method, based on the average depth.

Table 2. Recommended current meter and measurement method for various depths.

Depth (ft)	Recommended Meter	Measurement Method
0 - 0.3	Too shallow for current meter	Float or Weir
0.3 – 1.5	Pygmy	One-point
1.0 – 2.5	Type AA	One-point
2.5 and above	Type AA	Two-point

3.3.4 Defining the river cross-section

As discussed earlier, a river cross-section perpendicular to the direction of flow should have been identified. If there is no boat, canoe, or tubing traffic, a tagline may be used to delineate the cross-section during discharge measurement (Benson and Dalrymple 1967). A tagline is a sturdy cable strung across the river, marked with visible streamers, and secured at the cross-section markers on each bank. If there is continual traffic on the river or if the width of the river is too great to stretch a tagline, then the midpoint of each partial section should be triangulated along the sightlines of clearly visible markers or flags on the banks, using a laser range-finder to measure the distances. When using a laser range-finder, select a river cross-section that has a good target, a large tree or a vertical rock outcrop, on one bank. If the target is not located directly at the water's edge, the distance between the target and the water's edge must be recorded on the field form.

If necessary, the stream morphology at the cross-section can be modified on smaller, low-flow streams. This can be done by building dikes to cut off dead water and shallow flows, or by removing rocks, weeds and debris in the reach of stream 1 to 2 m upstream from the measurement cross section. After modifying a streambed, allow the flow to stabilize before starting the flow measurement.

Once the cross-section has been selected, measure and record the stream width (water's edge to water's edge). Estimate the average width and number of partial sections, according to the following rule of thumb:

- If the stream width is less than 5 ft, partial sections are 0.5 ft wide.
- If the stream width is greater than 5 ft but less than 10 ft, the minimum number of partial sections is 10.
- If the stream width is greater than 10 ft, the preferred number of partial sections is 20 to 30.

Though not required, it may be most convenient to select a uniform width for all the partial sections. For example: a 7-ft wide stream comprising 14 x 0.5-ft partial sections, a 26-ft wide stream comprising 26 x 1.0-ft partial sections, or a 120-ft wide stream comprising 24 x 5-ft partial sections. Some judgment is required to determine the spacing and locations of partial section midpoints, depending on the stream morphology. Fewer measurements are needed if the stream banks are straight, the depth nearly constant, the bottom is free of large obstructions, and the flow is homogeneous over a large section. In contrast, partial sections should be closer together where the flow depth or velocity increases or where the bed is heterogeneous. **To minimize measurement errors, no single partial section should contain greater than 10% of the total flow, and preferably should contain less than 5% of the total flow**. (It may be possible to estimate total flow in advance, by downloading real time data from a nearby USGS gaging station.)

3.3.5 Finding lateral positions within the cross-section

Flow depth and velocity are measured at the midpoint of each partial section. To find the midpoint of the first partial section, divide the partial section width in half, and measure that distance from the water's edge. As you work your way across the river, the midpoint of each subsequent partial section is measured one partial section width from the previous midpoint. When wading, a tagline (nylon cord that will not stretch when wet), knotted at the distance of one partial section width, can be used to measure the intervals, or you can stretch a tape measure along the tagline to keep track of the cumulative width as you work across.

Alternatively, a laser range-finder measures the distance as you work your way from one bank to the other bank, and will not block boat traffic. When a laser range-finder is used in conjunction with a flow calculator (e.g., AquaCalc500), only the distance from one riverbank to your current position need be recorded, since the flow calculator will calculate the distance between measurements or the width of each partial section. When measuring flow velocity from a boat, the boat must be navigated by sightlines to locate positions within the cross-section, and the range-finder can read the distance from the bank. For safety, the USGS recommends trying to hold the boat in position using the boat motor, rather than dropping anchor, but this may be difficult under certain flow conditions (Buchanan and Somers 1969).

Laser range-finders typically have upper and lower limits to the distances that they are capable of measuring. The upper limit of most models will not likely be exceeded by the width of the river monitoring sites of this protocol. The lower limit, usually 5 yd or 15 ft, will be encountered if the target is located within 15 ft of the water's edge. In this case, the lead person measuring flow rates holds onto the end of a measuring tape and remains standing at the position of the last range-finder reading, as their field assistant positions him/herself on the bank that is being approached. The tape measure is read at the water's edge, allowing for a daily check of the accuracy of the laser range-finder. Then, as subsequent flow measurements are taken, the field assistant reels-in the tape measure and reads the tape measure at the water's edge, ensuring to keep the tape measure taut between the two field personnel.

3.3.6 Measuring flow depth and velocity

Whenever possible avoid measuring flow in areas with back eddies. If back eddies cannot be avoided, then measure the back eddies as negative flows. These negative values will be included in the final flow calculation. Follow these steps for measuring depth and velocity:

1. After locating the midpoint of the partial section, measure the total depth and record it on the field form.

2. Position the meter on the rod or cable (see details below) at the correct depth (20, 60, or 80% of total depth), and lower it into the water.
3. When wading, stand a minimum of 1.5 ft downstream and off to the side of the flow meter to minimize the effect of your presence on the velocity of water passing the current meter.
4. Keep the wading rod or cable vertical, and keep the long axis of the flow meter perpendicular to the flow. If the flow is not perpendicular to the cross-section or tagline in this partial section, then calculated flow must be adjusted by multiplying by the cosine of the angle between the flow direction and the perpendicular to the tagline. Record the angle between the flow direction and the perpendicular to the tagline.
5. Permit the meter to equilibrate to the current for a few seconds. Measure the velocity for a minimum of 40 sec.
6. Record the flow velocity on the field form in the correct column (one-point or two-point method).

Following below are the details for adjusting the meter to the correct measurement depths when using 1) a top-setting rod, or 2) a cable suspension system.

The top-setting wading rod is designed to allow the user to easily set the current meter at 20-, 60-, or 80% of the total depth (Figure 3).

- **20% of total depth**: Multiply the total depth by 2. If the total depth is 3.1 ft, the rod is set at 6.2 ft. Line up the foot scale on the *sliding rod* with the *tenth scale*, located on top of the depth gauge rod. Line up the **6** on the sliding rod with the **2** on the tenth scale.
- **60% of total depth**: If the total depth is 3.1 ft, then line up the **3** on the foot scale with the **1** on the tenth scale.
- **80% of total depth**: To set the sensor at 80% of the depth, divide the total depth by two. For example, the total depth is 3.1 ft and the rod is set at 1.55 ft. Line up the **1** on the sliding rod between the **5** and **6** on the tenth scale.
- ***Note***: The point where the rod is set for 20 and 80% of the depth will not equal values derived by calculating 20 and 80%t of the total depth.

When using the current meter with a cable suspension system, these steps should be done in the following sequence to adjust the meter to the correct measurement depth:

1. Secure the current meter to a Columbus (type C) sounding weight (15 or 30 pounds).
2. Secure the sounding weight to the cable of a USGS handline (Figure 4A).
3. Lower the cable suspension system (Figure 4B) until it rests on the river bed, counting out 1-ft increments from calibrated markings on the cable to help keep track of the depth.

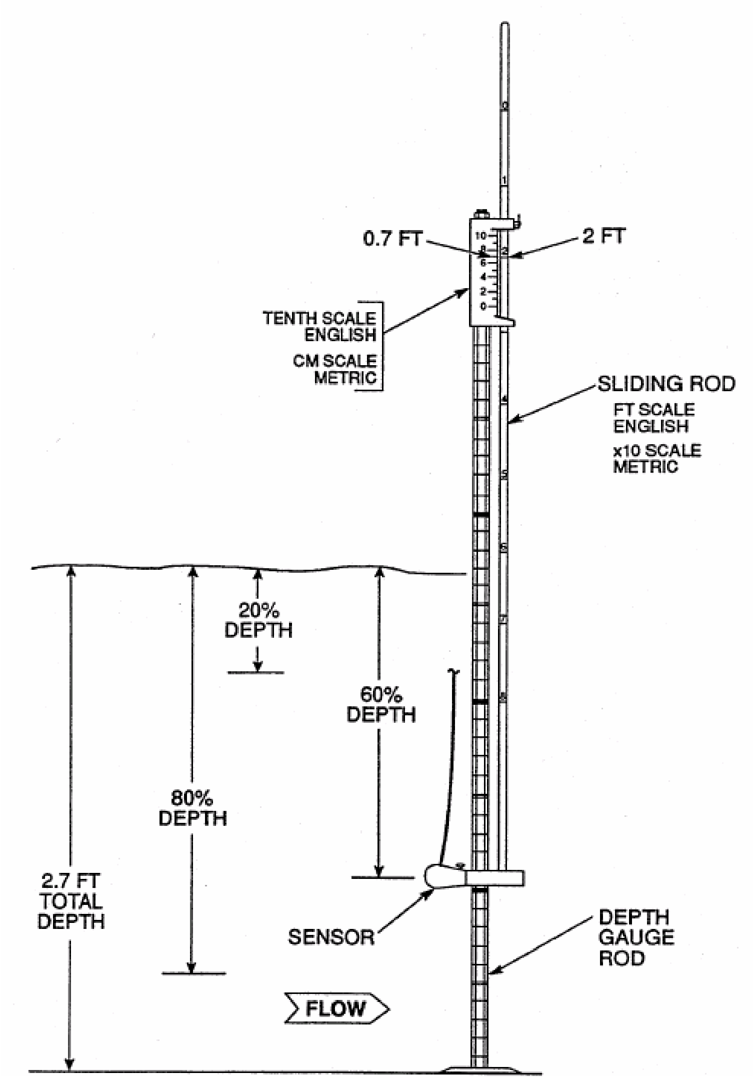


Figure 3. Top-setting wading rod, showing an example for measuring flow at 60% of depth.

4. Measure the total depth. The markings on the cable are relative to the horizontal axis of the flow meter, or the measurement depth. The total depth must be calculated by adding the distance of the meter above the bed (0.55 ft for both the 15-pound and 30-pound weights) to the measurement depth. Note: Although visible from a boat, it is difficult to read the calibrated depth markings from a bridge deck. In this case, measure the depth to water by dropping a measuring tape, weighted by a plumb bob, down to the water's surface alongside the sounding cable. Look for the wake on the surface of the water just as the tip of the plumb bob touches the water surface. Identify one of the calibrated markings on the sounding cable and its corresponding value on the tape measure. Add 0.55 ft to the value of the calibrated marking on the sounding cable and subtract the value from the tape measure. This is the total depth of water at that partial section. Record lateral position (from laser range finder or tape measure) and total depth at that location.
5. Calculate the 80% and 20% measurement depths, which are equivalent to 20% above the

bed and 20% below the water surface, respectively.

6. Raise the meter to the 80% depth (be sure to subtract 0.55 ft before raising the cable), allow the meter to equilibrate, measure the flow velocity, enter into the logger, and record it on the field form.
7. Raise the meter to the 20% depth (or one foot below the surface, whichever is greater), allow the meter to equilibrate, measure the flow velocity, enter into the logger, and record it on the field form.

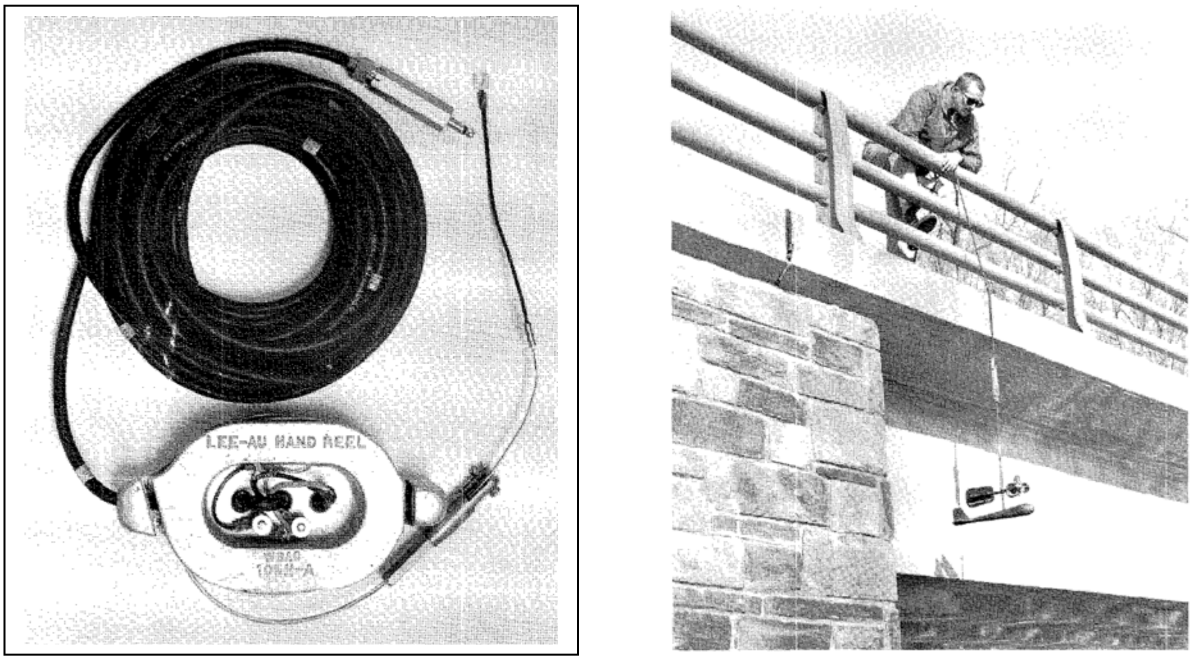


Figure 4. Cable suspension system: A) USGS handline, and B) example of handline, attached to flow meter and Columbus weight, in use from a bridge.

3.3.7 Recording flow measurements

At a minimum, the following information should be recorded on a flow measurement field form (see Appendix for a blank form):

- Station ID and location;
- Field personnel;
- Measurement date;
- Visual observations of flow conditions;
- At start, gage height reading (if available) and time (in military units);
- Total stream width (water's edge to water's edge);
- Distance from laser range-finder target to nearest water's edge;
- Preliminary velocity measurement and choice of instrumentation/method;
- For each partial section:
  - o Distance from partial section midpoint to the water's edge or to laser target,
  - o Water depth and flow velocity measurement(s) at the midpoint,

  - If necessary, angle between flow and perpendicular to tagline,
  - Unusual flow conditions (turbulence, back eddies, or flow blockages),
  - Distance measurements for the partial section endpoints (optional),
  - Calculated average flow velocity (from two-points) (optional),
  - Calculated flow discharge for partial section (optional);
- Cumulative discharge, from the first bank to each partial section (optional) and total discharge for the river cross-section;
- Distance from permanent marker to flow centroid (location of 50-percentile of cumulative discharge (optional);
- At finish, gage height reading (if available) and time (in military units), to check for rising or falling stage.

3.3.8 Calculating and reporting flow

Follow these steps when calculating total flow of the river cross-section:

1. Calculate flow at each partial section (Q_i, cfs or ft^3/sec) by multiplying the width (W_i, ft) by the depth (D_i, ft) and velocity (V_i, ft/s) measured at the midpoint, or $Q_i = W_i \times D_i \times V_i$.
2. For any partial section where the flow is not perpendicular to the cross-section or tagline, the flow must be adjusted by multiplying by the cosine of the angle between the flow direction and the perpendicular to the tagline.
3. When recording flow for each partial section, **do not** round flow values. Rounding each value on the worksheet could introduce an error in the final value. Only the final value is rounded.
4. **Do not** treat partial sections with negative flow values as zero. Negative values obtained from areas with back eddies should be subtracted from the total flow.
5. When flow is calculated for each partial section, add them together for the total flow, or $Q_w = (W_1 \times D_1 \times V_1) + (W_2 \times D_2 \times V_2) + ... + (W_n \times D_n \times V_n)$, for *n* sections.
6. In addition to total flow, calculate the cumulative discharge at each partial section in steps across the river cross-section, from one bank to the other bank. The 50-percentile location will be the flow centroid for water quality sampling.
7. Depending on the final value of total flow, round it to a reporting value based on the guidelines in Table 3.

Table 3. Reporting values for total flow (Qw), measured in cubic feet per second (cfs) (Rantz et al. 1982).

Measured value (cfs)	Reporting value (cfs)	Example
Qw < 0.01	< 0.01	0.003 reported as <0.01
0.01 < Qw < 0.1	Not rounded	0.07 reported as 0.07
0.1 < Qw < 10	Rounded to nearest 0.1	9.35 reported as 9.4
Qw > 10	Rounded to nearest 1	20.62 reported as 21

3.4 Discharge Rating Curves

After gathering several data points over the range of the stage-discharge relationship, plot the points of stage (measured in feet) versus discharge (measured in cubic feet per second) and draw a smooth curve through the points (see section 3.4.1, below). The more points, the more precise the rating curve is likely to be. There can be significant scatter around this curve, so a discharge value read from the curve is the most likely value and could be a little different from the measured value. Also, there can be significant errors in rating curves at high flow levels. Measurements of high flows are rare, and the widening shape at the top of river banks gives much larger discharges for small changes in stage height. Therefore at high flows, small errors in stage height measurement lead to much larger errors in discharge estimation.

A simple rating (discharge vs. stage only) may be a compound curve consisting of multiple segments for low, moderate, and high (bankfull) flow ranges; each segment is defined by its rating equation (section 3.4.2). More complex ratings (discharge vs. stage plus rate of change in stage, etc.) are not discussed here. Volume 2 of USGS Water Supply Paper 2175 (Rantz et al. 1982) discusses stage-discharge relations ranging from simple to complex and the various parameter variables (slope, velocity index) that should be considered when computing discharge rating curves under more complex situations. Kennedy (1984) provides complete details for calculating discharge ratings.

For increased precision, the rating curve should be developed from a minimum of 10 data points, covering a range from low to high flows. However, the rating curve may shift over time, and periodic measurements (2-3x/year) are necessary after the initial rating to either confirm the permanence of the rating or to follow changes/shifts in the rating (section 3.4.4). The rating curve should include measurements made at flow extremes (e.g., drought or flood conditions) to be most accurate.

3.4.1 Plotting gage height versus discharge

To plot discharge rating data, the independent variable (gage height) is traditionally plotted on the Y-axis, contrary to common graphing conventions. Therefore, the slope of the rating curve is the cotangent (b=dx/dy) rather than the usual tangent (b=dy/dx). The rating data should be plotted in rectangular coordinates to verify reasonable shape, but rating analysis is conducted using log-log graphs. On log-log plots, a straight line can be described by very few numbers or a simple equation. The rating curve should be limited to the range of measured stages.

3.4.2 Determining rating equations

If the initial plot of gage height (G) versus discharge (Q) is curved, then gage height values can be modified by a constant value (*e*, called scale offset) to achieve a straight-line plot of [log(G-*e*) vs. logQ] (see Figure 5). If G is adjusted before plotting, the log ordinate scale must be labeled "Gage height – (scale offset value) (feet)". The value of the scale offset *e* is usually the gage height at zero flow (GZF). The resulting plot does not need to be precisely straight, but a slight curve can be straightened by further adjustment of *e* rounded to 0.01 or 0.1 ft: concave upward curves should be rounded downward such that $e <$ GZF, and concave downward curves should be rounded upward such that $e >$ GZF. The hydrographer should avoid even slightly concave upward curvature in the lower part of the rating, as this causes scalloping (described later in this section). As stage increases to the upper part of the rating, changing the offset by larger values has negligible effect on the rating curvature. The equation of the straight line is

$$Q = P \cdot (G - e)^{b} \quad (1)$$

where Q = discharge
G = gage height
e = scale offset, or the constant value subtracted from G that results in a straight line plot of log(G-e) vs. logQ.
P = intercept, or value of Q when (G-e) = 1.0.
b = slope, or dx/dy.

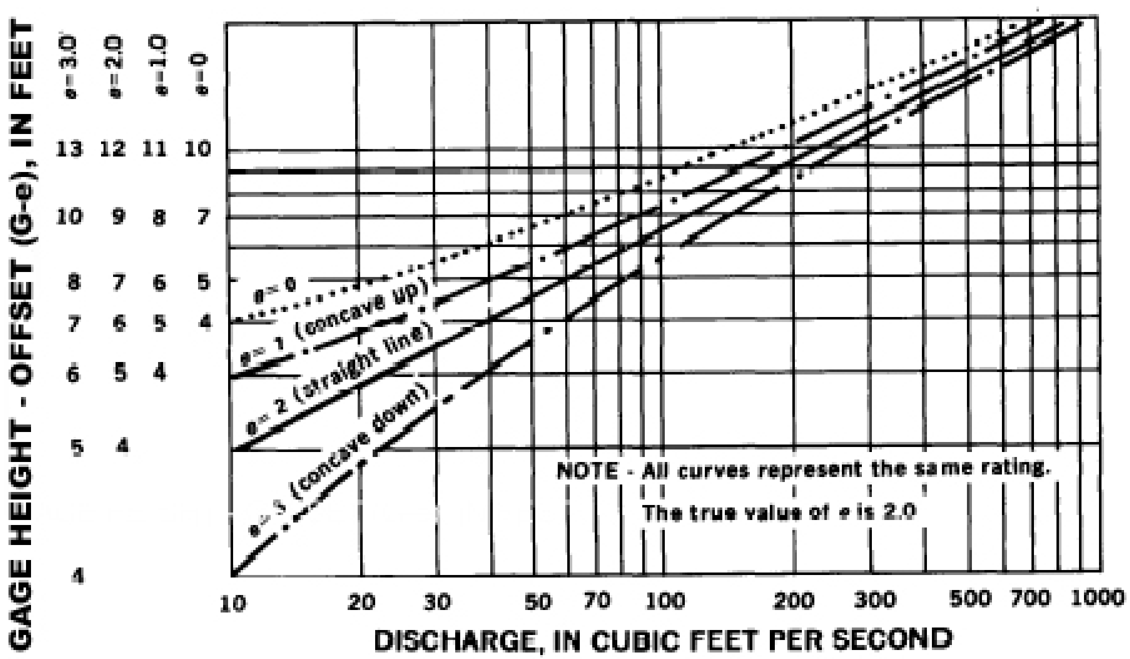


Figure 5. Rating curve shapes resulting from different gage-height scale offsets.

In addition to the trial-and-error method demonstrated in Figure 5, the value of e can be directly calculated. Using the logarithmic rating curve to be straightened, the coordinates for two points from the extremities of the curve are picked off of the axes (the points (G_1, Q_1) and (G_2, Q_2) in Figure 6). A value for Q_3 at the logarithmic midpoint is computed so that $Q_3 = +\sqrt{Q_1 \cdot Q_2}$. The corresponding value of G_3 is picked from the log ordinate scale. Solving for e using the three gage height values,

$$e = \frac{(G_1 \cdot G_2) - G_3^2}{G_1 + G_2 - 2G_3} \quad (2)$$

where e = scale offset, or the constant value subtracted from G that results in a straight line plot of log(G-e) vs. logQ,
G_1 = the gage height at one extreme,
G_2 = the gage height at the other extreme, and
G_3 = an intermediate gage height, then

the resulting offset curve [log(G-*e*) vs. logQ] will plot in a straight line (i.e., the dashed line in Figure 6).

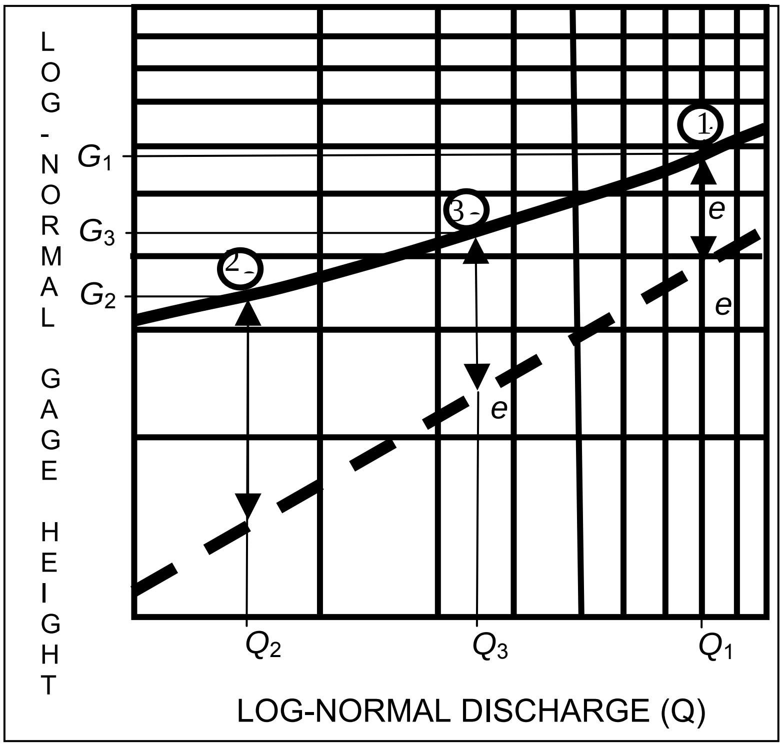


Figure 6. Direct calculation of scale offset (*e*) value.

A single rating plot whose scales cover the entire range of stage and discharge is preferable, and a single offset is chosen to suit the scale labels. However, separate rating plots for low- or high-water conditions may be necessary, each with its own optimum value of *e*. This especially may be the case when the initial rating plot contains both sharply curved upward and downward segments that may be straightened by applying different offsets. However, a high-water portion of the plot that is concave downward will remain concave downward regardless of the value of offset that is used. Kennedy (1983) gives additional guidelines for making adjustments to the rating curve:

- If the low-water measurements scatter due to varying amounts of aqueous growth or debris on the flow control, draw the curve to the right of the scatter and close to the measurements made while the control was clean.
- If measurement scatter reflects scour and fill at an unstable flow control, draw the curve near the middle of the scatter and close to measurements whose GZF is close to the scale offset used (i.e., $e \approx$ GZF).
- If the lower part of the curve is concave upward, use a larger scale offset to straighten the curve or make it slightly concave downward, to avoiding scalloping (described below).

Rating curves, however, are rarely sufficiently defined by a single straight-line segment. This is particularly true if more than one flow control is effective at different discharge levels. Typically, a logarithmic rating curve is approximated by a series of straight-line segments, usually less than ten segments, but as many as thirty segments (Figure 7). The maximum difference between the approximation line and the original curve (not shown in Figure 7) should be within 1 percent, but may be more for the lowest or sharply curved portions of the rating. Concave upward portions of the rating curve (see log(G - *e*) = 4 in Figure 7) can be susceptible to a condition called “scalloping”. When a very long straight-line segment is used to approximate a concave upward portion in log format, it forms a slightly scalloped curve, rather than a smooth curve, when transferred to rectangular format. This harmless condition can be avoided by using several shorter segments to approximate the concave upward portion.

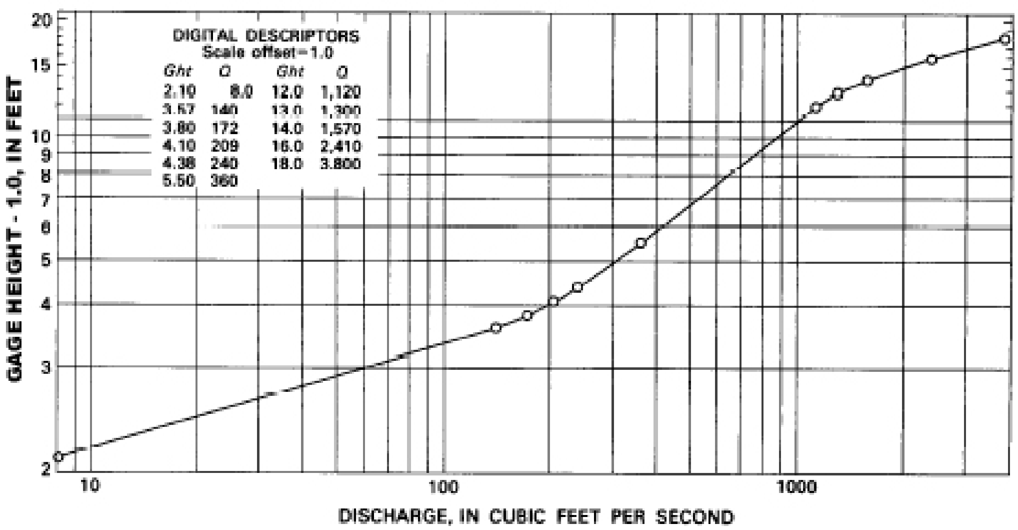


Figure 7. Typical logarithmic rating curve defined by several segments.

3.4.3 QA/QC – Assuring and checking data quality

3.4.3.1 Elevation of gage datum

A gage-supporting structure may settle, causing the gage to read too high; or the structure may be lifted by frozen ground, causing the gage to read too low. To document any of these fluctuations, survey each gage station periodically, with standard surveying methods and equipment, between the gage and a reference mark on stable ground, preferably a National Geodetic Vertical Datum (NGVD) benchmark. Elevations should be surveyed to the nearest hundredth of a foot. Where surveyed elevations are impractical, determine the approximate altitude of the gage from a map or with an aneroid barometer. When shifting occurs, gages can be repositioned or their readings can be adjusted by applying corrections based on the shift in elevations. If the shift in elevation occurred suddenly, the correction can be applied at a single time step in the discharge record. However, if there is evidence (e.g., field observations) that the shift occurred gradually, then the correction should be spread over the relevant time period. When flow controls are very precise, such as a permanent weir, corrections as small as 0.01 ft may be applied. However, in general, corrections less than 0.02 ft are disregarded (Kennedy 1983).

3.4.3.2 Checking discharge measurements

Discharge measurements and calculations require some checking before the results can be used to develop the discharge rating. When using a flow calculator (e.g., AquaCalc) at a river cross-section, verify the total discharge reading upon returning to the office, by manually entering the distance, depth, and flow for the partial sections into an electronic spreadsheet containing the appropriate formulae. After the manual calculation of discharge, check for: 1) correct addition of the partial widths and partial discharges, and 2) possible error wherever the partial discharge changes substantially without a corresponding change in width, depth, or velocity. Flag any measurement that includes a partial section containing more than 10% of the total flow. Errors can also be identified when several stage-discharge points are plotted on a rating curve. Check the calculation of every discharge measurement on a rating curve that: 1) varies by more than 10% from the rating curve defined by connecting the points between previous and subsequent measurements, 2) is the only measurement defining a substantial portion of the rating curve, or 3) was made during flood conditions (Kennedy 1983).

3.4.4 Shift adjustments to the rating equation

Once an initial rating curve has been developed, subsequent discharge readings may not agree with previous readings, sometimes for only certain ranges of discharge, or sometimes for the entire range of rating discharges. The downstream flow control of a river reach (a rock riffle, overflow dam, or natural constriction, etc.) is rarely permanent and unchanging. A sand bar, gravel bed, or drift pile that compromises the flow control may be scoured during flood periods, debris may be piled on rock riffles, and aquatic vegetation, silt, and drift may accumulate in channels or behind dams. As a result, the plotting position of discharge measurements on the rating curve will shift, and theoretically, a new rating curve should be developed for the gaging station. However, when the changes are small or temporary, a correction, called a shift adjustment, is applied to subsequent stage readings until another discharge measurement can be taken.

Shift adjustments may vary with either stage or time. If a stable low-flow control is scoured out or filled by sediment, debris, leaves or aquatic vegetation, then the corresponding rating shift is greatest at low water and normally tapers to zero at some higher stage; this requires a ‘stage-variable shift’. However, if the channel bed is alluvial and constantly shifting due to sediment transport, then the shift variation with stage is negligible relative to its variation with time; this requires a ‘time-variable shift’. Note that during the site selection process, selection of locations with alluvial beds are generally avoided. However, if selection of an alluvial-bedded site is unavoidable, one should expect to apply time-variable shifts.

3.4.4.1 Whether to apply shift adjustments

The total error range of most discharge measurements is 5%, less for the two-point measurement method than for the one-point method (Kennedy 1983). For this reason, shift adjustments are rarely applied to measurements that plot within 5% of the rating curve. Therefore, one should compute the percent difference (PD), to the nearest 0.1%, for any new measurements:

$$PD = \left(\frac{measured - rating}{rating} \right) \times 100 \tag{3}$$

where *measured* = the new discharge measurement and *rating* = the rating curve discharge value corresponding to the measured gage height. If a series of measurements during the year are all within 5% and plot on both sides of the rating curve, then a shift adjustment is not necessary. On the other hand, if a series of measurements are all within 5% but plot only on one side of the rating curve, then one should consider applying a shift adjustment to all of the measurements. Any new measurements that plot more than 10% away from the rating curve require a shift adjustment.

3.4.4.2 How to apply shift adjustments

To calculate a shift adjustment, compute from the rating curve (to the nearest 0.01 ft) the gage height that corresponds to the new discharge measurement. The shift adjustment is the difference between the computed gage height and the measured gage height. The sign of the shift is positive if the measured gage is less than the computed gage, or it plots below and to the right of the rating curve. The sign of the shift is negative if the measured gage is greater than the computed gage, or it plots above and to the left of the rating curve.

Rating curves will be used for this monitoring protocol when a nearby continuous gaging record is not available. Ideally, discharge will be measured every third or fourth visit, although more frequently if shifting occurs. The shift adjustments that apply during the periods between discharge measurements must be interpolated by an appropriate method before discharge can be calculated from stage readings. Small shifts that occur gradually between discharge measurements may be distributed satisfactorily by simple interpolation.

3.4.4.3 QA/QC

It is easy to err in the sign of the shift adjustment and to apply the shift in the wrong direction. One method to check the sign of the shift is add the shift adjustment to the measured gage height and use the adjusted gage height to compute its corresponding discharge from the rating curve. If the adjusted discharge is equal to the measured discharge, then the shift adjustment has been applied correctly.

Thus, if the percent differences are reasonably balanced (as many positive as negative) and the shift adjustments are satisfactory, then the rating curve may be considered final and ready to use.

3.4.5 Summary of rating curve method

The following is a summary of the rating curve method as applied within spreadsheet software (MS-Excel):

1. Tabulate field-measured flow gaging data for stage (H_w) and discharge (Q_w).
2. For those stations where the local datum is above stream level (i.e., measuring distance from datum down to water surface below), convert from a negative vertical distance to a positive vertical distance by subtracting all values from a constant (e.g., 20 ft - H_w).
3. Calculate e (see equation 2) using the minimum, maximum, and an intermediate value of the adjusted H_w.
4. For each H_w, tabulate a range of 5 to 7 (H_w - e) that encompasses and includes the calculated e.
5. Plot (H_w - e) vs Q_w on log-log paper and fit linear (y = mx+b) trendlines to each plotline.

6. Adjust the tabulated values of e, until one of the (H_w - e)-vs-Q_w plotlines fits a straight line on the log-log paper.
7. Record the best fit e and its linear best-fit equation for (H_w - e) = mQ_w + b.
8. For each measured H_w, calculate discharge based on the best-fit equation (Q_w = ((H_w - e - b)/m) and determine the percent-difference (PD, see equation 3) between the calculated and measured values.
9. Flag the calculated discharges where PD > ±5%.
10. For each flagged reading, apply a shift adjustment to the Hw (negative shifts for positive PDs, positive shifts for negative PDs) to bring all PDs within ±5%.
11. Tabulate the measured Q_w and adjusted H_w values, and go back to step 3, repeating steps 3-10 until step 8 results in all PDs < ±5%.

4 Results

4.1 SACN Methods Overview

During flow gaging events, horizontal distances were measured with a laser range finder or tape measure, and vertical distances were measured with wading rod or tape measure. The sites were accessed by bridge, motor boat, canoe, or wading, depending on the flow levels at the time of measurement. Cable suspension of the flow meter from bridge or boat was used for higher flows, and rod suspension of the flow meter with boat or wading was used for lower flows. Flow velocities were measured with a Type AA meter for high and moderate flows, and with a pygmy meter for the low flows encountered later in the summer. A summary of the methods used for various flow ranges at each site are summarized in each section 4.1, 4.2, and 4.3 below. Information on measurement methods and the measurements themselves were all recorded on field forms (see templates in Appendix) by field personnel. Field forms were photocopied for archive back-ups upon return to the office. Spreadsheets of the data collected during flow gaging events, including flow calculations and comparisons with flow at nearby USGS gages, and graphs of flow cross-sections are included in the Appendix. For each flow monitoring site, the three axes (left, top, and right) were held at a constant scale, to enable comparison of flow depths, stream widths, and flow velocities, respectively, across flow monitoring events. All of the graphs were plotted consistently from the upstream perspective, that is, the left bank is on the left side of the graph and the right bank is on the right side of the graph.

4.2 St. Croix River at Norway Point

The St. Croix River at Norway Point is marked by a public boat landing located on the downstream portion of a meander bend. Norway Point was the first flow monitoring site visited on 5/16/2006 for a test gaging event, and throughout the field season was accessed using boat or canoe via the boat landing. A 100-meter wide cross-section of the river was selected just upstream of the meander, on the downstream end of a long straight reach, where the flow should be more laminar than turbulent and relatively stable (see Figure 8). The right bank side (Figure 9A) of the cross-section is approximately at 45º 55′ 31″ and 92º 38′ 21″. The left bank side (Figure 9B) of the cross-section is approximately at 45º 55′ 32″ and 92º 38′ 17″. A laser range finder was used to measure distances from the right bank to the left bank.

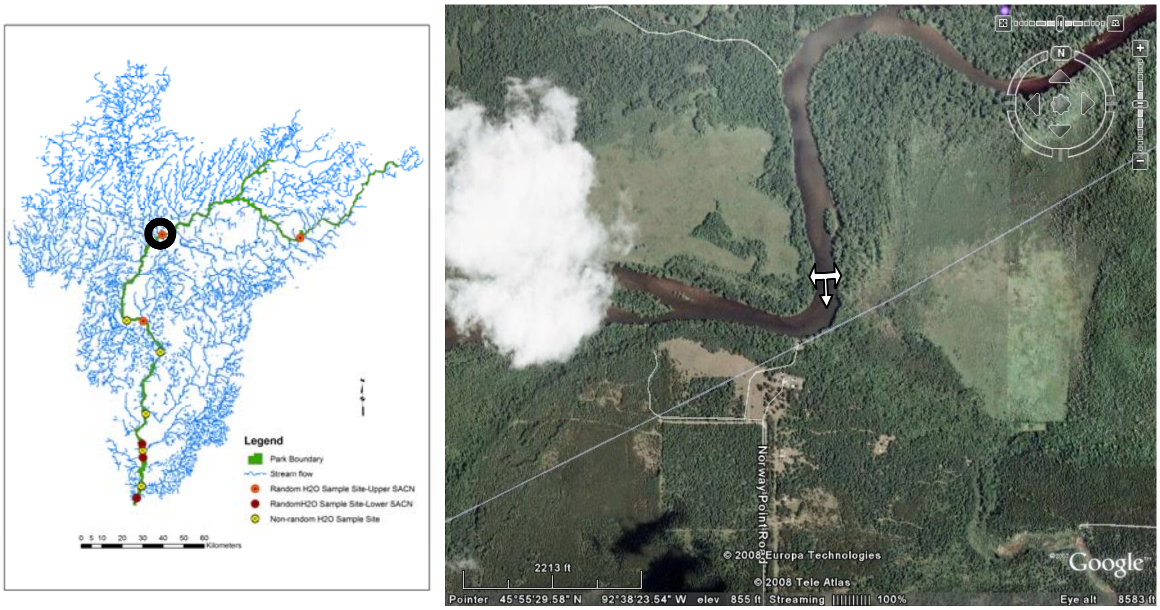


Figure 8. Monitoring site located on the St. Croix River at Norway Point. A) Index map indicating site's location within the St. Croix basin. B) Satellite image of site, where the crossbar of the white symbol indicates location and orientation of river cross-section used for flow monitoring, and the thin arrow indicates direction of streanflow.

Figure 9. St. Croix River at Norway Point flow monitoring site photos. A) View of left bank of river cross-section used for flow monitoring, from slightly downstream and showing downed tree used as a temporary reference benchmark. B) View of right bank of river cross-section, from the left bank.

An error occurred twice as part of the learning curve in using the AquaCalc5000. The instrument that was used for this project belonged to the St. Croix Watershed Research Station and was being used monthly for another project at the station. Unbeknownst to Magdalene, the other project was using the AquaCalc5000 with a pygmy meter, which uses a different setting on the AquaCalc5000 to account for the different flow meter rating equations, which equate spins of the meter to flow rate (i.e., not the same thing as stage-discharge rating equations). The error was identified for two flow gaging events at Norway Point (5/26/2006 and 6/30/2006) when the calculated flows were compared with flows measured at nearby USGS gages (see Appendix). Magdalene was able to determine the flow meter rating equations for the pygmy and Type AA meters used by the AquaCalc5000, and correcting the two errors was accomplished by using one equation to solve for the other equation. These corrections are reported in Table 4. Generally, flows at Norway Point were 1.3 to 1.6 times greater than flows at Danbury, and flow at Norway Point accounted for 38-58% of flow at St. Croix Falls.

Table 4. Summary of flow measurement methods on the St. Croix River at Norway Point and flow comparisons with nearby USGS gages.

	Methods			Flow Comparisons (cfs)		
Date	Meter	Suspension	Access	Danbury[1]	Norway Pt.	St.CroixFalls[2]
5/26/2006	AA	Cable	Motor boat	1040[3]	1650	4370[3]
6/14/2006	AA	Cable	Canoe+motor	686[3]	1068	2170[3]
6/30/2006	AA	Cable	Canoe	621[3]	793	1760[3]
7/12/2006	AA	Cable	Canoe	551[3]	687	1320[3]
7/27/2006	AA	Cable	Canoe	551[3]	735	1280[3]

[1]USGS Gage # 05333500 St. Croix River near Danbury
[2]USGS Gage # 05340500 St. Croix River at St. Croix Falls
[3]Mean daily value for that date

An examination of the Norway Point flow cross-sections in the Appendix reveal a consistently proportional relationship between flow depth and flow velocity: deeper flows were faster than shallow flows. When flow depth is plotted on the left-axis from top-down, and flow velocity is plotted on the right-axis from bottom-up, this relationship results in roughly inverse or mirrored images (see Appendix).

Initially, stage measurements at this location were made relative to a temporary reference benchmark nailed into a tree that over hangs the left bank of the flow gaging cross-section (Figure 9A). During the first field days, what looked like a gage or stage recorder house was observed just east of the boat landing at Norway Point, but NPS staff questioned by Magdalene were unfamiliar with its ownership or status. Throughout the field season, stage measurements continued to be measured at the temporary benchmark, while more information was gathered about the stage recorder house, ultimately revealing that the structure housed an active stage recorder for the U.S. Army Corps of Engineers (USACE). Therefore, this project used the USACE stage readings that were recorded during the hour that flow measurements were conducted at Norway Point, for the development of the stage-discharge rating equation.

None of the flow gaging events at Norway Point met the USGS recommendation that all of the partial sections contain less than 10%, or preferably less than 5%, of the total flow volume. While navigating the boat, what seemed like a small lateral distance was actually a large distance, and it was difficult to get small enough partial widths to achieve the 10% criteria. Continued field work at this location should give attention to this issue. However, very little adjustment to stage values was required during the development of the stage-discharge rating equation (see 4.2.1 below), possibly indicating the measured discharge values were not invalid.

4.2.1 Stage-discharge rating development for the St. Croix River at Norway Point

The rating equation development process followed the process summarized in section 3.4.5, where steps 3-10 were repeated until the best-fit criteria were met. As mentioned above, very few adjustments had to be made to achieve less than 5% difference between the measured discharges and those calculated from the best-fit stage-discharge rating curve for the St. Croix River at Norway Point (Table 5). The stage-discharge rating data for the final step are shown in Table 6, including a range of values of e, and Figure 10 shows the final stage-discharge rating curves from 2006 data collected from the St. Croix River at Norway Point. The final rating curve suggested by the data is:

$$Qw = \frac{(Hw - e) + 0.0069}{0.0012}$$

$$Qw = \frac{Hw - 1.94}{0.0012} \quad (4)$$

$$Qw = \frac{Hw}{0.0012} - 1617$$

where the offset (e) is 2.63.

Table 5. Summary of St. Croix River at Norway Point rating equation development process, showing progressive adjustment of individual stage levels to minimize the percent difference (%-Diff) between calculated and measured discharges. The color green highlights the values that fall within ± 5 %-Diff, blue highlights values that are too low, and red highlights values that are too high.

Date	Measured Discharge (cfs)	USACE Stage (ft)	Gage Ht (ft) = Stage
5/26/2006	1650	4.55	4.55
6/14/2006	1068	3.88	3.88
6/30/2006	793	3.69	3.69
7/12/2006	687	3.46	3.46
7/27/2006	735	3.29	3.29
Best fit equation: Hw vs Qw			y = 0.0012x + 2.6033
Pearson's correlation coefficient			R^2 = 0.9396
Calculation of e			-1.21
Best fit e			2.6
Best fit equation: (Hw-e) vs Qw			y = 0.0012x + 0.0033
Pearson's correlation coefficient			R^2 = 0.9396
Equation for calculating Qw			x = (y-0.0033)/0.0012
Calculated Discharge (cfs)	**%-Diff**	**Adj (ft)**	**Adj Gage (ft) = Stage + adj**
1622	-2%	0	4.55
1064	0%	0	3.88
906	12%	-0.13	3.59
714	4%	0	3.46
572	-28%	0.2	3.49
Calculation of e			2.87
Best fit e			2.65
Best fit equation: (Hw-e) vs Qw			y = 0.0011x + 0.0063
Pearson's correlation coefficient			R^2 = 0.9996
Equation for calculating Qw			x = (y-0.0063)/0.0011
Calculated Discharge (cfs)	**%-Diff**	**Adj (ft)**	**Adj Gage (ft) = Stage + adj**
1722	4.2%	0	4.55
1112	4.0%	0	3.88
822	3.5%	-0.13	3.56
731	6.0%	-0.05	3.41
758	3.0%	0.2	3.49
Calculation of e			2.43
Best fit e			2.63
Best fit equation: (Hw-e) vs Qw			y = 0.0012x - 0.0069
Pearson's correlation coefficient			R^2 = 0.9995
Equation for calculating Qw			x = (y+0.0069)/0.0012
Calculated Discharge (cfs)	**%-Diff**		
1606	-2.7%		
1047	-2.0%		
781	-1.6%		
656	-4.8%		
722	-1.7%		

Table 6. Final stage-discharge rating data for the St. Croix River at Norway Point. The bold data under "e=2.63" are those plotting a straight line in Figure 10.

Date	Discharge (cfs)	USACE Stage (ft)	Adj (ft)	Gage ht (ft)	e=3	e=2.63	e=2	e=1	e=0	e=-1
5/26/2006	1650	4.55	0	4.55	1.55	**1.92**	2.55	3.55	4.55	5.55
6/14/2006	1068	3.88	0	3.88	0.88	**1.25**	1.88	2.88	3.88	4.88
6/30/2006	793	3.69	-0.13	3.56	0.56	**0.93**	1.56	2.56	3.56	4.56
7/12/2006	687	3.46	-0.05	3.41	0.41	**0.78**	1.41	2.41	3.41	4.41
7/27/2006	735	3.29	0.2	3.49	0.49	**0.86**	1.49	2.49	3.49	4.49

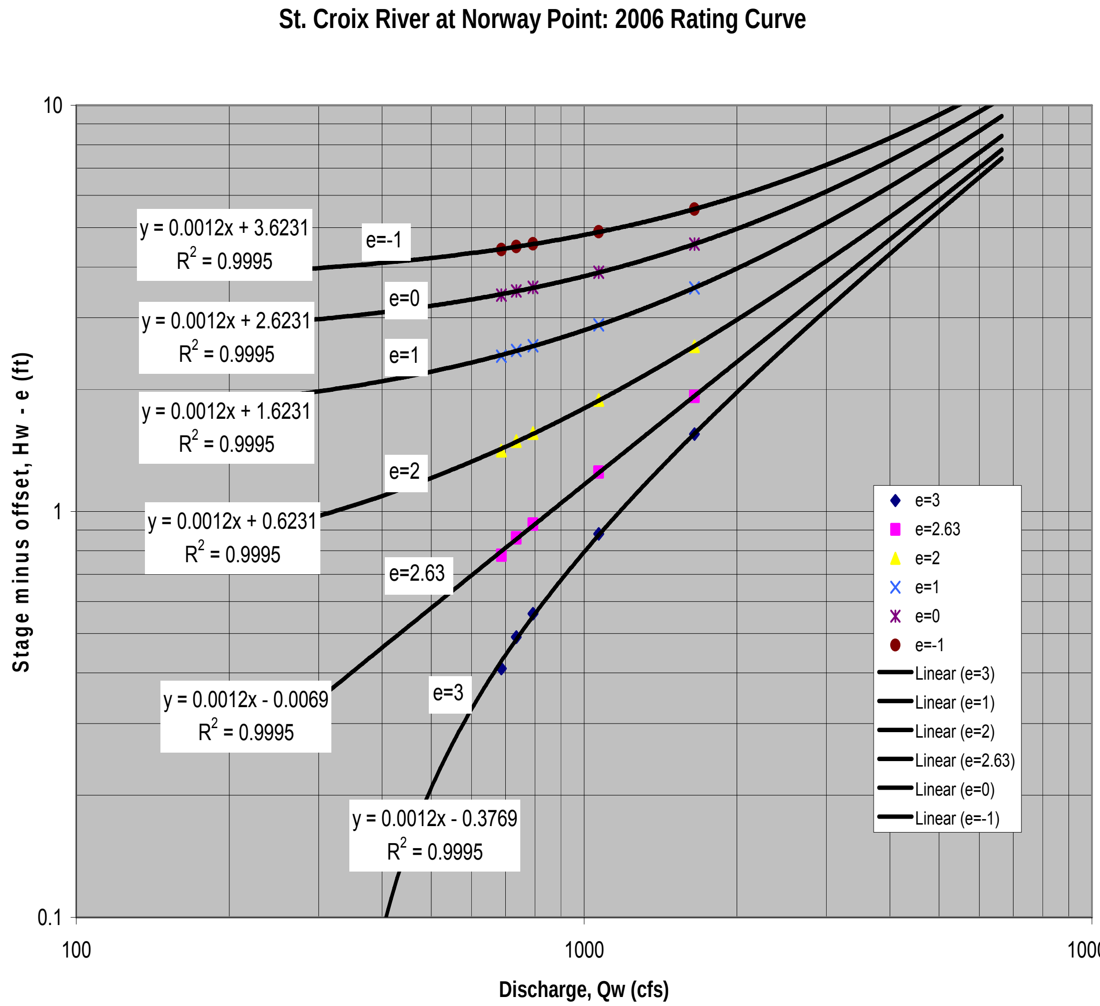


Figure 10. Final stage-discharge rating curves for the St. Croix River at Norway Point from 2006 data.

4.3 Snake River at Chengwatana State Forest Campground

The Snake River flow monitoring site is located upstream of a rapids next to the Chengwatana campground (Figure 11). To reach the river from the campground area, take the first right down a row of campsites, park the vehicle, and walk down the path to the river, where wide log steps lead down to the river. To avoid paddling upstream through the rapids, portage along the streamside path (turn left onto the path before descending the boat landing steps) for a few hundred feet, and enter the stream at the right bank of the flow monitoring cross-section. The right bank side of the cross-section is approximately at 45º 49′ 24″ and 92º 46′ 43″. The left bank side of the cross-section is approximately at 45º 49′ 24″ and 92º 46′ 41″.

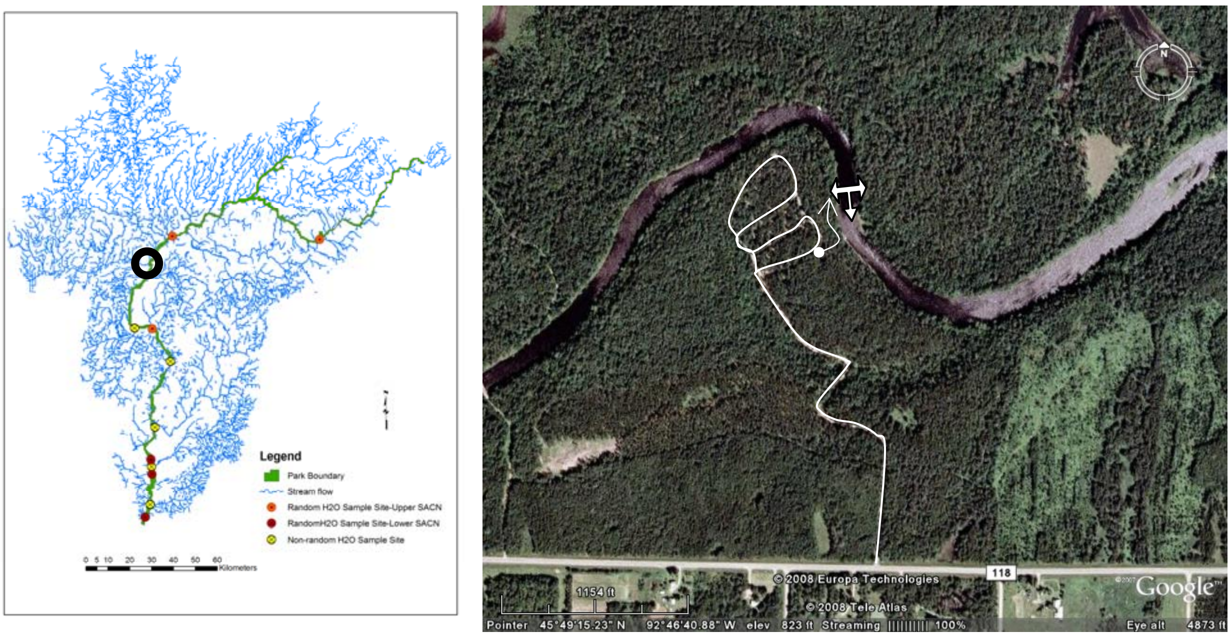


Figure 11. Monitoring site located on the Snake River at the Chengwatana State Forest Campground. A) Index map indicating site's location within the St. Croix basin. B) Satellite image of site, where the crossbar of the white symbol indicates location and orientation of river cross-section used for flow monitoring, and the thin arrow indicates the direction of streamflow.

One advantage of this location, besides relatively easy access, is that the left bank is confined by bedrock outcrop, which is considered by the USGS to be a favorable characteristic of a stable flow monitoring site. A vertical face on the bedrock outcrop (Figure 12A) served well during the 2006 field season as a target for a laser range finder. Due to the limitations of the laser range finder, the distances within fifteen yards of the rock face had to be measured by hand, using tape measure. When switching from laser to tape measure, care must be taken to account for the distance between the outcrop face and the edge of water.

The bedrock outcrop also provided a stable temporary benchmark for measurement of river stage (Figure 12B). Immediately north of the vertical rock face was a bedrock overhang that was approximately horizontal. To standardize the measurement and account for the slight curvature in the under face of the overhang (Figure 12C), the metal wading rod was inserted under the overhang and leveled with a small bubble-level. Then the distance of the stream surface below the rod was measured with a weighted tape measure.

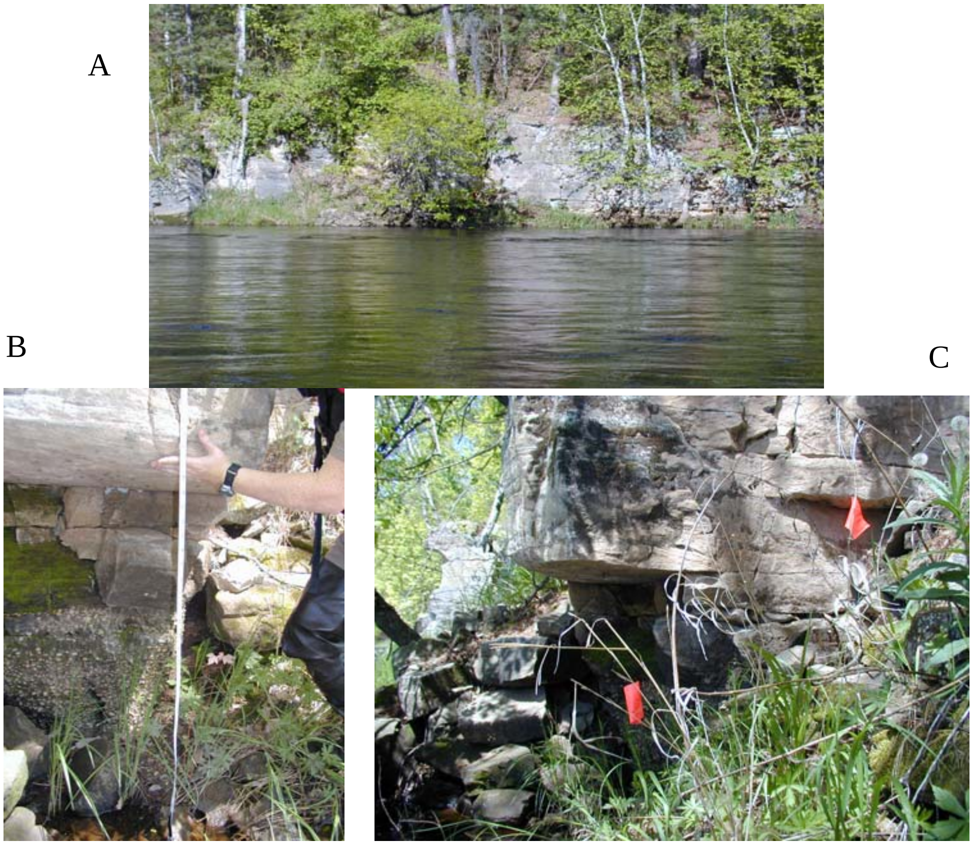


Figure 12. Snake River at the Chengwatana State Forest Campground (upstream from the steps leading down to the river) flow monitoring site photos. A) View along river cross-section from the right bank, looking at the left bank. Vertical bedrock face that serves well as laser range finder target is center-right, and bedrock overhang benchmark is behind stream-side shrub at center-left. B) Close-up view of measurement of stage, or the distance of the stream surface below the bedrock overhang benchmark, using weighted tape measure. C) Side-view of bedrock overhang.

It was extremely rocky (1- to 3-ft diameter boulders) at this location, causing turbulence and greater variability in the range of flow observed at any given vertical. It was a challenge to select consistent spacing between verticals and avoid taking a stagnant flow measurement in a ‘shadow’ behind a large boulder. This phenomenon can be seen in the flow cross-sections for the Snake River site in the Appendix (see graph for 5/31/2006): flow rates are not as consistently related to flow depth, as observed at the other two sites. Flow measurements at this site were more successful in meeting the USGS recommendation that each partial section contain no more than 10% of the total flow volume, three of six flow monitoring events met this criteria.

Flow measurement methods are summarized in Table 7. Occasionally, flow depths were shallow enough to require one-point measurements at 60%-depth, rather than two-point measurements at 20%- and 80%-depths (see tables and graphs in Appendix). Generally, suspending a flow meter from the rod and measuring by wading or from a canoe was sufficient; any higher flow rates than those measured would require cable suspension and a 12V trolling motor with more than 30-ft of thrust for the canoe, or launching a larger boat from the landing below the Crosslake dam and motoring downstream to the monitoring site. Flow rates were hard to manage on 5/19/2006, causing the canoe to wash downstream once; lateral position within the flow cross-section had to be re-established, resulting in a large gap in readings within the central flow of the river (see Appendix graph for 5/1/9/2006). This is the likely source of the measurement error observed for this date, in comparison to the flows gaged 10 miles upstream at USGS #05338500 (Table 7). Generally, Snake River flows at Chengwatana State Forest camp averaged 6% higher than those at Crosslake (not including 5/19/2006).

Table 7. Summary of flow measurement methods on the Snake River at Chengwatana State Forest Campground and flow comparisons with nearby USGS gage.

	Methods			Flow Comparisons (cfs)	
Date	Meter	Suspension	Access	Crosslake[1]	CSFcamp
5/19/2006	AA	Rod	Canoe+motor	1660[2]	711
5/31/2006	Pygmy	Rod	Wading & canoe	518[2]	580
6/28/2006	Pygmy	Rod	Wading	162[2]	179
7/6/2006	Pygmy	Rod	Wading	107[2]	109
7/26/2006	Pygmy	Rod	Wading	91[2]	104
8/25/2006	AA	Rod	Wading	121[2]	114

[1]USGS Gage # 05338500 Snake River at Crosslake
[2]daily value for that date

4.3.1 Stage-discharge rating development for the Snake River at Chengwatana State Forest

The rating equation development process (Table 8) followed the process summarized in section 3.4.5, where the distance below the overhang was converted to a distance above an artificial datum and steps 3-10 were repeated until the best-fit criteria were met. In the end, all stage measurements from Snake River received adjustments (mostly negative) to achieve within 5% difference between the measured discharges and the discharges calculated from the rating equation. The stage-discharge rating data for the final step are shown in Table 9, including a range of values of e, and Figure 13 shows the final stage-discharge rating curves from 2006 data collected from the Snake River at Chengwatana State Forest Campground. The final rating curve suggested by the data is:

$$Qw = \frac{(Hw - e) - 0.0027}{0.0027}$$

$$Qw = \frac{Hw - 4.3127}{0.0027} \tag{5}$$

$$Qw = \frac{Hw}{0.0027} - 1597$$

where the offset (e) is 4.31.

Table 8. Summary of Snake River at Chengwatana State Forest Campground rating equation development process, showing progressive adjustment of individual stage levels to minimize the percent difference (%-Diff) between calculated and measured discharges. The color green highlights the values that fall within ± 5 %-Diff, blue highlights values that are too low, and red highlights values that are too high.

Date	Measured Discharge (cfs)	Stage (ft below overhang)	Gage height (ft) = 10ft - stage
5/19/2006	711	3	7
5/31/2006	580	4.2	5.8
6/28/2006	179	4.5	5.5
7/6/2006	109	5.1	4.9
7/26/2006	104	5.29	4.71
8/25/2006	121	4.5	5.5
Best fit equation: Hw vs Qw			y = 0.0026x + 4.778
Pearson's correlation coefficient			R^2 = 0.7733
Calculation of e			3.83
Best fit e			4.8
Best fit equation: (Hw-e) vs Qw			y = 0.0026x - 0.022
Pearson's correlation coefficient			R^2 = 0.7733
Equation for calculating Qw			x = (y+0.022)/0.0026
Calculated Discharge (cfs)	**%-Diff**	**Adj (ft)**	**Adj Gage (ft) = 10ft - stage + adj**
1028	31%	-0.75	6.25
566	-2%	0	5.8
451	60%	-0.7	4.8
220	50%	-0.3	4.6
147	29%	-0.1	4.61
451	73%	-0.85	4.65
Calculation of e			4.57
Best fit e			4.32
Best fit equation: (Hw-e) vs Qw			y = 0.0026x + 0.0021
Pearson's correlation coefficient			R^2 = 0.9978
Equation for calculating Qw			x = (y-0.0021)/0.0026
Calculated Discharge (cfs)	**%-Diff**	**Adj (ft)**	**Adj Gage (ft) = 10ft - stage + adj**
742	4.1%	-0.75	6.25
568	-2.0%	0	5.8
184	2.6%	-0.7	4.8
107	-2.0%	-0.3	4.6
111	6.1%	-0.11	4.6
126	4.1%	-0.85	4.65
Calculation of e			4.57
Best fit e			4.32
Best fit equation: (Hw-e) vs Qw			y = 0.0027x - 0.0012
Pearson's correlation coefficient			R^2 = 0.9979
Equation for calculating Qw			x = (y+0.0012)/0.0027

Table 8 (cont). Summary of Snake River at Chengwatana State Forest Campground rating equation development process, showing progressive adjustment of individual stage levels to minimize the percent difference (%-Diff) between calculated and measured discharges. The color green highlights the values that fall within ± 5 %-Diff, blue highlights values that are too low, and red highlights values that are too high.

Calculated Discharge (cfs)	%-Diff	Adj (ft)	Adj Gage (ft) = 10ft - stage + adj
715	0.6%	-0.75	6.25
549	-5.7%	0.1	5.9
178	-0.4%	-0.7	4.8
104	-4.7%	-0.3	4.6
104	0.1%	-0.11	4.6
123	1.4%	-0.85	4.65
Calculation of e			4.57
Best fit e			4.31
Best fit equation: (Hw-e) vs Qw			y = 0.0027x + 0.0027
Pearson's correlation coefficient			R^2 = 0.9999
Equation for calculating Qw			x = (y-0.0027)/0.0027
Calculated Discharge (cfs)	%-Diff		
718	0.9%		
588	1.3%		
180	0.8%		
106	-2.4%		
106	2.3%		
125	3.1%		

Table 9. Final stage-discharge rating data for the Snake River at Chengwatana Campground. The bold data under "e=4.31" are those plotting a straight line in Figure 13.

Date	Stage (ft below overhang)	Adj (ft)	Gage height (ft) 10ft-stage	Discharge (cfs)	e=5	e=4.6	e=4.31	e=4	e=2
5/19/2006	3	-0.75	6.25	711	1.25	1.65	**1.94**	2.25	4.25
5/31/2006	4.2	0.1	5.9	580	0.9	1.3	**1.59**	1.9	3.9
6/28/2006	4.5	-0.7	4.8	179	-0.2	0.2	**0.49**	0.8	2.8
7/6/2006	5.1	-0.3	4.6	109	-0.4	0	**0.29**	0.6	2.6
7/26/2006	5.29	-0.11	4.6	104	-0.4	0	**0.29**	0.6	2.6
8/25/2006	4.5	-0.85	4.65	121	-0.35	0.05	**0.34**	0.65	2.65

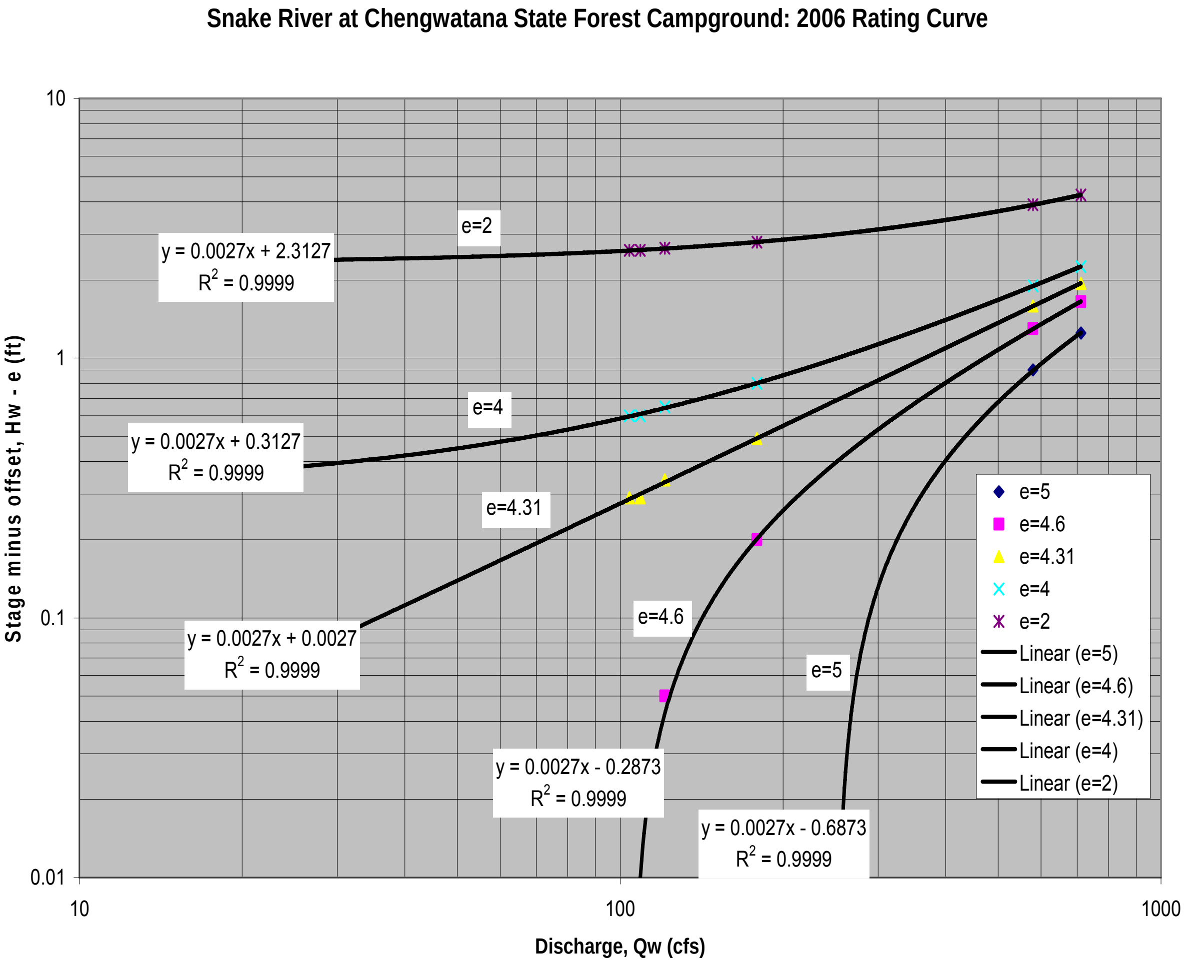


Figure 13. Final stage-discharge rating curves for the Snake River at Chengwatana Campground from 2006 data.

4.4 Namekagon River at Earl

The Namekagon River at Earl monitoring site is located in Earl, Wisconsin where the North Road bridge crosses over the Namekagon (at approximately 45º 54′ 56″ and 91º 45′ 50″; Figure 14). The advantage of this location is that the bridge deck provides a convenient platform from which to work (Figure 15), eliminating the need to add boating gear to the field workday. In addition, the boulder bank materials installed to protect the bridge from bank erosion provide a stable cross-section for taking consistent measurements. However, care should be taken to park the field vehicle in the shoulder on the north side of the southbound lane, with protective safety cones to alert southbound vehicles of the presence of field personnel.

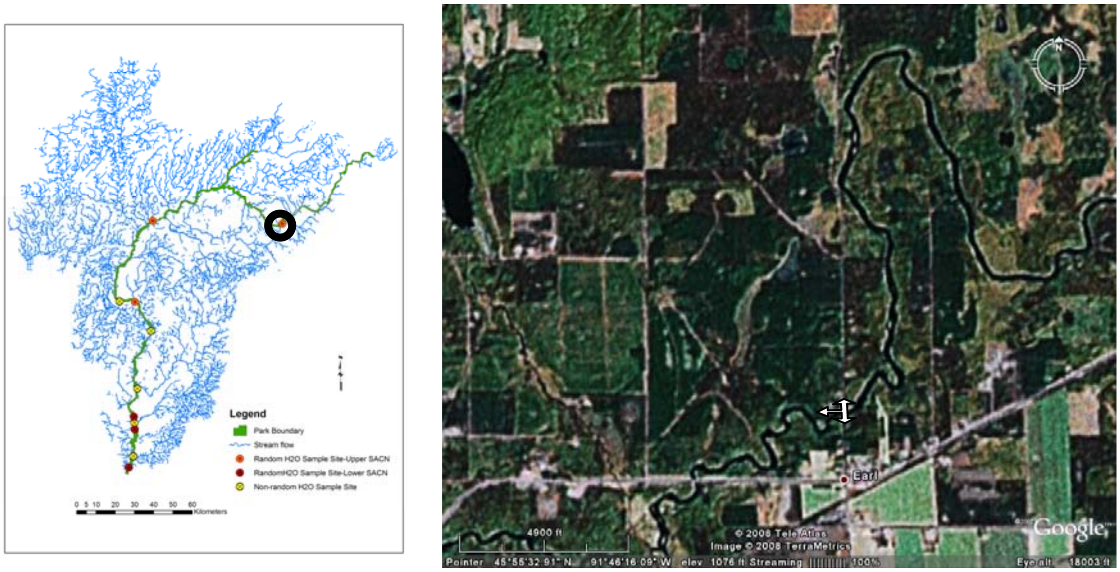


Figure 14. Monitoring site located on the Namekagon River at Earl. A) Index map indicating site's location within the St. Croix basin. B) Satellite image of site in relation to the crossroads of Hwys 53 and 63 at Trego. The crossbar of the white symbol indicates location and orientation of river cross-section used for flow monitoring, and the thin arrow indicates the direction of streamflow.

Flow measurement methods are summarized in Table 10. Generally, we followed the methods for measuring flow with a cable suspension system and a 15-lb weight, described in section 3.3.6. If flow at this location is less than two feet deep, using the wading rod should be considered, since using the wading rod might be more precise than taking measurements from the bridge deck. However, when using the wading rod, care should be taken to take as many flow measurements as the number used for cable suspension, so as to meet USGS recommendations that each partial section contain no more than 10% of the total flow volume (see spreadsheets for 7/5/2006 and 7/10/2006 in Appendix). On average, flows at Earl were 2.6 (range 1.2-4.4) times greater than flows at Leonards, and flow at Earl accounted for 27% (range 13-56) of flow at Danbury.

Figure 15. Namekagon River at Earl flow monitoring site photos. A) View along river cross-section from right bank, looking at the left bank (i.e., facing south on North Road). B) Close-up view of bridge railing benchmark used for measuring stage, or distance of water surface below benchmark. Benchmark (marked by arrow) is located at upper edge of I-beam column located 31.8 ft from the left bank edge-of-water.

Table 10. Summary of flow measurement methods on the Namekagon River at Earl and flow comparisons with nearby USGS gages.

	Methods			Flow Comparisons (cfs)		
Date	Meter	Suspension	Access	Leonards[1]	Earl	Danbury[2]
5/22/2006	AA	Cable	Bridge	126[3]	206	1150[3]
6/2/2006	AA	Cable	Bridge	110[3]	177	950[3]
6/15/2006	AA	Cable	Bridge	79[3]	111	754[3]
6/22/2006	AA	Cable	Bridge	66[3]	99	700[3]
7/5/2006	AA	Rod	Wading	61[3]	126	608[3]
7/10/2006	Pygmy	Rod	Wading	54[3]	221	574[3]
7/19/2006	AA	Cable	Bridge	52[3]	237	533[3]
8/16/2006	AA	Cable	Bridge	77[3]	328	610[3]

[1]USGS Gage # 05331855 Namekagon River near Leonards
[2]USGS Gage # 05333500 St. Croix River at Danbury
[3]Mean daily value for that date

4.4.1 Stage-discharge rating development for the Namekagon River at Earl

The rating equation development process followed the process summarized in section 3.4.5, where the distance below the overhang was converted to a distance above an artificial datum and steps 3-10 were repeated until the best-fit criteria were met (Table 11). The adjustments, applied to several of the stage readings, were all in the positive direction at Earl. Fitting the rating equation required progressively larger shift adjustments to stage readings during the latter half of the summer (the latter 4 of 8 readings). It is possible that at least part of these increasing adjustments may be due to stretching of the plastic-coated tape measure used to measure the distance from the bridge railing down to the water surface. This source of error could be eliminated by attaching the 16 oz. plumb bob to a metal tape measure. Conversely, the plumb bob could be attached to the end of a brass chain that is reeled-out at the same time as the plastic-coated tape measure, so that the weight of the plumb bob is supported by the brass chain, not the tape measure. Care would have to be taken to pull the tape measure taut during readings, but then the tape measure could be allowed to hang loosely in between readings. The stage-discharge rating data for the final step are shown in Table 12, including a range of values of e, and Figure 16 shows the final stage-discharge rating curves from 2006 data collected from the Namekagon River at Earl. The final rating curve suggested by the data is:

$$Qw = \frac{(Hw - e) - 0.0011}{0.0045}$$
$$Qw = \frac{Hw - 2.3511}{0.0045} \qquad (6)$$
$$Qw = \frac{Hw}{0.0045} - 522.5$$

where the offset (e) is 2.35.

Table 11. Summary of Namekagon River at Earl rating equation development process, showing progressive adjustment of individual stage levels to minimize the percent difference (%-Diff) between calculated and measured discharges. The color green highlights the values that fall within ± 5 %-Diff, blue highlights values that are too low, and red highlights values that are too high.

Date	Measured Discharge (cfs)	Stage (ft below bridge)	Gage height (ft) = 20ft – stage
5/22/2006	206	16.7	3.3
6/2/2006	177	16.95	3.05
6/15/2006	111	17.2	2.8
6/22/2006	99	17.22	2.78
7/5/2006	126	17.3	2.7
7/10/2006	221	17.33	2.67
7/19/2006	237.3	17.4	2.6
8/16/2006	328	17.2	2.8
Best fit equation: Hw vs Qw			y = 0.0047x + 2.2893
Pearson's correlation coefficient			R^2 = 0.9878
Calculation of e			2.47
Best fit e			2.3
Best fit equation: (Hw-e) vs Qw			y = 0.0047x – 0.0107
Pearson's correlation coefficient			R^2 = 0.9878
Equation for calculating Qw			x = (y+0.0107)/0.0047
Calc Discharge (cfs)	%-Diff	Adj (ft)	Adj Gage (ft) = 10ft – stage + adj
215	4%	0	3.3
162	-9%	0.1	3.15
109	-2%	0	2.8
104	5%	0	2.78
87	-44%	0.15	2.85
81	-173%	0.7	3.37
66	-259%	0.8	3.4
109	-202%	1.0	3.8
Calculation of e			2.63
Best fit e			2.28
Best fit equation: (Hw-e) vs Qw			y = 0.0046x + 0.0269
Pearson's correlation coefficient			R^2 = 0.9927
Equation for calculating Qw			x = (y-0.0269)/0.0046

Table 11 (cont). Summary of Namekagon River at Earl rating equation development process, showing progressive adjustment of individual stage levels to minimize the percent difference (%-Diff) between calculated and measured discharges. The color green highlights the values that fall within ± 5 %-Diff, blue highlights values that are too low, and red highlights values that are too high.

Calc Discharge (cfs)	%-Diff	Adj (ft)	Adj Gage (ft) = 10ft - stage + adj
216	4.6%	0	3.3
183	3.4%	0.1	3.15
107	-3.5%	0	2.8
103	3.7%	0	2.78
118	-6.7%	0.2	2.9
231	4.4%	0.7	3.37
238	0.1%	0.8	3.4
325	-1.1%	1.0	3.8
Calculation of e			2.29
Best fit e			2.32
Best fit equation: (Hw-e) vs Qw			y = 0.0046x + 0.0073
Pearson's correlation coefficient			R^2 = 0.9951
Equation for calculating Qw			x = (y-0.0073)/0.0046
Calc Discharge (cfs)	%-Diff	Adj (ft)	Adj Gage (ft) = 10ft - stage + adj
211	2.6%	0	3.3
179	1.0%	0.1	3.15
103	-8.0%	0.05	2.85
98	-0.6%	0	2.78
125	-1.2%	0.2	2.9
227	2.5%	0.7	3.37
233	-1.8%	0.8	3.4
320	-2.5%	1.0	3.8
Calculation of e			2.68
Best fit e			2.35
Best fit equation: (Hw-e) vs Qw			y = 0.0045x + 0.0011
Pearson's correlation coefficient			R^2 = 0.9968
Equation for calculating Qw			x = (y-0.0011)/0.0045
Calc Discharge (cfs)	%-Diff		
211	2.3%		
178	0.3%		
111	-0.1%		
95	-3.9%		
122	-3.3%		
226	2.4%		
233	-1.8%		
322	-1.9%		

Table 12. Final stage-discharge rating data for the Namekagon River at Earl. The bold data under "e=2.35" are those plotting a straight line in Figure 16.

Date	Stage (ft below bridge railing)	Adj (ft)	Gage height (ft)	Discharge (cfs)	e=2.8	e=2.6	e=2.4	e=2.35	e=2.0	e=1.0	e=0
5/22/2006	16.7	0	3.3	206	0.50	0.7	0.9	**0.95**	1.3	2.3	3.3
6/2/2006	16.95	0.1	3.15	177	0.35	0.55	0.75	**0.8**	1.15	2.15	3.15
6/15/2006	17.2	0.05	2.85	111		0.25	0.45	**0.5**	0.85	1.85	2.85
6/22/2006	17.22	0	2.78	99		0.18	0.38	**0.43**	0.78	1.78	2.78
7/5/2006	17.3	0.2	2.9	126	0.10	0.3	0.5	**0.55**	0.9	1.9	2.9
7/10/2006	17.33	0.7	3.37	221	0.57	0.77	0.97	**1.02**	1.37	2.37	3.37
7/19/2006	17.4	0.8	3.4	237.3	0.60	0.8	1	**1.05**	1.4	2.4	3.4
8/16/2006	17.2	1.0	3.8	328	1.00	1.2	1.4	**1.45**	1.8	2.8	3.8

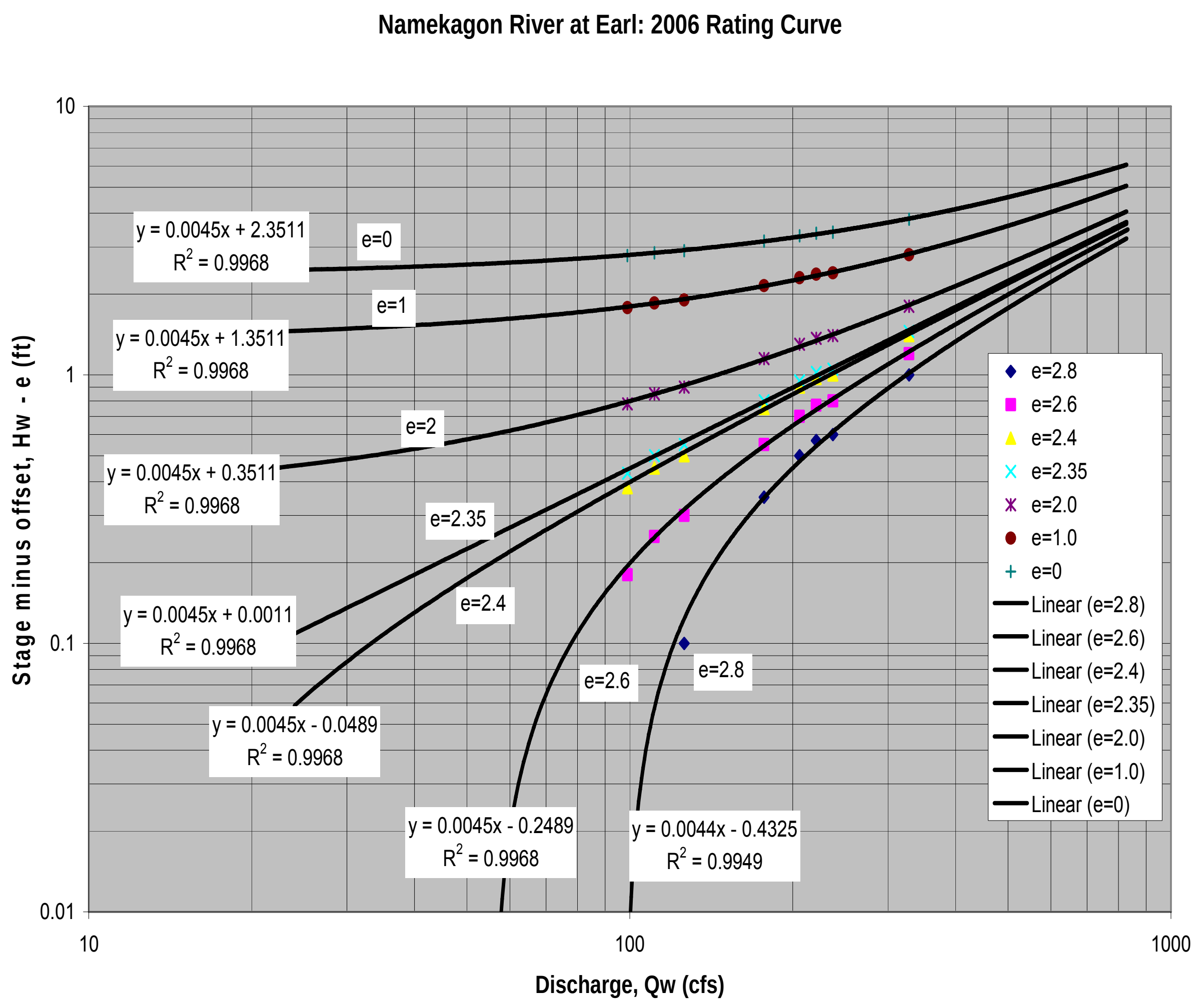


Figure 16. Final stage-discharge rating curves for the Namekagon River at Earl from 2006 data.

5 Recommendations

One general recommendation for field personnel who measure flow is to be sure to take more measurements (closer together) than you think is necessary, particularly in the streamflow around the centroid of flow. Specific recommendations are discussed below, and Table 13 contains a summary of the final recommendations for on-going flow monitoring at the NPS-GLKN large rivers water quality monitoring sites.

5.1 Continue Flow Measurements on Namekagon River at Earl

Flow at USGS #05332500 (Namekagon River Near Trego), located 9.6 miles downstream of the site at Earl, is annually reported to the USGS as daily mean discharge of water released from the Trego Dam by Xcel Energy, which manages Trego Dam for hydropower. The annual volume of water released from Trego Dam is probably equivalent to the mean annual flow volume of the Namekagon River at Earl. But since it is located downstream of Earl, the daily water releases at the dam will not be equivalent to the daily mean flows at Earl. In addition, ratios between flows at Earl and at the Leonards or Danbury gages were not consistent enough to estimate flows at Earl from either of those gages. Therefore, it is recommended that the GLKN program for measuring water quality of large rivers continue measuring flow on the Namekagon River at Earl, in conjunction with water quality monitoring events.

5.2 Discontinue Flow Measurements on the Snake River

During the course of 2006 field work, it was determined that the USGS Gage #05338500 near Crosslake accounts for 94% of flows measured less than a mile from the mouth of Snake River. Under the current water quality monitoring design for large rivers, the primary monitoring goal is to develop long-term trends in water quality concentrations (but not loads) and flow data is seen as supporting information for the interpretation of water quality results. Given this goal, and the challenge of flow measurement at this rocky location, it is recommended that NPS field personnel obtain the real-time data for flows at Crosslake at the time of water quality monitoring near the mouth of Snake River. However, if the program goals should ever switch to loading analysis, then flows need to be measured at the same location as where sampling occurs.

5.3 Discontinue Flow Measurements on the St. Croix River at Norway Point

As discussed earlier, it was determined that the USACE operates an active stage recorder on the St. Croix River at Norway Point (Figure 17). In cooperation with the NPS and USACE, the USGS will soon be establishing a new gage (#05336000) at Norway Point, which will use USACE stage data and a USGS-developed rating equation to calculate continuous discharge. Therefore, it is recommended that NPS field personnel no longer take flow measurements on the St. Croix River at Norway Point during water quality sampling. However, since they will benefit from the joint effort, the NPS should consider offering assistance in the field measurements required to further develop a rating curve for the St. Croix River at Norway Point.

Figure 17. A) USACE stage recorder house. B) View (from monitoring cross-section) of Norway Point public boat landing. The USACE stage recorder house is just off the left frame of the picture.

5.4 Add Willow River Flow Gaging

Flow gaging at the USGS gage #05341752 on the the Willow River in Willow River State Park was suspended on 9/30/2006. Until that gaging effort resumes, it is recommended that NPS Large River Water Quality personnel measure flows at the same time as water quality sampling. A likely location for flow measurement is under the Hwy 35 bridge (accessed by boat, not the bridge deck; Figure 18). This 360-ft span would entail an effort similar to the flow measurements at Norway Point.

Figure 18. Potential stage-discharge rating location on the Willow River.

Table 13. Final recommendations supporting (pro) or refuting (con) continued flow monitoring at the NPS-GLKN large rivers water quality monitoring sites.

New WQ Monitoring Sites	PRO	CON
1. Namekagon R. @ Earl (River mile = 42)	**·Closest USGS gages: 45 mi from Danbury, 40 mi from Leonards** **·USGS gage near Trego (9.6 miles downstream) is managed for hydropower** **·Easier to gage - nearby bridge**	
2. St. Croix R. @ Norway Point (River mile = 102.5)	·Closest USGS gage: 25 mi from Danbury ·Selected by Basin team as high priority mainstem monitoring site	**· USGS is developing new gage #05336000) at this location using USACE daily stage readings**
3. Snake R. @ mouth (River mile = 0.8)	· Selected by Basin team as high priority tributary monitoring site ·Easier to gage - narrow channel	**·Large discharge range challenging to measure** **·Nearby USGS gage: 10 mi from Pine City - appears to account for majority of flow at the mouth.**
4. St. Croix R. nr Trade R. (River mile = 65)		**·Nearby USGS gage: 15 mi from St. Croix Falls** **·Difficult to gage - wider channel**
5. St. Croix R. @ St. Croix Falls (River mile = 53)	·Selected by Basin team as high priority mainstem monitoring site	**·Existing USGS gage at this location**
6. Apple R. @ mouth (River mile = 2.7)	· Selected by Basin team as high priority tributary monitoring site	**·Nearby USGS gage: 5+ mi from Somerset, WI**
7. St. Croix R. @ Bayport Pool (River mile = 20)	·Selected by Basin team as high priority mainstem-lake monitoring site	**·Nearby USGS gages: 20 mi from Prescott, 5 miles from new Stillwater gage using USACE daily stage readings.** **·Location too wide (~0.5 mi) to gage accurately**
8. Willow R. @ mouth (River mile = 0.4)	**· Selected by Basin team as high priority tributary monitoring site** **·Nearby USGS gage: 2 mi from Willow R. State Park - was suspended in 2006**	
9. St. Croix R. @ Troy Beach Pool (River mile = 15)	·Selected by Basin team as high priority mainstem-lake monitoring site	**· Nearby USGS gages: 15 mi from Prescott, 10 miles from new Stillwater gage using USACE daily stage readings.** **·Location too wide (~1 mi) to gage accurately**
10. Kinnickinnic R. @ mouth (River mile = 2.3)	· Selected by Basin team as high priority tributary monitoring site	**·Nearby USGS gage: 1 mi from County Road F**
11. St. Croix R. @ Kinnickinnic Pool (River mile = 2)	·Selected by Basin team as high priority mainstem-lake monitoring site	**· Nearby USGS gage: 2 mi from Prescott** **·Location too wide (~0.3 mi) to gage accurately**

6 Literature Cited

Benson, M. A., and T. Dalrymple. 1967. General field and office procedures for indirect discharge measurements. U.S. Geological Survey, Techniques in Water Resources Investigations Book 3, Chapter A1. http://pubs.usgs.gov/twri/twri3-a1/

Buchanan, T.J., and W. P. Somers. 1969. Discharge measurements at gaging stations. U.S. Geological Survey, Techniques in Water Resources Investigations Book 3, Chapter A8. http://pubs.usgs.gov/twri/twri3a8/

Fulford, J. M., K. G. Thibodeaux., and W. R. Kaehrle. 1994. Comparison of current meters used for stream gaging. Pages 376-385 in C. A. Pugh, editor. Fundamentals and Advenacements in Hydraulic Measurements and Experimentation, ASCE Publications, N.Y., N.Y.

Hubbard, E. F., K. G. Thibodeaux, and M. N. Duong. 1999. Quality assurance of U.S. Geological Survey stream current meters: The meter exchange program 1988-98. U.S. Geological Survey OFR 99-221. http://water.usgs.gov/osw/pubs/ofr99-221/ofr99-221.pdf

Kennedy, E. J. 1984. Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. A10, accessed 1/25/2006 at http://pubs.usgs.gov/twri/twri3-a10/pdf/TWRI_3-A10.pdf

Kennedy, E. J. 1983. Computation of continuous records of streamflow. United States Geological Survey Techniques in Water-Resources Investigations Book 3 Chapter A13. http://water.usgs.gov/pubs/twri/twri3-a13

Magdalene, S., D. R. Engstrom, and J. Elias. 2007. Large rivers water quality monitoring protocol. Version 1.0. National Park Service, Great Lakes Network, Ashland, Wisconsin. http://science.nature.nps.gov/im/monitor/protocols/GLKN_WQ_Rivers.zip

Penoyer, P. 2003. Part C: Vital signs longterm aquatic monitoring projects, draft guidance on WRD required and other field parameter measurements, general monitoring methods and some design considerations in preparation of a detailed study plan, 2003 Aug 6 Draft. In: Guidance on water quality, contaminants, and aquatic biology vital signs monitoring under the Natural Resource Challenge Long-Term Water Quality Monitoring Program. Fort Collins (CO): National Park Service, Water Resources Division. Available from: http://science.nature.nps.gov/im/monitor/protocols/wqPartC.doc.

Rantz, S. E., and others. 1982. Measurement and computation of streamflow, Volume 1: Measurement of stage and discharge. Reston (VA): U. S. Geological Survey. Water Supply Paper 2175. Available from: http://water.usgs.gov/pubs/wsp/wsp2175/.

Stednick, J. D., and D. M. Gilbert. 1998. Water quality inventory protocol: riverine environments. National Park Service Technical Report NPS/NRWRD/NRTR-98/177. http://science.nature.nps.gov/im/monitor/protocols/wrdwq.wpd.

U.S. Geological Survey. September 2006. Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4. http://pubs.water.usgs.gov/twri9A4/

7 Appendix

The Appendix includes templates of 1) field forms, 2) spreadsheets of the data collected during flow gaging events, including flow calculations and comparisons with flow at nearby USGS gages, and 3) graphs of flow cross-section for each flow gaging event. The fraction of total flow volume (FracFlow column) for each partial section is color-coded by % of total flow: green = 0-5%, blue = 5-10%, and red = >10% of the total flow volume, indicating whether measurements met USGS recommendations that each partial section contain no more than 10% (and preferably less than 5%) of the total flow volume. For all flow cross-sections at each flow monitoring site, the three axes of the flow cross-sections (left, top, and right) were held at a constant scale, to enable comparison of flow depths, stream widths, and flow velocities, respectively, across flow monitoring events at each site. All of the graphs were plotted consistently from the upstream perspective, that is, with the left bank is on the left side of the graph and the right bank is on the right side of the graph. Flow gaging events are listed chronologically for each monitoring site:

I. St. Croix River at Norway Point
II. Snake River at Chengwatana State Forest Campground
III. Namekagon River at Earl

Date: ________________ Start time: ______________ End time: ___________

Name of Stream/River:____

Location Description:____

Field Personnel: ____

Gage height (start): __________________________ Gage height (end): ______________________

**Record measurement depth for cable suspension only

<== Circle which bank at start and which bank at finish ==>

					60% or 80% depth		20% depth (ft)	
	Distance from L / R bank (circle one)	Total depth (ft)	1-pt meas √	2-pt meas √	Meas depth (ft)	Flow velocity (fps)	Meas depth (ft)	Flow velocity (fps)
LB/RB		0.00				0.00		0.00
RB/LB		0.00				0.0		0.0

Method (circle one for each):

Type AA meter or Pygmy meter

Rod suspension or cable suspension

Wading access or boat access or bridge access

AquaCalc 5000Total flow:

Flow: _____________ cfs

Velocity: __________ fps

Flow Monitoring From Bridges Field Form

Distance from EOW	Cable length (ft)	plus 0.55 ft	Dist. to strm bed (ft)	less	Depth to water sfc (ft)	Total depth (ft)	20% of total (ft)	minus 0.55 ft	Amt to raise meter (ft)	depth @ 80%	flow @ 80%	depth @ 60%	flow @ 60%	depth @ 20%	flow @ 20%
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							
		+ 0.55 =		-	=			— 0.55 =							

St. Croix River at Norway Point: Flow Gaging 5/26/2006

************CORRECTED FOR INCORRECT METER SETTING (see next page)***********************

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Partial area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)
LB	312	312	307.5	4.5	0.0	0.0									0.00	0.3
	303	307.5	295.5	12	2.55	30.6	√		2.0	1.0					0.10	3
	288	295.5	285	10.5	5.05	53.0		√	4.0	3.6	0.11	1.0	1.0	0.19	0.15	8
	282	285	268.5	16.5	6.05	99.8		√	4.8	4.5	0.23	1.2	1.0	0.30	0.27	26
	255	268.5	252	16.5	6.45	106.4		√	5.2	4.8	0.41	1.3	1.25	0.62	0.52	55
	249	252	235.5	16.5	6.05	99.8		√	4.8	4.5	0.53	1.2	1.0	0.59	0.56	56
	222	235.5	219	16.5	5.85	96.5		√	4.7	4.25	0.62	1.2	1.0	0.74	0.68	66
	216	219	207	12	5.85	70.2		√	4.7	4.25	0.62	1.2	1.0	0.75	0.69	48
	198	207	195	12	5.55	66.6		√	4.4	4.0	0.66	1.1	1.0	0.74	0.70	47
	192	195	181.5	13.5	5.75	77.6		√	4.6	4.25	0.55	1.2	1.0	0.76	0.66	51
	171	181.5	168	13.5	6.05	81.7		√	4.8	4.5	0.65	1.2	1.0	0.79	0.72	59
	165	168	148.5	19.5	5.95	116.0		√	4.8	4.5	0.63	1.2	1.0	0.79	0.71	82
	132	148.5	129	19.5	6.05	118.0		√	4.8	4.5	0.67	1.2	1.0	0.73	0.70	83
	126	129	103.5	25.5	5.85	149.2		√	4.7	4.3	0.62	1.2	1.0	0.69	0.66	98
	81	103.5	78	25.5	3.80	96.9		√	3.0	2.5	0.35	0.8	1.0	0.39	0.37	36
	75	78	63	15	4.35	65.3		√	3.5	3.0	0.31	0.9	1.0	0.35	0.33	22
	51	63	48	15	3.55	53.3		√	2.8	2.5	0.11	0.7	1.0	0.17	0.14	7
	45	48	22.5	25.5	3.45	88.0		√	2.8	2.5	0.10	0.7	1.0	0.18	0.14	12
RB	0	22.5	0	22.5	0	0.0									0.00	3
						1468.9						Total Discharge (cfs)				761

<u>Method:</u>

Type AA meter

Cable suspension

Motor boat access

<u>Discharge comparisons:</u>

AquaCalc = 803.59 cfs ****INCORRECT METER SETTING?

AquaCalc mean vel = 0.58 fps * 1513.4 ft^2 = 877.8 cfs

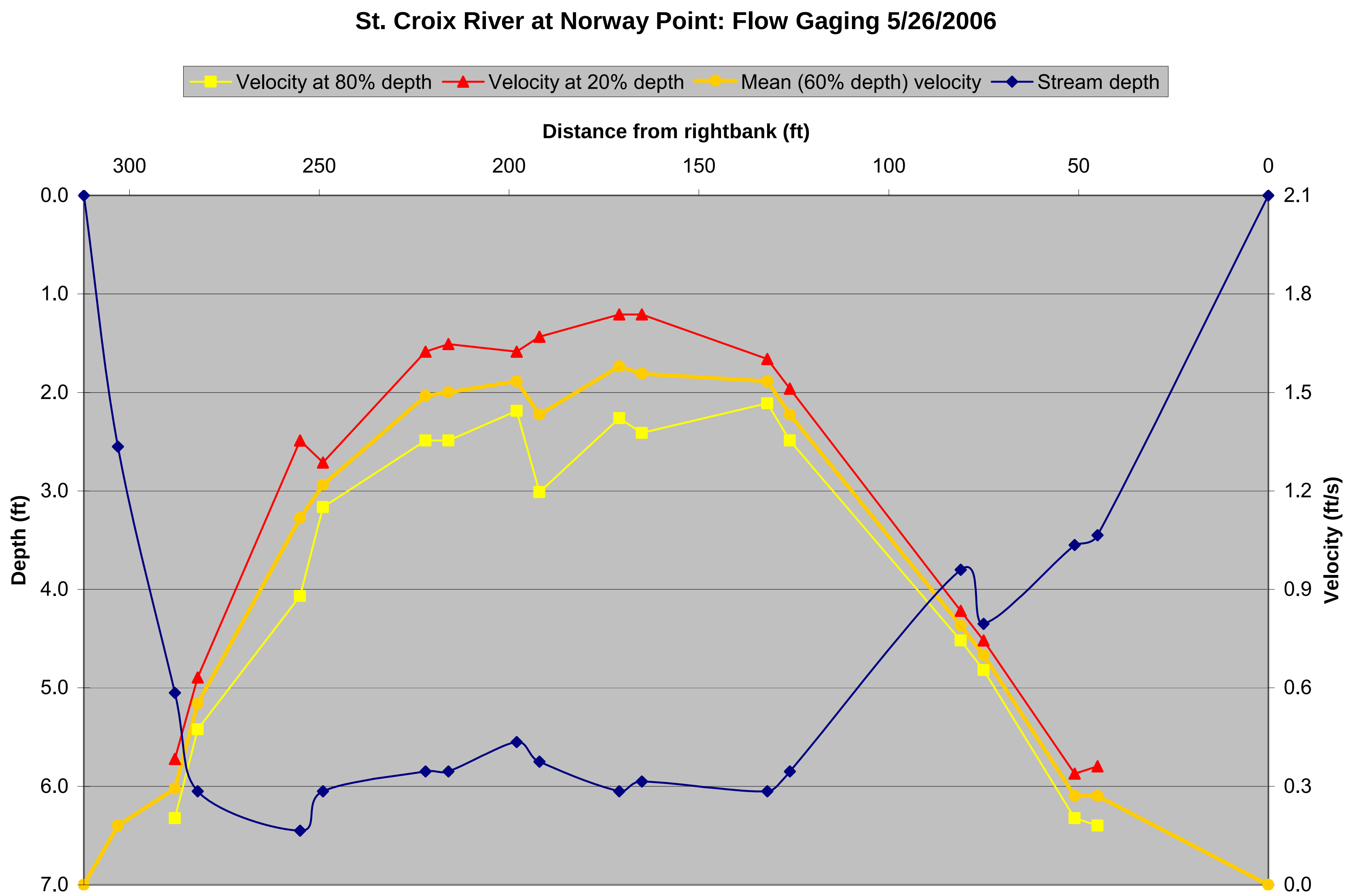
Corrected Spreadsheet (see next page) = 1649 cfs

Danbury (05333500) 5/26/06 daily mean 1040 cfs MDV = 63%

St. Croix Falls (05340500) 5/26/06 daily mean 4370 cfs MDV = 265%

St. Croix River at Norway Point: Flow Gaging 5/26/2006: Corrected Values

CORR VEL CALCS	Distance from L / R bank (circle one)	Total depth (ft)	.8Flow velocity (fps)	CORR .8Flow (fps)	.2Flow velocity (fps)	CORR .2Flow (fps)	Mean velocity (fps)	CORR Mean (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
	312	0					0.05	0.067447	0.5	0.0%
	303	2.55					0.10	0.180283	6	0.3%
	288	5.05	0.11	0.20285	0.19	0.383386	0.15	0.293118	16	0.9%
	282	6.05	0.23	0.473654	0.30	0.631624	0.27	0.552639	55	3.3%
	255	6.45	0.41	0.879861	0.62	1.353769	0.52	1.116815	119	7.2%
	249	6.05	0.53	1.150666	0.59	1.286068	0.56	1.218367	122	7.4%
	222	5.85	0.62	1.353769	0.74	1.624573	0.68	1.489171	144	8.7%
	216	5.85	0.62	1.353769	0.75	1.64714	0.69	1.500455	105	6.4%
	198	5.55	0.66	1.444037	0.74	1.624573	0.70	1.534305	102	6.2%
	192	5.75	0.55	1.1958	0.76	1.669707	0.66	1.432754	111	6.7%
	171	6.05	0.65	1.42147	0.79	1.737409	0.72	1.579439	129	7.8%
	165	5.95	0.63	1.376336	0.79	1.737409	0.71	1.556872	181	10.9%
	132	6.05	0.67	1.466604	0.73	1.602006	0.70	1.534305	181	11.0%
	126	5.85	0.62	1.353769	0.69	1.511738	0.66	1.432754	214	13.0%
	81	3.80	0.35	0.744459	0.39	0.834727	0.37	0.789593	77	4.6%
	75	4.35	0.31	0.654191	0.35	0.744459	0.33	0.699325	46	2.8%
	51	3.55	0.11	0.20285	0.17	0.338252	0.14	0.270551	14	0.9%
	45	3.45	0.10	0.180283	0.18	0.360819	0.14	0.270551	24	1.4%
	0	0					0.07	0.112582	5	0.3%
							Total Discharge (cfs)		1650	


St. Croix River at Norway Point: Flow Gaging 5/26/2006
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Stream depth
Distance from rightbank (ft)
300
250
200
150
100
50
0
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Velocity (ft/s)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0

St. Croix River at Norway Point: Flow Gaging 6/14/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	300	312	295	17	0									0	0.5	0.1%
	290	295	286	9	1.65	√		1.3	1.0					0.08	1	0.1%
	282	286	271.5	14.5	4.70		√	3.8	3.8	0.12	0.9	1.0	0.23	0.18	12	1.1%
	261	271.5	249	22.5	5.50		√	4.4	4.4	0.56	1.1	1.2	0.70	0.63	78	7.3%
	237	249	228	21	5.00		√	4.0	4.0	0.94	1.0	1.00	1.24	1.09	114	10.7%
	219	228	210	18	5.00		√	4.0	4.0	1.07	1.0	1.0	1.33	1.20	108	10.1%
	201	210	189	21	5.00		√	4.0	4.00	1.13	1.0	1.0	1.23	1.18	124	11.6%
	177	189	165	24	5.20		√	4.2	4.00	0.97	1.0	1.0	1.22	1.10	137	12.8%
	153	165	133.5	31.5	5.30		√	4.2	4.0	1.05	1.1	1.0	1.41	1.23	205	19.2%
	114	133.5	105	28.5	4.90		√	3.9	3.90	1.03	1.0	1.0	1.15	1.09	152	14.3%
	96	105	81	24	4.10		√	3.3	3.0	0.80	0.8	1.0	0.87	0.84	82	7.7%
	66	81	40.5	40.5	3.90	√		3.1	2.0		0.8			0.23	36	3.4%
	15	40.5	7.5	33	2.00	√		1.6	1.0		0.4			0.25	17	1.5%
RB	0	7.5	0	7.5	0					0.00				0	0.9	0.1%
												Total Discharge (cfs)			1068	

<u>Method:</u>

Type AA meter

Cable suspension

Canoe + motor access

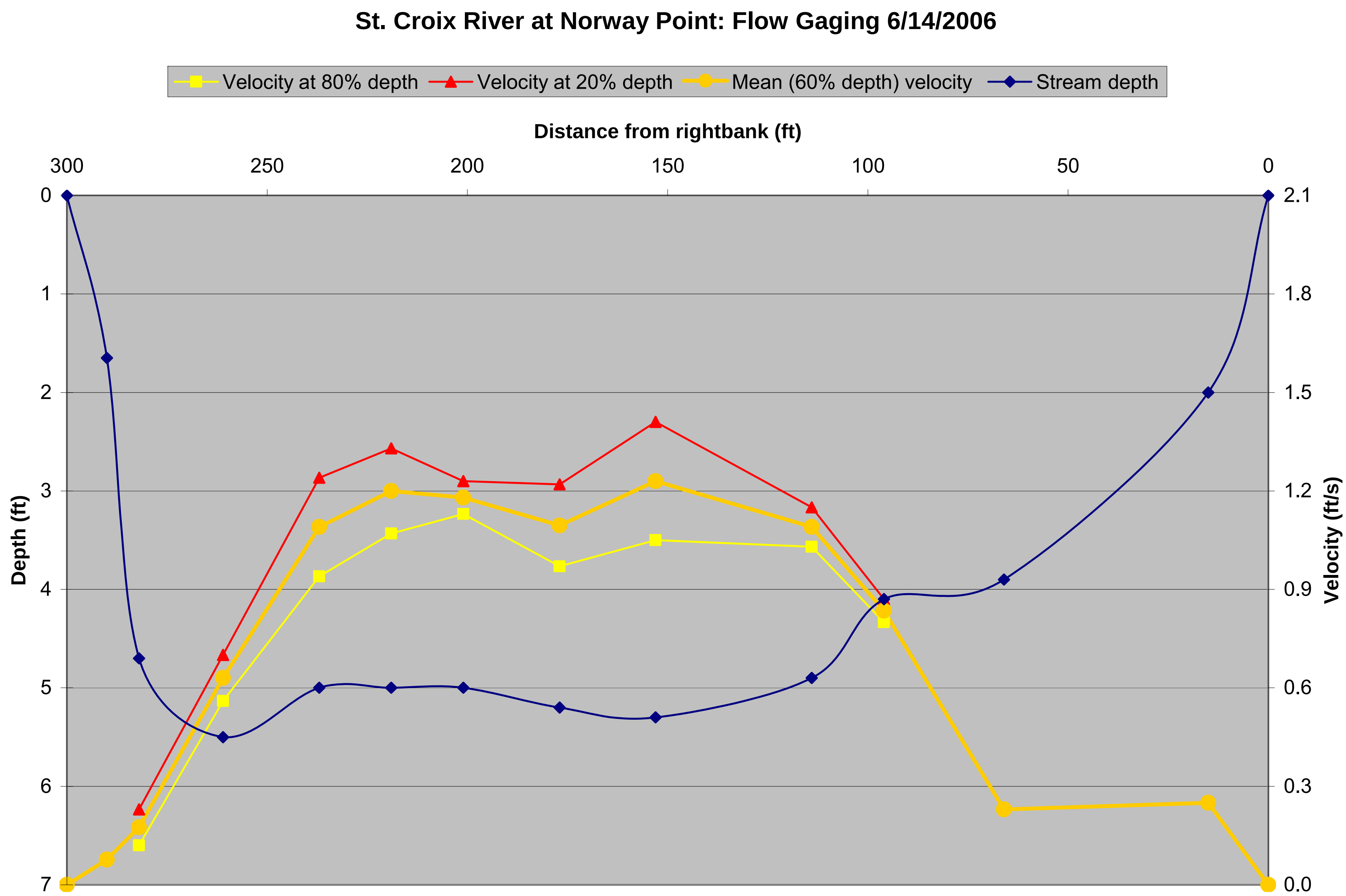
<u>Discharge comparisons:</u>

AquaCalc = ___N/A__ cfs ****NO READING

Spreadsheet (above) = 1068 cfs

Danbury (05333500) 6/14/06 daily mean 686 cfs MDV = 64%

St. Croix Falls (05340500) 6/14/06 daily mean 2170 cfs MDV = 203%


St. Croix River at Norway Point: Flow Gaging 6/14/2006
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Stream depth
Distance from rightbank (ft)
300
250
200
150
100
50
0
Depth (ft)
0
1
2
3
4
5
6
7
Velocity (ft/s)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0

St. Croix River at Norway Point: Flow Gaging 6/30/2006

************CORRECTED FOR INCORRECT METER SETTING (see next page)************************

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)		1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)
LB	300	300	291	9	0	0									0	0.9
	282	291	270	21	4.00	84		√	3.2		0.18	0.8	1.0	0.01	0.10	8
	258	270	249	21	5.00	105		√	4.0	4.0	0.22	1.0	1.0	0.30	0.26	27
	240	249	228	21	4.70	99		√	3.8	3.5	0.36	0.9	1.0	0.43	0.40	39
	216	228	205.5	22.5	4.80	108		√	3.8	3.8	0.43	1.0	1.0	0.51	0.47	51
	195	205.5	186	19.5	4.60	90		√	3.7	3.5	0.40	0.9	1.0	0.46	0.43	39
	177	186	169.5	16.5	4.70	78		√	3.8	3.50	0.48	0.9	1.0	0.49	0.49	38
	162	169.5	144	25.5	4.80	122		√	3.8	3.80	0.40	1.0	1.0	0.53	0.47	57
	126	144	115.5	28.5	4.70	134		√	3.8	3.5	0.40	0.9	1.0	0.51	0.46	61
	105	115.5	94.5	21	4.70	99		√	3.8	3.50	0.35	0.9	1.0	0.46	0.41	40
	84	94.5	75	19.5	3.50	68		√	2.8	2.5	0.12	0.7	1.0	0.17	0.15	10
	66	75	33	42	2.50	105	√		2.0	1.5		0.5	1.0		0.04	4
RB	0	33	0	33	0	0									0	0.8
						1091.3									Total Discharge (cfs)	375

Method:

Type AA meter

Cable suspension

Canoe access

Discharge comparisons:

AquaCalc flow = 375.72 cfs ****INCORRECT METER SETTING?

AquaCalc mean vel = 0.34 fps * 1150.5 ft^2 = 391.2 cfs

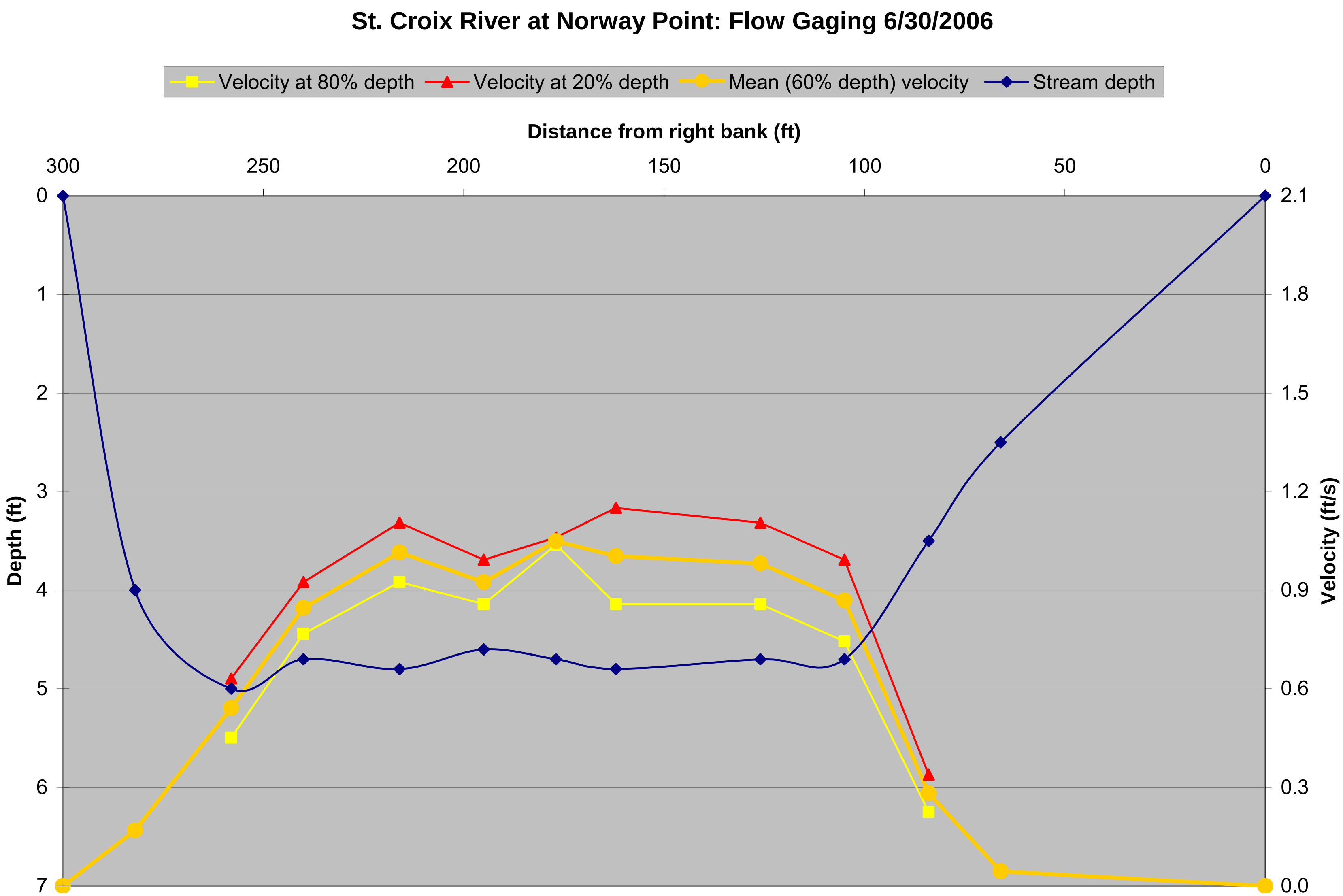
Corrected Spreadsheet (see next page) = 793 cfs

Danbury (05333500) 6/30/06 daily mean 621 cfs MDV = 78%

St. Croix Falls (05340500) 6/30/06 daily mean 1760 cfs MDV = 222%

St. Croix River at Norway Point: Flow Gaging 6/30/2006: Corrected Values

CORR VEL CALCS	Distance from L / R bank (circle one)	Total depth (ft)	.8Flow velocity (fps)	CORR .8Flow (fps)	.2Flow velocity (fps)	CORR .2Flow (fps)	Mean velocity (fps)	CORR Mean (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
	312	0					0.00	0	0	0.0%
	303	2.55	0.18		0.01		0.10	0.168999	14	1.8%
	288	5.05	0.22	0.451087	0.30	0.631624	0.26	0.541355	57	7.2%
	282	6.05	0.36	0.767026	0.43	0.924995	0.40	0.84601	84	10.5%
	255	6.45	0.43	0.924995	0.51	1.105531	0.47	1.015263	110	13.8%
	249	6.05	0.40	0.857294	0.46	0.992696	0.43	0.924995	83	10.5%
	222	5.85	0.48	1.03783	0.49	1.060397	0.49	1.049114	81	10.3%
	216	5.85	0.40	0.857294	0.53	1.150666	0.47	1.00398	123	15.5%
	198	5.55	0.40	0.857294	0.51	1.105531	0.46	0.981413	131	16.6%
	192	5.75	0.35	0.744459	0.46	0.992696	0.41	0.868577	86	10.8%
	171	6.05	0.12	0.225417	0.17	0.338252	0.15	0.281834	19	2.4%
	165	5.95					0.04	0.04488	5	0.6%
	0	0					0.00	0	0	0.0%
							Total Discharge (cfs)		793	


St. Croix River at Norway Point: Flow Gaging 6/30/2006
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Stream depth
Distance from right bank (ft)
300
250
200
150
100
50
0
Depth (ft)
0
1
2
3
4
5
6
7
Velocity (ft/s)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0

St. Croix River at Norway Point: Flow Gaging 7/12/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)		1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8depth velocity (fps)	20% depth (ft)	Meas depth (ft)	.2depth velocity (fps)	Mean (.6depth) velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	303	303	294	9	0	0									0	0.1	0.0%
	285	294	276	18	3.00	54		√	2.4		0.01	0.6		0.01	0.01	1	0.1%
	267	276	256.5	19.5	4.50	87.8		√	3.6		0.44	0.9		0.53	0.49	43	6.2%
	246	256.5	232.5	24	4.10	98.4		√	3.3		0.63	0.8		0.80	0.72	70	10.2%
	219	232.5	211.5	21	4.00	84		√	3.2		0.88	0.8		0.93	0.91	76	11.1%
	204	211.5	192	19.5	4.00	78		√	3.2		0.85	0.8		1.06	0.96	74	10.8%
	180	192	168	24	4.00	96		√	3.2		0.85	0.8		1.07	0.96	92	13.4%
	156	168	148.5	19.5	4.30	83.9		√	3.4		0.86	0.9		1.13	1.00	83	12.1%
	141	148.5	127.5	21	4.50	94.5		√	3.6		1.01	0.9		1.15	1.08	102	14.9%
	114	127.5	99	28.5	4.20	120		√	3.4		0.91	0.8		0.94	0.93	111	16.1%
	84	99	75	24	3.00	72		√	2.4		0.27	0.6		0.27	0.27	19	2.8%
	66	75	33	42	3.00	126		√	2.4		0.10	0.6		0.10	0.10	13	1.8%
RB	0	33	0	33	0	0									0	2.5	0.4%
						994.2							Total Discharge (cfs)			687	

Method:

Type AA meter

Cable suspension

Canoe access

Discharge comparisons:

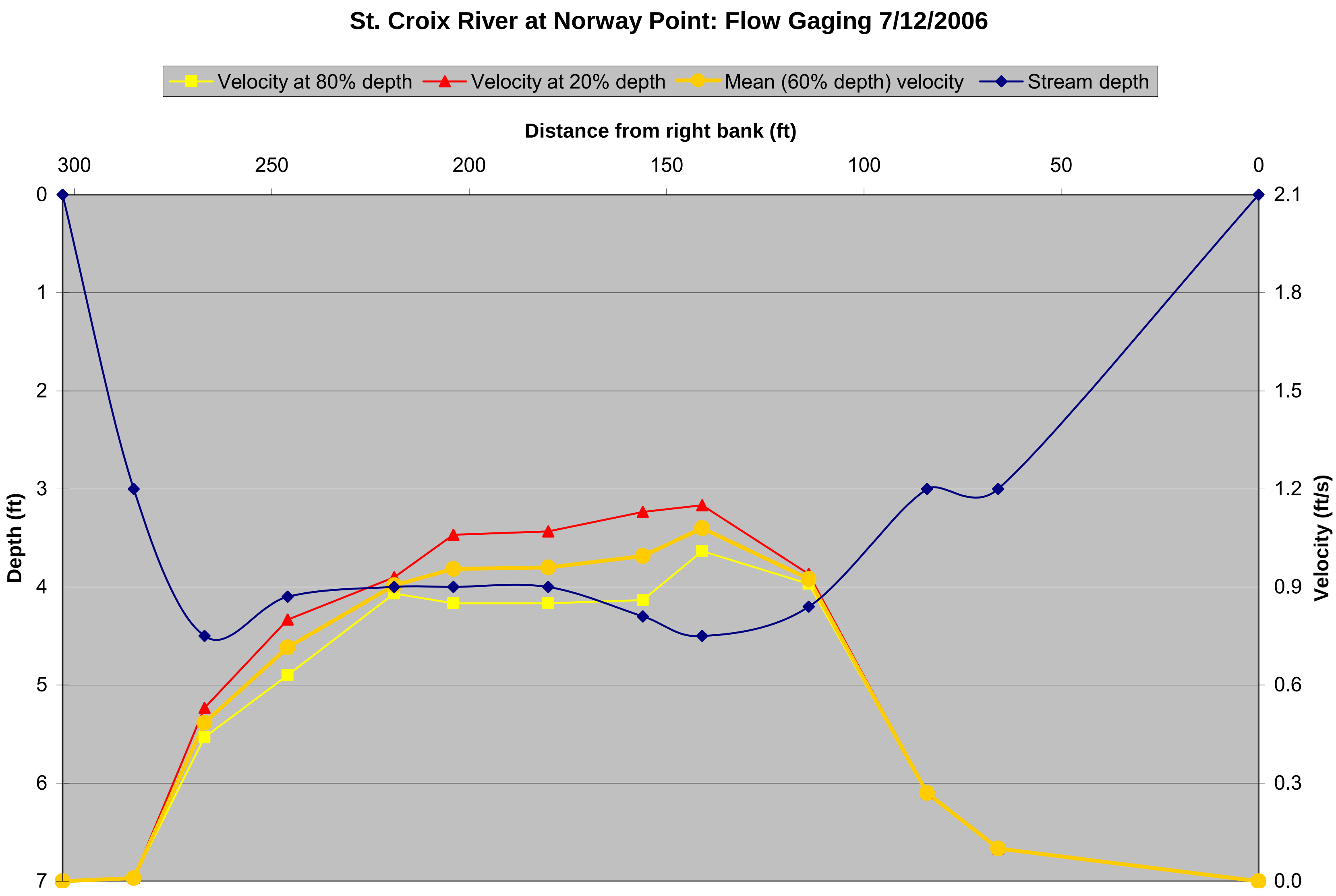
AquaCalc flow = 834.61 cfs

AquaCalc mean vel = 0.85 fps * 1057.2 ft^2 = 898.6 cfs

Spreadsheet calculation (above) = 687 cfs

Danbury (05333500) 7/12/06 daily mean 551 cfs MDV = 80 %

St. Croix Falls (05340500) 7/12/06 daily mean 1320 cfs MDV = 192%


St. Croix River at Norway Point: Flow Gaging 7/12/2006
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Stream depth
Distance from right bank (ft)
300
250
200
150
100
50
0
Depth (ft)
0
1
2
3
4
5
6
7
Velocity (ft/s)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0

St. Croix River at Norway Point: Flow Gaging 7/27/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	297	297	289.5	7.5	0	0									0	2	0.3%
	282	289.5	270	19.5	4.20	81.9		√	3.4		0.17	0.8		0.35	0.26	21	2.9%
	258	270	252	18	5.10	91.8		√	4.1	4.0	0.44	1.0	1.0	0.60	0.52	48	6.5%
	246	252	235.5	16.5	4.80	79.2		√	3.8	3.7	0.66	1.0	1.0	0.80	0.73	58	7.9%
	225	235.5	217.5	18	4.80	86.4		√	3.8	3.7	0.81	1.0	1.0	0.88	0.85	73	9.9%
	210	217.5	202.5	15	4.70	70.5		√	3.8	3.5	0.73	0.9	1.0	0.94	0.84	59	8.0%
	195	202.5	180	22.5	4.90	110		√	3.9	3.8	0.76	1.0	1.0	0.93	0.85	93	12.7%
	165	180	151.5	28.5	4.70	134		√	3.8	3.50	0.91	0.9	1.0	1.17	1.04	139	19.0%
	138	151.5	127.5	24	4.90	118		√	3.9	3.80	0.85	1.0	1.0	1.14	1.00	117	15.9%
	117	127.5	103.5	24	4.70	113		√	3.8	3.5	0.68	0.9	1.0	0.77	0.73	82	11.1%
	90	103.5	45	58.5	3.00	176		√	2.4	2.5	0.21	0.6	1.0	0.20	0.21	36	4.9%
RB	0	45	0	45	0	0									0.00	7	0.9%
						1059.9									Total Discharge (cfs)	735	

Method:

Type AA meter

Cable suspension

Canoe access

Discharge comparisons:

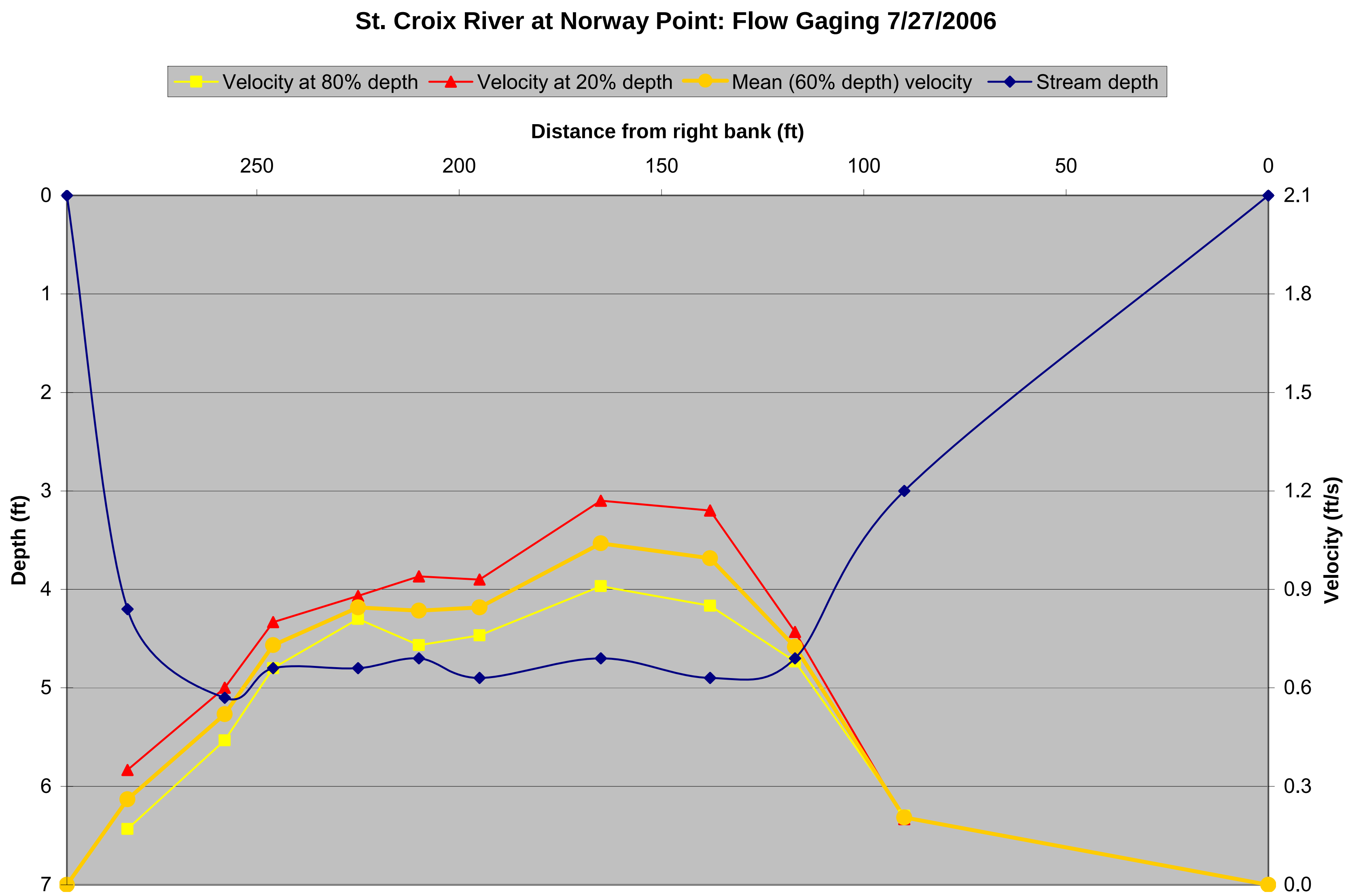
AquaCalc = 739.14 cfs

AquaCalc mean vel = 0.69 fps * 1101.5 ft^2 = 760.0 cfs

Spreadsheet calculation (above) = 735 cfs

Danbury (05333500) 7/27/06 daily mean 551 cfs MDV = 75%

St. Croix Falls (05340500) 7/27/06 daily mean 1280 cfs MDV = 174%


St. Croix River at Norway Point: Flow Gaging 7/27/2006
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Stream depth
Distance from right bank (ft)
250
200
150
100
50
0
Depth (ft)
0
1
2
3
4
5
6
7
Velocity (ft/s)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0

Snake River at Chengwatana State Forest Campground: Flow Gaging 5/19/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	2	2	0.00	0.00									0	1.5	0.2%
	4	2	19	17	1.60	27.20									1.52	41	5.8%
	34	19	36	17	1.90	32.30	√		1.5			0.4			1.63	53	7.4%
	38	36	46.5	10.5	2.00	21.00	√		1.6			0.4			1.66	35	4.9%
	55	46.5	57	10.5	2.10	22.05	√		1.7			0.4			2.05	45	6.4%
	59	57	85.5	28.5	2.10	59.85	√		1.7			0.4			1.82	109	15.3%
	112	85.5	114	28.5	4.00	114.00		√	3.2		0.89	0.8		1.94	1.42	161	22.7%
	116	114	124.5	10.5	3.80	39.90		√	3.0		1.22	0.8		1.89	1.56	62	8.7%
	133	124.5	135	10.5	3.70	38.85		√	3.0		1.10	0.7		1.94	1.52	59	8.3%
	137	135	139.5	4.5	3.60	16.20		√	2.9		0.89	0.7		1.89	1.39	23	3.2%
	142	139.5	144	4.5	4.30	19.35		√	3.4		1.13	0.9		1.82	1.48	29	4.0%
	146	144	153	9	4.20	37.80		√			1.23			1.22	1.23	46	6.5%
	160	153	162	9	3.30	29.70		√			1.04			1.59	1.32	39	5.5%
	164	162	165.5	3.5	1.70	5.95		√	1.4		0.81	0.3		1.40	1.11	7	0.9%
RB	167	165.5	167	1.5	0.00	0.00									0	0.704	0.1%
						464.2								Total Discharge (cfs)		711	

<u>Method:</u>

Type AA meter

Rod suspension

Canoe + motor access

<u>Discharge comparisons:</u>

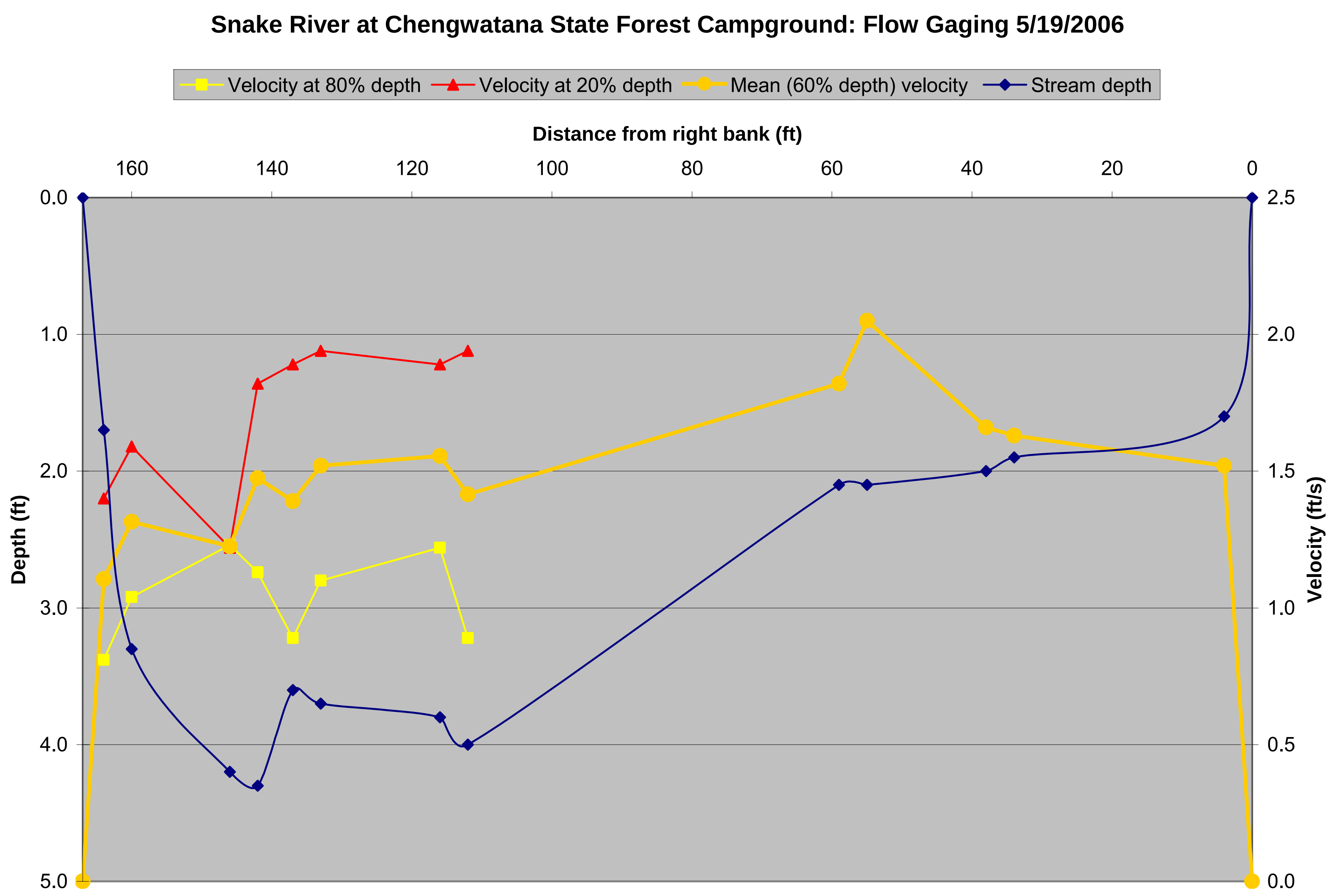
AquaCalc flow = 722.24 cfs

AquaCalc mean vel = 1.55 f/s * 467 ft^2 = 723.8 cfs

Spreadsheet calculation (above) = 711 cfs

Snake@Crosslake (05338500) 5/19/06 daily mean 1660 cfs MDV

Stage = 3.0 feet below ledge


Snake River at Chengwatana State Forest Campground: Flow Gaging 5/19/2006
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Stream depth
Distance from right bank (ft)
160
140
120
100
80
60
40
20
0
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
Velocity (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0

Snake River at Chengwatana State Forest Campground: Flow Gaging 5/31/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	165	165	163.5	1.5	0.00	0.00									0	0.3	0.1%
	162	163.5	156	7.5	0.65	4.88			0.5			0.1			0.89	4	0.7%
	150	156	148.5	7.5	0.90	6.75			0.7			0.2			1.32	9	1.5%
	147	148.5	142.5	6	1.00	6.00			0.8			0.2			1.74	10	1.8%
	138	142.5	133.5	9	1.40	12.60			1.1			0.3			1.77	22	3.8%
	129	133.5	127.5	6	1.55	9.30			1.2		1.67	0.3		2.39	2.03	19	3.3%
	126	127.5	118	9.5	2.15	20.43			1.7		0.15	0.4		2.56	1.35	28	4.8%
	110	118	108	10	3.10	31.00			2.5		1.63	0.6		2.44	2.04	63	10.9%
	106	108	105	3	3.30	9.90			2.6		1.54	0.7		2.34	1.94	19	3.3%
	104	105	102	3	3.50	10.50			2.8		1.51	0.7		2.44	1.98	21	3.6%
	100	102	96	6	3.30	19.80			2.6		1.53	0.7		2.33	1.93	38	6.6%
	92	96	90	6	2.70	16.20			2.2		1.49	0.5		2.41	1.95	32	5.4%
	88	90	82	8	2.50	20.00			2.0		1.30	0.5		2.48	1.89	38	6.5%
	76	82	73	9	2.30	20.70			1.8		1.39	0.5		2.36	1.88	39	6.7%
	70	73	67	6	2.35	14.10			1.9			0.5			1.83	26	4.4%
	64	67	58.5	8.5	2.10	17.85			1.7		0.66	0.4		2.43	1.55	28	4.8%
	53	58.5	41.5	17	2.05	34.85			1.6		1.22	0.4		2.05	1.64	57	9.8%
	30	41.5	27.5	14	2.10	29.40			1.7		1.02	0.4		1.87	1.45	42	7.3%
	25	27.5	21	6.5	2.55	16.58			2.0		1.34	0.5		2.09	1.72	28	4.9%
	17	21	13.5	7.5	2.30	17.25			1.8		1.10	0.5		1.98	1.54	27	4.6%
	10	13.5	7.5	6	2.25	13.50			1.8		1.20	0.5		1.81	1.51	20	3.5%
	5	7.5	3.5	4	1.90	7.60			1.5		0.79	0.4		1.19	0.99	8	1.3%
	2	3.5	1	2.5	0.85	2.13			0.7		0.46	0.2		1.40	0.93	2	0.3%
RB	0	1	0	1	0.00	0.00									0	0.198	0.0%
						341.3								Total Discharge (cfs)		580	

<u>Method:</u>

Pygmy meter

Rod suspension

Wading and canoe access

<u>Discharge comparisons:</u>

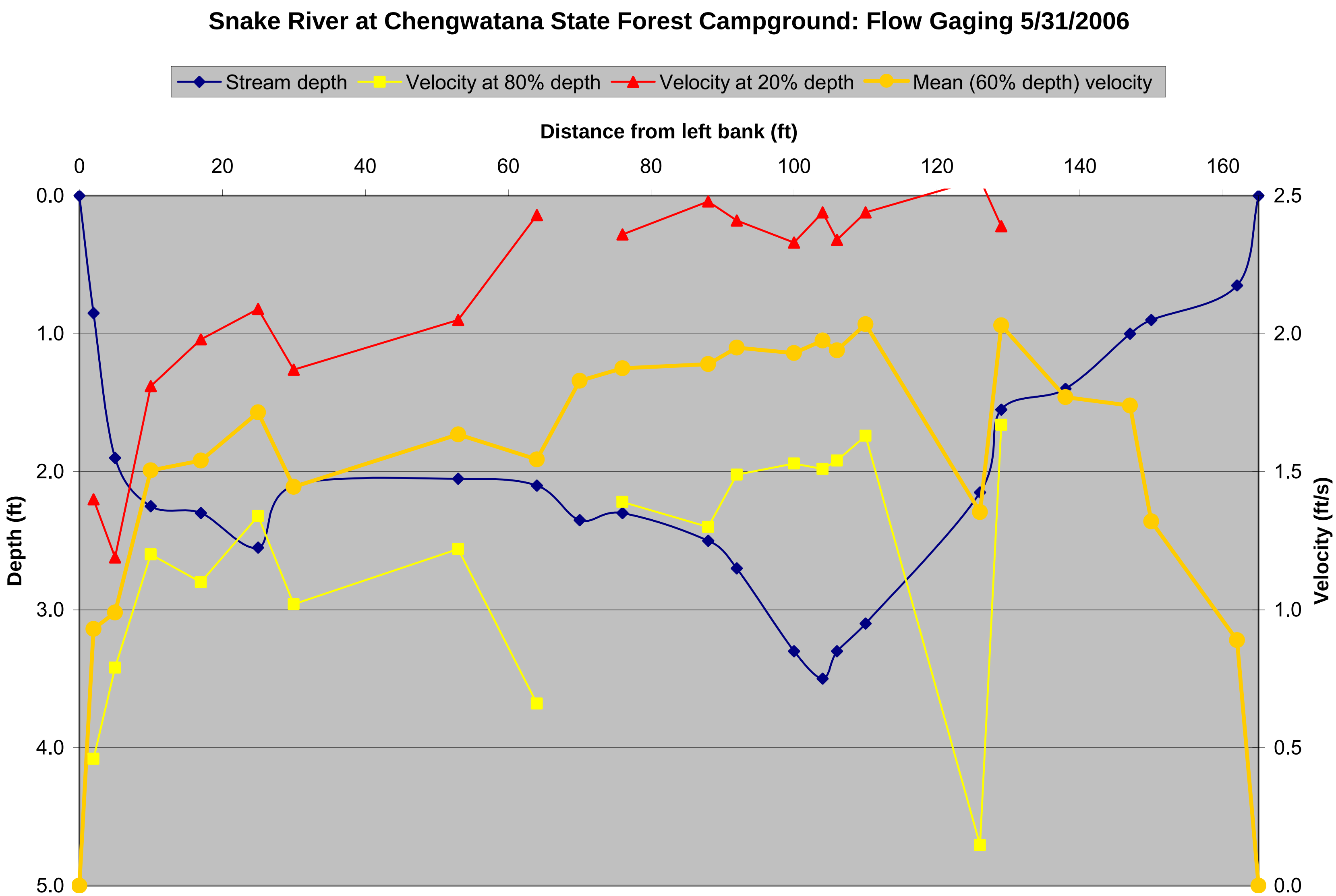
AquaCalc flow = 592.95 cfs

AquaCalc mean vel = 1.74 f/s * 342.2 ft^2 = 595.4 cfs

Spreadsheet calculation (above) = 580 cfs

Snake @ Crosslake (05338500) 5/31/06 daily mean 518 cfs MDV

Stage = 4.2 feet below ledge


Snake River at Chengwatana State Forest Campground: Flow Gaging 5/31/2006
Stream depth
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
20
40
60
80
100
120
140
160
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
Velocity (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0

Snake River at Chengwatana State Forest Campground: Flow Gaging 6/28/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	165	165	154.5	10.5	0.00	0.00									0	0.9	0.5%
	144	154.5	139.5	15	0.60	9.00			0.5			0.1			0.60	5	3.0%
	135	139.5	132	7.5	0.90	6.75			0.7			0.2			0.88	6	3.3%
	129	132	127.5	4.5	1.17	5.27			0.9			0.2			1.13	6	3.3%
	126	127.5	121.5	6	1.60	9.60			1.3		0.98	0.3		1.56	1.27	12	6.8%
	117	121.5	115.5	6	1.75	10.50			1.4		1.15	0.4		1.66	1.41	15	8.2%
	114	115.5	109.5	6	2.05	12.30			1.6		0.84	0.4		1.64	1.24	15	8.5%
	105	109.5	103.5	6	1.95	11.70			1.6		0.33	0.4		1.65	0.99	12	6.5%
	102	103.5	97.5	6	2.20	13.20			1.8		0.96	0.4		1.31	1.14	15	8.4%
	93	97.5	88.5	9	2.00	18.00			1.6		0.54	0.4		1.27	0.91	16	9.1%
	84	88.5	79.5	9	1.70	15.30			1.4		0.62	0.3		1.15	0.89	14	7.5%
	75	79.5	72	7.5	1.45	10.88			1.2		0.34	0.3		1.15	0.75	8	4.5%
	69	72	64.5	7.5	1.10	8.25			0.9			0.2			0.67	6	3.1%
	60	64.5	54	10.5	1.20	12.60			1.0			0.2			0.81	10	5.7%
	48	54	39.5	14.5	1.20	17.40			1.0			0.2			0.43	7	4.2%
	31	39.5	27	12.5	1.30	16.25			1.0			0.3			0.49	8	4.4%
	23	27	19.75	7.25	1.50	10.88			1.2			0.3			0.75	8	4.5%
	16.5	19.75	13.75	6	1.70	10.20			1.4		0.33	0.3		1.00	0.67	7	3.8%
	11	13.75	8.5	5.25	1.75	9.19			1.4			0.4			0.61	6	3.1%
	6	8.5	4.5	4	1.40	5.60			1.1			0.3			0.35	2	1.1%
	3	4.5	1.5	3	0.75	2.25			0.6			0.2			0.30	1	0.4%
RB	0	1.5	0	1.5	0.00	0.00									0	0.084	0.0%
						215.1								Total Discharge (cfs)		179	

Method:

Pygmy meter

Rod suspension

Wading access

Discharge comparisons:

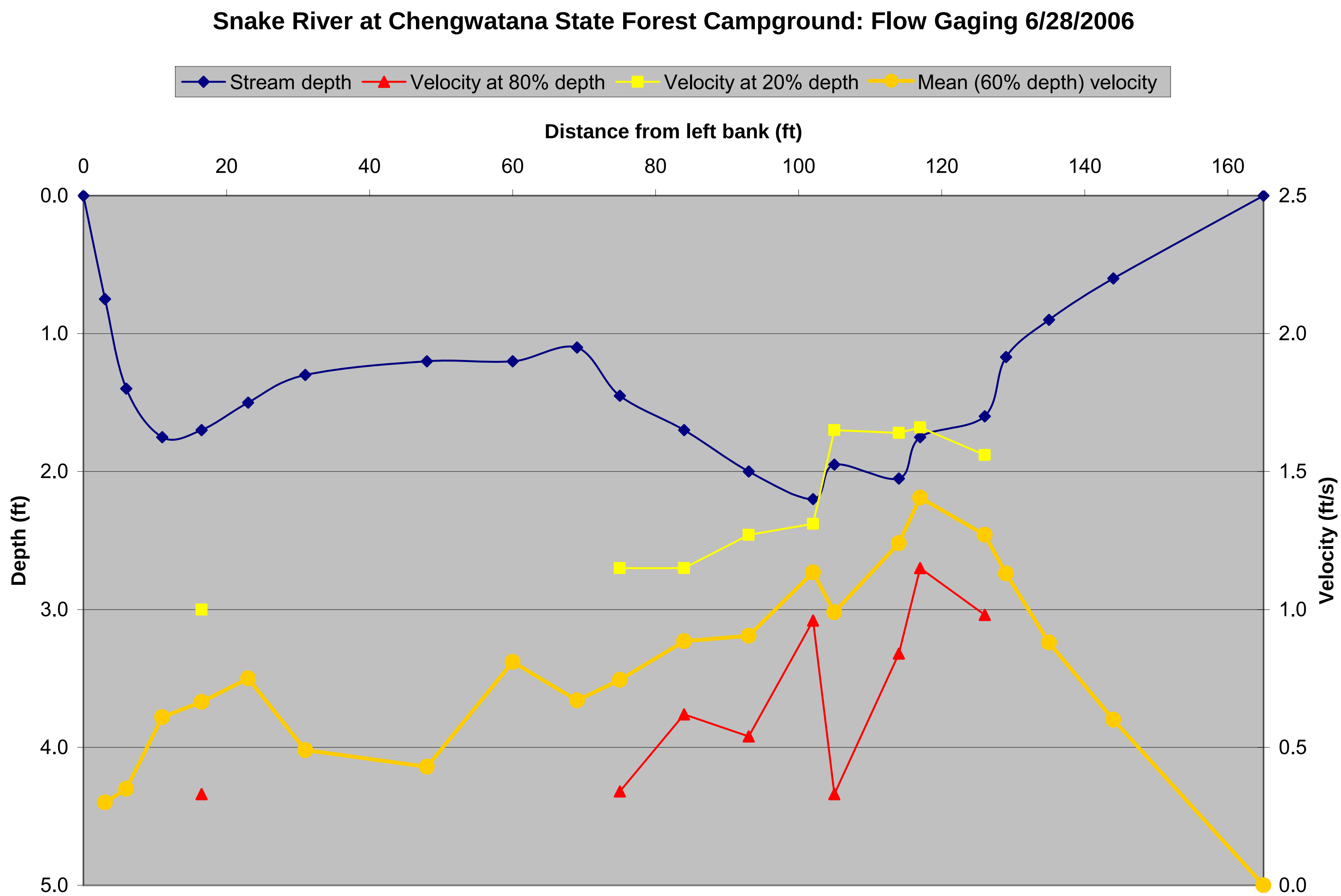
AquaCalc flow = 178.75 cfs

AquaCalc mean vel = 0.83 f/s * 218.8 ft^2 = 181.6 cfs

Spreadsheet calculation (above) = 179 cfs

Snake @ Crosslake (05338500) 6/28/06 daily mean 162 cfs MDV

Stage = 4.5 feet below ledge


Snake River at Chengwatana State Forest Campground: Flow Gaging 6/28/2006
Stream depth
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
20
40
60
80
100
120
140
160
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
Velocity (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0

Snake River at Chengwatana State Forest Campground: Flow Gaging 7/6/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	153	153	145.5	7.5	0.00	0.00									0	0.8	0.8%
	138	145.5	133.5	12	0.60	7.20			0.5			0.1			0.49	4	3.2%
	129	133.5	124.5	9	1.00	9.00			0.8			0.2			0.73	7	6.0%
	120	124.5	117	7.5	1.40	10.50			1.1			0.3			1.01	11	9.7%
	114	117	111	6	1.70	10.20			1.4		0.73	0.3		1.25	0.99	10	9.2%
	108	111	105	6	1.80	10.80			1.4		0.82	0.4		1.23	1.03	11	10.1%
	102	105	99	6	1.90	11.40			1.5		0.73	0.4		1.16	0.95	11	9.9%
	96	99	94.5	4.5	1.90	8.55			1.5		0.73	0.4		1.09	0.91	8	7.1%
	93	94.5	88.5	6	1.55	9.30			1.2			0.3			0.75	7	6.4%
	84	88.5	81	7.5	1.45	10.88			1.2			0.3			0.74	8	7.4%
	78	81	76.5	4.5	1.30	5.85			1.0			0.3			0.58	3	3.1%
	75	76.5	72	4.5	1.15	5.18			0.9			0.2			0.50	3	2.4%
	69	72	67.5	4.5	0.85	3.83			0.7			0.2			0.62	2	2.2%
	66	67.5	63	4.5	1.10	4.95			0.9			0.2			0.19	1	0.9%
	60	63	58.5	4.5	0.80	3.60			0.6			0.2			0.36	1	1.2%
	57	58.5	52.5	6	0.85	5.10			0.7			0.2			0.38	2	1.8%
	48	52.5	40.4	12.1	0.85	10.29			0.7			0.2			0.52	5	4.9%
	32.8	40.4	30.15	10.25	1.10	11.28			0.9			0.2			0.24	3	2.5%
	27.5	30.15	24.65	5.5	1.00	5.50			0.8			0.2			0.38	2	1.9%
	21.8	24.65	17.4	7.25	1.30	9.43			1.0			0.3			0.68	6	5.9%
	13	17.4	9.5	7.9	1.60	12.64			1.3			0.3			0.14	2	1.6%
	6	9.5	4.75	4.75	1.30	6.18			1.0			0.3			0.23	1	1.3%
	3.5	4.75	1.75	3	0.80	2.40			0.6			0.2			0.24	1	0.5%
RB	0	1.75	0	1.75	0.00	0.00									0	0.084	0.1%
						174.0								Total Discharge (cfs)		109	

Method:

Pygmy meter

Rod suspension

Wading access

Discharge comparisons:

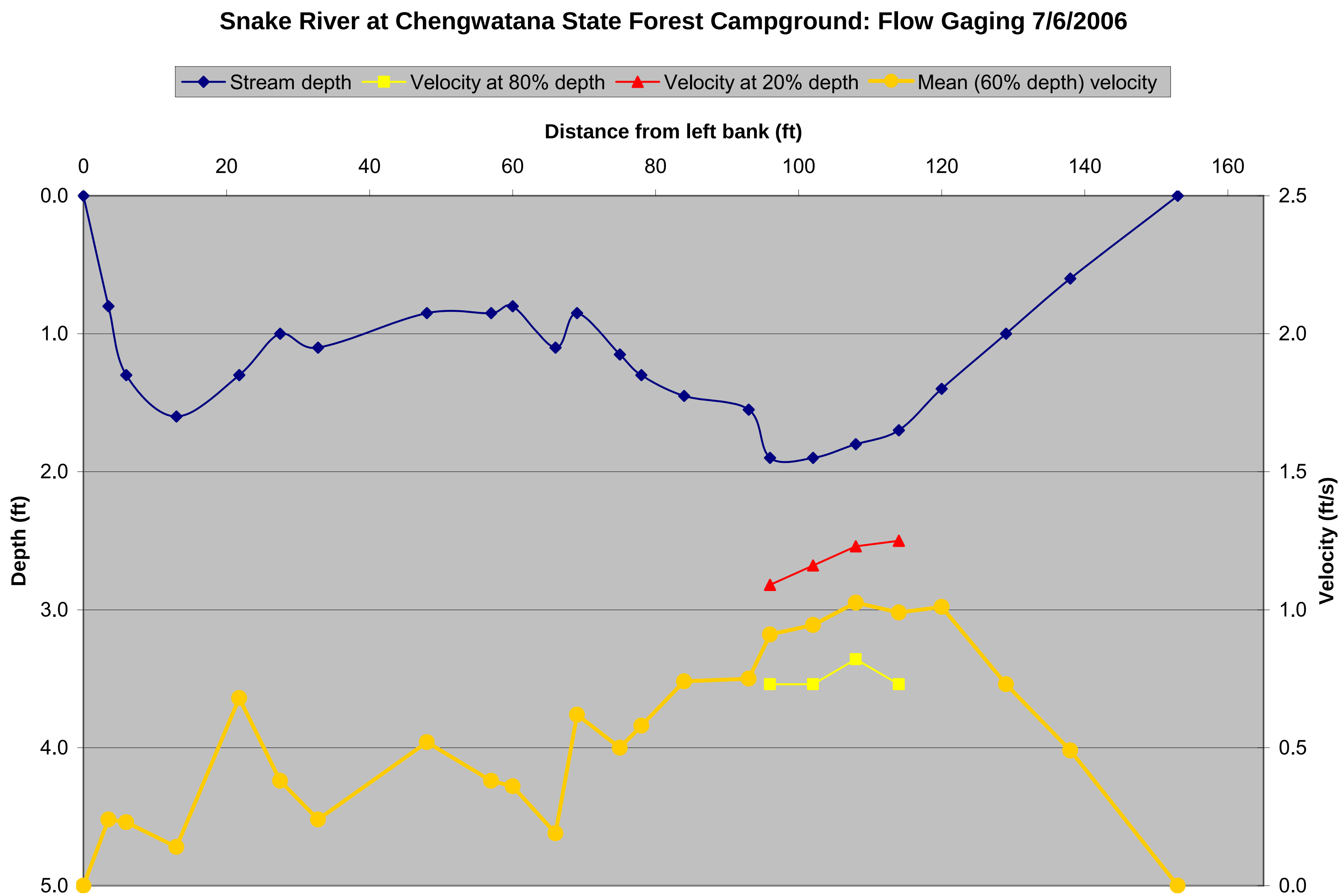
AquaCalc flow = 108.12 cfs

AquaCalc mean vel = 0.62 f/s * 177 ft^2 = 109.7 cfs

Spreadsheet calculation (above) = 109 cfs

Snake @ Crosslake (05338500) 7/6/06 daily mean 107 cfs MDV

Stage = 5.1 feet below ledge


Snake River at Chengwatana State Forest Campground: Flow Gaging 7/6/2006
Stream depth
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
20
40
60
80
100
120
140
160
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
Velocity (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0

Snake River at Chengwatana State Forest Campground: Flow Gaging 7/26/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	150	150	142.5	7.5	0.00	0.00									0	0.6	0.5%
	135	142.5	130.5	12	0.70	8.40			0.6			0.1			0.43	4	3.5%
	126	130.5	121.5	9	1.25	11.25			1.0			0.3			0.97	11	10.5%
	117	121.5	114	7.5	1.70	12.75			1.4		0.83	0.3		1.22	1.03	13	12.6%
	111	114	108	6	1.85	11.10			1.5		0.65	0.4		1.13	0.89	10	9.5%
	105	108	102	6	1.90	11.40			1.5		0.67	0.4		1.05	0.86	10	9.4%
	99	102	96	6	2.00	12.00			1.6		0.57	0.4		1.01	0.79	9	9.1%
	93	96	88.5	7.5	1.65	12.38			1.3		0.59	0.3		0.92	0.76	9	9.0%
	84	88.5	81	7.5	1.30	9.75			1.0			0.3			0.54	5	5.1%
	78	81	76.5	4.5	1.35	6.08			1.1			0.3			0.55	3	3.2%
	75	76.5	72	4.5	1.10	4.95			0.9			0.2			0.57	3	2.7%
	69	72	66	6	1.10	6.60			0.9			0.2			0.28	2	1.8%
	63	66	57	9	1.00	9.00			0.8			0.2			0.24	2	2.1%
	51	57	49.5	7.5	0.70	5.25			0.6			0.1			0.15	1	0.8%
	48	49.5	40.5	9	0.90	8.10			0.7			0.2			0.34	3	2.6%
	33	40.5	28	12.5	1.25	15.63			1.0			0.3			0.38	6	5.7%
	23	28	22	6	1.35	8.10			1.1			0.3			0.65	5	5.1%
	21	22	18	4	1.45	5.80			1.2			0.3			0.41	2	2.3%
	15	18	13	5	1.45	7.25			1.2			0.3			0.43	3	3.0%
	11	13	8	5	0.90	4.50			0.7			0.2			0.34	2	1.5%
RB	5	8	5	3	0.00	0.00									0	0.230	0.2%
						170.3								Total Discharge (cfs)		104.1	

Method:

Pygmy meter

Rod suspension

Wading access

Discharge comparisons:

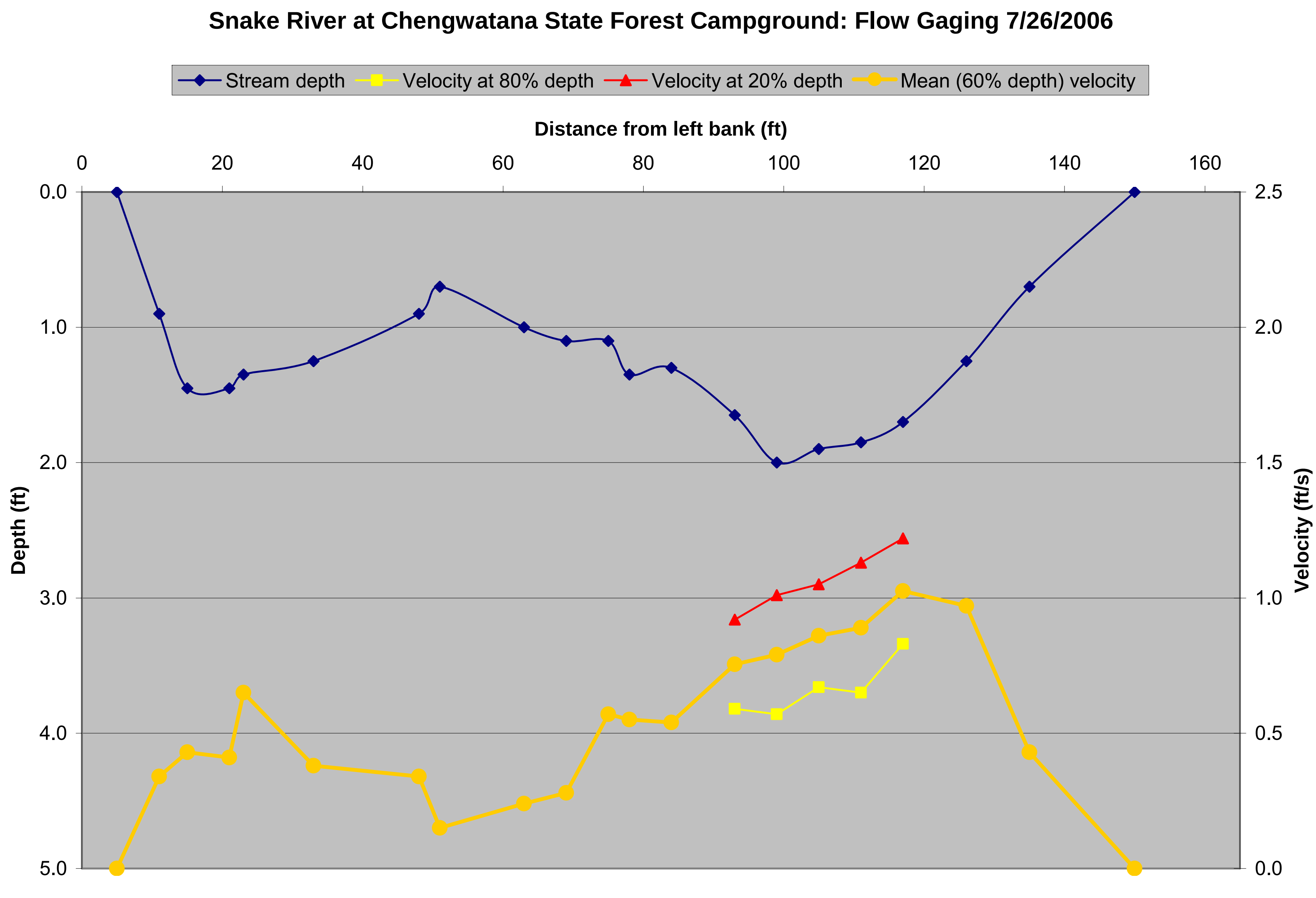
AquaCalc flow = 104.33 cfs

AquaCalc mean vel = 0.61 f/s * 174.3 ft^2 = 106.3 cfs

Spreadsheet calculation (above) = 104.1 cfs

Snake @ Crosslake (05338500) 7/26/06 daily mean 91 cfs MDV

Stage = 5.29 feet below ledge


Snake River at Chengwatana State Forest Campground: Flow Gaging 7/26/2006
Stream depth
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
20
40
60
80
100
120
140
160
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
Velocity (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0

Snake River at Chengwatana State Forest Campground: Flow Gaging 8/25/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	153	153	142.5	10.5	0.00	0.00									0	1.8	1.5%
	132	142.5	124.5	18	0.80	14.40			0.6		0.84	0.2			0.84	12	10.0%
	117	124.5	114	10.5	1.35	14.18			1.1		1.24	0.3			1.24	18	14.5%
	111	114	106.5	7.5	1.60	12.00			1.3		0.98	0.3			0.98	12	9.7%
	102	106.5	99	7.5	1.85	13.88			1.5		0.84	0.4			0.84	12	9.6%
	96	99	93	6	1.55	9.30			1.2		1.10	0.3			1.10	10	8.4%
	90	93	85.5	7.5	1.55	11.63			1.2		0.97	0.3			0.97	11	9.3%
	81	85.5	78	7.5	1.50	11.25			1.2		0.51	0.3			0.51	6	4.7%
	75	78	72	6	1.30	7.80			1.0		0.56	0.3			0.56	4	3.6%
	69	72	67.5	4.5	1.35	6.08			1.1		0.61	0.3			0.61	4	3.1%
	66	67.5	63	4.5	1.00	4.50			0.8		0.48	0.2			0.48	2	1.8%
	60	63	55.5	7.5	1.25	9.38			1.0		0.26	0.3			0.26	2	2.0%
	51	55.5	48	7.5	1.20	9.00			1.0		0.27	0.2			0.27	2	2.0%
	45	48	38.15	9.85	1.00	9.85			0.8		0.20	0.2			0.20	2	1.6%
	31.3	38.15	28.85	9.3	1.30	12.09			1.0		0.31	0.3			0.31	4	3.1%
	26.4	28.85	23.05	5.8	1.50	8.70			1.2		0.47	0.3			0.47	4	3.4%
	19.7	23.05	15.3	7.75	1.70	13.18			1.4		0.60	0.3			0.60	8	6.5%
	10.9	15.3	8.45	6.85	1.70	11.65			1.4		0.39	0.3			0.39	5	3.8%
	6	8.45	3	5.45	1.25	6.81			1.0		0.21	0.3			0.21	1	1.2%
RB	0	3	0	3	0.00	0.00									0	0.197	0.2%
						185.6								Total Discharge (cfs)		121.1	

Method:

Type AA meter

Rod suspension

Wading access

Discharge comparisons:

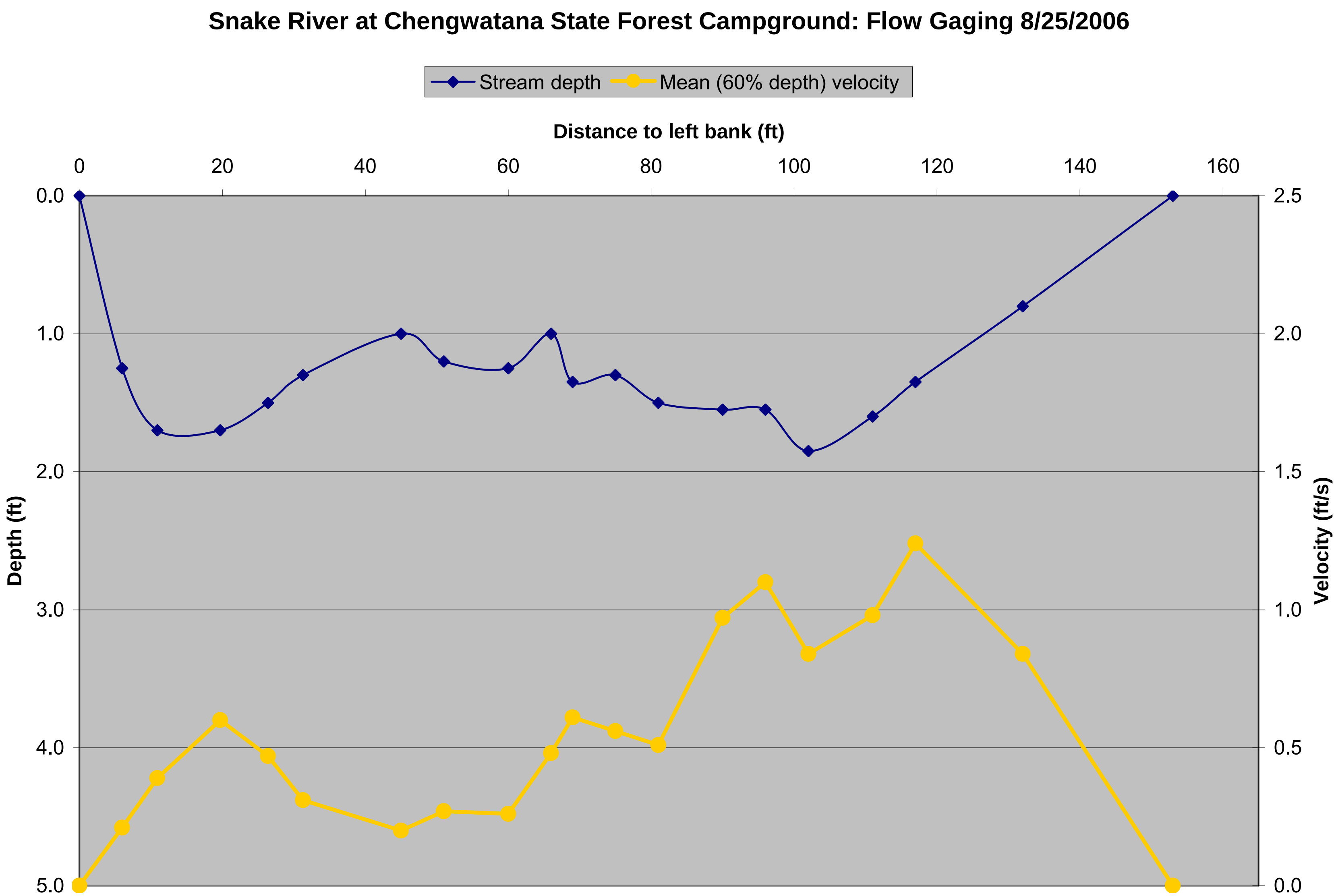
AquaCalc flow = 120.07 cfs

AquaCalc mean vel = 0.64 f/s * 191.7 ft^2 = 122.7 cfs

Spreadsheet calculation (above) = 121 cfs

Snake @ Crosslake (05338500) 8/25/06 daily mean 114 cfs MDV

Stage = 4.5 feet below ledge


Snake River at Chengwatana State Forest Campground: Flow Gaging 8/25/2006
Stream depth
Mean (60% depth) velocity
Distance to left bank (ft)
0
20
40
60
80
100
120
140
160
Depth (ft)
0.0
1.0
2.0
3.0
4.0
5.0
Velocity (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0

Namekagon River at Earl: Flow Gaging 5/22/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8depth velocity (fps)	20% depth (ft)	Meas depth (ft)	.2depth velocity (fps)	Mean (.6depth) velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	4.35	4.35	0.00	0.00									0	3.0	1.5%
	8.7	4.35	10.35	6	3.05	18.30		√	2.4		0.87	0.6		0.96	0.92	17	8.1%
	12	10.35	14.2	3.85	3.05	11.74		√	2.4		1.03	0.6		1.04	1.04	12	5.9%
	16.4	14.2	17.7	3.5	3.30	11.55		√	2.6		0.99	0.7		1.03	1.01	12	5.7%
	19	17.7	21.5	3.8	3.30	12.54		√	2.6		0.85	0.7		1.10	0.98	12	5.9%
	24	21.5	26	4.5	3.55	15.98		√	2.8		0.99	0.7		1.13	1.06	17	8.2%
	28	26	29.9	3.9	3.55	13.85		√	2.8		0.92	0.7		1.14	1.03	14	6.9%
	31.8	29.9	33.9	4	3.55	14.20		√	2.8		0.96	0.7		1.11	1.04	15	7.1%
	36	33.9	37.75	3.85	3.55	13.67		√	2.8		1.05	0.7		1.19	1.12	15	7.4%
	39.5	37.75	41.25	3.5	3.55	12.43		√	2.8		1.00	0.7		1.20	1.10	14	6.6%
	43	41.25	45	3.75	3.55	13.31		√	2.8		0.96	0.7		1.17	1.07	14	6.9%
	47	45	49	4	3.55	14.20		√	2.8		0.97	0.7		1.10	1.04	15	7.1%
	51	49	52.9	3.9	3.30	12.87		√	2.6		1.06	0.7		1.12	1.09	14	6.8%
	54.8	52.9	56.9	4	2.55	10.20	√		2.0			0.5			1.08	11	5.3%
	59	56.9	60.75	3.85	2.05	7.89	√		1.6			0.4			1.01	8	3.9%
	62.5	60.75	63.75	3	1.80	5.40	√		1.4			0.4			0.99	5	2.6%
	65	63.75	66.75	3	1.80	5.40	√		1.4			0.4			0.88	5	2.3%
	68.5	66.75	70.25	3.5	1.80	6.30	√		1.4			0.4			0.53	3	1.6%
RB	72	70.25	72	1.75	0.00	0.00									0	0.417	0.2%
						199.8								Total Discharge (cfs)		206	

Method:

Type AA meter

Cable suspension

Bridge access

Discharge comparisons:

AquaCalc flow = 190.69 cfs

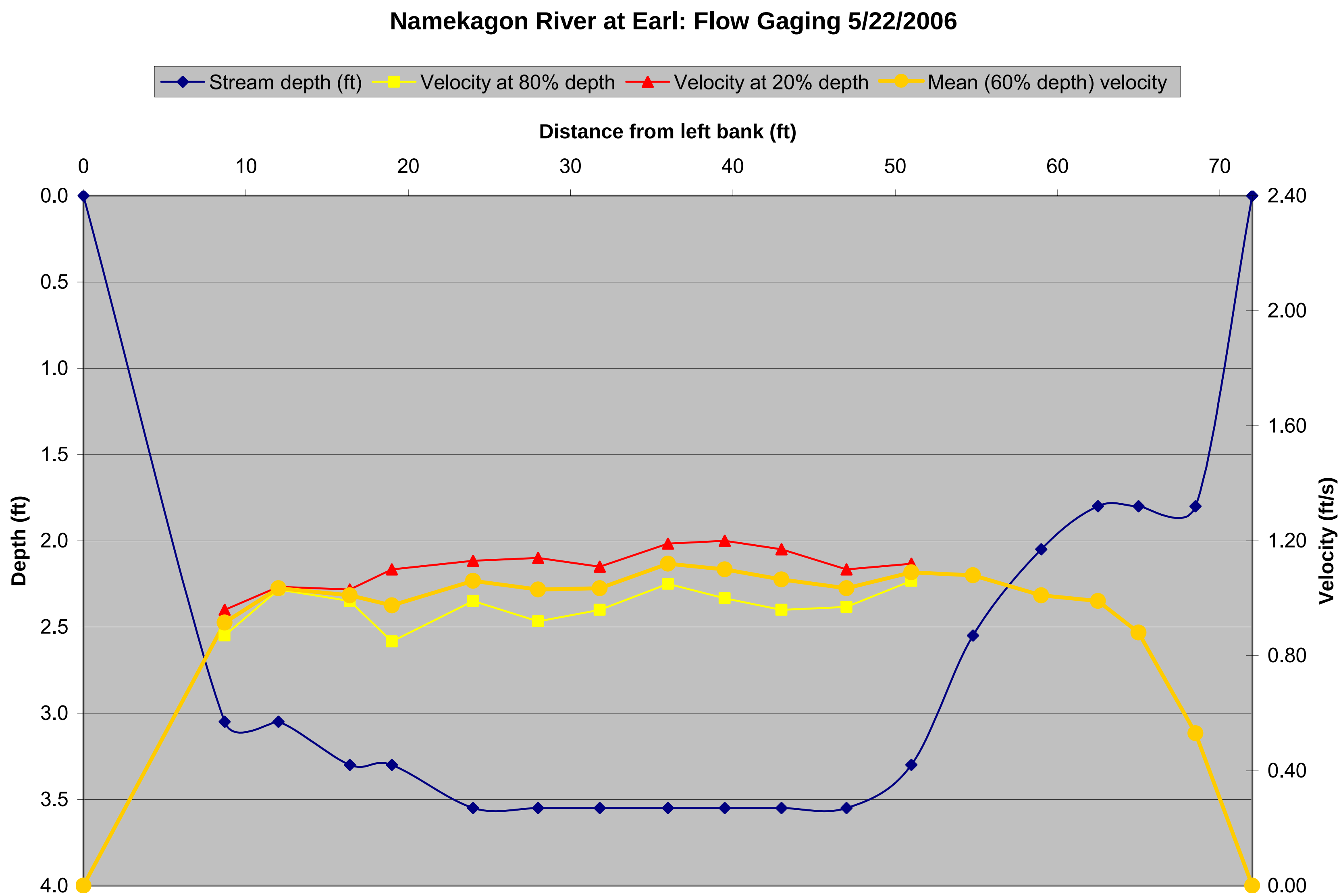
AquaCalc mean vel = 0.93 f/s * 208.9 ft^2 = 193.4 cfs

Spreadsheet calculation (above) = 206 cfs

Leonards (05331833) 5/22/06 daily mean 126 cfs MDV = 66%

Danbury (05333500) 5/22/06 daily mean 1150 cfs MDV = 602%

Stage = 16.7 feet below bridge railing


Namekagon River at Earl: Flow Gaging 5/22/2006
Stream depth (ft)
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Velocity (ft/s)
2.40
2.00
1.60
1.20
0.80
0.40
0.00

Namekagon River at Earl: Flow Gaging 6/2/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	2	2	0.00	0.00									0	0.6	0.3%
	4	2	6.35	4.35	1.80	7.83	√								0.62	5	
	8.7	6.35	10.35	4	2.55	10.20	√		2.0			0.5			0.86	9	5.0%
	12	10.35	14.5	4.15	2.80	11.62	√		2.2			0.6			0.93	11	6.1%
	17	14.5	18.5	4	3.30	13.20		√	2.6	2.3	0.75	0.7	1.0	0.92	0.84	11	6.2%
	20	18.5	22	3.5	3.05	10.68		√	2.4	2.0	0.83	0.6	1.0	1.00	0.92	10	5.5%
	24	22	26	4	3.55	14.20		√	2.8	2.5	0.99	0.7	1.0	1.04	1.02	14	8.1%
	28	26	30.5	4.5	3.55	15.98		√	2.8	2.5	0.97	0.7	1.0	1.03	1.00	16	9.0%
	33	30.5	34.5	4	3.55	14.20	√		2.8			0.7			0.93	13	7.5%
	36	34.5	37.75	3.25	3.55	11.54		√	2.8	2.5	0.96	0.7	1.0	1.08	1.02	12	6.7%
	39.5	37.75	41.25	3.5	3.30	11.55		√	2.6	2.5	0.99	0.7	1.0	1.10	1.05	12	6.8%
	43	41.25	45	3.75	3.55	13.31	√		2.8			0.7			1.07	14	8.1%
	47	45	49	4	3.05	12.20	√		2.4			0.6			1.01	12	7.0%
	51	49	52.9	3.9	3.05	11.90	√		2.4			0.6			0.94	11	6.3%
	54.8	52.9	56.9	4	2.55	10.20	√		2.0			0.5			1.01	10	5.8%
	59	56.9	60.75	3.85	1.55	5.97	√		1.2			0.3			0.89	5	3.0%
	62.5	60.75	63.75	3	1.55	4.65	√		1.2			0.3			0.87	4	2.3%
	65	63.75	67	3.25	1.55	5.04	√		1.2			0.3			0.78	4	2.2%
	69	67	70.5	3.5	1.35	4.73	√		1.1			0.3			0.45	2	1.2%
RB	72	70.5	72	1.5	0.00	0.00			0.0			0.0			0	0.228	0.1%
						189.0									Total Discharge (cfs)	177	

Method:

Type AA meter

Cable suspension

Bridge access

Discharge comparisons:

AquaCalc flow = 172.42 cfs

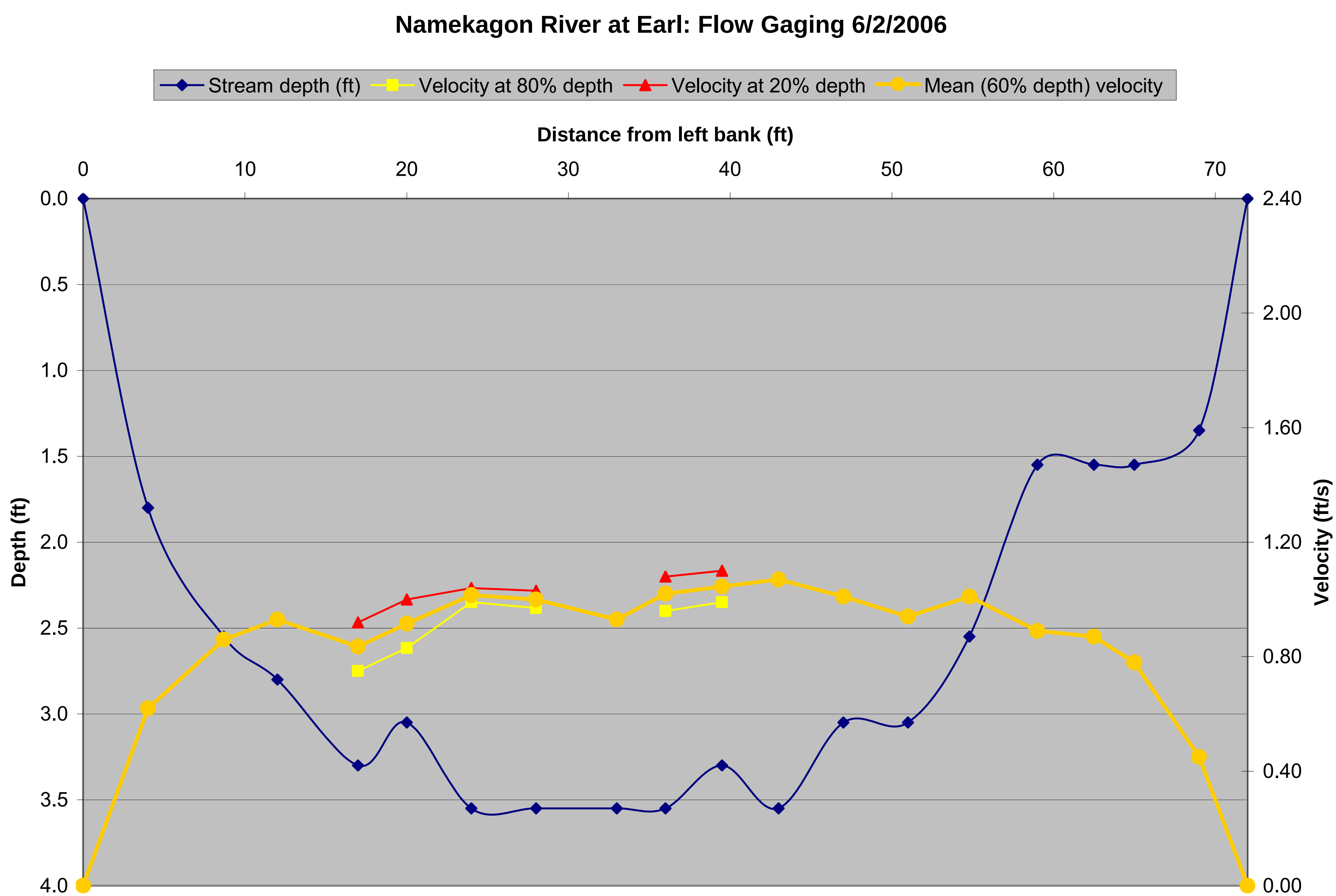
AquaCalc mean vel = 0.93 f/s * 192.5 ft^2 = 179.0 cfs

Spreadsheet calculation (above) = 177 cfs

Leonards (05331833) 6/2/06 daily mean 110 cfs MDV = 64%

Danbury (05333500) 6/2/06 daily mean 950 cfs MDV = 552%

Stage = 16.95 feet below bridge railing


Namekagon River at Earl: Flow Gaging 6/2/2006
Stream depth (ft)
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Velocity (ft/s)
2.40
2.00
1.60
1.20
0.80
0.40
0.00

Namekagon River at Earl: Flow Gaging 6/15/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	4.35	4.35	0.00	0.00									0	1.8	1.6%
	8.7	4.35	10.35	6	2.10	12.60	√		1.7		0.77	0.4			0.77	10	8.7%
	12	10.35	14.2	3.85	2.00	7.70	√		1.6		0.77	0.4			0.77	6	5.3%
	16.4	14.2	17.7	3.5	2.50	8.75	√		2.0		0.74	0.5			0.74	6	5.8%
	19	17.7	22	4.3	2.00	8.60	√		1.6		0.80	0.4			0.80	7	6.2%
	25	22	26.5	4.5	1.50	6.75	√		1.2		0.81	0.3			0.81	5	4.9%
	28	26.5	29.9	3.4	2.20	7.48	√		1.8		0.87	0.4			0.87	7	5.9%
	31.8	29.9	33.9	4	2.30	9.20	√		1.8		0.86	0.5			0.86	8	7.1%
	36	33.9	37.75	3.85	2.40	9.24	√		1.9		0.90	0.5			0.90	8	7.5%
	39.5	37.75	41.25	3.5	2.40	8.40	√		1.9		0.91	0.5			0.91	8	6.9%
	43	41.25	45	3.75	2.30	8.63	√		1.8		0.93	0.5			0.93	8	7.2%
	47	45	49	4	2.30	9.20	√		1.8		0.91	0.5			0.91	8	7.5%
	51	49	52.9	3.9	2.10	8.19	√		1.7		0.87	0.4			0.87	7	6.4%
	54.8	52.9	56.4	3.5	2.30	8.05	√		1.8		0.88	0.5			0.88	7	6.4%
	58	56.4	60.25	3.85	1.80	6.93	√		1.4		0.69	0.4			0.69	5	4.3%
	62.5	60.25	67.25	7	1.50	10.50	√		1.2		0.75	0.3			0.75	8	7.1%
RB	72	67.25	72	4.75	0.00	0.00									0	1.336	1.2%
						130.2								Total Discharge (cfs)		111	

Method:

Type AA meter

Cable suspension

Bridge access

Discharge comparisons:

AquaCalc flow = 98.23 cfs

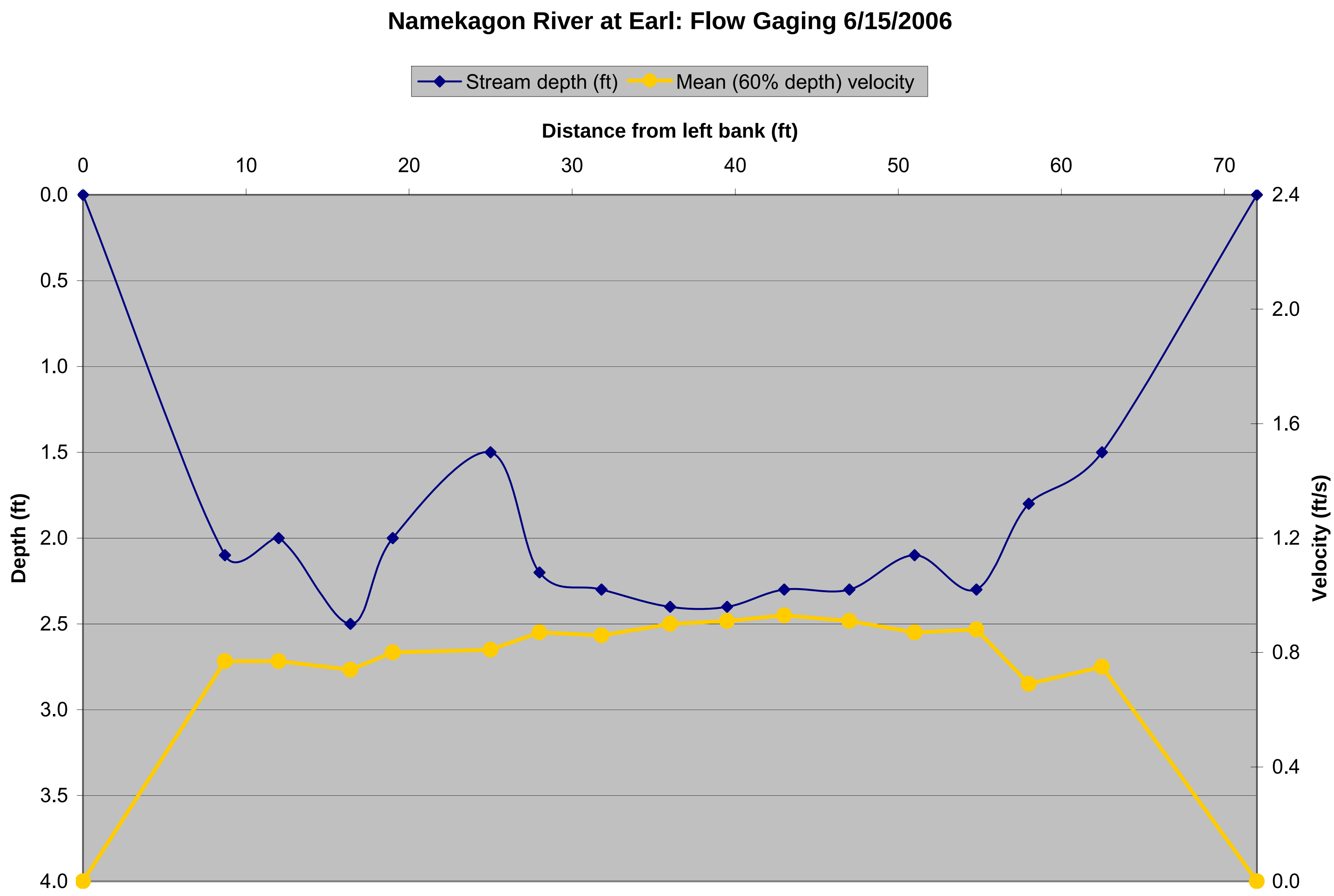
AquaCalc mean vel = 0.73 f/s * 138.3 ft^2 = 101.0 cfs

Spreadsheet calculation (above) = 111 cfs

Leonards (05331833) 6/15/06 daily mean 79 cfs MDV = 81%

Danbury (05333500) 6/15/06 daily mean 754 cfs MDV = 769%

Stage = 17.2 feet below bridge railing


Namekagon River at Earl: Flow Gaging 6/15/2006
Stream depth (ft)
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Velocity (ft/s)
2.4
2.0
1.6
1.2
0.8
0.4
0.0

Namekagon River at Earl: Flow Gaging 6/22/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	2	2	0.00	0.00									0	0.1	0.1%
	4	2	6.35	4.35	1.55	6.74	√				0.19				0.19	1	1.3%
	8.7	6.35	10.35	4	2.10	8.40	√		1.7		0.73	0.4			0.73	6	6.2%
	12	10.35	14.2	3.85	2.00	7.70	√		1.6		0.79	0.4			0.79	6	6.1%
	16.4	14.2	17.7	3.5	2.45	8.58	√		2.0		0.69	0.5			0.69	6	6.0%
	19	17.7	22	4.3	2.00	8.60	√		1.6		0.67	0.4			0.67	6	5.8%
	25	22	26.5	4.5	2.00	9.00	√		1.6		0.78	0.4			0.78	7	7.1%
	28	26.5	29.9	3.4	2.00	6.80	√		1.6		0.77	0.4			0.77	5	5.3%
	31.8	29.9	33.9	4	2.00	8.00	√		1.6		0.73	0.4			0.73	6	5.9%
	36	33.9	37.75	3.85	2.20	8.47	√		1.8		0.86	0.4			0.86	7	7.3%
	39.5	37.75	41.25	3.5	2.20	7.70	√		1.8		0.76	0.4			0.76	6	5.9%
	43	41.25	45	3.75	2.40	9.00	√		1.9		0.81	0.5			0.81	7	7.3%
	47	45	49	4	2.20	8.80	√		1.8		0.85	0.4			0.85	7	7.5%
	51	49	52.9	3.9	2.00	7.80	√		1.6		0.88	0.4			0.88	7	6.9%
	54.8	52.9	57.15	4.25	2.20	9.35	√		1.8		0.86	0.4			0.86	8	8.1%
	59.5	57.15	62.25	5.1	1.60	8.16	√		1.3		0.85	0.3			0.85	7	7.0%
	65	62.25	66	3.75	1.50	5.63	√		1.2		0.71	0.3			0.71	4	4.0%
	67	66	69	3	1.40	4.20	√		1.1		0.42	0.3			0.42	2	1.8%
RB	71	69	71	2	0.00	0.00									0	0.294	0.3%
						132.9									Total Discharge (cfs)	99.2	

Method:

Type AA meter

Cable suspension

Bridge access

Discharge comparisons:

AquaCalc flow = 93.68 cfs

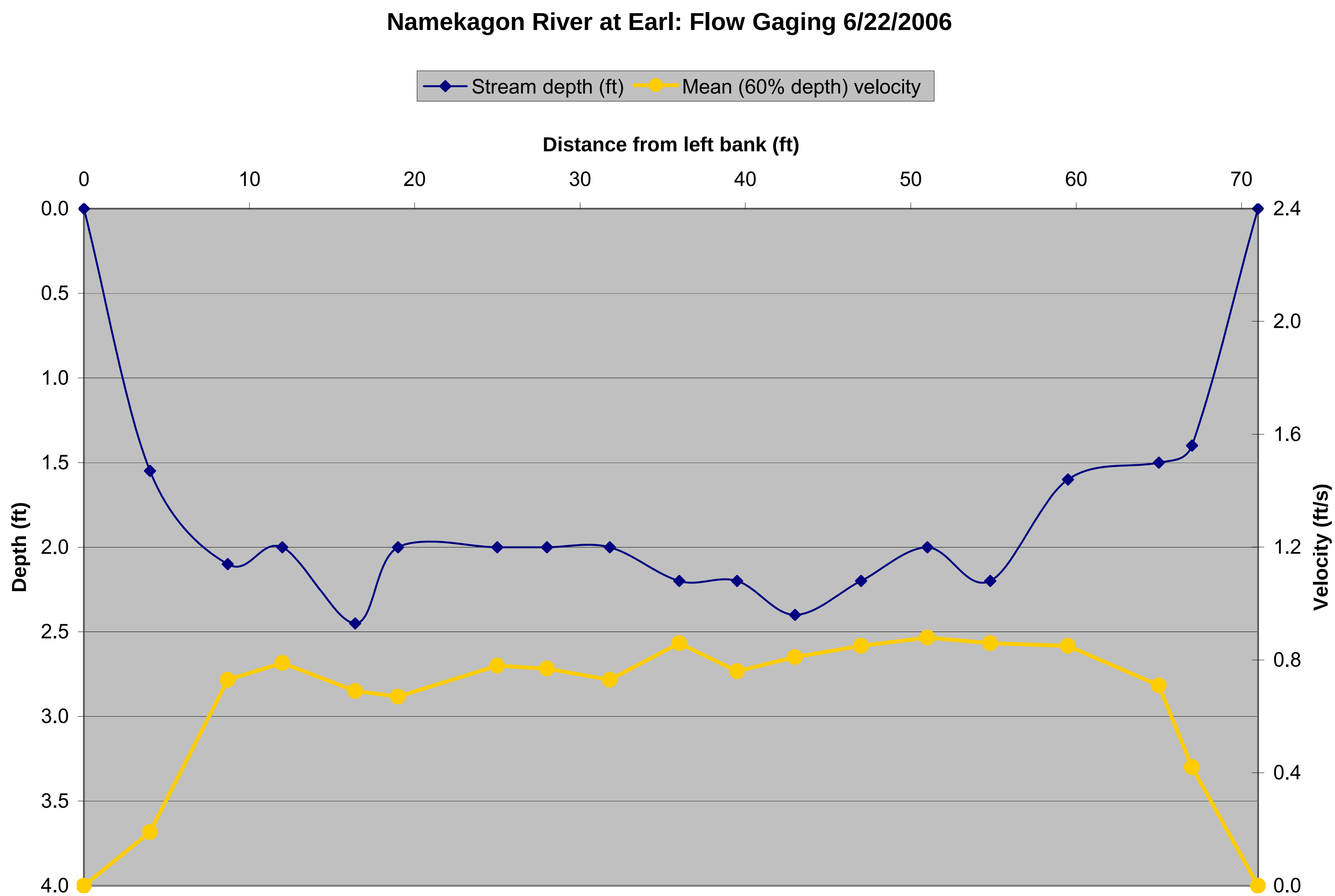
AquaCalc mean vel = 0.70 f/s * 135.9 ft^2 = 95.1 cfs

Spreadsheet calculation (above) = 99 cfs

Leonards (05331833) 6/22/06 daily mean 66 cfs MDV = 70%

Danbury (05333500) 6/22/06 daily mean 700 cfs MDV = 747%

Stage = 17.22 feet below bridge railing


Namekagon River at Earl: Flow Gaging 6/22/2006
Stream depth (ft)
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Velocity (ft/s)
2.4
2.0
1.6
1.2
0.8
0.4
0.0

Namekagon River at Earl: Flow Gaging 7/5/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	78	78	76.5	1.5	0.00	0.00									0	0.1	0.1%
	75	76.5	73.5	3	1.50	4.50	√		1.2						0.26	1	0.9%
	72	73.5	69	4.5	1.75	7.88	√		1.4			0.4			0.64	5	4.0%
	66	69	64.5	4.5	2.35	10.58	√		1.9			0.5			0.43	5	3.6%
	63	64.5	61.5	3	2.70	8.10		√	2.2		0.26	0.5		0.89	0.58	5	3.7%
	60	61.5	58.5	3	2.95	8.85		√	2.4		0.35	0.6		0.93	0.64	6	4.5%
	57	58.5	52.5	6	3.00	18.00		√	2.4		0.72	0.6		0.95	0.84	15	11.9%
	48	52.5	42.25	10.25	2.95	30.24		√	2.4		0.58	0.6		0.98	0.78	24	18.7%
	36.5	42.25	35	7.25	2.80	20.30		√	2.2		0.64	0.6		1.01	0.83	17	13.3%
	33.5	35	31.35	3.65	2.90	10.59		√	2.3		0.66	0.6		0.93	0.80	8	6.7%
	29.2	31.35	25.6	5.75	2.70	15.53		√	2.2		0.63	0.5		0.86	0.75	12	9.2%
	22	25.6	20.25	5.35	2.60	13.91		√	2.1		0.51	0.5		0.94	0.73	10	8.0%
	18.5	20.25	16.25	4	2.30	9.20	√		1.8			0.5			0.71	7	5.2%
	14	16.25	11.8	4.45	2.30	10.24	√		1.8			0.5			0.70	7	5.7%
	9.6	11.8	8.2	3.6	2.00	7.20	√		1.6			0.4			0.37	3	2.1%
	6.8	8.2	5.4	2.8	1.80	5.04	√		1.4			0.4			0.37	2	1.5%
	4	5.4	2	3.4	1.35	4.59	√		1.1			0.3			0.25	1	0.9%
RB	0	2	0	2	0.00	0.00									0	0.169	0.1%
						184.7								Total Discharge (cfs)		126.2	

Method:

Type AA meter

Rod suspension

Wading access

Discharge comparisons:

AquaCalc flow = 129.04 cfs

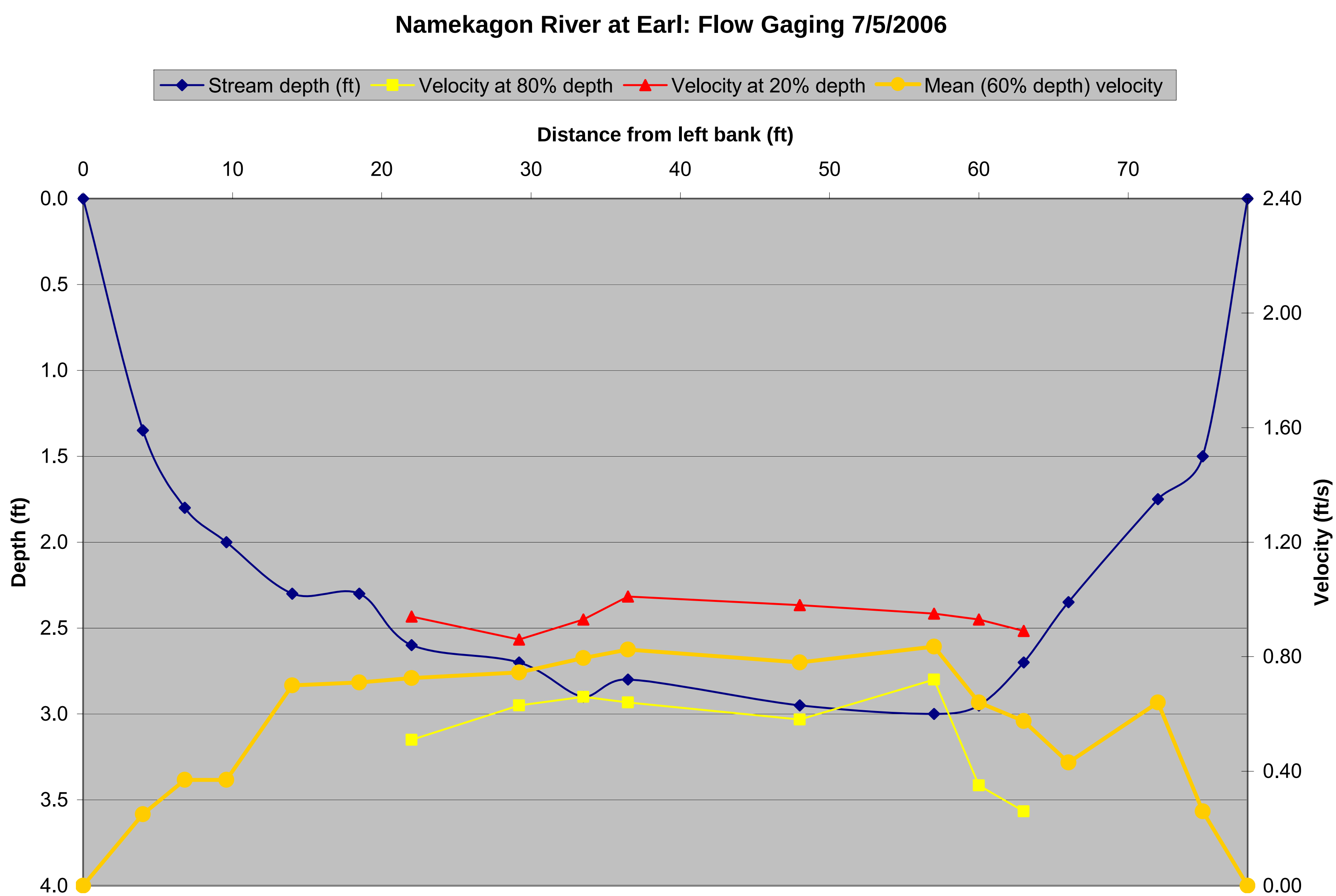
AquaCalc mean vel = 0.66 f/s * 187.2 ft^2 = 123.6 cfs

Spreadsheet calculation (above) = 126.2 cfs

Leonards (05331833) 7/5/06 daily mean 61 cfs MDV = 47%

Danbury (05333500) 7/5/06 daily mean 608 cfs MDV = 471%

Stage = 17.3 feet below bridge railing


Namekagon River at Earl: Flow Gaging 7/5/2006
Stream depth (ft)
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Depth (ft)
2.40
2.00
1.60
1.20
0.80
0.40
0.00
Velocity (ft/s)

Namekagon River at Earl: Flow Gaging 7/10/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	2	2	0.00	0.00									0	0.4	0.2%
	4	2	5.45	3.45	1.55	5.35	√		1.2						0.58	3	1.4%
	6.9	5.45	9.05	3.6	1.85	6.66		√	1.5		0.35	0.4		1.16	0.76	5	2.3%
	11.2	9.05	12.4	3.35	1.75	5.86		√	1.4		0.46	0.4		1.63	1.05	6	2.8%
	13.6	12.4	15.2	2.8	2.10	5.88		√	1.7		0.37	0.4		1.50	0.94	5	2.5%
	16.8	15.2	18.95	3.75	2.60	9.75		√	2.1		0.46	0.5		1.95	1.21	12	5.3%
	21.1	18.95	24.1	5.15	3.00	15.45		√	2.4		0.60	0.6		2.05	1.33	20	9.2%
	27.1	24.1	30.1	6	2.95	17.70		√	2.4		1.31	0.6		2.11	1.71	30	13.7%
	33.1	30.1	36.4	6.3	2.85	17.96		√	2.3		1.53	0.6		2.04	1.79	32	14.5%
	39.7	36.4	42.85	6.45	2.90	18.71		√	2.3		1.30	0.6		2.29	1.80	34	15.2%
	46	42.85	48.8	5.95	2.70	16.07		√	2.2		0.81	0.5		1.95	1.38	22	10.0%
	51.6	48.8	54.95	6.15	2.50	15.38		√	2.0		1.10	0.5		1.89	1.50	23	10.4%
	58.3	54.95	61.2	6.25	2.20	13.75		√	1.8		0.59	0.4		1.67	1.13	16	7.0%
	64.1	61.2	66.2	5	1.90	9.50	√		1.5			0.4			0.85	8	3.6%
	68.3	66.2	69.6	3.4	1.65	5.61	√		1.3			0.3			0.68	4	1.7%
	70.9	69.6	72.3	2.7	1.00	2.70	√		0.8			0.2			0.16	0	0.2%
RB	73.7	72.3	73.7	1.4	0.00	0.00									0	0.056	0.0%
						166.3								Total Discharge (cfs)		221.4	

Method:

Pygmy meter

Rod suspension

Wading access

Discharge comparisons:

AquaCalc flow = 215.68 cfs

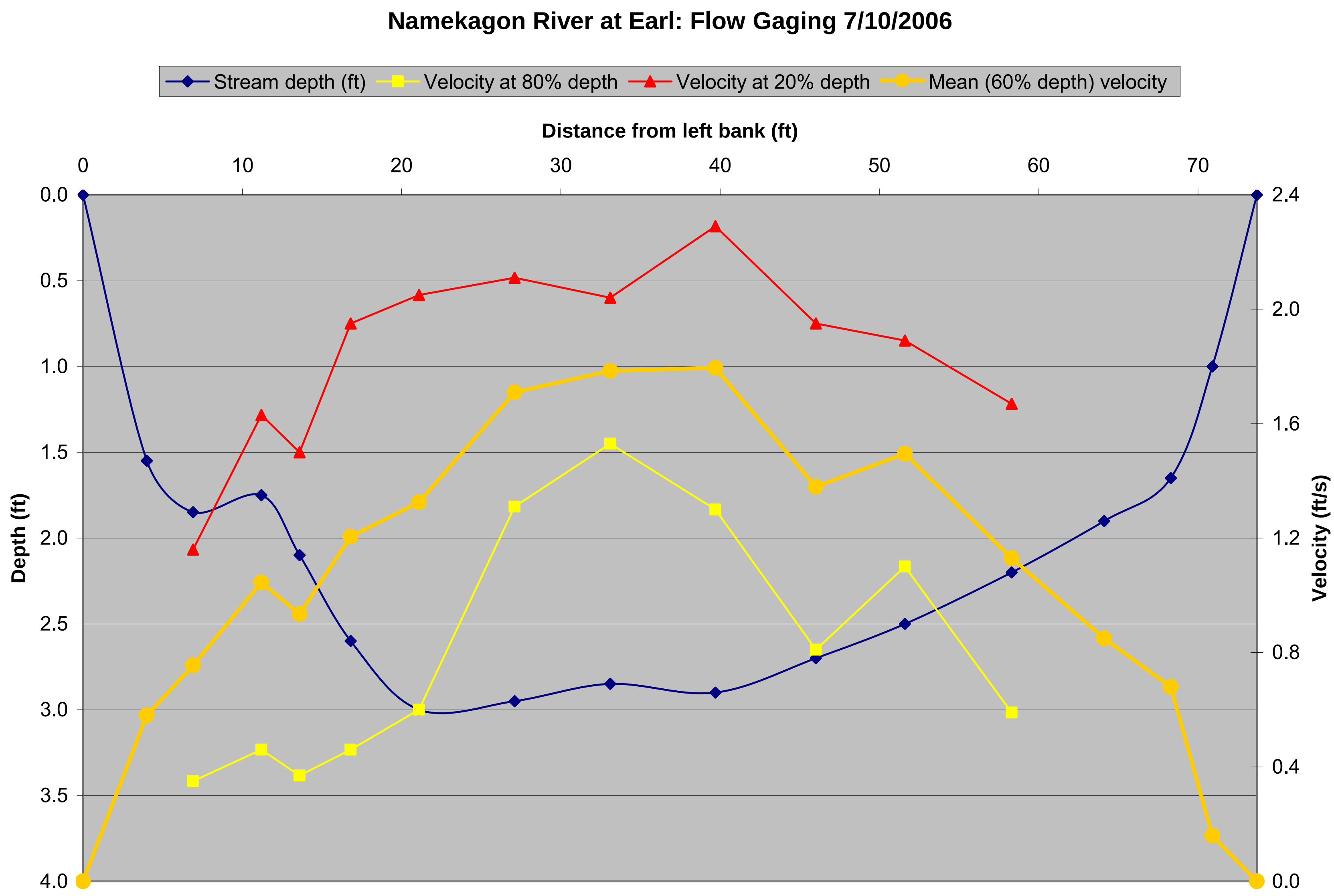
AquaCalc mean vel = 1.29 f/s * 168.6 ft^2 = 217.5 cfs

Spreadsheet calculation (above) = 221 cfs

Leonards (05331833) 7/10/06 daily mean 54 cfs MDV = 25%

Danbury (05333500) 7/10/06 daily mean 574 cfs MDV = 260%

Stage = 17.33 feet below bridge railing


Namekagon River at Earl: Flow Gaging 7/10/2006
Stream depth (ft)
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Velocity (ft/s)
2.4
2.0
1.6
1.2
0.8
0.4
0.0

Namekagon River at Earl: Flow Gaging 7/19/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	2	2	0.00	0.00									0	0.5	0.2%
	4	2	6.35	4.35	1.45	6.31	√		1.2						0.71	4	1.9%
	8.7	6.35	10.35	4	1.65	6.60	√		1.3			0.3			0.75	5	2.1%
	12	10.35	14.2	3.85	1.55	5.97	√		1.2			0.3			1.53	9	3.8%
	16.4	14.2	17.7	3.5	2.55	8.93		√	2.0		1.08	0.5		1.32	1.20	11	4.5%
	19	17.7	21.5	3.8	2.80	10.64		√	2.2		1.21	0.6		1.58	1.40	15	6.3%
	24	21.5	26	4.5	2.90	13.05		√	2.3		1.29	0.6		1.67	1.48	19	8.1%
	28	26	29.9	3.9	3.00	11.70		√	2.4		1.56	0.6		1.70	1.63	19	8.0%
	31.8	29.9	33.9	4	3.00	12.00		√	2.4		1.41	0.6		1.56	1.49	18	7.5%
	36	33.9	37.75	3.85	2.80	10.78		√	2.2		1.52	0.6		1.73	1.63	18	7.4%
	39.5	37.75	41.25	3.5	2.80	9.80		√	2.2		1.72	0.6		1.99	1.86	18	7.7%
	43	41.25	45	3.75	3.00	11.25		√	2.4		1.51	0.6		1.90	1.71	19	8.1%
	47	45	49	4	2.80	11.20		√	2.2		1.55	0.6		1.76	1.66	19	7.8%
	51	49	53	4	3.00	12.00		√	2.4		1.54	0.6		1.76	1.65	20	8.3%
	55	53	57	4	2.60	10.40		√	2.1		1.64	0.5		1.75	1.70	18	7.4%
	59	57	60.75	3.75	1.55	5.81	√		1.2			0.3			1.37	8	3.4%
	62.5	60.75	64.25	3.5	1.45	5.08	√		1.2			0.3			1.57	8	3.4%
	66	64.25	69	4.75	1.65	7.84	√		1.3			0.3			1.07	8	3.5%
RB	72	69	72	3	0.00	0.00									0	1.3	0.6%
						159.3								Total Discharge (cfs)		237.3	

Method:

Type AA meter

Cable suspension

Bridge access

Discharge comparisons:

AquaCalc flow = 227.36 cfs

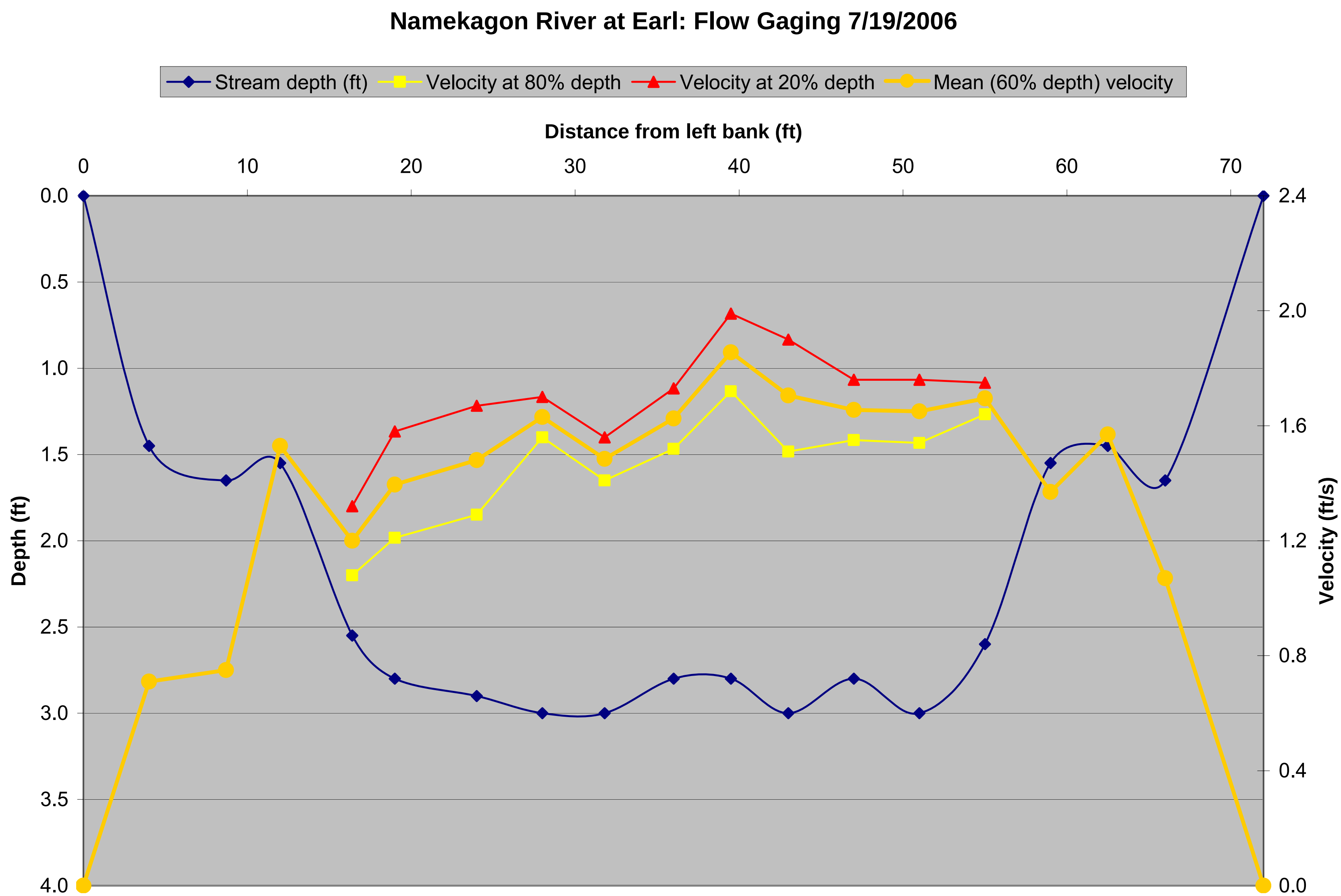
AquaCalc mean vel = 1.42 f/s * 163.3 ft^2 = 231.9 cfs

Spreadsheet calculation (above) = 237.3 cfs

Leonards (05331833) 7/19/06 daily mean 52 cfs MDV = 23%

Danbury (05333500) 7/19/06 daily mean 533 cfs MDV = 235%

Stage = 17.4 feet below bridge railing


Namekagon River at Earl: Flow Gaging 7/19/2006
Stream depth (ft)
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Velocity (ft/s)
2.4
2.0
1.6
1.2
0.8
0.4
0.0

Namekagon River at Earl: Flow Gaging 8/16/2006

	Distance from L / R bank (circle one)	Partial section start (ft)	Partial section end (ft)	Partial section width (ft)	Total depth (ft)	Area (ft^2)	1-pt meas √	2-pt meas √	80% depth (ft)	Meas depth (ft)	.8Flow velocity (fps)	20% depth (ft)	Meas depth (ft)	.2Flow velocity (fps)	Mean velocity (fps)	Discharge Q=V*W*D (cfs)	Frac Flow
LB	0	0	2	2	0.00	0.00									0	0.9	0.3%
	4	2	6.35	4.35	1.75	7.61	√		1.4						1.07	8	2.5%
	8.7	6.35	10.35	4	2.30	9.20	√		1.8			0.5			1.59	15	4.5%
	12	10.35	14	3.65	2.45	8.94	√		2.0			0.5			1.66	15	4.5%
	16	14	17.5	3.5	2.85	9.98		√	2.3		1.15	0.6		1.82	1.49	15	4.5%
	19	17.5	21.5	4	3.00	12.00		√	2.4		1.36	0.6		1.90	1.63	20	6.0%
	24	21.5	26	4.5	3.10	13.95		√	2.5		1.75	0.6		1.99	1.87	26	7.9%
	28	26	29.9	3.9	3.30	12.87		√	2.6		1.69	0.7		2.04	1.87	24	7.3%
	31.8	29.9	33.9	4	3.40	13.60		√	2.7		1.35	0.7		2.00	1.68	23	6.9%
	36	33.9	37.75	3.85	3.55	13.67		√	2.8		1.71	0.7		2.11	1.91	26	7.9%
	39.5	37.75	41.25	3.5	3.70	12.95		√	3.0		1.89	0.7		2.18	2.04	26	8.0%
	43	41.25	45	3.75	3.30	12.38		√	2.6		1.68	0.7		2.11	1.90	23	7.1%
	47	45	49	4	3.55	14.20		√	2.8		1.73	0.7		2.07	1.90	27	8.2%
	51	49	53	4	3.00	12.00		√	2.4		1.88	0.6		2.05	1.97	24	7.2%
	55	53	57	4	2.60	10.40		√	2.1		1.64	0.5		2.00	1.82	19	5.8%
	59	57	60.75	3.75	1.80	6.75	√		1.4			0.4			1.75	12	3.6%
	62.5	60.75	64.25	3.5	1.80	6.30	√		1.4			0.4			1.81	11	3.5%
	66	64.25	68.15	3.9	1.80	7.02	√		1.4			0.4			1.36	10	2.9%
	70.3	68.15	71.15	3	1.55	4.65	√		1.2			0.3			0.90	4	1.3%
RB	72	71.15	72	0.85	0.00	0.00									0	0.296	0.1%
						188.5								Total Discharge (cfs)		328.4	

Method:

Type AA meter

Cable suspension

Bridge access

Discharge comparisons:

AquaCalc flow = 311.96 cfs

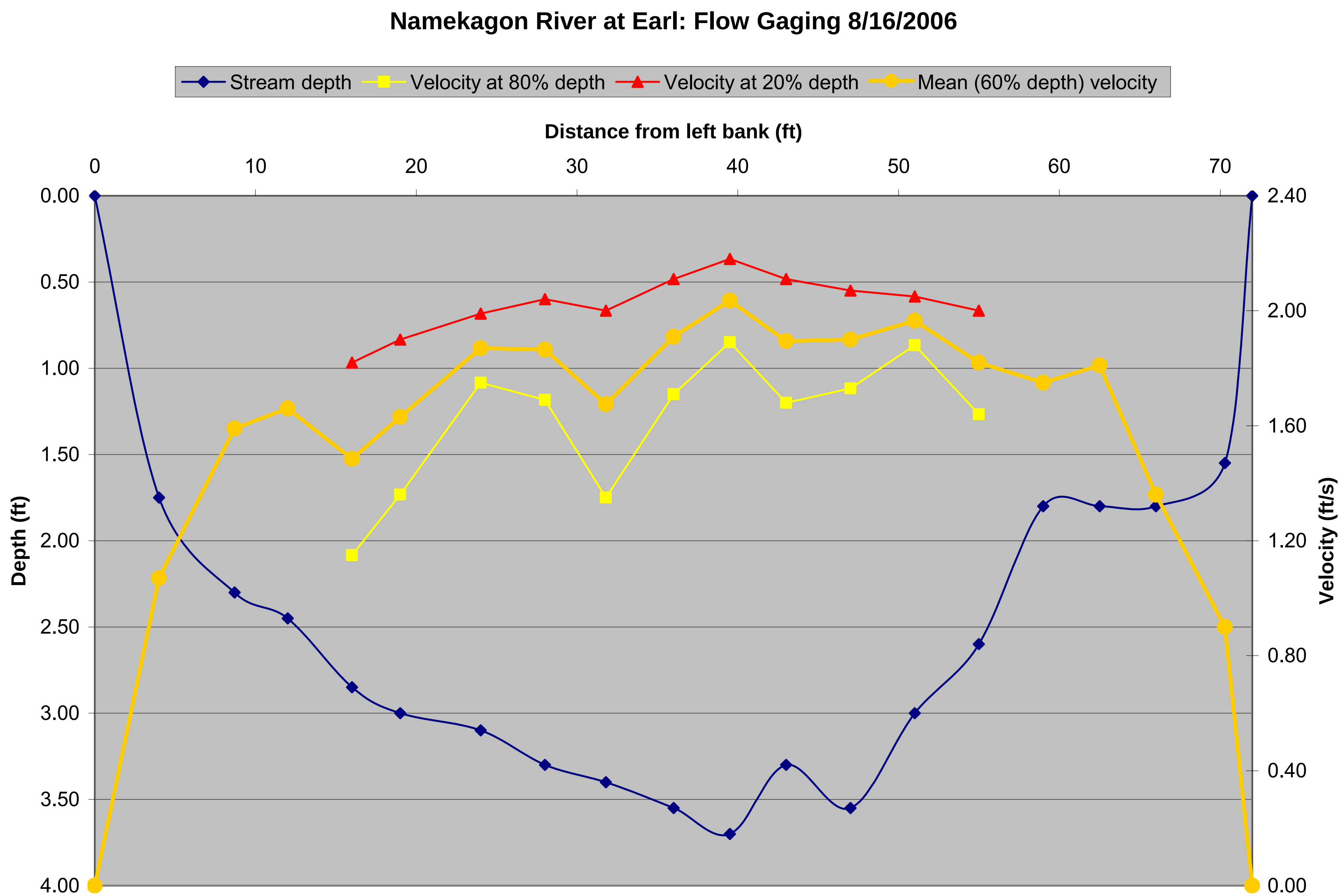
AquaCalc mean vel = 1.65 f/s * 190.9 ft^2 = 315.0 cfs

Spreadsheet calculation (above) = 328 cfs

Leonards (05331833) 8/16/06 daily mean 77 cfs MDV = 23%

Danbury (05333500) 8/16/06 daily mean 610 cfs MDV = 186%

Stage = 17.4 feet below bridge railing


Namekagon River at Earl: Flow Gaging 8/16/2006
Stream depth
Velocity at 80% depth
Velocity at 20% depth
Mean (60% depth) velocity
Distance from left bank (ft)
0
10
20
30
40
50
60
70
Depth (ft)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Velocity (ft/s)
2.40
2.00
1.60
1.20
0.80
0.40
0.00

National Park Service
U.S. Department of the Interior

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