City of Santa Cruz Water Department – 212 Locust St. Santa Cruz, CA 95060 – (831) 420-5483

August 30, 2010

Re: NOTICE OF PUBLIC SOLICITATION OF WATER QUALITY
DATA AND INFORMATION FOR 2012 CALIFORNIA INTEGRATED REPORT - SURFACE WATER QUALITY ASSESSMENT AND LIST OF IMPAIRED WATERS [Clean Water Act Sections 303(d) and 305(b)] and Majors Creek (Santa Cruz County)

Jeffrey Sh'u
State Water Resources Control Board
Division of Water Quality
P.o. Box 100
Sacramento, CA 95812-0100

Dear Mr. Sh’u,

Please accept this proposal to list Majors Creek under Section 303(d) of the Clean Water Act as a Sediment and Turbidity impaired waterbody. This waterbody is characterized by extreme sediment transport dynamics and persistent turbidity which impair a number of beneficial uses including COLD, MUN, REC1, REC2, WILD, MIGR, SPWN, RARE, EST, FRESH, etc. Specifically, the City of Santa Cruz relies on this waterbody for a substantial proportion of its domestic drinking water supply and this impairment reduces water production capacity and damages infrastructure in our already overtaxed system. In addition, this impairment degrades steelhead and California red-legged frog habitat found in this stream.

This waterbody was placed on a TMDL monitoring list, after originally being proposed for listing in 2002 (SWRCB 2003). At that time, the City of Santa Cruz submitted decades of turbidity data which showed that the overall turbidity trend in the waterbody was increasing. Additional submittals from the City and other stakeholders included historical data from fisheries habitat surveys which showed high embeddedness and pool filling in most stream reaches. Since this time, the impairment has continued to degrade beneficial uses (Balance Hydrologics 2007) - including making water operations for the City of Santa Cruz increasingly challenging by inundating the diversion intakes and impoundment, filling the pipeline and downstream infrastructure with sand, and incurring increased treatment costs due to the high levels of turbidity which must be treated.

As such, the City hired Balance Hydrologics to conduct persistent turbidity/sediment transport and geomorphological studies to better characterize these issues of concern. In addition, fisheries habitat and population surveys have been conducted by Hagar Environmental Science and City of Santa Cruz staff. All of these studies document impairment of beneficial uses in this waterbody. While not always directly related to sediment transport, the turbidity dynamics of this creek do have a close correlation with sediment transport dynamics (Balance Hydrologics 2010b). Therefore, it is useful to look at turbidity dynamics, as they not only directly influence use of the waterbody for domestic drinking water purposes, but they also affect beneficial uses related to aquatic biota.

For example, 15-minute turbidity data collected during 12/19/09 – 5/13/10 (Balance Hydrologics 2010a) showed that turbidity values > 25 ntu were present 10 percent of the time - leading to reduced drift feeding and potential respiratory impairment, etc. (Trush 2005, Ligon et al 1999, etc.). By comparison, San Lorenzo River mainstem (an urbanized and designated impaired waterbody) turbidity values were >25 ntu 13 percent of the time during the same period (Berry et al. 2010). With a reduction in drift feeding opportunities due to excessive turbidity, feeding on benthic invertebrates is increasingly important (Harvey and White 2008). However, Majors Creek substrate tends to be predominantly sand dominated (Hagar 2009, Harvey and Stanley 1982, Alley 1993, Balance Hydrologics 2010a, Bean, et al. 2007, Finstad, et al. 2010), thereby limiting habitat for this benthic food source. Most pools have some degree of filling, with sand being the dominant substrate in the majority of pools (Alley 1993, Finstad, et al. 2010, Balance Hydrologics 2010b). Additionally, riffles appear to be primarily dominated by smaller grain sizes (Alley 1993, Balance Hydrologics 2010b) and demonstrate – at least in water year 2010 - a slight “fining” throughout the winter (Balance Hydrologics 2010b); something that is potentially extremely detrimental to salmonid redds, as riffles scoured by early season storms suffer from embeddedness and “sealing” or conversely, mobilization, subsequent to mid-winter spawning (Lisle 1989). Despite its much larger drainage area, the estimated unit suspended sediment load for the San Lorenzo River at Big Trees station compares very closely to that estimated for Upper Majors Creek (Balance Hydrologics 2010a).. However, it should be noted that the mainstem of San Lorenzo River is currently designated as impaired, while Majors Creek is not.

Given the character of the bedload sediment in transport, it is perhaps unlikely to originate from that which is stored in the bed, and more likely from bank or hillslope contributions (e.g., landslides, bank failures) and tributaries upstream (Balance Hydrologics 2010a). Due to access constraints, watershed reconnaissance has been limited, but obvious evidence of bank failures, mass wasting, improperly abandoned road crossings, and the legacy impacts of the historic clear-cut logging abound (Berry 2001). Additionally, County planning code violations on private property (Balance Hydrologics 2007) and the recently increased vineyard and equestrian facility development since the time of the City’s original listing proposal (Berry 2001) may have contributed to this impairment as well (Balance Hydrologics 2007).

We are eager to learn what the SWRCB has found during the intervening years since Majors Creek was first placed on the 303(d) monitor list in 2002. In the meantime, we present the following information for your further consideration of designation of this waterbody as sediment impaired:

1) Site photos
2) Balance Hydrologics Supporting Documents

Thank you for the opportunity to comment on this process. Please do not hesitate to contact us if you need any clarification about the issues we have raised.

Sincerely,

Digitally signed by Chris Berry
DN: cn=Chris Berry, o=City of Santa Cruz, ou=Water,
email=cberry@ci.santa-cruz.ca.us, c=US
Date: 2010.08.30 08:57:42 -07'00'

Chris Berry –
Water Resources Manager

cc: Chris Coburn (County of SC), John Ricker (County of SC), Suzanne Deleon (DFG), Terry Tomkins (City of SC), Lena Chang (USFWS), Jon Ambrose (NOAA), Mary Adams (RWQCB)

References:

Alley, D. W. 1993. North Coast Diversion and Storage Project – Reconnaissance Level Study of Fishery Resources. Prepared for Camp Dresser and McKee, Inc., Walnut Creek, CA.

Balance Hydrologics 2007. Watershed Sanitary Survey for the San Lorenzo Valley and North Coast Watersheds, March 2007 – An Update to the San Lorenzo Valley and North Coast Watersheds Sanitary Survey, July 1996. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Balance Hydrologics. 2010a. Sediment Monitoring, Majors Creek above Majors Creek Dam, Water Years 2008, 2009 & 2010 (partial), Santa Cruz County, California. Prepared by Hastings, B., Owens, J., Chartrand, S. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Balance Hydrologics. 2010b. Bed Conditions Monitoring at Majors and Laguna Dams, City of Santa Cruz, Santa Cruz County, California. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Bean, R., Bean, E., Berry, C., Finstad, K., Hagar, J., Henkel, L. 2007. North Coast Anadromous Fish Sampling Data Summary For Years 2006 & 2007. Unpublished data. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Berry, C. 2001. Clean Water Act 303(d) Listing Proposal for Majors Creek. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Berry, C., Harris, K., Bean, E. 2010. San Lorenzo River Continuous Turbidity Monitoring – Water Year 2010. Unpublished data. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

California State Water Resources Control Board. 2003. Section 303(d) Monitoring List 2002. (http://www.swrcb.ca.gov/water_issues/programs/tmdl/docs/2002_mon_list_020403.pdf). Prepared for the State of California Environmental Protection Agency. Sacramento, CA.

Finstad, K., Bean, E., Berry, C., Harris, K., Hagar, J., Holloway, R.. North Coast Anadromous Fish Sampling Data Summary For Years 2008 & 2009. Unpublished data. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Harvey, B. White, J. 2008. Use of Benthic Prey by Salmonids under Turbid Conditions in a Laboratory Stream. Transactions of the American Fisheries Society 137:1756–1763, 2008. Washington, D.C.

Hagar, J., 2009. City of Santa Cruz Habitat Conservation Plan DRAFT Existing Conditions for Steelhead and Coho Salmon. Prepared for the City of Santa Cruz Water Department. Santa Cruz, CA.

Harvey and Stanley Associates, Inc. and John Gilchrist and Associates. 1982. Fish Habitat Assessments for Santa Cruz County Streams. Prepared for Santa Cruz County Planning Department. Santa Cruz, CA.

Ligon, F., Rich, A., Rynearson, G., Thornburgh, D., Trush, W. 1999. Report of the Scientific Review Panel on California Forest Practice Rules and Salmonid Habitat. Prepared for the Resources Agency of California and the National Marine Fisheries Service. Sacramento, California

Lisle, T.1989. Sediment Transport and Resulting Deposition in Spawning Gravels, North Coastal California. Water Resources Research, Vol. 25, No. 6, Pages 1303-1319, June 1989. Arcata, CA.

Trush, W. 2005. Chronic Turbidity and Streamflow Diversion Effects on Salmon Habitat Loss. Presented at the Healthy Rivers, Happy Fish Conference. Prepared for the San Lorenzo Valley Water District and the County of Santa Cruz Fish and Game Commission, et al. Santa Cruz, CA.

Attachment 1: Photos

Photos are included for informational purposes only and not intended for photo-monitoring/listing purposes. All photos taken by Chris Berry - City of Santa Cruz Water Department.


Upstream of the Majors Diversion
Note Sand filled pool - post 1/4-5/08 storm


Majors Upstream of the Diversion
Note: sand saltating along bed


Upstream of Majors Diversion
1/18/08
Note: Bed aggraded from bank to bank with new sand


Upstream of the Majors Diversion
Note: Wasting of banks and sandy bed


Road Crossing Failure Upstream of Smith Grade

Road Cutbank Failure Upstream of Smith Grade,
Adjacent to Creek

Attachment 2: Balance Hydrologics Supporting Documents

Balance
Hydrologics, Inc.

800 Bancroft Way, Suite 101 • Berkeley, CA 94710-2227
(510) 704-1000 • *(fax) 704-1001* • email: office@balancehydro.com

Mr. Chris Berry,
City of Santa Cruz Water Department
Water Resources Manager
715 Graham Hill Road
Santa Cruz, CA 95060

RE: Cover Letter for Majors Creek SWRCB Submittal – 303d Consideration for Sediment

Dear Mr. Berry,

We have assembled the required and relevant information and data to assist in your efforts to make a formal surface water quality submittal to the State Water Resources Control Board (SWRQB) pursuant to Clean Water Act Sections 305[b] and 303[d]. Material assembled includes:

- This cover letter and supporting three (3) figures[1]
- Complete 2012 Integrated Report Data Submittal Information Form
- SWAMP comparable sediment data (separate MS Excel file) – measurements of suspended sediment transport; V*, and quantification of suspended sediment loads for water year 2010 (partial)
- Draft QAPP + Appendices

We understand that your formal submittal is in response to the original January 14, 2010 SWRQB advertisement for the 2012 California Integrated Report Solicitation whose submittal deadline date was pushed back to August 30, 2010.

Results of monitoring efforts completed by Balance Hydrologics staff during water years 2008 – 2010 suggest that listing of Majors Creek for 303d listing as fine sediment impaired may be warranted. Specifically, our measurements of fine sediment transport (Figure 1) and subsequent quantification of fine sediment load illustrates that Majors Creek transports a regionally significant volume of fine sediment (Figures 2 and 3) – a load during water year 2009 which was similar to three local systems

[1] Figures 1 through 3 are from Hastings, B.K., Owens, J., Chartrand, S.M., Sediment Monitoring Upstream of Majors Dam, Water Years 2008, 2009 and 2010 (partial), Santa Cruz County, California. Consulting report prepared by Balance Hydrologics for the City of Santa Cruz Water Department. 39 pp.

which are listed as 303d sediment impaired (Zayante and Bean Creeks and the San Lorenzo River). Additionally, the various sediment measurements which have been conducted suggest that the present fine sediment load of Majors Creek may pose difficulties for aquatic organisms, especially those within the anadromous reach of the creek per the SWRQB List of Indicators for sediment grain size and residual pool volume.

Pursuant to Section 3.11 of the SWRQB Resolution No. 2004-0063 (Adoption of the Water Quality Control Policy for Developing California's Clean Water Act Section 303[d] List), the data and information provided with this submittal do provide a snapshot of current fine sediment conditions in Majors Creek and were collected using scientifically defensible methods and approaches. Additionally, since water year 2008 we have collected 27 samples of instantaneous suspended sediment discharge. As such it may be possible for the SWRQB to complete a binomial distribution test of the sampling results, provided pertinent water quality criteria data exist to complete the analysis.

Closing

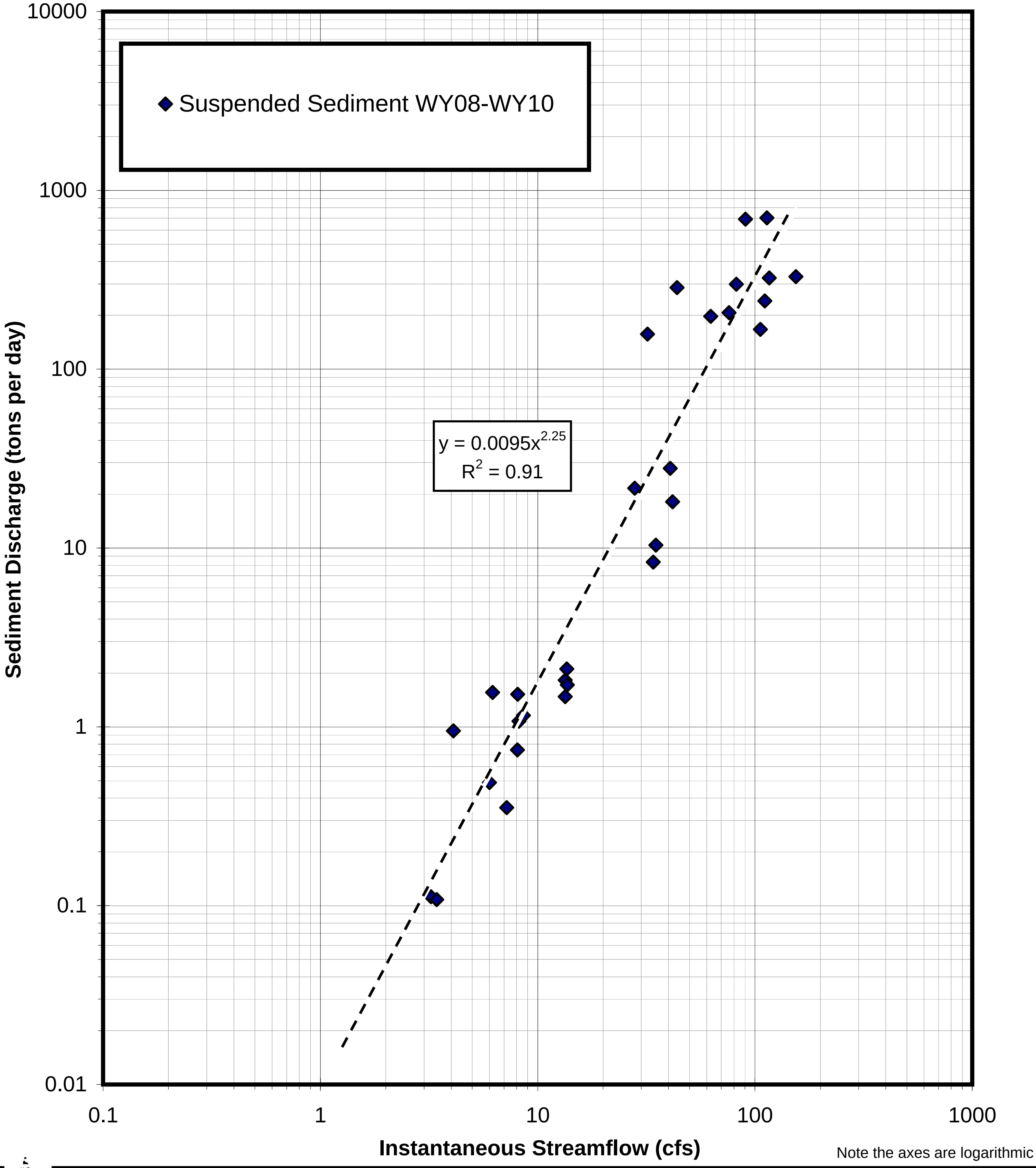
Please do not hesitate to contact me if you have any questions or require further data to support your submittal.

Sincerely,

BALANCE HYDROLOGICS, Inc.

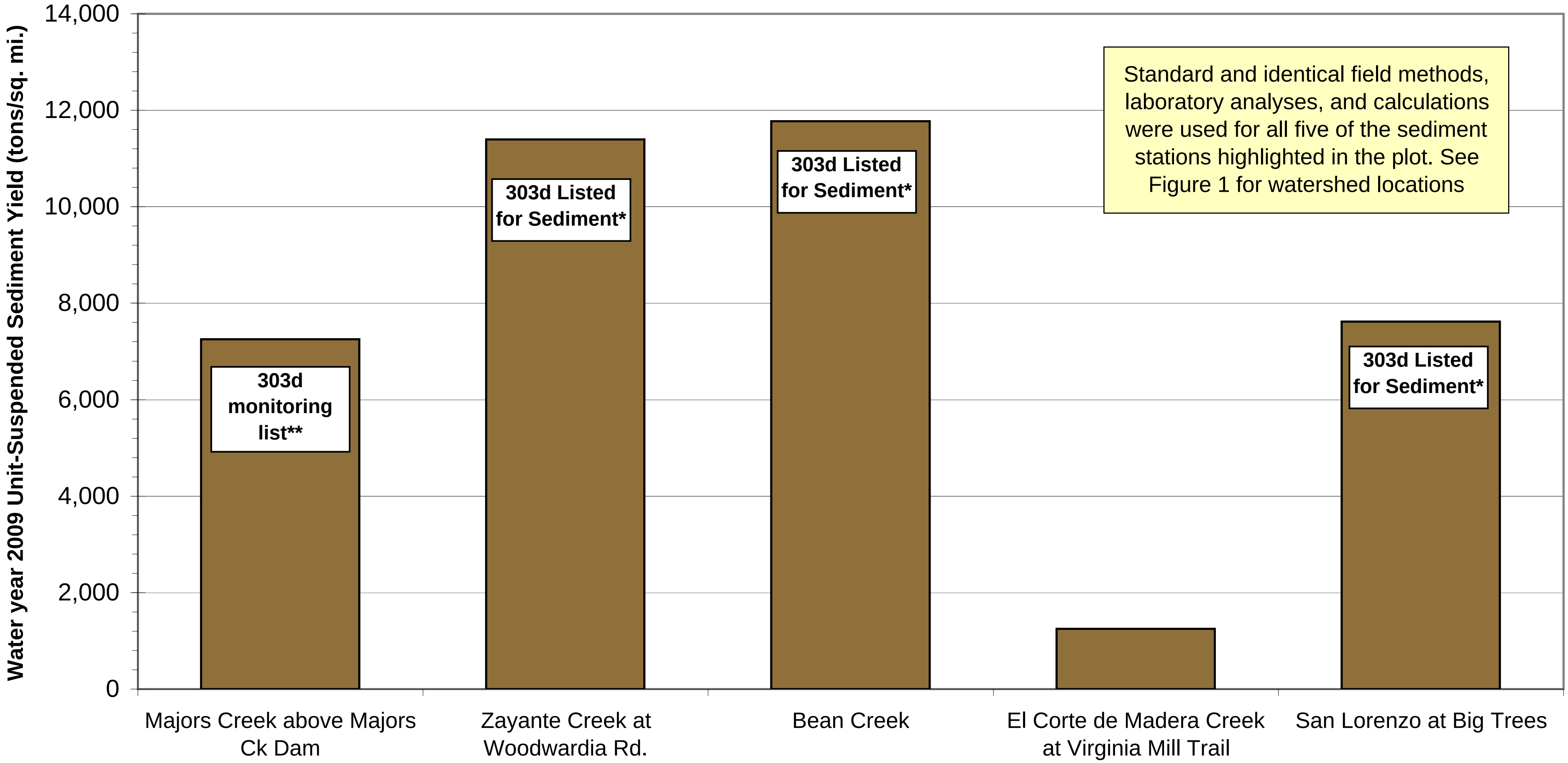
Shawn Chartrand, Principal Geomorphologist
PG 7817, CEG 2442

Encl.: Figures 1, 2 and 3
2012 Integrated Report Data Submittal Information Form
MS Excel file of SWAMP comparable sediment data for Majors Creek
QAPP + Appendices



Balance Hydrologics, Inc.

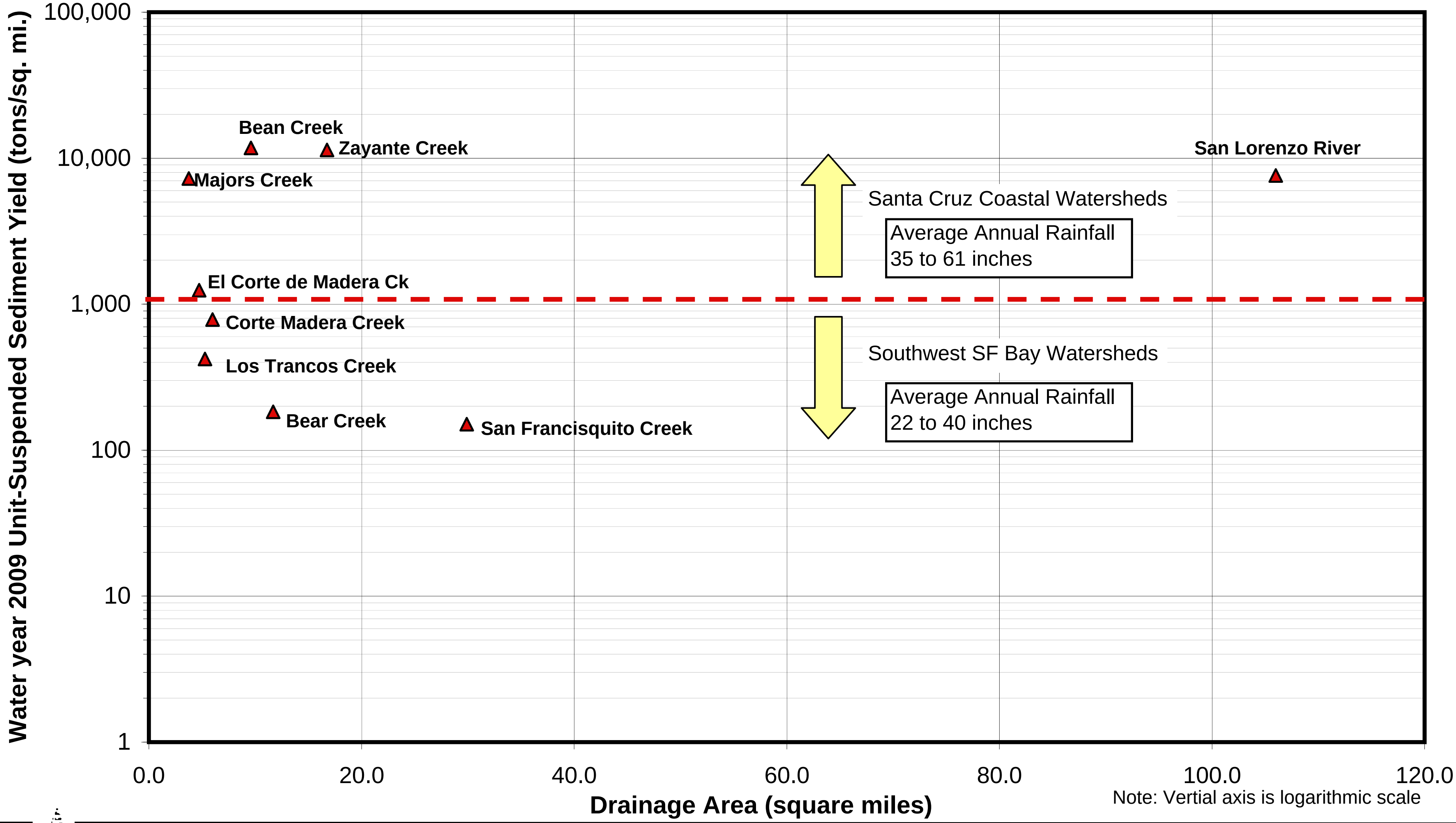
Figure 1. Suspended Sediment Rating, Majors Creek upstream of Majors Dam, Santa Cruz County, CA. Based on data collected over three years (WY2008-WY2010)



*RWQCB-Central Coast Region, 2006 CWA Section 303(d) List of Water Quality Limited Segments requiring TMDLs for sediment
**RWQCB-Central Coast Region, 2002 CWA Section 303(d) Monitoring List of Water Quality Limited Segments

Balance Hydrologics, Inc.

Figure 2. Comparison of unit suspended-sediment loads from selected coastal watersheds in the Santa Cruz Mountains. Based on sediment gaging during WY2009, annual suspended-sediment loads from Majors Creek appears lower relative to other regional watersheds impaired (303d) for sediment, but significantly higher than those characterized as natural (e.g., El Corte de Madera). These comparison data are from watersheds where Balance Hydrologics is carrying out continuing sediment studies. Balance has identified suspended sediment loads to be greater than 80 percent of the total load in most Santa Cruz Mountain streams.



Balance Hydrologics, Inc.

Figure 3. Comparison of unit suspended-sediment loads from selected watersheds in the Santa Cruz Mountains, water year 2009. In general, a comparison of small watersheds (<20 sq. miles) illustrates two potential groupings of sediment transport defined by watersheds located on the east or west side of the Santa Cruz Mountain divide. The difference in sediment loads here is partially due to varying geology, but more significantly, mean annual precipitation. The coastal watersheds receive 25 to 50 percent more annual rainfall (Nahn and Saah, 2005).

Enclosure 3

2012 Integrated Report Data Submittal Information Form

Contact Information

First Name:	Shawn	**Last Name:**	Chartrand
Organization:	Balance Hydrologics		
Mailing Address:	224 Walnut Ave, Suite 101, Bekeley CA, 94710-2227		
Email:	schartrand@balancehydro.com	**Preferred Contact Method:**	
Phone:	(510) 704 - 1000x213	X *Email*	X *Phone*

Submittal Information

Submittal Date:	08 / 27 / 2010		
Region data intended for: (Check all that apply)	☐ *(1) North Coast*	☐ *(2) San Francisco*	X *(3) Central Coast*
	☐ *(4) Los Angeles*	☐ *(5) Central Valley*	☐ *(6) Lahontan*
	☐ *(7) Colorado River*	☐ *(8) Santa Ana*	☐ *(9) San Diego*
GIS map layers included:	☐ Yes		
Pollutant Categories: (Check all that apply)	☐ *Hydromodification*	☐ *Other Organics*	☐ *Toxicity*
	☐ *Metals/Metalloids*	☐ *Pathogens*	☐ *Trash*
	☐ *Nuisance*	☐ *Pesticides*	☐ *Miscellaneous*
	☐ *Nutrients*	☐ *Salinity*	
	☐ *Other Inorganics*	X *Sediment*	
Time Period Data Collected:	12 / 19 / 2009 – 05 / 13 / 2010		

Summary of Data (Explanation of data included in submission or instructions on using data.):

Enclosed are SWAMP comparable data for Majors Creek in Santa Cruz County, California. Data submittal is by Balance Hydrologics on the behalf of City of Santa Cruz for the purpose of obtaining 303d listing and TMDL for this water course. Data include tons/day suspended sediment as well as V-star measurements which is the ratio between residual sediment volume/residual pool volume. Published and accepted methods were used in the collection of this data and are detailed in the QAPP also submitted in this transmittal.

Submittal format:	X *Electronic*	☐ *Hard Copy/Paper*

Internal Use Only (by Water Boards)

Control #:	______	**Date Received:**	__ / __ / ____

Date provided in a separate excel document titled:
Balance MajorsCK Data SWAMP_Chemistry_Results_v2 5_042110-1.xls

Quality Assurance Project Plan

Version 1.0

for

Majors Creek Sediment Monitoring,
Santa Cruz County, CA

August 25, 2010

Prepared for

City of Santa Cruz Water Department

Agreement Number ___________
State Water Resources Control Board
___________Grant Program

Group A Elements: Project Management

1: Title and Approval Sheets

Quality Assurance Project Plan

Version 1.0

for

Majors Creek Sediment Monitoring,
Santa Cruz County, CA

Proposal Identification Number___________

Date: August 25, 2010

Approval Signatures:

Grant Organization:

Title:	Name:	Signature:	Date*:
Project Director	Terrill Tompkins	For Terrill Tompkins	8/27/10
Project Manager	Chris Berry	Digitally signed by Chris Berry DN: cn=Chris Berry, o=City of Santa Cruz, ou=Water, email=cberry@ci. santa-cruz.ca.us, c=US Date: 2010.08.30 08:57:06 -07'00'	8/27/10
Project QA Officer	Shawn Chartrand	Shawn M. Chartrand	8-27-2010

Regional Water Quality Control Board:

Title:	Name:	Signature:	Date*:
Grant Manager			
QA Officer			

* This is a contractual document. The signature dates indicate the earliest date when the project can start.

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GROUP A. PROJECT MANAGEMENT

3. Distribution List

Title:	Name (Affiliation):	Tel. No.:	QAPP No:
Contractor Project Director	Terrill Tompkins	(831) 420-5454	
Contractor Project Manager	Chris Berry	(831) 420-5483	
Contractor QA Officer	Balance Hydrologics – Shawn Chartrad	(510) 704-1000 x213	
RWQCB Region 3 Contract Manager	Howard Kolb	(805) 549-3332	
Lab Manager	Mike Galloway	(831)724-5422	

4. Project/Task Organization

Involved parties and roles

The City of Santa Cruz (City) is the local lead agency for project implementation and completion, and will be responsible for project oversight. The City of Santa Cruz has hired Balance Hydrologics (Balance) to develop the monitoring program, install monitoring stations, conduct all monitoring fieldwork and data collection activities, and prepare data reports summarizing monitoring results and findings. Balance will work collaboratively with staff from the City of Santa Cruz to carry out joint responsibilities, but Balance will be ultimately responsible for satisfying those responsibilities according to the developed monitoring program (outlined herein).

Quality Assurance Officer role

Balance, will act as the City of Santa Cruz project Quality Assurance Officer. Our collective role is to establish the quality assurance and quality control procedures found in this QAPP, as part of the sampling, field analysis, and in-house analysis procedures. Balance will work with Soil Control Laboratories manager Mike Galloway to strictly adhere to all quality assurance and quality control issues contained in this QAPP. Formal initiation of communications with Mr. Galloway will be addressed by providing him a copy of this QAPP, once it has been accepted.

Balance will also review and assess all procedures during the life of the contract against QAPP requirements. Balance will report all findings to the City, including all requests for corrective action. They may stop all actions, including those conducted by Soil Control Laboratories, if there are significant deviations from required practices, or if there is evidence of a systematic failure.

Persons responsible for QAPP update and maintenance

Changes and updates to this QAPP may only be made after a formal review has been completed. Formal review will consist of providing evidence to support the requested change directly and in writing to the City by the Balance (Quality Assurance team). The County will then seek concurrence of both the Regional Water Quality Control Board's (RWQCB) Contract Manager, and Quality Assurance Program Manager (see Figure 1). Balance will ultimately re responsible for implementing any changes, submitting update drafts for review, preparing a final update copy, and submitting the final update QAPP for signature.

4.1 Involved parties and roles.

Figure 1 provides the organizational structure for the present project. All responsible main contacts are identified by organization, title and responsibility.

Figure 1 - Organizational Chart

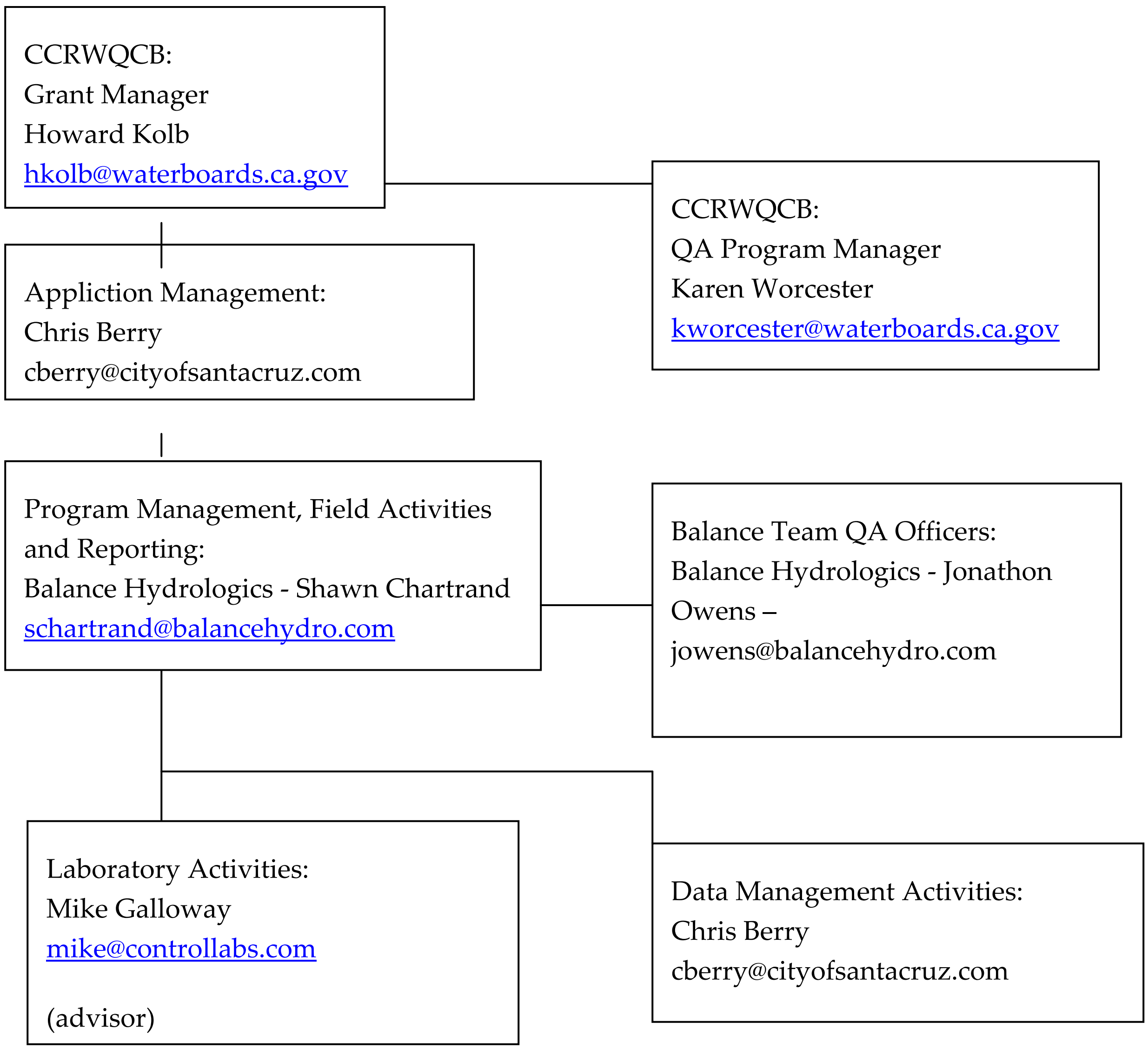


Table 1. (Element 4) Personnel responsibilities

Name	Organizational Affiliation	Title	Contact Information (Telephone number, fax number, email address.)
Shawn Chartrand	Balance Hydrologics	Program Manager	schartrand@balancehydro.com
Jonathan Owens	Balance Hydrologics	Field Coordinator & QA	jowens@balancehydro.com
Sarah Richmond	Balance Hydrologics	Field Coordinator & QA	srichmond@balancehydro.com
Mike Galloway	Soil Control Laboratories	Laboratory Activities advisor	mike@controllabs.com

4.2 Quality Assurance Officer role

The QA Officer role for the Project will be carried out by Jonathon Owens of Balance Hydrologics with assistance from Shawn Chartrand of Balance Hydrologics. Their joint role is to establish and monitor the quality assurance and quality control (QA/QC) procedures outlined in this QAPP. They will work with the Soil Control Laboratories QA officer, communicating all QA/QC information contained in this QAPP. They will also review and assess all procedures and findings during the life of the monitoring for compliance with the requirements of the QAPP. All findings will be reported to Shawn Chartrand of Balance Hydrologics, the Program Manager, including requests for corrective action.

4.3 Persons responsible for QAPP update and maintenance

Until the work described is completed, the QAPP shall be revised as necessary. Revisions to the QAPP may be recommended after the evidence for alteration has been reviewed by Shawn Chartrand (Program Manager) of Balance Hydrologics. Revisions will be presented to Howard Kolb, RWQCB Grant Manager, for his approval prior to finalization. Shawn Chartrand along with Jonathon Owens and Sarah Richmond will be responsible for making the formal revisions to the document once approval has been received, submitting draft updates for review, preparing the final update document and submitting it for signature. Expedited revisions to the QAPP may be necessary to:

- reflect changes in project organization, tasks, schedules, objectives or methods;
- address deficiencies or nonconformities; and
- accommodate unusual circumstances

Requests for expedited revisions shall be directed in writing to the RWQCB, and the revision shall be effective immediately upon approval notification by Howard Kolb, or his representative.

5. Problem Definition/ Background

5.1 Problem statement

Balance Hydrologics, Inc. was asked by the City of Santa Cruz Water Department (City) to monitor bed sedimentation conditions on Majors Creek in the vicinity of their surface water diversion (Figure 1). The bed sediment monitoring program was initiated because City of Santa Cruz staff must routinely clear the diversion screen of fine sediment and as such speculate that the fine sediment load in Majors Creek is high relative to other regional streams. If the fine sediment load is high it may warrant listing as 303d impaired in order to identify a regulatory driven process to lessen the fine sediment load. The basic technical approach used to explore the fine sediment load of Majors Creek with respect to other regional streams was to collect data using multiple lines of reasoning and then compare results with available results from other streams and rivers. Specific data we have collected during water year 2010 includes:

1. Pool Sedimentation: Pool sedimentation conditions in Majors Creek was quantified using the Vstar (V*) method, detailed in Hilton and Lisle (1993).

2. Sediment Transport: Event based suspended sediment-discharge suspended sediment volumes were quantified. (Edwards and Glysson, 1999)

Goals and Objectives

The present project has outlined several project goals, specifically tailored to address identified needs for monitoring water quality and effectiveness of non-point pollution control efforts. These goals include:

- Development of a cost-effective program that generates reliable load estimates on Majors Creek
- Provide methods to measure effectiveness of projects and TMDL implementation programs;
- Development of a program that can be implemented on an ongoing basis.

5.2 Decisions or outcomes

This project has several goals to meet the objectives of the grant funded efforts as well as long term needs for monitoring water quality and effectiveness of non-point pollution control efforts:

- To develop a cost-effective program that generates reliable load estimates and pool and pool sedimentation conditions in Majors Creek

- The evaluate bed conditions and any possible trends

- Provide methods to measure effectiveness of projects and TMDL implementation programs

- To develop a program that can be implemented on an ongoing basis

5.3 Water quality or regulatory criteria

Data generated by this project will not be compared against any specific water quality or regulatory criteria, but rather will be used to evaluate management effectiveness.

6. Project/Task Description

6.1 Work statement and produced products

Sampling under the current effort will began prior to the adoption of this QAPP (in water year 2010) however the research, methods and chain of responsibility outlined in this document were already in place prior to the beginning of the project. Monitoring will continue through water year 2011 with possible ongoing implementation if adequate funding is secured.

6.2 Constituents to be monitored and measurement techniques

As mentioned above, the primary thrust of the present project will include monitoring of suspended-sediment transport conditions at Majors Creek in Santa Cruz County. V-star measurements will be made after significant flow as determined by Balance Hydrologics.

Turbidity is a widely accepted surrogate for suspended-sediment concentration, and is increasingly used to compute suspended sediment loads during storm events.

The reach above dam operation at Majors Creek has had a continuous 15 minute record flow starting October 2, 2003 through the present time. Since the installation of the gage in 2003 it has moved from approximately 200 feet upstream of the dam to approximately 500 feet upstream of the dam due to changing channel conditions. The station is maintained on a monthly basis by Santa Cruz City staff who have been trained by Balance Hydrologics. Maintenance of the gage will continue to occur on a monthly basis by Santa Cruz City staff with storm sampling for suspended sediment to be carried out by Balance Hydrologics.

6.3 Project schedule

Table 2. (Element 6) Project schedule timeline

Activity	Date		Deliverable	Deliverable Due Date
	Anticipated Date of Initiation	Anticipated Date of Completion		
Baseline monitoring - surface flow	October, 2008	N / A	N / A	
Suspended-sediment Monitoring	Dependent on weather	Dependent on weather	N / A	

6.4 Geographical setting

The Majors Creek watershed drains an area of 4.7 square miles of the Santa Cruz Mountains, ranging in elevation from sea level to 1,835 feet in its headwaters. Mean annual precipitation in Majors Creek is largely dependent upon elevation and ranges from 26 (coast) to 42 inches (headwaters) (Rantz, 1971). Canopy vegetation is predominately red wood, fir and mixed deciduous. Present land uses are mostly rural residential, range land and public lands.

Upstream of Majors Creek Dam, the watershed is underlain by southwest-dipping mid- to late-Tertiary sedimentary rocks, primarily Lompico Sandstone, with scant amounts of granitic and metamorphic rocks occurring in the northernmost portion of the watershed.

The in-stream diversion structure on Majors Creeks is a cement dam with a broad crested over flow weir. The drainage area upstream of Majors Creek Dam is approximately3.76 square miles. The point of surface-water diversion on both streams occurs immediately upstream from each dam, on the southeast banks of the creek. Diverted surface flow is conveyed to the City's north coast water supply main under the force of gravity.

6.5 Constraints

Constraints on the design of this project include the limited amount of time over which sampling can, and will occur for each storm event sampled. For each storm, there will be one team mobilizing and conducting measurements and obtaining samples. This will ultimately limit the amount of data that will be collected and utilized in developing sediment load estimates.

7. Quality Objectives and Criteria for Measurement Data

Measurement quality objectives (MQO) for the Project will consist of the following:

Measurement or Analyses Type	Applicable Measurement Quality Objectives
Suspended sediment concentration (SSC)	Accuracy, Precision, Completeness
Turbidity	Accuracy, Precision, Recovery, Completeness

Suspended sediment samples collected in the field will be delivered to the Soil Control Laboratories for analysis. Campbel Scientific OBS3+ probe will have the factory calibration checked in the field using purchased turbidity standards prior to the study as well as at the end of the study. All MQOs address laboratory measurements.

The accuracy of an analysis is a measure of how much of the constituent actually present is measured during analysis. Accuracy will be determined by measuring one or more samples selected from performance samples or standard solutions from sources other than those used for calibration.

Analytical accuracy will be evaluated by daily scale and meter calibration results.

Precision of the data is a measure of the reproducibility of the measurement when an analysis is repeated. Precision will be determined on field replicates and laboratory duplicates as outlined in Table 3 below.

Table 3. (Element 7) Measurement quality objectives for laboratory measurements and In-situ field instruments

Group	Accuracy	Precision	Recovery	Target Reporting Limits	Completeness
Suspended sediment concentration (SSC)	Standard Reference Materials (SRM, CRM, PT) within 95% CI stated by provider of material. If not available then with 50% to 150% of true value	Field replicate, laboratory duplicate & MS/MSD with recommended RPD <25%	Matrix spike 80% - 120% or control limits at +/- 3 std devs based on actual lab data	0.5 mg/L	90%
Turbidity	Standard Reference Materials (SRM, CRM, PT) within 95% CI stated by provider of material.	Field replicate, laboratory duplicate & MS/MSD with recommended RPD <15%	Factory calibration and in-field calibration check with purchased turbidity standards	0.25 NTU or 1% for factory calibration or 5 to 15% of reading using field calibration check	90%

Explanation of Abbreviations in Table 3

SRM	standard reporting method
CRM	conventional reporting method
CI	confidence interval
MS	matrix spike
MSD	matrix spike duplicate
RPD	relative percent difference

Recovery measurements will be determined by laboratory spiking of a replicate sample with a known concentration of the analyte. The target level of addition is at least twice the original sample concentration.

The completeness of data is a relationship of how much of the data are available for use, compared to the total potential data, before any conclusion is reached. Completeness is represented by the number of analyses generating useable data for each analysis divided by the number of samples collected for that analysis. This objective is a measure of how well data capture and analysis is being carried out.

Data collected from previous studies, including the baseline data collected for this Project, will be assessed against the same measurement quality objectives listed above.

Data quality will be reviewed to verify that reported results represent the general stream conditions at the time of sampling (i.e. if streamflow was visually clear it would be unlikely that sampling at that time would generate a high concentration of suspended solids), and that the data may therefore be used with appropriate levels of confidence. The following parameters will be reviewed:

- reporting limits
- holding times
- contamination checks (method blanks)
- precision analysis results (laboratory duplicates)
- accuracy analysis results (laboratory control samples)

Each of the above parameters will be compared to the MQOs presented in Table 3. This comparison will include:

- compilation of a complete set of the QA/QC results for the parameter,
- comparison of the lab QA/QC results to the project MQOs, and
- compilation of any out-of-range values, reporting them to the lab for verification.
- Bias or Misrepresentation

Data in this study can have bias toward the lower end of flow and turbidity spectrum due to storm events occurring at times when the site is not accessible (night time) or is happening at times when it is logistically infeasible to obtain data due to the limited number of people available to sample on the given storm event. This bias will be addressed in the report to the best of our ability.

8. Special Training Requirements

8.1 Specialized training or certifications

The QA Officer is responsible for overseeing overall training. The Program Manager will be responsible for specialized training and overseeing of professional personnel to properly conduct the above field data collection. Monitoring staff is already familiar and experienced with the procedures, materials, equipment, and record keeping that are a part of this QAPP and water quality monitoring project.

Balance Hydrologics staff will follow the company's ordinary procedures for field measurements, sample collection, and data analysis, and where applicable, follows sampling guidelines set forth by the Federal Interagency Sedimentation Program (FISP). No special training is necessary because Balance staff already use these methods. Should any new staff be added, training will be carried out in our normal manner.

Work is directed by Shawn Chartrand (Program Manager) and Jonathon Owens (QA Officer). Mr. Chartrand has worked with these methods for more than 14 years, as part of both academic research teams and in closely-scrutinized consulting settings. Mr Owens has participated in the development of the manual titled "Using a datalogger and pressure-transducer system to create a streamflow record" for the Golden Gate National Recreation Area of the National Park Service. He has more than 15 years of experience with these methods.

Balance Hydrologics, Inc. has continuously applied similar sampling methods since the founding of the firm in 1988. All work will be performed under current State of California registration in geology or engineering geology, meeting the state's requirements vested within its Business and Professional Practices Code.

Balance has been using these procedures successfully at many other sites for a number of years, and we believe that these procedures allow us to produce high-quality measurements of sediment transport.

8.2 Training and certification documentation

If additional staff or students are trained during data collection for this project, training will be documented by Balance Hydrologics in the log of activities book commonly referred to as the observer log. The observer log is a standard part of the data reporting procedure when reports are submitted.

8.3 Training personnel

Balance Hydrologics staff have been provided with instruction in proper use of sediment sampling equipment so that an accurate picture of suspended sediment transport is reflected in the laboratory results. Routine and annual refresher training of Balance field staff has followed FISP instructions for use of the DH-48 Depth-Integrating Suspended-Sediment Sampler. Instruction has been hands-on.

Balance staff are also well trained in field based hydrologic measurements that include dealing safely with high flow observations. Protocol for measurements are in accordance with USGS protocol for direct and indirect measurement of stream flow.

Laboratory QA officers are responsible for providing adequate training for laboratory personnel.

9. Documents and Records

Balance Hydrologics will create records of sample collection (field notes) and delivery. Samples sent to Soil Control Laboratories will be accompanied by a Chain of Custody form (COC). Soil Control Laboratories will generate records of sample receipt and storage, analyses, and reporting for sediment analysis.

During the study, Balance Hydrologics staff will maintain all records generated by the Soil Control Laboratories in the project file. The files will remain with Balance Hydrologics indefinitely and will be available upon request. Field notes, all field forms and chain of custody forms have electronic backup as well (scanned image, excel spreadsheets, pdf, ect.) and will also be available upon request.

GROUP B. DATA GENERATION AND ACQUISITION

10. Sampling Process Design

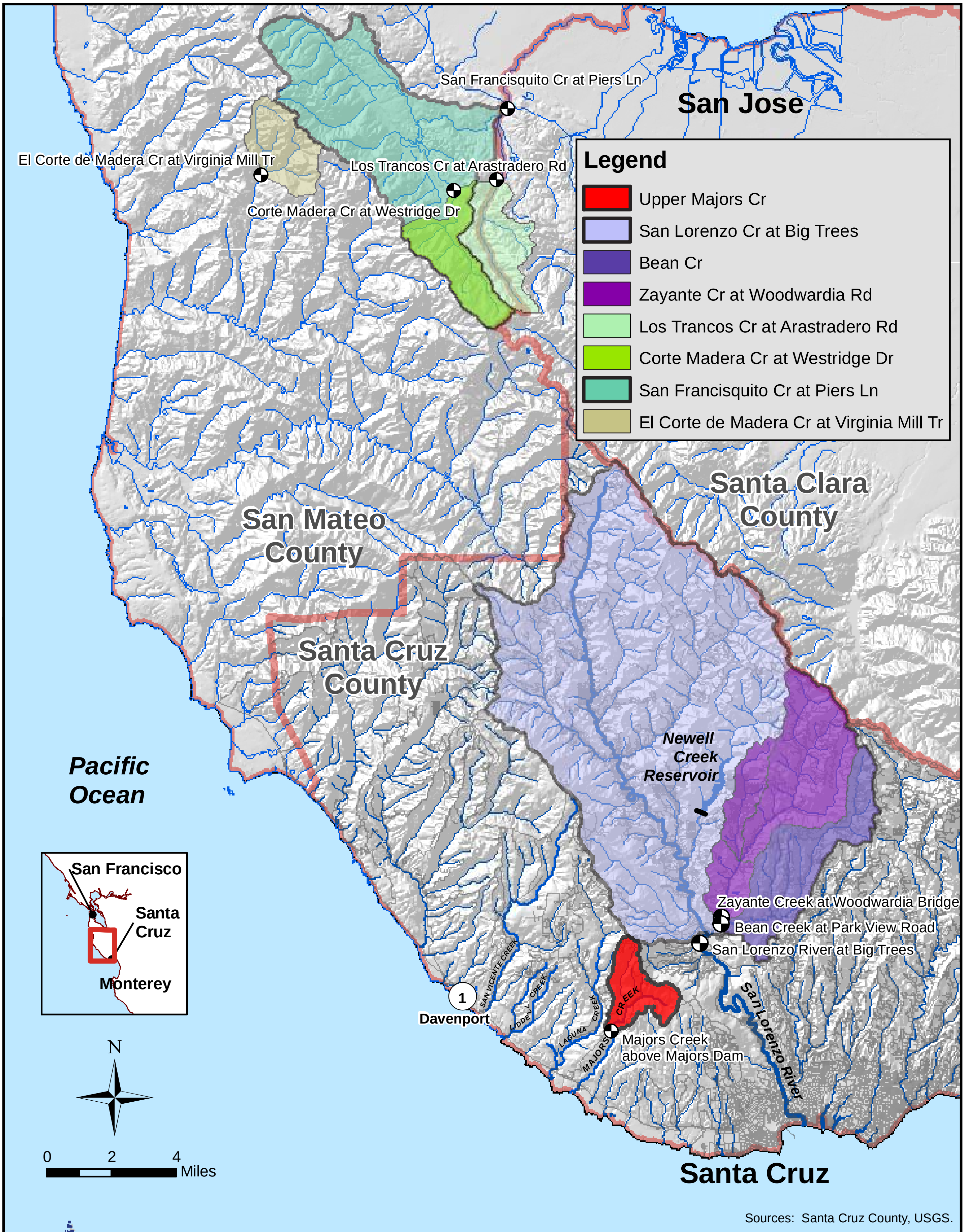
The program will consist of monthly visits to download, maintain and calibrate equipment performed by the City of Santa Cruz who have been trained by Balance Hydrologics as well as storm event measurements performed by Balance Hydrologics to obtain flow measurement and suspended sediment samples. More intensified field measurements will be preformed during storm periods to define the flow to water level (stage) relationship, as well as the turbidity to suspended sediment relationship.

Information from visits will be processed within a short time after completion of the observation, in the event that more maintenance needs to occur. Short turn around time on data processing will ensure continuity in the calibration process, and permit evaluation of data quality and observational success.

All work will be performed by or closely supervised by Balance Hydrologics staff with potential assistance from City of Santa Cruz staff.

Sampling location is shown in Figures 2 and 3. At the reach-selection and station selection level, some of the conditions that we sought included:

- Station location within reasonably uniform longitudinal reaches, without major geologic or structural changes in gross slope, and avoiding sharp bends or constrictions;
- Access that is reasonable and safe under storm conditions, and a path suited for carrying heavy storm gear during dark and wet winter conditions while wearing full storm gear;
- A reasonably safe wading section, such that wading measurements can be made at flows of up to 0.2 to 0.25 bankfull depths;
- Sites sufficiently far upstream from major confluences such that backwater effects from large tributaries or major confluences will not significantly affect sediment-transport observations;
- Locations at least two to three pool/riffle sequences downstream from a major confluence;



Balance Hydrologics, Inc.

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Figure 2. **Majors Creek and location of other compared watersheds, Santa Cruz Mountains, California**

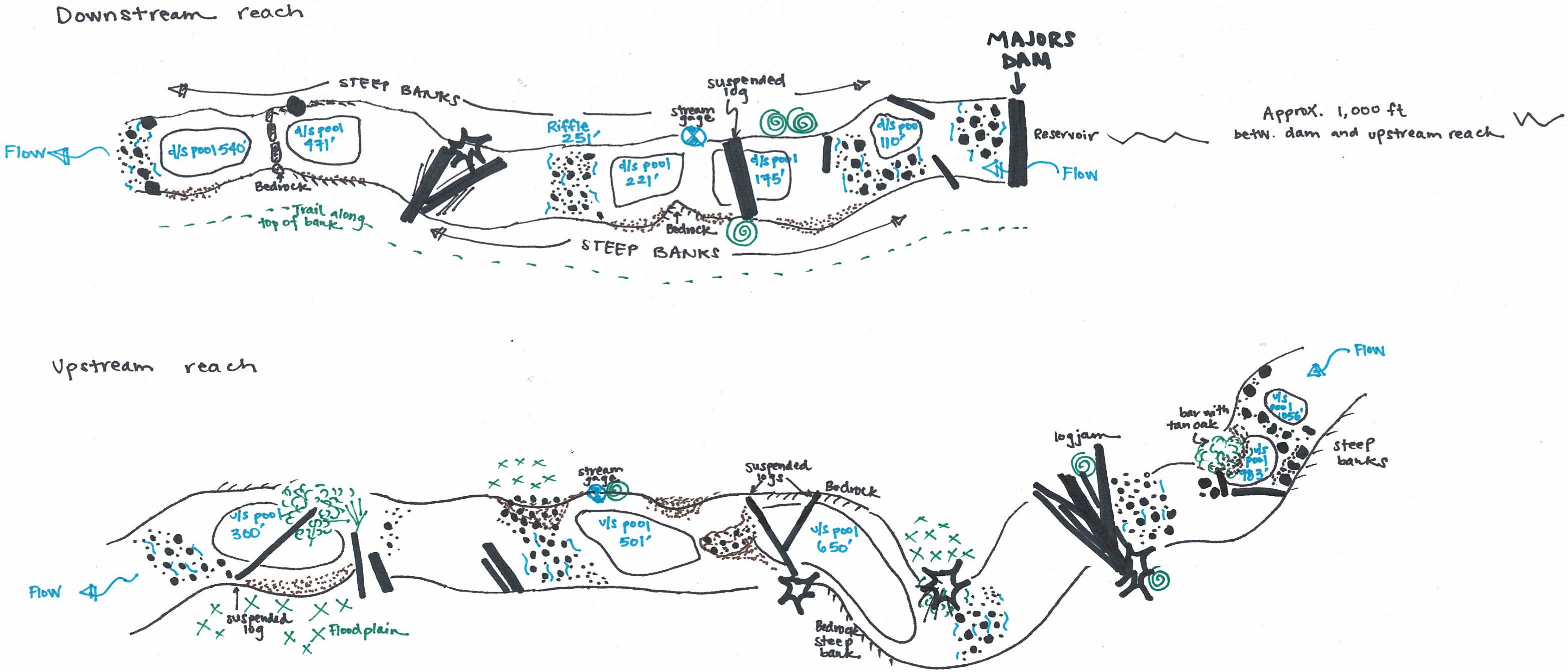

Figure 3. **Plan view sketch of Majors Creek.** This map shows key features in our monitoring reaches.

Balance Hydrologics, Inc.®

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- Locations which we believe will not be especially vulnerable to logjams forming immediately upstream of the gage, or within five to seven channel widths downstream, such that a transient backwater be avoided.

Health and Safety

Matters and consideration for protecting the health and safety of the monitoring personnel are of foremost importance. Monitoring personnel will leave the area if their health and/or safety is threatened and all such instances will be reported to the Project Manager.

In the event a sampling location becomes inaccessible, the monitoring team will advise the Project Manager, who will select an alternative and representative sampling location. The results and data derived from field analysis and sampling will be noted with an explanation of the need for the alternate site and whether/why such data is valid.

The State Surface Water Ambient Monitoring Program, Quality Assurance Project Plan contains a broad summary of health and safety practices that should be followed while conducting water sampling activities.

10.1 Vstar (V*) Sampling Design

Pool sedimentation conditions in Majors Creek are quantified using the V* method, detailed in Hilton and Lisle (1993). V* is residual sediment volume divided by residual pool volume. See notes below and Figure 4 for sketch of a V* pool, showing residual pool volume, residual sediment volume, and riffle-crest depth. Residual pool volume is defined as the portion of the pool that is deeper than the riffle crest forming the downstream lip of the pool, that is, the pool that would remain if there were negligible surface flow.

V* surveys are carried out by Balance Hydrologics very closely to the published guidelines. Description of terms used in this document can be found on Figure 4. Some subjective choices are made (as is necessary with this method) when defining the riffle crest height and the edge of the channel where the channel bank material is similar to the bed material.

Balance has selected 10 pools on Majors Creek for V* measurements, two pools upstream of a large pronounced logjam, three pools between the logjam and the dam, and five pools downstream of the dam. These sites are listed below in section 11.1 and shown in Figure 2.

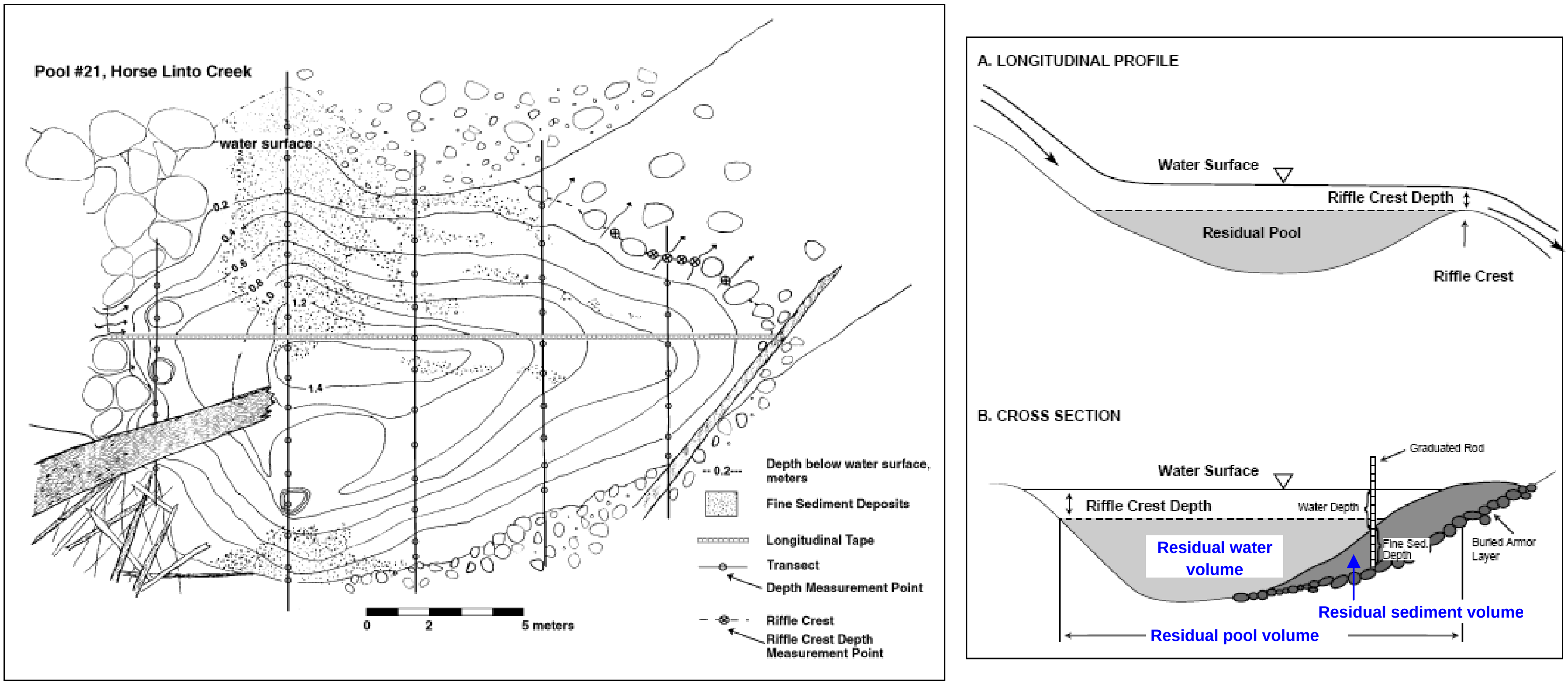

Figure 4. V* method for evaluating pool sedimentation. Plan and cross section views of a pool with metrics and measurements locations used for the V* technique. Figures adapted from Hilton and Lisle, 1993.

Large wood jams are located upstream of both dams and these jams influence flow hydraulics, sediment storage, and ecological habitat. Therefore, Balance has lengthened the upstream monitoring reaches to include these logjams since they have a significant effect on sediment transport downstream.

11. Sampling Methods

11.1 Sampling locations

As noted above, sampling locations are shown in Figures 2 and 3 of this document. They include:

- Suspended sediment at the Majors Creek stream gage
- V-star residual sediment measurements at the following pools:
    - Upstream of the dam 540 feet, 471 feet, 221 feet, 175 feet, 110 feet
    - Downstream of the dam 300 feet, 501 feet, 650 feet, 983 feet, 1056 feet

11.2 Sampling methods – suspended sediment/turbidity field protocols

The suspended sediment sampling/turbidity method for the Project will follow a) FISP protocols, and b) protocols established by Porterfield (1972). These protocols are further described herein.

Width- and depth-integrated water quality samples will be collected with a DH-48 sampler[1] and transferred to 500 ml polyethylene bottles. A total of 500 ml will be collected at each location on each sampling visit. On one sampling event during each season (see Element 11.5 below), a field replicate will be collected from each site. The sample bottles will be preserved upon returning from collection and immediately placed in a dark cooler and cooled to 4° C. Samples will be driven to the Soil Control Laboratories located at 42 Hangar Way, Watsonville, CA in a cooler with double-bagged ice or "blue ice", for processing.

Flow through the basin will be measured by using standard USGS stream gaging methods described in USGS—TWRI Book 3, Chapter A8. 1969.

Standard operating procedures (SOP) for collecting suspended sediment samples for this Project generally follow the procedures detailed in the sampling protocol published by the Federal Interagency Sedimentation Project (FISP) and provided with the DH-48 sampler (found

[1] The DH-48 sampler may be supplemented and eventually replaced for these purposes by the DH-81 sampler, under consideration for adoption by the member agencies of the Federal Interagency Sedimentation Project. When the term DH-48 is used in this QAPP, it also presumes use of the DH-81.

in Appendix A of this document). These procedures have been amended for this application as follows:

- Triple-rinse the DH-48 sampler and sampler bottle in ambient water in order to remove any sediment from previous sampling events or sediment that may have entered the nozzle if the sampler was placed on the ground. Check that the nozzle has not become partially blocked or plugged.

- Divide the cross section of the stream to be sampled into three zones of approximately equal flow (not necessarily equal width).

- Avoid disturbing the stream bed or basin floor upstream of the sample collection site.

- Obtain a width- and depth-integrated sample from the three equal-flow zones by lowering and raising the sampler at the approximate equal transit rate (ETR), such that the DH-48 sampler bottle is almost, but not totally full after a sample from all three zones is collected. If the sampler bottle becomes full, that sample will be discarded and another sample will be taken.

- Empty the *sampler* (DH-48) bottle into the *sample* bottle, making sure to swirl out the coarsest particles.

Sample bottles are to be labeled with the location, date and time as detailed in Element 12. The same sample information is also recorded in a field book along with additional information noted in Element 11.6.

11.3 Sampling frequency

Suspended sediment samples will be collected from locations during periods of runoff when sediment is in suspension in the water column. Field replicate samples will be collected at each sampling site during one sampling event each season. Samples may also be collected during periods of base flow in order to establish the lower end relationship of turbidity to suspended sediment.

11.4 Field observations

Field observations will be recorded in a Field Data Logbook or Field Folder that is taken into the field on each sampling trip. Should problems arise during any sampling event or relative to sampling frequency or season, the problem should be brought to the attention of Shawn Chartrand or Jonathon Owens of Balance Hydrologics who will be the field supervisors. The problem should be recorded in the project log and, if necessary the QA Officer should be notified. If QA/QC of a sample is compromised such that it cannot be corrected, another sampling event should be scheduled as soon as possible to avoid data gaps.

11.5 V* Sampling methods

Pool-wide sedimentation conditions were monitored according to the V* protocol described in Hilton and Lisle (1993). The V* technique uses a repeatable grid-based pattern of depth measurements from which is calculated the decimal fraction of pool that is filled with fine sediment. Refer to Figure 4 for a complete illustration of V* terms and their measurement characteristics. For example, a V* value of 0.63 means that about 63% of the residual pool volume is filled with fine sediment; it is important to note that the residual pool volume is a function of the downstream riffle controlling depth. A V* value of 0.63 is not inherently good or bad, nor do changes in one pool from storm to storm indicate "improving" or "deteriorating" conditions. However, sampling a large number of pools over time can be used to infer general trends in pool sedimentation and storage of sediment along monitored reaches of the creeks.

Two inherent difficulties associated with the V* method are (a) measurement accuracy of the downstream riffle crest depth, and (b) clear identification of the residual pool boundaries. It is easiest to perform these assessments at low flows when the water is clear. However, since our measurements were taken in between storms, flows were above baseflow and often associated with moderately turbid conditions thus complicating visibility into the water column. Our general approach towards difficulty (a) entailed use of the V* rod to find the thalweg, and subsequent measurement of the riffle crest depth. V* pool length was bounded by the location of the downstream riffle crest measurement point and the downstream end of upstream bounding riffle. Vegetation along either bank of the creeks set the lateral limits of the V* pools. We decided the number of cross sections and number of depth measurements per cross to create an evenly spaced sampling grid through each V* monitoring pool. We measured at least100 points in each pool. At each point, we measured the water depth, and then pushed the V* rod into the bed until rod advancement was refused and recorded this depth.

12. Sample Handling and Custody

The following information will be recorded on each sample container:

- sample location (site ID):
- date: yymmdd
- time: hhmm

This will be a continuous string e.g. XXXXyymmdd:hhmm. This information will also be recorded in the field notes.

Table 4. (Element 12) Sample handling and custody

Parameter	Container	Volume	Initial Preservation	Holding Time
Suspended sediment concentration (SSC) and	500 ml polyethylene bottle	500 ml (one jar)	cool to 4° C, dark and preserved with 1-2 drops of house hold bleach	Indeffinate - preserved with household bleach and kept at approximately 4°C

Suspended sediment/turbidity samples will be preserved with two drops of household bleach to prevent biologic fouling and stored in a cool (4°C), dark place until they are shipped to the laboratory for analysis which usually occurs with in a few weeks of the sampling date. Samples will be accompanied by a Chain of Custody form that is initiated by the field sampler. An example of the COC is included here as Appendix C. Samples will always be under the control of a designee recorded on the COC form until the laboratory analyses are complete.

The following office procedures will be followed:

1. Shortly after return from the field (within 48 hours) update the project log with data points (staff readings), samples taken, and field observations.

2. Shortly after return from the field, update the flow calculation spreadsheet

3. Add the flow value from the flow calculation spreadsheet to the project log entry for the sampling event.

4. After results are received from the laboratory, add the concentration of suspended sediment to the flow suspended load calculation spreadsheet.

13. Analytical Methods

Field equipment required for sample collection includes the DH-48 sampler for suspended sediment and turbidity samples. The following discussion applies to laboratory analysis of the samples.

Samples collected with the DH-48 will be analyzed for SSC using method EPA 160.2 with a TRL of 0.5 mg/L. This analysis will be performed by Soil Control Laboratories.

Table 5. (Element 13) Laboratory analytical methods

Analyte	Laboratory / Organization	Matrix	Reporting Units	Analytical Method/ SOP	Target Reporting Limit	Detection Limit for Reporting
Suspended sediment concentration (SSC)	Soil Control Laboratories	water	mg/L	EPA 160.2	0.5	0.5

The instruments, and associated method performance criteria, that Soil Control Laboratories will use for this project are:

- Analytical Balance (for suspended sediment concentration)

Soil Control Laboratories will be using EPA method 160.2 found in appendix D. No special considerations for sample disposal are anticipated.

The laboratory QAO will notify Shawn Chartrand, the Program Manager, and Jonathon Owens of any problems arising at the laboratory that cannot be resolved within the laboratory protocols. Documentation of these notifications, discussions and resolutions will be recorded in the project log and included in the Supplemental Project Report.

The laboratories will be required to complete their analyses and provide reports within four weeks after receiving samples.

13.1 In-situ recording turbidity using Campbell Scientific OBS3+

All in-situ field equipment is checked for function prior to field placement. The OBS3+ sensor will be placed at a stationary position relative to stream depth. Sensor position will be approximately 0.5 to 1.0 foot off the bed in order to capture turbidity signal in the stream flow that minimizes detection of bed load movement. The placement of the sensor will also be close if not submerged at winter time base flow levels.

Average, maximum and point sample of turbidity will be recorded at 15-minute intervals to allow for direct correlation to the flow records. The turbidity probe at Majors Creek will be set to read over the scale of 0 to 4000 NTU. Campbell Scientific is a leader in scientific instrumentation. The OBS3+ sensor measures turbidity by optical backscatter method. The accuracy of the probe is 1% of reading and has a greater than 98% linear response over a 1,000-fold change in sediment concentration (SSC) and turbidity when tested under ideal laboratory conditions.

Since ideal laboratory conditions to not exist in the field theturbidity record generated by the OBS3+ sensor calibration will be checked with standard solution of turbidity over the range of the signal output at the start of the wet season and at the end. If the turbidity signal is more than 15% of the standard solution the signal will be considered for validity and use in the study. At the end of the study the instrument will be sent to the manufacturer for laboratory calibration.

Maintenance of the OBS3+ includes cleaning the sensor window during monthly visits as well as storm visits if possible. The degree of fouling through siltation will be noted in the field and will be cross referenced in the data record. Excessive fouling (greater than 15% of the measured value) may result in the data not being used for that time period.

14. Quality Control

Quality assurance and quality control activities for sampling processes include field replicates for SSC testing and observation of procedures. Field replicates will be collected at least once per sampling season for the water quality (i.e. SSC) analysis; if conditions permit (stream flow remains constant).

Table 6. (Element 14) Analytical QC (Laboratory)

Parameter	Element 14 Quality Control
Conventional constituents in water (SSC)	Blanks – no detectible amount of substance in blanks. Frequency – Accuracy, precision, recovery, and blanks at 1 in 20 (5%) with at least one in every batch. All quality assurance and quality control procedures and criteria specified by selected method.

Laboratory QA/QC procedures are required to maintain sample integrity and assess the precision of laboratory analytical techniques. Quality Control samples are normally analyzed with each batch of samples for each analysis. For environmental samples the Quality Control samples include a Method Blank (MB), Laboratory Control Sample (LCS) and a Matrix Spike and Matrix Spike Duplicate. These QC samples are included in each batch of twenty samples or less for each matrix (frequency equivalent to 5% of all samples analyzed). If spike analyses are not feasible, a duplicate sample analysis is generally performed (eg; turbidity).

Field QA/QC procedures are required to demonstrate sample integrity and assess precision of field sampling techniques. Specific requirements include field decontamination to prevent cross-contamination, the collection of at least one field blank per matrix sampled per day of collection. The field blank (distilled water) will be analyzed to evaluate sample container integrity and decontamination technique.

Procedures for calculating QC statistics are also covered in the QAPP in Section 7.

14.1 V* data QA/QC

V* spreadsheet calculations are inspected after data entry to check that data were entered correctly. A graphical check is performed to compare water depth to sediment depth. Area and volume calculations are checked to include all the data. Spreadsheet results are then inspected to check that residual pool lengths are consistent and that residual pool volumes are consistent from one monitoring visit to the next.

15. Instrument/Equipment Testing, Inspection, and Maintenance

15.1 Suspended Sediment – DH-48

The suspended-sediment sampler (DH-48) will be inspected before each measurement to make sure that the nozzle is free of debris. Jeff Conway, the Field Supervisor, is responsible for carrying out this inspection. The sampler and sample-collection bottle will be triple rinsed in ambient water before each sample is collected. Sampling bottles obtained from the laboratory will be kept with Balance Hydrologics and replaced as necessary. Replacement nozzles and bottles for the DH-48 are available through FISP authorized distributors found at the FISP website http://fisp.wes.army.mil/index.htm.

15.2 Campbell Scientific OBS3+ Turbidity Sensor

The OBS3+ will be inspected and cleaned on a monthly basis at a minimum. During monthly visits to the stream gages conditions are noted and appropriate measurements are made (flow, suspended sediment). Prior to measurements of turbidity and suspended sediment the OBS3+ sensor will be cleaned. Immediately following all field activity the data logger will be downloaded and the data since the previous visit will be scrutinized in the office shortly after the field visit. This ensures that if follow up maintenance is needed it can be performed in short order.

15.3 Campbell Scientific CR10x Data Logger

This data logger will be maintained on a monthly basis. Maintenance on the data logger is minimal and includes:

- Ensuring the housing is dry and desiccant is performing properly.
- Down loading and ensuring all sensors and data logging is functioning properly
- Changing the battery as needed
- Checking for vandalism
- Flow Measurement Equipment – Pygmy and Standard (AA) Flow Meters

15.4 AA Velocimeter

The AA meter is a precisely balanced bucket wheel is mounted on a vertical pivot and is rotated by water flow. A rotating stainless steel shaft inside the meter's "contact chamber" makes contact with a thin wire (cat's whisker) which is attached to a binding post. There are two binding posts, one which produces a signal every revolution, and one every fifth revolution (for use in higher velocities). The rate of rotation is proportional to water velocity. Revolutions are monitored manually using either a headset or handheld beeper over a given period of time. The "AA" may be mounted on a wading rod for shallow stream measurements or by cable from a boat or overhead structure, using either a hand line or sounding reel.

15.5 Pygmy Velocimeter

The Pygmy (or "Mini") Current Meter is the smaller counterpart (4/10 scale) of the standard "AA" and is used to measure streams too shallow for the standard "AA". Unlike the "AA", the yoke and contact chamber of the "Pygmy" is one unit with only a single binding post for connection to a headset or beeper. The small size of the "Pygmy" allows it to be mounted by means of a Top-Setting, or Conventional Wading Rod only.

Both meters are maintained by being kept clean, lubricated and housed in a shock resistant housing. Prior to field measurement the meters are tested for rotation. In order to ensure that the velocity of the stream is represented by the rotation of the meter a spin test is performed where the AA meter must spin for 120 seconds or greater and the pygmy meter must spin for 45 seconds or greater. Meters are adjusted until they meet these criteria or they are not used in the measurement. Spin test results are recorded on the field measurement sheet and kept with Balance Hydrologics.

15.6 Suspended Sediment Analysis

5. Soil Control Laboratories will maintain their equipment in accordance with their SOPs, which include those specified by the manufacturer and those specified by the method.

6. The previously listed instruments that Soil Control Laboratories will use for this project, along with a brief description of criteria for instrument testing, follows:

- *Analytical Balance (Suspended Sediment):* The analytical balance is calibrated against Class "S" weights before use. The calibration weights bracket the weight to be measured. This calibration is recorded in the calibration notebook. Analytical balances are calibrated annually by outside service technician.

Each instrument has an associated logbook to record calibration and/or maintenance and repairs. It is the responsibility of the laboratory project manager to document any deficiency noted and corrective action taken in the instrument logbook. Further information is available on request from the laboratory.

15.7 V* equipment

V* equipment consists of tape measures and a thick stainless steel metal rod made by Rickly Hydrological Company. This equipment has no suggested or required maintenance

16. Instrument/Equipment Calibration and Frequency

The suspended-sediment sample-storage refrigerator is maintained at a temperature that does not freeze the samples. Detailed laboratory QA/QC programs for Soil Control Laboratories cover equipment maintenance specified by the manufacturers and methods. Turbidity probe calibration will be checked prior to the start of the anticipated rain season and at the end. Calibration records are maintained by the laboratories and Balance are available for inspection by the Project QAO.

Laboratory instruments requiring calibration are listed above in Element 15. Calibration procedures, frequency and documentation are found in the Soil Control Laboratories QAP and may be obtained on request from Soil Control Laboratories. It is the responsibility of the laboratory project manager to document any deficiency noted and corrective action taken in the instrument logbook.

17. Inspection/Acceptance of Supplies and Consumables

The Project Field Supervisor is responsible for obtaining the required sample bottles as outlined in Element 12 of this document. During sampling, suspended-sediment sample bottles are inspected for leakage around the lid. If leakage is noted, the sample is discarded and a new sample is taken and poured into a new sample bottle. Laboratory supplies are inspected before use to ensure that they are of appropriate quality to meet the MQOs of the Project. Soil Control Laboratories QA/QC programs provide additional details of their acceptance requirements for supplies and consumables and may be reviewed upon request.

18. Non-direct Measurements (Existing Data)

Existing data to be used includes the flow measurements performed by the City of Santa Cruz and Balance Hydrologic over the period of record for the Majors Creek gage. This data will be used to as part of the existing stage to flow or rating curve relationship for this gage and will be used to create the record of sediment transport. Previous measurements of suspended sediment performed by Balance and the City of Santa Cruz will also be taken in to consideration for this study.

All baseline data from gages and data collected within the study watersheds will be assessed against the measurement quality objectives listed in Element 7. If the data is found to be inconsistent with the design of this program or does not meet quality objectives it will not be considered valid background information.

19. Data Management

Data management is generally the responsibility of the Project Director and Lab Managers as outlined in Element 9. The Project Director will maintain an inventory of data and its forms and will periodically check the inventory against the records. Laboratory data will be submitted electronically, as an Adobe file from Soil Control Laboratories. Microsoft Excel will be used for load calculations as shown in the sample pages from the spreadsheet presented in Appendix C of this document. Reports will be prepared and presented in Microsoft Word. All software will be assumed acceptable if the programs run as expected and do not return error messages.

The data collected for calculated for daily suspended sediment loads will be formatted and submitted to SWAMP according to the instructions provided in Appendix J of the SWAMP QAPP. This task will be performed by Balance Hydrologics

GROUP C. ASSESSMENT AND OVERSIGHT

20. Assessments and Response Actions

Balance Hydrologics staff will conduct one on-site technical assessment of field sampling. Ongoing assessments will be carried out by the Project Director and QA Officer at the end of each monitoring season. If any discrepancies are noticed, they will be resolved as soon as possible. Resolution would normally be done by consulting the original records and interviewing the staff members who collected the samples or performed the calculations. Assessments, including any discrepancies and their resolutions will be documented by the Project Director in a letter report and submitted to the Grant Manager within the calendar quarter that follows the assessment date.

21. Reports to Management

Interim and final reports will be issued by Balance Hydrologics to Soil Control Laboratories according to data availability.

GROUP D. DATA VALIDATION AND USABILITY

22. Data Review, Verification and Validation

Data generated by the project activities will be reviewed against the MQOs cited in Element 7 and the QA/QC practices cited in Elements 14, 15, 16 and 17. Data will be separated into three categories: 1) data meeting all quality objectives, 2) data failing to meet precision or recovery criteria, and 3) data failing to meet accuracy criteria. Data falling into the second category will be re-assessed. If sufficient evidence is found supporting data quality use for this Project, it will be moved to the first category, but will be flagged with a "J" per EPA specifications; otherwise it will be moved to the third category.

Data meeting all MOQs, but with failures of QA/QC practices will be set aside until the impact of the failure on data quality is determined. Once determined, the data will be moved into either category one or three.

Data falling into the first category (either initially or after re-assessment) will be considered usable for the Project, data remaining in the second category after re-assessment and data assigned to the third category will not be considered usable.

23. Validation and Verification Methods

All data records will be checked visually and recorded as checked by initials and dates. The Project QA Officer will perform all reviews and the Project Director will check 10% of the reports. Soil Control Laboratories will perform checks of their records in accordance with their SOPs. All checks by the laboratories will be reviewed by the Project QAO.

Issues will be noted. Reconciliation and correction (if necessary) will be handled by a committee of the Project Director, Project QAO and the laboratory manager and QAO of the laboratory involved (if any). Any corrections require unanimous agreement that the correction is appropriate. A sample discharge calculation is included as appendix F. Checklists and forms are not involved in the data review process.

24. Reconciliation with User Requirements

The City of Santa Cruz faces several water resource-related challenges that would benefit from sediment reduction programs including:

- Provision of a more reliable water supply source for City residents as periods of high fine sediment transport result in loss of divertable streamflow;
- Fostering action which would work towards improving downstream fish habitat through a reduction in fine sediment loading to the Majors Creek

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Measuring the Fraction of Pool Volume Filled with Fine Sediment

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The fraction of pool volume filled with fine sediment (usually fine sand to medium gravel) can be a useful index of the sediment supply and substrate habitat of gravel-bed channels. It can be used to evaluate and monitor channel condition and to detect and evaluate sediment sources. This fraction (V*) is the ratio of fine-sediment volume to pool water volume plus fine-sediment volume. These volumes are computed for the residual portion of the pool that lies below the elevation of the downstream riffle crest. Fine-sediment thickness is measured by driving a graduated metal probe into a fine-grained deposit until the underlying coarser substrate is felt. Water depth and fine-sediment thickness are measured across transects, and volumes are computed by summing products of cross-sectional areas and distances between transects. Replicate measurements of V* were made in 20 pools, and the variability of V^*_w, the weighted mean value of V* for a reach, was analyzed in 12 reaches. The largest source of variability in V* was the measurement of fine sediment volume. Topographic irregularities in pools and on riffle crests and effects of variation in discharge on measurement of riffle crest elevation also affected V*. Ten to 20 pools are needed to estimate V^*_w in a reach, depending on acceptable error and variability between pools.

Retrieval Terms: fine sediment, pools, monitoring, sedimentation, fish habitat

Experienced hydrologists and geomorphologists can estimate the relative mobility of a streambed by looking at indicators of bedload transport, such as the freshness of bed-surface material. Another such indicator is the amount of fine sediment in pools. Pools in gravel-bed streams commonly contain deposits of fine sediment (mostly sand and gravel) that overlie a coarser substrate of coarse gravel, cobbles, or boulders. In such channels, the fraction of pool volume filled with fine sediment can be used as an index of the supply of mobile sediment. This fraction (V*) is the ratio of fine-sediment volume to pool water volume plus fine-sediment volume. In a previous paper, we investigated the relationship of V^*_w, the weighted mean value of V* for a reach, to qualitative evaluations of sediment yield in eight tributary basins of the Trinity River in northwestern California.[1] This study suggested that V^*_w could be used to evaluate sediment supply in gravel-bed channels without directly measuring sediment transport or sediment delivery from hillslopes. In one channel, V* increased abruptly downstream of a sediment source, suggesting that V* could be used to identify significant sediment sources.

We are conducting ongoing research on the relationship between V^*_w, sediment supply, and basin characteristics and are attempting to link V* to habitat suitability for aquatic organisms. If this is successful, V* could be used to simultaneously evaluate sediment supply and its effects on aquatic ecosystems. These relationships could then provide a needed link between watershed condition and fish habitat.

This paper describes a method to measure V* and discusses factors affecting the accuracy of estimates of V* and V^*_w.

APPLICATIONS AND LIMITATIONS

V* can be used to evaluate and monitor channel condition and to identify and quantify effects of discrete sediment sources. There are, however, limits to the types of channels where it can be used, and care must be taken in interpreting differences in V* between channels.

The usefulness of V* is limited to channels in which significant volumes of fine sediment can be deposited in pools. To date, we have found that V* can be accurately measured and results consistently interpreted in channels that have:

• a wide range in particle size between armor layers and fine sediment in pools. Sediment supply needs to include at least moderate proportions of sand and fine gravel. We have found V* to be very low and insensitive to sediment supply in basins that are formed in basalt or competent, fine-grained metamorphic or sedimentary rocks, for example.

• stable banks of densely rooted alluvium, bedrock, or armored colluvium.

• a single thread. In braided channels, the volume and proportion of fine sediment can vary widely between anabranches and thus create wide variations in V*.

• gradients less than about 5 percent. We are uncertain about how V* varies inherently between step pools, which are associated with steep slopes, and bar pools, which are commonly associated with gentle slopes.

Care should be taken in interpreting differences in V^*_w between different stream channels. Knowledge of variations of V* between streams with different geologies and stream types is needed to interpret variations in V* with respect to sediment supply. For example, a value of V^*_w of 0.15 would be expected to represent high sediment supplies in basins underlain by competent metamorphic rocks, but would be considered low for basins in weathered granite. V* values can be expected to be associated with substrate conditions important to aquatic organisms, such as embeddedness or infiltration, but specific responses will depend on the community present, which will in turn depend on the natural range and variability of substrate conditions in the channel.

These problems are not encountered when monitoring changes in V^*_w over time or in using V* to evaluate sediment sources. Volumes of sediment from landslides, for example, can be easily measured from air photos or in the field, but evaluating the intensity, extent, and duration of their impacts on channels has been problematical. V^*_w measurements upstream and downstream of such sources can potentially be used to evaluate and monitor their mobile sediment inputs.

Measuring V* in large rivers has practical limitations, although pools can be sounded and fine sediments probed from tethered rafts. We have measured V* in pools as wide as 30 m and 2000 m^3 in volume. Small pools create no logistical problems, but measurement precision may need to be increased in very small pools (<1 m^3 in volume). We have measured V* in second- through fifth-order channels.

METHODS

V^*_w is estimated in a section of a stream channel by measuring the water and fine sediment volume in the residual pool in all of the pools in a study reach and then calculating the weighted average value of V* for the reach.

Time and Equipment

Two or three experienced people can measure a wadable pool in half an hour to an hour, but accurate measurement of large pools requires a raft, which takes more people and more time. The minimum equipment required is two tapes, chaining pins, and a graduated rod. The rod must be long enough to measure water depth plus fines depth in the deepest part of the pool. A rod made of one-half inch diameter stainless steel probes fine sediment deposits well without bending. Systematic sampling also requires a calculator with a random number generator or a random number table. We use a palmtop computer with a spreadsheet to choose transect locations, enter the data, and calculate V*. This reduces data processing time and provides an opportunity to catch and correct errors in the field.

Choosing a Study Reach and Identifying Pools

The general location of a study reach is set by the purpose of the study. Reaches may be located upstream and downstream of a sediment source or downstream of a watershed rehabilitation project, for example. The specific location is chosen to avoid complicating factors which might affect V* within the reach, such as intra-reach sediment inputs, braided sections, or tributaries. A reach should include enough pools to provide an accurate estimate of V^*_w for the stream segment. The number of pools needed depends on the variability of V* between pools and on the desired accuracy of the estimate of V^*_w. In channels where V* does not vary greatly between pools, 10 to 15 pools are often sufficient (see Discussion).

After a study reach has been selected, the length of the reach is surveyed to identify pools to measure and determine what constitutes fine sediment in this channel. For our purposes, a measurable pool is an area of channel which (1) has a significant residual depth[2,3] (the deepest part of the pool must be at least twice as deep as the water flowing out of the pool at the downstream end); (2) has an essentially flat water surface during low flow (water surface slope <0.05 percent); and (3) includes most of the channel (it must include the thalweg and occupy at least half of the width of the low-flow channel). The specific criteria can vary, as long as they are repeatable and consistent across all reaches compared. We allow for possible variation in depositional patterns between different types of pools by measuring all pools in a reach, regardless of origin, but pool type could be a selection factor if enough pools are available. One should avoid measuring potential pools with unclear boundaries, such as long glides containing small deep areas or small deep areas in rocky channels, because it is difficult to measure such pools consistently.

What constitutes fine sediment in a channel is determined by the distribution of particle sizes and patterns of fine-sediment deposition in the channel. Fine sediment is defined as the material forming the matrix among the gravel framework of the bed material.[4] This material is commonly winnowed from areas of high shear stress, such as riffles, and deposited in pools.[1] Fine sediment in a reach is defined as material which (1) is distinctly finer than the bed surface (median particle size (D_{50}) of fine sediment approximately one tenth or less of the D_{50} of the bed surface) and (2) can be distinguished from underlying coarser sediment by probing with the rod. Deposits of fine sediment that are armored (covered by a layer of larger sediment) or densely occupied by roots of riparian plants are not considered available for transport and are not measured. In most channels, fine sediment is defined for working purposes as deposits with a D_{50} of 11 mm or less, but deposits with a D_{50} of 16 mm (medium gravel) can be measured in channels with large surface particle sizes and high transport energy.

Measuring Riffle-Crest Depth and Defining Pool Boundaries

Calculation of V* requires measuring the volume of water and fine sediment in the "residual" pool. The residual pool is defined as the portion of the pool that is deeper than the riffle crest forming the downstream lip of the pool, that is, the pool that would remain if there were negligible surface flow *(figure 1A)*.[3] The riffle crest is a high point on a longitudinal profile and usually the shallowest place at the downstream end of a pool. During low flows, when the water surface in pools is nearly flat, the riffle crest can be identified by the beginning of the riffled, more sloping water surface.

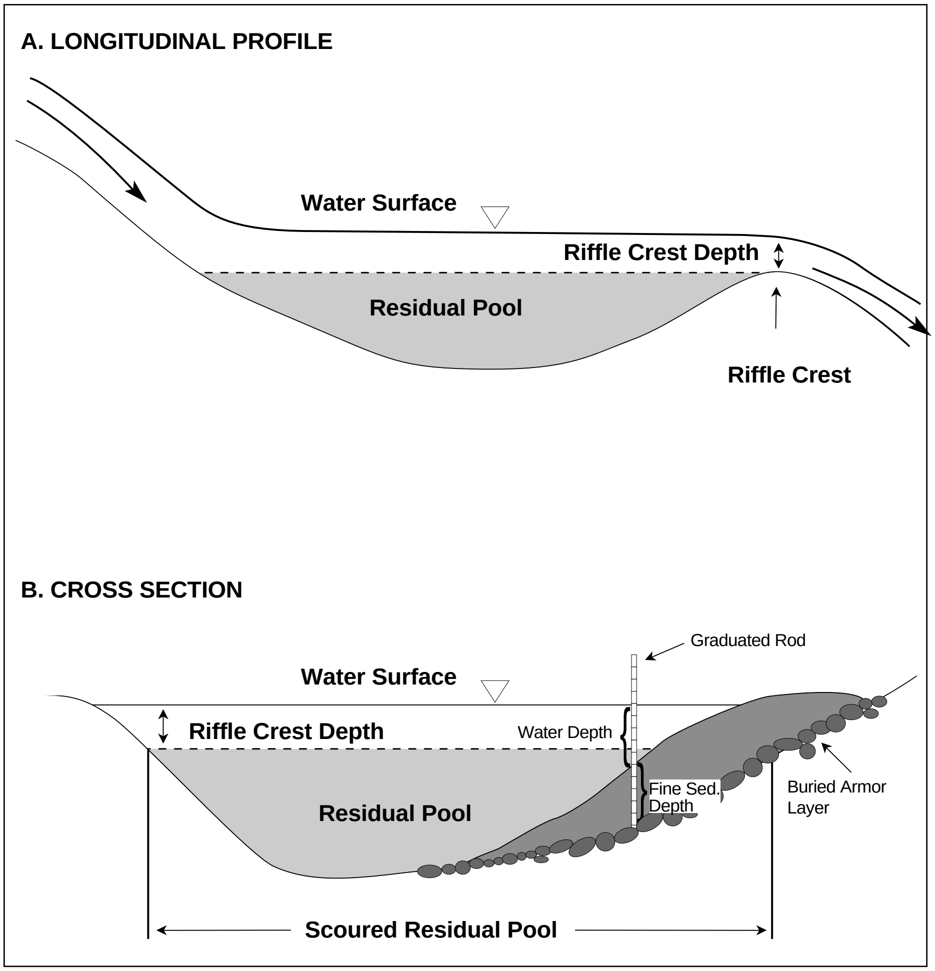

Figure 1—(A) Longitudinal profile of a pool, showing the riffle crest and the area included in the residual pool volume. (B) Cross section of a pool, showing measurement of water and fine sediment depth and volume of water and fine sediment in the scoured residual pool.

The first step in calculating V* is to measure the riffle-crest depth and define the pool boundaries. Water depth at the riffle crest is measured by taking the median of several depth measurements taken across the thalweg at the riffle crest *(figure 2).* Because the riffle-crest depth defines the residual pool, it is important to measure it consistently. Near the riffle crest, the water surface may break in several places, discontinuously, or gradually over a distance. The riffle crest is identified as the shallowest continuous line (usually not straight) across the channel close to where the water surface becomes continuously riffled. Depths are measured across the deepest part of the flow at 5-20 evenly spaced locations along this line, depending on the width and irregularity of the measured section. To consistently measure the same section of the riffle crest, measurements are taken where we expect water to flow at minimum discharge. Thus the measured section occupies a smaller proportion of the total wetted width at high flows than at low flows. Defining and measuring the riffle crest can be confusing. Survey teams should discuss measurement locations and periodically take duplicate measurements to maintain consistency.

Water depths and fine-sediment depths are measured within the "scoured residual pool," which is the residual pool that would result if all of the fine sediment in the pool were removed. If the water surface over the pool is essentially horizontal, the boundary of the scoured residual pool is where water depth plus fine-sediment depth equals riffle-crest depth *(figure 1B).* Where the water surface is not completely horizontal, as at the upstream ends of many pools, the boundary is where a plane at the elevation of the riffle crest would intersect the streambed with fine sediment removed (see *figure 1A).* In a few situations, we exclude sections of stream channel which would be included in this definition. For example, a long glide extending into a pool may be excluded, even if the glide is deeper than the riffle-crest depth. Similarly, if the upstream end of the pool is a riffle that is deeper than the riffle crest, the upstream boundary of the pool is defined as where the nearly horizontal water surface would begin at a minimum flow.

Measuring Water and Fine Sediment Volume

Volumes of water and fine sediment in the residual pool are calculated from measurements of water and fine-sediment depth along a series of cross sections in the pool. The basic technique is essentially a systematic sample, with cross sections spaced evenly along the length of the pool. Zero-area cross sections are assumed at the ends of the pool. Depth-measurement points are spaced evenly across each cross section and at either end. The locations of both the cross sections and the depth-measurement points are determined from a random start. The basic system is modified in some cases to improve the accuracy of the estimate. The basic systematic sample will be described first, followed by examples of modifications for specific situations.

Basic systematic sample (figure 2).

1. Stretch a tape along the length of the pool, from the upstream end to the furthest point on the riffle crest or along the longest dimension of the pool. This tape must be straight, since bends will distort the volume calculations. If the pool is so irregular that a bend cannot be avoided, divide the pool into sections and measure each separately *(figure 3).*

2. Draw a sketch map of the pool, showing locations of the upstream end of the pool, riffle crest, areas of fine-sediment deposition, and major features of the pool, such as logs and outcrops.

3. Decide on the number of cross sections and the distance between depth-measurement points. The appropriate sampling intensity depends on the complexity of the pool and on the accuracy required. We take from 4 to 10 cross sections in each pool and

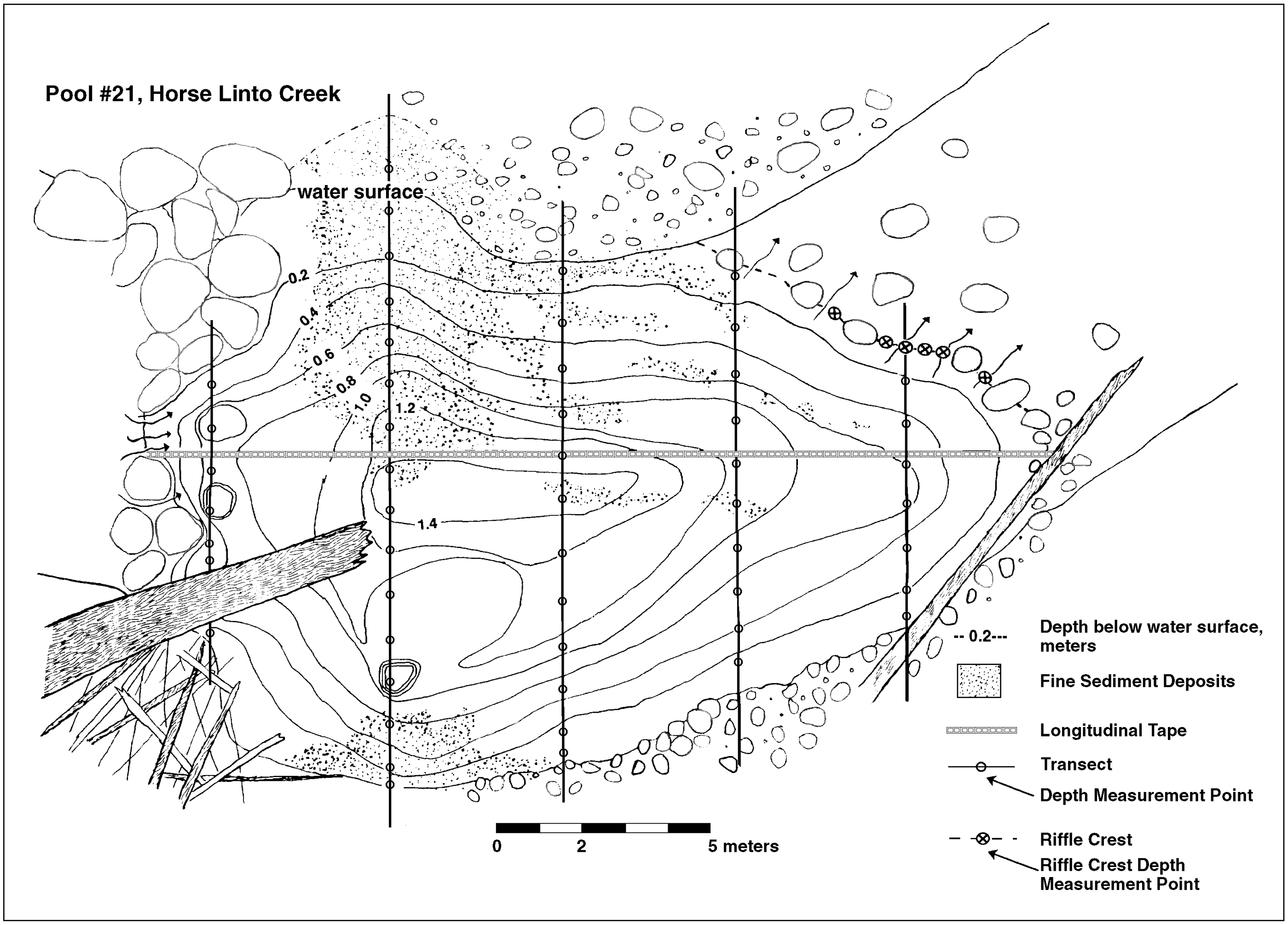

Figure 2—Pool #21, Horse Linto Creek, showing location of the longitudinal tape, transects, measurement points for water and fine sediment depth, the riffle crest, and measurement points for riffle crest depth.

set the distance between depth locations to provide 7 to 16 points across the widest cross section.

4. Determine the locations of cross sections and depth-measurement points. Divide the total length of the pool by the number of cross sections to find the distance between sections. Choose a random number between zero and this distance to locate the first cross section, and add the chosen spacing to locate the remaining sections. Choose random numbers between zero and the distance between depth-measurement points to locate the first point in from the edge of each cross section.

5. Run a tape perpendicular to the lengthwise tape at each cross-section location. Measure water depth and the thickness of any fine sediment present at each measurement point with a graduated rod. Fine-sediment depth is determined by probing with the rod until a change in resistance is felt as it strikes coarser material *(figure 1B)*. A small sledge may be useful for probing deep deposits. The cross section begins at the edge of the scoured residual pool, where water depth plus fines depth becomes greater than riffle-crest depth *(figure 1B)*. Record total water depth and fines depth at both edges of the pool, and at regular intervals across the pool as determined in step 4. If a fines deposit deep enough to be included in the scoured pool extends above the water surface, record height above the water surface as a negative water depth.

Modifications. The advantage of the basic systematic sample is that it is simple, repeatable, and statistically unbiased. The main disadvantage is that it does not use information about the pool (such as the location of fines deposits) that is available to the people taking the measurements. The basic sample can be modified in a variety of ways, from decreasing the distance between cross sections or depth-measurement points at some locations to dropping the systematic sample entirely and deliberately choosing cross-section or depth-measurement locations or both. Because deliberately chosen locations introduce potential bias, locations are chosen only when it will clearly improve the accuracy of the estimate. These are some common situations in which modifications can improve accuracy:

- In most pools, fines occupy less than one-half of the substrate area. To measure fines volume more accurately, the distance between depth measurement points is usually reduced over fines deposits, and points are added at their edges. Also, cross sections are often added to measure an area of fines more intensely or to define its upstream or downstream limits.

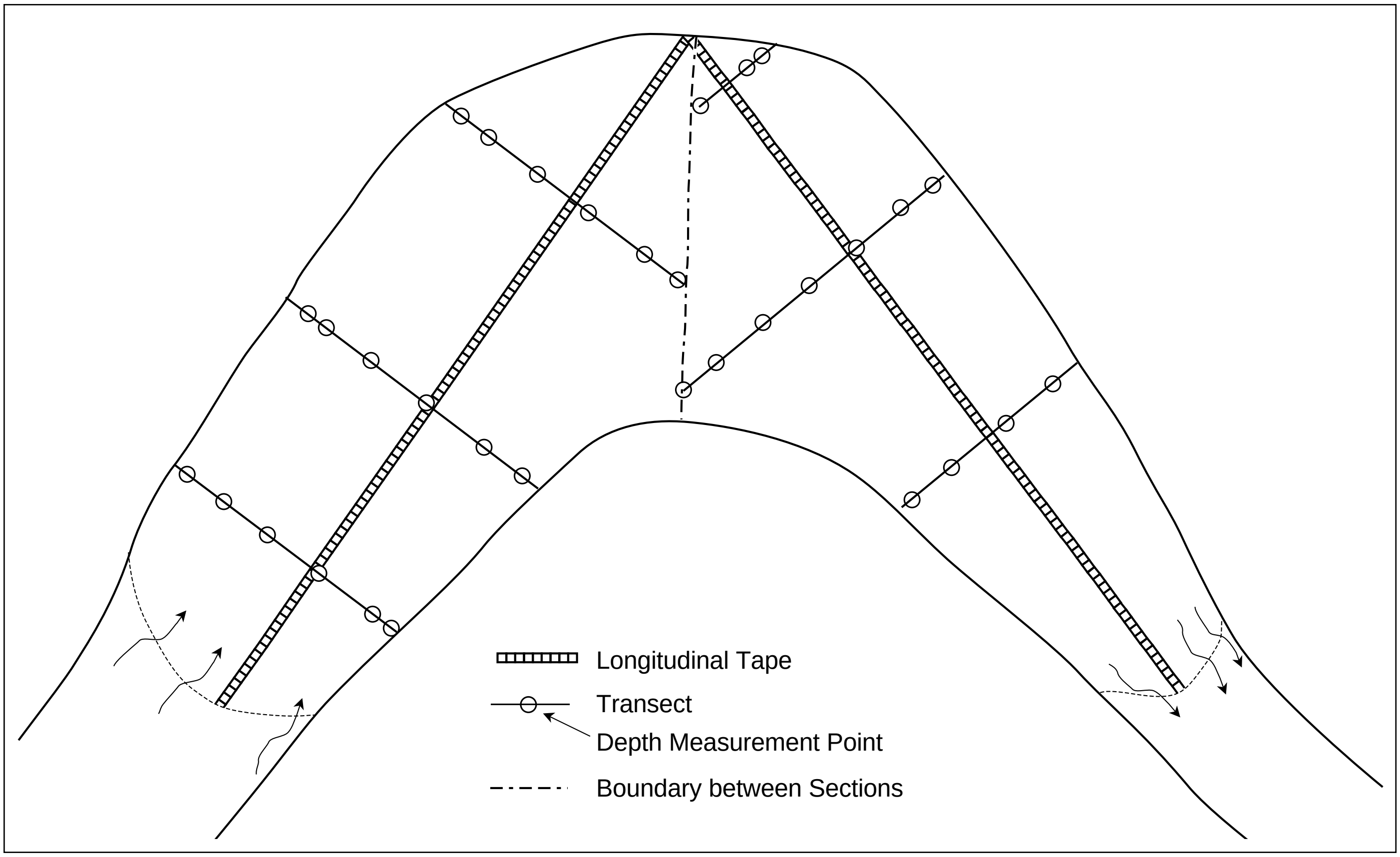

Figure 3—Measuring a pool with a bend. The longitudinal tape is strung in two straight segments, transects are located systematically along the tape, and a zero-area cross section is recorded at the location of the bend in the tape.

• If a pool has a deep, complex segment and another segment that is fairly long, simple, and shallow, the pool may be divided into two segments and the more complex segment sampled more intensely. A cross section at the boundary between segments makes the volume estimates for each more accurate.

• Cross sections or depth-measurement points or both may be added to adjust for irregularities in pool shape, such as large rocks, holes, or shoals.

• If most or all of the fines in a pool are in a few discrete deposits, their volume can be measured separately. The pool volume is measured using the basic systematic technique, as though fines in the discrete deposits were absent (fines depth measurements in the deposits are recorded as zero). The residual-pool volume of fine sediment in the deposits is then measured more intensively, and the volumes of the discrete deposits are added to the fine sediment volume measured in the rest of the pool.

Calculating V* and V*$_w$

V* is calculated as follows:

1. Calculate the residual cross-sectional area (the area deeper than the depth at the riffle crest) of fines and water in each cross section.
2. Set a zero-area cross section at the upstream and downstream ends of the pool.
3. Calculate the average residual cross-sectional area of fines and water between each pair of adjacent cross sections.
4. Multiply the average cross-sectional area for each pair by the distance between them.
5. Add the volumes of the water and fine sediment in all the segments to find the totals for the pool.
6. Calculate V* for the pool:

$$V^* = \frac{\text{residual fines volume}}{\text{scoured residual pool volume}}$$

where scoured residual pool volume = residual fines volume + residual water volume.

A sample data set with detailed instructions and examples of the calculations is shown in *appendix A.* Worksheets are available to do these calculations in Lotus 1-2-3 and in SQL*Calc.

V*$_w$ is the average of the V*'s for all the pools in a reach weighted by the scoured pool volume of each pool. Because V* is the ratio of fines volume to scoured pool volume, the weighted mean for the reach can be simply calculated as:

$$V_w^* = \frac{\Sigma\text{ (residual fines volume)}}{\Sigma\text{ (scoured residual pool volume)}}$$

The variance of the estimated residual water volume, fines volume, and V* for individual pools may be assessed by remeasuring a sample of the pools and treating each measurement as a random sample of all possible measurements of that pool. The variability of V*$_w$ for the reach can also be estimated, but since V* is a ratio of two estimates (fines volume and water volume), calculating the variability of the weighted mean is complex. A formula for estimating the variability of V^*_w is in *appendix B*, along with a process for testing for significant differences in V^*_w between reaches.

ACCURACY OF THE ESTIMATES

The accuracy of the estimated value of V^*_w for a reach depends on the accuracy of the estimates of V* for each pool and on the variability of V* between pools in the reach. To find out how precise our individual pool volume measurements were, we measured variability due to sampling and measurement error by repeating measurements of several pools. We also investigated how discharge at the time of measurement affected the measured surface elevation of the residual pool and consequent values of V*. To find out how variability between pools affected V^*_w, we studied the relationship between the estimated value of V^*_w and the variability of the estimate of V^*_w in 12 reaches, eight in the Trinity River watershed and four others in northern California.

Individual Pool Estimates

Nine pools in Trinity River tributaries were measured three times each in 1990, and six of these were remeasured two or three times each in 1991. For these duplicate measurements, we kept riffle-crest depth and pool length constant and varied the starting point for the systematic sample. The standard deviation of V* ranged from 0.00 to 0.08, and increased slightly with V*. Coefficients of variation ranged from 0 to 170 percent, with the higher values concentrated at very low values of V* *(figure 4)*. The coefficient of variation of V* in a pool was highly correlated to that of the fine sediment volume in that pool (r = 0.995). *Figure 4* also includes the coefficients of variation for five pools in the Salmon River, California, which were measured three times each in 1991. These measurements were taken a week apart, by different people, and riffle-crest depth and pool length varied somewhat between measurements. The standard deviations and coefficients of variation of those pools were similar to those of the other replicate measurements.

Effect of Discharge on V*

Because we measure only within residual pools, the measured water and fine-sediment volumes (and thus V*) should not vary with discharge. If the riffle crest is always measured in the same place, the riffle-crest depth will increase exactly as much as the water surface of the pool rises, the elevation of the surface of the residual pool (riffle-crest elevation) will be constant, and the same volume will be measured at any discharge. However, because locating the riffle crest and selecting the section to measure are somewhat subjective, there is some potential for error. Systematic errors could occur if the measured riffle-crest elevation is consistently affected by discharge and if V* is consistently affected by riffle-crest elevation. To determine whether discharge affects riffle-crest elevation, we measured riffle-crest elevation (water-surface elevation minus the measured riffle-crest depth) at three pools in Jacoby Creek at four different flow levels. Elevations were measured at extremely low base flows, normal summer base flows, and flows significantly above summer base flows. To find out whether riffle-crest elevation affects V*, V*'s calculated at different riffle-crest depths were compared for sample pools from five creeks in northern California.

Measured riffle-crest elevations in Jacoby Creek tended to be higher at low flows than at high flows, possibly because the width of the minimum flow channel was underestimated at high flows. Riffle-crest elevations did change less than water-surface elevations, however. Maximum changes in water-surface elevation ranged from 0.10 to 0.20 m, whereas changes in riffle-crest elevation ranged from 0.01 to 0.07 m. Maximum changes in residual elevation were equivalent to 10 percent, 25 percent, and 70 percent of the riffle-crest depth of the respective pools at moderately low flows.

To evaluate the effect of an error of this magnitude in riffle-crest elevation on V*, we calculated V* using a riffle-crest depth equivalent to 150 percent of the original value (measured at moderately low flows) in 19 pools. Original values of V* ranged from 0.01 to 0.62. The deeper riffle-crest depths resulted in smaller residual pools, which had higher V* values in 18 of the 19 cases. The mean percent change in V* was 13 percent (16 percent if the negative change was omitted), which corresponded to a mean absolute change in V* of 0.05.

Variability in V^*_w

We calculated the standard error of the estimate of V^*_w for all of the reaches we measured using the formula in *appendix B*. We then modified the formula to predict the number of samples (pools) required to

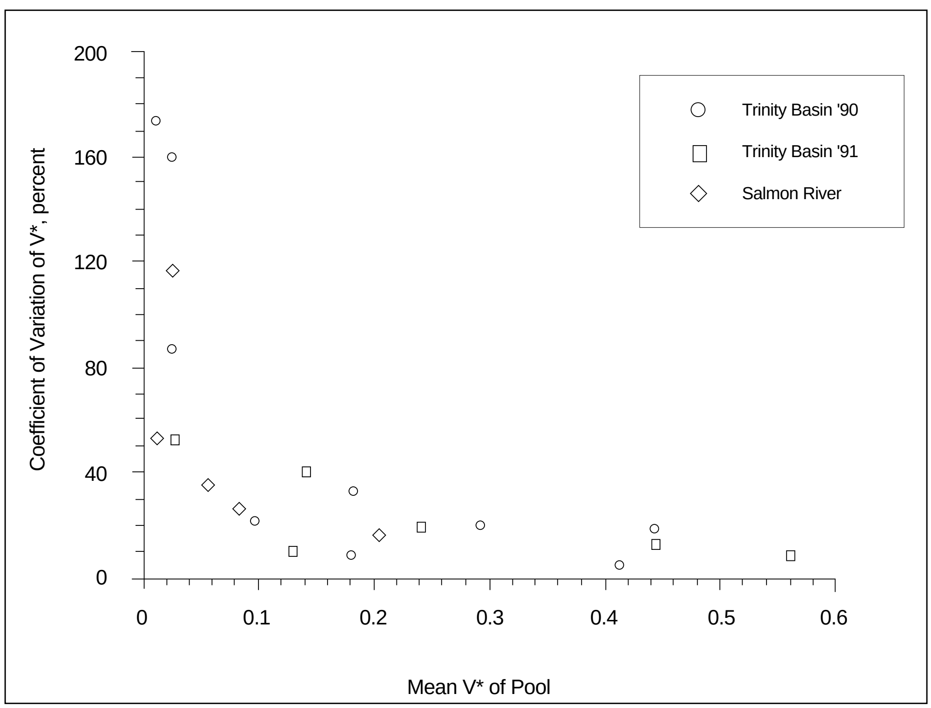

Figure 4—Variability of the estimate of V*, from multiple measurements of V* on pools in Trinity River tributaries in 1990 and 1991 and in the South Fork Salmon River in 1991. The coefficient of variation is the percentage ratio of the standard error of the mean to the mean value of V* for each set of measurements.

achieve a standard error of 20 percent of V^*_w for each reach. The standard errors of our reaches, each of which included 10 to 20 pools, ranged from 0.01 to 0.06 and averaged 17 percent of the value of V^*_w. The calculated sample size necessary to obtain a 20 percent error in V^*_w ranged from 4 to 26 pools and generally decreased as V^*_w increased. Exceptions were reaches in Grouse Creek, which had extremely irregular pools due to the presence of very large boulders, and in North Fork Caspar Creek, which had irregular pools caused by large woody debris. These two reaches had high standard errors and required higher sample sizes.

DISCUSSION

The main factor affecting the variability of the estimate of V* for a pool seems to be the amount of fines in the pool. In pools with moderate to high values of V* (V* >0.10), most (80 percent) of the standard deviations were less than 20 percent of the mean V* for the pool. In pools with lower V* values, the standard deviations ranged up to 170 percent of V*. Although it is not practical to expect the same percent errors in these pools as in those with higher V* values (because a small percent of a small number is a very small number), it may still be important to measure V* in these pools more precisely than in pools with a higher proportion of fine sediment. Error in V* was strongly correlated with error in fines-volume measurement, and fine sediment does tend to be measured less intensively when it occupies a small proportion of the area of the pool. Therefore, we strongly recommend increasing sampling intensity in areas of fines or measuring fine-sediment deposits separately, or both, particularly where fine-sediment deposits occupy a small proportion of the surface area of the pool or when it is important to measure low values of V* accurately.

Estimates of the maximum possible error in V* due to variations in discharge (13-16 percent of V* measured at moderately low flow) were slightly less than the 18 percent average measurement error for replicate measurements at a constant discharge. However, measurement error from systematic samples with a random start is random, whereas errors due to changes in water depth appear to be consistent and thus have the potential to bias V^*_w. We recommend measuring at moderately low flows. Riffle-crest depths can be difficult to measure accurately at very low flows when the pattern of the flow is affected by surface rocks. At moderately high flows the water surface over a pool is likely to slope appreciably and affect pool volume measurements. For monitoring over time, comparisons will be more accurate if V^*_w is measured at a consistent stage or discharge. Similarly, comparisons between reaches will be more reliable if all reaches are measured at nearly the same relative flow. If this is not possible, allowance should be made for the possibility that values of V^*_w measured at high base flow could be elevated relative to those measured at low flow.

Our estimates of the variability of V^*_w include the effects of measurement errors in V* but do not include any possible bias due to variations in discharge, since all pools in a reach were measured at approximately the same discharge. The desired standard error of V^*_w depends on the precision required to detect changes in a reach, deviations from a reference value, or differences between reaches. We found that the standard errors from measuring 10-20 pools per reach enabled us to distinguish fairly well between reaches, and the sample size calculations indicated that fewer pools would probably have been enough in most reaches. The calculated sample size *(figure 5)* is not necessarily the number of pools that should be measured in each reach, since the percent error in V^*_w needed to distinguish between reaches will depend on both the value of V^*_w (a 20 percent error is a large range of V^*_w values when V^*_w is high and a small range when V^*_w is small) and on the closeness of the values being compared. The sample size calculation does, however, indicate the relative sampling intensity required to be able to measure reaches with high standard errors at the same precision as reaches with lower variability between pools. We recommend evaluating the irregularity of the pools and the variation in V* before and during data collection in a reach. If all of the pools in a reach have similar values of V*, then differences between the estimates of V* caused by measurement error could have a significant effect on the variance of the estimate of V^*_w, and V^*_w can be best estimated by measuring a few (6-10) pools accurately. For most reaches we recommend measuring 10-15 pools, and if the value of V* varies widely between pools, the best strategy might be to measure as many pools as possible (20 or more), perhaps with less sampling intensity on each. If V* is highly variable but the number of pools available

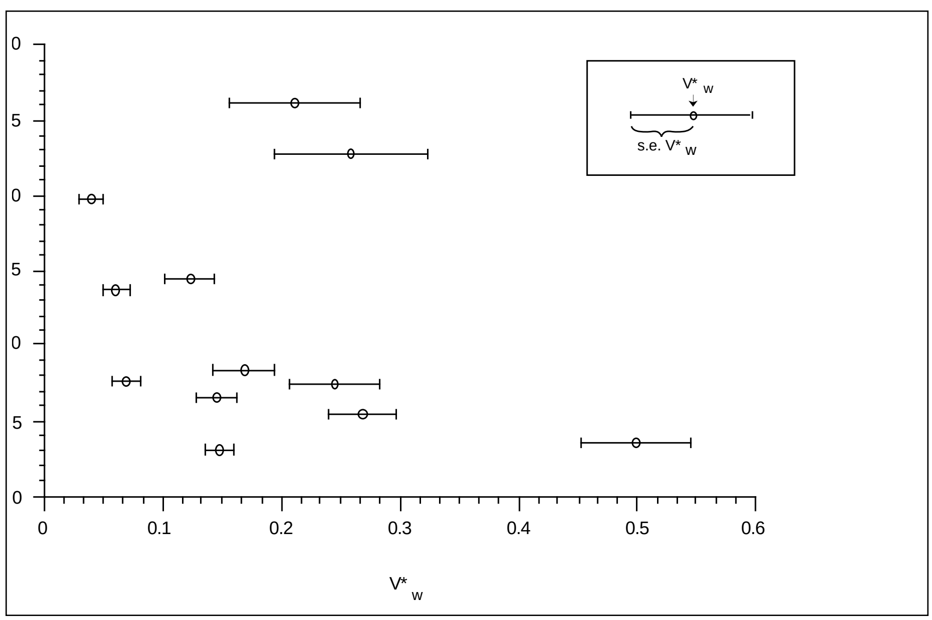

Figure 5—Predicted sample sizes necessary to limit the error in V^*_w to 20 percent of the value of V^*_w for that reach, calculated for 12 reaches. Our estimate of V^*_w for each reach is shown with our standard error of the estimate for that reach, which was based on 10-20 pools.

in the reach is limited (by sediment sources, changes in slope, etc.), putting more effort into sampling each pool will at least reduce the measurement-error component of the total variability. If the objective is to monitor a reach over time, and if the structure of the pools in a reach is fairly stable, accurate measurements of a few major pools at approximately the same discharge each year may give the best information.

SUMMARY OF RECOMMENDATIONS

To minimize variability of the estimates and eliminate potential bias, we make the following recommendations:

Fine Sediment Measurements

• When fine-sediment deposits occupy a third or less of the pool substrate area, increase measurement intensity in fine-sediment deposits, either by decreasing the distance between depth-measurement points or by making separate measurements of deposits.

Discharge Levels

• Measure all pools at moderately low flows.

• If a reach is being monitored over time, measure at approximately the same discharge each year.

• If reaches are being compared, measure all reaches at approximately the same relative flow.

Sample Size

• If all pools in a reach have similar values of V*, measure 6-10 pools relatively intensively.

• If V* varies somewhat (V* for all pools is within 20-30 percent of the mean), measure 10-15 pools.

• If V* is highly variable (some V*'s of 0.4 or more and others 0.1 or less), measure as many pools as possible, up to 20 or so.

• If the objective is to monitor changes over time in a single reach, and if the pools in the reach are structurally stable, intensive measurement of a few pools (4-5 minimum) may minimize variability and provide additional information about changes in individual pools.

APPENDIX A

Calculating Residual Pool Water Volume, Fine-Sediment Volume, and V*

Follow these basic steps to compute residual-water and fine-sediment volumes for a pool:

1. Calculate cross-sectional areas of the water and fine sediment in the residual pool at each cross section.
2. Assume a zero-area cross section at the beginning and end of the pool. Calculate water and sediment volumes in cells between each pair of adjacent cross sections, including the zero-area cross sections at the endpoints.
3. Sum residual-water and fine-sediment volumes for all of the cells to compute total volumes.

The following example of the calculations uses the data from a very small pool. In this example, d = water depth, d_{rc} = riffle-crest depth, and y_f = fine-sediment thickness. These are the data:

riffle-crest depth (d_{rc}) = 0.10 m; total length of pool = 12.0 m

cross section #1 at 2.4 m

distance (m)	0	0.5	1.5	2.5	2.7
d (m)	0.10	0.50	0.88	0.40	0.10
y_f (m)	0	0	0.02	0.02	0

cross section #2 at 6.4 m

distance (m)	0	1	2	3	4	5	6	6.2
d (m)	0.06	0.62	0.74	1.12	0.96	0.70	0.56	0.10
y_f (m)	0.04	0.10	0.02	0.01	0	0	0	0

cross section #3 at 10.4 m

distance (m)	0	0.8	1.8	2.8	3.8	4.6
d (m)	-0.02	0.08	1.08	1.14	0.94	0.10
y_f (m)	0.12	0.10	0.14	0.06	0.04	0

The first step is to compute depths of the water and fines in the residual pool. The residual water depth, d_r, is the water depth minus the riffle crest depth. The residual fine-sediment thickness, y_{rf}, is the thickness of the fine sediment below the riffle crest *(figure 1)*. If the water depth at any location is less than the riffle crest depth, the fines thickness at that location is reduced by a corresponding amount. That is, $d_r = d - d_{rc}$ and IF $d < d_{rc}$, THEN $y_{rf} = y_f - (d_{rc} - d)$, ELSE $y_{rf} = y_f$. After these calculations, the data look like this:

cross section #1

distance (m)	0	0.5	1.5	2.5	2.7
d_r (m)	0	0.40	0.78	0.30	0
y_{rf} (m)	0	0	0.02	0.02	0

cross section #2

distance (m)	0	1	2	3	4	5	6	6.2
d_r (m)	-0.04	0.52	0.64	1.02	0.86	0.60	0.46	0
y_{rf} (m)	0	0.10	0.02	0.01	0	0	0	0

cross section #3

distance (m)	0	0.8	1.8	2.8	3.8	4.6
d_r (m)	-0.12	-0.02	0.98	1.04	0.84	0
y_{rf} (m)	0	0.08	0.14	0.06	0.04	0

The next step is to compute cross-sectional areas of water and fine sediment. We start by calculating the width w_i, average residual depth $(d_r)_i$, and average fine-sediment thickness $(y_{rf})_i$ of each segment of the cross section (between two adjacent measurement points).

cross section #1

segment number	1	2	3	4
w_i (m)	0.5	1	1	0.2
$(d_r)_i$ (m)	0.20	0.59	0.54	0.15
$(y_{rf})_i$ (m)	0	0.01	0.02	0.01

cross section #2

segment number	1	2	3	4	5	6	7
w_i (m)	1	1	1	1	1	1	0.2
$(d_r)_i$ (m)	0.24	0.58	0.83	0.94	0.73	0.53	0.23
$(y_{rf})_i$ (m)	0.05	0.06	0.015	0.005	0	0	0

cross section #3

segment number	1	2	3	4	5
w_i (m)	0.8	1	1	1	0.8
$(d_r)_i$ (m)	-0.07	0.48	1.01	0.94	0.42
$(y_{rf})_i$ (m)	0.04	0.11	0.10	0.05	0.02

In each segment, the cross-sectional area of residual water $(a_r)_i$ equals $(d_r)_i \times w_i$, and cross-sectional area of fine sediment $(a_{rf})_i$ equals $(y_{rf})_i \times w_i$. Negative average water depths are set equal to zero. This gives us:

cross section #1

segment number	1	2	3	4
$(a_r)_i$ (m^2)	0.10	0.59	0.54	0.03
$(a_{rf})_i$ (m^2)	0	0.01	0.02	0.002

cross section #2

segment number	1	2	3	4	5	6	7
$(a_r)_i$ (m^2)	0.24	0.58	0.83	0.94	0.73	0.53	0.046
$(a_{rf})_i$ (m^2)	0.05	0.06	0.015	0.005	0	0	0

cross section #3

segment number	1	2	3	4	5
$(a_r)_i$ (m^2)	0	0.48	1.01	0.94	0.336
$(a_{rf})_i$ (m^2)	0.032	0.11	0.10	0.05	0.016

The total cross-sectional area of residual water, A_r, and fine sediment, A_{rf}, of each cross section equals the sum of the corresponding segment areas. Cross sections are added to upstream and downstream ends of the pool and given areas of zero.

cross-section #	0	1	2	3	4
location (m downstream)	0	2.4	6.4	10.4	12
A_r (m^2)	0	1.26	3.90	2.77	0
A_{rf} (m^2)	0	0.032	0.130	0.308	0

To compute the water and fine sediment volume in each cell of the pool, between each two adjacent cross sections, we calculate the average cross-sectional areas of residual water $(A_r)_j$ and fine sediment $(A_{rf})_j$ and the length (l_j) for each cell. The cell in the upstream end of the pool, for example, has an average residual area equal to one-half of the area of the first cross section downstream.

cell number	1	2	3	4
l_j (m)	2.4	4.0	4.0	1.6
$(A_r)_j$ (m^2)	0.63	2.58	3.33	1.38
$(A_{rf})_j$ (m^2)	0.016	0.081	0.219	0.154

The volumes for each cell, $(V_r)_j$ and $(V_{rf})_j$, are the average areas times the length, and the total for the pool is the sum of the volumes of all the cells.

cell number	1	2	3	4	total
$(V_r)_j$ (m^3)	1.5	10.3	13.3	2.2	27.4
$(V_{rf})_j$ (m^3)	0.04	0.32	0.88	0.25	1.48

Finally we calculate V^* as: $\frac{\text{total fines volume}}{(\text{total fines} + \text{total residual pool volume})} = 0.051$

and we're done!

APPENDIX B

Estimating the Variance of the Estimate of V^*_w

The formula we used for estimating the variance of V^*_w was developed using the Delta method[5] for estimating the variance of a variable that is a function of other variables. The variance of V^*_w for a reach is calculated as:

$$\widehat{Var}\left(V_w^*\right) \cong n\left(\sum_{i=1}^{n} f_i + \sum_{i=1}^{n} w_i\right)^{-4}\left[\left(\left(\sum_{i=1}^{n} f_i\right)^2 \sigma_w^2 + \left(\sum_{i=1}^{n} w_i\right)^2 \sigma_f^2\right) - 2\sum_{i=1}^{n} f_i \sum_{i=1}^{n} w_i\left(\mathrm{cov}(f, w)\right)\right]$$

where f_i is the fines volume and w_i is the residual pool water volume of the ith pool in the reach, and $\widehat{cov}\,(f,w)$ is the covariance of the fines volume and the water volume in the reach. The covariance is calculated as:

$$\widehat{cov}\,(f, w) = \frac{\sum_{i=1}^{n}\left(f_i - \bar{f}\right)\left(w_i - \bar{w}\right)}{n-1}$$

The covariance can be obtained from many statistical programs by printing a variance-covariance matrix.

The calculated variance can be used to test for significant differences in V^*_w between two reaches by assuming that the test statistic,

$$\frac{V_{w1}^* - V_{w2}^*}{\sqrt{\widehat{Var}\left(V_{w1}^*\right) + \widehat{Var}\left(V_{w2}^*\right)}},$$

has a standard normal distribution.

ACKNOWLEDGMENTS

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SAMPLING WITH THE US DH-48 DEPTH-INTEGRATING SUSPENDED-SEDIMENT SAMPLER

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Sampling with the US DH-48 Depth-Integrating Suspended-Sediment Sampler

Characteristics

Description: The US DH-48 is a lightweight sampler used for collection of isokinetic depth-integrated suspended-sediment samples where wading rod suspension is used (Figure 1). The instrument can sample to within 3 ½ inches of the streambed. The sampler consists of a streamlined aluminum casting, 9 5/8 inches long (less nozzle), which partially encloses a round pint glass milk bottle sample container (must be purchased separately). The sampler weighs 4 1/2 pounds including the sample container. A plastic (dyed yellow) or brass nozzle extends horizontally from the nose of the sampler body. A streamlined projection, pointing toward the rear on the side of the sampler head, accommodates the air exhaust port from which air may escape from the bottle as the sample is being collected. A standard 1/2 inch wading rod (must be purchased separately) is threaded into the top of the sampler body for suspending the sampler. The sample container is held in place and sealed against a neoprene gasket in the sampler head by a hand-operated spring-tension bottle retainer at the rear of the sampler.

Sample container: The sampler is designed for use with a round pint glass milk bottle. A gasket inside the front of the sampler provides a seal between the sampler and sample container. To install the sample container the bottle retainer is pulled rearward and swiveled to either side of the centerline of the sampler to provide clearance for inserting the bottle. The bottle can then be slid into the body of the sampler while making sure the bottle mouth seats squarely on the gasket. Removal of the sample container is accomplished by reversing the procedure.

Sampler function: When the sampler containing a sample bottle is submerged and oriented into the flow (nozzle horizontal and pointed upstream) a continuous stream filament is discharged into the sample container during the entire time of submergence, even after the sample bottle is completely filled. The air in the sample container displaced by the sample may escape through the air exhaust port. A fixed head differential of 11/16 inch between the intake nozzle and the air exhaust port facilitates sampling in stream with low velocities or slack water. If the bottle becomes entirely full, the sample may not be representative and should be discarded. Although the capacity of the sample bottle is approximately 470 mL, the tilt of the bottle is such that any sample containing more than 420 mL of a water-sediment mixture may be in error. In order to provide sufficient sample for a laboratory analysis, the length of time the sampler remains submerged should be adequate to produce a sample volume greater than 375 mL but not exceed 420 mL. It is generally preferable to save an initial sample smaller than 375 mL and sample the stream vertical a second time, or even a third time. Each of the supplemental samples should be collected in the same sample bottle. However, sufficient latitude in minimum sample volumes should be permitted to obviate retaking a large number of samples.

Limitations

Velocity limitations: The US DH-48 sampler will collect acceptable flow weighted samples in streams with velocities from 1 to 9 ft/sec. An acceptable velocity range is one at which a representative flow weighted sample is collected at a sampler inflow efficiency between 90% and 110%. Inflow efficiency is defined as the ratio of the sample velocity entering the nozzle to the ambient stream velocity. An inflow efficiency of 100% is referred to as isokinectic. A graphical presentation of inflow efficiencies for the US DH-48 is presented in (figure 2)[1].

Depth limitation: The US DH-48 sampler will collect flow-weighted samples to a maximum depth of approximately 9 ft at sea level. This depth is much greater than can be waded. To sample at depths greater than wade-able, wading rod extensions (available from FISP in 1- and 3-foot lengths) can be added to the sampler. The sampler can then be deployed from a low bridge or boat.

Maximum safe wading depths depend on the size of the field technician, the stream velocity, and the streambed material. A wading factor can be easily determined by multiplying the depth (in feet) of the stream by the stream velocity (in ft/sec). For safety, a stream condition that produces a factor of 10 or greater should not be waded. In addition, if the stream depth is greater than three feet caution should be used. A field technician that is 5 ft tall weighing 120 lbs should likely avoid streams with 3-ft and greater depths. However, a field technician that is 6 ft tall and weighs 200 lbs would normally be able to wade 3-ft deep streams with little difficulty. It is important that field technicians know and strictly adhere to their personal wading limits. Additional caution should be used when the streambed is composed of loose or slippery material. Algae coated cobbles can be as slippery and dangerous as ice. Safety should always be a field technician's first priority. Always wear a personal flotation device when collecting a wading sample.

Unsampled zone: The US DH-48 can sample to within 3 1/2 inches of the streambed. This unsampled zone is due to the distance between the nozzle and the bottom of the sampler.

Transit rate limitations: The transit rate (R_t) is the speed of lowering and raising the sampler in the sampling vertical. A transit rate diagram for the US DH-48 is presented in figure 3[2,3]. Acceptable transit rates for the US DH-48 sampler can be selected by using this diagram. The light blue shaded area of the transit rate diagram corresponds to combinations of sampling depths, transit rates, and mean velocities that will produce sample volumes between 300 and 420 mL. The dark blue shaded area of the transit rate diagram corresponds to combinations of sampling depths, transit rates, and mean velocities that will produce sample volumes less than 300 mL. The white or non shaded areas of the transit rate diagram corresponds to combinations of sampling depths, transit rates, and mean velocities that will produce overfilled samples (to the left of the shaded areas) or compression induced excessive nozzle inflow velocities (to the right of the shaded areas).

The following factors should be considered when selecting a transit rate:

1. R_t must be fast enough so that the bottle is not overfilled.
2. R_t must be slow enough to obtain a sample of sufficient volume to provide enough sediment for analysis.
3. R_t must be slow enough to not exceed the approach angle limit. The approach angle limit for the US DH-48 (and all isokinetic FISP samplers) is 0.4 the mean stream velocity.
4. R_t must be slow enough to not exceed the compression rate limit.

Instruction for use of the US DH-48 sampler

Sampler inspection: The sampler body should be inspected for damage and missing parts. Both ends of the exhaust port should be clear and unobstructed. The exhaust port can be damaged if the sampler is struck against a rock while sampling or dropped during transportation. An obstructed air exhaust port can adversely affect the sampler inflow efficiency. The threads in nozzle hole and wading rod receptacle should be checked for stripping and obstructions. The threads in the wading rod receptacle can be chased with a 3/8-20 NS threading tap. The threads in the nozzle hole can be chased with a 7/16-20 NF threading tap. Check the bottle retainer for adequate tension to hold the sample container in place. Check the gasket seat area inside the head of the sampler for burrs and obstructions that would interfere with the seating of the gasket.

The sampler nozzle, bottle gasket, sampler container, wading rod, and wading rod extensions should also be inspected. Plastic nozzles produced by FISP for the US DH-48 sampler are dyed yellow and the brass nozzles are stamped with the numerals "48". The nozzle should be straight with no visible signs of damage. The bore should also be inspected for straightness and any signs of burrs or deformity. The threads on the nozzle should be checked for damage. If thread damage is found the threads can be chased with a 7/16-20 NF threading die. If damage or burrs are found in the bore or at either opening it should be discarded and replaced with a new nozzle.

FISP recommends neoprene gaskets for the US DH-48 sampler. If the gasket is hard to the touch, torn, or deformed to the point that it will not fit flush in the gasket seat area of the sampler, it should be discarded and replaced with a new gasket. The gasket is press fit by hand into the seat in the head of the sampler. If the gasket is in good condition, it should remain in place once it is pressed into the seat. No adhesives or mechanical devices are required to retain the gasket in the sampler.

A 1-pint glass milk bottle is the recommended sample container for the US DH-48 sampler. It should be inspected for cracks or chips and should be cleaned prior to going to the field. Cracked bottles should be replaced. A bottle with a chipped area can be used if it does not impair the soundness of the bottle and the chip is not in the mouth area of the bottle and would prevent an adequate seal with the bottle gasket.

The wading rod and any wading rod extensions should be checked for damage to the screw threads. If damage is found, the threads can be chased with a 3/8-20 NS threading die. The female threads of wading rod extensions can be chased with a 3/8-20 NS threading tap. Attempting to mate a wading rod or wading rod extension with damaged threads to a US DH-48 sampler can damage the threads in the softer material (aluminum) of the US DH-48.

Sampler assembly: Once the sampler body and associated equipment has been checked for damage, screw the wading rod into the top the sampler. If the stream depth is near 3 ft deep or greater, a wading rod extension can be added to allow easier control of the sampler in the deeper streams. Wading rod extensions are available in 1- and 3-ft lengths.

The nozzle should be screwed into the sampler by hand. FISP strongly advises that wrenches and pliers not be used to install the nozzle. It is easy to over tighten the nozzle and damage the threads. If the threads in the sampler and on the nozzle are not damaged, the use of tools to insert the nozzle should not be required.

The final step in the assembly of the sampler is installation of the sample container (1-pint milk bottle). The sampler should be turned upside down and the bottle retainer rotated approximately 90° to the left or right of the centerline of the sampler. This will allow the bottle to be slid into the sampler body. Once the bottle is in place and its mouth pressed against the gasket; the bottle retainer should be pulled rearward to clear the base of the bottle, turned until it is centered over the base of the bottle, and tension gently released to press the bottle against the gasket. To assure the mouth of the bottle is properly sealed against the bottle gasket, the bottle should be rotated left and right. To check for an air-tight seal between the bottle and the sampler; place a short length of clean flexible tubing over the nozzle, block the air exhaust port with a finger, and gently blow (by mouth) into the tube that is attached to the nozzle. Do not place mouth directly on the sampler or nozzle. They may be contaminated from previous sampling. No air should escape from the sampler. If air escapes, the bottle should be reseated against the bottle gasket and rechecked.

Sampling: Prior to collecting a sample, measure or estimate the mean stream velocity. The time required to fill the sample container to 395 mL can be selected from table 1. The transit rate can be determined by dividing the sampling time by two times the depth of the stream. Once calculated, the transit rate diagram in figure 4 should be checked to determine that it falls within acceptable limits.

Example:

If $V_{(\text{mean stream velocity})} = 4.0$ ft/sec,
$T_{(\text{sampling time})} = 10$ (selected from table 1).
For a stream with $D_{(\text{stream depth})} = 2.5$ ft,
$R_t = (2 \times D_{(\text{stream depth})}) \div T_{(\text{sampling time})} = (2 \times 2.5 \text{ ft}) \div 10 \text{ sec} = 0.5$ ft/sec.
This example assumes that a sample of 395 mL is collected.

The transit rate can also be selected by using the transit rate diagram. Using the information from the previous example; draw a horizontal line on the diagram that corresponds to the depth of 4 ft. Next select a point on the previously drawn line in the middle of the light blue shaded area. From this point draw a vertical line to intercept the bottom axis. The number that corresponds to the intersection of the vertical line and the bottom axis is multiplied by the mean stream velocity to produce the transit rate.

When wading a stream to collect a sample, the field technician should attempt to minimize flow resistance and maximize stability. By turning sideways the force of the water that would push the field technician downstream can be minimized. Using this stance while slightly bending the upstream knee and leaning into the flow will increase stability.

The sampler should be held away from the field technician's body and as far upstream as possible while still maintaining stability (figure 4). The wading rod should be held vertically with the sampler and nozzle pointing upstream and as far away from any disturbance to the flow caused by the field technician. Using a constant transit rate, previously selected, lower the sampler through the water until it reaches the bottom. Care should used to avoid breaking the sample bottle as it touches the bottom and to prevent stirring up loose sediment that could bias the sample. Once the sampler touches the bottom, immediately reverse the direction of the transit and raise the sampler, using the same transit rate, until it clears the surface of the water. If sample volumes are not being composited, cap and label each bottle. Each sample label should contain adequate information to identify the sample and to satisfy the purposes of the investigation. The following items are suggested:

- Name of stream
- Location of the cross section
- Location of the vertical
- Stream depth covered by the sample
- Stage of the stream
- Date
- Time of day
- Identification of personnel
- Sampling time
- Water temperature
- Coordination with sample groups
- Serial number of sample

Questions and comments regarding sampler operation should be addressed to:

FEDERAL INTERAGENCY SEDIMENTATION PROJECT
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS. 39180-6199
(601) 634-2721
woneal@usgs.gov

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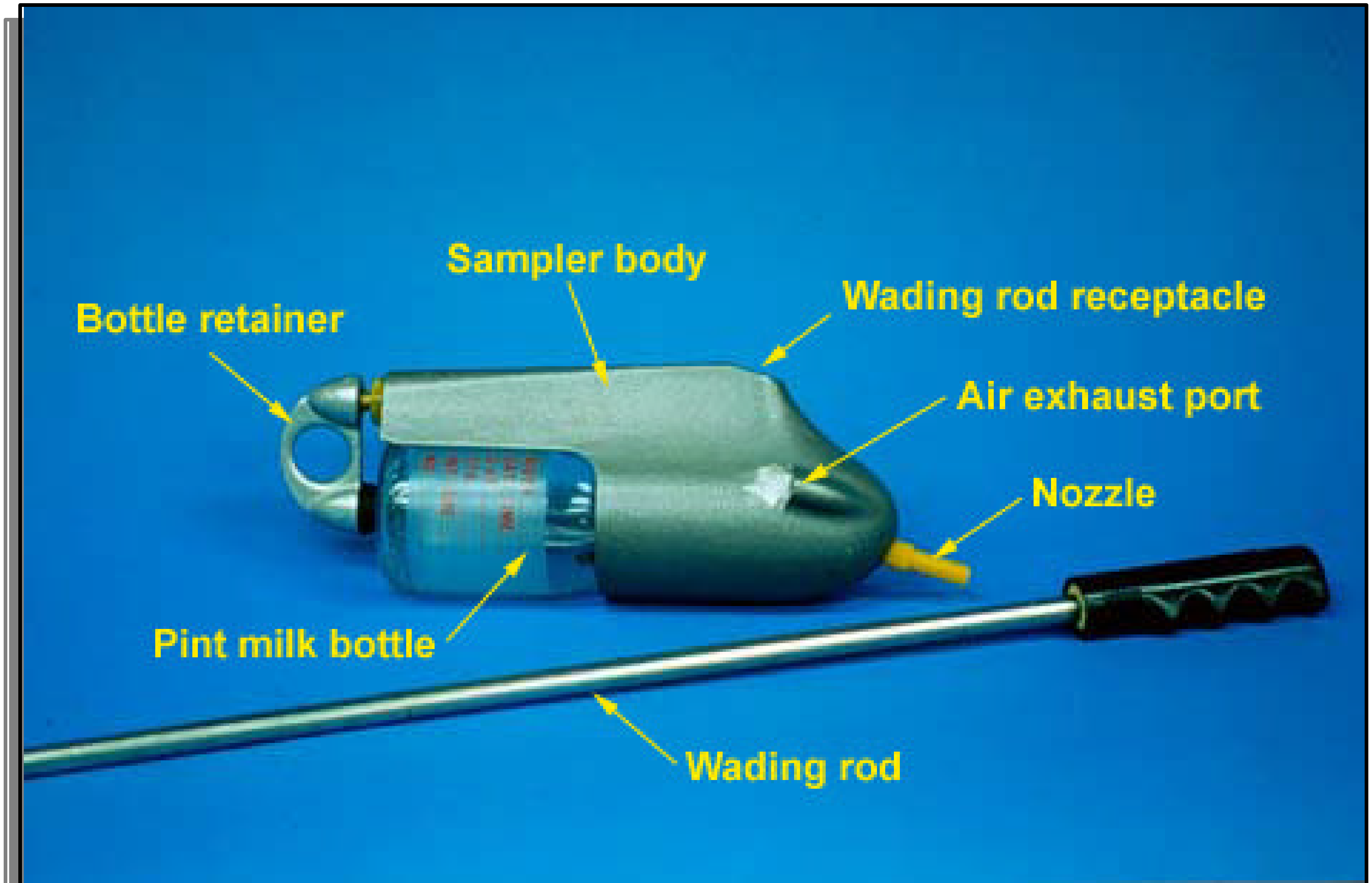


Figure 1. US DH-48 Suspended-Sediment Sampler

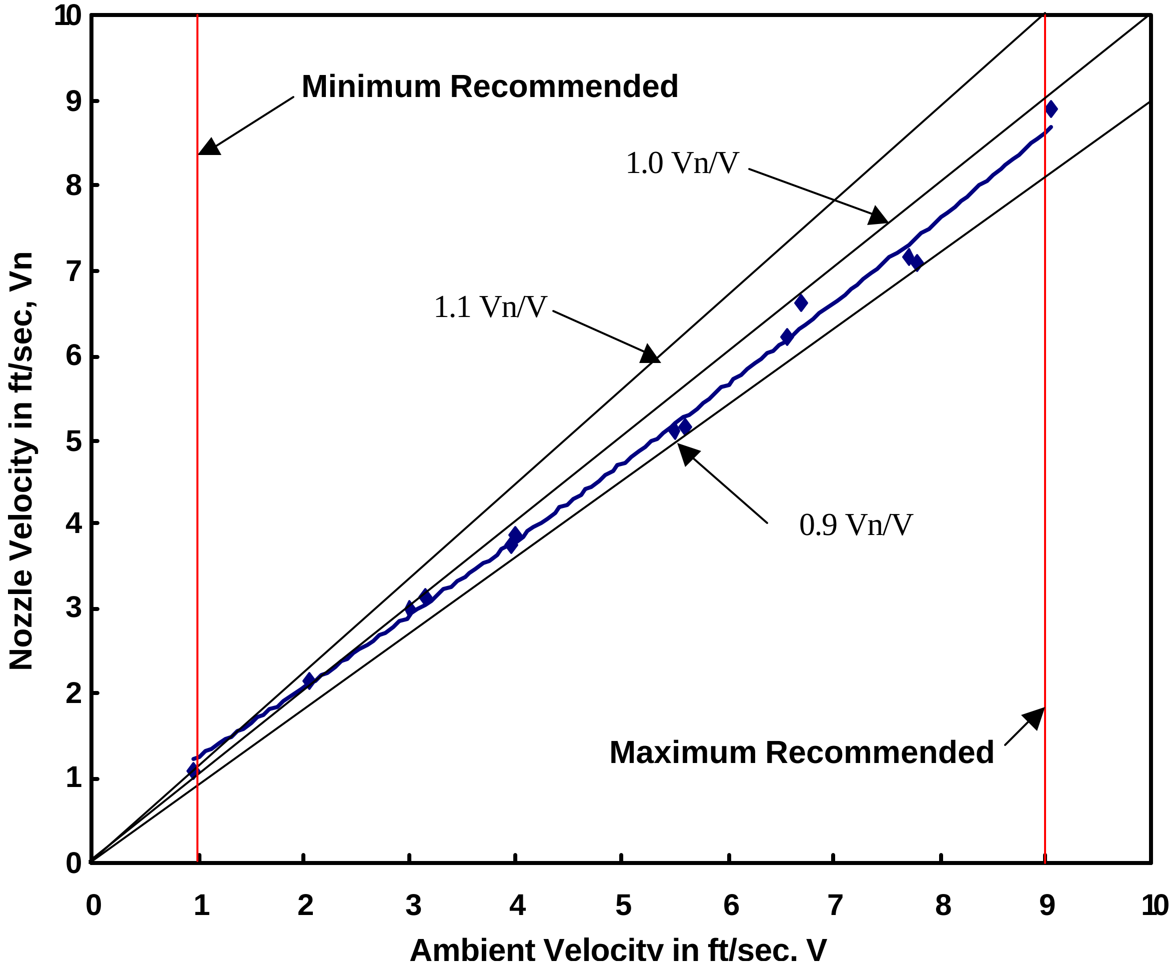
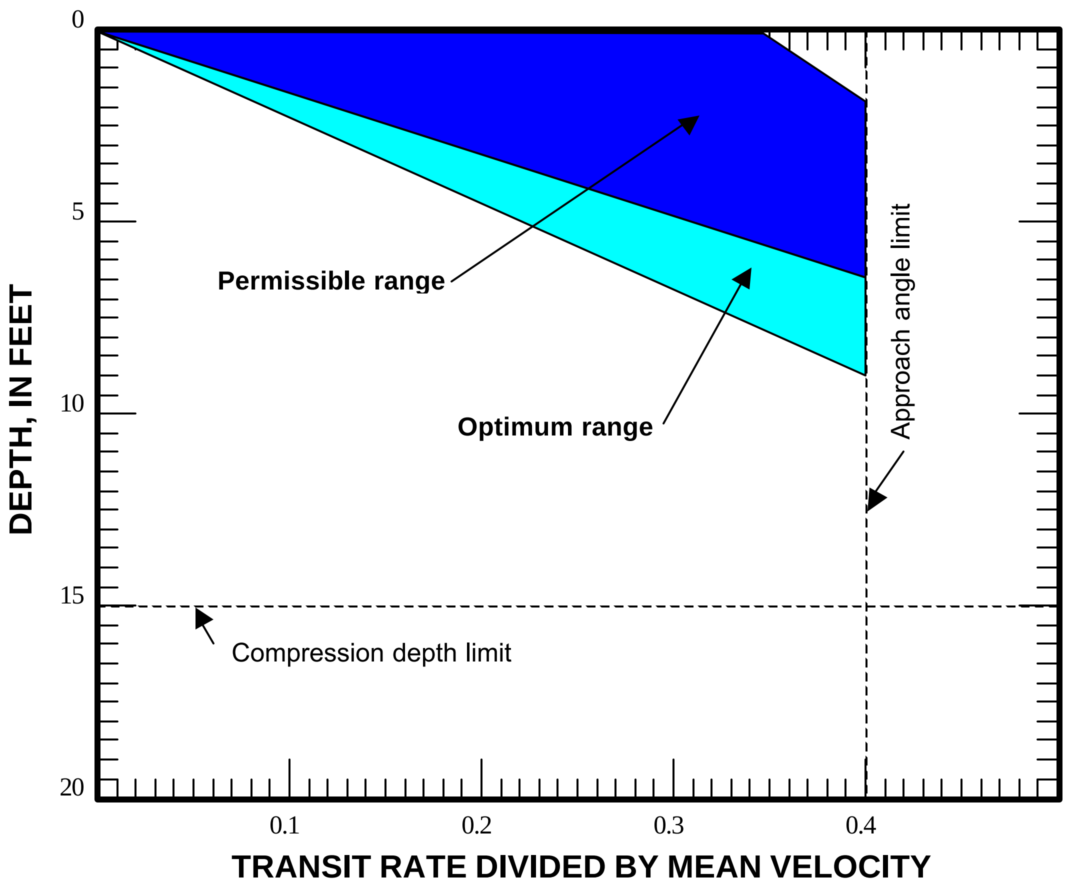


Figure 2. Inflow Efficiency diagram for the US DH-48



Note: The following configuration and volumes were used to produce this diagram. The total volume of the sampler container was 470 mL. The maximum optimum sample volume was 420 mL. The minimum optimum sample volume was 300 mL.

Figure 3. Transit Rate Diagram for the US DH-48 sampler

Figure 4. Proper wading sampling stance using a US DH-48 sampler

Velocity in ft/sec	Volume in ml	Time in seconds
1.0	395	41
1.2	395	34
1.4	395	29
1.6	395	26
1.8	395	23
2.0	395	20
2.2	395	19
2.4	395	17
2.6	395	16
2.8	395	15
3.0	395	14
3.2	395	13
3.4	395	12
3.6	395	11
4.0	395	10
4.8	395	9
5.2	395	8
5.8	395	7
6.8	395	6
7.6	395	5
9.0	395	4

TABLE 1. Filling times for the US DH-48 Sampler

CHAIN OF CUSTODY RECORD

BALANCE HYDROLOGICS

SAMPLERS: *(Signature)*

____

Phone: ______________________________

SHIP TO:

____

____

____

____

ATTENTION: ______________________________

Phone No. ______________________________

SHIPPING INFORMATION

Shipper ______________________________

Address ______________________________

Date Shipped ______________________________

Shipment Service ______________________________

Airbill No. ______________________________

Cooler No. ______________________________

____

Relinquished by: *(Signature)*	Received by: *(Signature)*	Date/Time
Relinquished by: *(Signature)*	Received by: *(Signature)*	Date/Time
Relinquished by: *(Signature)*	Received by: *(Signature)*	Date/Time
Relinquished by: *(Signature)*	Receive for laboratory by*: *(Signature)*	Date/Time

*Analysis lab should complete, "sample condition upon receipt" section below, sign and return top copy to Balance Hydrologics 800 Bancroft Way, Suite 101, Berkeley, CA 94710

Sample Number	Site Identification	Date Sampled	Analysis Requested	Sample Condition Upon Receipt

INSTRUCTIONS: Laboratory reports should reference and be billed by site ID# and contain the following:

summary of analytical methodology and QA work (blanks, spikes, duplicates)
dates for (a) sampling, (b) lab receipt, (c) extraction, (d) injection/analysis
detection limits for all constituents analyzed for and reporting of all constituents detected which were not specifically designated

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METHOD #: 160.2	Approved for NPDES (Issued 1971)
TITLE:	Residue, Non-Filterable (Gravimetric, Dried at 103-105°C)
ANALYTE:	Residue ,Non-Filterable
INSTRUMENTATION:	Drying Oven
STORET No.	00530

1.0 Scope and Application

1.1 This method is applicable to drinking, surface, and saline waters, domestic and industrial wastes.

1.2 The practical range of the determination is 4 mg/L to 20,000 mg/L.

2.0 Summary of Method

2.1 A well-mixed sample is filtered through a glass fiber filter, and the residue retained on the filter is dried to constant weight at 103-105°C.

2.2 The filtrate from this method may be used for Residue, Filterable.

3.0 Definitions

3.1 Residue, non-filterable, is defined as those solids which are retained by a glass fiber filter and dried to constant weight at 103-105°C.

4.0 Sample Handling and Preservation

4.1 Non-representative particulates such as leaves, sticks, fish, and lumps of fecal matter should be excluded from the sample if it is determined that their inclusion is not desired in the final result.

4.2 Preservation of the sample is not practical; analysis should begin as soon as possible. Refrigeration or icing to 4°C, to minimize microbiological decomposition of solids, is recommended.

5.0 Interferences

5.1 Filtration apparatus, filter material, pre-washing, post-washing, and drying temperature are specified because these variables have been shown to affect the results.

5.2 Samples high in Filterable Residue (dissolved solids), such as saline waters, brines and some wastes, may be subject to a positive interference. Care must be taken in selecting the filtering apparatus so that washing of the filter and any dissolved solids in the filter (7.5) minimizes this potential interference.

6.0 Apparatus

6.1 Glass fiber filter discs, without organic binder, such as Millipore AP-40, Reeves Angel 934-AH, Gelman type A/E, or equivalent.
NOTE: Because of the physical nature of glass fiber filters, the absolute pore size cannot be controlled or measured. Terms such as "pore size", collection efficiencies and effective retention are used to define this property in glass fiber filters. Values for these parameters vary for the filters listed above.

6.2 Filter support: filtering apparatus with reservoir and a coarse (40-60 microns) fritted disc as a filter support.
NOTE: Many funnel designs are available in glass or porcelain. Some of the most common are Hirsch or Buchner funnels, membrane filter holders and Gooch crucibles. All are available with coarse fritted disc.

6.3 Suction flask.

6.4 Drying oven, 103-105°C.

6.5 Desiccator.

6.6 Analytical balance, capable of weighing to 0.1 mg.

7.0 Procedure

7.1 Preparation of glass fiber filter disc: Place the glass fiber filter on the membrane filter apparatus or insert into bottom of a suitable Gooch crucible with wrinkled surface up. While vacuum is applied, wash the disc with three successive 20 mL volumes of distilled water. Remove all traces of water by continuing to apply vacuum after water has passed through. Remove filter from membrane filter apparatus or both crucible and filter if Gooch crucible is used, and dry in an oven at 103-105°C for one hour. Remove to desiccator and store until needed. Repeat the drying cycle until a constant weight is obtained (weight loss is less than 0.5 mg). Weigh immediately before use. After weighing, handle the filter or crucible/filter with forceps or tongs only.

7.2 Selection of Sample Volume
For a 4.7 cm diameter filter, filter 100 mL of sample. If weight of captured residue is less than 1.0 mg, the sample volume must be increased to provide at least 1.0 mg of residue.If other filter diameters are used, start with a sample volume equal to 7 mL/cm^2 of filter area and collect at least a weight of residue proportional to the 1.0 mg stated above.
NOTE: If during filtration of this initial volume the filtration rate drops rapidly, or if filtration time exceeds 5 to 10 minutes, the following scheme is recommended: Use an unweighed glass fiber filter of choice affixed in the filter assembly. Add a known volume of sample to the filter funnel and record the time elapsed after selected volumes have passed through the filter. Twenty-five mL increments for timing are suggested. Continue to record the time and volume increments until filtration rate drops rapidly. Add additional sample if the filter funnel volume is inadequate to reach a reduced rate. Plot the observed time versus volume filtered. Select the proper filtration volume as that just short of the time a significant change in filtration rate occurred.

7.3 Assemble the filtering apparatus and begin suction. Wet the filter with a small volume of distilled water to seat it against the fritted support.

7.4 Shake the sample vigorously and quantitatively transfer the predetermined sample volume selected in 7.2 to the filter using a graduated cylinder. Remove all traces of water by continuing to apply vacuum after sample has passed through.

7.5 With suction on, wash the graduated cylinder, filter, non-filterable residue and filter funnel wall with three portions of distilled water allowing complete drainage between washing. Remove all traces of water by continuing to apply vacuum after water has passed through.

NOTE: Total volume of wash water used should equal approximately 2 mL per cm^2. For a 4.7 cm filter the total volume is 30 mL.

7.6 Carefully remove the filter from the filter support. Alternatively, remove crucible and filter from crucible adapter. Dry at least one hour at 103-105°C. Cool in a desiccator and weigh. Repeat the drying cycle until a constant weight is obtained (weight loss is less than 0.5 mg).

8.0 Calculations

8.1 Calculate non-filterable residue as follows:

$$\text{Non-filterable residue, mg/L} = \frac{(A - B) \times 1{,}000}{C}$$

where:

A = weight of filter (or filter and crucible) + residue in mg
B = weight of filter (or filter and crucible) in mg
C = mL of sample filtered

9.0 Precision and Accuracy

9.1 Precision data are not available at this time.

9.2 Accuracy data on actual samples cannot be obtained.

Bibliography

1. NCASI Technical Bulletin No. 291, March 1977. National Council of the Paper Industry for Air and Stream Improvement, Inc., 260 Madison Ave., NY.

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A8

DISCHARGE MEASUREMENTS AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Book 3

APPLICATIONS OF HYDRAULICS

UNITED STATES DEPARTMENT OF THE INTERIOR

THOMAS S. KLEPPE, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

First printing 1969
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PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called books and further subdivided into sections and chapters; section A of book 3 is on surface-water techniques.

Provisional drafts of chapters are distributed to field offices of the U.S. Geological Survey for their use. These drafts are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment. After the technique described in a chapter is sufficiently developed, the chapter is published and is sold by the U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202 .(authorized agent of Superintendent of Documents, Government Printing Office).

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DISCHARGE MEASUREMENTS AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Abstract

The techniques used in making discharge measurements at gaging stations are described in this report. Most of the report deals with the current-meter method of measuring discharge, because this is the principal method used in gaging streams. The use of portable weirs and flumes, floats, and volumetric tanks in measuring discharge are briefly described.

Introduction

The U.S. Geological Survey makes thousands of streamflow measurements each year. Discharges measured range from a trickle in a ditch to a flood on the Amazon. Several methods are used, but the Geological Survey makes most streamflow measurements by current meter. The purpose of this report is to describe in detail the procedures used by the Geological Survey for making current-meter measurements and to describe briefly several of the other methods of measuring streamflow.

Streamflow, or discharge, is defined as the volume rate of flow of the water including any sediment or other solids that may be dissolved or mixed with it. Dimensions are usually expressed in cubic feet per second. Other common units are million gallons per day and acre-feet per day.

Current-Meter Measurements

A current-meter measurement is the summation of the products of the partial areas of the stream cross section and their respective average velocities. The formula

$$Q=\Sigma(a\ v) \qquad (1)$$

represents the computation where Q is total discharge, a is an individual partial cross-section area, and v is the corresponding mean velocity of the flow normal to the partial area.

In the midsection method of making a current-meter measurement it is assumed that the velocity sample at each location represents the mean velocity in a partial rectangular area. The area extends laterally from half the distance from the preceding meter location to half the distance to the next and vertically, from the water surface to the sounded depth. (See fig. 1.)

The cross section is defined by depths at locations 1, 2, 3, 4, . . . n. At each location the velocities are sampled by current meter to obtain the mean of the vertical distribution of velocity. The partial discharge is now computed for any partial section at location x as

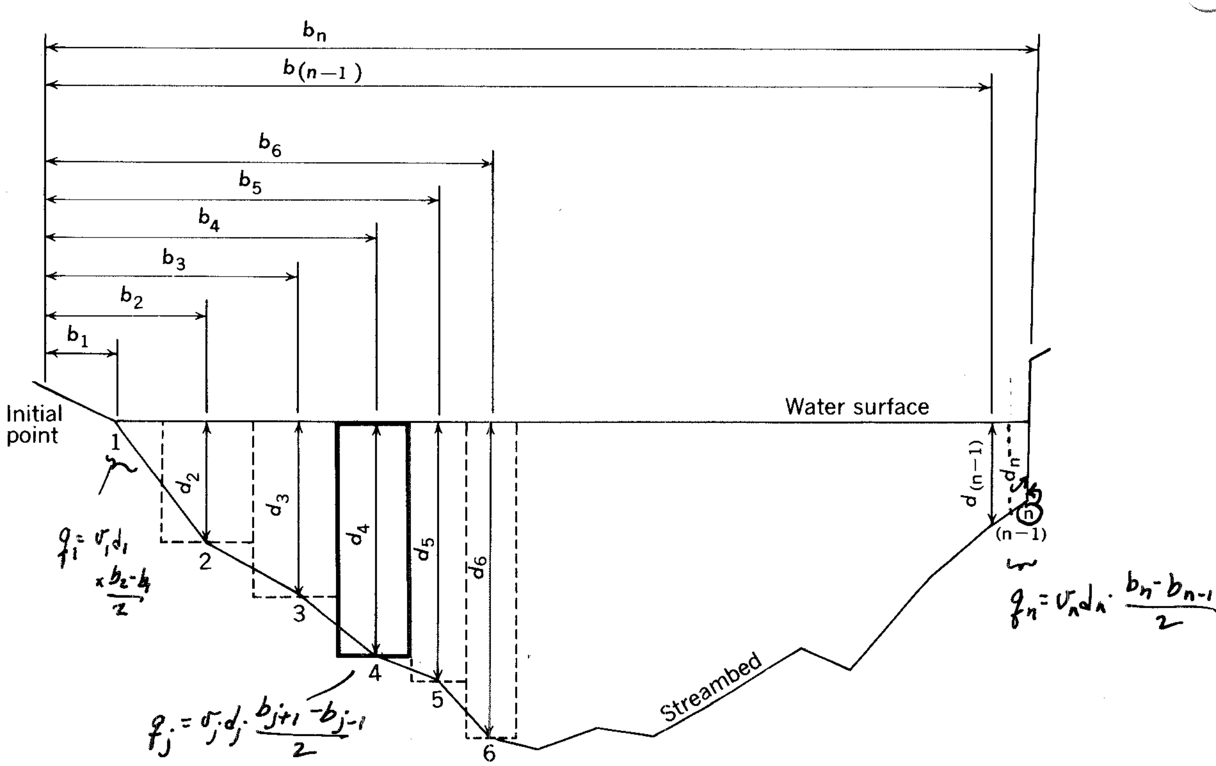
$$q_x=v_x\left[\frac{(b_x-b_{(x-1)})}{2}+\frac{(b_{(x+1)}-b_x)}{2}\right]d_x$$

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

where

q_x = discharge through partial section x,
v_x = mean velocity at location x,
b_x = distance from initial point to location x,
$b_{(x-1)}$ = distance from initial point to preceding location,
$b_{(x+1)}$ = distance from initial point to next location,
d_x = depth of water at location x.

326-253 O—69——2



EXPLANATION

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

Figure 1.—Definition sketch of midsection method of computing cross-section area for discharge measurements.

Thus, for example, the discharge through partial section 4 (heavily outlined in fig. 1) is

$$q_4 = v_4\left[\frac{b_5 - b_3}{2}\right]d_4. \quad = v_i d_i \frac{b_{i+1}-b_{i-1}}{2}$$

The procedure is similar when x is at an end section. The "preceding location" at the beginning of the cross section is considered coincident with location 1; the "next location" at the end of the cross section is considered coincident with location n. Thus,

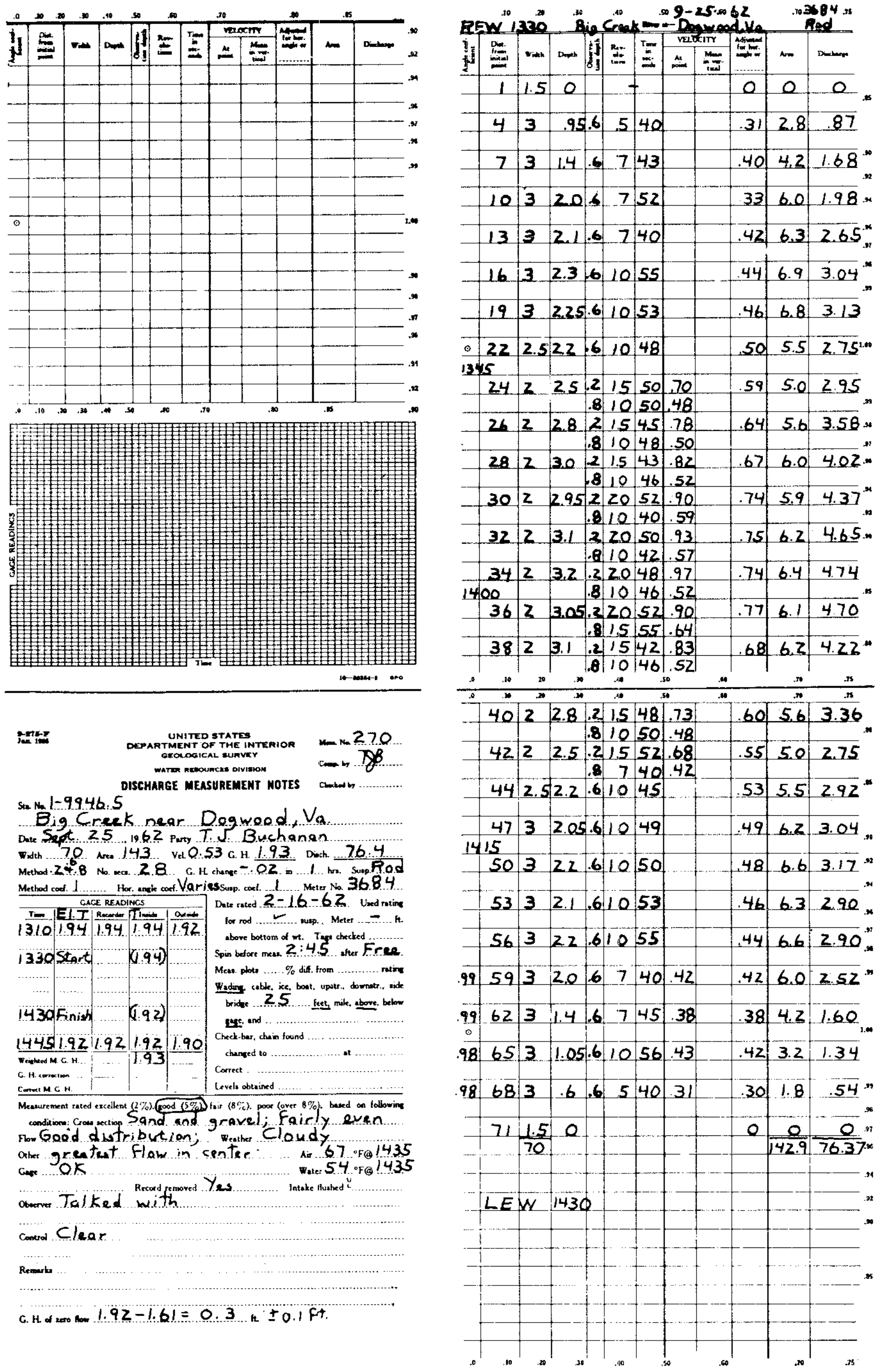
$$q_1 = v_1\left[\frac{b_2 - b_1}{2}\right]d_1, \text{ and}$$

$$q_n = v_n\left[\frac{b_n - b_{(n-1)}}{2}\right]d_n.$$

For the example shown in figure 1, q_1 is zero because the depth at observation point 1 is zero. However, when the cross-section boundary is a vertical line at the edge of the water as at location n, the depth is not zero and velocity at the end section may or may not be zero. The formula for q_1 or q_n is used whenever there is water only on one side of an observation point such as at piers, abutments, and islands. It usually is necessary to estimate the velocity at an end section as some percentage of the adjacent section because it normally is impossible to measure the velocity accurately with the current meter close to a boundary. There also is the possibility of damage to the equipment if the flow is turbulent.

The summation of the discharges for all the partial sections is the total discharge of the stream. An example of the measurement notes is shown in figure 2.

The mean-section method used by the Survey prior to 1950 differs from the midsection method in computation procedure. Partial discharges are computed for partial sections between successive locations. The velocities and depths at successive locations are each averaged, and



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

GAGE READINGS

Time

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

DISCHARGE MEASUREMENT NOTES

Meas. No. 270
Comp. by TJB
Checked by

Sta. No. 1-9946.5
Big Creek near Dogwood, Va.
Date Sept. 25 1962 Party T. J. Buchanan
Width 70 Area 143 Vel. 0.53 G. H. 1.93 Disch. 76.4
Method .2-.8 / .6 No. secs. 28 G. H. change -.02 in 1 hrs. Susp. Rod
Method coef. 1 Hor. angle coef. Varies Susp. coef. 1 Meter No. 3684

GAGE READINGS Time	ELT	Recorder	Inside	Outside
1310	1.94	1.94	1.94	1.92
1330	Start		(1.94)	
1430	Finish		(1.92)	
1445	1.92	1.92	1.92	1.90
Weighted M. G. H.			1.93	
G. H. correction				
Correct M. G. H.				

Date rated 2-16-62. Used rating for rod ✓ susp., Meter — ft. above bottom of wt. Tags checked
Spin before meas. 2:45 after Free
Meas. plots % diff. from rating
Wading, cable, ice, boat, upstr., downstr., side bridge 25 feet, mile, above, below gage, and
Check-bar, chain found
changed to at
Correct
Levels obtained

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions: Cross section Sand and gravel; Fairly even
Flow Good distribution; Weather Cloudy
Other greatest flow in center Air 67 °F@ 1435
Gage OK Water 54 °F@ 1435
Record removed Yes Intake flushed
Observer Talked with
Control Clear
Remarks
G. H. of zero flow 1.92 - 1.61 = 0.3 ft. ± 0.1 Ft.

REW 1330 Big Creek near Dogwood, Va. 9-25-62 3684 Rod

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	1.5	0						0	0	0
	4	3	.95	.6	5	40			.31	2.8	.87
	7	3	1.4	.6	7	43			.40	4.2	1.68
	10	3	2.0	.6	7	52			33	6.0	1.98
	13	3	2.1	.6	7	40			.42	6.3	2.65
	16	3	2.3	.6	10	55			.44	6.9	3.04
	19	3	2.25	.6	10	53			.46	6.8	3.13
⊙	22	2.5	2.2	.6	10	48			.50	5.5	2.75
1345											
	24	2	2.5	.2	15	50	.70		.59	5.0	2.95
				.8	10	50	.48				
	26	2	2.8	.2	15	45	.78		.64	5.6	3.58
				.8	10	48	.50				
	28	2	3.0	.2	15	43	.82		.67	6.0	4.02
				.8	10	46	.52				
	30	2	2.95	.2	20	52	.90		.74	5.9	4.37
				.8	10	40	.59				
	32	2	3.1	.2	20	50	.93		.75	6.2	4.65
				.8	10	42	.57				
	34	2	3.2	.2	20	48	.97		.74	6.4	4.74
1400				.8	10	46	.52				
	36	2	3.05	.2	20	52	.90		.77	6.1	4.70
				.8	15	55	.64				
	38	2	3.1	.2	15	42	.83		.68	6.2	4.22
				.8	10	46	.52				
	40	2	2.8	.2	15	48	.73		.60	5.6	3.36
				.8	10	50	.48				
	42	2	2.5	.2	15	52	.68		.55	5.0	2.75
				.8	7	40	.42				
	44	2.5	2.2	.6	10	45			.53	5.5	2.92
	47	3	2.05	.6	10	49			.49	6.2	3.04
1415											
	50	3	2.2	.6	10	50			.48	6.6	3.17
	53	3	2.1	.6	10	53			.46	6.3	2.90
	56	3	2.2	.6	10	55			.44	6.6	2.90
.99	59	3	2.0	.6	7	40	.42		.42	6.0	2.52
.99	62	3	1.4	.6	7	45	.38		.38	4.2	1.60
⊙											
.98	65	3	1.05	.6	10	56	.43		.42	3.2	1.34
.98	68	3	.6	.6	5	40	.31		.30	1.8	.54
	71	1.5	0						0	0	0
		70								142.9	76.37
	LEW	1430									

Figure 2.—Computation notes of a current-meter measurement by the midsection method.

the section extends laterally from one observation point to the next. Discharge is the product of the average of two mean velocities, the average of two depths, and the distance between locations. A study by Young (1950) concluded that the midsection method is simpler to compute and is a slightly more accurate procedure than the mean-section method.

Current-meter measurements usually are classified in terms of the means used to cross the stream during the measurement, such as wading, cableway, bridge, boat, or ice.

Instruments and equipment

Current meters, timers, and counting equipment are used when making conventional types of measurements. Additional equipment used depends on the type of measurements being made. Instruments and equipment used in making current-meter measurements are described in this section under the following categories: current meters, sounding equipment, width-measuring equipment, equipment assemblies, and miscellaneous equipment.

Current meters

A current meter is an instrument used to measure the velocity of flowing water. The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a current meter at a point in a stream and counting the number of revolutions of the rotor during a measured interval of time, the velocity of water at that point is determined.

The number of revolutions of the rotor is obtained by an electrical circuit through the contact chamber. Contact points in the chamber are designed to complete an electrical circuit at selected frequencies of revolution. Contact chambers can be selected having contact points that will complete the circuit twice per revolution, once per revolution, or once per five revolutions. The electrical impulse produces an audible click in a headphone or registers a unit on a counting device.

The counting intervals are measured by a stopwatch.

Current meters generally can be classified into two main types, those meters having vertical-axis rotors and those having horizontal-axis rotors. The comparative characteristics of these two types are summarized below:

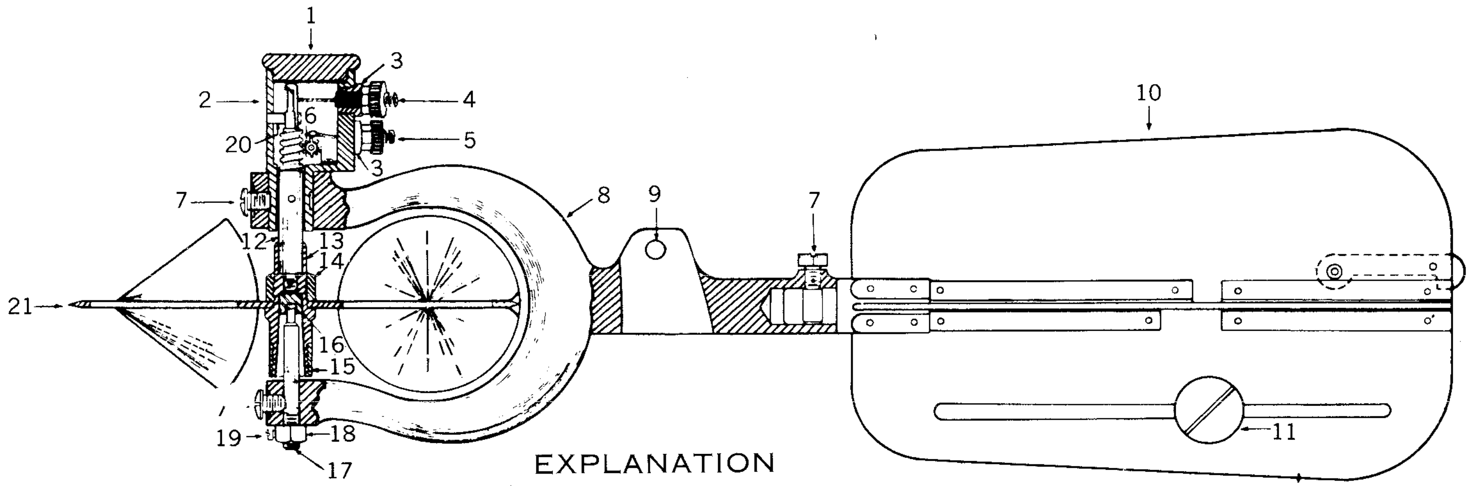
1. Vertical-axis rotor with cups or vanes.
   a. Operates in lower velocities than do horizontal-axis meters.
   b. Bearings are well-protected from silty water.
   c. Rotor is repairable in the field without adversely affecting the rating.
   d. Single rotor serves for the entire range of velocities.
2. Horizontal-axis rotor with vanes.
   a. Rotor disturbs flow less than do vertical-axis rotors because of axial symmetry with flow direction.
   b. Rotor is less likely to be entangled by debris than are vertical-axis rotors.
   c. Bearing friction is less than for vertical-axis rotors because bending moments on the rotor are eliminated.

Vertical-axis current meters

The most common type of vertical-axis current meter is the Price meter, type AA. (See fig. 3.) This meter is used extensively by the Geological Survey. The standard Price meter has a rotor 5 inches in diameter and 2 inches high with six cone-shaped cups mounted on a stainless-steel shaft. A pivot bearing supports the rotor shaft. The contact chamber houses the upper part of the shaft and an an eccentric contact that wipes a bead of solder on a slender bronze wire (cat's whisker) attached to the binding post. A separate reduction gear (pentagear), wire, and binding post provide a contact each time the rotor makes five revolutions. A tailpiece keeps the meter pointing into the current.

In addition to the standard type AA meter for general use there is a type AA meter for low velocities. No pentagear is provided. This modification reduces friction. The shaft usually has two eccentrics making two contacts per revolution. The low-velocity meter normally is rated from 0.2 to 2.5 fps (feet per second) and is recommended when the mean velocity at a cross section is less than 1 fps.

In addition to the type AA meters, the Geological Survey uses a Price pygmy meter



EXPLANATION

1 Cap for contact chamber
2 Contact chamber
3 Insulating bushing for contact binding post
4 Single-contact binding post
5 Penta-contact binding post
6 Penta gear
7 Set screws
8 Yoke
9 Hole for hanger screw
10 Tailpiece
11 Balance weight
12 Shaft
13 Bucket-wheel hub
14 Bucket-wheel hub nut
15 Raising nut
16 Pivot bearing
17 Pivot
18 Pivot adjusting nut
19 Keeper screw for pivot adjusting nut
20 Bearing lug
21 Bucket wheel

Figure 3.—Assembly drawing of small Price type AA current meter.

in shallow depths. (See fig. 4.) The pygmy meter is scaled two-fifths as large as the standard meter and has neither a tailpiece nor a pentagear. The contact chamber is an integral part of the yoke of the meter. The pygmy meter makes one contact each revolution and is used only for rod suspension.

The Geological Survey has recently developed a four-vane vertical-axis meter. (See fig. 5.) This meter is useful for measurements under ice cover because the vanes are less likely to fill with slush ice, and because it requires a much smaller hole to pass through the ice. One yoke of the vane meter is made to be suspended at the end of a rod and will fit holes made by an ice drill. Another yoke is made for regular suspensions. (See fig. 5.) The vane meter has a disadvantage of not responding as well as the Price type AA meter at velocities below 0.5 fps.

A new contact chamber has been designed by the Geological Survey to replace the wiper contact of the type AA and vane meters. The new contact chamber contains a magnetic switch, glass enclosed in a hydrogen atmosphere and hermetically sealed. The switch assembly is rigidly fixed in the top of the meter head just above the tip of the shaft. The switch is operated by a small permanent magnet rigidly fastened to the shaft. The switch quickly closes when the magnet is alined with it, and then promptly opens when the magnet moves away. The magnet is properly balanced on the shaft. Any type AA meter can have a magnetic switch added by replacing the shaft and the contact chamber. (See fig. 6.) The magnetic switch is placed in the special contact chamber through the tapped hole for the binding post. The rating of the meter is not altered by the change. An automatic counter (see p. 31) is used with the magnetic-switch contact chamber. If a headphone is used, arcing can weld the contacts.

A Price meter accessory that indicates the direction of flow is described on page 27.

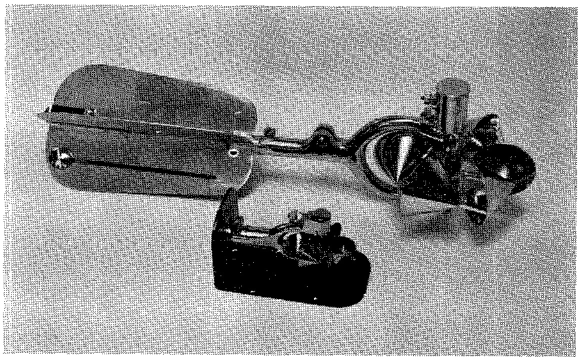


Figure 4.—Price type AA meter, top; and Price pygmy meter, bottom

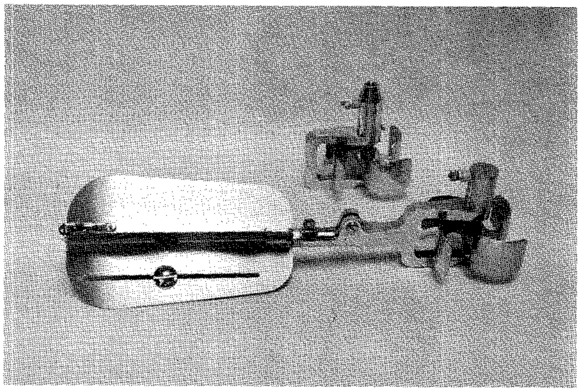


Figure 5 —Vane ice meter, top; and vane meter with cable suspension yoke, bottom.

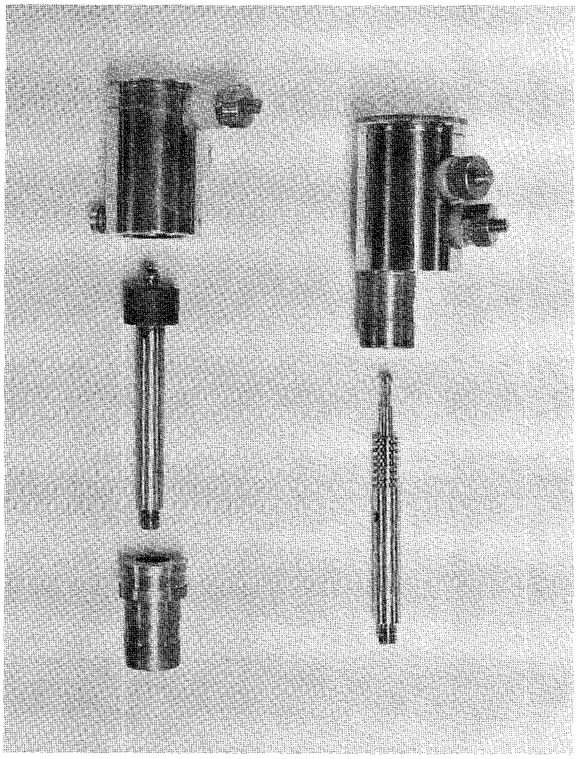


Figure 6 —Magnetic switch contact chamber, shaft, and adapter bushing, left; and cat's whisker contact chamber and shaft, right.

The care and rating of vertical-axis meters is described below and by Smoot and Novak (1968).

Horizontal-axis current meters

The types of horizontal-axis meters in use are the Ott, Neyrpic, Haskell, and Hoff. The Ott meter is made in Germany, the Neyrpic meter in France, and both are used extensively in Europe. The Haskell and Hoff meters were developed in the United States where they are used to a limited extent.

The Ott meter is a precision instrument but is not used extensively in this country because it is not as durable as the Price meter under extreme conditions. (See fig. 7.) The makers of the Ott meter have developed a component propeller which in oblique currents automatically registers the velocity projection at right angles to the measuring section for angles as much as 45° and velocities as much as 8 fps. For example, if this component propeller were held in the position *AB* in figure 8 it would register *V* cos *α* rather than *V*, which the Price meter would register.

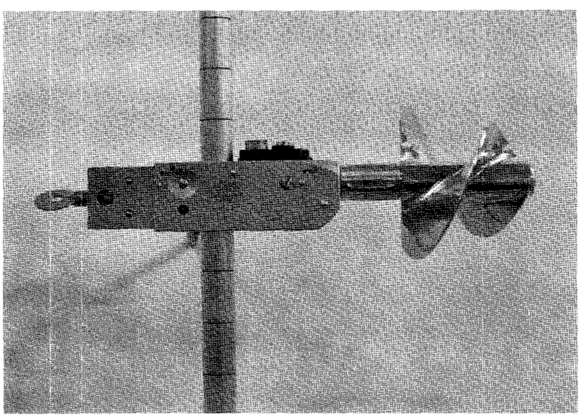


Figure 7.—Ott current meter.

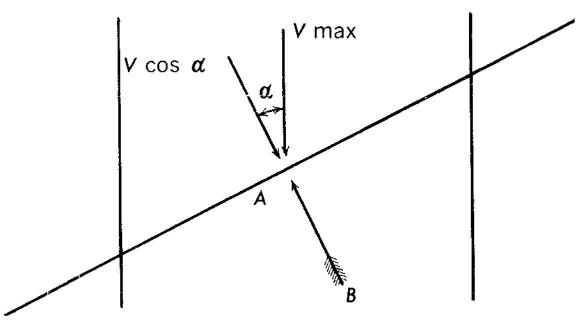


Figure 8.—Velocity components measured by Ott and Price current meters.

The Neyrpic meter is used rarely in this country because it has the same disadvantages as the Ott meter.

The Haskell meter has been used by the U.S. Lake Survey, Corps of Engineers, in streams that are deep, swift, and clear. By using propellers with a variety of screw pitches, a considerable range of velocity can be measured. The meter is durable, but has most of the other disadvantages of horizontal-axis meters.

The Hoff meter is used by the Geological Survey, the Department of Agriculture, and others, especially for measuring pipe flow. (See fig. 9.) The lightweight propeller has three or four vanes of hard rubber. The meter is suited to measurement of low velocities, but not for rugged use.

Optical current meter

The Geological Survey, in cooperation with the California Department of Water Resources, has developed an optical current meter. (See fig. 10.) This meter is a stroboscopic device designed to measure surface velocities in open channels without immersing equipment in the stream. The optical current meter will find its principal use in measurements of surface velocity during floods when it is impossible to use conventional stream-gaging equipment because of extremely high velocities and a high debris content in the stream.

Care of the vertical-axis current meter

The calibration and maintenance of vertical-axis type current meters is presented in detail

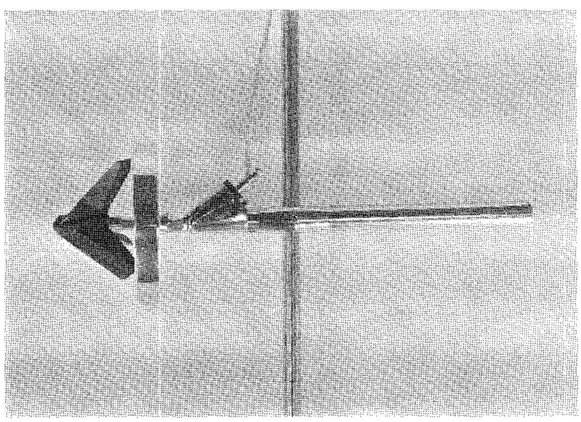


Figure 9.—Hoff current meter.

Balance Hydrologics, Inc.

Balance Hydrologics, Inc.
800 Bancroft Way, Suite 100
Berkeley, CA 94710
(510) 704-1000
www.balancehydro.com

Project No.	**Sample**
Gage No.	
Stream	**Sample**
Location	
Date	**Sample**

Conditions and Observations

Observer(s): **JP,MS**
Weather & Conditions: **sunny partial clouds -> post storm**
Temperatures: 55-60F

Hydrograph: __Rising X Falling __Uncertain __Baseflow
If falling, approximate time of previous peak: NA

Procedures

Measurement at:
on concrete sill by usgs gage

Method: 0.6 0.2/0.8 Other
Meter Type: **X pygmy __standard**
Spin Test: **>60sec**
Suspension: Rod Cable

Measurement rated:		
	Excellent(±2%)	
	Good (±5%)	**x**
	Fair (±8%)	**falling**
	Poor ( )	

Gage Heights

Time	Staff	Other
10:30	**1.81**	
10:35	**1.77**	
10:44	**1.76**	
11:11	**1.74**	
10:56	**1.55**	**usgs**
11:09	**1.53**	**usgs**
during measure ment:	**1.75**	

Observed High-Water Marks
~1.99 from today

Remarks

eaf dam cleared just below gage ~10:30 did not look to be enough cause shift - stage falling anyway
moved xsection to just below the usgs staff plate due to turbulent verticals

water moderatly turbid (not from tanin at all)

Coefficients Utilized and Explanation: ______________________________________

NA

Changes in conditions since last visit? na

Concurrent water quality, sediment or biological measurements/sampling conducted
na

Discharge Measurement Notes

bank shape	Time	Sta-tion (ft)	Width (ft)	Flow Depth (ft)	Obs. Depth (ft)	Meter revs.	Meter sec.	Velocity At point	Velocity Avg.	Horiz. or Vert. Adjust.	Area (ft^2)	Dis-charge (cfs)
R	10:44	61.00										
		59.80	**-**	0.13							0.1755	0.0000
		59.50	**0.300**	0.1							0.0300	0.0000
		59.20	**0.750**	0.31	s	3	41.0	0.081179			0.2325	0.0189
		58.00	**1.100**	0.32		5	43.5	0.141591			0.3520	0.0498
		57.00	**1.000**	0.4		10	48.0	0.231283			0.4000	0.0925
		56.00	**1.000**	0.52		12	42.0	0.305600			0.5200	0.1589
		55.00	**1.000**	0.55		18	44.0	0.424091			0.5500	0.2333
		54.00	**1.000**	0.57		27	45.0	0.607440			0.5700	0.3462
		53.00	**1.000**	0.54		31	38.0	0.814684			0.5400	0.4399
		52.00	**1.000**	0.52		31	36.0	0.858211			0.5200	0.4463
		51.00	**1.000**	0.52		35	37.0	0.939686			0.5200	0.4886
		50.00	**1.000**	0.53		35	35.0	0.991600			0.5300	0.5255
		49.00	**1.000**	0.54		40	37.0	1.069470			0.5400	0.5775
		48.00	**1.000**	0.57		33	35.0	0.936720			0.5700	0.5339
		47.00	**1.000**	0.5		36	46.0	0.782817			0.5000	0.3914
		46.00	**1.000**	0.48		31	39.0	0.794595			0.4800	0.3814
		45.00	**1.000**	0.4		37	41.0	0.897902			0.4000	0.3592
		44.00	**1.000**	0.38		26	39.0	0.671467			0.3800	0.2552
R		43.00		0.45	s	4	40.5	0.100843			0.3375	0.0340
	11:11	42.5										

total area	no.verts	width = lew-rew	avg depth =area/width	avg vel = q/area	max vel	
						5.333
8.1475	19	18.5	0.4404054	0.655	1.069	2393.28

***Bed Key:** M (Mud, Muck), S(Silt, Sand), G(Gravel), C(Cobbles), B(Boulders), BR(Bedrock), RP(Riprap), CON(Concrete), FP(Floodplain, Overbank), Other

Computations
Pygmy velocity = 0.9604*(r/s)+0.0312
Standard velocity (AA) = 2.2048*(r/s)+0.0178

Date: 10/24/2008 13:12 By: JP Reviewed: