Resolving the Water Crisis in the Russian River Watershed, CA: Demonstrating How Grapegrowers Can Monitor Stream flow and Implement Irrigation Water Management Plans to Benefit Listed Salmonids

Final Report

December 2013

Conservation Innovation Grants
NRCS Agreement #69-3A75-10-153

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Timeframe: September 2010 - September 2013
Project Manager: Laurel Marcus, California Land Stewardship Institute
Deliverables:

1. Demonstrate the use of technology to numerous grapegrowers in the Russian River watershed to lead to improvement in water management and produce benefits to multiple ecosystem services.
2. Demonstrate new technology which can be easily adopted by small-scale producers to address water supply issues.
3. Transfer conservation practices to additional growers through written protocols specifically designed for grapegrowers and intended for use in conjunction with NRCS Irrigation Water Management Plans.
4. Develop an innovative long-term solution to an environmental problem by implementing operational improvements to agriculture and by providing a method for growers to solve their own water issues.
5. Produce and distribute a new technology and innovative approach fact sheet.
6. Attend at least one NRCS CIG showcase or comparable NRCS event during the period of the agreement.
7. Provide the Natural Resources Conservation Service with quarterly progress reports and a final report outlining all deliverables at the end of the fiscal year.

Table of Contents

Executive Summary

The CIG grant funding agreement #69-3A75-10-153 supported a project completed by the California Land Stewardship Institute (CLSI) in the Russian River watershed to perform outreach and training workshops, conservation technology transfer to targeted groups for them to monitor stream flows and implement water conservation. The overall goal of the project was to increase grapegrower capacity for agricultural water and stream flow monitoring and diversion coordination in the Russian River watershed with the end result of maintaining adequate instream flows for listed salmonids. The specific objectives of the project were:

1) Demonstrate the use of technology to numerous grapegrowers in the Russian River watershed to lead to improvement in water management and produce benefits to multiple ecosystem services;
2) Demonstrate new technology which can be easily adopted by small-scale producers to address water supply issues;
3) Transfer conservation practices to additional growers through written protocols specifically designed for grapegrowers and intended for use in conjunction with NRCS Irrigation Water Management Plans;
4) Develop an innovative long-term solution to an environmental problem by implementing operational improvements to agriculture and by providing a method for growers to solve their own water issues.

As a result of this project, 48 training workshops were held for grapegrowers in the Russian River watershed to introduce stream gaging technology, train growers in installing and maintaining stream gages, discuss with growers how to coordinate their diversions and teach frost control water conservation practices. In addition, 19 stream gages were installed in four tributary watersheds of the Russian River. Hydrologists at CLSI continue to maintain the gage networks and will continue to work with growers to coordinate water diversions in the watershed.

Introduction

The Russian River watershed is an important water resource that supports a thriving wine grape industry while also providing habitat to many fish species, including three federally listed salmonids. The wine grape industry in the watershed annually generates over $2 billion in crop value, winery production, and associated tourism business making it a large employer and a mainstay of the local economy. In the past, water use by grapegrowers during spring frost events has been blamed for reducing flows and stranding listed salmonids; however, there is insufficient data available to draw such a general conclusion for the entire watershed.

It is obvious that maintaining adequate instream flows is essential to support salmonid populations and that beyond the basic physical features of tributary sub-basins (i.e. geology, topography, and rainfall), instream flows are affected by the timing and magnitude of agricultural diversions, their locations, and, in the case of shallow groundwater, subsurface geology. In the Russian River watershed, agricultural water supply is developed and managed on individual farms in the form of shallow wells (<60 ft.), deep wells, on-stream reservoirs, off-stream reservoirs filled by groundwater or direct surface water diversions, and direct diversions of surface water. In the past, stream diversions have not been coordinated potentially leading to short-term stream de-watering, particularly during spring frost events when continuous application of water is required to protect vines from spring frost. This method is used by most growers in the region and results in a large instantaneous demand for water

The purpose of this project was to increase grapegrower capacity for agricultural water monitoring and diversion coordination in the Russian River watershed with the end result of maintaining adequate instream flows. Under this grant, the California Land Stewardship Institute, a nonprofit organization in Napa, Ca., carried out a training program to build the capacity of the grower community to integrate stream flow monitoring, coordinated diversions, and protection of instream flows for fish into agricultural operations. This project set up two demonstration stream flow gaging networks with growers and trained growers by using on-site workshops. This approach integrated cost-effective environmental protections into agricultural operations. The specific objectives of the project were:

- Demonstrate the use of technology to numerous grapegrowers in the Russian River watershed to lead to improvement in water management and produce benefits to multiple ecosystem services;
- Demonstrate new technology which can be easily adopted by small-scale producers to address water supply issues;
- Transfer conservation practices to additional growers through written protocols specifically designed for grapegrowers and intended for use in conjunction with NRCS Irrigation Water Management Plans;
- Develop an innovative long-term solution to an environmental problem by implementing operational improvements to agriculture and by providing a method for growers to solve their own water issues.

The project was part of the Russian River Frost Program (RRFP) a two-county coalition of agricultural organizations formed to address water management issues in the Russian River watershed. The organizations involved include the Sonoma and Mendocino County Farm Bureaus, the Mendocino County Russian River Flood Control and Water Conservation District, California Land Stewardship Institute (CLSI), Russian River Water Conservation Council, UC Cooperative Extension, and the Sonoma and Mendocino Winegrape Commissions. The RRFP also includes hundreds of growers and represents those growers in negotiations with regulators, in development of water conservation programs and construction of water infrastructure, and in training and educating growers in new technology to address water issues. The RRFP provided the organizational capacity to deliver the transfer of technology and practices encompassed by this proposal to a larger grower community. CLSI provided the technical expertise and experience with the agricultural community to assure the implementation and successful completion of the project.

To achieve its objectives, this project incorporated well-established hydrologic monitoring protocols for selecting stream flow station locations, installing and mounting equipment, performing Quality Assurance/Quality Control (QA/QC), maintaining equipment and performing regular calibration measurements to assure data accuracy. In addition, in alluvial stream areas, monitoring subsurface water levels was included.

In addition to the CIG grant, this project was funded by matching and in-kind services totaling $190,259.00. These included a state watershed coordinator grant and cash contributions. In-kind services from local agricultural organizations – Sonoma County Farm Bureau, Mendocino County Farm Bureau and Sonoma County Winegrape Commission also added to the total effort.

Background

The Russian River watershed in Sonoma and Mendocino counties supports a winegrape industry estimated at generating $2 billion annually in crop value, winery production, and associated tourism businesses. This industry is the largest employer in both counties and therefore a mainstay of the local economy. Winegrapes require very low volumes of irrigation water, averaging 0.5-0.8 acre-ft. of water per acre per year. In valleys and low lying areas of the Russian River drainage frost protection is carried out using water.

In the valleys along the river—Redwood, Ukiah, Hopland, Alexander, Knights, Green, and Russian River—springtime temperatures may drop below 29°F, making the use of sprinklers the only reliable method of frost protection. Hillside vineyards and higher elevation areas along valleys typically do not need frost protection. When frost occurs, all low-lying areas of the watershed are affected simultaneously, creating a large need for water. If frost control is not performed, growers can lose their entire crop and will see reduced yields for the following year. Stream flow gages in the Russian River drainage are largely located along the mainstem river channel. There are a few gages on tributary streams and a number of historic flow records. All of these gages are operated by the US Geologic Survey (USGS). Another important consideration is the interaction of surface and groundwater in the large alluvial basins which dominate this system. There have been few long-term or large area studies of stream flow and the effects of agriculture or other land uses.

In Spring 2008, grapegrowers faced a set of conditions which rarely occur simultaneously. These included: the second year of a state-wide drought, the driest March on record, and the worst frost season in over 30 years. These unusual circumstances led to a large demand for water in a year with little stream flow. The result was the stranding of juvenile Coho salmon in one tributary stream in Sonoma County and of 10 juvenile steelhead trout along the mainstem Russian River near Hopland in Mendocino County. The stream flow gage at Hopland showed a rapid drop in flow of 83 cfs, or two inches in stage coincident with the stranding. These incidents led to a series of meetings between growers, the Farm Bureaus, CLSI, National Marine Fisheries Service (NMFS), California Division of Water Rights, and the California Department of Fish and Game in July 2008. The group was called the Frost Task Force and meetings ended in November 2009.

In the upper Russian River in Mendocino County, CLSI, the Farm Bureau, the Russian River Flood Control District (RRFC), and numerous growers formed the Upper River Sustainability Alliance (URSA) to address the frost issue. URSA prepared a comprehensive program of actions to reduce conflicts with the fishery. Additionally CLSI applied for and received approval of an Agricultural Water Enhancement Program (AWEP) grant from the Natural Resources Conservation Service. Under AWEP numerous off-stream storage ponds were built along the upper Russian River to reduce the instantaneous water diversions that caused the Hopland standing. In addition the AWEP program funded changes to the water system of the farm implicated in the stranding in a Sonoma County tributary.

Despite the causes of the two fish stranding incidents having been addressed, NMFS requested in February 2009 that the Ca. State Water Resources Control Board (SWRCB) place a complete moratorium on the use of water for frost control in the entire Russian River drainage. This moratorium would have superseded all water rights and was based on the assumption by the regulatory agencies that the effects of frost diversion from the extremely dry and cold conditions of 2008 occur every spring.

With this proposed moratorium, growers in Sonoma County, which had not been a part of the Frost Task Force, were asked to participate. The Sonoma growers decided to join with the Mendocino County effort to create the Russian River Frost Program (RRFP). The RRFP is organized as a coalition of organizations—Sonoma and Mendocino Farm Bureaus, Sonoma and Mendocino Winegrape Commissions, CLSI, RRFC, and UC Cooperative Extension. Through extensive outreach the RRFP was able to involve hundreds of grapegrowers covering 50,000 acres of land. In November 2009 the RRFP submitted a major proposal to address water issues to SWRCB (http://www.swrcb.ca.gov/waterrights/water_issues/programs/hearings/russian_river_frost/presentations2009nov/winegrape_growers.pdf).

The RRFP program includes the following elements:

- Coordination between RRFC, Mendocino Farm Bureau, and Sonoma County Water Agency to release water from Lake Mendocino to assure adequate flow levels in the upper Russian River during frost events;
- Implementation of water conservation using both CLSI's BMPs for frost operations and NRCS Irrigation Water Management Plans;
- Construction of off-stream reservoirs through the AWEP program to reduce the effects of direct diversions;
- Creation of an Independent Science Review Panel (ISRP)to provide objective scientific review of the monitoring program and analysis and prioritization of improvements;
- Implementation of stream flow monitoring programs in tributaries and coordination among growers to reduce the potential for instream flow reductions;
- Surveys of the extent of direct diversions were completed by the Frost Program in January 2010.

The SWRCB has pursued new regulations, extensive enforcement, and punitive approaches. The SWRCB, NMFS, and Sonoma County Coho Partnership have installed stream flow gages to be used as enforcement devices against farmers. This contentious regulatory process convinced the growers in the RRFP of the need for the program to train growers in stream flow monitoring and diversion coordination to avoid additional enforcement activities.

Review of Methods

This project achieved its objectives through five main approaches: (1) tributary watershed analyses, (2) grower outreach and involvement, (3) hydrologic monitoring, and (4) coordinating diversions and maintaining instream flow.

Tributary Watershed Analyses

The project evaluated eight tributary watersheds in the Russian River basin and selected two sub-basins for monitoring. CLSI used a Geographic Information System (GIS) database in ArcView and digital data layers for slope, geology, soils, ownership, vineyards, water rights, stream network, and salmonid occurrence to create an information matrix. In addition, CLSI evaluated the likely EQIP eligibility of grapegrowers in each tributary. Through a meeting of the Russian River Frost Program these analyses were used to select two sub-basins, Redwood Creek and McNab Creek for monitoring and coordination of diversions and demonstration of these methods to growers (Figure 1).

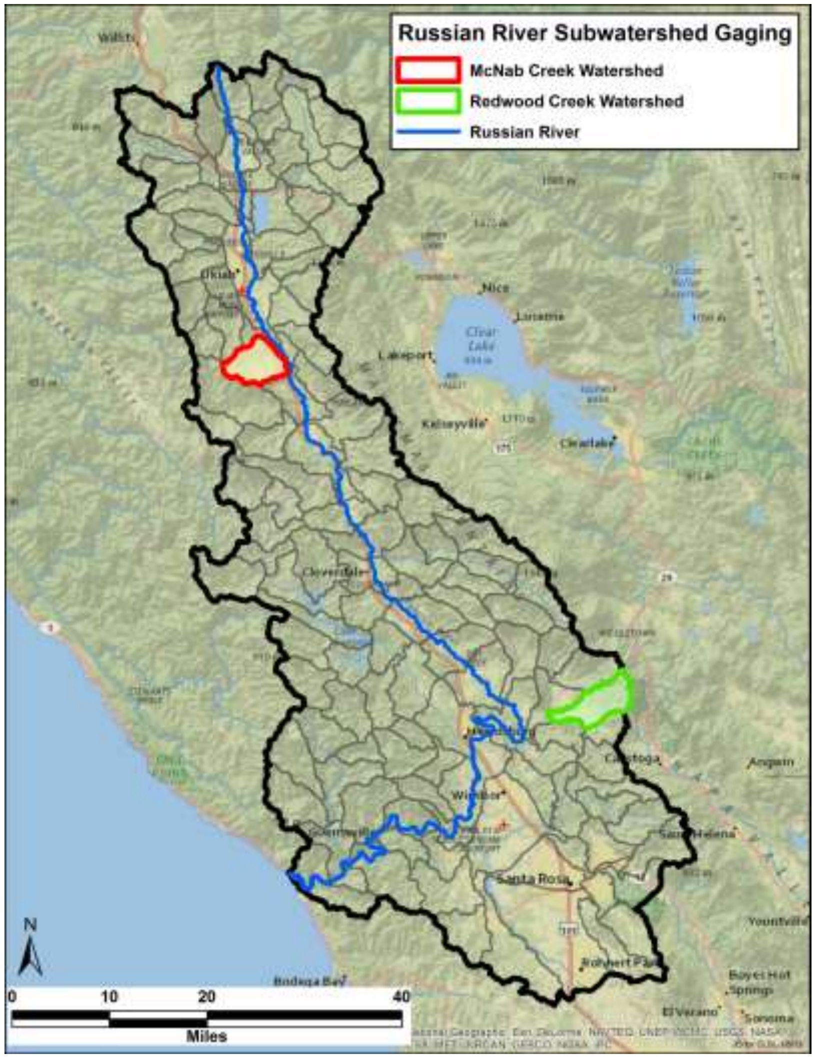


Figure 1. Redwood Creek and McNab Creek were the two tributary watersheds chosen for pilot projects.

Grower Outreach and Involvement

CLSI worked closely with both county Farm Bureaus and Winegrape Commissions to maximize grower involvement and training. CLSI, which operates the Fish Friendly Farming program, also contacted the large numbers of growers enrolled in this program. Between the memberships of these organizations, the project was able to reach hundreds of growers in both counties.

Hydrologic Monitoring

The project demonstrated the use of the US Geologic Survey's protocols for stream flow monitoring. CLSI prepares an easy to understand protocol (Appendix 1). This protocol defines: the appropriate locations for stream flow and groundwater gaging stations, restrictions based on channel type, form, subsurface geology and location; instrument selection and installation methods completing a topographic survey of the stream at a gage site; measuring stream stage; measuring discharge using a current meter; and the creation of a rating curve for the station. Pressure transducers to record stage and instruments with a high level of accuracy at the low flow level were recommended.

Trainings were held on each step in the process of setting up a stream flow gage. Additionally workshops were held on the concepts of establishing networks of gages and their use in determining how to coordinate diversion between growers in a tributary sub basin.

CLSI established two networks of stream flow gages on Redwood and McNab Creeks. Growers contributed sites, materials and labor. Gages were located to measure flow at a downstream locations, to measure additions to flow by major tributaries and changes to flow from major diversions or reservoirs. Figures 2 and 3 depict the two gaging networks. In addition to these two networks a continuous recording gage and two staff gages were installed on McClure Creek. A staff gage was also installed on Forsythe Creek to demonstrate how growers can determine their bypass flows required by water right permits.

Coordinating Diversions and Maintaining Instream Flows

The data from the surface water gages and subsurface water level gages were analyzed with records of diversion rates and times. Depending on the type of water supply facility, an inline meter stage recorder or other method was used to provide accurate records at 15-30 minute intervals. The GPS coordinates and elevation of each gaging station, subsurface monitor and diversion have been recorded. The stream channel dimensions of width, length, roughness, and bed composition have also been surveyed. For each stream reach, some assumptions regarding the movement of surface flow to groundwater and groundwater to surface flow and the seasonality and magnitude of this movement were made and are being refined over time with the gaging data.

Once the tributary gaging networks were established, a series of trials were carried out in coordinating diversions, reducing diversions, etc. and the results analyzed. The results were evaluated with growers and the RRFP and additional changes to diversion rates and timing were discussed. Because many of the tributary streams in the Russian River watershed have complex geology and variable topographic and hydrologic features, this trial analysis provides a broadly applicable methodology.

Discussion of Quality Assurance

Several steps were taken to assure that data from the project are accurate, reliable and will result in achieving the ultimate goal of increasing grapegrower capacity for agricultural water monitoring and diversion coordination. Capacity building workshops for growers were all led by expert hydrologists and included field training. These workshops taught grapegrowers how to properly install and monitor stream gages and provided the technical training necessary to certify growers as competent to perform hydrologic monitoring tasks. In addition, a professional hydrologist directed all site selection and installation of stream gages in McNab and Redwood Creeks. To ensure that the data from the installed gages continues to be accurate and useful, the Independent Science Review Panel (ISRP) will provide oversight to data interpretation as gage data is collected and decisions about coordinated diversions are made.

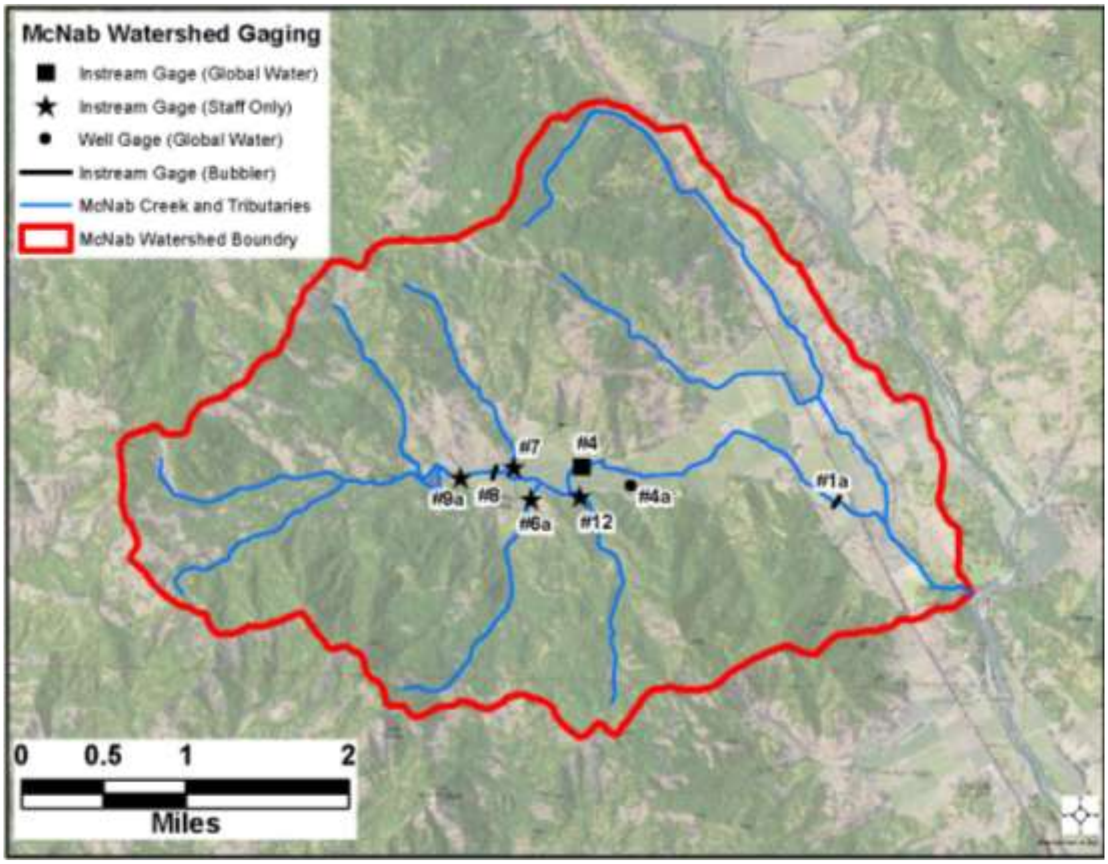


Figure 2. Gages Installed in the McNab Creek Tributary Watershed

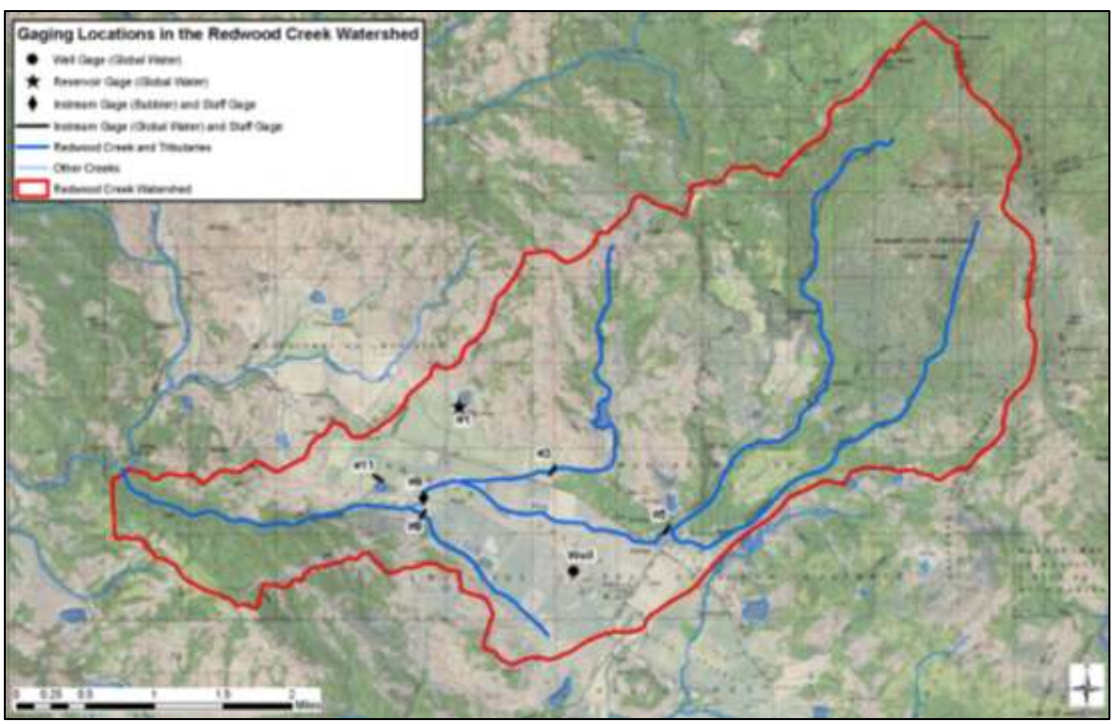


Figure 3. Gages Installed in the Redwood Creek Tributary Watershed

Methods were standardized for this project through the creation of a Quality Assurance Project Plan (QAPP) (Appendix 2) on the stream flow gaging protocol (Appendix 1). The QAPP provides procedures for QA/QC checks that include field measurements, station maintenance, data and records management, meter calibration, and rating curve validation. The QAPP was developed by CLSI under a separate grant and approved by the Environmental Protection Agency.

Findings

This project accomplished its purpose of building grapegrower capacity for stream flow monitoring and coordinated diversions in the Russian River watershed through the four main approaches outlined in the Review of Methods section above. Using these methods, CLSI and its project partners, created 7 different deliverables outlined in the CIG grant agreement. The deliverables resulting from this project are summarized below.

Deliverables 1, 2, & 4: Grower Outreach

Forty-eight workshops were held in the Russian River watershed from Fall 2010 to Fall 2013. These workshops varied in subject matter but were all focused on training growers to monitor stream flow and water levels. They included general workshops on stream flow monitoring, gag site selection, small group gage installation trainings, workshops on stream flow discharge measurement techniques, water use and diversion meters, and presentations of BMPs for water conservation during frost control (Figure 4). The training workshops were planned by CLSI and member organizations of the RRFP and included professional hydrologists and water conservation experts.

Deliverables 3 & 5: Written Protocols

Several written work products were produced to provide standardized protocols for stream flow monitoring and Beneficial Management Practices (BMPs) for frost control water conservation. All of these materials were distributed to grapegrowers during workshops and continue to be freely available to any interested grower. The Stream Flow Monitoring Protocol (Appendix 1) details all the steps necessary to establish a stream flow monitoring station, including:

1. Selecting the gaging station location
2. Selecting the type of gage
3. Installing the gage
4. Surveying the channel cross section at the gage site and incorporate a point of known elevation
5. Completing discharge measurements
6. Creating a stage/discharge rating curve for the station
7. Maintaining the elevation and stage/discharge rating through continued measurements
8. Maintaining the gage and downloading data
9. Managing and interpreting the data

Figure 4. Workshops with grapegrowers demonstrating stream flow monitoring techniques.

A fact sheet in the form of a decision matrix that simplifies the information found in the monitoring protocol was produced to complement this protocol (Appendix 3). Growers are able to use this fact sheet to choose a type of gage installation based on their specific site characteristics. It also provides general information on data collection and maintenance of gages.

In addition to stream flow monitoring resources, CLSI produced a series of BMPs for frost control that emphasize water conservation (Appendix 4). These BMPs were incorporated into an environmental certification program that CLSI runs called Fish Friendly Farming and are currently being used by numerous farms throughout the Russian River watershed.

Deliverable 4: Stream Gaging

As a result of grower outreach, CLSI and the RRFP helped established 15 stream gages over two pilot tributary watersheds (McNab Creek and Redwood Creek; Figure 1) as well as gages in McClure and Forsythe Creeks. Expert hydrologists helped choose the type of gages to use, where to site the gages, and helped conduct the cross sectional survey at each gaging location. The types of gages installed were dependent on site-specific characteristics and varied between Global Water stream and well gages, staff gages, and bubbler gages (Figures 5abc). At each gage location, a topographic survey was completed to establish the channel cross section to use for gage data interpretation. The result of these efforts was the establishment of eight gaging stations in the McNab Creek watershed and seven gaging stations in the Redwood Creek watershed (Figures 2 & 3) and three gages in the McClure Creek watershed and one gage in the Forsythe Creek watershed. CLSI continues to provide operational support to the growers with installed gages and the ISRP of the RRFP is continuing to provide scientific oversight of data management and data interpretation of the installed gages. As more data are gathered from these operations, it will assist growers to coordinate diversions to ensure that adequate instream flow is maintained during spring frost events.

Figure 5a. Global Water gage installed in the McNab Creek Watershed

Figure 5b. Staff gage Installed in the McNab Creek Watershed

Figure 5c. Bubbler gage Installed in the McNab Creek Watershed with staff gage.

Deliverables 6 & 7: Project Presentation and Reporting

In addition to deliverables 1-5 outlined above, deliverables 6 & 7 were completed during this time period. To satisfy deliverable 6, CLSI presented a poster at the CIG showcase at the Soil and Water Conservation Society in Washington D.C. in July 2011. Deliverable 7 was achieved with timely submission of quarterly progress reports and with this final grant report.

Conclusions and Recommendations

Capacity building among grapegrowers to conduct stream flow monitoring is essential to sustain the long-term viability of the industry while also maintaining adequate instream flows for other uses, including salmonid habitat. Under this grant, CLSI and the RRFP conducted extensive outreach to growers in the Russian River watershed to increase use of water conservation BMPs and install and monitor stream flow gages. So far, this has resulted in 19 gage installations in four tributary watersheds and has provided a framework for grapegrowers to coordinate their water use, especially during spring frost events. While helping to maintain adequate instream flows, the data gathered from this type of stream gaging in the Russian River will inform growers about water demand and natural flow changes resulting from site specific hydrology. In the future, the RRFP and CLSI will continue to work with growers in the Russian River watershed to gather, organize, and interpret the data gathered from stream flow gages and continue to refine a coordinated approach to water management that will satisfy both industry demands and salmonid habitat needs.

Appendices

APPENDIX 1

RUSSIAN RIVER FROST CONTROL PROGRAM

Stream Flow Monitoring Protocol

Prepared by the California Land Stewardship Institute

With funding from the Conservation Innovation Grant Program of the Natural Resource Conservation Service

STREAM FLOW GAGING PROTOCOL

INTRODUCTION

Monitoring stream flow involves a series of steps to develop a reliable dataset. Each step requires attention to detail and may need professional judgment to evaluate field conditions and determine the best location for measurements.

In tributary basins, stream flow may need to be monitored in a number of locations. The steps in establishing a stream flow monitoring station include:

1) Selecting the gaging station location
2) Selecting the type of gage
3) Installing the gage
4) Surveying the channel cross section and points of known elevation at the gage site
5) Completing discharge measurements
6) Creating a stage/discharge rating curve for the station
7) Maintaining the elevation and stage/discharge rating through continued measurements
8) Maintaining the gage and downloading the data
9) Managing and interpreting the data

Stream flow is typically described in cubic feet per second (cfs) or the volume of water moving past the monitoring station per unit of time. This volume can vary greatly throughout the year, so stream flow needs to be continuously monitored in the most accurate manner possible.

There are several types of instruments used for stream flow monitoring that measure the stage or depth of the flow. Stage is the elevation of the surface of the water above the channel bottom. Several additional steps are needed to relate the stage measurements to actual elevations and to convert them to discharge or cubic feet per second. These additional steps make the stage measurements at one station relevant to other stations and to diversions. These measurements are carried out when establishing the station and revised over time to maintain the accuracy of the monitoring data.

These are key references for stream flow monitoring:

- Harrelson, Cheryl, C.L. Rawlins and John Potyondy. 1994. ***Stream Channel Reference Sites: An Illustrated Guide to Field Techniques***. USDA Forest Service Report RM-245.

- McCobb, Timothy D. and Peter K. Weiskel. 2003. ***Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems***. U.S. Geological Survey Open-File Report 02-497

- Rantz, S. E. 1982. Measurement and Computation of Stream Flow: Volume 1. ***Measurement of Stage and Discharge*****.** U.S. Geological Survey Water-Supply Paper 2175

- Sauer, V.B., and Turnipseed, D.P., 2010, ***Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods*** book 3, chap. A7, 45 p. (Also available at http://pubs.usgs.gov/tm/tm3-a7/.)

- U.S. Geologic Survey website, www.usgs.gov

Constraints

The biggest constraint to the development of high quality datasets for stream flow monitoring is the location of the monitoring station. Poorly located stations will not provide accurate measurements of streamflow. Typical problems include: stations that do not allow for measurement of all of the flow passing the site due to losses to groundwater, a site with multiple channels, a wide area of flow at higher flows, a wide and shallow flow at low water, sites located in a meander of an alluvial channel. Data from poorly selected stations have limited value. Another constraint is a lack of frequent checks and measurements to maintain the gage site and rating curve. Finally, it should be recognized that several-to-many years of data and analysis are needed to produce datasets to characterize stream flow for a particular location.

Quality Assurance/Quality Control (QA/QC)

Quality Assurance/Quality Control is a critical component of all monitoring. QA/QC provides the necessary checks to determine if a dataset is reliable.

The features of a QA/QC program address the following:

- Precision is the measure of how similar repeated measurements are to each other. It describes how well repeated measurements agree.
- Accuracy measures how close results are to a true value and can be determined through comparison to a standard or reference measurement.
- Completeness is the fraction of data that must be collected in order to fulfill the statistical criteria of the project.
- Comparability is the degree to which data can be compared directly to similar studies.
- Representativeness is the degree to which data can truly characterize the actual environmental conditions.

A separate QAPP (Quality Assurance Project Plan) has been prepared for this protocol and approved by the EPA. QA/QC procedures are included here.

1. SELECTING STREAM FLOW GAGING STATION LOCATIONS

The selection of stream flow gaging sites is the most critical step in producing reliable data which accurately represents stream flow levels in a creek.

The purpose of installing a stream flow gage is to create a continuous record of the depth and volume of flow at the station. There are a number of features needed for a good stream gaging location including:

- The general course of the stream is straight for about 300 ft. upstream and downstream from the stream gaging site
- The total flow is confined to one channel at all stages, and little to no flow bypasses the site as subsurface flow
- The streambed is not subject to excessive scour and deposition and is free of aquatic growth
- Banks are permanent, high enough to contain floods, and free of brush
- A pool is present upstream from the channel grade control at extremely low stages to ensure gage can record stage at extremely low flow and to avoid high velocities near stream gaging station intakes during periods of high flow

- The stream gaging site is far enough upstream from the confluence with another stream to escape from any variable influence the other stream may have on the stage at the stream gaging location
- A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the stream gaging station (it is not necessary that the low and high flows be measured at the same stream cross-section)
- The site is readily accessible for ease in installation and operation of the stream gaging station

In the Russian River, there are two large categories of stream channels: those confined in a canyon or within a streambed of bedrock, and those unconfined with an erodible gravel/cobble bed. Confined channels occur mostly in the mountains. Rock dominates the streambed controlling the channel location and width. Alluvial channels are not confined in canyons or gorges, but instead course over the broad river valley. The channel bottom is made up of cobble, gravel and sand and stream flow may infiltrate into the gravel bed at certain times of the year (Figure 1).

Methods

For a particular tributary basin of interest, the perennial streams provide the main area for stream gaging.

- On a topographic map or using a Geographic Information System (GIS), identify the blue line streams in the tributary basin.
- Identify the reaches of each stream in rockbound areas such as mountain gorges. These are likely naturally confined channels.
- Identify the reaches of each stream in alluvial valleys. These are probably unconfined channels.
- Identify the alluvial fans in the basin

Choosing a Location

In the rockbound confined channels (Figure 2), it may be easier to find locations which fit the needed features for gaging stations. These include:

- straight channel
- limited scour and deposition
- little loss of flow to groundwater
- no secondary channels
- banks are permanent and high enough to contain floods
- pools are more likely to be present year-round
- upstream of a cross-channel weir can be an excellent site for a gaging station

In these confined channels, flood flows can be deep and very swift so the instrument may need to be carefully placed to avoid damage or loss. It may also be difficult to access the site at high flow to complete discharge measurements.

In alluvial channels (Figure 3 and 4), it is more difficult to identify sites which fit the needed features for a gaging station. These include:

- Alluvial fans located at the rock canyon outlet of the creek infiltrate large amounts of stream flow. The channel may be straight though the fan, but the loss of flow to groundwater makes these poor gaging locations (Figure 5)
- Alluvial channels may also gain flow from groundwater during certain seasons or in particular locations

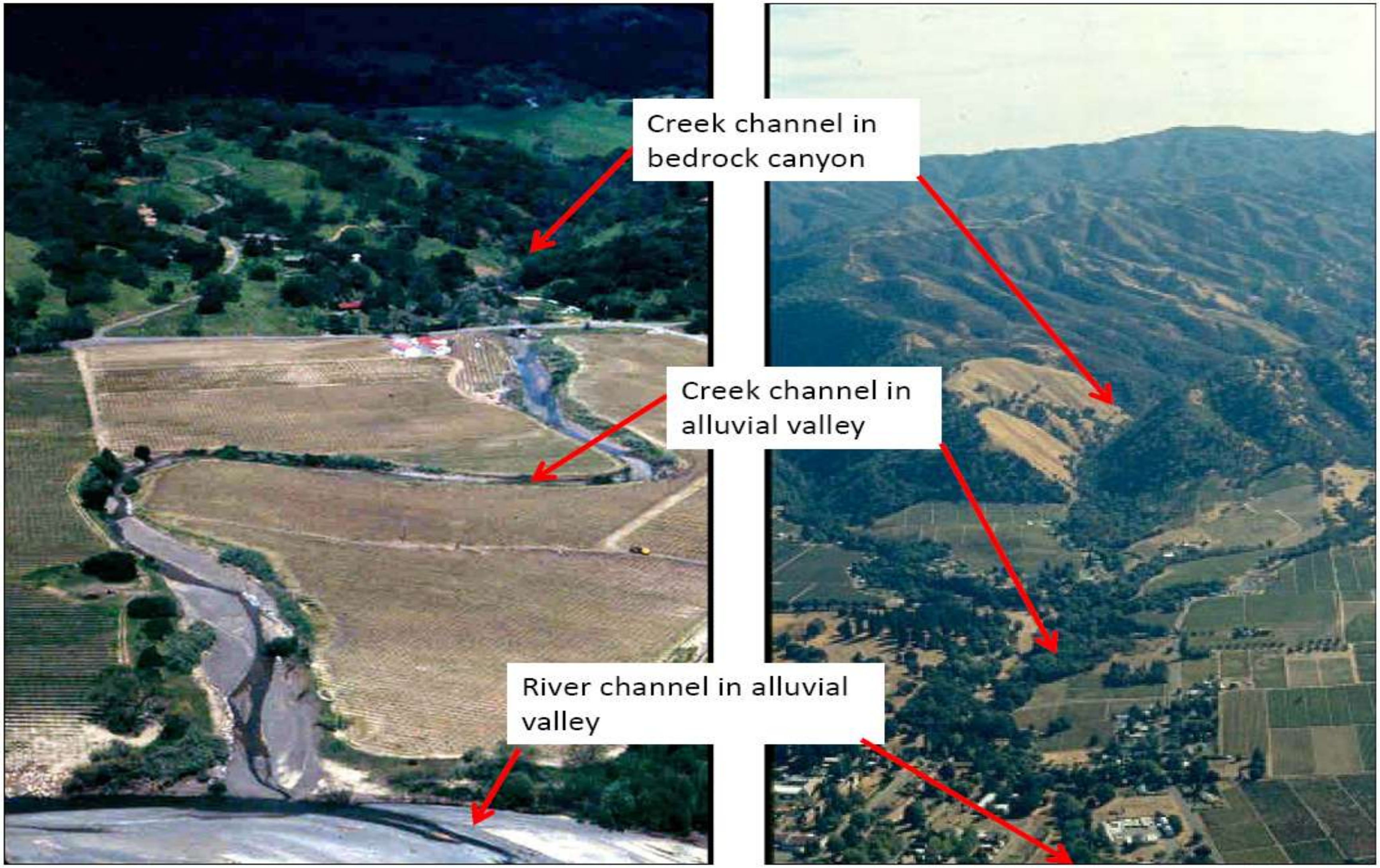


Figure 1: Different types of channels occur in different areas of the watershed

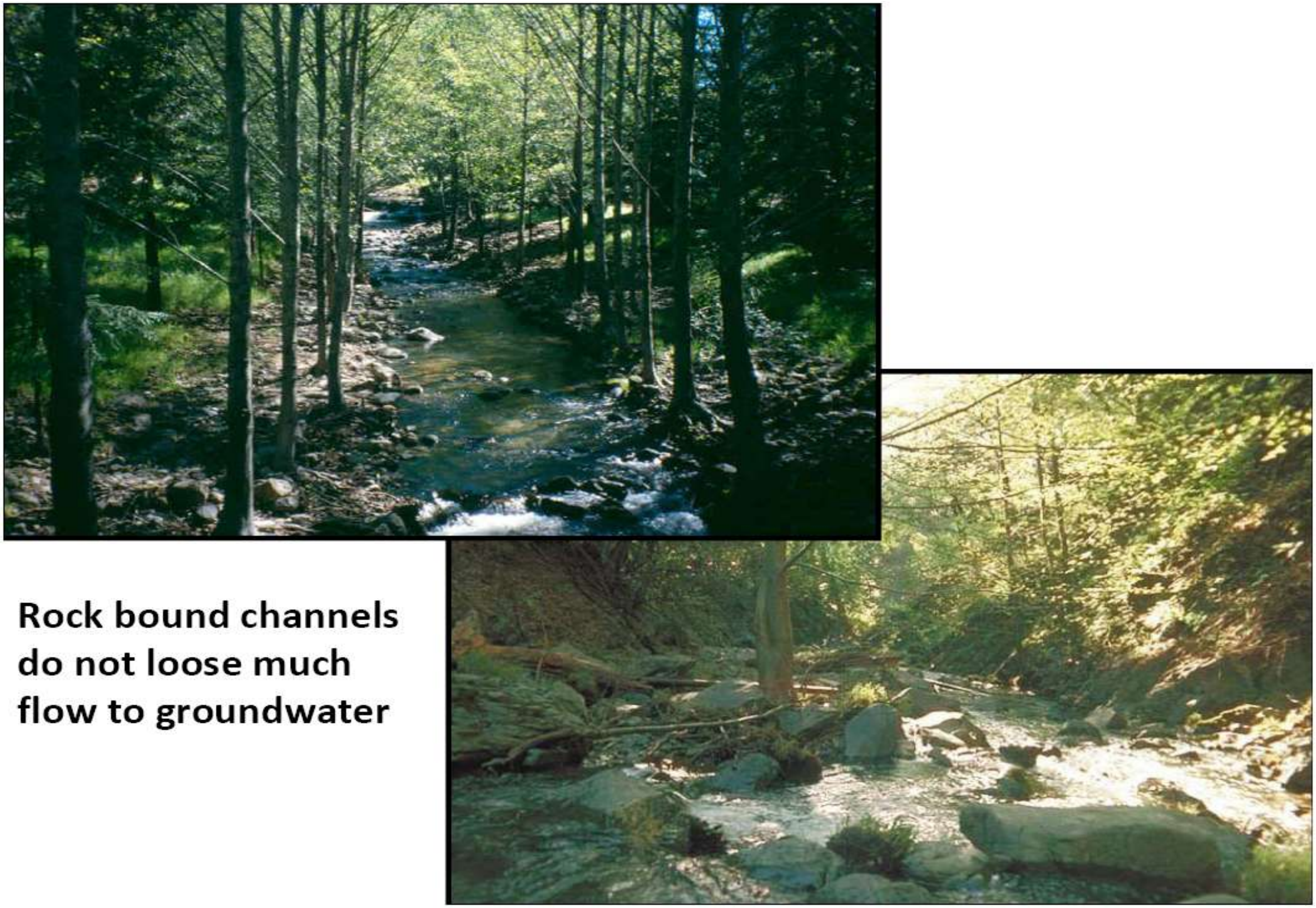


Figure 2: Confined stream channels

Figure 3: Example of an alluvial stream channel

General course of the stream is straight for about 300 ft upstream and downstream from the stream gaging site. These example streams meander.

Figure 4: Selection of the gaging site should avoid meandering stream areas

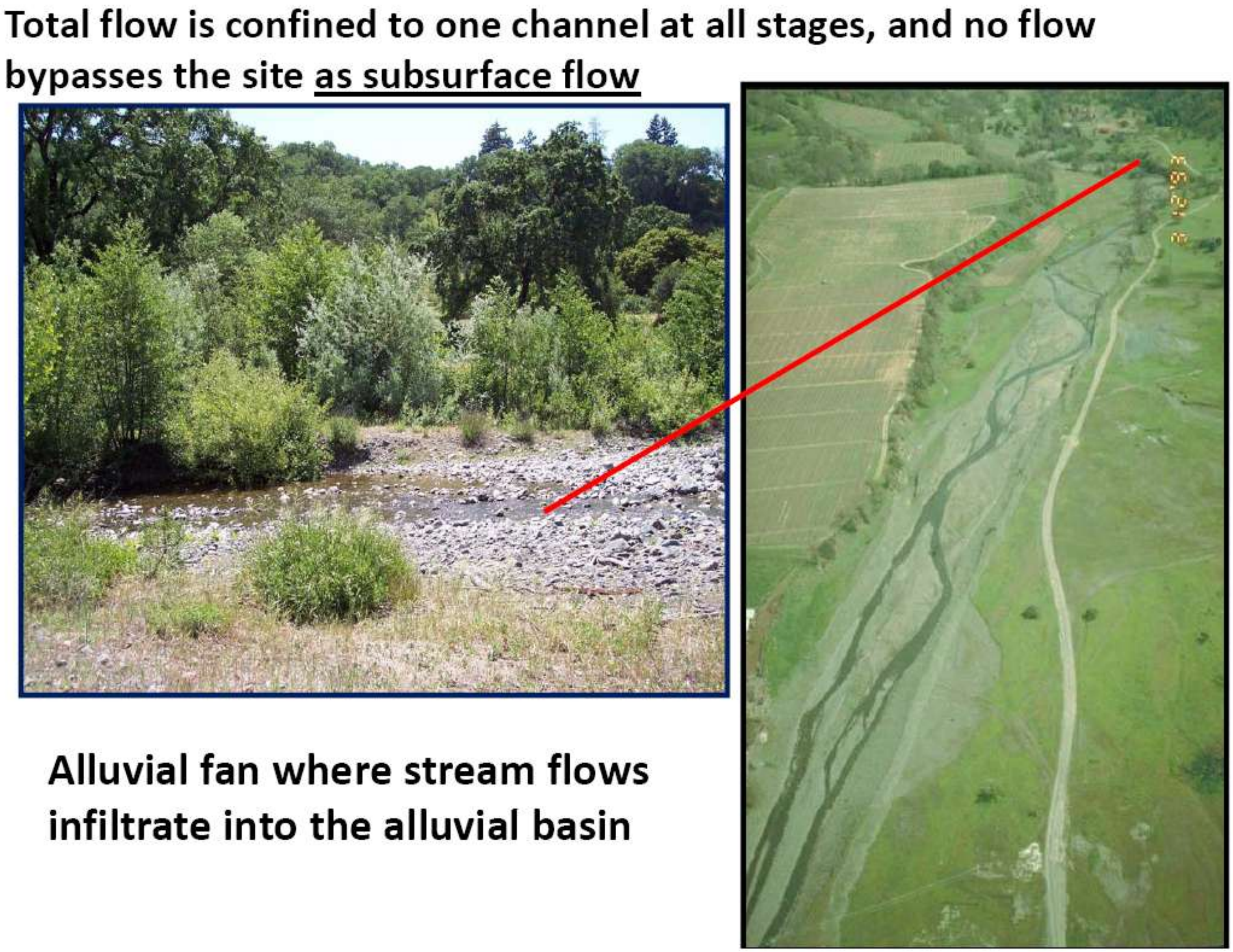


Figure 5: Alluvial fans are areas of high infiltration of surface flows into groundwater and are not good locations for gaging stations

The stream gaging site is far enough upstream from the confluence with another stream to escape from any variable influence the other stream may have on the stage at the stream gaging location

Figure 6: Tributary confluences do not make good gaging sites

A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the stream gaging station (it is not necessary that the low and high flows be measured at the same stream cross-section)

General course of the stream is straight for about 300 ft upstream and downstream from the stream gaging site

Figure 7: Straight channel reach

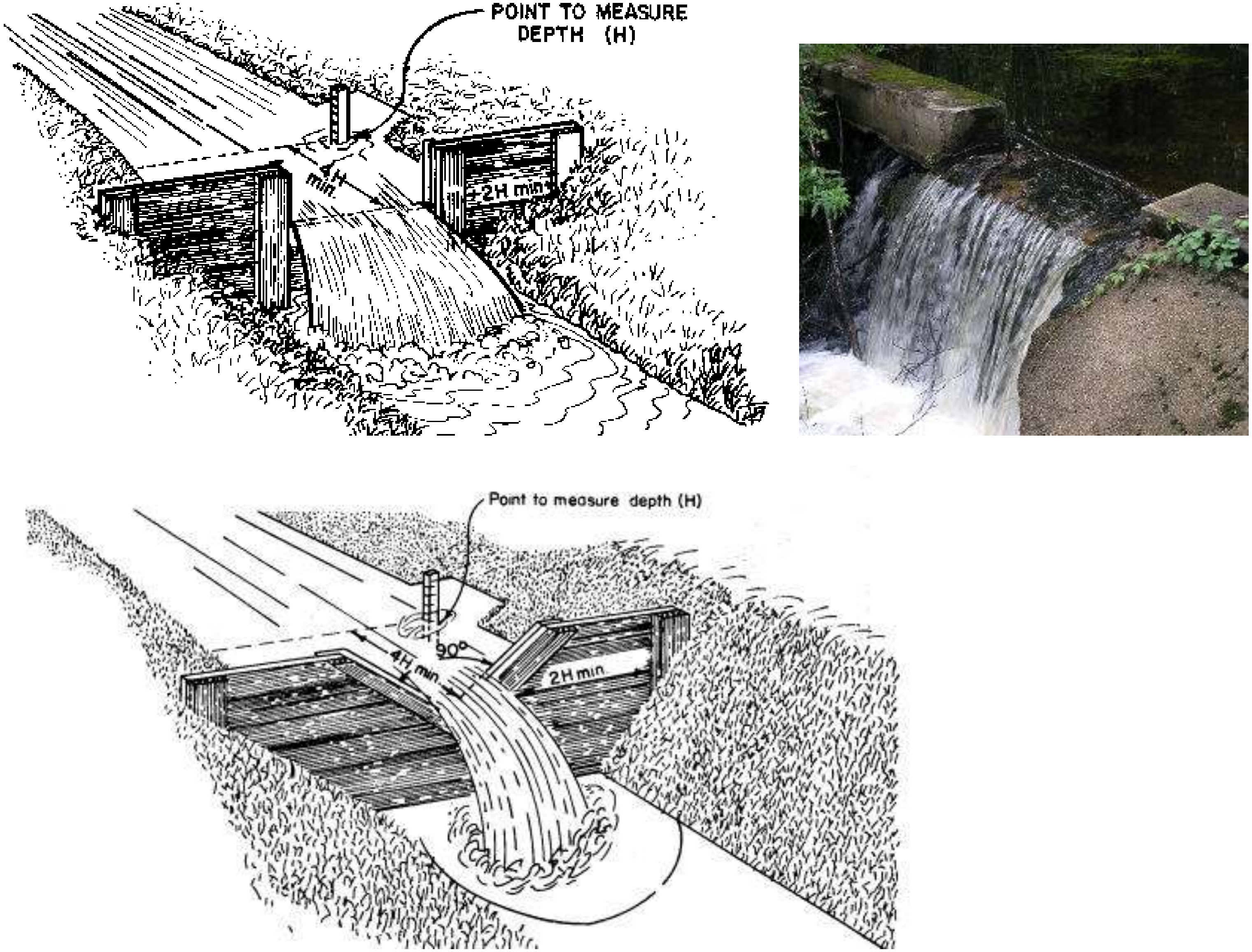


Figure 8: Weirs are often good locations for gaging sites and provide a stable grade control for low flow measurements

- Many unconfined alluvial channels meander and straight channel sections are often short (Figures 4, 6 and7)
- Most alluvial channels experience scour and deposition and do not have “permanent” banks
- Alluvial streams may not have pools during low flow conditions and may dry up in summer

Locations for stream flow gages in alluvial channels need to be carefully chosen. Upstream of bridges and weirs can be good choices (Figure 8). The weir can provide a long term grade control to create a stable site for measuring discharge. It may also be possible to install a Parshall flume. Because alluvial channels lose flow to groundwater, subsurface water levels and, in some locations, river stage also has to be measured in order to correctly characterize stream flow processes.

In choosing a stream gage site, the landowner will need to approve of the use of the site and sign a landowner access agreement. Data Sheet #1 (Appendix 1) allows for the features of each gage site to be recorded.

2. SELECTING THE TYPE OF GAGE AND INSTALLING THE GAGE

The most common stream flow monitoring instruments are: 1) water level recorder installed in a stilling well on the stream bank or at a bridge pier; 2) bubble system gage; 3) pressure transducer installed in a pipe set on the bed of the stream; 4) acoustic water level recorder installed on the underside of a bridge or similar structure. Each type of instrument provides continuous recording of water stage or elevation. The accuracy level of the gage in recording water stage should be ±0.01 ft.

Stilling Well

Water from the creek enters and leaves the stilling well through underwater pipes, allowing the water surface in the stilling well to be the same elevation as the creek water surface (Figure 9). The stage is measured inside the stilling well using a pressure, optic, or acoustic sensor. Many locations are not physically appropriate for installing a stilling well and pipe system in the stream bank.

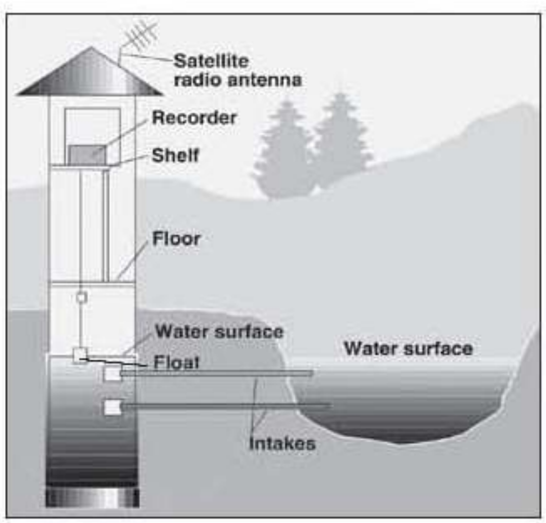


Figure 9: Stilling well type stream flow gage

Bubble System

This type of gage is established with a permanent gage house similar to the stilling well. A long, open-ended pipe extends from the gage to the waterway. The end of the pipe in the creek is fixed securely below the water surface. Pressurized gas is forced through the pipe from the gage house and out the orifice of the pipe. The pressure in the pipe is determined by how deep the water is over the orifice. Change in creek flow provides a change in the pressure in the pipe which is sensed by a pressure transducer in the gage house and recorded by a data logger in the gage house. This type of system is best for a long term permanent gage site.

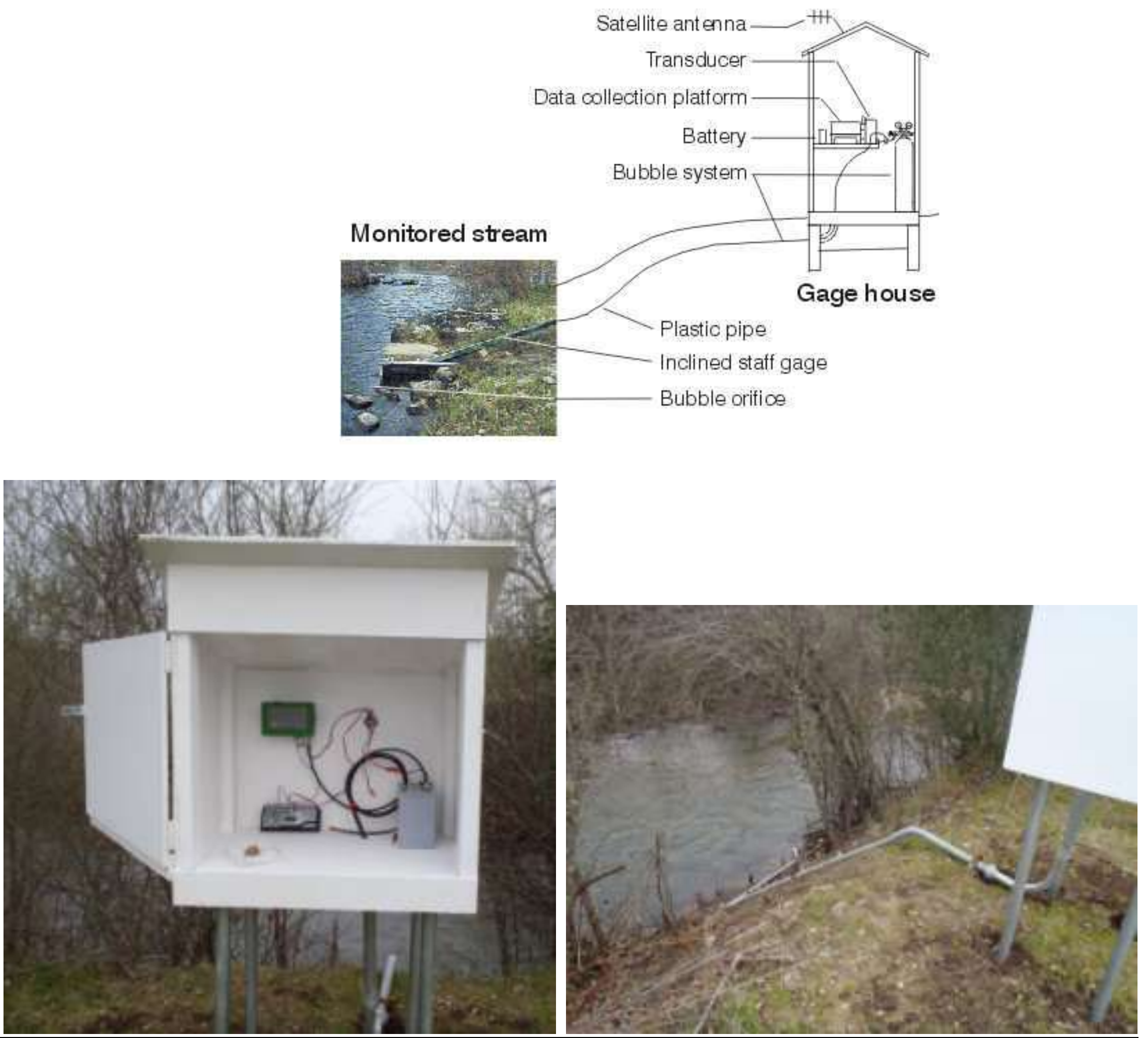


Figure 10: Bubble system type stream gage

Pressure Transducer

These instruments measure the weight or pressure of the water above the sensor. There are two types of pressure transducers: a differential pressure transducer and an absolute pressure transducer. The differential pressure transducer corrects for barometric pressure by having a vent tube. The vent cannot be submersed and so must be long enough to stay outside the flood zone.

Figure 11: Example of a differential-pressure transducer. Note the cable extended above the transducer . Gage installed in pipe along stream bank.

The absolute pressure transducer is enclosed and submersible. It does not correct for barometric pressure. Data have to be corrected for barometric pressure recorded by a separate barometer in the immediate vicinity of the transducer.

Figure 12: Absolute pressure transducer attached to a wooden lath and secured with nylon ties.

The pressure transducer records stage at a selected time interval (every 30 minutes, for example). Most transducers record after 0.15 ft. of submergence of the transducer.

The differential pressure transducer is typically placed in a plastic pipe with an open end and the vent cable is stretched through the pipe to a location outside the creek flow. The transducer is submersible but the data logger is on the "dry" end of the cable. Only the differential pressure transducer can be used with telemetry to produce real time data available on the internet.

<u>Acoustic Water Level Recorder</u>
These instruments are mounted above the water and emit a sound pulse that bounces back to the instrument, providing a depth reading. High levels of algae or debris can lead to false readings.

<u>Non-Recording Staff Gage</u>
This type of gage is manually read and provides for a comparison with data from a recording gage. A staff gage consists of a scale marked in feet and tenths on a post or bridge pier in the stream to show the elevation of the water surface. The staff gage should be located where a continuous recording gage will be used in order to provide an accuracy check for the recording gage. The staff gage is located such that the lower end of the scale is in the channel at low flow. The scale can be calibrated to elevation using the same surveyed cross section as the recording gage.

Figure 13: Staff gage

3. INSTALLING THE GAGE

The selection of gage sites should reflect consideration of the purpose of the stream flow gaging project. If floods levels are interest fewer sites may be preferable with sturdy gage installations. If low flows are of interest, more stream flow gages coupled with groundwater measurements may be needed.

The installation process for the gages will be very site specific and should be overseen by a professional hydrologist. The sites will need to be suitable for answering the primary monitoring question and for fulfilling the site selection criteria listed previously.

If a stilling well of bubble system gage is to be installed, there needs to be an area adjacent to the channel that can accommodate the gage house and well. It is only feasible to go through the expense of installing these if the gage is meant to be permanent and used for a long period time. A hydrologist with significant experience in establishing gages should determine if this type of gage is appropriate for a particular site.

Pressure transducer gages are easier to install, but are also more prone to damage and loss than the more permanent types of gages. The differential pressure transducer requires a pipe housing with an open pipe at the creek end that extends along the bank to allow for the cable and datalogger to be secured outside the creek flow.

Figure 14: Pressure transducer in pipe housing with adjacent outside staff gage

Sometimes a separate battery is also attached at the upland end. Absolute pressure transducers also require a pipe housing of some type. For both of these gages, the pressure transducer needs to be as close to the channel bottom as possible, or maintained at a fixed elevation above the bottom.

The pipe housing needs to be secured to a post, a bridge, or other structure if the gage is to withstand flood flows. If this site does not allow for securing the gage, it should be removed for the flood season.

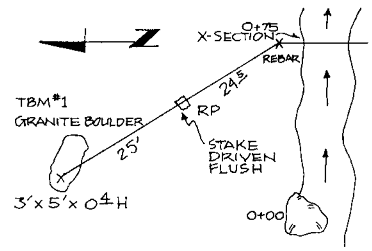


Figure 15: Map of a benchmark set in a boulder.

The holes in the pipe should provide for water level in the pipe to rapidly equalize. However, depending on the gage location, large holes may allow the sediment to accumulate in the pipe. If this occurs, measure the offset from the bottom of the pipe the sediment caused for the transducer and the dates it occurred. It the gage is upstream of a weir, algae buildup on the weir should be cleared frequently to assure proper function and that no debris to other problem is occurring. The staff gage should be read and the value recorded during each visit.

4. SURVEYING THE CHANNEL CROSS SECTION AND POINTS OF KNOWN ELEVATION AT THE STATION

This section on surveying was revised from instructions prepared by Dennis Jackson.

The gage will measure stage or the elevation of water above the stream bed at the station. This elevation needs to be related to a constant reference elevation known as a datum.

A surveyed cross section of the channel is completed at the gage site. The end points are surveyed to an object outside the channel with a known elevation. This object serves as the elevation benchmark allowing for the stage measurements to be converted to elevation and compared to fish habitat surveys and other information.

Establishing a Project Benchmark

The project benchmark is a permanent mark near the area to be surveyed that can be located every year. The benchmark serves as the vertical or elevation reference point for the survey. Establishing a permanent benchmark is the first step in every survey. A benchmark is a point of known elevation. Sometimes an existing benchmark may be available, for example, benchmarks are often found on or near a bridge. Benchmarks are also marked on USGS topographic maps. If an existing benchmark is found near your survey, use it. Otherwise, establish your own benchmark.

Directions for establishing a benchmark

- Use a piece of rebar or pipe 3' to 4' long.
- Locate the benchmark where it can be seen from the stream channel. It must be located above the stream channel so that it will not be washed away by high water. Figure 15.
- Chose a location that will not interfere with the landowner's operations.
- Locate the benchmark near an obvious landmark such as a large boulder or tree.

- Drive the rebar into the ground until the top is within a half inch of the ground surface. Write an identifying note on a piece of flagging and tie it to the stake. Bury the flagging with dirt to protect it from the sun.
- Mark the benchmark stake with a second stake. Drive the second stake about 6” from the benchmark stake. It should be 18” to 24” long and rise 6” to 12” above the ground. Increase its visibility by spray painting it or wrap duct tape around it. Tie a piece of flagging to it.
- Draw a detailed map of the location of the benchmark in the survey notebook. Mark the elevation of the benchmark if you know it. Note the distance from the benchmark to two or more obvious landmarks, such as large trees, boulders, fence posts etc. (Figure 15). Use a GPS to record the coordinates of the benchmark.

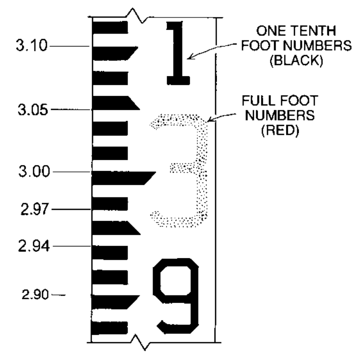


Figure 16: Face of the survey rod

If you do not know the elevation of the benchmark, temporarily assume an elevation of 100 feet for the benchmark. Later, you should determine the actual elevation of your benchmark. If your benchmark is destroyed or lost you will then be able to use the actual elevation to establish another benchmark. This will allow you to compare your original survey to a subsequent survey. Another advantage to determining the actual elevation of your benchmark is that you will then be able to compare the elevation data of one gaging station to another, and to in-stream habitat sites. Determine the actual elevation of your benchmark by running a *differential level survey* (see page28) between a point with known elevation and your benchmark.

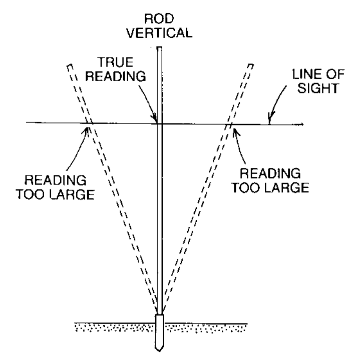
<u>Surveying: Directions for Instrument Person</u>

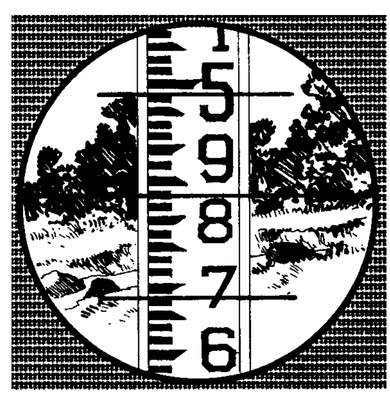
Step 1: Setting Up the Tripod

- Extend the legs of the tripod until the top of the tripod is level with your chin.
- Push one of the legs firmly into the ground. Spread the tripod legs 3’ to 4’ apart. Push the other two legs into the ground.
- Level the top of the tripod by raising or lowering the legs. The head of the tripod does not need to be perfectly horizontal. However, leveling the instrument will be easier if the tripod head is on a nearly horizontal plane.
- After the head is level check that the leg adjusting screws are tight and that the legs are firmly in the ground.

Step 2: Setting Up the Level

- Place the instrument on the tripod.
- Screw the level snugly (finger-tight) to the head of the tripod. Do not over-tighten the screw.
- Move the level screws in pairs to bring the bubble into the target circle on the level vial.
- Rotate the scope 90^{0} degrees and re-level.





Figures 17 and 18: Reading the rod. The elevation is read at the middle line. The upper and lower lines are called stadia.

- Repeat until the bubble stays in the target circle throughout a 360^0-degree rotation. This procedure brings the instrument into the range where the self-leveling pendulum prism can operate.
- Turn the telescope to bring the rod into the field of vision.

Step 3: Reading the Rod
The numbers on the face of the rod show the distance measured from the ground in feet. The scale can be read to one hundredths of a foot. Whole numbers of feet are marked off on the scale on the left of the rod by the longer line with an angled end. For example, see the number 3.00 in Figure 16. The number of feet is read at the top of this line and is indicated by the large red numbers. Tenths-of-feet are also marked by a line with an angled end. For example, see the number 2.90 in Figure 16. The black numbers indicates the number of tenths-of-feet.

Each black line and each white space on the scale is exactly one hundredths of a foot. The top of each black line, between the angled tenth-of-a-foot lines, mark off 2/100th's of a foot. Even number hundredths of a foot can be read at the top of the lines. Odd number hundredths of a foot are read at the bottom.

Point the telescope towards the rod. The center crosshairs should cross the face of the rod (Figure 18). Turn the focus knob until the rod can be clearly seen. Adjust the eyepiece to darken or lighten the cross hairs. If the rod is leaning to the side, ask the rod person to move the top of the rod until it is vertical (Figure 17). The rod person should try to keep the rod vertical along your line-of-sight. The center crosshair gives the elevation. Do not use the upper or lower lines for elevation. The upper and lower lines are called stadia. Using the stadia lines to measure distance will be described later.

Step 4: Recording the Data
The survey notebook is the most important piece of surveying equipment. Be neat and orderly so that the data you record can be easily read. Note all pertinent details in your descriptions and field maps. Over the years, the field book will be used to re-locate the benchmark and various survey stakes or markers. The field book will also be the source of data used to analyze the changes in stream shape with time.

Use a *Rite-in-the-Rain* (or equivalent brand) All-Weather Level Notebook No. 311. These books are about 5" x7". They have 48 numbered pages. Each page has six columns. The first page is a blank *Table of Contents*. Be sure to fill in the *Table of Contents* after your survey. Write your name, phone number and project description inside the front cover in the space provided.

Use Figure 21 as a guide to labeling the columns and recording the information for a differential survey. Be sure to draw a map, see Figure 21, showing the location of all the instrument setups, turning points and benchmarks.

<u>Surveying: Directions for the Rod Person</u>

The rod person decides where to set the rod, which is the most critical part of the survey.
Place the level on the back of the rod. Use the bubble on the level to adjust and maintain the rod so that it is vertical. Stand behind the rod so that the rod can be held vertical and the level can be read. Holding the rod vertical is essential. If the rod leans forward or backwards the reading will be larger than the true value, see Figure 17.

The rod can be extended to 16 feet. When changing the length of the rod it is essential that each section be fully extended and properly secured. When a section of the rod is fully extended a locking button should pop into place.

Measuring Distance

Measuring with Tape

- Tapes marked in feet that can be read to the hundredth of a foot can be used to measure distance.
- When measuring horizontal distance stretch the tape tight before making the reading.
- Do not use a tape to measure the horizontal distance if the tape cannot be stretched out on a horizontal line between the points.

Measuring distance with surveying level

Use the level and the survey rod to estimate distances where stretching a tape would be difficult. To do this read the *stadia,* the short crosshairs above and below the central crosshair on the survey rod.

- Set up the level at one end of the distance to be measured. Place the Survey Rod at the other point.
- Read the rod at the upper and the lower stadia line.
- Subtract the lower stadia reading from the upper stadia reading
- Multiply the difference by 100 to get the distance from the instrument to the rod.

Figure 19: Surveying the channel cross section at a stream flow gaging station

Survey the Cross Section at the Gage Station

Step 1: Stretch the tape from the left bank stake to the right bank stake, Figure 19. Read and record the horizontal distance between the stakes. Leave the tape stretched to guide the rod person as he moves from point to point along the cross section.

Step 2: Start the survey at the left bank stake. Starting at the left bank facilitates graphing the data. Distances will be referenced to the left bank stake; that is, the distance of the left bank stake will be zero. Take a GPS point for the left bank stake and the right bank stake as the end points of the cross section.

Step 3: Set up the surveyor's level along the cross section where you can clearly see both ends of the cross section. A good location to setup is a few feet behind one of the stakes so that the instrument and the two stakes are in line. The instrument can also be set up between the stakes, as long as the top of the stakes are lower than the instrument's line of sight. Setting up on the cross section line ensures that all points on the cross section will be visible and simplifies the calculations.

Step 4: Shoot the *backsight* by placing the rod on top of the cross section stake, or other point, whose elevation you have already established. Read the rod and record the value as a *backsight*. Determine the *instrument height* by adding the rod reading to the elevation of the stake.

Step 5: Place the rod vertically on top of the left bank stake. Read the rod and record the value as a *foresight*. The distance along the cross section of the left bank stake is zero.

Step 6: Place the rod vertically on the ground next to the stake. Read the rod and record the value as a foresight. The cross section distance of this shot is also zero.

Step 7: The rod person then proceeds to the next slope break or the next channel feature, such as a bankfull indicator, terrace or floodplain. The rod person calls out the type of feature the rod is placed on. The instrument man records the rod reading as a *foresight*.

Step 8: The horizontal distance from the left bank stake to the rod is measured and recorded. The distance can be measured using the tape stretched between the cross section stakes. If the tape is too high for the rod person to read the instrument person can read the distance from the instrument to the rod using the stadia lines. If the distance between the rod and the instrument is measured, make sure that it is recorded as such. It will be necessary to convert the distance from, "*the distance from the instrument*" to, "*the distance from the left bank stake*".

Step 9: Continue shooting the elevation and recording the distance at each point along the cross section. Finish the cross section by shooting the elevation at the ground next to the right bank stake and on then the top of the right bank stake.

Step 10: It is important to determine the elevation of the top of each stake. Each year the elevation of the cross section stakes is checked. Comparing the new elevation of the stake to the elevation of the stake from prior surveys is a good check for errors in the survey. It is also a way of verifying that the stake has not been altered.

Step 11: Occasionally you will have to move the instrument to complete the cross section survey. This may happen if an obstacle such as a large tree limb is blocking your line of sight. Remember to set one or two turning points before you move the instrument.

Step 12: If you move the instrument remember to close the survey by running a differential survey back to the stake you used as the backsight.

Step 13: Plot the data in the field book before you leave the site (Figure 20). Plotting the data helps you catch errors. Make sure that all distances have been converted to, "*distance from the left bank stake".* Draw a vertical scale that covers the range of elevation values. Draw a horizontal scale that covers the distance between the stakes. The horizontal and vertical scales will be different. Plot each elevation point at the appropriate distance.

Step 14: If you discover errors in the data, re-shoot points as needed to correct the problem.

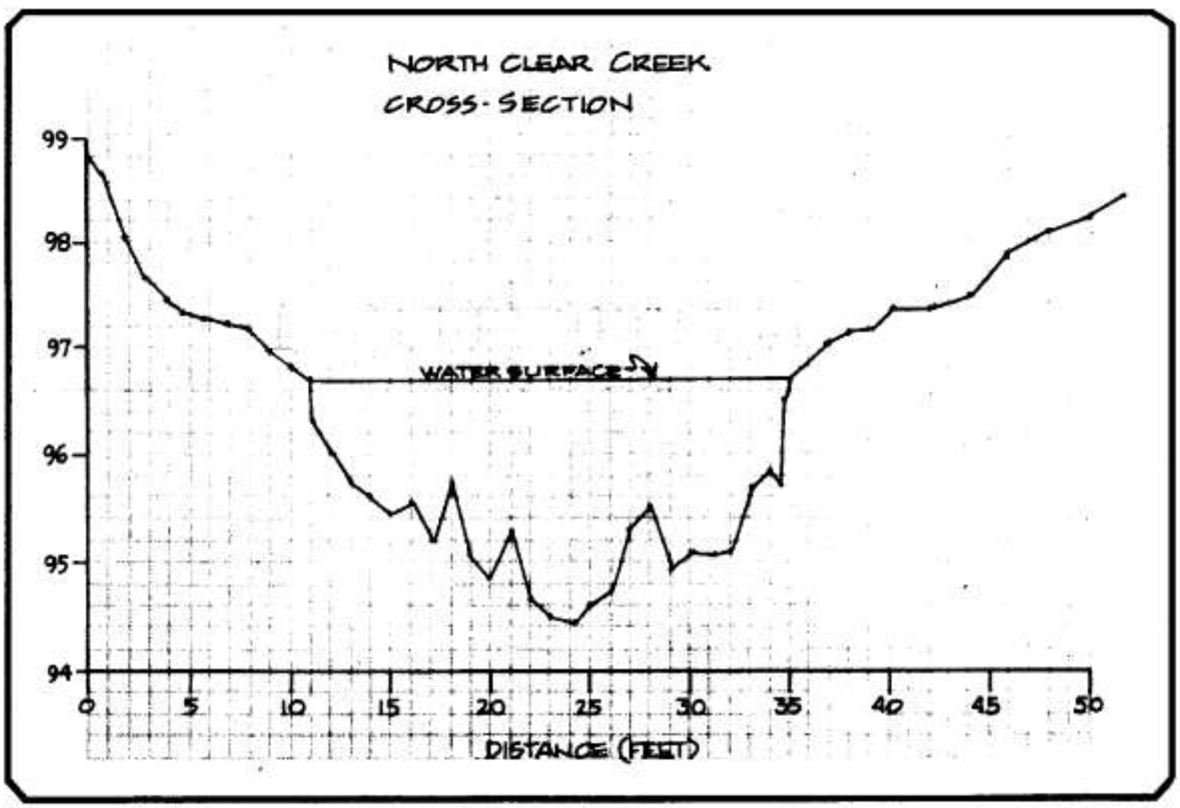


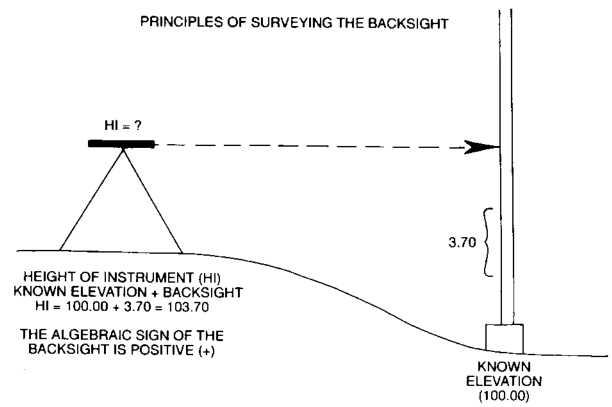
Figure 20: An example of a field plot of a cross section. The line labeled "water surface" indicates the water surface at the time of the survey (from Harrelson et al 1994).

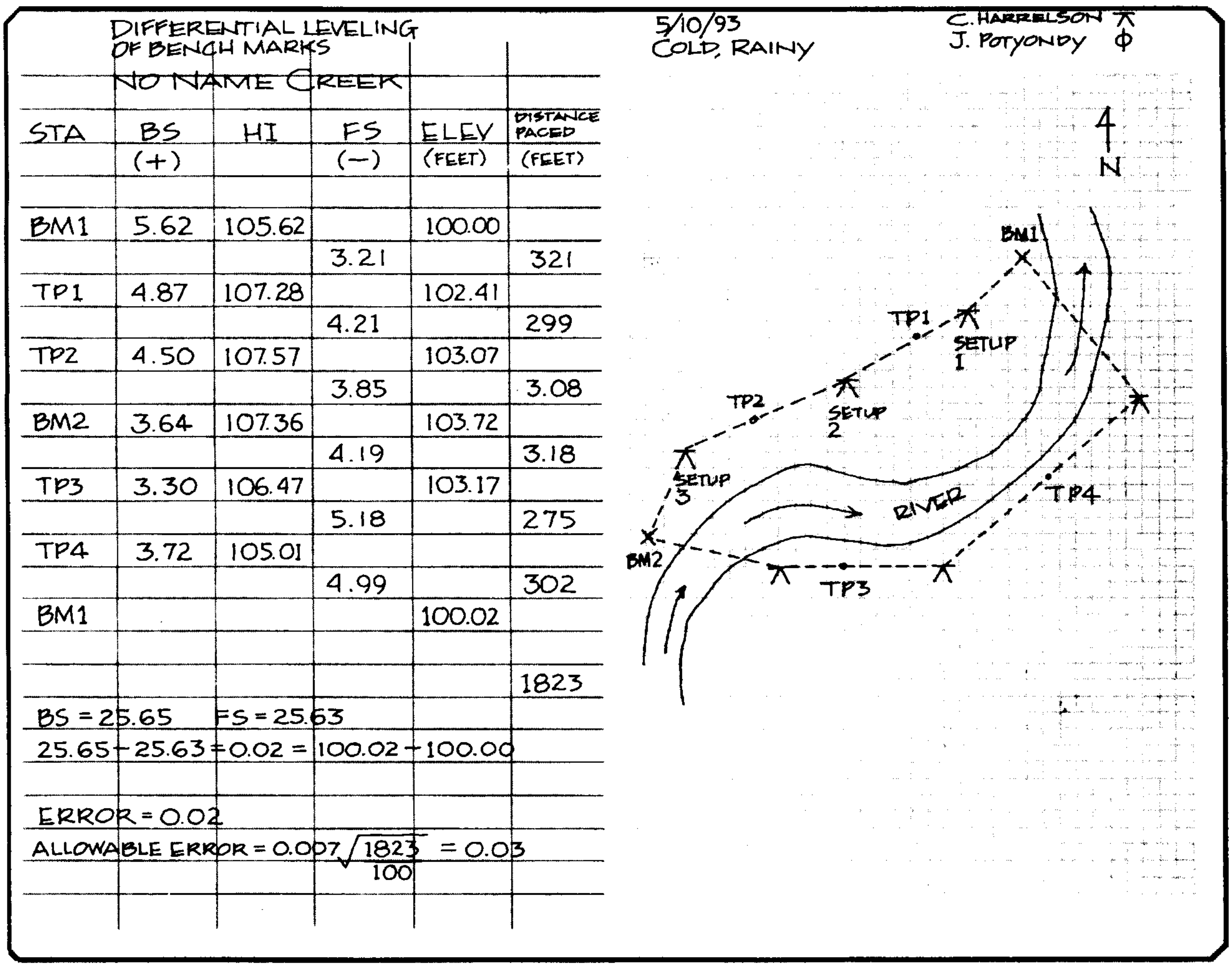
Differential Level Survey

A differential level survey is used to measure the relative elevation of points that are quite far apart. For example, a differential level survey can be used to determine the true elevation of your benchmark if a point of known true elevation is several hundred feet from your site. It consists of making a series of instrument setups along a route that ends back where it began. The route of the survey is called a *traverse*. From each instrument setup, the rod is taken to a point of known elevation to establish the *instrument height*. The instrument height is used to calculate the elevation of new points after the rod is read on the new point. Temporary reference points, called *turning points*, are established before the instrument is moved to a new location. The details of the process are described below.

Step 1: The first reading (a reading is also called a *shot*) is to the benchmark. In Figure 21, the benchmark is BM-1. The elevation of the benchmark is known or assumed, Figure 22. If the elevation of the benchmark is assumed it is strongly recommended that you survey from your benchmark to a benchmark with known elevation.

- Place the rod on the benchmark.





STA	BS (+)	HI	FS (−)	ELEV (FEET)	DISTANCE PACED (FEET)
BM1	5.62	105.62		100.00	
			3.21		321
TP1	4.87	107.28		102.41	
			4.21		299
TP2	4.50	107.57		103.07	
			3.85		3.08
BM2	3.64	107.36		103.72	
			4.19		3.18
TP3	3.30	106.47		103.17	
			5.18		275
TP4	3.72	105.01			
			4.99		302
BM1				100.02	
					1823

BS = 25.65 FS = 25.63

25.65 − 25.63 = 0.02 = 100.02 − 100.00

ERROR = 0.02

ALLOWABLE ERROR = $0.007\sqrt{\frac{1823}{100}} = 0.03$

Figure 21: Field notes from a differential survey. The purpose of the survey is to find the elevation of BM-2 relative to BM-1. The traverse starts at BM-1. Returning to BM-1 closes the survey (from Harrelson et al 1994).

- Get the rod vertical.
- Read the scale where the crosshair crosses the rod face.
- Record the reading in the field book as a *backsight*. In the notes, *backsight* is abbreviated as BS.

Step 2: The shot to the benchmark is called a backsight. The backsight reading is added to the elevation of the benchmark to calculate the *instrument height*, see Figure 22. The instrument height is the elevation of the instrument crosshair.
The notes shown in Figure 21 give an example of a differential survey. The elevation of BM-1 is given as 100.00 feet. The backsight to BM-1 is 5.62 feet. Thus, the height of the instrument, for the first setup, is 105.62 feet.

Step 3: Use a tape, the stadia method, or pacing to measure the distance from the instrument to the benchmark. Record the distance in the field book. The total distance covered by the survey is used to calculate the allowable error of the survey. This will be explained below.
In Figure 21, the distance was determined by pacing. The distance between BM-1 and TP-1 is shown as 321 feet.

Step 4: The rod person should drive a stake in the ground as a temporary reference known as a turning point, TP. The TP should be in the direction of the survey and about the same distance from the instrument as the benchmark. The stake should be solidly in the ground so that it does not shift.

Step 5: The rod is then placed on the TP and the instrument person reads the elevation and records it as a foresight, see Figure 23. For example, in Figure 21, the foresight, FS, of TP-1 is 3.21.
Step 6: The foresight of TP-1 is subtracted from the instrument height to determine the elevation of TP-1.For example, in Figure 21, the foresight of TP-1 (3.21) is subtracted from the instrument height (105.62) to calculate the elevation of TP-1 (102.41).

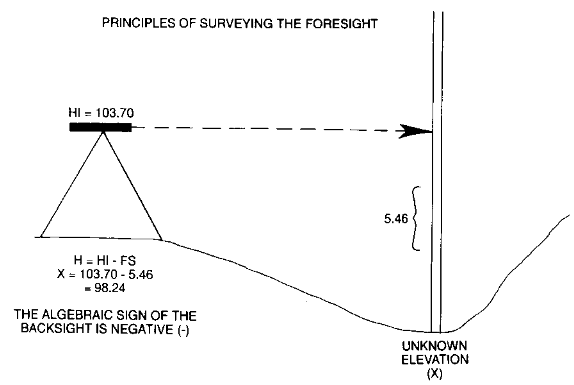


Figure 23: Shooting a foresight. The instrument height is already known.

Step 7: The instrument is then moved to the other side of TP-1.

Step 8: The rod is then placed on TP-1 and the rod is read as a backsight, after the instrument has been setup and leveled. The backsight is added to the elevation of TP-1 to calculate the instrument height, see Figure 24.

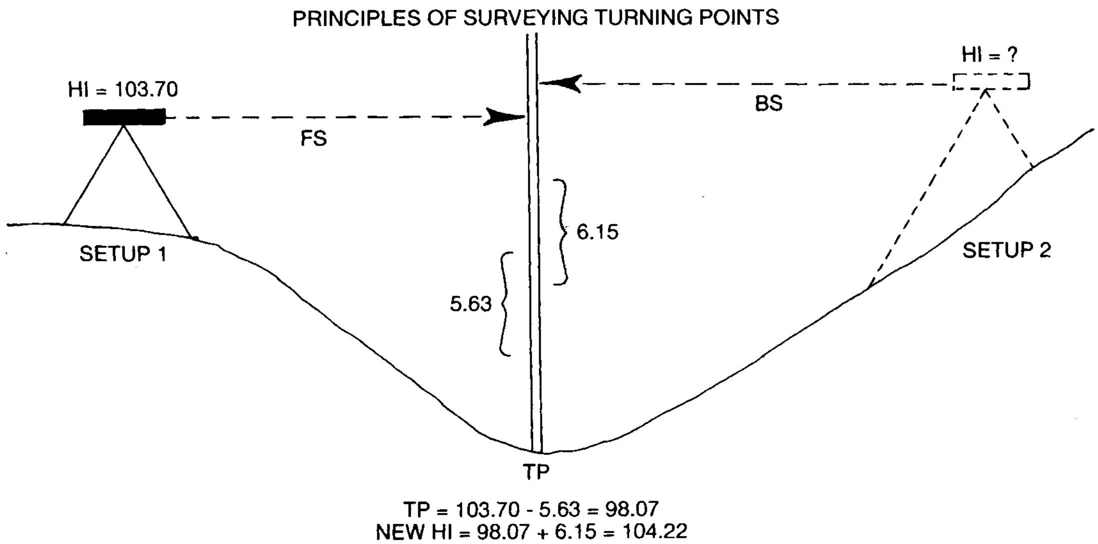


Figure 24: Using *turning points* to move the instrument.

For example, in Figure 21, the backsight to TP-1 from setup 2 is 4.87 feet. The backsight (4.87) is added to the elevation of TP-1 (102.41) to calculate the instrument height (107.28) at setup 2.

Step 9: The process outlined in steps 1-8 is repeated until the traverse is closed by shooting the original benchmark as a foresight. See the map in Figure 21.

Step 10: After you have closed the survey, the elevation of the benchmark at the end of the survey is compared to its original value. This process is known as closing the survey. The difference between the calculated elevation of the benchmark and its original value is the error.

$$Acceptable\ Error\ \leq 0.007\sqrt{(total\ distance)/100}$$

The acceptable amount of error depends on the total distance of the differential level survey. One equation to estimate the acceptable error is:

Where the *total distance* is the sum of the distances between the instrument stations in the differential level survey loop. For example, in Figure 21, the total distance of the differential level survey is 1,823 feet and the acceptable error is 0.03 feet.

5. COMPLETING DISCHARGE MEASUREMENTS

Although measuring stage produces valuable information, most gaging data are changed to discharge or volume of water per unit time such as cubic feet per second (cfs). Stage data are changed into discharge data through the completion of discharge measurements and creation of a stage-discharge relation for the particular station.

In general, discharge is computed by multiplying the area of water in the channel cross section by the average velocity of the water in that cross section (Figure 25). The continuity of flow equation describes this relationship:

*discharge = area * velocity*

Velocity varies over the channel cross section so many measurements must be done to accurately calculate discharge.

A current meter is used to measure velocity at numerous points along a cross section near the gaging station. In this method, the stream channel cross section is divided into a number of vertical subsections. In each subsection, the area is obtained by measuring the width and depth of the subsection, and the water velocity is determined using the current meter. The discharge in each subsection is then computed by multiplying the subsection area by the measured velocity. The total discharge is then computed by summing the discharge of each subsection.

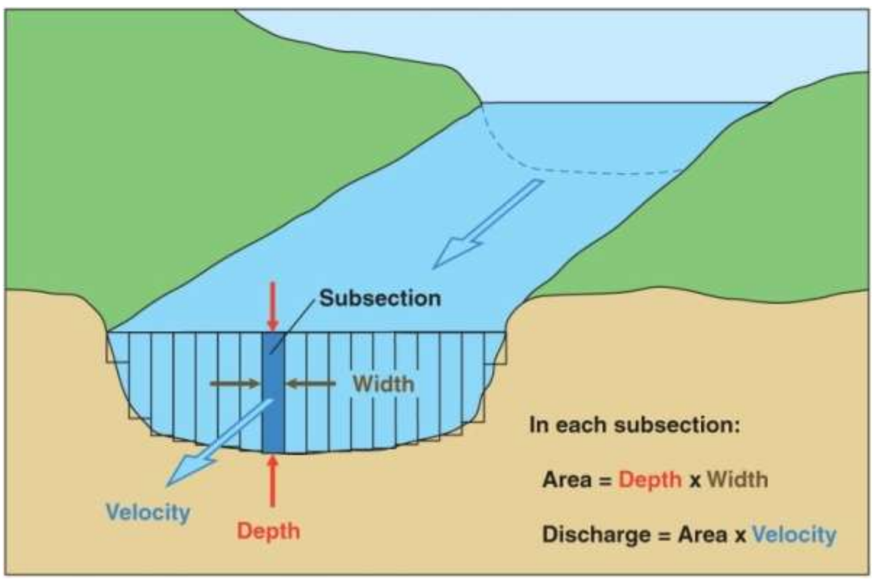


Figure 25: Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge (drawing from USGS website).

Selecting the cross section for the measurement

Choose a location near the gage site where there is a stable channel cross section and a straight section of channel where velocity threads are parallel and there is little slope change. The current should be uniform, free of eddies, dead water near banks, or excessive turbulence. The flow should have primarily downstream current uninterrupted by rocks of different sizes or vegetation. If there is a weir in the channel, measure the current just upstream of the structure. The location of the cross section will not be the same at different flow levels but the features of the location of the cross section should always be the same - even level of flow, minimal turbulence, primarily smooth downstream moving currents without eddies, vertical or side moving currents, unbroken by vegetation. Sometimes rocks need to be re-arranged to create these conditions. Features of the cross section and measurement should be recorded on Data Sheet 2.

Measure channel width and defining subsections

The width of the cross section is measured by stretching a vinyl measuring tape marked in tenths of feet from on edge of the wetted width to the other and perpendicular to the direction of flow. Stake the tape across the width for use in the measurement. This width is then split into subsections with no single subsection carrying more than 5-10% of the total flow. For stream widths of less than 5 ft., the subsections should be spaced at least 0.25 ft. apart. If the stream width is greater than 5 ft. the minimal number of subsections is 15-25. The preferred number is 20 to 30.

Laying out the subsections

The cross section is determined by measuring the width and dividing it by the number of subsections. For example, if the wetted width is 26 ft. with 20 subsections, each subsection will cover 1.3 ft. The first subsection will extend from the edge of the flow to 1.3 ft (0.0 on the tape) on the measuring tape. The midpoint of this subsection is 0.65 ft. This midpoint is where the current meter reading is completed. The rest of the subsection midpoints are determined by adding 1.3 ft. to the prior midpoint location.

Current Meters

The velocity of the streamflow is measured using a current meter (Figure 26). There are several types of current meters. Some have rotating cups, other have a pair of electronic contacts on a small head. The older types click for each complete rotation and the operator uses headphones and counts clicks for a set time period. Newer technology has a digital readout. The most common current meter used is the Price AA current meter. The Price AA current meter has a wheel of six metal cups that revolve around a vertical axis. Because the rate at which the cups revolve is directly related to the velocity of the water, counting the revolutions determines the water velocity. Current meters are attached to a wading rod for measuring in shallow waters or are mounted just above a weight suspended from a cable and reel system for measuring in fast or deep water. In shallow water, a pygmy current meter can be used. It is a two-fifths scale version of the meter and is designed to be attached to a wading rod. The pygmy meter can measure velocity in water as shallow as 0.3 ft. Velocity in water shallower than this cannot be readily measured.

Testing the meter before use

The current meter is a precision instrument, treat it with care. The meter is put together and the cups must spin freely and evenly in order to produce accurate measurements. Every time the meter is used, a test is needed. Using the headphones or digital readout, count the number of revolutions the meter cups make once spun. A count over 45-60 seconds with the manufacturer's specified number of revolutions shows the meter is operating properly.

Making current measurements using a current meter and top setting wading rod

The wading rod is adjustable to allow for placement of the meter at the 20%, 60%, and 80% level of depth. The depth is measured by placing the wading rod on the streambed and reading the total depth on the wading rod.

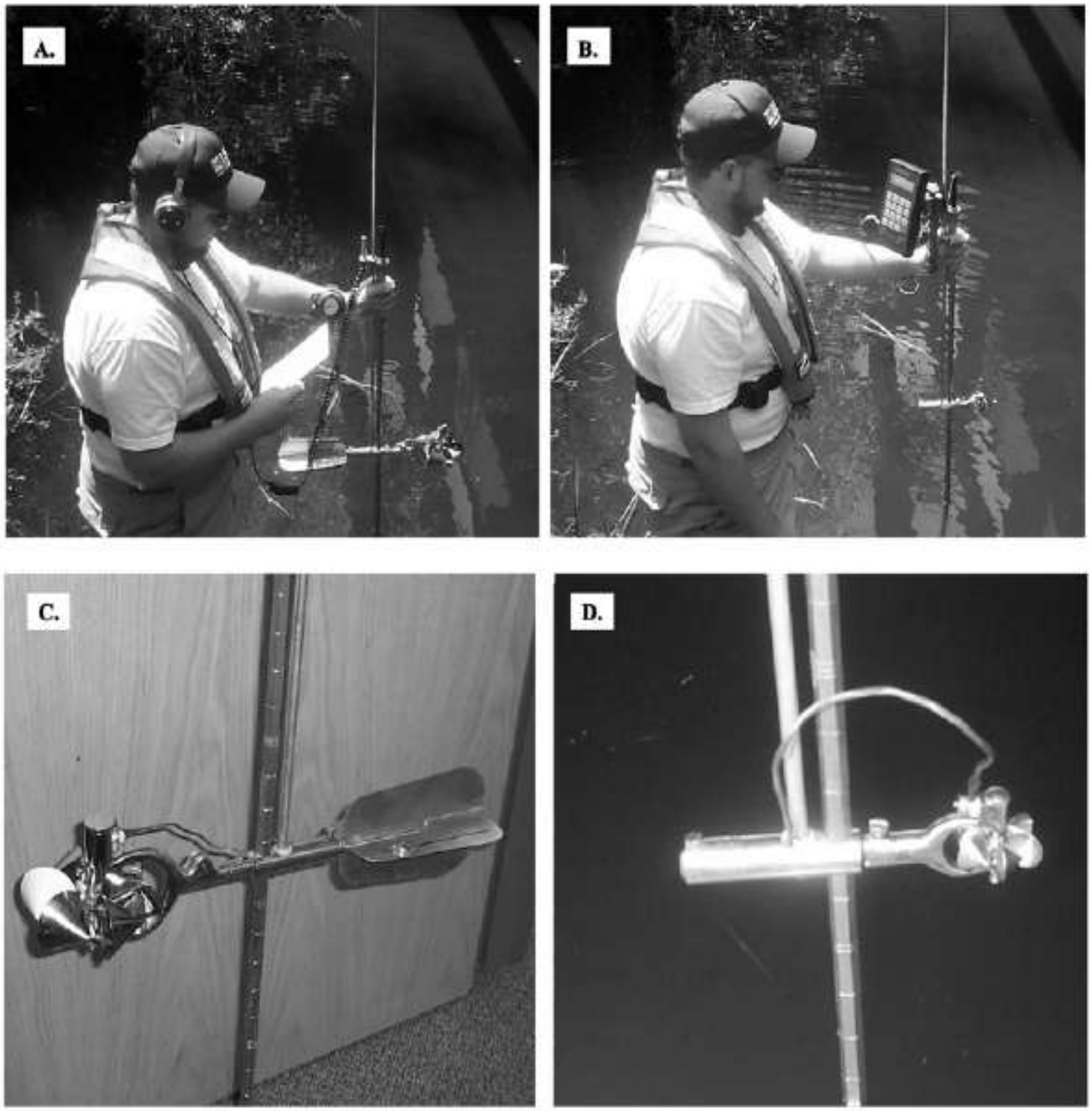


Figure 26: Types of current meters from McKobb and Weiskel 2003)

If the depth at the subsection is greater than 30 inches, the velocity is measured at the 20% and 80% water depths at the midpoint of the subsection.

If the water depth is less than 30 inches, the velocity is measured at 60% of the water depth. Keep the wading rod vertical and the current meter perpendicular to the flow.

A team of two people is needed. One person records the data and the other reads and reports the measurements (Figure 27). The measurements start at the left (facing downstream) edge of the water and progresses to the right. The left edge should be recorded as 0.0. At the center of each subsection the

Figure 27: Discharge measurements

reader reports the distance (from the 0.0 pt), the total depth, sets the current meter to the appropriate percentage of the depth, and makes the current meter measurement (Figure 28). The reader needs to stand downstream of the cross section when completing the current meter reading. In areas of the channel where the water is deeper or faster, additional readings within the subsection are done. After the reader reports the measurements, the recorder repeats them to confirm the correct number. The current meter reading, if using the type of meter where clicks are counted, is done with a timer. The clicks are counted for a 40-60 second period. Then the number is translated to velocity with a standard table for the particular meter (Attachment 1). Digital meters read out as velocity.

Calculating the Discharge

After all the measurements are made before removing the tape across the channel, the discharge calculation should be completed in case additional measurements are needed.

When velocity measurement is complete, calculate the total discharge (Q). Determining total discharge accurately is a complex issue, and a variety of methods and equations exist. The mid-section method is currently recommended by the U.S. Geological Survey. (At the risk of offending those with the proper math skills, the method is explained step-by-step.)

The following formula defines the basic method for calculating discharge:

$$\mathbf{Q = \sum (\mathit{a}\, V)}$$

Where Q is the total discharge, a is the area of a rectangular subsection, the product of width (w) and depth (d) for that subsection, and **V** is the mean velocity of the current in a subsection.

Step 1 Using the mid-section method, compute the area (a_n) of each subsection:

$$a_n = d_n\,(b_{(n+1)} - b_{(n-1)})/2$$

where ***b*** is the distance along the tape from initial point. “Lost” discharge in the triangular areas at the edges is assumed negligible.

Step 2 Next, multiply the subsectional area a_n by the mean velocity **V** for the subsection to get the subsection discharge (**Q**). If only one velocity measurement was taken at 0.6 depth, it is the mean velocity. If two measurements (v_1 and v_2) were taken at 0.2 and 0.8 depth, compute the mean value as below:

$$V = (v_1 + v_2)/2$$

Step 3 To compute the discharge for each subsection, use the equation:

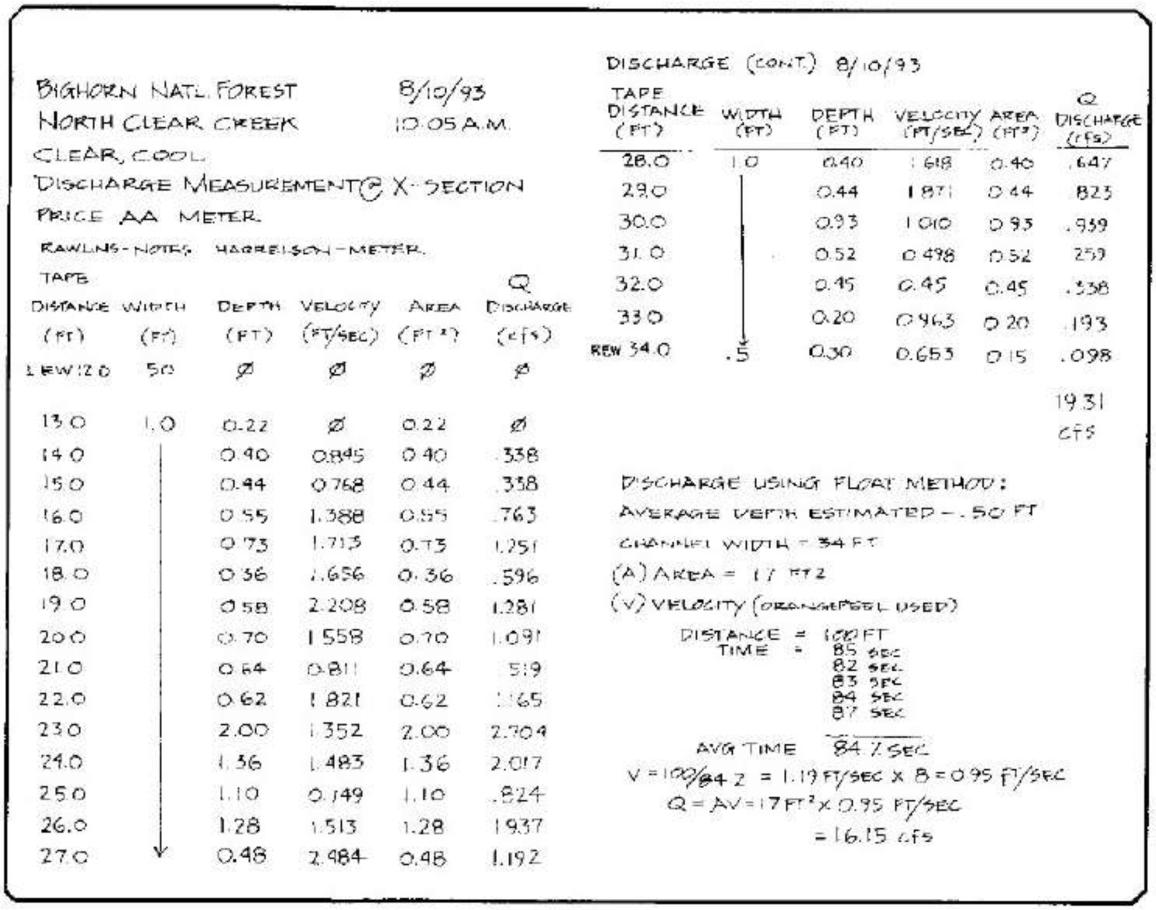
$$Q_n = (a_n V_n)$$

where

Q_n = discharge for subsection n
a_n = area of subsection n, and
V_n = mean velocity for subsection n.

The calculation repeats this process for each subsection, as shown below:

$Q_1 = (a_1 V_1)$, $Q_2 = (a_2 V_2)$, $Q_3 = (a_3 V_3)$, $Q_4 = (a_4 V_4)$, and so on…



BIGHORN NATL. FOREST 8/10/93
NORTH CLEAR CREEK 10:05 A.M.
CLEAR, COOL
DISCHARGE MEASUREMENT @ X-SECTION
PRICE AA METER
RAWLINS - NOTES HARRELSON - METER

TAPE DISTANCE (FT)	WIDTH (FT)	DEPTH (FT)	VELOCITY (FT/SEC)	AREA (FT²)	Q DISCHARGE (cfs)
LEW 12.0	5.0	∅	∅	∅	∅
13.0	1.0	0.22	∅	0.22	∅
14.0	↓	0.40	0.845	0.40	.338
15.0		0.44	0.768	0.44	.338
16.0		0.55	1.388	0.55	.763
17.0		0.73	1.713	0.73	1.251
18.0		0.36	1.656	0.36	.596
19.0		0.58	2.208	0.58	1.281
20.0		0.70	1.558	0.70	1.091
21.0		0.64	0.811	0.64	.519
22.0		0.62	1.821	0.62	1.165
23.0		2.00	1.352	2.00	2.704
24.0		1.36	1.483	1.36	2.017
25.0		1.10	0.749	1.10	.824
26.0		1.28	1.513	1.28	1.937
27.0	↓	0.48	2.484	0.48	1.192

DISCHARGE (CONT.) 8/10/93

TAPE DISTANCE (FT)	WIDTH (FT)	DEPTH (FT)	VELOCITY (FT/SEC)	AREA (FT²)	Q DISCHARGE (cfs)
28.0	1.0	0.40	1.618	0.40	.647
29.0	↓	0.44	1.871	0.44	.823
30.0		0.93	1.010	0.93	.939
31.0		0.52	0.498	0.52	.259
32.0		0.45	0.45	0.45	.338
33.0		0.20	0.963	0.20	.193
REW 34.0	.5	0.30	0.653	0.15	.098
					19.31 cfs

DISCHARGE USING FLOAT METHOD:
AVERAGE DEPTH ESTIMATED – .50 FT
CHANNEL WIDTH = 34 FT
(A) AREA = 17 FT2
(V) VELOCITY (ORANGEPEEL USED)
DISTANCE = 100 FT
TIME = 85 SEC, 82 SEC, 83 SEC, 84 SEC, 87 SEC
AVG TIME 84.2 SEC
V = 100/84.2 = 1.19 FT/SEC x .8 = 0.95 FT/SEC
Q = AV = 17 FT² x 0.95 FT/SEC
= 16.15 cfs

Figure 28: Field notes of discharge measurement (from Harrelson et al 1994).

Step 4 The subsection products are then added to get total discharge (**Q**):
Q = Q + Q + Q + Q + and so on…

Thus, total discharge (Q) equals the sun of all discharges **∑ (*a* V)**, as stated earlier in the basic equation:

$$Q = \sum (a V)$$

A current meter reading should be done every few weeks after the gage is installed and, if water levels fluctuate, more frequently to include low and high flow.

6. CREATING THE STAGE-DISCHARGE RATING CURVE

Stream gages continuously measure stage. This continuous record of stage is translated to river discharge by applying the stage-discharge relation (also called the rating curve). The stage-discharge relation is developed by measuring width and depth and velocity with a current meter over a wide range of stages. These measurements are used to calculate discharge, then plotted against a corresponding measurement of stage recorded with a water level gage. This plot is refined as more discharge measurements are made, especially at the high and low flow levels.

An example of a stage-discharge relation is shown in Figure 29. The stage-discharge relation depends upon the shape, size, slope, and roughness of the channel at the stream gage and is different for every stream gage.

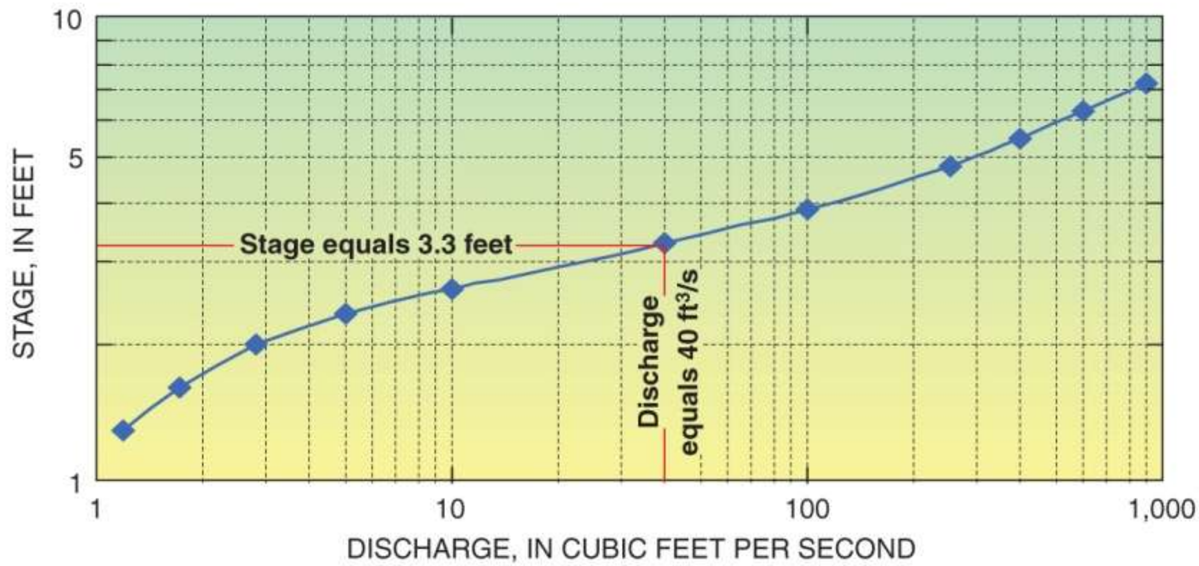


Figure 29: Example of a typical stage-discharge relation; here, the discharge of the river is 40 cubic feet per second (ft^3/s) when the stage is 3.30 feet (ft). The dots on the curve represent concurrent measurement of stage and discharge (from USGS website).

7. MAINTAINING THE ELEVATION AND STAGE/DISCHARGE RATING THROUGH CONTINUED MEASUREMENTS

The development of an accurate stage-discharge relation requires numerous discharge measurements at all ranges of stage and streamflow. In addition, these relations must be continually checked against on-going discharge measurements because stream channels are constantly changing. Changes in stream channels are often caused by erosion or deposition of streambed materials, seasonal vegetation growth or debris. Figure 30 shows an example of how erosion in a stream channel increases a cross-sectional area for the water, allowing the river to have a greater discharge with no change in stage. New discharge measurements plotted on an existing stage-discharge relation graph would show this, and the rating could be adjusted to allow the correct discharge to be estimated for the measured stage.

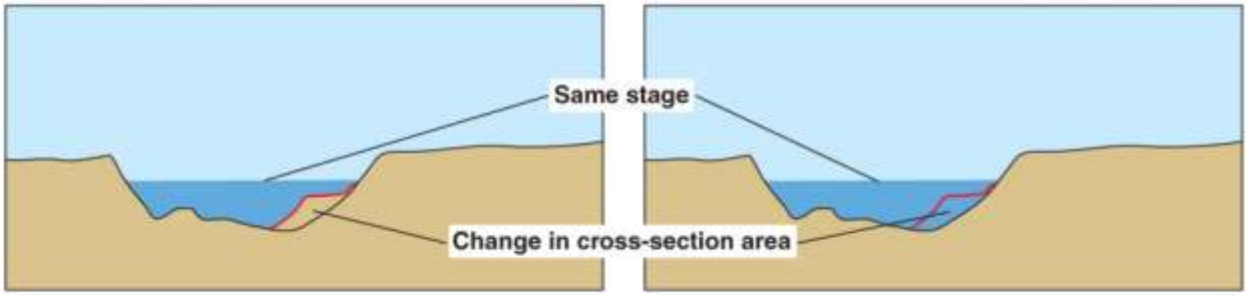


Figure 30: Erosion of part of a channel results in an increased cross-sectional area in the diagram on the right and the potential for conveying a larger quantity of water at the same stage (from USGS website).

The cross section at the gage site also needs to be resurveyed after major floods and at least once every 5 years. The survey should verify the datum used when establishing the gage and if the gage has moved determine the change and correct the record as needed.

8. MANAGING DATA

Implementation of this protocol will create two types of data: digital data from data loggers, GPS units and, if used, digital survey data and current meter measurements and surveying notes recorded in field logbooks. Following a field day when the field books are returned to the office all of the prior day's notes and data sheets are copied and placed in a separate file. This assures that the loss of the field book I on a future date will not result in data loss.

Digital flies will also be copied and stored on a hard drive that is separate from the location where the original files are stored.

When data sets are reviewed if any adjustments are made a separate spreadsheet of notes will be created with the reviewers initials the date and the reason for the change including the location of other data sources used for the revision.

Data interpretation and analysis need to be completed by a profession al hydrologist, geologist or other professional with experience in hydrological analysis.

Attachment 1

DATA SHEET #1: STREAM FLOW GAGING STATION: SITE SELECTION

Rate the location of the stream flow gaging station for each of these features

Station Name:	
GPS Coordinates	

☐ **Confined Channel Location**

☐ **Alluvial Channel Location**

Rating	*Characteristic*	*Notes, description*
H M L	Perennial	
H M L	Artificial structure (bridge, dam, weir or flume)	
H M L	Straight channel ~300 ft upstream and downstream of site	
H M L	Limited scour, deposition, algal growth	
H M L	Low loss to groundwater	
H M L	No secondary channel	
H M L	Permanent banks high enough to contain floods, brush-free	
H M L	Persistent pool upstream of site (how far?)	
H M L	Upstream of a confluence (how far?)	
H M L	Good for measuring discharge at all stages (how far from site?)	
H M L	Accessible and safe	
H M L	Streambed characteristics (stable, even, not soft)	
H M L	**OVERALL**	

Assessment of site, advantages, disadvantages

DATA SHEET #2: STREAM FLOW GAGING STATION: DISCHARGE SITE

Rate the location of the discharge measurement for each of these features

rating	***criteria***	***notes, description***
H M L	Perennial flow	
H M L	Artificial structure (bridge, dam, weir or flume)*	
H M L	Stable cross section*	
H M L	Straight channel ~100 ft upstream and downstream of measurement site	
H M L	Little slope change	
H M L	Velocity threads are parallel	
H M L	Uniform current at measurement site free of eddies, side currents and dead water	
H M L	Little water turbulence at measurement site	
H M L	Flow has primarily downstream current uninterrupted by rocks of different sizes or vegetation	
H M L	**OVERALL**	
	*Describe grade control at measurement site below including if rocks in channel were rearranged to improve measurement	
	Take a photo of the site where the discharge measurement was done and record a GPS point	

Assessment of site, advantages, disadvantages, affect on discharge measurements

DATA SHEET #3: STREAMFLOW GAGING: STAGE-DISCHARGE MEASUREMENT

PAGE 1

Date	
Field Team	
Weather conditions	
Stream observations	
Flow conditions	

Current meter instrument number and model:

Was spin test completed prior to measurement

CURRENT METER READINGS

Start time: ____ Water level Staff gage: ____

					Velocity readings					
					20% depth	60% depth	80% depth	Mean velocity		
Distance from reference point	Panel number	Panel width	Time	Water depth	fps	fps	fps	fps	Panel discharge	Notes
feet			hh:mm	feet					cfs	
	1									
	2									
	3									
	4									
	5									
	6									
	7									
	8									
	9									
	10									
	11									
	12									
	13									
	14									
	15									

COMPLETE ON PAGE 2

CURRENT METER READINGS CONT.

Distance from reference point	Panel number	Panel width	Time	Water depth	Velocity readings: 20% depth	60% depth	80% depth	Mean velocity	Panel discharge	Notes
					fps	fps	fps	fps		
feet			hh:mm	feet					cfs	
	16									
	17									
	18									
	19									
	20									
	21									
	22									
	23									
	24									
	25									
	26									
	27									
	28									
	29									
	30									

Total of panel discharges ______ cfs

Stop time ______

Water level

Staff gage: ______

APPENDIX 2

Quality Assurance Project Plan

For

Stream Flow Monitoring and Coordinated Diversions

Pilot Study

May 31, 2011

California Land Stewardship Institute
550 Gateway Drive, #108, Napa, CA 94558

APPROVAL SIGNATURES

Title:	Name:	Signature:	Date:
Project Manager	Laurel Marcus	____________	____________
QA Officer	____________	____________	____________
Staff Specialist	____________	____________	____________
Land Manager	____________	____________	____________

DISTRIBUTION LIST

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Laurel Marcus, CLSI	707-253-1226	laurelm@fishfriendlyfarming.org
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____________	____________	____________
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SECTION 1.0 PROJECT DESCRIPTION AND OBJECTIVES

The Stream Flow Monitoring and Coordinated Diversions Pilot Study encourages growers to integrate stream flow monitoring into agricultural operations. Stream flow data will contribute to a fact-based assessment of the variation in water availability and whether diversion need to be coordinated in a particular tributary.

A number of stream flow monitoring stations will be established in a tributary basin. A relationship between the water level or stage and discharge at the site will be developed by taking discharge measurements over the expected range of flows. The discharge measurement and corresponding stage is plotted to generate a stage-discharge rating curve for each gaging station. The rating curve is used with a gage that records continuous water level to derive a discharge time series for the site.

The Stream Flow Gaging Procedure

1. Evaluate locations for the stream flow gaging station
2. Estimate the expected range of flow rate and flow depth at the chosen site to select the type of continuous water level recorder
3. Install a staff gage and a continuous water level recorder at each site
4. Survey the channel cross-section at the gaging station and relate it to known elevation points
5. Measure discharge at or near the gaging station for a range of flow levels
6. Generate a rating curve for the gaging station using the discharge and stage measurements
7. Maintain the data generated by the water level recorder, using the stage/discharge rating to produce time series stream flow data
8. Assess the data and operation of equipment, checking it against the stream gage

SECTION 2.0 PROJECT ORGANIZATION

California Land Stewardship Institute (CLSI) is a nonprofit organization interested in the enhancement of riparian and aquatic habitat and improvement of water quality. CLSI will work with landowners in tributary basins to select the location, estimate the expected flow rate and depth ranges, install a staff gage and a continuously recording water level gage, survey a cross section at the monitoring site with a benchmark that is surveyed to points of known elevation, and measure discharge sufficient to generate a rating curve. CLSI will consolidate the data from each site and review for accuracy and representativeness.

Title/Responsibility	Name/Qualification	Agency Affiliation	Email/Phone
Project Manager/directs day-to-day work of project	Laurel Marcus, 30 years watershed professional	Director, CLSI	laurelm@fishfriendlyfarming.org (707) 253-1226
Quality Assurance manager	Qualified professional, hydrologist,	CLSI	
Contractor /Staff	Field work	CLSI	
Land Manager			

SECTION 3.0 EXPERIMENTAL APPROACH

For details on the approach and procedures for establishing a stream flow gaging station, refer to APPENDIX A: Stream Flow Monitoring Protocol. The following subsections provide an overview of the approach and identify relevant QA/QC procedures.

3.1 Site Selection

Because the location of the monitoring station is the crucial step in providing representative data, a qualified professional will determine the site selection. At sites on alluvial channels, where few locations will meet the criteria, the choice will be identified as the best available, with an assessment of how the flow measurement may be affected. The qualified professional will fill out the Data Sheet #1 in Appendix B: Site Selection Checklist. Site selection will be assessed as achieving the requirements according to a low, medium, or high rating, with notes to explain the choice. This rating will help assess the quality of the gaging data.

The site for the stream gaging station should be the best available and meet as many of the criteria listed in Appendix A: Stream Flow Monitoring as possible. The site will need to accommodate the water level recorder and the staff gage. It will also be where the cross section is surveyed and related to a permanent benchmark that can be located easily every year.

Discharge measurements will be taken in the general area of the site. An evaluation form to assess how the site's features will affect discharge measurements is listed in Appendix B.

These considerations will be taken into account by the qualified professional, who, in consultation with the landowner or manager, will determine the site selection for the stream gaging station.

3.2 Water Level Recorder Device Selection

The qualified professional, in consultation with the landowner or manager, will determine if the site is appropriate for a stilling well, a bubble system, a pressure transducer, an acoustic recorder, or another water level recorder device. Stilling wells and bubble systems need adequate space for the gaging house and require significant investment; pressure transducers are the most likely fit for most sites, but are susceptible to scour and siltation; acoustic recorders are good choices for sites beneath bridges, but need water free of algae and debris.

The Stream Flow Monitoring Protocol in Appendix A includes Table 1, which compares pressure transducer devices currently available, one bubble system device, and acoustic recorders. To assure data accuracy, the qualified professional will choose a water level recorder device with a range of water depth closest to the expected range to be monitored.

The devices listed in Table 1 range in accuracy claims depending on the device and temperature. The accuracy standard expected for data in the Stream Flow Monitoring and Coordinated Diversions Pilot Study is 0.01 ft. or 0.2% of the total depth the instrument is rated for, whichever is greater. The staff gage is the reference for the water level recording device. A staff gage that can be read to 0.01 ft. is required to conduct the accuracy checks on the continuously recording water level device (see “Station Maintenance QA/QC Checks” in Section 6.0 QA/QC checks).

3.3 Installation of Water Level Recorder and the Staff Gage

The water level recorder installation will depend on the type of device selected for the station (refer to Stream Flow Monitoring Protocol, Appendix A). The stilling well and bubble system require a site that can accommodate gage housing. The pressure transducers need a site where a plastic pipe can be affixed to a stable structure or post near the point of low flow

The staff gage is a non-recording, physical gage secured to a post or other structure on the bank. Low flows and high flows may require two separate but related staff gages. The staff gage is used as a reference and a check for the water level recorder. The expected accuracy of the staff gage is ± 0.01 ft. or 0.2% of effective range, whichever is greater.

For both the water level recorder and the staff gage, installation should take into account accessibility and safety, especially in times of wet weather and high flow. If the bank is steep, a site to secure a rope, such as around a large tree or a built structure, could provide a hold to prevent slipping down a slick bank while trying to take a reading or retrieve a sensor.

3.3 Cross Section Survey and Benchmark

The cross section survey will be overseen by a qualified professional experienced in conducting surveys. The final survey will be reviewed by the qualified professional. The protocol for the cross section survey is covered in the Stream Flow Monitoring Protocol in Appendix A.

The person selecting points to measure for the cross-section must recognize slope breaks and take an adequate number of points to assure a reasonably accurate topographic representation of the cross section.

The cross section survey will be tied to point of known elevation using a differential level survey. The protocol for the differential survey is covered in the Stream Flow Monitoring Protocol in Appendix A. A permanent benchmark is chosen that won't wash away, that is adequately identified by GPS readings so that it can be found again each year, and that will provide a point to resurvey the station should an event require relocation. The differential survey needs to be a closed loop so that the elevation of the point at the end of the survey is compared with its beginning value. The acceptable error depends on the total distance of the survey:

$$Acceptable\ \ Error \leq 0.007\sqrt{(total\ distance)/100}$$

The cross section survey determines the bottom of the stream used for the stage height zero point for both the staff gage and the water level recorder. It should be accurate to the nearest 0.015 ft. The elevations of the water level recorder and the staff gage will be verified every 1 to 3 years by checking them against the benchmark to make sure they haven't moved.

SECTION 4.0 SAMPLING PROCEDURES

Sampling procedures are covered in Experimental Approach, Section 3.

SECTION 5.0 TESTING AND MEASUREMENT PROTOCOLS

Testing and measurement protocols are covered in Experimental Approach, Section 3.

SECTION 6.0 QA/QC CHECKS

Quality assurance requirements will be the responsibility of a qualified professional. The professional will have expertise in hydrology, open-channel hydraulics, flow measurement techniques and procedures, and data reduction techniques.

Attention to procedures and maintenance of equipment can reduce errors in measurement and discharge calculations.

Errors in discharge measurements include errors in depth because of soft, uneven, or mobile streambeds, uncertainties in mean velocity associated with vertical-velocity distribution errors, pulsating errors, and systematic errors due to improperly calibrated equipment or improper use of the equipment. Good site selection, which includes an assessment of streambed characteristics, will minimize errors in discharge measurement errors due to depth (see Section 3.1, Site Selection and Appendix B, Stream Flow Gaging Station: Site Selection). Calibration of the current meter is addressed in section 6. 4.

6. 1 Station Maintenance QA/QC Checks

The elevations of the water level recorder and the staff gage will be verified every 1 to 3 years by checking them against the benchmark using surveys to make sure they haven't moved. Variations greater than 0.015 ft. will be recorded in the field log book and incorporated into corrections for subsequent readings.

Read the staff gage to 0.01 ft and compare with the water level recorder. If the recorder is more than 0.01 ft. off (or 0.2% of depth, whichever is greater), record the difference in the logbook and consult with the qualified professional. If the difference is more than 5%, then remove the water level sensor to inspect it. If it is malfunctioning, then replace it with a new sensor. Make sure to record the time and readings in the field logbook before and after removal and re-installation so that errors in flow records can be annotated and pro-rated correctly.

At low flow:

- Check the staff gage to make sure it is clear of debris, readable, sturdily attached, and intact
- Check vent tube and confirm that sensor is in the water
- Inspect sensors for changed positions or blockages that might affect function or reliability
- Check gage housing for accumulated sediment and record the amount if it is affecting the sensor
- Remove woody debris that might alter the water surface elevation at the station and record sediment deposition

- Note flow conditions that are recorded as zero flow, but have flow that is by-passing the station gage

At high flow:

- Inspect for erosion and deposition that will affect the cross section, the sensor, or the staff gage
- Note large scale changes that would increase or decrease resistance to flowing water at high stages

6.2 Data Management and Records Management

The qualified professional and the landowner /manager share responsibility for the field logbook. The qualified professional will set up and periodically review the field logbook, and the landowner or manager at the site will be trained by the qualified professional to maintain the logbook. The field logbook will be routinely reviewed and audited as part of the QA/QC procedures (see Data Review, Audit, and Approval, Section 6.5.1). The field logbook may be an electronic logbook. Following each field day all data entries and data sheets will be copied and filed separately from the logbook in case the field book is lost or damaged.

Continuous water-level data will be stored in computer data files. All raw data files downloaded from the field data logger will be stored in a central office location and a copy burned to a CD or DVD.

Digital photos documenting flow conditions during discharge measurements will be kept in a central office location.

6. 3 Quality Control for Continuous Water Level Recorder

Water level sensor operation and accuracy will be verified weekly if possible or at least once every 14 days after installation by comparing the sensor reading with a water level measurement taken from the staff gage installed at the site (see Station Maintenance QA/QC Checks, Section 6. 1). The time and result of each check will be recorded in the field logbook.

Data logger operation will be checked and verified at the same time. The stored data will be accessed and reviewed to determine if there has been drift, unexplained variation in recorded water levels, or malfunction. If troubleshooting does not resolve a malfunction, the data logger will be replaced, and the time and serial number of the replacement will be recorded in the field logbook.

If the check reveals that the water-level sensor is in error by more than 5% of the water depth at the sensor, then the sensor will be removed and inspected. The time of sensor removal will be recorded in the field logbook. If no reason for the error can be found, the sensor will be replaced by a new sensor, and the time of replacement will be recorded in the field logbook.

6. 4 Calibration of Current Meter (Water Velocity Meter)

Maintenance and calibration of the current meter will be done in accordance with the manufacturer's operations manual for proper calibration and maintenance procedures. Current meters should be inspected before and after each measurement and tested at the beginning of each round of measurements. Calibration of the current meter by performing a spin test should be done at the beginning of each field trip.

6.5 Validation of the Rating Curve Data

6.5.1 Data Review, Audit, and Approval

Immediately after taking discharge measurements at a gaging station, the results of that measurement will be reviewed to determine the adequacy of each measurement for use in developing the station's rating curve. The review will consist of an audit of the field logbook, data records, and data reduction calculations on the stage-discharge measurement data sheet (see Appendix B), and an interview with the personnel who took the measurement. Flow data are inspected for missing entries, sufficiency of significant digits, spurious values, and for elevated flows not associated with runoff events noted at other stations or rainfall records.

If results are judged acceptable, then the stage-discharge measurement data sheet will be approved. If any deficiencies are found, then they will be reviewed in detail with the personnel who took the measurement so that appropriate corrective action is taken to ensure adequacy of future measurements.

6.5.2 Maintaining Approved Rating Curve Data

The qualified professional will maintain a copy of approved stage-discharge measurements for all stations and will be responsible for developing each station's rating curve. The flow measurements and discharge calculations will be completed and reviewed in the field by the qualified professional. If the measurements and calculations are not approved, they will be redone.

The current meter measurements and the cross section used will be rated according to ideal conditions, noting features that will produce less accurate measurements (see Stream Flow Monitoring Protocol Appendix A).

The accuracy of the rating curve developed for each stream flow gaging station depends on the number of stage-discharge measurements made at each location and the flow range of those measurements. The minimum requirement is that ten separate stage-discharge measurements be made at each location, consisting of:

- 3 measurements under relatively low flow conditions (dry weather)
- 4 measurements under moderate flow conditions (shortly after a runoff peak, during hydrograph recession)
- 3 measurements under high flow conditions (during the peak of a significant runoff episode)

The rating curve for each station is generated by plotting the stage-discharge pairs on graph paper or using a computer program, then, using visual or mathematical curve-fitting techniques, drawing a smooth curve over the range of the data.

Once a rating curve with a good fit has been established over multiple years at a site, gaging during subsequent years may continue on an as-needed basis to provide three new points per year, one each for low, medium, and high flow, and to fill in any uncertainty or resolve variability on the rating curve.

SECTION 7.0 DATA REPORTING, REDUCTION, AND VALIDATION

A field logbook (such as *Rite-in the-Rain* All-Weather Level Notebook No. 311) or electronic field logbook will be the record of surveys, measurements, notes, and observation on each gaging station for each visit, including the conditions of:

- Weather
- Staff gage, water level sensor and datalogger (to the 0.01 ft)
- Flow (in cubic feet per second, cfs)
- Floating debris
- Streambank and streambed erosion
- Deposition or debris accumulation
- Upstream and downstream

Water level readings from the water level sensor and the staff gage and the time (date, hour, minute) will be recorded in the logbook when depth-velocity measurements begin and end. Photographs of the site and the flow will be taken on each visit. (Use Appendix B: Stage-Discharge Measurement Data Sheet.)

SECTION 8.0 ASSESSMENTS

Flow data are inspected for missing entries, sufficiency of significant digits, spurious values, and for elevated flows not associated with runoff events noted at other stations or rainfall records.

SECTION 9.0 REFERENCES

Harrelson, Cheryl C; Rawlins, C. L.; Potyondy, John P. 1994. ***Stream Channel Reference Sites: An Illustrated Guide to Field Technique.*** Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

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Sauer, V. B., and Meyer, R. W. 1992. ***Determination of Error in Individual Discharge Measurements***: U.S. Geological Survey, Open-File Report 92-144, 21p.

Sauer, V.B., and Turnipseed, D.P. 2010. ***Stage Measurement at Gaging Stations: U.S. Geological Survey Techniques and Methods*** book 3, chap. A7, 45 p. (Also available at http://pubs.usgs.gov/tm/tm3-a7/.)

U.S. Geologic Survey website, www.usgs.gov

Washington Conservation District. 2007. ***Standard Operating Procedure (S.O.P.) No. 1: Flow Monitoring***, Version 2.

APPENDIX A

STREAM FLOW MONITORING PROTOCOL

APPENDIX A: Stream Flow Monitoring

INTRODUCTION

Monitoring stream flow involves a series of steps to develop a reliable dataset. Each step requires attention to detail and may need professional judgment to evaluate field conditions and determine the best location for measurements.

In tributary basins, stream flow may need to be monitored in a number of locations. The steps in establishing a stream flow monitoring station include:

1) Selecting the gaging station locations
2) Selecting the type of gage
3) Installing the gage
4) Surveying the channel cross section and points of known elevation at the gage site
5) Completing discharge measurements
6) Creating a stage/discharge rating curve for the station
7) Maintaining the elevation and stage/discharge rating through continued measurements
8) Managing data

Stream flow is typically described in cubic feet per second (cfs) or the volume of water moving past the monitoring station per unit of time. This volume can vary greatly throughout the year, so stream flow needs to be continuously monitored in the most accurate manner possible.

There are several types of instruments used for stream flow monitoring that measure the stage or depth of the flow. Stage is the elevation of the surface of the water above the channel bottom. Several additional steps are needed to relate the stage measurements to actual elevations and to convert them to discharge or cubic feet per second. These additional steps make the stage measurements at one station relevant to other stations and to diversions. These measurements are carried out when establishing the station and revised over time to maintain the accuracy of the monitoring data.

These are key references for stream flow monitoring:

- Harrelson, Cheryl, C.L. Rawlins and John Potyondy. 1994. ***Stream Channel Reference Sites: An Illustrated Guide to Field Techniques***. USDA Forest Service Report RM-245.

- McCobb, Timothy D. and Peter K. Weiskel. 2003. ***Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems***. U.S. Geological Survey Open-File Report 02-497

- Rantz, S. E. 1982. Measurement and Computation of Stream Flow: Volume 1. ***Measurement of Stage and Discharge*****.** U.S. Geological Survey Water-Supply Paper 2175

- Sauer, V.B., and Turnipseed, D.P., 2010, ***Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods*** book 3, chap. A7, 45 p. (Also available at http://pubs.usgs.gov/tm/tm3-a7/.)

- U.S. Geologic Survey website, www.usgs.gov

APPENDIX A: Stream Flow Monitoring

Constraints

The biggest constraint to the development of high quality datasets for stream flow monitoring is the location of the monitoring station. Poorly located stations will not provide accurate measurements of streamflow. Typical problems include stations that do not allow for measurement of all of the flow passing the site due to losses to groundwater, choice of a site with multiple channels, or a wide area of flow at higher flows, or a wide and shallow flow at low water, or sites located in a meander of an alluvial channel. Data from poorly selected stations have limited value. Another constraint is a lack of frequent checks and measurements to maintain the gage site and rating curve. Finally, it should be recognized that several-to-many years of data and analysis are needed to produce datasets to characterize stream flow for a particular location.

Quality Assurance/Quality Control (QA/QC)

Quality Assurance/Quality Control is a critical component of all monitoring. QA/QC provides the necessary checks to determine if a dataset is reliable.

The features of a QA/QC program address the following:

- Precision is the measure of how similar repeated measurements are to each other. It describes how well repeated measurements agree.
- Accuracy measures how close results are to a true value and can be determined through comparison to a standard or reference measurement.
- Completeness is the fraction of data that must be collected in order to fulfill the statistical criteria of the project.
- Comparability is the degree to which data can be compared directly to similar studies.
- Representativeness is the degree to which data can truly characterize the actual environmental conditions.

A separate QAPP (Quality Assurance Project Plan) has been prepared for this protocol and QA/QC procedures are included here.

1. SELECTING STREAM FLOW GAGING STATION LOCATIONS

The selection of stream flow gaging sites is the most critical step in producing reliable data which accurately represents stream flow levels in a creek.

The purpose of installing a stream flow gage is to create a continuous record of the depth and volume of flow at the station. There are a number of features needed for a good stream gaging location including:

- The general course of the stream is straight for about 300 ft. upstream and downstream from the stream gaging site
- The total flow is confined to one channel at all stages, and no flow bypasses the site as subsurface flow
- The streambed is not subject to scour and deposition and is free of aquatic growth
- Banks are permanent, high enough to contain floods, and free of brush
- A pool is present upstream from the control at extremely low stages to ensure recording a stage at extremely low flow and to avoid high velocities near stream gaging station intakes during periods of high flow

- The stream gaging site is far enough upstream from the confluence with another stream to escape from any variable influence the other stream may have on the stage at the stream gaging location
- A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the stream gaging station (it is not necessary that the low and high flows be measured at the same stream cross-section)
- The site is readily accessible for ease in installation and operation of the stream gaging station

In the Napa River, there are two large categories of stream channels: those confined in a canyon or within a streambed of bedrock, and those unconfined with an erodible gravel/cobble bed. Confined channels occur mostly in the mountains. Rock dominates the streambed controlling the channel location and width. Alluvial channels are not confined in canyons or gorges, but instead course over the broad river valley. The channel bottom is made up of cobble, gravel and sand and stream flow may infiltrate into the gravel bed at certain times of the year (Figure 1).

Methods

For a particular tributary basin of interest, the perennial streams provide the main area for stream gaging.

- On a topographic map or using a Geographic Information System (GIS), identify the blue line streams in the tributary basin.
- Identify the reaches of each stream in rockbound areas such as mountain gorges. These are likely naturally confined channels.
- Identify the reaches of each stream in alluvial valleys. These are probably unconfined channels.
- Identify the alluvial fans in the basin

Choosing a Location

In the rockbound confined channels (Figure 2), it may be easier to find locations which fit the needed features for gaging stations. These include:

- straight channel
- limited scour and deposition
- little loss of flow to groundwater
- no secondary channels
- banks are permanent and high enough to contain floods
- pools are more likely to be present year-round
- a cross-channel weir can be an excellent site for a gaging station

In these confined channels, flood flows can be deep and very swift so the instrument may need to be carefully placed to avoid damage or loss. It may also be difficult to access the site at high flow to complete discharge measurements.

In alluvial channels (Figure 3 and 4), it is more difficult to identify gaging sites which fit the needed features for a gaging station. These include:

- Alluvial fans located at the rock canyon outlet of the creek infiltrate large amounts of stream flow. The channel may be straight though the fan, but the loss of flow to groundwater makes these poor gaging locations (Figure 5)
- alluvial channels may also gain flow from groundwater during certain seasons or in particular locations

APPENDIX A: Stream Flow Monitoring

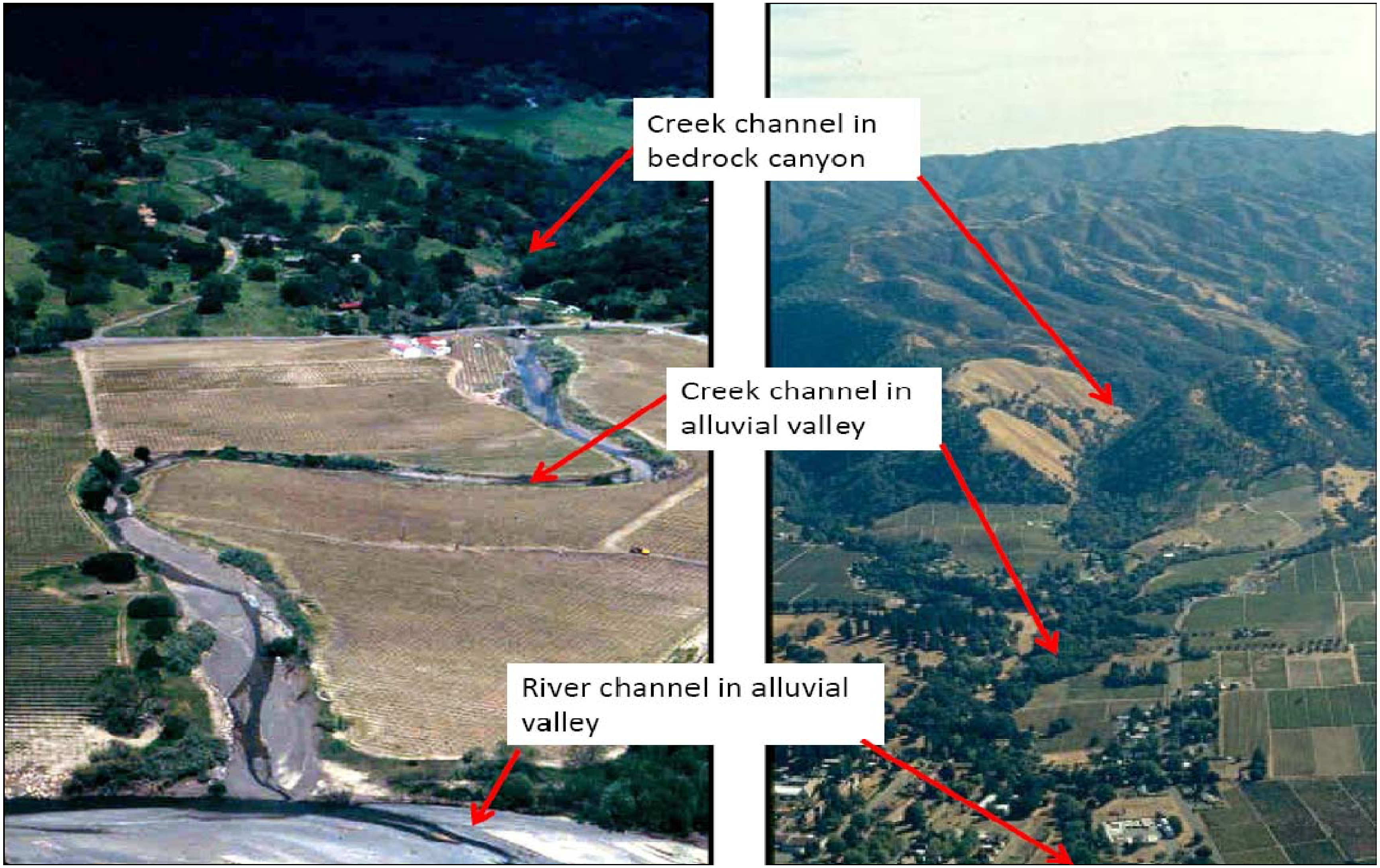


Figure 1: Different types of channel occur in different areas of the watershed

APPENDIX A: Stream Flow Monitoring

Rock bound channels do not loose much flow to groundwater

Figure 2: Confined stream channels

APPENDIX A: Stream Flow Monitoring

Figure 3: Example of an alluvial stream channel

General course of the stream is straight for about 300 ft upstream and downstream from the stream gaging site. These example streams meander.

Figure 4: Selection of the gaging site should avoid meandering stream areas

Total flow is confined to one channel at all stages, and no flow bypasses the site as subsurface flow

Alluvial fan where stream flows infiltrate into the alluvial basin

Figure 5: Alluvial fans are areas of high infiltration of surface flows into groundwater and are not good locations for gaging stations

The stream gaging site is far enough upstream from the confluence with another stream to escape from any variable influence the other stream may have on the stage at the stream gaging location

Figure 6: Tributary confluences do not make good gaging site

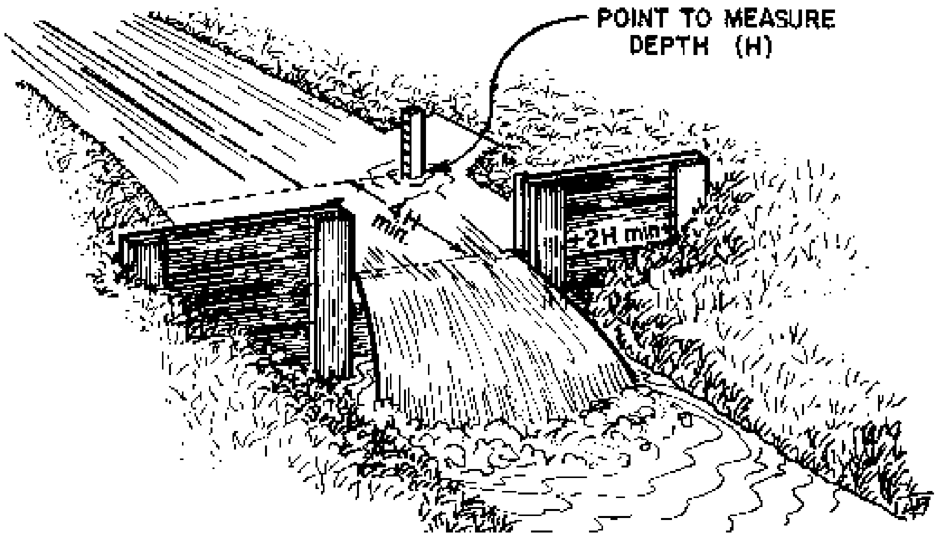
APPENDIX A: Stream Flow Monitoring

A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the stream gaging station (it is not necessary that the low and high flows be measured at the same stream cross-section)

General course of the stream is straight for about 300 ft upstream and downstream from the stream gaging site

Figure 7: Straight channel reach

APPENDIX A: Stream Flow Monitoring



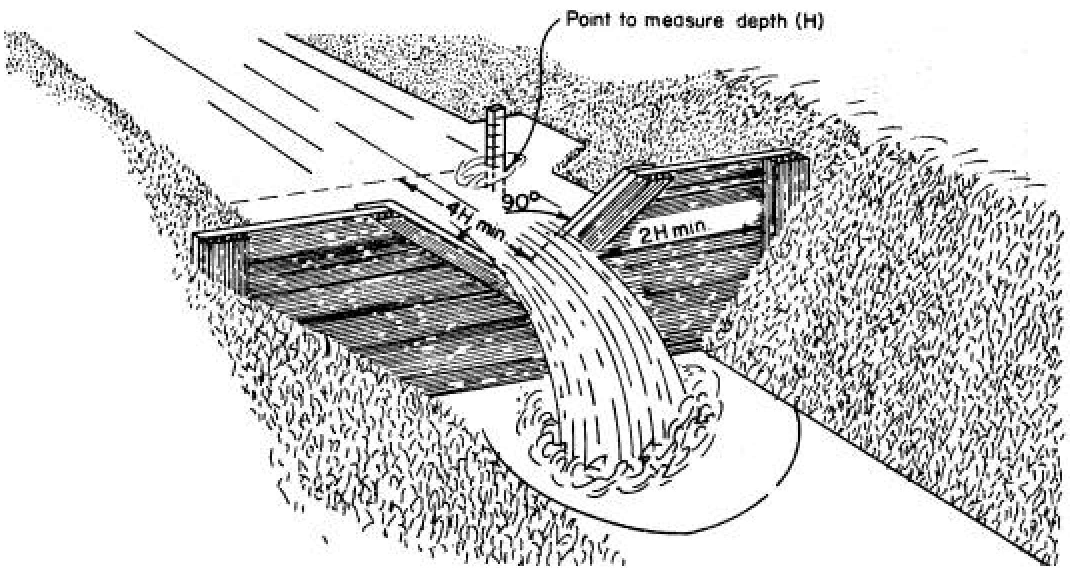


Figure 8: Weirs are often good locations for gaging sites and provide a stable grade control for low flow measurements

- many unconfined alluvial channels meander and straight channel sections are often short (Figures 4, 6 and7)
- most alluvial channels experience scour and deposition and do not have "permanent" banks
- alluvial streams may not have pools during low flow conditions and may dry up in summer

Locations for stream flow gages in alluvial channels need to be carefully chosen. Bridges and weirs are often good choices (Figure 8). The weir can provide a long term grade control to create a stable site for measuring discharge. It may also be possible to install a Parshall flume. Because alluvial channels lose flow to groundwater, subsurface water levels and, in some locations, river stage also has to be measured in order to correctly characterize stream flow processes.

In choosing a stream gage site, the landowner will need to approve of the use of the site and sign a landowner access agreement. Fill out Data Sheet #1 for each gage site.

2. SELECTING THE TYPE OF GAGE AND INSTALLING THE GAGE

The most common stream flow monitoring instruments are: 1) water level recorder installed in a stilling well on the stream bank or at a bridge pier; 2) bubble system gage; 3) pressure transducer installed in a pipe set on the bed of the stream; 4) acoustic water level recorder installed on the underside of a bridge or similar structure. Each type of instrument provides continuous recording of water stage or elevation. The accuracy level of the gage in recording water stage should be ±0.01 ft.

Stilling Well

Water from the creek enters and leaves the stilling well through underwater pipes, allowing the water surface in the stilling well to be the same elevation as the creek water surface (Figure 9). The stage is measured inside the stilling well using a pressure, optic, or acoustic sensor. Many locations are not physically appropriate for installing a stilling well and pipe system in the stream bank.

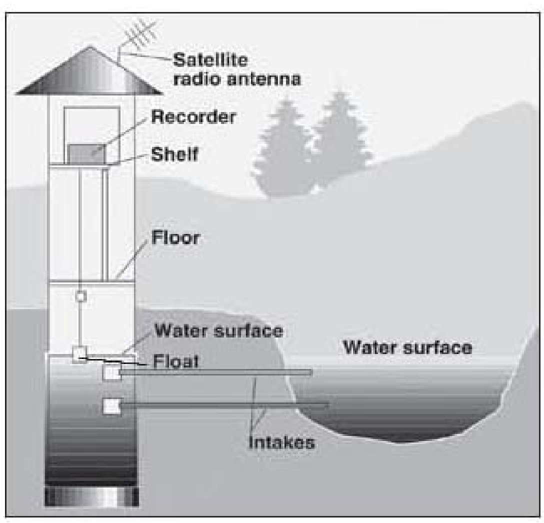


Figure 9: Stilling well type stream flow gage

APPENDIX A: Stream Flow Monitoring

Bubble System

This type of gage is established with a permanent gage house similar to the stilling well. A long, open-ended pipe extends from the gage to the waterway. The end of the pipe in the creek is fixed securely below the water surface. Pressurized gas is forced through the pipe from the gage house and out the orifice of the pipe. The pressure in the pipe is determined by how deep the water is over the orifice. Change in creek flow provides a change in the pressure in the pipe which is sensed by a pressure transducer in the gage house and recorded by a data logger in the gage house. This type of system is best for a long term permanent gage site.

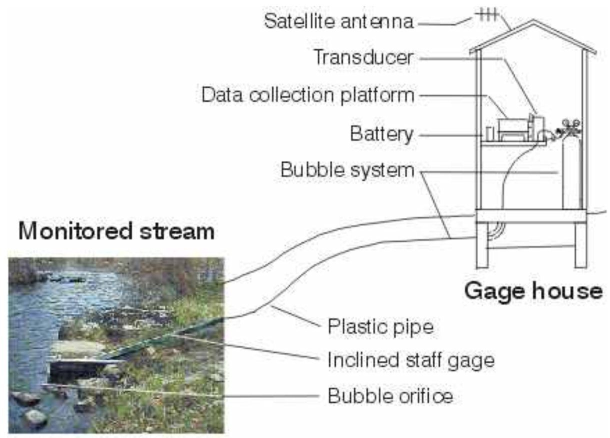


Figure 10: Bubble system type stream gage

Pressure Transducer

These instruments measure the weight or pressure of the water above the sensor. There are two types of pressure transducers: a differential pressure transducer and an absolute pressure transducer. The differential pressure transducer corrects for barometric pressure by having a vent tube. The vent cannot be submersed and so must be long enough to stay outside the flood zone.

Figure 11: Example of a differential-pressure transducer. Note the cable extended above the transducer on the wooden lath.

APPENDIX A: Stream Flow Monitoring

The absolute pressure transducer is enclosed and submersible. It does not correct for barometric pressure. Data have to be corrected for barometric pressure recorded by a separate barometer in the immediate vicinity of the transducer.

Figure 12: Absolute pressure transducer attached to a wooden lath and secured with nylon ties.

The pressure transducer records stage at a selected time interval (every 30 minutes, for example). Most transducers record after 0.15 ft. of submergence of the transducer.

The differential pressure transducer is typically placed in a plastic pipe with an open end and the vent cable is stretched through the pipe to a location outside the creek flow. The transducer is submersible but the data logger is on the “dry” end of the cable. Only the differential pressure transducer can be used with telemetry to produce real time data available on the internet.

Acoustic Water Level Recorder
These instruments are mounted above the water and emit a sound pulse that bounces back to the instrument, providing a depth reading. High levels of algae or debris can lead to false readings.

Non-Recording Staff Gage
This type of gage is manually read and provides for a comparison with data from a recording gage. A staff gage consists of a scale marked in feet and tenths on a post or bridge pier in the stream to show the elevation of the water surface. The staff gage should be located where a continuous recording gage will be used in order to provide an accuracy check for the recording gage. The staff gage is located such that the lower end of the scale is in the channel at low flow. The scale can be calibrated to elevation using the same surveyed cross section as the recording gage.

Figure 13: Staff gage

APPENDIX A: Stream Flow Monitoring

Table 1 provides a comparison of the features of some water level recorders.

TABLE 1. STREAMFLOW MONITORING INSTRUMENTS

Company & Product	Logger	Available Applications	Memory Size	Battery Life	Accuracy	Telemetry Compatible	Cost	Comments
Solinst Levelogger www.solinst.com	Levelogger – sealed, cable not required, user defined, linear and event-based sampling modes, need Barologger to correct for barometric pressure (in 20 mile radius). Several types					Yes, using data logger with cable. Solinst telemetry system or SDI-12 network via cable. 9100 STS telemetry system has cellular, satellite, landline, and radio options	Levelogger: $595 Barologger: $487	In field download cable and 3001 leveloader. Logger can be used for wells also. Cable, software extra.
	3001 Gold Levelogger 7/8" x 6"	Depth—Pressure transducer and temperature	40,000 data points	10 years	0.05% FS[1] ±0.05°C	Yes		
	3001 Levelogger Junior	Depth—Pressure transducer and temperature	32,000 data points	5 years	0.1% FS	Yes		
	LTC Levelogger Junior	Depth—Pressure transducer , temperature, and conductivity	16,000 data points	5 years	0.1% FS	Yes		

[1] Full Scale or FS is the maximum measurable pressure for a particular measurement instrument. To have the most accurate data, choose a pressure transducer with a range of water depths closest to conditions to be monitored.

APPENDIX A: Stream Flow Monitoring

TABLE 1. STREAMFLOW MONITORING INSTRUMENTS								
Company & Product	**Logger**	**Available Applications**	**Memory Size**	**Battery Life**	**Accuracy**	**Telemetry Compatible**	**Cost**	**Comments**
Onset Water Level Logger www.onset.com	Loggers defined by depth range; available in stainless steel or titanium							
	U20 Water Level Data Logger 1– 13 ft. depth	Depth-pressure transducer and temperature	21,700 data points	5 years	0.05% FS 0.1°C	No. Need to use a data logger with vented cable so that "live" data is corrected.	USB base station: $230; shuttle: $230; Hoboware software with USB cable: $99; U20 data loggers 1— 13 ft. depth stainless steel (1-9 units): $495 each; 10-99 units: $458 each; 100+ units: $424 each;	Need barometric pressure logger. Can launch and download pressure transducer in field with shuttle. Can purchase kit with datalogger shuttle, software, and case. Also can purchase loggers rated for deeper water.

APPENDIX A: Stream Flow Monitoring

TABLE 1. STREAMFLOW MONITORING INSTRUMENTS								
Company & Product	**Logger**	**Available Applications**	**Memory Size**	**Battery Life**	**Accuracy**	**Telemetry Compatible**	**Cost**	**Comments**
Rickly Hydrological Company www.rickly.com	Model 3500 Aqualor Submersible Pressure Transducer has cable and vent tube to automatically compensate for barometric pressure	Depth-pressure transducer and temperature	Need to use separate datalogger mounted out of water. CR 510 – 62,000 data points	Battery is separate	0.002% FSO[2] ± 0.01 ft. ±1.0°C	Yes		25 ft. standard vented cable; logger located out of water
	Model 3550 Submersible Pressure Transducer	Depth-pressure transducer and temperature			±0.1% FS			Cable length must be specified when ordered
	Model 2490 Aqua SPT Submersible PT & Logger	Depth-pressure transducer	6,000 data points	3 years	0.2% FS	Yes		Cable with data logger
	Model 2495 Aqua SPT Submersible PT & Logger	Depth-pressure transducer	24,400 data points	3 years	0.2% FS	Yes		25 ft. cable is standard. Can order up to 500 ft. Comes with software. Deploy in PVC pipe vented for barometric pressure compensation.

[2] FSO=full scale output over temperature range

APPENDIX A: Stream Flow Monitoring

TABLE 1. STREAMFLOW MONITORING INSTRUMENTS								
Company & Product	**Logger**	**Available Applications**	**Memory Size**	**Battery Life**	**Accuracy**	**Telemetry Compatible**	**Cost**	**Comments**
Automata www.automata-inc.com	Pressure transducer	Depth-pressure transducer		Separate from sensor	±1% FS	Yes – with NanoCourier field station and custom web access at www.automatic-inc.com	$280	Comes with a 9 ft. cable; can order a longer cable
	Ultra Ultrasonic Level Sensor Sonic velocity	Depth- programmable water level		Separate from sensor	0.25% over temperature range of 40-70°C	Yes – with NanoCourier field station and custom web access at www.automatic-inc.com	$718	Mounted above stream on bridge or pole
	Bubbler Water Level	Depth- water level		Separate from sensor	±1% FS	Yes – with NanoCourier field station and custom web access at www.automatic-inc.com		Requires stilling well

APPENDIX A: Stream Flow Monitoring

TABLE 1. STREAMFLOW MONITORING INSTRUMENTS								
Company & Product	**Logger**	**Available Applications**	**Memory Size**	**Battery Life**	**Accuracy**	**Telemetry Compatible**	**Cost**	**Comments**
Global Water www.globalw.com	WL-16 Water Level Logger	Depth-pressure transducer	81,759 data points	1 year	1% FS	Yes	$913	25 ft. vented cable with longer cables available; comes with software. Deploy in 2" PVC with data logger located out of creek.
	DCX-22 Self-Contained Level Logger	Depth-pressure transducer and temperature	28,000 data points	10 years	1% FS, 1°C	No	$989	No cable required; need DCX-22 Baro for barometric pressure correction; comes with software, separate USB cable to computer; order based on expected water depth range
	WL400 – good low flow sensitivity (0.3 ft.) and sensitivity in small stage change WL- 450 transmitter	Depth -pressure transducer and vented cable			1% FS	Yes	$566 and $646	Vented 25 ft. cable

APPENDIX A: Stream Flow Monitoring

TABLE 1. STREAMFLOW MONITORING INSTRUMENTS								
Company & Product	**Logger**	**Available Applications**	**Memory Size**	**Battery Life**	**Accuracy**	**Telemetry Compatible**	**Cost**	**Comments**
Global Water www.globalw.com	WL -700 Ultrasonic Level Logger and WL-750 Ultrasonic Level Transmitter	Water level measured from above. Data logger available in four ranges based on distance from water surface			0.5% FS		$641 and $877	10 ft. cable
Azonde www.azonde.com	Azonde 2220CRV	Depth-pressure transducer, temperature		Solar or battery	0.15 ft.	Yes – designed for telemetry using cellular, wireless, or radio		20-40 ft. cable
Adcon www.adcon.com	LEV1 level sensor	Depth-pressure transducer	Designed to work with telemetry stored remotely	3-4 days, but mostly solar-powered	0.1%FS (@ 0-40°C)	Yes	$2,200 with telemetry	Works with Adcon stations

3. INSTALLING THE GAGE

The selection of gage sites should reflect consideration of the purpose of the stream flow gaging project. If floods levels are interest fewer sites may be preferable with sturdy gage installations. If low flows are of interest, more stream flow gages coupled with groundwater measurements may be needed.

The installation process for the gages will be very site specific and should be overseen by a professional hydrologist. The sites will need to be suitable for answering the primary monitoring question and for fulfilling the site selection criteria listed in section 1.

If a stilling well of bubble system gage is to be installed, there needs to be an area adjacent to the channel that can accommodate the gage house and well. It is only feasible to go through the expense of installing these if the gage is meant to be permanent and used for a long period time. A hydrologist with significant experience in establishing gages should determine if this type of gage is appropriate for a particular site.

Pressure transducer gages are easier to install, but are also more prone to damage and loss than the more permanent types of gages. The differential pressure transducer requires a pipe housing with an open pipe at the creek end that extends along the bank to allow for the cable and datalogger to be secured outside the creek flow.

Figure 14: Pressure transducer in plastic pipe housing

Sometimes a separate battery is also attached at the upland end. Absolute pressure transducers also require a pipe housing of some type. For both of these gages, the pressure transducer needs to be as close to the channel bottom as possible, or maintained at a fixed elevation above the bottom.

The pipe housing needs to be secured to a post, a bridge, or other structure if the gage is to withstand flood flows. If this site does not allow for securing the gage, it should be removed for the flood season.

The holes in the pipe should provide for water level in the pipe to rapidly equalize. However, depending on the gage location, large holes may allow the sediment to accumulate in the pipe. If this occurs, measure the offset from the bottom of the pipe the sediment caused for the transducer and the dates it occurred. It the gage is upstream of a weir, algae buildup on the weir should be cleared frequently to assure proper function and that no debris to other problem is occurring. The staff gage should be read and the value recorded during each visit.

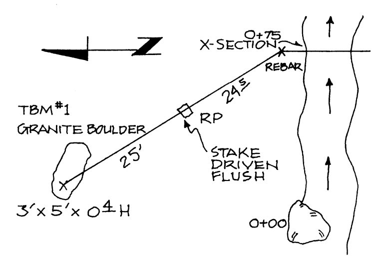


Figure 15: Map of a benchmark set in a boulder.

4. SURVEYING THE CHANNEL CROSS SECTION AND POINTS OF KNOWN ELEVATION AT THE STATION

The gage will measure stage or the elevation of water above the stream bed at the station. This elevation needs to be related to a constant reference elevation known as a datum.

A surveyed cross section of the channel is completed at the gage site. The end points are surveyed to an object outside the channel with a known elevation. This object serves as the elevation benchmark allowing for the stage measurements to be converted to elevation and compared to fish habitat surveys and other information.

Establishing a Project Benchmark

The project benchmark is a permanent mark near the area to be surveyed that can be located every year. The benchmark serves as the vertical or elevation reference point for the survey. Establishing a permanent benchmark is the first step in every survey. A benchmark is a point of known elevation. Sometimes an existing benchmark may be available, for example, benchmarks are often found on or near a bridge. Benchmarks are also marked on USGS topographic maps. If an existing benchmark is found near your survey, use it. Otherwise, establish your own benchmark.

Directions for establishing a benchmark

- Use a piece of rebar or pipe 3’ to 4’ long.
- Locate the benchmark where it can be seen from the stream channel. It must be located above the stream channel so that it will not be washed away by high water. Figure 15.
- Chose a location that will not interfere with the landowner’s operations.
- Locate the benchmark near an obvious landmark such as a large boulder or tree.
- Drive the rebar into the ground until the top is within a half inch of the ground surface. Write an identifying note on a piece of flagging and tie it to the stake. Bury the flagging with dirt to protect it from the sun.
- Mark the benchmark stake with a second stake. Drive the second stake about 6” from the benchmark stake. It should be 18” to 24” long and rise 6” to 12” above the ground. Increase its visibility by spray painting it or wrap duct tape around it. Tie a piece of flagging to it.
- Draw a detailed map of the location of the benchmark in the survey notebook. Mark the elevation of the benchmark if you know it. Note the distance from the benchmark to two or more obvious landmarks,

such as large trees, boulders, fence posts etc. (Figure 15). Use a GPS to record the coordinates of the benchmark.

If you do not know the elevation of the benchmark, temporarily assume an elevation of 100 feet for the benchmark. Later, you should determine the actual elevation of your benchmark. If your benchmark is destroyed or lost you will then be able to use the actual elevation to establish another benchmark. This will allow you to compare your original survey to a subsequent survey. Another advantage to determining the actual elevation of your benchmark is that you will then be able to compare the elevation data of one gaging station to another, and to in-stream habitat sites. Determine the actual elevation of your benchmark by running a *differential level survey* (see page28) between a point with known elevation and your benchmark.

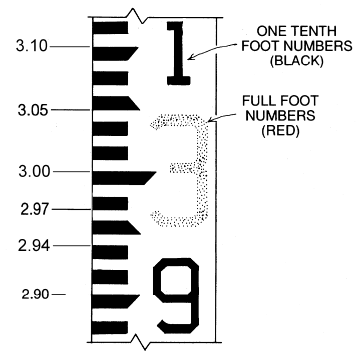


Figure 16: Face of the survey rod

Surveying: Directions for Instrument Person

Step 1: Setting Up the Tripod

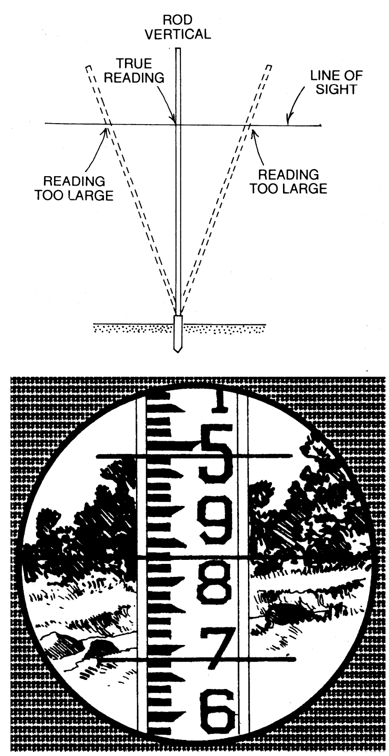
- Extend the legs of the tripod until the top of the tripod is level with your chin.
- Push one of the legs firmly into the ground. Spread the tripod legs 3’ to 4’ apart. Push the other two legs into the ground.
- Level the top of the tripod by raising or lowering the legs. The head of the tripod does not need to be perfectly horizontal. However, leveling the instrument will be easier if the tripod head is on a nearly horizontal plane.
- After the head is level check that the leg adjusting screws are tight and that the legs are firmly in the ground.

Step 2: Setting Up the Level

- Place the instrument on the tripod.
- Screw the level snugly (finger-tight) to the head of the tripod. Do not over-tighten the screw.
- Move the level screws in pairs to bring the bubble into the target circle on the level vial.
- Rotate the scope 90^0 degrees and re-level.
- Repeat until the bubble stays in the target circle throughout a 360^0-degree rotation. This procedure brings the instrument into the range where the self-leveling pendulum prism can operate.
- Turn the telescope to bring the rod into the field of vision.

Step 3: Reading the Rod

The numbers on the face of the rod show the distance measured from the ground in feet. The scale can be read to one hundredths of a foot. Whole numbers of feet are marked off on the scale on the left of the rod by the longer line with an angled end. For example, see the number 3.00 in Figure 16. The number of feet is read at the top of this line and is indicated by the large red numbers. Tenths-of-feet are



Figures 17 and 18: Reading the rod. The elevation is read at the middle line. The upper and lower lines are called stadia.

also marked by a line with an angled end. For example, see the number 2.90 in Figure 16. The black numbers indicates the number of tenths-of-feet.

Each black line and each white space on the scale is exactly one hundredths of a foot. The top of each black line, between the angled tenth-of-a-foot lines, mark off 2/100th's of a foot. Even number hundredths of a foot can be read at the top of the lines. Odd number hundredths of a foot are read at the bottom.

Point the telescope towards the rod. The center crosshairs should cross the face of the rod (Figure 18). Turn the focus knob until the rod can be clearly seen. Adjust the eyepiece to darken or lighten the cross hairs. If the rod is leaning to the side, ask the rod person to move the top of the rod until it is vertical (Figure 17). The rod person should try to keep the rod vertical along your line-of-sight. The center crosshair gives the elevation. Do not use the upper or lower lines for elevation. The upper and lower lines are called stadia. Using the stadia lines to measure distance will be described later.

Step 4: Recording the Data
The survey notebook is the most important piece of surveying equipment. Be neat and orderly so that the data you record can be easily read. Note all pertinent details in your descriptions and field maps. Over the years, the field book will be used to re-locate the benchmark and various survey stakes or markers. The field book will also be the source of data used to analyze the changes in stream shape with time.

Use a *Rite-in-the-Rain* (or equivalent brand) All-Weather Level Notebook No. 311. These books are about 5" x7". They have 48 numbered pages. Each page has six columns. The first page is a blank *Table of Contents*. Be sure to fill in the *Table of Contents* after your survey. Write your name, phone number and project description inside the front cover in the space provided.

Use Figure 21 as a guide to labeling the columns and recording the information for a differential survey. Be sure to draw a map, see Figure 21, showing the location of all the instrument setups, turning points and benchmarks.

<u>Surveying: Directions for the Rod Person</u>

The rod person decides where to set the rod, which is the most critical part of the survey.
Place the level on the back of the rod. Use the bubble on the level to adjust and maintain the rod so that it is vertical. Stand behind the rod so that the rod can be held vertical and the level can be read. Holding the rod vertical is essential. If the rod leans forward or backwards the reading will be larger than the true value, see Figure 17.

The rod can be extended to 16 feet. When changing the length of the rod it is essential that each section be fully extended and properly secured. When a section of the rod is fully extended a locking button should pop into place.

<u>Measuring Distance</u>

Measuring with Tape
- Tapes marked in feet that can be read to the hundredth of a foot can be used to measure distance.
- When measuring horizontal distance stretch the tape tight before making the reading.

APPENDIX A: Stream Flow Monitoring

Figure 19: Surveying the channel cross section at a stream flow gaging station

- Do not use a tape to measure the horizontal distance if the tape cannot be stretched out on a horizontal line between the points.

Measuring distance with surveying level

Use the level and the survey rod to estimate distances where stretching a tape would be difficult. To do this read the *stadia,* the short crosshairs above and below the central crosshair on the survey rod.

- Set up the level at one end of the distance to be measured. Place the Survey Rod at the other point.
- Read the rod at the upper and the lower stadia line.
- Subtract the lower stadia reading from the upper stadia reading
- Multiply the difference by 100 to get the distance from the instrument to the rod.

Survey the Cross Section at the Gage Station

Step 1: Stretch the tape from the left bank stake to the right bank stake, Figure 19. Read and record the horizontal distance between the stakes. Leave the tape stretched to guide the rod person as he moves from point to point along the cross section.

Step 2: Start the survey at the left bank stake. Starting at the left bank facilitates graphing the data. Distances will be referenced to the left bank stake; that is, the distance of the left bank stake will be zero. Take a GPS point for the left bank stake and the right bank stake as the end points of the cross section.

Step 3: Set up the surveyor's level along the cross section where you can clearly see both ends of the cross section. A good location to setup is a few feet behind one of the stakes so that the instrument and the two stakes are in line. The instrument can also be set up between the stakes, as long as the top of the stakes are lower than the instrument's line of sight. Setting up on the cross section line ensures that all points on the cross section will be visible and simplifies the calculations.

Step 4: Shoot the *backsight* by placing the rod on top of the cross section stake, or other point, whose elevation you have already established. Read the rod and record the value as a *backsight*. Determine the *instrument height* by adding the rod reading to the elevation of the stake.

Step 5: Place the rod vertically on top of the left bank stake. Read the rod and record the value as a *foresight*. The distance along the cross section of the left bank stake is zero.

Step 6: Place the rod vertically on the ground next to the stake. Read the rod and record the value as a foresight. The cross section distance of this shot is also zero.

Step 7: The rod person then proceeds to the next slope break or the next channel feature, such as a bankfull indicator, terrace or floodplain. The rod person calls out the type of feature the rod is placed on. The instrument man records the rod reading as a *foresight*.

Step 8: The horizontal distance from the left bank stake to the rod is measured and recorded. The distance can be measured using the tape stretched between the cross section stakes. If the tape is too high for the rod person to read the instrument person can read the distance from the instrument to the rod using the stadia lines. If the distance between the rod and the instrument is measured, make sure that it is recorded as such. It will be necessary to convert the distance from, "*the distance from the instrument*" to, "*the distance from the left bank stake*".

Step 9: Continue shooting the elevation and recording the distance at each point along the cross section. Finish the cross section by shooting the elevation at the ground next to the right bank stake and on then the top of the right bank stake.

Step 10: It is important to determine the elevation of the top of each stake. Each year the elevation of the cross section stakes is checked. Comparing the new elevation of the stake to the elevation of the stake from prior surveys is a good check for errors in the survey. It is also a way of verifying that the stake has not been altered.

Step 11: Occasionally you will have to move the instrument to complete the cross section survey. This may happen if an obstacle such as a large tree limb is blocking your line of sight. Remember to set one or two turning points before you move the instrument.

Step 12: If you move the instrument remember to close the survey by running a differential survey back to the stake you used as the backsight.

Step 13: Plot the data in the field book before you leave the site (Figure 20). Plotting the data helps you catch errors. Make sure that all distances have been converted to, "*distance from the left bank stake".* Draw a vertical scale that covers the range of elevation values. Draw a horizontal scale that covers the distance between the stakes. The horizontal and vertical scales will be different. Plot each elevation point at the appropriate distance.

Step 14: If you discover errors in the data, re-shoot points as needed to correct the problem.

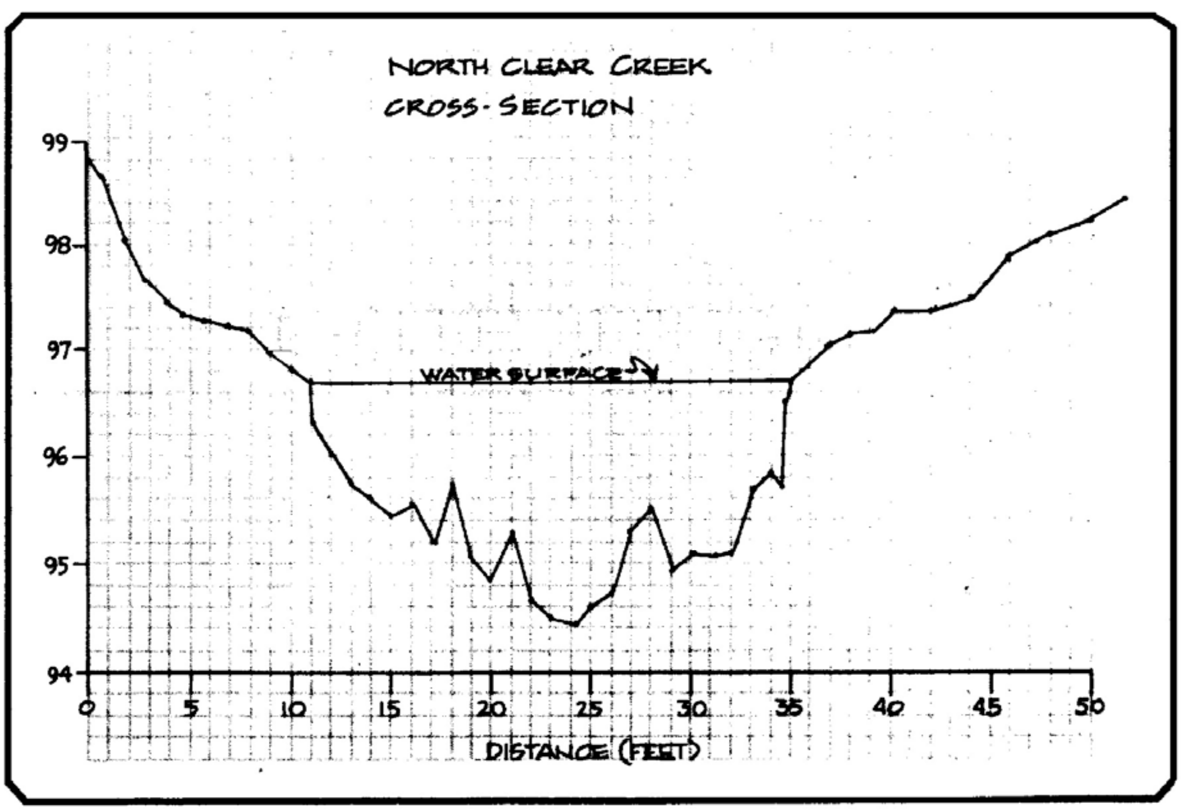


Figure 20: An example of a field plot of a cross section. The line labeled "water surface" indicates the water surface at the time of the survey (from Harrelson et al 1994).

Differential Level Survey

A differential level survey is used to measure the relative elevation of points that are quite far apart. For example, a differential level survey can be used to determine the true elevation of your benchmark if a point of known true elevation is several hundred feet from your site. It consists of making a series of instrument setups along a route that ends back where it began. The route of the survey is called a *traverse*. From each instrument setup, the rod is taken to a point of known elevation to establish the *instrument height*. The instrument height is used to calculate the elevation of new points after the rod is read on the new point. Temporary reference points, called *turning points*, are established before the instrument is moved to a new location. The details of the process are described below.

DIFFERENTIAL LEVELING OF BENCH MARKS
NO NAME CREEK

5/10/93
COLD, RAINY

C. HARRELSON
J. POTYONDY

STA	BS (+)	HI	FS (−)	ELEV (FEET)	DISTANCE PACED (FEET)
BM1	5.62	105.62		100.00	
			3.21		321
TP1	4.87	107.28		102.41	
			4.21		299
TP2	4.50	107.57		103.07	
			3.85		3.08
BM2	3.64	107.36		103.72	
			4.19		3.18
TP3	3.30	106.47		103.17	
			5.18		275
TP4	3.72	105.01			
			4.99		302
BM1				100.02	
					1823

BS = 25.65 FS = 25.63

25.65 − 25.63 = 0.02 = 100.02 − 100.00

ERROR = 0.02

ALLOWABLE ERROR = $0.007\sqrt{\frac{1823}{100}} = 0.03$

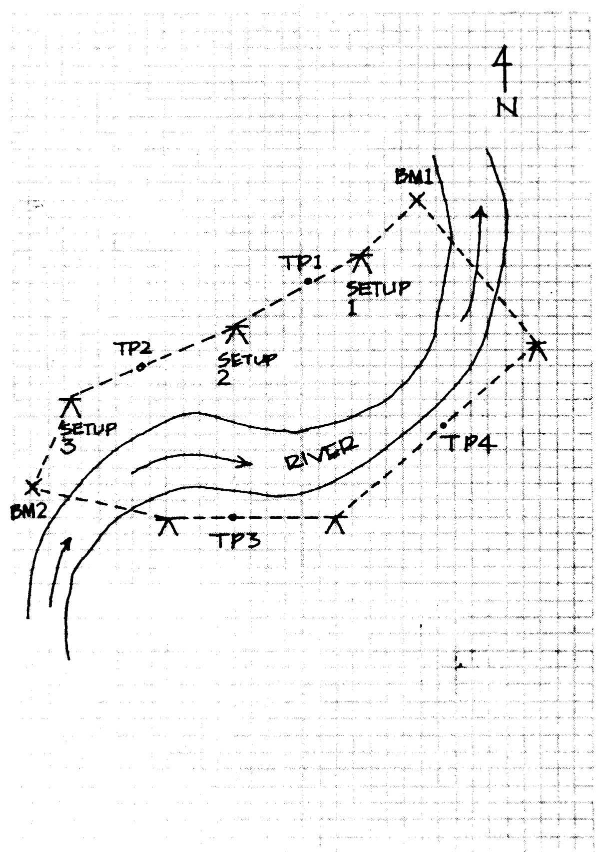


Figure 21: Field notes from a differential survey. The purpose of the survey is to find the elevation of BM-2 relative to BM-1. The traverse starts at BM-1. Returning to BM-1 closes the survey (from Harrelson et al 1994).

Step 1: The first reading (a reading is also called a *shot*) is to the benchmark. In Figure 21, the benchmark is BM-1. The elevation of the benchmark is known or assumed, Figure 22. If the elevation of the benchmark is assumed it is strongly recommended that you survey from your benchmark to a benchmark with known elevation.

- Place the rod on the benchmark.
- Get the rod vertical.
- Read the scale where the crosshair crosses the rod face.
- Record the reading in the field book as a *backsight*. In the notes, *backsight* is abbreviated as BS.

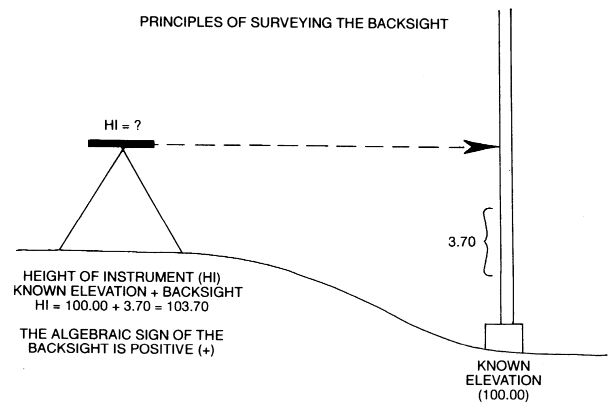


Figure 22: Shooting the backsight to find the instrument height.

Step 2: The shot to the benchmark is called a backsight. The backsight reading is added to the elevation of the benchmark to calculate the *instrument height*, see Figure 22. The instrument height is the elevation of the instrument crosshair.
The notes shown in Figure 21 give an example of a differential survey. The elevation of BM-1 is given as 100.00 feet. The backsight to BM-1 is 5.62 feet. Thus, the height of the instrument, for the first setup, is 105.62 feet.

Step 3: Use a tape, the stadia method, or pacing to measure the distance from the instrument to the benchmark. Record the distance in the field book. The total distance covered by the survey is used to calculate the allowable error of the survey. This will be explained below.
In Figure 21, the distance was determined by pacing. The distance between BM-1 and TP-1 is shown as 321 feet.

Step 4: The rod person should drive a stake in the ground as a temporary reference known as a turning point, TP. The TP should be in the direction of the survey and about the same distance from the instrument as the benchmark. The stake should be solidly in the ground so that it does not shift.

Step 5: The rod is then placed on the TP and the instrument person reads the elevation and records it as a foresight, see Figure 23. For example, in Figure 21, the foresight, FS, of TP-1 is 3.21.
Step 6: The foresight of TP-1 is subtracted from the instrument height to determine the elevation of TP-1.For example, in Figure 21, the foresight of TP-1 (3.21) is subtracted from the instrument height (105.62) to calculate the elevation of TP-1 (102.41).

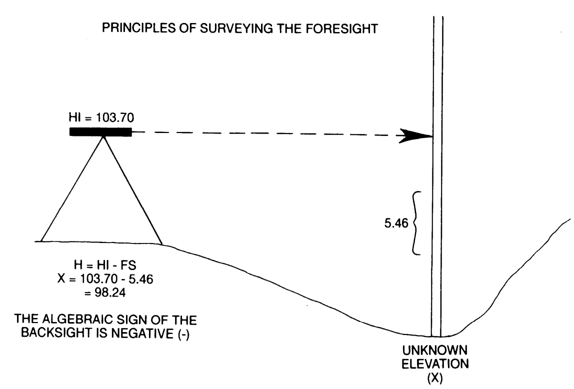


Figure 23: Shooting a foresight. The instrument height is already known.

Step 7: The instrument is then moved to the other side of TP-1.

Step 8: The rod is then placed on TP-1 and the rod is read as a backsight, after the instrument has been setup and leveled. The backsight is added to the elevation of TP-1 to calculate the instrument height, see Figure 24.

APPENDIX A: Stream Flow Monitoring

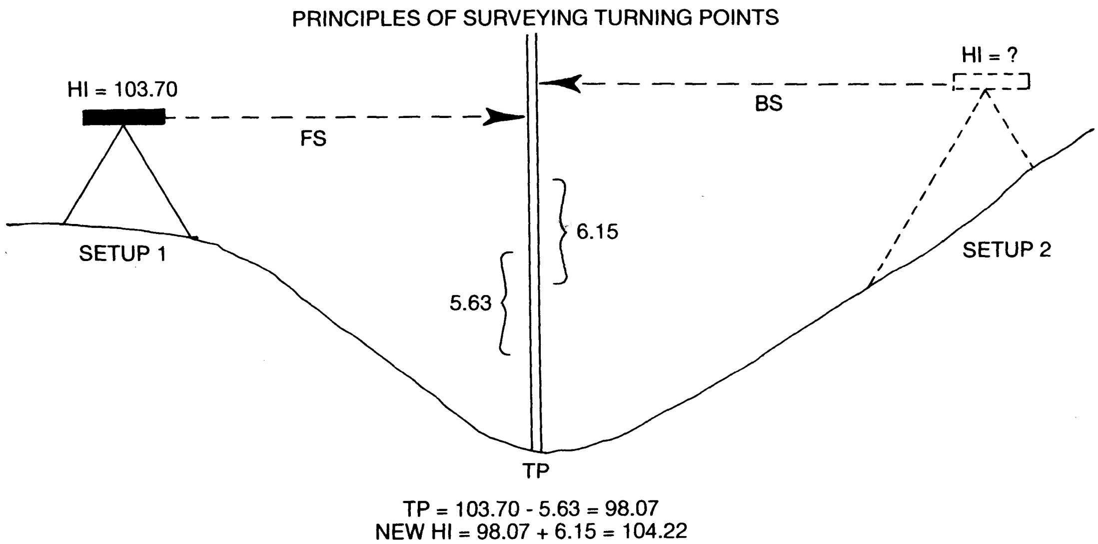


Figure 24: Using *turning points* to move the instrument.

For example, in Figure 21, the backsight to TP-1 from setup 2 is 4.87 feet. The backsight (4.87) is added to the elevation of TP-1 (102.41) to calculate the instrument height (107.28) at setup 2.

Step 9: The process outlined in steps 1-8 is repeated until the traverse is closed by shooting the original benchmark as a foresight. See the map in Figure 21.

Step 10: After you have closed the survey, the elevation of the benchmark at the end of the survey is compared to its original value. This process is known as closing the survey. The difference between the calculated elevation of the benchmark and its original value is the error.

$$Acceptable\ Error\ \leq 0.007\sqrt{(total\ distance)/100}$$

The acceptable amount of error depends on the total distance of the differential level survey. One equation to estimate the acceptable error is:

Where the *total distance* is the sum of the distances between the instrument stations in the differential level survey loop. For example, in Figure 21, the total distance of the differential level survey is 1,823 feet and the acceptable error is 0.03 feet.

5. COMPLETING DISCHARGE MEASUREMENTS

Although measuring stage produces valuable information, most gaging data are changed to discharge or volume of water per unit time such as cubic feet per second (cfs). Stage data are changed into discharge data through the completion of discharge measurements and creation of a stage-discharge relation for the particular station.

APPENDIX A: Stream Flow Monitoring

In general, discharge is computed by multiplying the area of water in the channel cross section by the average velocity of the water in that cross section (Figure 25). The continuity of flow equation describes this relationship:

*discharge = area * velocity*

Velocity varies over the channel cross section so many measurements must be done to accurately calculate discharge.

A current meter is used to measure velocity at numerous points along a cross section near the gaging station. In this method, the stream channel cross section is divided into a number of vertical subsections. In each subsection, the area is obtained by measuring the width and depth of the subsection, and the water velocity is determined using the current meter. The discharge in each subsection is then computed by multiplying the subsection area by the measured velocity. The total discharge is then computed by summing the discharge of each subsection.

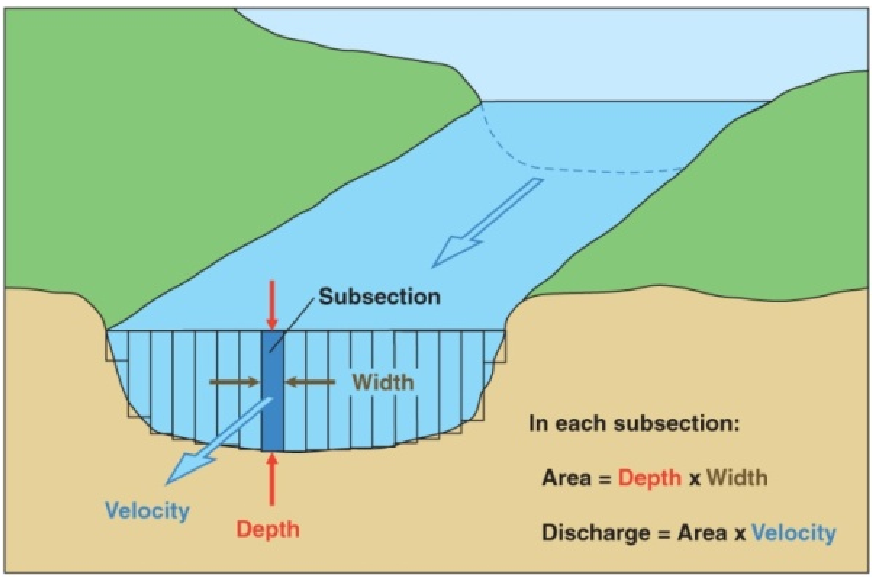


Figure 25: Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge (drawing from USGS website).

Selecting the cross section for the measurement

Choose a location near the gage site where there is a stable channel cross section and a straight section of channel where velocity threads are parallel and there is little slope change. The current should be uniform, free of eddies, dead water near banks, or excessive turbulence. The flow should have primarily downstream current uninterrupted by rocks of different sizes or vegetation. If there is a weir in the channel, measure the current just upstream of the structure. The location of the cross section will not be the same at different flow levels but the features of the location of the cross section should always be the same - even level of flow, minimal turbulence, primarily smooth downstream moving currents without eddies, vertical or side moving currents, unbroken by vegetation. Sometimes rocks need to be re-arranged to create these conditions. Features of the cross section and measurement should be recorded on Data Sheet 2.

APPENDIX A: Stream Flow Monitoring

Measure channel width and defining subsections
The width of the cross section is measured by stretching a vinyl measuring tape marked in tenths of feet from on edge of the wetted width to the other and perpendicular to the direction of flow. Stake the tape across the width for use in the measurement. This width is then split into subsections with no single subsection carrying more than 5-10% of the total flow. For stream widths of less than 5 ft., the subsections should be spaced at least 0.25 ft. apart. If the stream width is greater than 5 ft. the minimal number of subsections is 15-25. The preferred number is 20 to 30.

Laying out the subsections
The cross section is determined by measuring the width and dividing it by the number of subsections. For example, if the wetted width is 26 ft. with 20 subsections, each subsection will cover 1.3 ft. The first subsection will extend from the edge of the flow to 1.3 ft (0.0 on the tape) on the measuring tape. The midpoint of this subsection is 0.65 ft. This midpoint is where the current meter reading is completed. The rest of the subsection midpoints are determined by adding 1.3 ft. to the prior midpoint location.

Current Meters
The velocity of the streamflow is measured using a current meter (Figure 26). There are several types of current meters. Some have rotating cups, other have a pair of electronic contacts on a small head. The older types click for each complete rotation and the operator uses headphones and counts clicks for a set time period. Newer technology has a digital readout. The most common current meter used is the Price AA current meter. The Price AA current meter has a wheel of six metal cups that revolve around a vertical axis. Because the rate at which the cups revolve is directly related to the velocity of the water, counting the revolutions determines the water velocity. Current meters are attached to a wading rod for measuring in shallow waters or are mounted just above a weight suspended from a cable and reel system for measuring in fast or deep water. In shallow water, a pygmy current meter can be used. It is a two-fifths scale version of the meter and is designed to be attached to a wading rod. The pygmy meter can measure velocity in water as shallow as 0.3 ft. Velocity in water shallower than this cannot be readily measured.

Testing the meter before use
The current meter is a precision instrument, treat it with care. The meter is put together and the cups must spin freely and evenly in order to produce accurate measurements. Every time the meter is used, a test is needed. Using the headphones or digital readout, count the number of revolutions the meter cups make once spun. A count over 45-60 seconds with the manufacturer’s specified number of revolutions shows the meter is operating properly.

Making current measurements using a current meter and top setting wading rod
The wading rod is adjustable to allow for placement of the meter at the 20%, 60%, and 80% level of depth. The depth is measured by placing the wading rod on the streambed and reading the total depth on the wading rod.

APPENDIX A: Stream Flow Monitoring

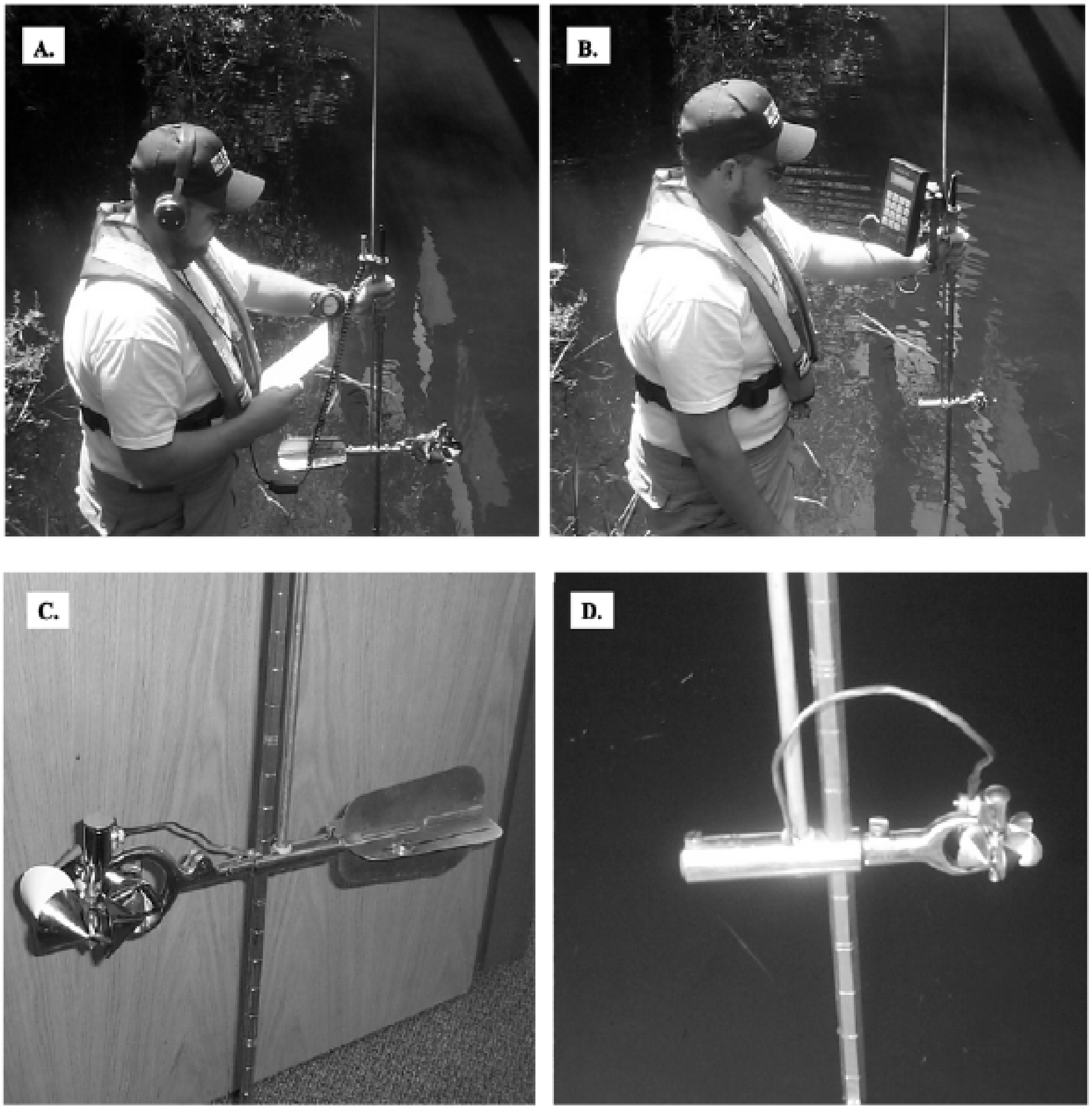


Figure 26: Types of current meters from McKobb and Weiskel 2003)

If the depth at the subsection is greater than 30 inches, the velocity is measured at the 20% and 80% water depths at the midpoint of the subsection.

If the water depth is less than 30 inches, the velocity is measured at 60% of the water depth. Keep the wading rod vertical and the current meter perpendicular to the flow.

A team of two people is needed. One person records the data and the other reads and reports the measurements (Figure 27). The measurements start at the left (facing downstream) edge of the water and progresses to the right. The left edge should be recorded as 0.0. At the center of each subsection the

APPENDIX A: Stream Flow Monitoring

Figure 27: Discharge measurements

reader reports the distance (from the 0.0 pt), the total depth, sets the current meter to the appropriate percentage of the depth, and makes the current meter measurement (Figure 28). The reader needs to stand downstream of the cross section when completing the current meter reading. In areas of the channel where the water is deeper or faster, additional readings within the subsection are done. After the reader reports the measurements, the recorder repeats them to confirm the correct number. The current meter reading, if using the type of meter where clicks are counted, is done with a timer. The clicks are counted for a 40-60 second period. Then the number is translated to velocity with a standard table for the particular meter (Attachment 1). Digital meters read out as velocity.

Calculating the Discharge

After all the measurements are made before removing the tape across the channel, the discharge calculation should be completed in case additional measurements are needed.

When velocity measurement is complete, calculate the total discharge (Q). Determining total discharge accurately is a complex issue, and a variety of methods and equations exist. The mid-section method is currently recommended by the U.S. Geological Survey. (At the risk of offending those with the proper math skills, the method is explained step-by-step.)

The following formula defines the basic method for calculating discharge:

$$Q = \sum (a\,V)$$

Where Q is the total discharge, a is the area of a rectangular subsection, the product of width (w) and depth (d) for that subsection, and **V** is the mean velocity of the current in a subsection.

Step 1 Using the mid-section method, compute the area (a_n) of each subsection:

$$a_n = d_n\,(b_{(n+1)} - b_{(n-1)})/2$$

where ***b*** is the distance along the tape from initial point. "Lost" discharge in the triangular areas at the edges is assumed negligible.

Step 2 Next, multiply the subsectional area a_n by the mean velocity **V** for the subsection to get the subsection discharge (**Q**). If only one velocity measurement was taken at 0.6 depth, it is the mean velocity. If two measurements (v_1 and v_2) were taken at 0.2 and 0.8 depth, compute the mean value as below:

$$V = (v_1 + v_2)/2$$

Step 3 To compute the discharge for each subsection, use the equation:

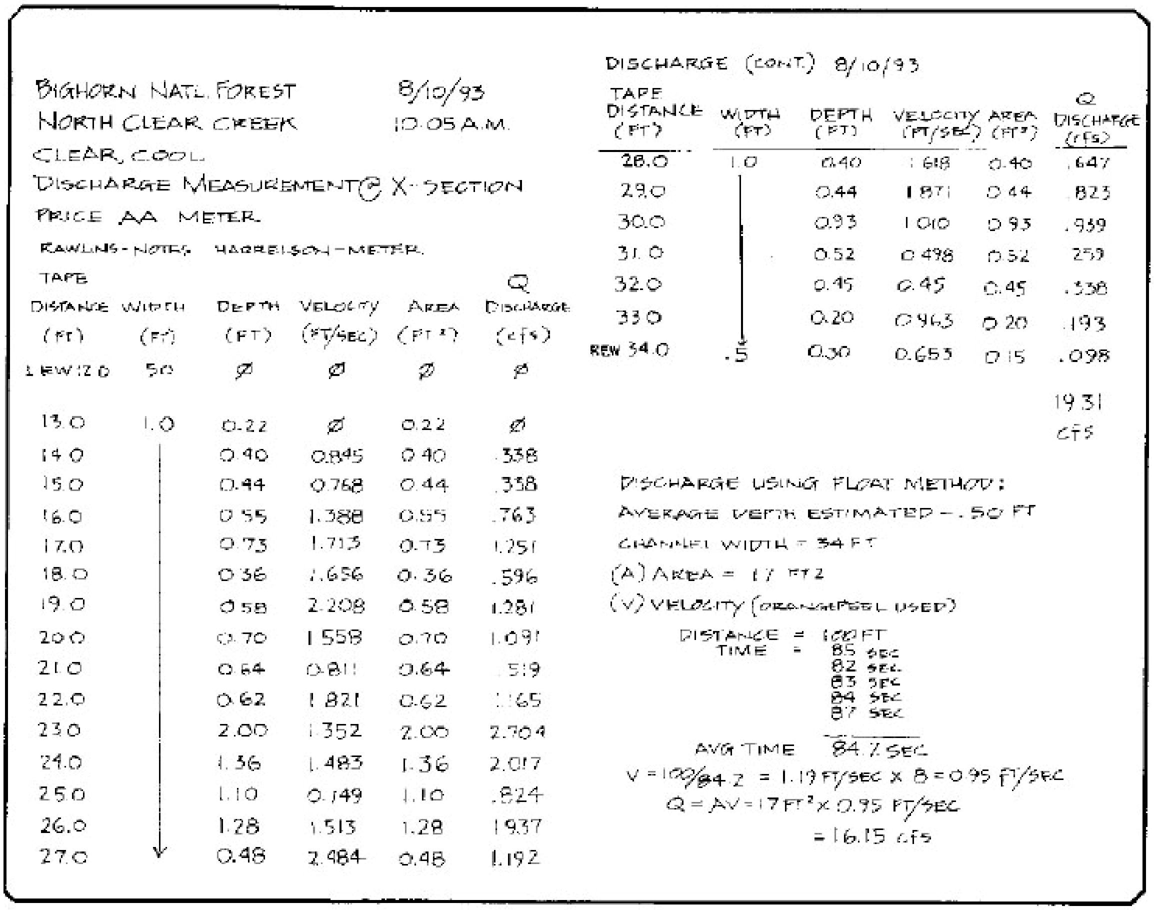
$$Q_n = (a_n\,V_n)$$

where

Q_n = discharge for subsection n
a_n = area of subsection n, and
V_n = mean velocity for subsection n.

The calculation repeats this process for each subsection, as shown below:

$Q_1 = (a_1\,V_1)$, $Q_2 = (a_2\,V_2)$, $Q_3 = (a_3\,V_3)$, $Q_4 = (a_4\,V_4)$, and so on…



BIGHORN NATL. FOREST 8/10/93
NORTH CLEAR CREEK 10:05 A.M.
CLEAR, COOL
DISCHARGE MEASUREMENT @ X-SECTION
PRICE AA METER
RAWLINS - NOTES HARRELSON - METER

TAPE DISTANCE (FT)	WIDTH (FT)	DEPTH (FT)	VELOCITY (FT/SEC)	AREA (FT²)	Q DISCHARGE (cfs)
LEW 12.0	.50	Ø	Ø	Ø	Ø
13.0	1.0	0.22	Ø	0.22	Ø
14.0		0.40	0.845	0.40	.338
15.0		0.44	0.768	0.44	.338
16.0		0.55	1.388	0.55	.763
17.0		0.73	1.713	0.73	1.251
18.0		0.36	1.656	0.36	.596
19.0		0.58	2.208	0.58	1.281
20.0		0.70	1.558	0.70	1.091
21.0		0.64	0.811	0.64	.519
22.0		0.62	1.821	0.62	1.165
23.0		2.00	1.352	2.00	2.704
24.0		1.36	1.483	1.36	2.017
25.0		1.10	0.749	1.10	.824
26.0		1.28	1.513	1.28	1.937
27.0	↓	0.48	2.484	0.48	1.192

DISCHARGE (CONT.) 8/10/93

TAPE DISTANCE (FT)	WIDTH (FT)	DEPTH (FT)	VELOCITY (FT/SEC)	AREA (FT²)	Q DISCHARGE (cfs)
28.0	1.0	0.40	1.618	0.40	.647
29.0		0.44	1.871	0.44	.823
30.0		0.93	1.010	0.93	.939
31.0		0.52	0.498	0.52	.259
32.0		0.45	0.45	0.45	.338
33.0	↓	0.20	0.963	0.20	.193
REW 34.0	.5	0.30	0.653	0.15	.098
					19.31 cfs

DISCHARGE USING FLOAT METHOD:
AVERAGE DEPTH ESTIMATED – .50 FT
CHANNEL WIDTH = 34 FT
(A) AREA = 17 FT2
(V) VELOCITY (ORANGE PEEL USED)
DISTANCE = 100 FT
TIME = 85 SEC, 82 SEC, 83 SEC, 84 SEC, 87 SEC
AVG TIME 84.2 SEC
V = 100/84.2 = 1.19 FT/SEC x .8 = 0.95 FT/SEC
Q = AV = 17 FT² x 0.95 FT/SEC
= 16.15 cfs

Figure 28: Field notes of discharge measurement (from Harrelson et al 1994).

Step 4 The subsection products are then added to get total discharge (**Q**):
Q = Q + Q + Q + Q + and so on…

Thus, total discharge (Q) equals the sun of all discharges **∑ (*a* V)**, as stated earlier in the basic equation:

$$Q = \sum (a V)$$

A current meter reading should be done every few weeks after the gage is installed and, if water levels fluctuate, more frequently to include low and high flow.

6. CREATING THE STAGE-DISCHARGE RATING CURVE

Stream gages continuously measure stage. This continuous record of stage is translated to river discharge by applying the stage-discharge relation (also called the rating curve). The stage-discharge relation is developed by measuring width and depth and velocity with a current meter over a wide range of stages. These measurements are used to calculate discharge, then plotted against a corresponding measurement of stage recorded with a water level gage. This plot is refined as more discharge measurements are made, especially at the high and low flow levels.

An example of a stage-discharge relation is shown in Figure 29. The stage-discharge relation depends upon the shape, size, slope, and roughness of the channel at the stream gage and is different for every stream gage.

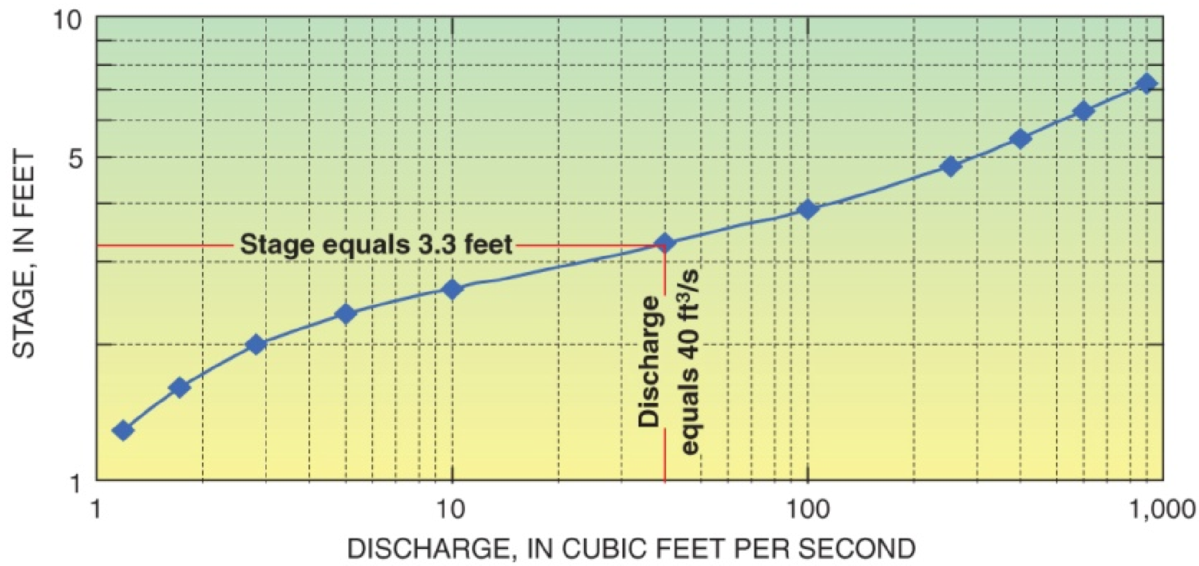


Figure 29: Example of a typical stage-discharge relation; here, the discharge of the river is 40 cubic feet per second (ft^3/s) when the stage is 3.30 feet (ft). The dots on the curve represent concurrent measurement of stage and discharge (from USGS website).

7. MAINTAINING THE ELEVATION AND STAGE/DISCHARGE RATING THROUGH CONTINUED MEASUREMENTS

The development of an accurate stage-discharge relation requires numerous discharge measurements at all ranges of stage and streamflow. In addition, these relations must be continually checked against on-going discharge measurements because stream channels are constantly changing. Changes in stream channels are often caused by erosion or deposition of streambed materials, seasonal vegetation growth or debris. Figure 30 shows an example of how erosion in a stream channel increases a cross-sectional area for the water, allowing the river to have a greater discharge with no change in stage. New discharge measurements plotted on an existing stage-discharge relation graph would show this, and the rating could be adjusted to allow the correct discharge to be estimated for the measured stage.

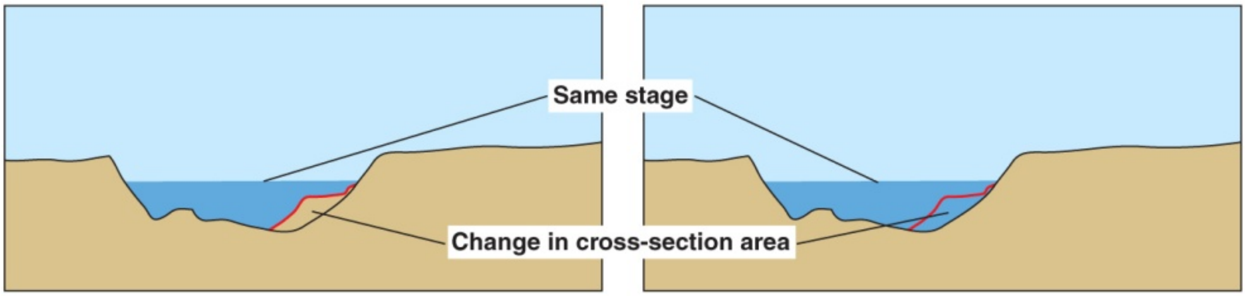


Figure 30: Erosion of part of a channel results in an increased cross-sectional area in the diagram on the right and the potential for conveying a larger quantity of water at the same stage (from USGS website).

The cross section at the gage site also needs to be resurveyed after major floods and at least once every 5 years. The survey should verify the datum used when establishing the gage and if the gage has moved determine the change and correct the record as needed.

8. MANAGING DATA

Implementation of this protocol will create two types of data: digital data from data loggers, GPS units and, if used, digital survey data and current meter measurements and surveying notes recorded in field logbooks. Following a field day when the field books are returned to the office all of the prior day's notes and data sheets are copied and placed in a separate file. This assures that the loss of the field book I on a future date will not result in data loss.

Digital flies will also be copied and stored on a hard drive that is separate from the location where the original files are stored.

When data sets are reviewed if any adjustments are made a separate spreadsheet of notes will be created with the reviewers initials the date and the reason for the change including the location of other data sources used for the revision.

APPENDIX A: Stream Flow Monitoring

Attachment 1

STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream Date

Station Description

Time Begin Time Ended Meter Type

Observers Stream Width[1] Section Width

Observations

Section Midpoint (ft)(m)	Section Depth (ft)(m)(cm)	Observational Depth[2] ft-m-cm	Velocity At Point (ft/s) (m/s)	Velocity Average (ft/s) (m/s)	Area W x D (ft^2) (m^2)	Flow (Q) V x A (m^3/s) (ft^3)
①						
②						
③						
④						
⑤						
⑥						
⑦						
⑧						
⑨						
⑩						
					Total Discharge (ΣQ)(ft^3/s)	

[1]Make a minimum of 10 measurements when the total width is > 5.0 ft., 20 measurements preferred.

[2]Measure at 60% of depth from surface where < 2.5 ft. deep. Measure at 20% and 80% of depth in waters > 2.5 ft. deep.

9-275-F
(Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Meas. No. . . . . . .
Comp. by. . . . . . .

Sta. No. . . . . **DISCHARGE MEASUREMENT NOTES** Checked by . . . . .

. . . .

Date . . . ., 19 . . . . . . Party . . . .
Width . . . . Area. . . . . Vel. . . . . G. H. . . . . Disch. . . . .
Method . . . . . . No. secs. . . . . . G. H. change. . . . . . in . . . . . hrs. Susp. . . . . . .
Method coef. . . . . . . Hor. angle coef. . . . . . Susp. coef. . . . . . Meter No. . . . . . .
Type of meter . . . . .Date rated . . . . .Tag checked . . . .
Meter . . . . ft. above bottom of wt. Spin before meas. . . . . after . . . .
Meas. plots. . . . . % diff. from. . . . . rating. Levels obtained. . . . .

GAGE READINGS						WATER QUALITY MEASUREMENTS
Time		Inside	ADR	Graphic	Outside	No . . . . . Yes. . . . . Time . . . . .
						Samples Collected
						No . . . . . Yes. . . . . Time . . . . .
						Method Used
						EDI . . . . . EWI . . . . . Other. . . . .
						SEDIMENT SAMPLES
						No . . . . . Yes. . . . . Time . . . . .
						Method Used
						EDI . . . . . EWI . . . . . Other. . . . .
Weighted M.G.H.						BIOLOGICAL SAMPLES
G. H. correction						Yes. . . . . Time . . . .
Correct M.G.H.						No . . . . Type . . . .

Check bar. chain found . . . . changed to . . . . at . . . .
Wading, cable, ice, boat, upstr., downstr., side bridge. . . . . feet, mile, above, below gage.
Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:
Flow. . . . .
Cross section . . . .
Control . . . .
Gage operating . . . . Weather . . . .
Intake/Orifice cleaned . . . . . . Air . . . . . . °C@ . . . . . Water . . . . . . °C@ . . . . . .
Record removed . . . . Extreme Indicator: Max. . . . . Min. . . . .
Manometer N_2 Pressure Tank . . . . Feed . . . . Bbl rate . . . . per min.
CSG checked . . . . Stick reading . . . .
Observer . . . .
HWM . . . . outside, in well
Remarks . . . .
. . . .
. . . .
G.H. of zero flow . . . . ft. Sheet No. . . . . of . . . . sheets

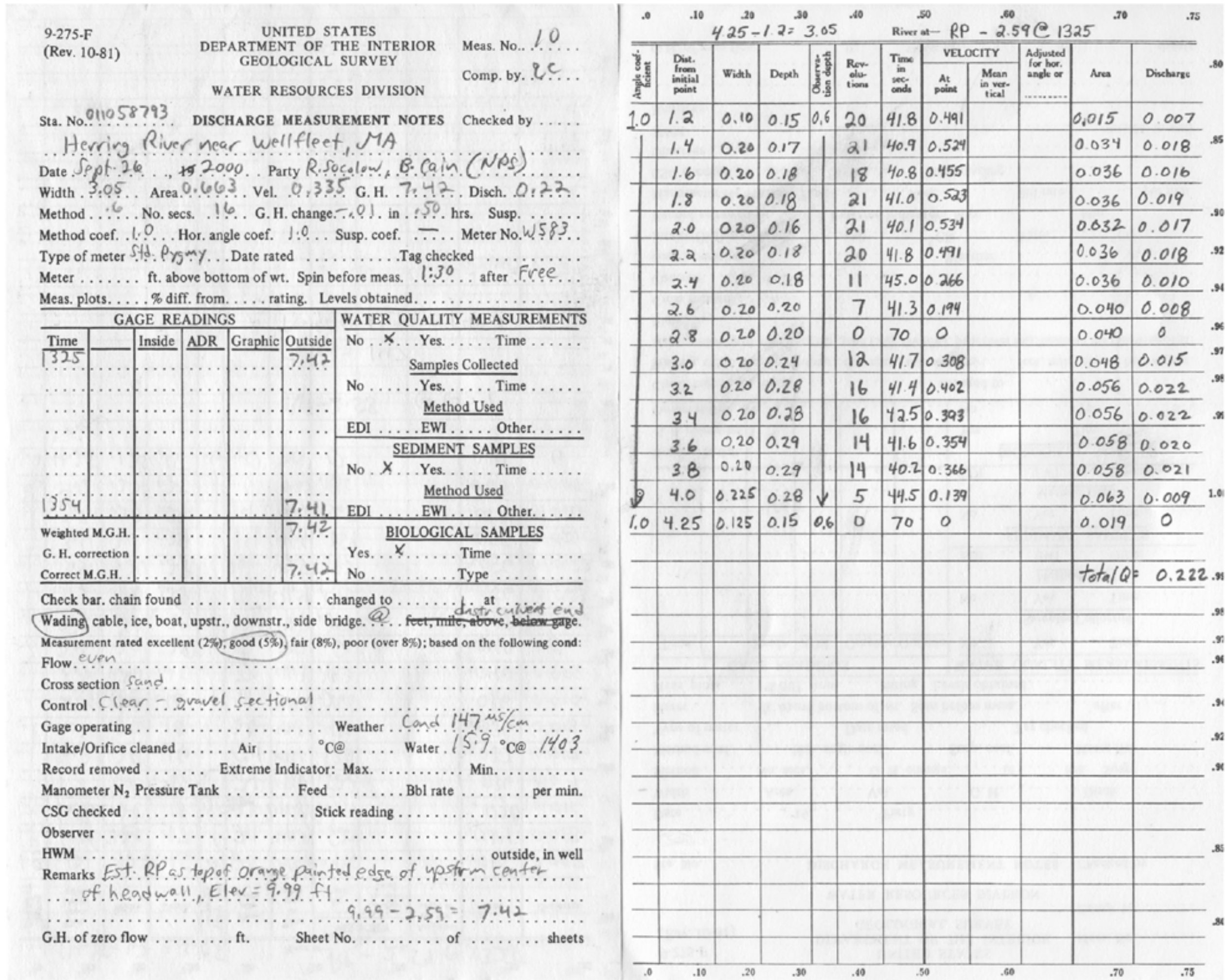
Angle coef-ficient	Dist. from initial point	Width	Depth	Observa-tion depth	Rev-olu-tions	Time in sec-onds	VELOCITY At point	VELOCITY Mean in ver-tical	Adjusted for hor. angle or	Area	Discharge

.0 .10 .20 .30 .40 .50 .60 .70 .80 .85 .90 .92 .94 .96 .97 .98 .99 1.00 .99 .98 .97 .96 .94 .92 .90

GAGE READINGS

Time

Appendix 6a. Example of a USGS discharge measurement field sheet



9-275-F
(Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Meas. No. 10
Comp. by. RC

Sta. No. 011058793 DISCHARGE MEASUREMENT NOTES Checked by ......

Herring River near Wellfleet, MA

Date Sept 26, 19 2000. Party R. Socolow, B. Cain (NPS)

Width 3.05 Area 0.663 Vel. 0.335 G. H. 7.42 Disch. 0.222

Method .6 No. secs. 16 G. H. change -.01 in :50 hrs. Susp. ......

Method coef. 1.0 Hor. angle coef. 1.0 Susp. coef. — Meter No. W583

Type of meter Std. Pygmy Date rated ...... Tag checked ......

Meter ...... ft. above bottom of wt. Spin before meas. 1:30 after Free

Meas. plots ...... % diff. from ...... rating. Levels obtained ......

GAGE READINGS

Time	Inside	ADR	Graphic	Outside
1325				7.42
1354				7.41
Weighted M.G.H.				7.42
G. H. correction				
Correct M.G.H.				7.42

WATER QUALITY MEASUREMENTS

No X Yes ...... Time ......

Samples Collected

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

SEDIMENT SAMPLES

No X Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

BIOLOGICAL SAMPLES

Yes X ...... Time ......

No ...... Type ......

Check bar, chain found ...... changed to ...... at ......

(Wading), cable, ice, boat, upstr., downstr., side bridge @ dist culvert end ~~feet, mile, above, below gage~~.

Measurement rated excellent (2%), (good (5%)), fair (8%), poor (over 8%); based on the following cond:

Flow even

Cross section Sand

Control Clear - gravel sectional

Gage operating ...... Weather Cond 147 uS/cm

Intake/Orifice cleaned ...... Air ...... °C@ ...... Water 15.9 °C@ 1403

Record removed ...... Extreme Indicator: Max. ...... Min. ......

Manometer N_2 Pressure Tank ...... Feed ...... Bbl rate ...... per min.

CSG checked ...... Stick reading ......

Observer ......

HWM ...... outside, in well

Remarks Est. RP as top of orange painted edge of upstrm center of headwall, Elev = 9.99 ft

9.99 - 2.59 = 7.42

G.H. of zero flow ...... ft. Sheet No. ...... of ...... sheets

4.25 - 1.2 = 3.05 River at — RP - 2.59 @ 1325

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Adjusted for hor. angle or	Area	Discharge
1.0	1.2	0.10	0.15	0.6	20	41.8	0.491			0.015	0.007
	1.4	0.20	0.17		21	40.9	0.524			0.034	0.018
	1.6	0.20	0.18		18	40.8	0.455			0.036	0.016
	1.8	0.20	0.18		21	41.0	0.523			0.036	0.019
	2.0	0.20	0.16		21	40.1	0.534			0.032	0.017
	2.2	0.20	0.18		20	41.8	0.491			0.036	0.018
	2.4	0.20	0.18		11	45.0	0.266			0.036	0.010
	2.6	0.20	0.20		7	41.3	0.194			0.040	0.008
	2.8	0.20	0.20		0	70	0			0.040	0
	3.0	0.20	0.24		12	41.7	0.308			0.048	0.015
	3.2	0.20	0.28		16	41.4	0.402			0.056	0.022
	3.4	0.20	0.28		16	42.5	0.393			0.056	0.022
	3.6	0.20	0.29		14	41.6	0.354			0.058	0.020
	3.8	0.20	0.29		14	40.2	0.366			0.058	0.021
	4.0	0.225	0.28		5	44.5	0.139			0.063	0.009
1.0	4.25	0.125	0.15	0.6	0	70	0			0.019	0
										total Q=	0.222

Appendix 6b. Discharge measurement field sheet from Herring River near Wellfleet, MA, September 2000.

STANDARD RATING TABLE NO. 2 FOR AA CURRENT METERS (6/99)
EQUATION: V = 2.2048 R + 0.0178 (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions									Seconds
	3	5	7	10	15	20	25	30	40	
40	0.183	0.293	0.404	0.569	0.845	1.12	1.40	1.67	2.22	40
41	0.179	0.287	0.394	0.556	0.824	1.09	1.36	1.63	2.17	41
42	0.175	0.280	0.385	0.543	0.805	1.07	1.33	1.59	2.12	42
43	0.172	0.274	0.377	0.531	0.787	1.04	1.30	1.56	2.07	43
44	0.168	0.268	0.369	0.519	0.769	1.02	1.27	1.52	2.02	44
45	0.165	0.263	0.361	0.508	0.753	0.998	1.24	1.49	1.98	45
46	0.162	0.257	0.353	0.497	0.737	0.976	1.22	1.46	1.94	46
47	0.159	0.252	0.346	0.487	0.721	0.956	1.19	1.43	1.89	47
48	0.156	0.247	0.339	0.477	0.707	0.936	1.17	1.40	1.86	48
49	0.153	0.243	0.333	0.468	0.693	0.918	1.14	1.37	1.82	49
50	0.150	0.238	0.326	0.459	0.679	0.900	1.12	1.34	1.78	50
51	0.147	0.234	0.320	0.450	0.666	0.882	1.10	1.31	1.75	51
52	0.145	0.230	0.315	0.442	0.654	0.866	1.08	1.29	1.71	52
53	0.143	0.226	0.309	0.434	0.642	0.850	1.06	1.27	1.68	53
54	0.140	0.222	0.304	0.426	0.630	0.834	1.04	1.24	1.65	54
55	0.138	0.218	0.298	0.419	0.619	0.820	1.02	1.22	1.62	55
56	0.136	0.215	0.293	0.412	0.608	0.805	1.00	1.20	1.59	56
57	0.134	0.211	0.289	0.405	0.598	0.791	0.985	1.18	1.57	57
58	0.132	0.208	0.284	0.398	0.588	0.778	0.968	1.16	1.54	58
59	0.130	0.205	0.279	0.391	0.578	0.765	0.952	1.14	1.51	59
60	0.128	0.202	0.275	0.385	0.569	0.753	0.936	1.12	1.49	60
61	0.126	0.199	0.271	0.379	0.560	0.741	0.921	1.10	1.46	61
62	0.124	0.196	0.267	0.373	0.551	0.729	0.907	1.08	1.44	62
63	0.123	0.193	0.263	0.368	0.543	0.718	0.893	1.07	1.42	63
64	0.121	0.190	0.259	0.362	0.535	0.707	0.879	1.05	1.40	64
65	0.120	0.187	0.255	0.357	0.527	0.696	0.866	1.04	1.37	65
66	0.118	0.185	0.252	0.352	0.519	0.686	0.853	1.02	1.35	66
67	0.117	0.182	0.248	0.347	0.511	0.676	0.840	1.01	1.33	67
68	0.115	0.180	0.245	0.342	0.504	0.666	0.828	0.991	1.31	68
69	0.114	0.178	0.241	0.337	0.497	0.657	0.817	0.976	1.30	69
70	0.112	0.175	0.238	0.333	0.490	0.648	0.805	0.963	1.28	70
	3	5	7	10	15	20	25	30	40	

STANDARD RATING TABLE NO. 2 FOR AA CURRENT METERS (6/99)
EQUATION: V = 2.2048 R + 0.0178 (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions									Seconds
	50	60	80	100	150	200	250	300	350	
40	2.77	3.33	4.43	5.53	8.29	11.04	13.80	16.55	19.31	40
41	2.71	3.24	4.32	5.40	8.08	10.77	13.46	16.15	18.84	41
42	2.64	3.17	4.22	5.27	7.89	10.52	13.14	15.77	18.39	42
43	2.58	3.09	4.12	5.15	7.71	10.27	12.84	15.40	17.96	43
44	2.52	3.02	4.03	5.03	7.53	10.04	12.55	15.05	17.56	44
45	2.47	2.96	3.94	4.92	7.37	9.82	12.27	14.72	17.17	45
46	2.41	2.89	3.85	4.81	7.21	9.60	12.00	14.40	16.79	46
47	2.36	2.83	3.77	4.71	7.05	9.40	11.75	14.09	16.44	47
48	2.31	2.77	3.69	4.61	6.91	9.20	11.50	13.80	16.09	48
49	2.27	2.72	3.62	4.52	6.77	9.02	11.27	13.52	15.77	49
50	2.22	2.66	3.55	4.43	6.63	8.84	11.04	13.25	15.45	50
51	2.18	2.61	3.48	4.34	6.50	8.66	10.83	12.99	15.15	51
52	2.14	2.56	3.41	4.26	6.38	8.50	10.62	12.74	14.86	52
53	2.10	2.51	3.35	4.18	6.26	8.34	10.42	12.50	14.58	53
54	2.06	2.47	3.28	4.10	6.14	8.18	10.23	12.27	14.31	54
55	2.02	2.42	3.22	4.03	6.03	8.04	10.04	12.04	14.05	55
56	1.99	2.38	3.17	3.95	5.92	7.89	9.86	11.83	13.80	56
57	1.95	2.34	3.11	3.89	5.82	7.75	9.69	11.62	13.56	57
58	1.92	2.30	3.06	3.82	5.72	7.62	9.52	11.42	13.32	58
59	1.89	2.26	3.01	3.75	5.62	7.49	9.36	11.23	13.10	59
60	1.86	2.22	2.96	3.69	5.53	7.37	9.20	11.04	12.88	60
61	1.83	2.19	2.91	3.63	5.44	7.25	9.05	10.86	12.67	61
62	1.80	2.15	2.86	3.57	5.35	7.13	8.91	10.69	12.46	62
63	1.77	2.12	2.82	3.52	5.27	7.02	8.77	10.52	12.27	63
64	1.74	2.08	2.77	3.46	5.19	6.91	8.63	10.35	12.08	64
65	1.71	2.05	2.73	3.41	5.11	6.80	8.50	10.19	11.89	65
66	1.69	2.02	2.69	3.36	5.03	6.70	8.37	10.04	11.71	66
67	1.66	1.99	2.65	3.31	4.95	6.60	8.24	9.89	11.54	67
68	1.64	1.96	2.61	3.26	4.88	6.50	8.12	9.74	11.37	68
69	1.62	1.94	2.57	3.21	4.81	6.41	8.01	9.60	11.20	69
70	1.59	1.91	2.54	3.17	4.74	6.32	7.89	9.47	11.04	70
	50	60	80	100	150	200	250	300	350	

Appendix 7. Standard rating table No. 2 for AA current meters (USGS, 1999a)

STANDARD RATING TABLE NO. 2 FOR PYGMY CURRENT METER (6/99)
EQUATION: V = 0.9604 R+ 0.0312 (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions														
	3	5	7	10	15	20	25	30	40	50	60	80	100	150	200
40	0.103	0.151	0.199	0.271	0.391	0.511	0.631	0.752	0.992	1.23	1.47	1.95	2.43	3.63	4.83
41	0.101	0.148	0.195	0.265	0.383	0.500	0.617	0.734	0.968	1.20	1.44	1.91	2.37	3.54	4.72
42	0.100	0.146	0.191	0.260	0.374	0.489	0.603	0.717	0.946	1.17	1.40	1.86	2.32	3.46	4.60
43	0.098	0.143	0.188	0.255	0.366	0.478	0.590	0.701	0.925	1.15	1.37	1.82	2.26	3.38	4.50
44	0.097	0.140	0.184	0.249	0.359	0.468	0.577	0.686	0.904	1.12	1.34	1.78	2.21	3.31	4.40
45	0.095	0.138	0.181	0.245	0.351	0.458	0.565	0.671	0.885	1.10	1.31	1.74	2.17	3.23	4.30
46	0.094	0.136	0.177	0.240	0.344	0.449	0.553	0.658	0.866	1.08	1.28	1.70	2.12	3.16	4.21
47	0.093	0.133	0.174	0.236	0.338	0.440	0.542	0.644	0.849	1.05	1.26	1.67	2.07	3.10	4.12
48	0.091	0.131	0.171	0.231	0.331	0.431	0.531	0.631	0.832	1.03	1.23	1.63	2.03	3.03	4.03
49	0.090	0.129	0.168	0.227	0.325	0.423	0.521	0.619	0.815	1.01	1.21	1.60	1.99	2.97	3.95
50	0.089	0.127	0.166	0.223	0.319	0.415	0.511	0.607	0.800	0.992	1.18	1.57	1.95	2.91	3.87
51	0.088	0.125	0.163	0.220	0.314	0.408	0.502	0.596	0.784	0.973	1.16	1.54	1.91	2.86	3.80
52	0.087	0.124	0.160	0.216	0.308	0.401	0.493	0.585	0.770	0.955	1.14	1.51	1.88	2.80	3.73
53	0.086	0.122	0.158	0.212	0.303	0.394	0.484	0.575	0.756	0.937	1.12	1.48	1.84	2.75	3.66
54	0.085	0.120	0.156	0.209	0.298	0.387	0.476	0.565	0.743	0.920	1.10	1.45	1.81	2.70	3.59
55	0.084	0.119	0.153	0.206	0.293	0.380	0.468	0.555	0.730	0.904	1.08	1.43	1.78	2.65	3.52
56	0.083	0.117	0.151	0.203	0.288	0.374	0.460	0.546	0.717	0.889	1.06	1.40	1.75	2.60	3.46
57	0.082	0.115	0.149	0.200	0.284	0.368	0.452	0.537	0.705	0.874	1.04	1.38	1.72	2.56	3.40
58	0.081	0.114	0.147	0.197	0.280	0.362	0.445	0.528	0.694	0.859	1.02	1.36	1.69	2.51	3.34
59	0.080	0.113	0.145	0.194	0.275	0.357	0.438	0.520	0.682	0.845	1.01	1.33	1.66	2.47	3.29
60	0.079	0.111	0.143	0.191	0.271	0.351	0.431	0.511	0.671	0.832	0.992	1.31	1.63	2.43	3.23
61	0.078	0.110	0.141	0.189	0.267	0.346	0.425	0.504	0.661	0.818	0.976	1.29	1.61	2.39	3.18
62	0.078	0.109	0.140	0.186	0.264	0.341	0.418	0.496	0.651	0.806	0.961	1.27	1.58	2.35	3.13
63	0.077	0.107	0.138	0.184	0.260	0.336	0.412	0.489	0.641	0.793	0.946	1.25	1.56	2.32	3.08
64	0.076	0.106	0.136	0.181	0.256	0.331	0.406	0.481	0.631	0.782	0.932	1.23	1.53	2.28	3.03
65	0.076	0.105	0.135	0.179	0.253	0.327	0.401	0.474	0.622	0.770	0.918	1.21	1.51	2.25	2.99
66	0.075	0.104	0.133	0.177	0.249	0.322	0.395	0.468	0.613	0.759	0.904	1.20	1.49	2.21	2.94
67	0.074	0.103	0.132	0.175	0.246	0.318	0.390	0.461	0.605	0.748	0.891	1.18	1.46	2.18	2.90
68	0.074	0.102	0.130	0.172	0.243	0.314	0.384	0.455	0.596	0.737	0.879	1.16	1.44	2.15	2.86
69	0.073	0.101	0.129	0.170	0.240	0.310	0.379	0.449	0.588	0.727	0.866	1.14	1.42	2.12	2.81
70	0.072	0.100	0.127	0.168	0.237	0.306	0.374	0.443	0.580	0.717	0.854	1.13	1.40	2.09	2.78
	3	5	7	10	15	20	25	30	40	50	60	80	100	150	200

Appendix 8. Standard rating table No. 2 for Pygmy current meters (USGS, 1999b)

APPENDIX B

STREAM FLOW MONITORING

DATA SHEETS 1-3

DATA SHEET #1: STREAM FLOW GAGING STATION: SITE SELECTION

Rate the location of the stream flow gaging station for each of these features

Station Name:	
GPS Coordinates	
	Confined Channel Location

	Alluvial Channel Location

Rating			***Characteristic***	***Notes, description***
H	M	L	Perennial	
H	M	L	Artificial structure (bridge, dam, weir or flume)	
H	M	L	Straight channel ~300 ft upstream and downstream of site	
H	M	L	Limited scour, deposition, algal growth	
H	M	L	Low loss to groundwater	
H	M	L	No secondary channel	
H	M	L	Permanent banks high enough to contain floods, brush-free	
H	M	L	Persistent pool upstream of site (how far?)	
H	M	L	Upstream of a confluence (how far?)	
H	M	L	Good for measuring discharge at all stages (how far from site?)	
H	M	L	Accessible and safe	
H	M	L	Streambed characteristics (stable, even, not soft)	
H	**M**	**L**	**OVERALL**	

Assessment of site, advantages, disadvantages

DATA SHEET #2: STREAM FLOW GAGING STATION: DISCHARGE SITE

Rate the location of the discharge measurement for each of these features

rating	***criteria***	***notes, description***
H M L	Perennial flow	
H M L	Artificial structure (bridge, dam, weir or flume)*	
H M L	Stable cross section*	
H M L	Straight channel ~100 ft upstream and downstream of measurement site	
H M L	Little slope change	
H M L	Velocity threads are parallel	
H M L	Uniform current at measurement site free of eddies, side currents and dead water	
H M L	Little water turbulence at measurement site	
H M L	Flow has primarily downstream current uninterrupted by rocks of different sizes or vegetation	
H M L	**OVERALL**	
	*Describe grade control at measurement site below including if rocks in channel were rearranged to improve measurement	
	Take a photo of the site where the discharge measurement was done and record a GPS point	

Assessment of site, advantages, disadvantages, affect on discharge measurements

DATA SHEET #3: STREAMFLOW GAGING: STAGE-DISCHARGE MEASUREMENT

PAGE 1

Date	
Field Team	
Weather conditions	
Stream observations	
Flow conditions	

Current meter instrument number and model:

Was spin test completed prior to measurement

CURRENT METER READINGS

Start time		Water level	Staff gage:

					Velocity readings					
					20% depth	60% depth	80% depth	Mean velocity		
Distance from reference point	Panel number	Panel width	Time	Water depth	fps	fps	fps	fps	Panel discharge	Notes
feet			hh:mm	feet					cfs	
	1									
	2									
	3									
	4									
	5									
	6									
	7									
	8									
	9									
	10									
	11									
	12									
	13									
	14									
	15									
	16									

COMPLETE ON PAGE 2

CURRENT METER READINGS CONT.

Distance from reference point	Panel number	Panel width	Time	Water depth	Velocity readings: 20% depth	Velocity readings: 60% depth	Velocity readings: 80% depth	Velocity readings: Mean velocity	Panel discharge	Notes
					fps	fps	fps	fps		
feet			hh:mm	feet					cfs	
	17									
	18									
	19									
	20									
	21									
	22									
	23									
	24									
	25									
	26									
	27									
	28									
	29									
	30									

Total of panel discharges ______ cfs

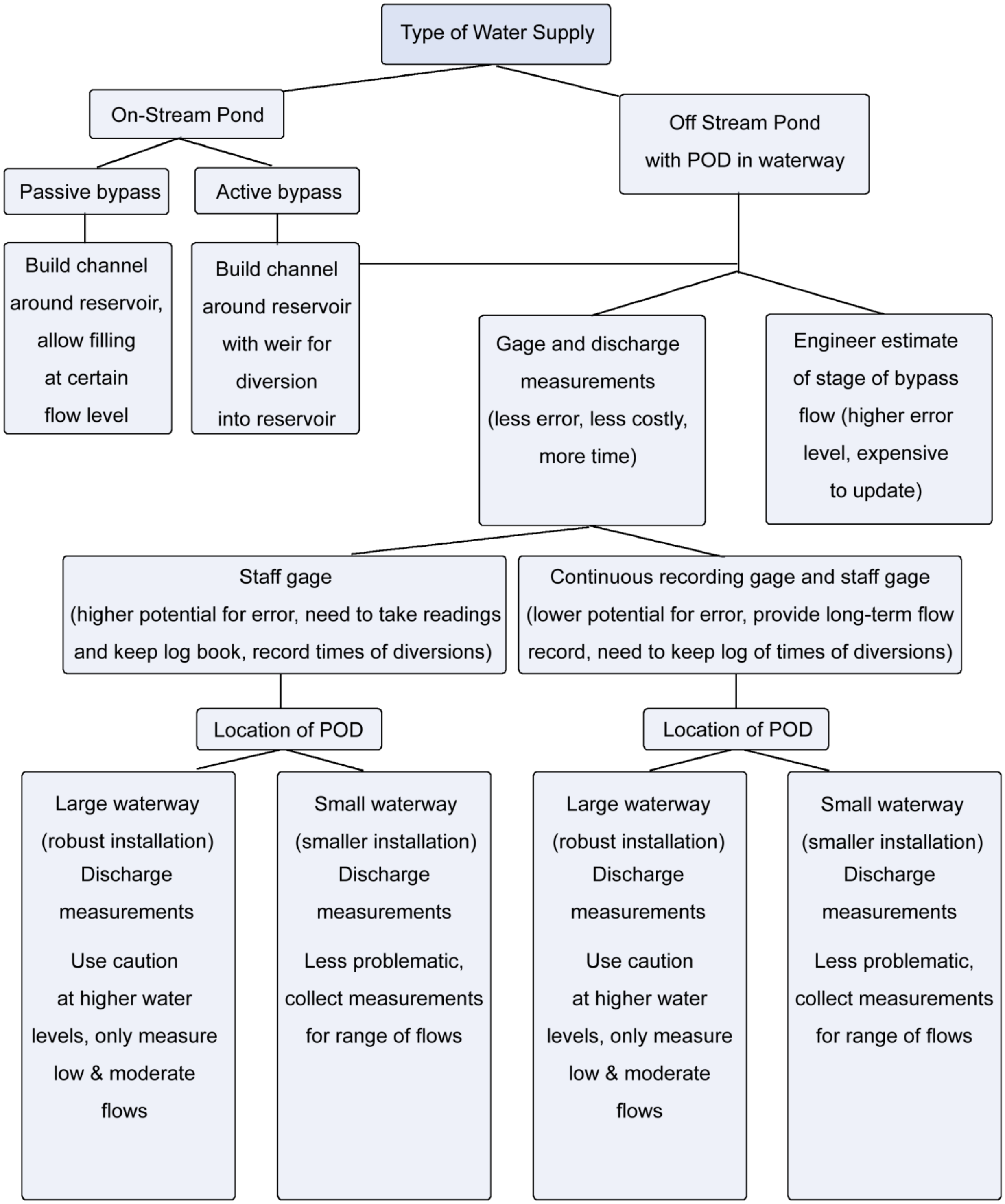
Stop time ______

Water level

Staff gage: ______

APPENDIX 3

Decision chart for bypass flow monitoring:



For each gaging station:

At establishment of gage - survey cross sections at an established benchmark (or establish a benchmark if none available)

Generate rating curve with at least 10 discharge data points. Check fit of curve to data points to determine the need for more points. Conduct additional discharge measurements if needed.

Maintenance - check around gage after storms and clear debris from gage area, resurvey cross sections after major floods or after channel changing flows. Alternatively if channel changes with a flood, a new rating curve can be prepared with 10 new discharge measurements.

APPENDIX 4

Frost BMPs

Water Conservation: Frost Control

In certain areas, spring can bring freezing temperatures after grapevines have budded out. These frosts will burn tender vegetation and damage the plant if no measures are taken. Frost conditions come from two different types of climatic events. Advection frost occurs when a large mass of arctic air occupies a valley, creating frost conditions on both the valley floor and hillsides. The frost season of 2008 included an advection frost event on April 20-21.

More common are radiation frost events. In these events, cold air pools at the lowest points in a river valley, along tributary creeks, and in hollows. Above this layer of cold air, a warmer air mass may be present, creating a strong inversion layer. If the difference in air temperature between the valley floor and upper layers is small, this is a weak inversion layer. Radiation frost events are also marked by clear skies and calm winds. Radiation frost events occur in the valleys and low hollows of the Russian River watershed on a frequent basis. Only frost events that occur during and after grape bud break are of concern to farmers. This is usually the March 15 to May 15 period. Typically vineyards and orchards on the valley floor and in hollows or low spots in the hilly areas require frost protection. Most hillside vineyards do not need frost protection due to the infrequent occurrence of advection frost.

In order to understand frost control measures, it is essential to understand the physical processes that occur during a radiation frost event. During a radiation frost event, more energy is lost to clear, cold skies from the vines than is gained. Cloudy or windy conditions may have adequate energy transfer to avoid energy loss from the vines. Typically there are several types of energy transfer:

- **Conduction** is the transfer of energy through objects that don't move. Soil heat moves through conduction.
- **Convection** is the transfer of heat in moving air.
- **Radiation** is the transfer of electromagnetic energy such as sunlight. Crops radiate energy as does the atmosphere.
- **Latent heat** is the energy stored in the bonds that join water molecules together. For example, when water changes form from a liquid to a solid state, the environment around the water changes temperature due to the change of the latent heat in the water to sensible heat. Sensible heat is measured with a thermometer and is "sensed" by us. When water changes from liquid to a solid, the localized air temperature rises. When water changes from a liquid to a vapor state, the localized air temperature falls. This cooling effect of evaporating water is the principle used by swamp coolers. Similarly, there is a warming effect of freezing water.

One of the physical factors besides air temperature that determines frost effects is humidity. Humidity plays a major role in frost events. Humid air or air with a high water vapor content has a higher energy content than dry air, due to the increase in air temperature produced when vapor condenses or changes to a liquid form.

The severity and timing of a frost event is affected by both the air temperature and the timing of freezing temperatures (32°F or 0°C), as well as the dew point or temperature (DPT) at which water vapor condenses to liquid or dew. The wet bulb temperature (WBT) is another important measure and is the evaporatively cooled temperature of a moist surface in a given air mass. WBT is approximately halfway between ambient air temperature and dew point temperature.

During very low humidity conditions, damage to vines may occur before freezing temperatures (32°F or 0°C) occur. For this reason, air temperatures, dew point, and wet bulb temperature must be monitored to determine when to begin frost prevention measures.

Water freezes onto plants more readily if ice-nucleating bacteria are present. The bacteria act as surface particles that make it easier for ice crystals to form. These bacteria have the greatest effect in the range between 23°F to 32°F (-5°C and 0°C). Spraying anti-bacterial copper or introducing competing bacteria that do not nucleate ice can reduce the ice-nucleating bacteria.

For most of the valleys where grapes are grown, frost control is essential to avoid major damage and loss of both a year's crop and sometimes the vines themselves. Vineyards on hillsides or near the coast or San Francisco Bay typically do not have frost problems or require frost protection most of the time.

In the Upper Russian River and Navarro River drainages, springtime temperatures can become very cold (27°F or -3.9°C wet bulb temperature) and these areas are in a severe frost zone. The Sonoma County portion of the Russian River watershed, Alexander Valley, Knights Valley, and many small valleys and hollows are also severe frost zones. Upper Napa River watershed, Pope Valley, Wooden Valley, and Upper Sonoma Creek watershed are severe frost zones. Other parts of these watersheds are moderate frost zones (28-29°F or -2.2°C wet bulb temperature). Lower Napa River watershed, lower Sonoma Creek watershed, and Suisun Valley have mild frost events (31-32°F or -0.5 – 0.0°C wet bulb temperature) due to the moderating effect of San Francisco Bay.

Small topographic changes between the low-lying areas of a valley and adjoining lands can create different levels of severity in frost events and allow for different frost prevention methods.

Temperature monitoring in the vineyard is the only way to determine what frost prevention methods can be used. Detailed weather forecasts, particular for local areas, can provide important information on whether freezing air temperatures and low dew point temperatures will occur, where they will occur on a local basis, and what time of day or night critical temperatures will occur. But site specific air temperature and wet bulb temperature monitoring are needed to determine when frost prevention measures should begin for a particular location.

Passive Frost Control Measures
There are a number of passive measures that can be implemented to reduce frost damage in vineyards. These are cultural measures which can allow for lower temperatures to occur without damaging vines. These measures used alone can be adequate in areas with very little frost risk. They can also be incorporated into a program which includes active measures.

Passive Frost Control Measures include:

- **Site selection**. Some varieties of grape vines bud later in spring and will require less frost protection. Chardonnay is an early budding variety, while Cabernet is not. If the soil and climate are appropriate, the lowest-lying valley areas can be planted or replanted to the later-budding grape variety to reduce water use.

Grape variety	Seasonal date of budbreak
Chardonnay	Early
Pinot noir	Early
Gewürztraminer	Early
Pinot gris	Early
Petite Sirah	Middle
Merlot	Middle
Zinfandel	Middle
Syrah	Middle
Viognier	Middle
Sauvignon blanc	Middle/Late
Cabernet Sauvignon	Late

- **Increase cold air drainage** out of the vineyard. The row orientation and location of ornamental vegetation around the vineyard may be modified to allow for cold air moving to lower areas to drain rather than pool in the vineyard.

- **Restrict cold air movement** into the vineyard. For low-lying sites, row orientation and bordering vegetation can be used to block cold air moving into the vineyard, thereby limiting damage or active control measures to the outer vineyard edge.

- **Late pruning**. By pruning grapevines later (early March), the onset of budding can be delayed and the need for frost control can be delayed.

- **Cover crop and vineyard floor management**. Cover crops are a required BMP during the rainy season, but they need to be managed to reduce frost problems. Decisions on what type of vineyard floor management is needed should consider if a drought is occurring and the level of frost risk for a particular site. Cover crops reduce the amount of heat absorbed by the soil. Cover crops also host ice-nucleating bacteria, which can increase frost damage. Mowing cover crops and strip-spraying with herbicides can reduce some of the negative effects of cover crops during frost events. Disking and rolling the soil surface is also suggested by some experts to increase solar radiation inputs into the soil, which will then radiate heat into the crop during nighttime hours. This practice can result in soil erosion and should only be used in dry years when water supplies are low. Vineyards with cover crops can be 1 to 3°F (0.5 to 2.0°C) colder than vineyards with mowed and disked cover crops.

- **Copper applications**. Copper sulfate is a commonly used, organically-certified fungicide. Copper applications can kill ice-nucleating bacteria and therefore reduce frost damage in marginally frost-prone areas and on nights with low, but not extremely low temperatures. Care in the application process is needed to avoid any drift of copper spray, any rinse-off, and any soil erosion as copper binds to soil particles. Copper is acutely toxic to aquatic organisms. Copper applications are known to allow for 1-1.5°F (0.5 to 1.0 °C) colder conditions without damage than on vines without copper.

- **Risk management**. The risk of frost damage in marginally frost-prone areas may be low enough that only passive BMPs are needed.

Active Frost Control Measures
There are a few active frost control techniques currently in use – wind machines, diesel heaters, and water.

Wind machines have a limited application, depending upon the vineyard location. Most wind machines are a large horizontal fan that stirs up air masses, mixing the cold air near the ground with warmer layers above. In areas with marine influence, or certain microclimates, wind machines can work to prevent frost damage. However, in many interior valleys, the air layers above the ground are also at freezing temperatures, so mixing the air masses is not effective. Another type of wind machine is a Selective Inverted Sink (SIS), which is a fan oriented parallel to the ground and housed in a small tower. The fan, which is close to ground level, shoots cold air upward and draws warm air to the ground. Generally wind machines can provide frost protection down to 29°F (-1.6°C) and can only work where an inversion layer occurs at 6 to 50 feet above the ground and is at least 2.7°F (1.5°C) warmer than the ground layer air.

Vineyard Heaters. Diesel fuel heaters were once in common use for frost protection. In a few areas, diesel vineyard heaters may still be used, but most growers stopped using them in the 1970s due to the air pollution problems they create.

Water. In colder areas with moderate to severe frost conditions, water is the only frost control measure. The concept behind this technique is based on the latent heat released as water moves from a liquid to solid state. By continuously applying water to the vineyard, the water changing from a liquid to a solid state on the vines creates heat and protects the vegetation from frost damage. Use of water can protect against temperatures of 27°F (-2.7°C) but will not work at 23°F (-5.0°C).

There are several different types of sprinklers in use for frost control in vineyards:

- **Standard size overhead sprinkler system** emit 50 gallons/minute/acre or 3,000 gallons/hour/acre. These are rotating head sprinklers, which wet the entire vineyard canopy and vineyard floor. They typically rotate every 30-60 seconds and 25-30 sprinklers are needed per acre regardless of the vine spacing or trellis type. A minimum of 0.1 inches of water must be applied per hour. Within the vineyard, these sprinklers have a separate system of water pipes than the drip-irrigation system.

- **Low-flow overhead sprinklers** emit 35-40 gallons/minute/acre or 2,400 gallons/hour/acre. These are also rotating head sprinklers, but wet a smaller area. These sprinklers are used at the same density as the standard overhead sprinklers. In vineyards with dense spacing standard sprinklers should be used. These sprinklers also run off a different set of waterlines than the irrigation system. If water availability is a limiting feature spacing the vines to be able to use these sprinklers may be advantageous.

- **Micro-sprinklers** are of two types: pulsating and constant. Both types operate as part of the drip-irrigation system. The micro-sprinklers are placed in the vine canopy and have a localized effect. To provide adequate frost protection there needs to be 280-400 micro-sprinklers/acre. Pulsating micro-sprinkler systems use 12-20 gallons/minute/acre or up to 1,200 gallons/hour/acre. Micro-sprinklers with constant water output use 25-35 gallons/minute/acre or up to 2,100 gallons/hour/acre. Micro-sprinklers do not work in divided canopy trellis systems; they work only in single canopy systems.

There are several considerations in choosing one type of sprinkler over another. Areas with severe frost events, such as Ukiah Valley, Upper Napa Valley or Pope Valley, can theoretically use micro-sprinklers as long as the system is turned on several hours earlier than standard set systems. However, there are many growers who have had problems with the small water lines of micro-sprinklers freezing in severe frost zones. It is not clear why these problems have occurred and if improved management with the micro-sprinklers would prevent frost damage in these vineyards. Another consideration is the vine-row spacing. In densely planted vineyards, the number of micro-sprinklers needed and the water use can exceed standard set sprinklers.

A final consideration is the method of harvest used. Machine harvesters are often used on flat ground in valley areas also typically frost-prone. Prior to harvest, all types of sprinklers have to be removed and then reinstalled prior to spring. Micro-sprinklers can be very labor intensive to remove and re-install due to their numbers in the vineyard.

Frost Zones and average annual hours of frost

Severe	hours	Moderate	hours	Mild	hours
Redwood Valley	100	Upper Napa Valley		Lower Napa Valley	
Potter Valley	150				
Ukiah Valley	80				
Hopland Valley	80				
Pope Valley	100				
Chiles Valley	80				
Anderson Valley	80				

When to turn on the sprinklers
Determining when to turn on the sprinklers on a frost night will partially depend on the type of sprinklers used. For all systems, several types of temperature monitoring in the vineyard are needed.

Even if accurate localized weather forecasts are available, conditions in the vineyard's most frost-prone areas have to be monitored. Standard set sprinklers need to be turned on when the wet bulb temperature is above the critical damage temperature for the crop. For grape vines, the critical damage temperature is 31.5°F for 30 minutes. Micro-frost systems need to be turned on several hours earlier that standard sprinklers. Under low dew point temperatures (a very dry cold), sprinklers need to be turned on earlier than under higher dew point temperatures for the same air temperature. Under low dew point temperatures the wet bulb temperature is lower than the air temperature and, when the sprinklers are turned on the water reduces air temperatures to the wet bulb temperature and frost damage can occur. For this reason, sprinklers must be turned on early.

Wet bulb temperatures can be measured directly or determined from measurements of the dew point or relative humidity and air temperature. A wet bulb temperature above 31.5°F, the critical damage temperature for grapes is selected. Using Table 1 the selected wet bulb temperature, and measured/predicted dew point can be selected and the air temperature for standard sprinklers turn-on can be read. If relative humidity and temperature are known, Table 2 can be used to determine dew point temperature for use in Table 1. Direct measurements of wet bulb temperature in the vineyard allow for different types of sprinklers to be turned on at the needed time before the critical damage temperature will occur.

Wet bulb and dry bulb temperature can be measured in the vineyard with a manual instrument called a sling psychrometer or a digital version. The digital version, if fixed to a location in the canopy of the low part of the vineyard, often has the ability to be read remotely by a computer or cell phone. A network of instruments can give the greatest coverage and determine the need to turn on the sprinklers most accurately.

Water is continuously applied to the vines during frost events. As the water is applied and it freezes, it releases heat, warms the leaves, but then the temperature drops to the wet bulb temperature as evaporation occurs. If the leaves are not wetted again immediately, frost damage will occur. Therefore, the interval between water applications is critical to avoiding damage. This interval is the sprinkler rotation rate, which for standard overhead sprinklers is typically 30 seconds, but may be as long as 60 seconds. The entire bud/leaf/stem area needs to be covered on each rotation. Table 3 lists the water volumes applied for 30 or 60 second rotation sprinklers at various temperatures and wind speeds. The water is turned off when the air temperature and the wet bulb temperature are above 32°F (0°C). It is not necessary to wait for all the ice to melt.

Table 1. Minimum turn-on and turn-off air temperatures (ºF) for sprinkler frost protection for a range of wet-bulb and dew-point temperatures (ºF)*

Dew-point Temperature	Wet-bulb Temperature (ºF)										
ºF	22	23	24	25	26	27	28	29	30	31	32
32											32.0
31										31.0	32.7
30									30.0	31.7	33.3
29								29.0	30.6	32.3	34.0
28							28.0	29.6	31.2	32.9	34.6
27						27.0	28.6	30.2	31.8	33.5	35.2
26					26.0	27.6	29.2	30.8	32.4	34.0	35.7
25				25.0	26.5	28.1	29.7	31.3	32.9	34.6	36.3
24			24.0	25.5	27.1	28.6	30.2	31.8	33.5	35.1	36.8
23		23.0	24.5	26.0	27.6	29.1	30.7	32.3	34.0	35.6	37.3
22	22.0	23.5	25.0	26.5	28.1	29.6	31.2	32.8	34.5	36.1	37.8
21	22.5	24.0	25.5	27.0	28.5	30.1	31.7	33.3	34.9	36.6	38.2
20	22.9	24.4	25.9	27.4	29.0	30.6	32.1	33.7	35.4	37.0	38.7
19	23.4	24.9	26.4	27.9	29.4	31.0	32.6	34.2	35.8	37.5	39.1
18	23.8	25.3	26.8	28.3	29.8	31.4	33.0	34.6	36.2	37.9	39.5
17	24.2	25.7	27.2	28.7	30.2	31.8	33.4	35.0	36.6	38.3	39.9
16	24.6	26.1	27.6	29.1	30.6	32.2	33.8	35.4	37.0	38.7	40.3
15	25.0	26.4	27.9	29.5	31.0	32.6	34.2	35.8	37.4	39.0	40.7

***Select a wet-bulb temperature that is at or above the critical damage temperature for your crop and locate the appropriate column. Then choose the row with the correct dew-point temperature and read the corresponding air temperature from the table to turn your sprinklers on or off. This table assumes a barometric pressure of 1013 millibars (101.3 kPa).**

Table 2 Dew-point temperatures (ºF) for a range of air temperature and relative humidity*.

Relative humidity	Temperature (ºF)					
%	32	36	40	44	48	52
	32	36	40	44	48	52
90	29	33	37	41	45	49
80	27	30	34	38	42	46
70	23	27	31	35	39	43
60	20	23	27	31	35	39
50	16	19	23	27	30	34
40	10	14	18	21	25	28
30	4	8	11	15	18	22
20	-4	-1	2	6	9	12
10	-18	-15	-12	-9	-6	-3

***Select a relative humidity in the left column and an air temperature from the top row. Then find the corresponding dew point in the table.**

Table 3 Application Rates for Overhead Sprinklers for Frost Protection of Grapevines

Temperature	Wind Speed	30 second rotation	60 second rotation	30 second rotation	60 second rotation
ºF	Mph	in/hr	in/hr	gpm/acre	gpm/acre
29	0.0-1.1	0.08	0.10	36	45
26	0.0-1.1	0.11	0.13	50	59
23	0.0-1.1	0.15	0.17	68	77
29	2.0-3.0	0.10	0.12	45	54
26	2.0-3.0	0.13	0.15	59	68
23	2.0-3.0	0.18	0.20	81	90

Tables 1-3 from: Snyder, Richard and J. Paulo de Melo-Abreu. 2005. Frost Protection: fundamentals, practice and economics. Food and Agriculture Organization of the United Nations Rome; Snyder, Richard L. 2001. Principles of Frost Protection FP005 Quick Answer. University of California, Davis.; Snyder, R. L., 2000. Sprinkler Application Rates for Freeze Protection FP004 Quick Answer. Department of Land, Air and Water Resources, University of California, Davis.

Assessment: Frost Control Water Conservation

- ❑ On the aerial photos/maps:
  - ❑ Indicate those vineyard areas with frost control.
  - ❑ Indicate vineyards as early, mid or late budding varieties.
  - ❑ Indicate the locations of main water lines used in frost control operation, secondary and lateral water lines, water source, pumps, and any valves in the pipe system.
  - ❑ Indicate any areas where water pressure can be a problem during frost events.
  - ❑ Determine whether the site is in a severe, moderate or mild frost zone.
- ❑ On the Farm Plan Template, describe the features of the frost control system, including:
  - ❑ Identify sources of weather data used for frost forecasts.
  - ❑ Describe the number of locations in the vineyards regularly monitored and the frequency of monitoring during frost events.
- ❑ Do you monitor:
  - ❑ Air temperature
  - ❑ Humidity
  - ❑ Dew point
  - ❑ Wet bulb temperature
- ❑ Indicate the type of sprinklers in each vineyard area.
- ❑ Indicate the water use per hour per acre for frost.
- ❑ Indicate the diversion rate of the pump if direct diversion from streams and river methods are used. Also indicate if the pump has variable speeds.
- ❑ Indicate diversion rate and refill timing if a reservoir is used for frost water supply.
- ❑ Indicate is a sump system is in place to re-capture applied water
- ❑ Fill out tables and review potential for changes.

Water Conservation: Frost Control

Frost control operations require a large amount of water over a short period of time. If direct diversions are used, water levels can drop quickly in creeks and rivers, causing small salmonids to be stranded and die. This part of the template allows a grower to calculate the water use for each vineyard with no BMPs applied and then select BMPs that will work for the site and calculate both the cost and the potential water savings. If these BMPs are already being applied then this section can validate the water savings occurring and determine if additional BMPs are feasible. In addition, the template identifies vineyards with direct diversions as water sources which pose a potentially high impact to fish in order to prioritize sites for off-stream pond construction.

- ❑ Check your frost control system for leaks on a regular basis and fix them to reduce losses of water.
- ❑ Using the farmplan template and spreadsheets, determine your frost water demand with no BMPs.
- ❑ Document the BMPs currently used or evaluate all that could be applied.
- ❑ Calculate the potential water savings and costs for implementation of BMPs
- ❑ The conservation goal is 15% of the total water demand without BMPs. Determine the best mix of BMPs for the site and determine the total water savings.
- ❑ Determine if the site uses more than 1 cfs in instantaneous diversion from a creek.