Clean Water Act Section 319(h) Nonpoint Source Pollution Control Program

Surface Water Quality Monitoring and Additional Data Collection Activities to Support the Implementation of the Plum Creek Watershed Protection Plan

TSSWCB Project 10-07
Revision 2

Quality Assurance Project Plan

Texas State Soil and Water Conservation Board

Prepared by

Guadalupe-Blanco River Authority

Effective Period: January 1, 2011 – October 31, 2013
with annual revisions required

Questions concerning this quality assurance project plan should be directed to:

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A1 APPROVAL PAGE

Surface Water Quality Monitoring and Additional Data Collection Activities to Support the Implementation of the Plum Creek Watershed Protection Plan

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Name: Mark Null
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Signature: _____ Date: _____

Name: Larry Thomas
Title: Data Chief, South Texas Program Office

Signature: _____ Date: _____

The GBRA will secure written documentation from each sub-tier project participant (e.g., subcontractors, other units of government, laboratories) stating the organization's awareness of and commitment to requirements contained in this QAPP and any amendments or added appendices of this QAPP. The GBRA will maintain this documentation as part of the project's QA records, and will be available for review. (See sample letter in Attachment 1 of this document.)

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List of Acronyms

AWRL	Ambient Water Reporting Limit
BMP	Best Management Practice
BOD	Bio-chemical Oxygen Demand
CAR	Corrective Action Report
CBOD	Carbonaceous Biological Oxygen Demand
COC	Chain of Custody
COD	Chemical Oxygen Demand
CR	County Road
CRP	Clean Rivers Program
DO	Dissolved Oxygen
DQO	Data Quality Objective
EPA	U.S. Environmental Protection Agency
GBRA	Guadalupe-Blanco River Authority
ITRAX	Imaging Software used by GBRA
LCS	Laboratory Control Standard
LOD	Limit of Detection
LOQ	Limit of Quantitation
MPN	Most Probable Number
NWIS	National Water Information System
NCR	Nonconformance Report
NRCS	U.S. Department of Agriculture Natural Resources Conservation Service
PCWP	Plum Creek Watershed Partnership
QA	Quality Assurance
QASM	Quality Assurance System Manual
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	Quality Control
RL	Reporting Limit
RPD	Relative Percent Difference
SA	Sample Amount (reference concentration)
SARA-EL	San Antonio River Authority - Environmental Laboratory
SM	Standard Methods
SOP	Standard Operating Procedure
SR	Sample Result
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System (formerly TRACS)
TCEQ	Texas Commission on Environmental Quality
TSS	Total Suspended Solids
TSSWCB	Texas State Soil and Water Conservation Board
TSWQS	Texas Surface Water Quality Standards
TWQI	Texas Water Quality Inventory
TWSC	Texas Water Science Center
USGS	U.S. Geological Survey
WPP	Watershed Protection Plan

WQMP Water Quality Management Plan

A3 DISTRIBUTION LIST

Organizations, and individuals within, which will receive copies of the approved QAPP and any subsequent revisions include:

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Name: Debbie Magin
Title: GBRA Project Manager/Data Manager

Name: Josie Longoria
Title: GBRA QAO/Regional Laboratory Director

Name: Lee Gudgell
Title: Water Quality Technician

SARA-EL
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Name: Chuck Lorea
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Name: Patricia Carvajal
Title: SARA-EL QAO

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Name: Mark Null
Title: Chief, South Texas Program Office

Name: Larry Thomas
Title: Data Chief, South Texas Program Office

The GBRA will provide copies of this QAPP and any amendments or appendices of this QAPP to each person on this list and to each sub-tier project participant, e.g., subcontractors, other units of government, laboratories. The GBRA will document distribution of the QAPP and any amendments and appendices, maintain this documentation as part of the project's QA records, and will be available for review.

A4 PROJECT/TASK ORGANIZATION

The following is a list of individuals and organizations participating in the project with their specific roles and responsibilities:

EPA

Henry Brewer, EPA Project Officer
Responsible for managing the project for EPA. Reviews project progress and reviews and approves QAPP and QAPP amendments.

TSSWCB

Jana Lloyd, TSSWCB Project Manager
Responsible for ensuring that the project delivers data of known quality, quantity, and type on schedule to achieve project objectives. Provides the primary point of contact between the GBRA and the TSSWCB. Tracks and reviews deliverables to ensure that tasks in the workplan are completed as specified in the contract. Responsible for verifying that the QAPP is followed by the GBRA. Notifies the TSSWCB QAO of significant project nonconformances and corrective actions taken as documented in quarterly progress reports from GBRA Project Manager.

Pamela Casebolt, TSSWCB QAO
Reviews and approves QAPP and any amendments or revisions and ensures distribution of approved/revised QAPPs to TSSWCB participants. Assists the TSSWCB Project Manager on QA-related issues. Coordinates reviews and approvals of QAPPs and amendments or revisions. Conveys QA problems to appropriate TSSWCB management. Monitors implementation of corrective actions. Coordinates and conducts audits.

GBRA

Debbie Magin, Project Manager/Data Manager
Responsible for implementing and monitoring requirements in the contract, and the QAPP. Responsible for writing and maintaining records of the QAPP and its distribution, including appendices and amendments. Responsible for maintaining written records of sub-tier commitment to requirements specified in this QAPP. Coordinates project planning activities and work of project partners. Ensures monitoring systems audits are conducted to ensure QAPP is followed by project participants and that project is producing data of known quality. Responsible for ensuring that field data are properly reviewed and verified. Responsible for the transfer of project quality-assured water quality data to the TSSWCB. Ensures that subcontractors are qualified to perform contracted work. Maintains quality-assured data on GBRA Internet sites. Ensures TSSWCB project manager and/or QAO are notified of deficiencies and nonconformances, and that issues are resolved. Responsible for validating that data collected are acceptable for reporting to the TSSWCB.

Josie Longoria, QAO/Regional Laboratory Director
Responsible for coordinating the implementation of the QA program. Responsible for maintaining the QAPP and monitoring its implementation. Responsible for identifying, receiving, and maintaining project QA records. Responsible for coordinating with the TSSWCB QAO to resolve QA-related issues. Notifies the GBRA Project Manager of particular circumstances which may adversely affect the quality of data. Coordinates and monitors deficiencies, nonconformances and corrective action. Coordinates the research and review of technical QA material and data related to water quality monitoring system design and analytical techniques. Supervises laboratory, purchasing of equipment, maintain QA manual for laboratory operations, and supervision of lab safety program. Ensures that field staff are properly trained and that training records are maintained.

Lee Gudgell, Water Quality Technician
Responsible for coordinating sampling events, including maintenance of sampling bottles, supplies, and equipment. Maintains records of field data collection and observations.

Laboratory Analyst I
Performs laboratory analysis for inorganic constituents, nutrients, etc.; assists in collection of field data and samples for stream monitoring and chemical sampling of environmental sites.

Laboratory Technician II
Performs laboratory analysis for inorganic constituents, nutrients, etc.; assists in collection of field data and samples for stream monitoring and chemical sampling of environmental sites.

Sample Custodian
Perform sample custodial duties, collect field data and samples as directed by laboratory director.

San Antonio River Authority

Chuck Lorea, Laboratory Director
Supervises laboratory, lab safety program, and purchasing of equipment. Reviews and verifies all laboratory data for integrity and continuity, reasonableness and conformance to project requirements, and then validates the data against the measurement performance specifications listed in Table A7.1.

Patricia Carvajal, QAO
Maintains QA manual for laboratory operations, maintains operating procedures that are in compliance with the QAPP. Responsible for the overall QC and QA of analyses performed by SARA's Environmental Services Department.

United States Geologic Survey

Mark Null, Chief/Project Manager
Responsible for managing and directing the South Texas Program Office, including all surface-water activities and ensuring that all aspects of the QAPP are understood and followed by Texas Water Science Center (TWSC) personnel. This is accomplished by his direct involvement or

through clearly stated delegation of his responsibility to other appropriate personnel in the TWSC. Provide final resolution of any conflicts or disputes related to the Plum Creek Gain/Loss Synoptics and for reviewing and ensuring all funding, budgeting, accounting, and expenditures associated with the Plum Creek Gain/Loss Synoptic.

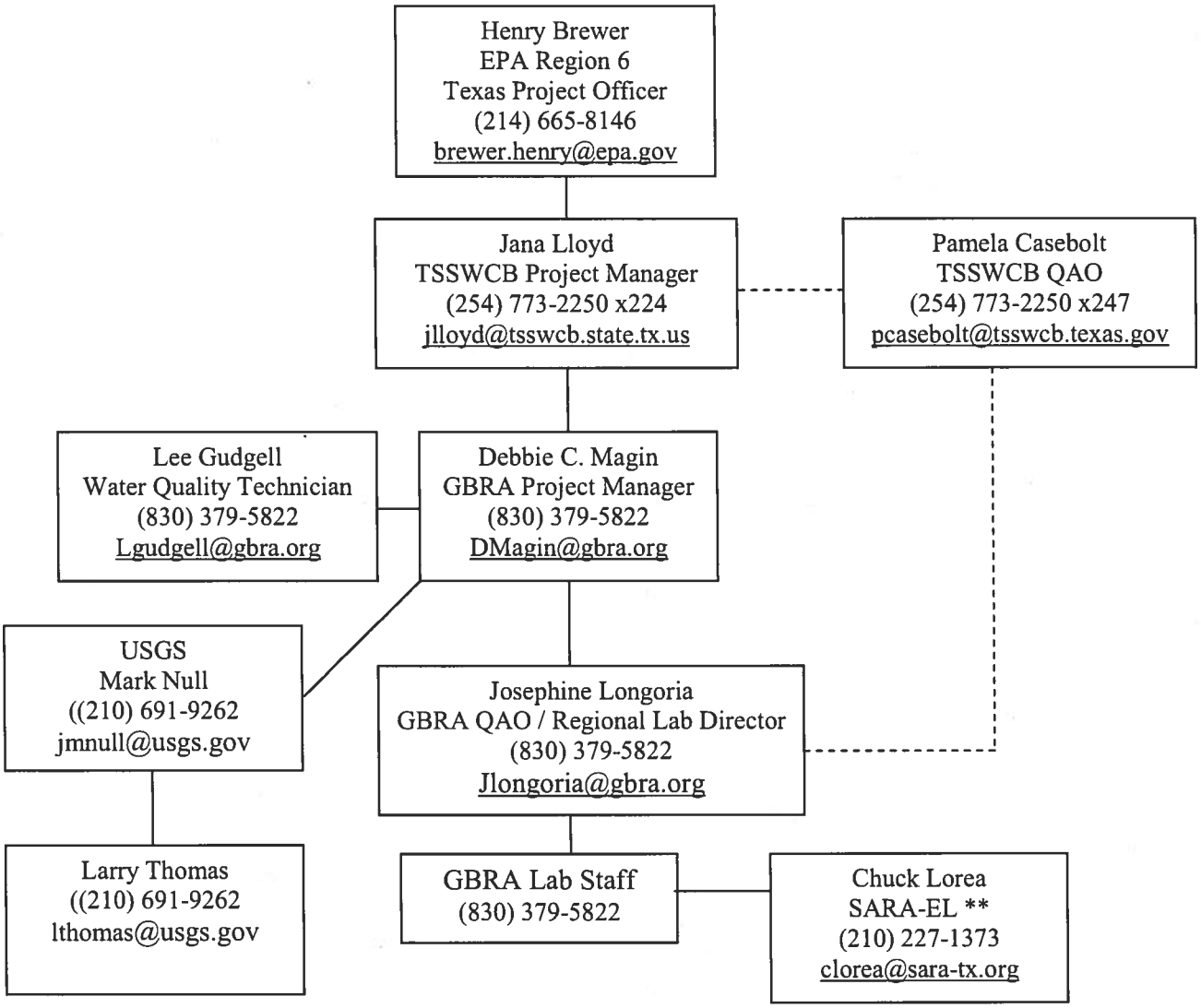
Larry Thomas, Field Manager/Data Chief

Ensure that field staff follow the TWSC Surface-Water Quality-Assurance Plan (TWSC-QAPP) for collection and analysis of any data associated with the Plum Creek Gain/Loss Synoptic Survey. The TWSC-QAPP documents that standards, policies, and procedures used in activities related to the collection, processing, storage, analysis, presentation, and publication of surface-water data. Responsible for checking, reviewing, and finalizing data values associated with the survey. The Field/Data manager may, at his discretion, delegate that duty to a senior hydrologic technician with final review and approval by the Field Manager/Data Manager.

Field Staff, Hydrologic Technicians

The field staff involved in the Plum Creek Gain/Loss survey will consist of teams of two trained hydrologic technicians that will provide the manpower necessary to complete the survey. The field staff that will be assigned to the survey are mid-level and senior hydrologic technicians that have prior experience in conducting gain/loss surveys at other sites on rivers in Texas.

Figure A4.1 Project Organizational Chart* – Lines of Communication



* See Project/Task Organization in this section for a description of each position's responsibilities.
** SARA-EL to be used to meet holding times in the event of equipment failure at the GBRA Regional laboratory.

A5 PROBLEM DEFINITION/BACKGROUND

Plum Creek rises in Hays County north of Kyle and runs south through Caldwell County, passing Lockhart and Luling, and eventually joins the San Marcos River at their confluence north of Gonzales County. Plum Creek is 52 miles in length and has a drainage area of 389 mi^2. According to the *2008 TWQI and 303(d) List*, Plum Creek (Segment 1810) is impaired by elevated bacteria concentrations (category 5c) and exhibits nutrient enrichment concerns for ammonia, nitrate+nitrite nitrogen and total phosphorus.

TSSWCB and Texas AgriLife Extension Service established the Plum Creek Watershed Partnership (PCWP) in April 2006. The PCWP Steering Committee completed the *Plum Creek WPP* in February 2008. Information about the PCWP is available at http://plumcreek.tamu.edu/. Sources of pollutants identified in the Plum Creek WPP include urban storm water runoff, pet waste, failing or inadequate on-site sewage facilities (septic systems), wastewater treatment facilities, livestock, wildlife, invasive species (feral hogs), and oil and gas production.

Originally, the Plum Creek WPP was to be developed using only existing water quality data. However, discussions with stakeholders identified data gaps which would make source identification and establishment of water quality goals difficult. Accurate source identification is key to prioritizing implementation projects for funding. Through TSSWCB project 03-19, *SWQM to Support Plum Creek WPP Development*, GBRA collected water quality data to fill the identified data gaps.

Facilitated by Texas AgriLife Extension Service, implementation of the Plum Creek WPP is currently underway. TSSWCB project 08-07 *Implementing Agricultural Nonpoint Source Components of the Plum Creek WPP* provides technical assistance and financial incentives through the local soil and water conservation districts to agricultural producers in developing and implementing WQMPs. In order to reduce feral hog impacts on the stream, education and technical assistance is being provided, through project 08-07, by Texas AgriLife Extension Service to landowners in the watershed on strategies to reduce and manage feral hog populations. The cities of Kyle and Lockhart have received TCEQ CWA §319(h) funding to retrofit detention facilities to improve water quality, educate and stencil storm sewer inlets, map existing storm water facilities, implement a dog waste collection station program, and coordinate city "housekeeping" activities designed to improve water quality (street sweeping, creek cleanup days, etc). Additionally, Lockhart will evaluate their existing storm water system, identify and prioritize upgrades to the city's storm water management system including cleaning out and installing storm drain filters, and coordinate creek cleanup days, and household hazardous and electronic waste collection days. Any stream monitoring funded in the TCEQ project will be at sites associated with retrofitted or newly installed storm water BMPs. An education and outreach campaign was initiated during the watershed planning process that focused on educating watershed residents and landowners on the impacts of specific land use activities, illegal dumping, proper operation and maintenance of OSSFs and proper disposal of pet waste.

To demonstrate improvements in water quality, the Plum Creek WPP describes a water quality monitoring program designed to evaluate the effectiveness of BMPs implemented across the watershed and their impacts on in-stream water quality. Water quality data will be used in the

adaptive management of the WPP in order to evaluate progress in implementing the Plum Creek WPP and achieving water quality restoration. Sampling locations and frequencies (routine and targeted) are located so that the effectiveness of BMPs implemented in the watershed can be assessed. The city of Kyle is implementing a storm water management program that includes improvements to storm water retention ponds. The city of Lockhart is implementing a storm water management program that includes the installation of storm drain filters and an illicit discharge detection project. Both cities have included public education and outreach in their programs. Monitoring sites downstream of these two cities will collect base flow as well as flows impacted by storm water. Data collected under previous projects (TSSWCB project 03-19 and 10-54) will be used as background for comparison of data collected after the cities have implemented their respective programs. Additionally, monitoring sites have been located so that other BMPs that are recommended in the PC WPP, such as conversion of septic tanks to public wastewater system collection systems, feral hog control and water quality management plans on agricultural lands within the watershed, can be assessed for their impacts on in-stream water quality as well as their progress in achieving water quality restoration.

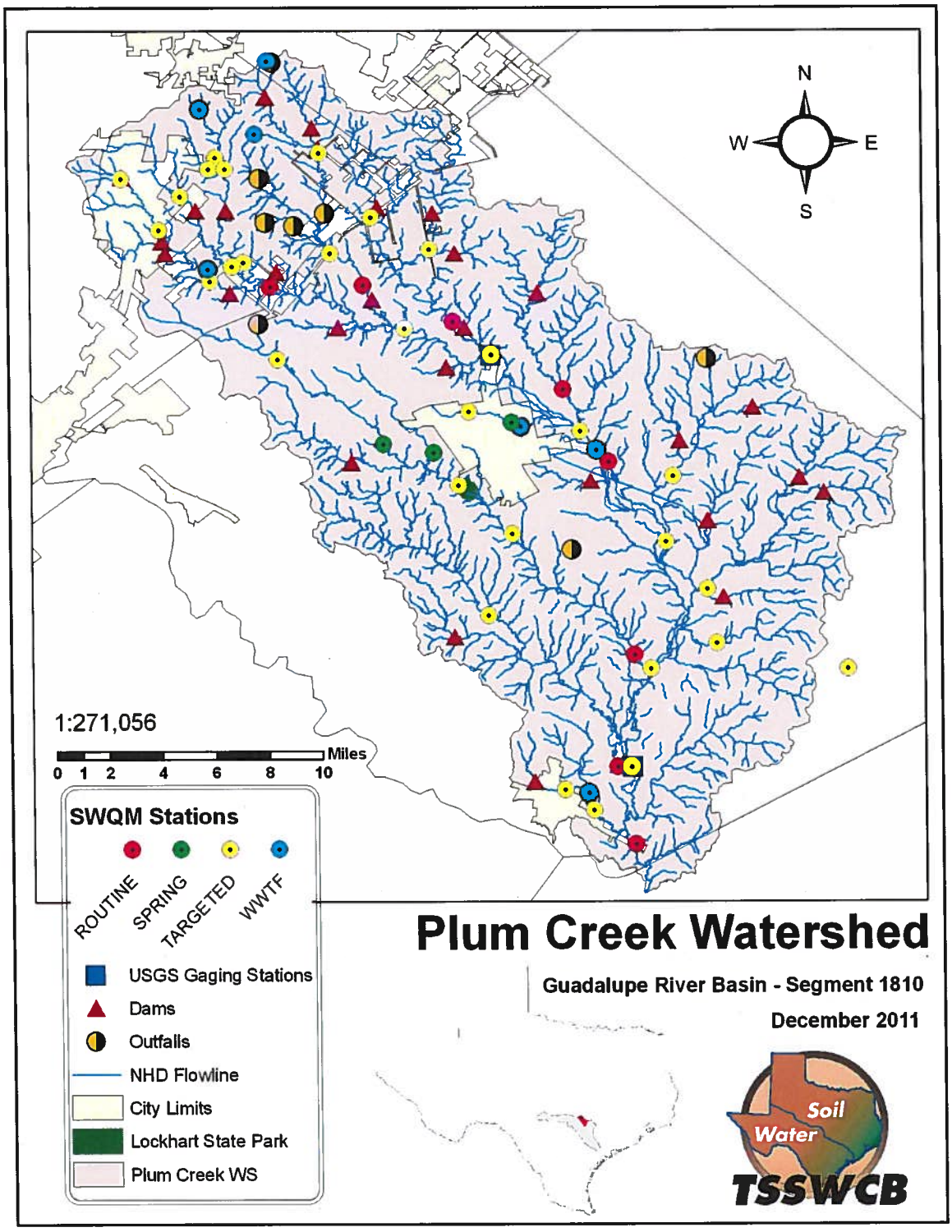
To avoid a data collection gap between the closing of TSSWCB project 03-19 and the initiation of this project, TSSWCB utilized state general revenue funds for project 10-54 *SWQM to Support the Implementation of the Plum Creek WPP* to continue main stem and some tributary snapshot SWQM.

There is a need to continue the monitoring regime originally funded through TSSWCB project 03-19 and to implement the monitoring program described in the Plum Creek WPP which has begun, short-term, through TSSWCB project 10-54.

When the load duration curves for the Watershed Protection Plan were being developed there was an observed loss of flow between mid and lower index sites. As a result, the need to perform a gain/loss survey was identified to better define the relation between streamflow and groundwater recharge in the Plum Creek watershed.

The purpose of this QAPP is to clearly delineate GBRA QA policy, management structure, and procedures, which are used to implement the QA requirements necessary to verify and validate the surface water quality data collected. Figure A5.1 is a map of the Plum Creek watershed.

Figure A5.1 Plum Creek Watershed and Sampling Locations



A6 PROJECT/TASK DESCRIPTION

Through this project, GBRA will collect SWQM data to characterize the Plum Creek watershed, including the contributing wastewater effluents. Monitoring data will be used to assess and evaluate the effectiveness of the BMPs that have been or will be implemented in the watershed as a result of the Plum Creek WPP. The sampling regime will include diurnal, spring flow, storm event and targeted monitoring under more typical base flow conditions over the next three years. This will provide a more complete and representative data set to characterize the Plum Creek watershed and document water quality improvements.

GBRA will conduct the majority of the work performed under this project including technical and financial supervision, preparation of status reports, coordination with local stakeholders, SWQM sample collection and analysis, and data management. GBRA will participate in the PCWP, Steering Committee, and Technical Advisory Group in order to communicate project goals, activities and accomplishments to affected parties. GBRA will continue to host and maintain an Internet webpage http://www.gbra.org/plumcreek/ for the dissemination of information.

Currently, routine ambient water quality data is collected monthly at 3 main stem stations by GBRA (17406, 12640 and 12647) through the CRP. Through this project, GBRA will conduct routine ambient monitoring at an additional 5 sites monthly over 34 months, collecting field, conventional, flow and bacteria parameter groups. This will complement existing routine ambient monitoring regime conducted by GBRA such that routine water quality monitoring is conducted monthly at 8 sites in the Plum Creek watershed.

GBRA will conduct targeted watershed monitoring at 35 sites twice per season, once under dry weather conditions and once under wet weather conditions, collecting field, conventional, flow and bacteria parameter groups. Sampling period extends through 11 seasons. Spatial, seasonal and meteorological variation will be captured in these snapshots of watershed water quality.

GBRA will conduct 24-hour DO monitoring at 7 sites monthly during the index period collecting field and flow parameter groups. These sites shall be the same as the sites for routine ambient monitoring, except for the site at CR202 because GBRA currently maintains a continuous water quality monitoring module that collects the flow and field parameters every fifteen minutes. Sampling period extends over 8 months during the index period of each year of the project, except for year 3, in which the diurnal sampling will end at the end of the contract period.

GBRA will conduct effluent monitoring at seven wastewater treatment facilities (WWTFs) once per month collecting field, conventional, flow, bacteria and effluent parameter groups. The sampling period will extend over 34 months. This will characterize WWTF contributions to flow regime and pollutant loadings. To supplement the data collected at the WWTFs, GBRA will compile all the weekly permit effluent monitoring data as submitted by permitees that includes BOD, TSS, volatile suspended solids, *E. coli*, ammonia nitrogen and total phosphorus from seven WWTFs.

GBRA will conduct spring flow monitoring at 3 springs once per season collecting field, conventional, flow and bacteria parameter groups. The sampling period will extend over 11 seasons. Spatial and seasonal variation in spring flow will be captured. This will characterize spring contributions to flow regime and pollutant loadings.

Through this project, GBRA will contract with the United States Geologic Survey (USGS) to perform two gain/loss synoptic surveys during sustained base flow conditions in the Plum Creek Watershed. The USGS will conduct the surveys at five locations in the Plum Creek watershed The timing of the synoptic surveys will be dependent on hydrologic conditions. Surface-water discharge measurements will be collected at each gain/loss locations and will include, at a minimum, two independent flow measurements, for a total of 20 discharge measurements for both synoptic events. All measurements will be quality assured and the results will be entered into the USGS's National Water Information System (NWIS) database and will be published in the USGS's annual report of water-resource data.

GBRA will post monitoring data to the GBRA website in a timely manner. GBRA will summarize the results and activities of this project through inclusion in GBRA's CRP Basin Highlights Report and/or Basin Summary Report. Additionally, the results and activities of this project will be summarized in quarterly reports to the stakeholders of the PCWP Steering Committee and in revisions to the Plum Creek WPP. GBRA will develop a final Assessment Data Report summarizing water quality data collected through Tasks 3-8 of the workplan. The Report shall, at a minimum, provide an assessment of water quality with respect to effectiveness of BMPs implemented and a discussion of interim short-term progress in achieving the Plum Creek WPP water quality goals.

See Appendix A for sampling design and monitoring pertaining to this QAPP.

Table A6.1 QAPP Milestones

TASK	PROJECT MILESTONES	AGENCY	START	END
2.1	Develop DQOs and QAPP for review by USEPA.	GBRA	M1	M2
2.2	Submit revisions to QAPP as necessary.	TSSWCB, GBRA	M3	M36
3.1	GBRA will monitor at 5 routine sites monthly, collecting field, conventional, flow and bacteria parameter groups.	GBRA	M3	M36
4.1	GBRA will conduct targeted monitoring at 35 sites, twice per season, once under dry conditions and once under wet conditions, collecting field, conventional, flow and bacteria parameter groups.	GBRA	M3	M36
6.1	GBRA will conduct 24-hour DO monitoring at 7 sites monthly during the index period, collecting field and flow parameter groups.	GBRA	M3	M36
7.1	GBRA will conduct wastewater effluent monitoring at 7 WWTFs once per month, collecting field, conventional, flow, effluent and bacteria parameter groups.	GBRA	M3	M36
8.1	GBRA will conduct spring flow monitoring at 3 springs once per season, collecting field, conventional, flow and bacteria parameter groups.	GBRA	M3	M36
10.1	USGS will conduct a gain/loss survey.	USGS	M3	M36

A7 QUALITY OBJECTIVES AND CRITERIA FOR DATA QUALITY

The purpose of routine water quality monitoring is to collect surface water data needed for water quality assessments in accordance with TCEQ's *Guidance for Assessing and Reporting Surface Water Quality in Texas*. These water quality data, and data collected by other organizations (e.g., USGS, TCEQ, etc.), will be subsequently reconciled for use by the TSSWCB.

Systematic watershed monitoring, i.e., targeted monitoring, is defined by sampling that is planned for a short duration (1 to 2 years) and is designed to: screen waters that would not normally be included in the routine monitoring program, monitor at sites to check the water quality situation, and investigate areas of potential concern. Targeted monitoring in the Plum Creek watershed, done under wet and dry conditions, will be collected to capture spatial, seasonal and meteorological snapshots of water quality.

GBRA will conduct diurnal water quality monitoring monthly during the index period. The diurnal monitoring will adhere to the specifications described in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415). GBRA will also conduct effluent monitoring at 7 WWTFs to characterize the contributions to flow and pollutant loadings. Monitoring will be conducted on spring flow to characterize contributions to the flow and pollutant loadings. Spatial, seasonal and meteorological variations will be captured. The data will be used to determine whether any of the springs contribute significantly to the flow regime or to the loading of pollutants that have led to the impairment of the stream. These water quality data will be subsequently reconciled for use and assessed by the TSSWCB.

The monitoring regime (targeted, routine, storm, 24-hour DO, effluent, and spring sampling) is designed to evaluate the effectiveness of BMPs (both rural and urban) across the watershed and measure their impacts on in-stream water quality. Water quality trends will be continually evaluated to document progress in implementing the WPP and progress in achieving restoration. This project is a part of a long-term monitoring program which will extend over the 10 year implementation schedule of the WPP.

The USGS will conduct two gain/loss synoptic surveys during sustained base flow conditions in the Plum Creek watershed. The timing of the synoptic surveys will be dependent on hydrologic conditions. Surface-water discharge measurements collected at each gain/loss location will include at a minimum, two independent flow measurements, for a total of 20 discharge measurements for both synoptic events. Subsequent additional flow measurements may be collected during each synoptic, if the measurements exceed the measurement criteria of greater than 3% deviation from the preceding measurement. All measurements will be entered into the USGS's NWIS database and stored under the USGS station number. Each of the measurement sites will be assigned a USGS discharge measurement number. Results of the synoptic measurements will be published in the USGS's annual report of water-resources data.

The measurement performance specifications to support the project objectives for a minimum data set are specified in Table A7.1 and in the text following.

Table A7.1 GBRA Measurement Performance Specifications

PARAMETER	UNITS	MATRIX	METHOD	PARA-METER CODE	AWRL	LOQ	LOQ CHECK STD %Rec	PRECISION (RPD of LCS/LCS dup)	BIAS (%Rec. of LCS)	Lab
Field Parameters										
pH	pH/ units	water	SM 4500-H⁺ B. & TCEQ SOP, V1	00400	NA[1]	NA	NA	NA	NA	Field
DO	mg/L	water	SM 4500-O G. & TCEQ SOP, V1	00300	NA[1]	NA	NA	NA	NA	Field
Conductivity	umhos/cm	water	SM 2510 & TCEQ SOP, V1	00094	NA[1]	NA	NA	NA	NA	Field
Temperature	°C	water	SM 2550 & TCEQ SOP, V1	00010	NA[1]	NA	NA	NA	NA	Field
Flow	cfs	water	TCEQ SOP, V1	00061	NA[1]	NA	NA	NA	NA	Field
Flow measurement method	1-gage 2-electric 3-mechanical 4-weir/flume 5-doppler	water	TCEQ SOP, V1	89835	NA[1]	NA	NA	NA	NA	Field
Flow severity	1-no flow 2-low 3-normal 4-flood 5-high 6-dry	water	TCEQ SOP, V1	01351	NA[1]	NA	NA	NA	NA	Field
Flow Estimate	cfs	water	TCEQ SOP, V1	74069	NA[1]	NA	NA	NA	NA	Field
Conventional and Bacteriological Parameters										
Conductivity[3]	umhos/cm	water	SM 2510	00095	NA[1]	NA	NA	NA	NA	GBRA
Residue, Total Nonfiltrable (TSS)	mg/L	water	SM 2540D	00530	4	1[7]	NA	20	80-120	GBRA[6]
Turbidity	NTU	water	SM 2130B	82079	0.5	0.5	NA	20	NA	GBRA[6]
Sulfate	mg/L	water	EPA 300.0 Rev. 2.1 (1993)	00945	5	1	70-130	20	80-120	GBRA[6]
Chloride	mg/L	water	EPA 300.0 Rev. 2.1 (1993)	00940	5	1	70-130	20	80-120	GBRA[6]
Chlorophyll-a, spectro-photometric method	ug/L	water	SM 10200-H[4]	32211	3	1[7]	70-130	20	NA	GBRA
Pheophytin, spectro-photometric method	ug/L	water	SM 10200-H[4]	32218	3	1	70-130	20	NA	GBRA
E. coli, IDEXX™ Colilert	MPN/100 mL	water	Colilert - 18	31699	1	1	NA	0.5[2]	NA	GBRA
Ammonia-N, total	mg/L	water	EPA 350.1 Rev. 2.0 (1993)	00610	0.1	0.1	70-130	20	80-120	GBRA
Hardness, total (as $CaCO_3$)	mg/L	water	SM 2340 C	00900	5	5	NA	20	80-120	GBRA
Nitrate-N, total	mg/L	water	EPA 300.0 Rev. 2.1 (1993)	00620	0.05	0.05	70-130	20	80-120	GBRA[6]
Total phosphorus[5]	mg/L	water	EPA 365.3	00665	0.06	0.05	70-130	20	80-120	GBRA[6]
Total Kjeldahl Nitrogen	mg/L	water	EPA 351.2 Rev. 2 (1993)	00625	0.2	0.2	70-130	20	80-120	GBRA[6]

PARAMETER	UNITS	MATRIX	METHOD	PARA-METER CODE	AWRL	LOQ	LOQ CHECK STD %Rec	PRECISION (RPD of LCS/LCS dup)	BIAS (%Rec. of LCS)	Lab
BOD, 5-day	mg/L	water	SM 5210B	00310	2	1.0	NA	<10 = 33.3 >10 = 15.4	NA	GBRA
CBOD, 5-day	mg/L	water	SM 5210B	80082	2	1.0	NA	<10 = 33.3 >10 = 15.4	NA	GBRA
COD	mg/L	water	SM 5220D	00335	10	10.0	70-130	20	80-120	GBRA
Diurnal monitoring summary statistics										
24-hour average DO	mg/L	water	TCEQ SOP, V1	89857	NA	NA	NA	NA	NA	GBRA
Maximum daily DO	mg/L	water	TCEQ SOP, V1	89856	NA	NA	NA	NA	NA	GBRA
Minimum daily DO	mg/L	water	TCEQ SOP, V1	89855	NA	NA	NA	NA	NA	GBRA
Number of DO measurements	none	none	TCEQ SOP, V1	89858	NA	NA	NA	NA	NA	GBRA
Number of temperature measurements	none	none	TCEQ SOP, V1	00221	NA	NA	NA	NA	NA	GBRA
Number of conductivity measurements	none	none	TCEQ SOP, V1	00222	NA	NA	NA	NA	NA	GBRA
Number of pH measurements	none	none	TCEQ SOP, V1	00223	NA	NA	NA	NA	NA	GBRA
24-hour average water temperature	°C	water	TCEQ SOP, V1	00209	NA	NA	NA	NA	NA	GBRA
Maximum daily water temperature	°C	water	TCEQ SOP, V1	00210	NA	NA	NA	NA	NA	GBRA
Minimum daily water temperature	°C	water	TCEQ SOP, V1	00211	NA	NA	NA	NA	NA	GBRA
24-hour average conductivity	umhos/cm	water	TCEQ SOP, V1	00212	NA	NA	NA	NA	NA	GBRA
Maximum daily conductivity	umhos/cm	water	TCEQ SOP, V1	00213	NA	NA	NA	NA	NA	GBRA
Minimum daily conductivity	umhos/cm	water	TCEQ SOP, V1	00214	NA	NA	NA	NA	NA	GBRA
Maximum daily pH	s.u.	water	TCEQ SOP, V1	00215	NA	NA	NA	NA	NA	GBRA
Minimum daily pH	s.u.	water	TCEQ SOP, V1	00216	NA	NA	NA	NA	NA	GBRA
Gain/Loss Survey										
Flow	cfs	water	USGS	00061	NA[1]	NA	NA	NA	NA	USGS
Flow measurement method	1-gage 2-electric 3-mechanical 4-weir/flume 5-doppler	water	USGS	89835	NA[1]	NA	NA	NA	NA	USGS

1 Reporting to be consistent with TCEQ SWQM guidance and based on measurement capability.
2 Based on range statistic as described in Standard Methods, 20th Edition, Section 9020-B, "Quality Assurance / Quality Control – Intralaboratory Quality Control Guidelines." This criterion applies to bacteriological duplicates with concentrations greater than 10 MPN/100 mL or greater than 10 organisms/100 mL.
3 Secondary method listed. To be used in the event that the primary method cannot be used or needs to be confirmed, i.e. automated method cannot be used due to instrument failure.
4 In addition to SM 10200 H. cited for chlorophyll a, the SOP posted on the TCEQ CRP web site will be followed as well.
5 Automated method for total phosphorus on the Konelab Aquakem 200, following the GBRA SOP written based on the EPA method 365.3 and the Konelab operating procedures. The manual method will be used as a secondary method in case of instrument failure.

6 The SARA-EL may be used in the event of lab equipment failure so that samples will be processed within prescribed holding times. In the case of *E. coli*, SARA-EL will analyze the samples using method SM9223B for which they are accredited.
7 Reporting limit. Not a NELAP-defined LOQ (no commercially available spiking solution used as LOQ check standard.)

References for Table A7.1:

United States Environmental Protection Agency (USEPA) "Methods for Chemical Analysis of Water and Wastes," Manual #EPA-600/4-79-020
American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF), "Standard Methods for the Examination of Water and Wastewater," 20th Edition, 1998
TCEQ SOP, V1 - TCEQ SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, June 2008 or subsequent editions (RG-415)

Ambient Water Reporting Limits (AWRLs)

The AWRL establishes the reporting specification at or below which data for a parameter must be reported to be compared with freshwater screening criteria. The AWRLs specified in Table A7.1 are the program-defined reporting specifications for each analyte and yield data acceptable for TCEQ water quality assessment. The LOQ (formerly known as reporting limit) is the minimum level, concentration, or quantity of a target variable (e.g., target analyte) that can be reported with a specified degree of confidence. The following requirements must be met in order to report results to the TSSWCB:

- The laboratory's LOQ for each analyte must be at or below the AWRL as a matter of routine practice
- The laboratory must demonstrate its ability to quantitate at its LOQ for each analyte by running an LOQ check standard for each batch of samples analyzed.

Laboratory Measurement QC Requirements and Acceptability Criteria are provided in Section B5.

Precision

Precision is the degree to which a set of observations or measurements of the same property, obtained under similar conditions, conform to themselves. It is a measure of agreement among replicate measurements of the same property, under prescribed similar conditions, and is an indication of random error. Subsequent flow measurements, collected through the gain/loss survey, will be collected during each synopsis if the measurements exceed the measurement criteria of greater than 3% deviation from the preceding measurement.

Field splits are used to assess the variability of sample handling, preservation, and storage, as well as the analytical process, and are prepared by splitting samples in the field. Control limits for field splits are defined in Section B5.

Laboratory precision is assessed by comparing replicate analyses of laboratory control samples in the sample matrix (e.g. deionized water, sand, commercially available tissue) or sample/duplicate pairs in the case of bacterial analysis. Precision results are compared against measurement performance specifications and used during evaluation of analytical performance. Program-defined measurement performance specifications for precision are defined in Table A7.1.

Bias

Bias is a statistical measurement of correctness and includes multiple components of systematic error. A measurement is considered unbiased when the value reported does not differ from the true value. Bias is determined through the analysis of laboratory control samples and LOQ check standards prepared with verified and known amounts of all target analytes in the sample matrix (e.g. deionized water) and by calculating percent recovery. Results are compared against measurement performance specifications and used during evaluation of analytical performance. Program-defined measurement performance specifications for LCSs are specified in Table A7.1.

Representativeness

Site selection, the appropriate sampling regime, the sampling of all pertinent media according to TCEQ SWQM SOPs, and use of only approved analytical methods will assure that the measurement data represents the conditions at the monitoring sites. Routine data collected for this project and submitted to TSSWCB for water quality assessments, are considered to be spatially and temporally representative of routine water quality conditions. Water quality data are collected on a routine frequency and are separated by approximately even time intervals. At a minimum, samples are collected over four seasons (to include inter-seasonal variation) and in the case of diurnal sampling, monthly during an index period (March 15 - October 15). Although data may be collected during varying regimes of weather and flow, the data sets collected during routine monitoring will not be biased toward unusual conditions of flow, runoff, or season. The goal for meeting total representation of the waterbody will be tempered by the availability of stream and meteorological conditions during the project and the potential funding for complete representativeness.

Data collection for targeted sampling will be toward both ambient conditions and those conditions that are influenced by storm events. Spring flow will be collected spatially, seasonally and under varying meteorological conditions. Sampling of wastewater treatment facilities will be conducted once per quarter and at the same time of day and week, without regard to specific meteorological conditions or facility flow regimes. Representativeness will be measured with the completion of sample collection in accordance with the approved QAPP.

Gain/Loss Survey: Site selection, the appropriate sampling regime, the measurement of flow according to the USGS's SOPs (Appendix F), will assure that the measurement data represents the conditions at the monitoring sites. The goal for meeting total representation of the water body will be tempered by the availability of stream and meteorological conditions during the project and the potential funding for complete representativeness.

Comparability

Confidence in the comparability of routine data sets for this project and for water quality assessments is based on the commitment of project staff to use only approved sampling and analysis methods and QA/QC protocols in accordance with quality system requirements and as described in this QAPP and in TCEQ SWQM SOPs. Comparability is also guaranteed by

reporting data in standard units, by using accepted rules for rounding figures, and by reporting data in a standard format as specified in Section B10.

Completeness

The completeness of the data is basically a relationship of how much of the data is available for use compared to the total potential data. Ideally, 100% of the data should be available. However, the possibility of unavailable data due to accidents, insufficient sample volume, broken or lost samples, etc. is to be expected. Therefore, it will be a general goal of the project that 90% data completion is achieved.

A8 SPECIAL TRAINING/CERTIFICATION

New field personnel receive training in proper sampling and field analysis. Before actual sampling or field analysis occurs, they demonstrate to the GBRA QAO (or designee) their ability to properly calibrate field equipment and perform field sampling and analysis procedures. Field personnel training is documented and retained in the personnel file and are available during a monitoring systems audit.

Contractors and subcontractors must ensure that laboratories analyzing samples under this QAPP meet the requirements contained in section 5.4.4 of the NELAC® standards (concerning Review of Requests, Tenders and Contracts).

Gain/Loss Survey: New field personnel receive training in proper methods described in Appendix B. Before actual sampling or field analysis occurs, they demonstrate to the QA Officer (or designee) their ability to properly calibrate field equipment and perform field sampling and analysis procedures. Field personnel training is documented and retained in the personnel file and are available during a monitoring systems audit.

A9 DOCUMENTS AND RECORDS

The documents and records that describe, specify, report, or certify activities are listed. These reports may or may not be kept in paper form since the reports can be regenerated from the lab database at any time. If kept, the paper form is kept for a minimum of one year and then scanned into the GBRA ITRAX for permanent record.

The GBRA laboratory database is housed on the laboratory computer and is backed up on the network server nightly. A back up copy of the network server files, including ITRAX, is made every Monday and that copy is stored off-site at a protected location. The GBRA network administrator is responsible for the servers and back up generation.

Gain/Loss Survey: The documents and records that describe, specify, report, or certify activities are listed. These reports may or may not be kept in paper form since the reports can be regenerated from the USGS NWIS database at any time. If kept, the paper form is kept for a minimum of one year and then scanned for permanent record (Appendix G).

Table A9.1 Project Documents and Records

Document/Record	Location	Retention (yrs)	Format
QAPPs, amendments and appendices	TSSWCB/GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
QAPP distribution documentation	GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
QAPP commitment letters	GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
Field notebooks or data sheets	GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
Field staff training records	GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
Field equipment calibration/maintenance logs	GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
COC records	GBRA/SARA/USGS	One Year/ Indefinitely	Paper/ Electronic
Field SOPs	GBRA/USGS	One Year/ Indefinitely	Paper/ Electronic
Laboratory QA Manuals	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic
Laboratory SOPs	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic
Laboratory data reports/results	GBRA/SARA	One Year/ Indefinitely	Paper/electronic
Laboratory staff training records	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic
Instrument printouts	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic
Laboratory equipment maintenance logs	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic
Laboratory calibration records	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic
Corrective Action Documentation	GBRA/SARA	One Year/ Indefinitely	Paper/ Electronic

The TSSWCB may elect to take possession of records at the conclusion of the specified retention period.

Laboratory Test Reports

Test reports from the laboratory will document the test results clearly and accurately. The requirements for reporting data and the procedures are provided.

* title of report and unique identifiers on each page
* name and address of the laboratory
* name and address of the client
* a clear identification of the sample(s) analyzed
* date and time of sample receipt
* date and time of collection
* sample depth
* identification of method used
* identification of samples that did not meet QA requirements and why (i.e., holding times exceeded)
* sample results
* units of measurement
* sample matrix
* dry weight or wet weight (as applicable)
* clearly identified subcontract laboratory results (as applicable)
* a name and title of person accepting responsibility for the report
* project-specific QC results to include field split results (as applicable); equipment, trip, and field blank results (as applicable); and LOQ and LOD confirmation (% recovery)
* narrative information on QC failures or deviations from requirements that may affect the quality of results or is necessary for verification and validation of data
* certification of NELAC® compliance on a result by result basis.

Electronic Data

Data will be submitted electronically to the TSSWCB for inclusion in the TCEQ SWQMIS. A completed Data Summary (see Appendix D), as described in the most recent version of *TCEQ SWQM Data Management Reference Guide*, will be submitted with each data submittal.

Amendments to the QAPP

Revisions to the QAPP may be necessary to address incorrectly documented information or to reflect changes in project organization, tasks, schedules, objectives, and methods. Requests for amendments will be directed from the GBRA Project Manager to the TSSWCB Project Manager electronically. Amendments are effective immediately upon approval by the GBRA Project Manager, the GBRA QAO, the TSSWCB Project Manager, and the TSSWCB QAO. They will be incorporated into the QAPP by way of attachment and distributed to personnel on the distribution list by the GBRA Project Manager.

B1 SAMPLING PROCESS DESIGN

The sample design is based on the intent of this project as recommended by the PCWP Steering Committee. Under their direction, the TSSWCB and GBRA have been tasked with providing data to characterize water quality conditions in support of the 305(b) assessment, and to identify significant long-term water quality trends. Based on PCWP Steering Committee input, achievable water quality objectives and priorities and the identification of water quality issues were used to develop the workplan, which are in accord with available resources. As part of the PCWP Steering Committee process, the TSSWCB and GBRA coordinate closely with other participants to ensure a comprehensive water monitoring strategy within the watershed.

Routine monitoring will complement existing routine ambient monitoring being conducted by GBRA. The five new routine monitoring sites have been selected to increase the spatial distribution of data. Monthly routine monitoring includes the conventional, bacterial and field parameter groups (*E. coli*, pH, DO, temperature, specific conductance, chloride, sulfate, chlorophyll a, pheophytin, nitrate-nitrogen, ammonia-nitrogen, total hardness, TSS, turbidity, total phosphorus and total kjeldahl nitrogen) that are currently collected at the three existing sites being monitored by GBRA. Analytical results will be used in assessments conducted by TCEQ and compared to historical data at the existing monitoring locations in the watershed. Flow will be measured by the USGS gaging station for sites 12642 and 12640. Flow at the remaining routine sites will be measured manually (mechanically, electronically or by Doppler.)

In addition to routine monitoring at these locations, 24-hour diurnal monitoring will be conducted once per month during the index period, March 15 through October 15, except at station 12647, Plum Creek at CR202, where GBRA maintains a continuous water quality monitoring station. DO, pH, temperature, and specific conductance will be recorded hourly through the diurnal cycle. Flow at station 12640 will be measured using the nearest USGS gage station. At the remaining six stations, stream flow will be measured manually at the time of data sonde deployment. Minimum, maximum, range, average (not pH) and number of measurements will be reported for each parameter.

Sites for targeted monitoring were selected to represent spatial, seasonal and meteorological conditions throughout the Plum Creek and contributing subwatersheds. Sampling will be conducted two times per season for 11 seasons, once under dry weather conditions and once during wet weather conditions. The area has been known to experience scattered showers, i.e., afternoon heat-related showers of short duration that may cause some portions of the watershed to be under wet weather conditions while others are not. Targeted monitoring sites will be visited when the overall watershed is under the specific weather conditions, dry or wet. There may be times, during dry weather conditions, when there is no water in the stream in the subwatersheds. Those visits will be documented but no stream data will be collected. During wet weather conditions, the safety of the sampling crew will not be compromised in case of lightning or flooding. In the instance that a sampling site is inaccessible due to weather conditions or flooding, "no sample due to inaccessibility" will be documented in the field notebook. The routine monitoring sites will be targeted for wet weather conditions during each quarter if none of the routine monitoring events conducted met those conditions during that season, or targeted for dry conditions if those conditions were not met during that season.

Seven WWTFs will be sampled once per month over the span of the project (34 months). Data will be collected to characterize the wastewater facilities' contributions to the flow regime and pollutant loading. Samples will be collected at the outfall of each facility, before it mixes with the receiving stream. Parameters will include flow, field, and conventional parameters, including BOD, CBOD and COD. The WWTFs measure the effluent flow in million gallons per day. At the time of sampling, the flow will be obtained from the WWTF and converted to cubic feet per second.

Three spring flow sites have been identified using local and historical knowledge. GBRA will conduct spring flow monitoring at the 3 springs once per season collecting field, conventional, flow and bacteria parameter groups. Sampling period extends through 11 seasons. The data will be collected at a location that is in the closest proximity to the headwaters of each spring and with enough depth to collect a representative sample. Care will be given to sample above stream features such as riffles that could influence water quality after the spring emerges from the ground. Flow will be measured manually at each spring.

To better understand the sources of flow in the Plum Creek watershed, two sets of synoptic gain/loss measurements will be collected by USGS at five selected surface water locations within the watershed. Surface-water discharge measurements collected at each gain/loss location will include at a minimum, two independent flow measurements, for a total of 20 discharge measurements for both synoptic events. Subsequent additional flow measurements may be collected during each synopsis, if the measurements exceed the measurement criteria of greater than 3% deviation from the preceding measurement.

See Appendix A for sampling process design information and monitoring tables associated with data collected under this QAPP.

B2 SAMPLING METHODS

Field Sampling Procedures

Field sampling will be conducted according to procedures documented in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415). Additional aspects outlined in Section B below reflect specific requirements for sampling under this project and/or provide additional clarification.

Gain/Loss Survey: Field sampling will be conducted according to procedures documented in the *USGS Techniques and Methods 3-A8, Discharge Measurements at Gaging Stations, Chapter 8 of Book 3, Section A* (Appendix F) and *Quality Management Plan for Environmental Projects* (Appendix G).

Table B2.1 Sample Storage, Preservation and Handling Requirements

Parameter	Matrix	Container	Preservation*	Sample Volume	Holding Time
Turbidity	Water	Plastic or glass	Cool, 0-6°C	100 mL	48 hours
Hardness	Water	Plastic or glass	Cool, 0-6°C, H_2SO_4 to pH < 2*	1 L	28 days
TSS	Water	Plastic or glass	Cool, 0-6°C	1 L	7 days
Nitrate-nitrogen	Water	Plastic or glass	Cool, 0-6°C	1 L	48 hours
Ammonia-nitrogen	Water	Plastic or glass	Cool, 0-6°C, H_2SO_4 to pH < 2*	1 L	28 days
Total Kjeldahl Nitrogen	Water	Plastic or glass	Cool, 0-6°C, H2SO4 to pH < 2*	1 L	28 days
Total phosphorus	Water	Plastic or glass	Cool, 0-6°C, H_2SO_4 to pH < 2*	1 L	28 days
Sulfate	Water	Plastic or glass	Cool, 0-6°C	1 L	28 days
Chloride	Water	Plastic or glass	Cool, 0-6°C	1 L	28 days
Chlorophyll a /Pheophytin	Water	Amber plastic or glass	Dark, Cool, 0-6°C before filtration; Dark, 0°C after filtration	1 L	Filter within 48 hours/28 days at 0°C
E. coli	Water	Sterile, plastic	Cool, 0-6°C	100 mL	6 hours
BOD	Water	Plastic	Cool, 0-6°C	1 L	48 hours
C-BOD	Water	Plastic	Cool, 0-6°C	1 L	48 hours
COD	Water	Plastic	Cool, 0-6°C, H_2SO_4 to pH < 2*	1 L	28 days

* Preservation occurs within 15 minutes of sample collection.

Sample Containers

Sample containers are plastic one liter bottles that are cleaned and reused for conventional parameters. The bottles are cleaned with the following procedure: 1) wash containers with tap water and alconox (laboratory detergent), 2) triple rinse with hot tap water, and 3) triple rinse with deionized water. Amber plastic bottles are used routinely for chlorophyll samples. Disposable, pre-cleaned, sterile bottles are purchased for bacteriological samples. Certificates of analysis and/or sterility sample containers for bacteriological sampling are maintained in a notebook by each laboratory.

Processes to Prevent Contamination

Procedures outlined in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415) outline the necessary steps to prevent contamination of samples, including direct collection into sample containers, when possible. Field QC samples (identified in Section B5) are collected to verify that contamination has not occurred.

Documentation of Field Sampling Activities

Field sampling activities are documented on field data sheets as presented in Appendix B. The following will be recorded for all visits:

- Station ID
- Sampling date
- Location
- Sampling depth
- Sampling time
- Sample collector's name/signature
- Values for all field parameters, including flow and flow severity
- Detailed observational data, including:
- water appearance
- weather
- biological activity
- unusual odors
- pertinent observations related to water quality or stream uses (i.e., exceptionally poor water quality conditions/standards not met; stream uses such as swimming, boating, fishing, irrigation pumps)
- watershed or instream activities (i.e., bridge construction, livestock watering upstream)
- missing parameters (i.e., when a scheduled parameter or group of parameters is not collected)

Recording Data

For the purposes of this section and subsequent sections, all field and laboratory personnel follow the basic rules for recording information as documented below:

- Legible writing in indelible ink with no modifications, write-overs or cross-outs;
- Correction of errors with a single line followed by an initial and date;
- Close-out on incomplete pages with an initialed and dated diagonal line.

Deficiencies, Nonconformances and Corrective Action Related to Sampling Requirements

Deficiencies are defined as unauthorized deviations from procedures documented in the QAPP or other applicable documents. Nonconformances are deficiencies which affect data quantity and/or quality and render the data unacceptable or indeterminate. Deficiencies related to sampling methods requirements include, but are not limited to, such things as sample container, volume,

and preservation variations, improper/inadequate storage temperature, holding-time exceedances, and sample site adjustments.

Deficiencies are documented in logbooks, field data sheets, etc., by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the GBRA Project Manager. The GBRA Project Manager will notify the GBRA QAO of the potential nonconformance. The GBRA QAO will initiate a NCR to document the deficiency.

The GBRA Project Manager, in consultation with the GBRA QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the GBRA Project Manager, in consultation with GBRA QAO, will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the GBRA QAO by completion of a CAR.

CARs document: root cause(s); impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TSSWCB immediately both verbally and in writing.

Deficiencies, Nonconformances and Corrective Action Related to Gain/Loss Measurement Requirements

Deficiencies are defined as unauthorized deviations from procedures documented in the QAPP or other applicable documents. Nonconformances are deficiencies which affect data quantity and/or quality and render the data unacceptable or indeterminate. Deficiencies related to sampling methods requirements include, but are not limited to, such things as sample container, volume, and preservation variations, improper/inadequate storage temperature, holding-time exceedances, and sample site adjustments.

Deficiencies are documented in logbooks, field data sheets, etc. by field staff and reported to the cognizant field supervisor who will notify the USGS Project Manager. The USGS Project Manager will notify the GBRA Project Manager of the potential nonconformance. The GBRA Project Manager will initiate a Nonconformance Report (NCR) to document the deficiency.

The USGS Project Manager, in consultation with the GBRA Project Manager (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the USGS Project Manager, in consultation with GBRA Project Manager, will determine the disposition of the nonconforming activity or item

and necessary corrective action(s); results will be documented by the USGS Project Manager by completion of a Corrective Action Report.

Corrective Action Reports (CARs) document: root cause(s); impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TSSWCB immediately both verbally and in writing.

B3 SAMPLE HANDLING AND CUSTODY

Sample Tracking

Proper sample handling and custody procedures ensure the custody and integrity of samples beginning at the time of sampling and continuing through transport, sample receipt, preparation, and analysis.

A sample is in custody if it is in actual physical possession or in a secured area that is restricted to authorized personnel. The COC form is a record that documents the possession of the samples from the time of collection to receipt in the laboratory. The following information concerning the sample is recorded on the COC form (See Appendix C). The following list of items matches the COC form in Appendix C.

- Date and time of collection
- Site identification
- Sample matrix
- Number of containers and respective volumes
- Preservative used or if the sample was filtered
- Analyses required
- Name of collector
- Custody transfer signatures and dates and time of transfer
- Bill of lading (if applicable)
- Subcontract laboratory, if used

Sample Labeling

Samples from the field are labeled on the container with an indelible marker. Label information includes:

- Site identification
- Date and time of sampling
- Preservative added, if applicable
- Designation of "field-filtered" as applicable
- Sample type (i.e., analysis(es)) to be performed

Sample Handling

After collection of samples are complete, sample containers are immediately stored in an ice chest for transport to the GBRA laboratory, accompanied by the COC form. Ice chests will remain in the possession of the field technician or in the locked vehicle until delivered to the lab. After receipt at the GBRA lab, the samples are stored in the refrigeration unit or given to the analyst for immediate analysis. Only authorized laboratory personnel will handle samples received by the laboratory.

Deficiencies, Nonconformances and Corrective Action Related to Chain of Custody

Deficiencies are defined as unauthorized deviations from procedures documented in the QAPP or other applicable documents. Nonconformances are deficiencies which affect data quantity and/or quality and render the data unacceptable or indeterminate. Deficiencies related to COC include but are not limited to delays in transfer, resulting in holding time violations; incomplete documentation, including signatures; possible tampering of samples; broken or spilled samples, etc.

Deficiencies are documented in logbooks, field data sheets, etc. by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the GBRA Project Manager. The GBRA Project Manager will notify the GBRA QAO of the potential nonconformance. The GBRA QAO will initiate a NCR to document the deficiency.

The GBRA Project Manager, in consultation with GBRA QAO, will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the GBRA Project Manager in consultation with the GBRA QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the GBRA QAO by completion of a CAR.

CARs document: root cause(s); impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TSSWCB immediately both verbally and in writing.

B4 ANALYTICAL METHODS

The analytical methods, associated matrices, and performing laboratories are listed in Table A7.1. The authority for analysis methodologies under this project is derived from the TSWQS (Texas Administrative Code §§307.1 - 307.10) in that data generally are generated for comparison to those standards and/or criteria. The standards state that "Procedures for laboratory analysis must be in accordance with the most recently published edition of the book entitled Standard Methods for the Examination of Water and Wastewater, the TCEQ Texas Surface Water Quality Monitoring Procedures as amended, 40 CFR Part 136, or other reliable procedures acceptable to the commission, and in accordance with Chapter 25 of this title."

Laboratories collecting data under this QAPP are compliant with the NELAC® standards, at a minimum. Copies of laboratory QASMs and SOPs are available for review by the TSSWCB.

Standards Traceability

All standards used in the field and laboratory are traceable to certified reference materials. Standards preparation is fully documented and maintained in a standards log book. Each documentation includes information concerning the standard identification, starting materials, including concentration, amount used and lot number; date prepared, expiration date and preparer's initials/signature. The reagent bottle is labeled in a way that will trace the reagent back to preparation. Table A7.1 lists the methods to be used for field and laboratory analyses.

Deficiencies, Nonconformances and Corrective Action Related to Analytical Methods

Deficiencies are defined as unauthorized deviations from procedures documented in the QAPP or other applicable documents. Nonconformances are deficiencies which affect quantity and/or quality and render the data unacceptable or indeterminate. Deficiencies related to field and laboratory measurement systems include, but are not limited to, instrument malfunctions, blank contamination, QC sample failures, etc.

Deficiencies are documented in logbooks, field data sheets, etc. by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the GBRA Project Manager. The GBRA Project Manager will notify the GBRA QAO of the potential nonconformance. The GBRA QAO will initiate a NCR to document the deficiency.

The GBRA Project Manager, in consultation with GBRA QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the GBRA Project Manager, in consultation with the GBRA QAO, will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the GBRA QAO by completion of a CAR (see Appendix E).

CARs document: root cause(s); impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TSSWCB immediately both verbally and in writing.

B5 QUALITY CONTROL

Sampling Quality Control Requirements and Acceptability Criteria

The minimum Field QC Requirements are outlined in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415). Specific requirements are outlined below. Field QC sample results are submitted with the laboratory data report (see Section A9).

Field Split - A field split is a single sample subdivided by field staff immediately following collection and submitted to the laboratory as two separately identified samples according to procedures specified in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415). Split samples are preserved, handled, shipped, and analyzed identically and are used to assess variability in all of these processes. Field splits apply to conventional samples only and are collected on a 10% basis, or one per batch, whichever is more frequent.

The precision of field split results is calculated by RPD using the following equation:

$$RPD = (X_1-X_2)/((X_1+X_2)/2)) * 100\%$$

A 30% RPD criteria will be used to screen field split results as a possible indicator of excessive variability in the sample handling and analytical system. If it is determined that elevated quantities of an analyte (i.e., > RL) were measured and analytical variability can be eliminated as a factor, then variability in field split results will primarily be used as a trigger for discussion with field staff to ensure samples are being handled in the field correctly. Some individual sample results may be invalidated based on the examination of all extenuating information. The information derived from field splits is generally considered to be event specific and would not normally be used to determine the validity of an entire batch; however, some batches of samples may be invalidated depending on the situation. Professional judgment during data validation will be relied upon to interpret the results and take appropriate action. The qualification (i.e., invalidation) of data will be documented on the Data Summary. Deficiencies will be addressed as specified in this section under Deficiencies, Nonconformances, and Correction Action related to QC.

Sampling Quality Control Requirements and Acceptability Criteria-Gain/Loss Survey

The minimum Field QC Requirements for the synoptic surveys are outlined in the *USGS Techniques and Methods 3-A8, Discharge Measurements at Gaging Stations, Chapter 8 of Book 3, Section A* (Appendix F) and *Quality Management Plan for Environmental Projects* (Appendix G).

Laboratory Measurement Quality Control Requirements and Acceptability Criteria

Method Specific QC requirements – QC samples, other than those specified later this section, are run (i.e., sample duplicates, surrogates, internal standards, continuing calibration samples,

interference check samples, positive control, negative control, and media blank) as specified in the methods. The requirements for these samples, their acceptance criteria or instructions for establishing criteria, and corrective actions are method-specific.

Detailed laboratory QC requirements and corrective action procedures are contained within the individual laboratory QASMs. The minimum requirements that all participants abide by are stated below.

Limit of Quantitation (LOQ) – The laboratory will analyze a calibration standard (if applicable) at the LOQ on each day the project samples are analyzed. Calibrations including the standard at the LOQ will meet the calibration requirements of the analytical method or corrective action will be implemented.

LOQ Check Standard – An LOQ check standard consists of a sample matrix (e.g., deionized water, sand, commercially available tissue) free from the analytes of interest spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes. It is used to establish intra-laboratory bias to assess the performance of the measurement system at the lower limits of analysis. The LOQ check standard is spiked into the sample matrix at a level less than or near the LOQ for each analyte for each batch of samples that are run.

The LOQ check standard is carried through the complete preparation and analytical process. LOQ check standards are run at a rate of one per analytical batch. A batch is defined as samples that are analyzed together with the same method and personnel, using the same lots of reagents, not to exceed the analysis of 20 environmental samples.

The percent recovery of the LOQ check standard is calculated using the following equation in which %R is percent recovery, SR is the sample result, and SA is the reference concentration for the check standard:

$$\%R = SR/SA * 100$$

Measurement performance specifications are used to determine the acceptability of LOQ Check Standard analyses as specified in Table A7.1.

Laboratory Control Standard (LCS) - A LCS consists of a sample matrix (e.g., deionized water) free from the analytes of interest spiked with verified known amounts of analyte. The LCS is spiked into the sample matrix at a level less than or equal to the mid-point of the calibration curve for each analyte. In cases of test methods with very long lists of analytes, LCSs are prepared with all the target analytes and not just a representative number.

The LCS is carried through the complete preparation and analytical process. The LCS is used to document the bias of the analytical process. LCSs are run at a rate of one per batch. A batch is defined as a set of environmental samples that are prepared and/or analyzed together within the same process using the same lot of reagents.

Results of LCSs are calculated by percent recovery (%R), which is defined as 100 times the measured concentration, divided by the true concentration of the spiked sample.

The following formula is used to calculate percent recovery, where %R is percent recovery; SR is the measured result; and SA is the true result:

$$\%R = SR/SA * 100$$

Performance limits and control charts are used to determine the acceptability of LCS analyses. Project control limits are specified in Table A7.1.

Laboratory Duplicates - A laboratory duplicate is prepared in the laboratory by splitting aliquots of an LCS. Both samples are carried through the entire preparation and analytical process. LCS duplicates are used to assess precision and are performed at a rate of one per batch. A batch is defined as a set of environmental samples that are prepared and/or analyzed together within the same process using the same lot of reagents.

For most parameters, precision is calculated by the RPD of LCS duplicate results as defined by 100 times the difference (range) of each duplicate set, divided by the average value (mean) of the set. For duplicate results, X_1 and X_2, the RPD is calculated from the following equation:

$$RPD = (X_1 - X_2)/\{(X_1 + X_2)/2\} * 100$$

A bacteriological duplicate is considered to be a special type of laboratory duplicate and applies when bacteriological samples are run in the field as well as in the lab. Bacteriological duplicate analyses are performed on samples from the sample bottle on a 10% basis. Results of bacteriological duplicates are evaluated by calculating the logarithm of each result and determining the range of each pair.

Performance limits and control charts are used to determine the acceptability of duplicate analyses. Project control limits are specified in Table A7.1. The specifications for bacteriological duplicates in Table A7.1 apply to samples with concentrations > 10 org/100mL.

Matrix spike (MS) –Matrix spikes are prepared by adding a known mass of target analyte to a specified amount of matrix sample for which an independent estimate of target analyte concentration is available. Matrix spikes are used, for example, to determine the effect of the matrix on a method's recovery efficiency.

Percent recovery of the known concentration of added analyte is used to assess accuracy of the analytical process. The spiking occurs prior to sample preparation and analysis. Spiked samples are routinely prepared and analyzed at a rate of 10% of samples processed, or one per batch whichever is greater. A batch is defined as samples that are analyzed together with the same method and personnel, using the same lots of reagents, not to exceed the analysis of 20 environmental samples. The information from these controls is sample/matrix specific and is not used to determine the validity of the entire batch. The MS is spiked at a level less than or equal to the midpoint of the calibration or analysis range for each analyte. Percent recovery (%R) is

defined as 100 times the observed concentration, minus the sample concentration, divided by the true concentration of the spike.

The results from matrix spikes are primarily designed to assess the validity of analytical results in a given matrix and are expressed as percent recovery (%R). The laboratory shall document the calculation for %R. The percent recovery of the matrix spike is calculated using the following equation in which %R is percent recovery, SSR is the observed spiked sample concentration, SR is the sample result, and SA is the reference concentration of the spike added:

$$\%R = (SSR - SR)/SA * 100$$

Measurement performance specifications for matrix spikes are not specified in this document.

The results are compared to the acceptance criteria as published in the mandated test method. Where there are no established criteria, the laboratory shall determine the internal criteria and document the method used to establish the limits. For matrix spike results outside established criteria, corrective action shall be documented or the data reported with appropriate data qualifying codes.

Method blank –A method blank is a sample of matrix similar to the batch of associated samples (when available) that is free from the analytes of interest and is processed simultaneously with and under the same conditions as the samples through all steps of the analytical procedures, and in which no target analytes or interferences are present at concentrations that impact the analytical results for sample analyses. The method blank is carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination from the analytical process. The analysis of method blanks should yield values less than the LOQ. For very high-level analyses, the blank value should be less than 5% of the lowest value of the batch, or corrective action will be implemented.

Deficiencies, Nonconformances and Corrective Action Related to Quality Control

Deficiencies are defined as unauthorized deviations from procedures documented in the QAPP. Nonconformances are deficiencies which affect data quantity and/or quality and render the data unacceptable or indeterminate. Deficiencies related to QC include but are not limited to field and laboratory QC sample failures.

Deficiencies are documented in logbooks, field data sheets, etc., by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the GBRA Project Manager. The GBRA Project Manager will notify the GBRA QAO of the potential nonconformance. The GBRA QAO will initiate a NCR to document the deficiency.

The GBRA Project Manager, in consultation with GBRA QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the GBRA Project Manager in consultation with the

GBRA QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the GBRA QAO by completion of a CAR (see Appendix E).

CARs document: root cause(s); impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TSSWCB immediately both verbally and in writing.

B6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

All sampling equipment testing and maintenance requirements are detailed in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415). Sampling equipment is inspected and tested upon receipt and is assured appropriate for use. Equipment records are kept on all field equipment and a supply of critical spare parts is maintained.

All laboratory tools, gauges, instrument, and equipment testing and maintenance requirements are contained within laboratory QASM(s).

Gain/Loss Survey: All sampling equipment testing and maintenance requirements are detailed in the *USGS Techniques and Methods 3-A8, Discharge Measurements at Gaging Stations, Chapter 8 of Book 3, Section A* (Appendix F) and *Quality Management Plan for Environmental Projects* (Appendix G).

B7 INSTRUMENT CALIBRATION AND FREQUENCY

Field equipment calibration requirements are contained in the TCEQ *SWQM Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue, 2008* (RG-415). Post-calibration error limits and the disposition resulting from error are adhered to. Data not meeting post-error limit requirements invalidate associated data collected subsequent to the pre-calibration and are not submitted to the TSSWCB.

Detailed laboratory calibrations are contained within the QASM(s).

Gain/Loss Survey: Field equipment calibration requirements are contained in the *USGS Techniques and Methods 3-A8, Discharge Measurements at Gaging Stations, Chapter 8 of Book 3, Section A* (Appendix F) and *Quality Management Plan for Environmental Projects* (Appendix G).

B8 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

No special requirements for acceptance are specified for field sampling supplies and consumables. All field supplies and consumables are accepted upon inspection for breaches in shipping integrity.

All new batches of field and laboratory supplies and consumables received by the GBRA laboratory are inspected upon receipt for damage, missing parts, expiration date, and storage and handling requirements. Chemicals, reagents, and standards are logged into an inventory database that documents grade, lot number, manufacturer, dates received, opened, and emptied. All reagents shall meet ACS grade or equivalent where required. Acceptance criteria are detailed in organization's SOPs.

Gain/Loss Survey: All new batches of field supplies and consumables received by the USGS are inspected upon receipt for damage, missing parts storage and handling requirements (See *USGS Techniques and Methods 3-A8, Discharge Measurements at Gaging Stations, Chapter 8 of Book 3, Section A* (Appendix F) and *Quality Management Plan for Environmental Projects* (Appendix G).

B9 NON-DIRECT MEASUREMENTS

This QAPP does not include the use of routine data obtained from non-direct measurement sources.

B10 DATA MANAGEMENT

Data Management Process

Field technicians and laboratory personnel follow protocols that ensure that data collected for this project maintains its integrity and usefulness in the WPP implementation process. Field data collected at the time of the sampling event is logged by the field technician, along with notes on sampling conditions on field data sheets. The field sheet is the responsibility of the field technician and is transported with the sample to the laboratory. The lab technician /sample custodian logs the sample in the Lab Samples Database. Each sample is assigned a separate and distinct sample number. The sample is accompanied by a COC form. The lab technician /sample custodian must review the COC to verify that it is filled out correctly and complete. Lab technicians take receipt of the sample and review the COC, begin sample prep or analysis and transfer samples into the refrigerator for storage. The field data sheet and COC form used can be found in Appendices B and C.

Data generated by lab technicians are logged permanently on analysis bench sheets. The data are reviewed by the analyst prior to entering the data into the Lab Samples Database. In the review, the analyst verifies that the data includes date and time of analysis, that calculations are correct, that data includes documentation of dilutions and correction factors, that data meets DQOs and that the data includes documentation of instrument calibrations, standard curves and control standards. A second review by another lab analyst/technician validates that the data meets the DQOs and that the data includes documentation of instrument calibrations, standard curves and control standards. After this review the lab analyst/technician inputs the data and QC information into the Lab Samples Database for report generation and data storage.

The GBRA Regional Laboratory Director supervises the GBRA Regional laboratory and reviews the report that is generated when all analyses are complete. Again, the report is reviewed to see that all necessary information is included and that the DQOs have been met. When the report is complete, the lab director signs the report. If the GBRA lab director or QAO designee feel there has been an error or finds that information is missing, the report is returned to the analyst for review and tracking to correct the error and generate a corrected copy. The GBRA Project Manager reviews the data for reasonableness and if errors or anomalies are found the report is returned to the laboratory staff for review and tracking to correct the error. After review for reasonableness the data is cross-checked to the analysis logs by the GBRA Project Manager. If at any time errors are identified, the laboratory and water quality databases are corrected.

The GBRA Project Manager, in consultation with GBRA QAO (and other affected individuals/organizations), will determine if the error constitutes a nonconformance. If it is determined a nonconformance does exist, the GBRA Project Manager in consultation with the GBRA QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the GBRA QAO by completion of a CAR (see Appendix E).

CARs document: root cause(s); impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for

completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with data summary report that accompanies the data submittal. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TSSWCB immediately both verbally and in writing.

The GBRA Project Manager is responsible for electronically transmitting the data to the TSSWCB Project Manager for inclusion in the TCEQ SWQMIS. A completed Data Summary, as described in the most recent version of *TCEQ SWQM Data Management Reference Guide*, will be submitted with each data submittal. If errors are found after the TSSWCB or TCEQ reviews, those errors are corrected by the GBRA Project Manager, logged in a data correction log and all participants are notified.

The following flow diagram outlines the path that data that is generated in the field takes:

> Field data collected → Field data sheets → Lab database → Report generation → QC review by GBRA QAO → Data checked for reasonableness by GBRA Project Manager → Data transferred to GBRA water quality database → Data verification to analysis logs by GBRA Project Manager → ASCII file format created → TSSWCB Project Manager

The following flow diagram outlines the path that data that is generated by the lab takes:

> Laboratory data → Laboratory analysis logs → Lab database → Report generation → QC review by GBRA QAO → Data checked for reasonableness by GBRA Project Manager → Data transferred to GBRA water quality database → Data verification to analysis logs by GBRA Project Manager → ASCII file format created → TSSWCB Project Manager

Gain/Loss Survey: The Data Management process utilized by the USGS is described in the Appendix G *USGS Quality Management Plan for Environmental Projects*

Data Errors and Loss

The GBRA Regional Laboratory Director supervises the GBRA Regional laboratory and reviews the report that is generated when all analyses are complete. The report is reviewed to see that all necessary information is included and that the DQOs have been met. When the report is complete, the lab director signs the report. If the GBRA lab director or QAO designee feel there has been an error or finds that information is missing, the report is returned to the analyst for review and tracking to correct the error and generate a corrected copy. The GBRA Project Manager reviews the data for reasonableness and if errors or anomalies are found the report is returned to the laboratory director for review and tracking to correct the error. After review for reasonableness the data is cross-checked to the analysis logs by the GBRA Project Manager. If at any time errors are identified, the laboratory and water quality databases are corrected. The GBRA Project Manager is responsible for electronically transmitting the data to the TSSWCB Project Manager for inclusion in the TCEQ SWQMIS. A completed Data Summary, as described in the most recent version of *TCEQ SWQM Data Management Reference Guide*, will be

submitted with each data submittal. If errors are found after the TSSWCB or TCEQ reviews, those errors are corrected by the GBRA Project Manager, logged in a data correction log and all participants are notified.

To minimize the potential for data loss, the databases, both lab and server files are backed up nightly and copies of the files are stored off-site weekly. If the laboratory database or network server fails, the backup files can be accessed to restore operation or replace corrupted files.

Record Keeping and Data Storage

After data is collected and recorded on field data sheets, the data sheets are filed for review and use later. These files are kept in paper form for a minimum of one year and then scanned into the GBRA ITRAX for permanent record.

The data produced during each analysis is recorded on analysis benchsheets. The information contained on the benchsheet includes all QC data associated with each day's or batch's analysis. The data from the benchsheet are transferred to the laboratory database for report generation. The analysis benchsheets are kept in paper form for a minimum of one year and then scanned into the GBRA ITRAX for permanent record.

The data reports that are generated are reviewed by the GBRA laboratory director and signed. They are then given to the GBRA Project Manager for verification. If an anomaly or error is found the report is marked and returned to the laboratory for review, verification and correction, if necessary. These reports may or may not be kept in paper form since the reports can be regenerated from the lab database at any time. If kept, the paper form is kept for a minimum of one year and then scanned into the GBRA ITRAX for permanent record.

The GBRA laboratory database is housed on the laboratory computer and is backed up on the network server nightly. A back up copy of the network server files is made every Monday and that copy is stored off-site at a protected location. The GBRA network administrator is responsible for the servers and back up generation.

After data is electronically submitted to the TSSWCB for inclusion in the TCEQ SWQMIS, the file that has been created is kept on the network server permanently. The network server is backed up nightly. Paper copies of the data and field duplicate sample reports are kept for a minimum of one year and then scanned into the GBRA ITRAX for permanent record.

The GBRA ITRAX is part of the network that is backed up each evening. The GBRA records manager is the custodian of these files.

Data Handling, Hardware, and Software Requirements

The laboratory database is housed on a GBRA server and backed up each evening. The laboratory database uses Sequel 2000. The systems are operating in Windows 2010 and any additional software needed for word processing, spreadsheet or presentations uses Microsoft Office 2010.

Information Resource Management Requirements

Data will be managed in accordance with the TCEQ *SWQM Data Management Reference Guide*, GIS Policy (TCEQ OPP 8.11), GPS Policy (TCEQ OPP 8.12) and applicable GBRA information resource management policies. The personnel collecting data for this project do not create TCEQ certified locational data using Global Positioning System (GPS) equipment. GPS equipment may be used as a component of the information required by the Station Location (SLOC) request process, but TCEQ staff are responsible for creating the certified locational data that will ultimately be entered into the TCEQ SWQMIS. Any information developed for this project using a Geographic Information System (GIS) will be used solely to meet deliverable requirements and will not be submitted to the TCEQ as a certified data set.

C1 ASSESSMENTS AND RESPONSE ACTIONS

The following table presents the types of assessments and response actions for data collection activities applicable to the QAPP.

Table C1.1 Assessments and Response Requirements

Assessment Activity	Approximate Schedule	Responsible Party	Scope	Response Requirements
Status Monitoring Oversight, etc.	Continuous	GBRA	Monitoring of the project status and records to ensure requirements are being fulfilled	Report to TSSWCB in Quarterly Progress Report
Monitoring Systems Audit of GBRA	Dates to be determined by TSSWCB	TSSWCB	Field sampling, handling and measurement; facility review; and data management as they relate to this project	30 days to respond in writing to the TSSWCB to address corrective actions
Laboratory Inspection	Dates to be determined by TSSWCB	TSSWCB	Analytical and QC procedures employed at the GBRA laboratory and the contracted laboratories	30 days to respond in writing to the TSSWCB to address corrective actions

Corrective Action

The GBRA Project Manager is responsible for implementing and tracking corrective action resulting from audit findings outlined in the audit report. Records of audit findings and corrective actions are maintained by both the TSSWCB and the GBRA Project Managers. Audit reports and corrective action documentation will be submitted to the TSSWCB with the Quarterly Progress Report.

If audit findings and corrective actions cannot be resolved, then the authority and responsibility for terminating work are specified in the agreements in contracts between participating organizations.

C2 REPORTS TO MANAGEMENT

Reports to GBRA Project Management

Laboratory data reports contain QC information so that this information can be reviewed by the GBRA Project Manager. After review, if the GBRA Project Manager finds no anomalies or questionable data, the process of data transmittal to TSSWCB begins. Project status, assessments and significant QA issues will be dealt with by the GBRA Project Manager who will determine whether it will be included in reports to the TSSWCB Project Manager.

Reports to TSSWCB

All reports detailed in this section are contract deliverables and are transferred to the TSSWCB in accordance with contract requirements.

Quarterly Progress Report - Summarizes the GBRA's activities for each task; reports monitoring status, problems, delays, and corrective actions; and outlines the status of each task's deliverables.

Monitoring Systems Audit Report and Response - Following any audit performed by the GBRA, a report of findings, recommendations and response is sent to the TSSWCB in the quarterly progress report.

D1 DATA REVIEW, VERIFICATION, AND VALIDATION

For the purposes of this document, the term verification refers to the data review processes used to determine data completeness, correctness, and compliance with technical specifications contained in applicable documents (i.e., QAPPs, SOPs, QASMs, analytical methods). Validation refers to a specific review process that extends the evaluation of a data set beyond method and procedural compliance (i.e., data verification) to determine the quality of a data set specific to its intended use.

All field and laboratory will be reviewed and verified for integrity and continuity, reasonableness, and conformance to project requirements, and then validated against the project objectives and measurement performance specifications which are listed in Section A7. Only those data which are supported by appropriate QC data and meet the measurement performance specifications defined for this project will be considered acceptable, and will be reported to TSSWCB.

D2 VERIFICATION AND VALIDATION METHODS

All field and laboratory data will be reviewed, verified and validated to ensure they conform to project specifications and meet the conditions of end use as described in Section A7 of this document.

Data review, verification, and validation will be performed using self-assessments and peer and management review as appropriate to the project task. The data review tasks to be performed by field and laboratory staff are listed in the first two sections of Table D.2, respectively. Potential errors are identified by examination of documentation and by manual examination of corollary or unreasonable data. If a question arises or an error is identified, the manager of the task responsible for generating the data is contacted to resolve the issue. Issues which can be corrected are corrected and documented. If an issue cannot be corrected, the task manager consults with higher level project management to establish the appropriate course of action, or the data associated with the issue are rejected. Field and laboratory reviews, verifications, and validations are documented.

After the field and laboratory data are reviewed, another level of review is performed once the data are combined into a data set. This review step, as specified in Table D2.1, is performed by the GBRA Data Manager and QAO. Data review, verification, and validation tasks to be performed on the data set include, but are not limited to, the confirmation of laboratory and field data review, evaluation of field QC results, additional evaluation of anomalies and outliers, analysis of sampling and analytical gaps, and confirmation that all parameters and sampling sites are included in the QAPP.

Another element of the data validation process is consideration of any findings identified during the monitoring systems audit conducted by the TSSWCB QAO. Any issues requiring corrective action must be addressed, and the potential impact of these issues on previously collected data will be assessed. After the data are reviewed and documented, the GBRA Project Manager validates that the data meet the DQOs of the project and are suitable for reporting to TSSWCB.

If any requirements or specifications of this project are not met, based on any part of the data review, the responsible party should document the nonconforming activities (with a CAR) and submit the information to the GBRA Data Manager with the data. This information is communicated to the TSSWCB by the GBRA in the Data Summary. The data is not transmitted to TSSWCB.

Table D2.1 Data Review Tasks

Field Data Review	Responsibility
Field data reviewed for conformance with data collection, sample handling and COC, analytical and QC requirements	GBRA Field Technicians
Post-calibrations checked to ensure compliance with error limits	GBRA Field Technicians
Field data calculated, reduced, and transcribed correctly	GBRA Project Manager
Gain/Loss Survey: Field data reviewed for conformance with data collection, and QC requirements	USGS Field Technicians
Gain/Loss Survey: Post-calibrations checked to ensure compliance with error limits	USGS Field Technicians
Gain/Loss Survey: Field data calculated, reduced, and transcribed correctly	USGS Project Manager
Laboratory Data Review	**Responsibility**
Laboratory data reviewed for conformance with data collection, sample handling and COC, analytical and QC requirements to include documentation, holding times, sample receipt, sample preparation, sample analysis, project and program QC results, and reporting	GBRA/SARA (QAOs)
Laboratory data calculated, reduced, and transcribed correctly	GBRA/SARA (QAOs) and GBRA Project Manager
LOQs consistent with requirements for AWRLs	GBRA/SARA (QAOs) and GBRA Project Manager
Analytical data documentation evaluated for consistency, reasonableness and/or improper practices	GBRA/SARA (QAOs) and GBRA Project Manager
Analytical QC information evaluated to determine impact on individual analyses	GBRA/SARA (QAOs) and GBRA Project Manager
All laboratory samples analyzed for all parameters	GBRA Project Manager
Data Set Review	**Responsibility**
The test report has all required information as described in Section A9 of the QAPP	GBRA Project Manager
Confirmation that field and lab data have been reviewed	GBRA Laboratory Director(QAO) and GBRA Project Manager
Data set (to include field and laboratory data) evaluated for reasonableness and if corollary data agree	GBRA Project Manager
Outliers confirmed and documented	GBRA Project Manager
Field QC acceptable (e.g., field splits and trip, field and equipment blanks)	GBRA Field Technicians
Sampling and analytical data gaps checked and documented	GBRA Field Technicians and GBRA Project Manager
Verification and validation confirmed. Data meets conditions of end use and are reportable	GBRA Project Manager

D3 RECONCILIATION WITH USER REQUIREMENTS

Data produced in this project, and data collected by other organizations (i.e., USGS, TCEQ, etc.), will be analyzed and reconciled with project data quality requirements. Data meeting project requirements will be used in the implementation and adaptive management of the Plum Creek WPP and will be submitted to TSSWCB for submittal to TCEQ in SWQMIS for use in the development of the biennial Texas Integrated Report for Clean Water Act Sections 305(b) and 303(d).

Appendix A Sampling Process Design and Monitoring Schedule

Sample Design Rationale

The sample design is based on the intent of this project as recommended by the PCWP Steering Committee. Under their direction, the TSSWCB and GBRA have been tasked with providing data to characterize water quality conditions in support of the 305(b) assessment, and to identify significant long-term water quality trends. Based on PCWP Steering Committee input, achievable water quality objectives and priorities and the identification of water quality issues were used to develop the workplan, which are in accord with available resources. As part of the PCWP Steering Committee process, the TSSWCB and GBRA coordinate closely with other participants to ensure a comprehensive water monitoring strategy within the watershed.

Site Selection Criteria

This data collection effort involves monitoring routine water quality, using procedures that are consistent with the TCEQ SWQM program, for the purpose of data entry into the SWQMIS database maintained by the TCEQ. To this end, some general guidelines are followed when selecting sampling sites, as basically outlined below, and discussed thoroughly in the TCEQ *SWQM Procedures, Volume 1* (RG-415). Overall consideration is given to accessibility and safety. All monitoring activities have been developed in coordination with the PCWP Steering Committee and with the TSSWCB.

1. Locate stream sites so that samples can be safely collected from the centroid of flow. Centroid is defined as the midpoint of that portion of stream width which contains 50 percent of the total flow. If few sites are available for a stream segment, choose one that would best represent the waterbody, and not an unusual condition or contaminant source. Avoid backwater areas or eddies when selecting a stream site.

2. Because historical water quality data can be very useful in assessing use attainment or impairment, those historical sites were selected that are on current or past monitoring schedules.

3. Routine monitoring sites were selected to bracket sources of pollution, influence of tributaries, changes in land uses, and hydrological modifications.

4. Sites should be accessible. When possible, stream sites should have a USGS stream flow gauge. If not, flow measurement will be made during routine and targeted monitoring visits.

Monitoring Sites

The Monitoring Table for this project is presented on the following pages.

Legend:

RT = Program code for routine samples
BF = Program code for targeted monitoring samples (biased flow)
BS = Program code for diurnal monitoring conducted during index period (biased season)
DO 24hr = diurnal monitoring for DO, conductivity, temperature and pH; measurements taken every hour for 24 hours; includes minimum, maximum and average.
Bacteria = *E. coli*
Conventional = TSS, turbidity, sulfate, chloride, nitrate nitrogen, ammonia nitrogen, total kjeldahl nitrogen, chlorophyll a, pheophytin, total hardness, total phosphorus, BOD (effluent only), CBOD (effluent only) and COD (effluent only)
Flow = flow collected by gage, electric, mechanical or Doppler; includes severity
Field = pH, temperature, conductivity, DO

Sampling Site Locations and Monitoring Regime

TCEQ Station ID	Site Description	Workplan Task	Monitor Type	DO 24hr	Bacteria	Conventional	Flow	Field	Comments
12556	Clear Fork Plum Creek at Salt Flat Road	3	RT		34	34	34	34	1
12556	Clear Fork Plum Creek at Salt Flat Road	6	BS	22			22	22	
12556	Clear Fork Plum Creek at Salt Flat Road	4	BF		11	11	11	11	
12556	Clear Fork Plum Creek at Salt Flat Road	10	BF				2		
12558	Elm Creek at CR 233	3	RT		34	34	34	34	1
12558	Elm Creek at CR 233	6	BS	22			22	22	
12558	Elm Creek at CR 233	4	BF		11	11	11	11	
12640	Plum Creek at CR 135	3	RT		34	34	34	34	1, 3
12640	Plum Creek at CR 135	6	BS	22			22	22	
12640	Plum Creek at CR 135	4	BF		11	11	11	11	
12640	Plum Creek at CR 135	10	BF				2		
12647	Plum Creek at Old McMahan Road (CR 202)	3	RT		34	34	34	34	1, 3
12647	Plum Creek at Old McMahan Road (CR 202)	6	BS	22			22	22	
12647	Plum Creek at Old McMahan Road (CR 202)	4	BF		11	11	11	11	
12647	Plum Creek at Old McMahan Road (CR 202)	10	BF				2		
17406	Plum Creek at Plum Creek Road	3	RT		34	34	34	34	1, 3
17406	Plum Creek at Plum Creek Road	6	BS	22			22	22	
17406	Plum Creek at Plum Creek Road	4	BF		11	11	11	11	
17406	Plum Creek at Plum Creek Road	10	BF				2		
20488	Brushy Creek at Rocky Road (Upstream of NRCS 14)	3	RT		34	34	34	34	1
20488	Brushy Creek at Rocky Road (Upstream of NRCS 14)	6	BS	22			22	22	
20488	Brushy Creek at Rocky Road (Upstream of NRCS 14)	4	BF		11	11	11	11	
20491	Dry Creek at FM 672	3	RT		34	34	34	34	1
20491	Dry Creek at FM 672	6	BS	22			22	22	
20491	Dry Creek at FM 672	4	BF		11	11	11	11	
20500	West Fork Plum Creek at Biggs Road (CR 131)	3	RT		34	34	34	34	1
20500	West Fork Plum Creek at Biggs Road (CR 131)	6	BS	22			22	22	
20500	West Fork Plum Creek at Biggs Road (CR 131)	4	BF		11	11	11	11	
20500	West Fork Plum Creek at Biggs Road (CR 131)	10	BF				2		
12555	Salt Branch at FM 1322	4	BF		22	22	22	22	
12557	Town Creek at E. Market St. (Upstream of Lockhart #I WWTP)	4	BF		22	22	22	22	
12559	Porter Creek at Dairy Road	4	BF		22	22	22	22	
12642	Plum Creek at Biggs Road (CR 131)	4	BF		22	22	22	22	

TCEQ Station ID	Site Description	Workplan Task	Monitor Type	DO 24hr	Bacteria	Conventional	Flow	Field	Comments
12643	Plum Creek at FM 1322	4	BF		22	22	22	22	
12645	Plum Creek at Young Lane (CR 197)	4	BF		22	22	22	22	
12648	Plum Creek at CR 186	4	BF		22	22	22	22	
12649	Plum Creek at CR 233	4	BF		22	22	22	22	
14945	Clear Fork Plum Creek at Old Luling Road (CR 213)	4	BF		22	22	22	22	
16709	Town Creek West of Lockhart	4	BF		22	22	22	22	
18343	Plum Creek Upstream of US 183	4	BF		22	22	22	22	
20480	Plum Creek Downstream of NRCS 1 Spillway	4	BF		22	22	22	22	
20481	Bunton Branch at Heidenreich Lane	4	BF		22	22	22	22	
20482	Brushy Creek at FM 2001 (Downstream of NRCS 12)	4	BF		22	22	22	22	
20487	Brushy Creek at SH 21	4	BF		22	22	22	22	
20483	Elm Creek at SH 21 (Downstream of NRCS 16)	4	BF		22	22	22	22	
20489	Cowpen Creek at Schuelke Road	4	BF		22	22	22	22	
20496	Tenney Creek at Tenney Creek Road	4	BF		22	22	22	22	
20490	Clear Fork Plum Creek at Farmers Road	4	BF		22	22	22	22	
20493	Clear Fork Plum Creek at PR 10 (State Park)	4	BF		22	22	22	22	
20497	West Fork Plum Creek at FM 671	4	BF		22	22	22	22	
12538	Andrews Branch at CR 131	4	BF		22	22	22	22	
20495	Dry Creek at FM 713	4	BF		22	22	22	22	
20484	Plum Creek at Heidenreich Lane (Downstream of Kyle WWTP)	4	BF		22	22	22	22	
20501	Salt Branch at Salt Flat Road (Upstream of Luling WWTP)	4	BF		22	22	22	22	
20498	Copperas Creek at Tenney Creek Road/Bronco Lane (CR 141, Downstream of Cal-Maine)	4	BF		22	22	22	22	
20505	Richmond Branch at Dacy Lane	4	BF		22	22	22	22	
20504	Porter Creek Tributary at Quail Cove Road	4	BF		22	22	22	22	
20510	Hines Branch at Tenney Creek Road (CR 141, Downstream of Cal-Maine)	4	BF		22	22	22	22	
20503	Plum Creek at Lehman Road	4	BF		22	22	22	22	
20502	Bunton Branch at Dacy Lane (upstream of NRCS 5)	4	BF		22	22	22	22	
20479	Unnamed Tributary at FM 150 near Hawthorn Dr.	4	BF		22	22	22	22	
20492	10210-001 City of Lockhart and GBRA #1(Larremore plant)	7	-		11	11	11	11	2
20494	10210-002 City of Lockhart and GBRA #2 (FM 20 plant)	7	-		11	11	11	11	2
20499	10582-001 City of Luling	7	-		11	11	11	11	2
20486	11041-002 City of Kyle and Aquasource Inc.	7	-		11	11	11	11	2
99923	11060-001 City of Buda and GBRA	7	-		11	11	11	11	2
99936	14431-001 GBRA Shadow Creek	7	-		11	11	11	11	2
99937	14377-001 GBRA Sunfield	7	-		11	11	11	11	2
20509	Lockhart Springs	8	BS		11	11	11	11	
20507	Clear Fork Springs at Borchert Loop (CR 108)	8	BS		11	11	11	11	
20508	Boggy Creek Springs at Boggy Creek Road (CR 218)	8	BS		11	11	11	11	

1. The eight "routine" sites double as "targeted" sites. "Targeted" sampling will collect biased flow (BF) samples twice per quarter – once under wet weather conditions and once under dry weather conditions. Whether these samples will satisfy the wet (biased high flow) or dry (biased low flow) weather conditions depends on the flow condition when samples are collected during the "routine' sampling that quarter.
2. The data collected from WWTF sampling will not be used for enforcement or compliance monitoring by TCEQ. As such, results will not be reported to TCEQ for inclusion in any data tracking system. Monitor type code is not applicable.
3. These samples are collected/analyzed by GBRA utilizing Texas CRP funding and serve as a portion of the non-federal match for this project.
4. Sites were adjusted to accommodate access.

Appendix B Field Data Sheet

Texas Commission on Environmental Quality
Surface Water Quality Monitoring Program

Field Data Reporting Form

RTAG# | REGION | EMAIL-ID: | COLLECTOR

STATION ID | SEGMENT | SEQUENCE | DATA SOURCE

Station Description _____

GRAB SAMPLE

M M D D Y Y Y Y — DATE | H H M M — TIME | DEPTH | M = meters F = feet

COMPOSITE SAMPLE

COMPOSITE CATEGORY: T=Time S=Space (i.e. Depth) B=Both F=Flow Weight

M M D D Y Y Y Y — START DATE | H H M M — START TIME | START DEPTH (SURFACE) | M = meters F = feet

M M D D Y Y Y Y — END DATE | H H M M — END TIME | END DEPTH (DEEPEST) | M = meters F = feet

COMPOSITE TYPE: ## = Number of Grabs in Composite CN = Continuous

00010		WATER TEMP (°C only)
00400		pH (s u)
00300		D.O. (mg/L)
00094		SPECIFIC COND (µmhos/cm)
00480		SALINITY (ppt, marine only)
50060		CHLORINE RESIDUAL (mg/L)
00078		SECCHI DISK (meters)
82078		TURBIDITY-FIELD (NTU)
31616		FECAL COLIFORM (#/100 ml)
31699		E coli (#/100 ml) (Colilert Method)
31701		Enterococci (#/100 ml) (Enterolert Method)

72053		DAYS SINCE LAST SIGNIFICANT PRECIPITATION
01351		FLOW SEVERITY 1-no flow 2-low 3-normal 5-high 4-flood 6-dry
00061		INSTANTANEOUS STREAM FLOW (ft³/sec)
89835		FLOW MEASUREMENT METHOD 1- Flow Gage Station 2- Electric 3- Mechanical 4- Weir/Flume
74069		FLOW ESTIMATE (ft³/sec)
82903		TOTAL WATER DEPTH (meters)
00055		WATER VELOCITY (maximum)(ft/sec)
89864		MAXIMUM POOL WIDTH (meters) *
89869		POOL LENGTH (meters) *
89865		MAXIMUM POOL DEPTH (meters) *
89870		% POOL COVERAGE IN 500 M REACH *

*Parameters related to data collection in perennial pools; i.e., Flow Severity of 1 and Flow of zero reported.

Measurement Comments and Field Observations:

Chain of Custody

Guadalupe-Blanco River Authority Regional Laboratory

933 E. Court Street, Seguin, Texas 78155
830-379-5822 • Fax 830-379-7478

Customer Information

Customer Acct. #_____

Name: _____ Phone: _____

Address: _____ Fax: _____

_____ E-mail: _____

Sample Collected By: _____ _____
Signature Printed Name Residual Chlorine (Total/Free) Results _____

Thermometer No._____ pH Paper GBRA reagent no. _____

Temp C	Date Collected	Time Collected	Matrix WW=Wastewater DW=Drinking Water SW=Surface Water S=Soils/Sludge O=Other	Sx Vol. P=Plastic G=Glass	Sample Name/Description	TCEQ ID Number	Grab/ Comp.	Analysis Requested	GBRA Sample ID	Bottle ID No.	pH	GBRA# Preservation

Delivered By: _____ Date/Time _____ Received By: _____ Date/Time: _____

Delivered By: _____ Date/Time _____ Received By: _____ Date/Time: _____

**Special Notes/Ship To: _____

Ice:_____ (Y or N) Number of Containers:_____ Condition of Container(s): (intact)_____

RL-042-0101/2010 (QASM App. c) GBRA Doc. 3019-C Rev 14 Eff: 7/30/2010 by JT

Appendix D Data Summary Report

Data Summary

Data Information

Data Source: _____

Date Submitted: _____

Tag_id Range: _____

Date Range: _____

Comments

Please explain in the space below any data discrepancies including:

- **Inconsistencies with AWRL specifications;**
- **Failures in sampling methods and/or laboratory procedures that resulted in data that could not be reported to the TSSWCB; and**
- **Other discrepancies.**

_____
-
-
-
-
-
-
-

Data Manager: _____

Date: _____

Appendix E Corrective Action Form

Corrective Action(s) for: _____

Date:_____ **Document # 3016-A**

Analyst:_____ **rev. 3 Eff. 2/16/07 by: JL**

Sample #'s affected_____

STATE THE PROBLEM:

CAUSE OF THE PROBLEM(s) (if known):

ACTIONS TAKEN TO RESOLVE PROBLEM (s):

FOLLOW UP:

REVIEWED BY QA OFFICER:(date/sign)

Appendix F USGS Protocol – Discharge Measurements at Gaging Locations

USGS
science for a changing world

Discharge Measurements at Gaging Stations

Chapter 8 of Book 3, Section A

Techniques and Methods 3–A8

U.S. Department of the Interior
U.S. Geological Survey

Front cover: On the left, photograph of a USGS hydrographer making a FlowTracker acoustic Doppler velocimeter discharge measurement at Little Eagle Creek at Speedway, Ind. (USGS station no. 03353600); on the right, photograph of a USGS hydrographer making a tethered boat acoustic Doppler current profiler discharge measurement from a cableway at the Snake River near Moran, Wyo. (USGS station no. 13011000).

Back cover: In the background, 1890 black and white photograph of USGS hydrographers making a mechanical current meter discharge measurement from a cableway at the Arkansas River near Canyon City, Colo. (USGS station no. 07096000); and on the right, 1958 black and white photograph of a USGS hydrographer making a mechanical current meter discharge measurement at the Cedar River at Belgrade, Nev. (USGS station no. 06791800).

Discharge Measurements at Gaging Stations

By D. Phil Turnipseed and Vernon B. Sauer

Techniques and Methods 3–A8

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

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Preface

This series of manuals on techniques and methods (TM) describes approved scientific and data-collection procedures and standard methods for planning and executing studies and laboratory analyses. 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.

The unit of publication, the chapter, is limited to a narrow field of subject matter. These publications are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment, and this format permits flexibility in revision and publication as the need arises. Chapter A8 of book 3 (TM 3–A8) deals with discharge measurements at gaging stations. The original version of this chapter was published in 1969 as U.S. Geological Survey (USGS) Techniques for Water-Resources Investigations, chapter A8 of book 3. New and improved equipment, as well as some procedural changes, have resulted in this revised second edition of "Discharge measurements at gaging stations."

This edition supersedes USGS Techniques of Water-Resources Investigations 3A–8, 1969, "Discharge measurements at gaging stations," by T.J. Buchanan and W.P. Somers, available at *http://pubs.usgs.gov/twri/twri3a8/*, and supplements USGS Water-Supply Paper 2175, volume 1, 1982, "Measurement and computation of streamflow: Measurement of stage and discharge," by S.E. Rantz and others, available at *http://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_vol1.html*.

This revised second edition of "Discharge measurements at gaging stations" is published online at *http://pubs.usgs.gov/tm/tm3-a8/* and is for sale by the U.S. Geological Survey, Science Information Delivery, Box 25286, Federal Center, Denver, CO 80225.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile [$(gal/d)/mi^2$]	0.001461	cubic meter per day per square kilometer [$(m^3/d)/km^2$]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [$(Mgal/d)/mi^2$]	1,461	cubic meter per day per square kilometer [$(m^3/d)/km^2$]
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Multiply	By	To obtain
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
pound-force per square inch (lbf/in^2)	6.895	kilopascal (kPa)
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Vertical Datum of 1988 (NAVD 88)."

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Datum of 1983 (NAD 83)."

Elevation, as used in this report, refers to distance above sea level. Because this report is based on a large number of previously published scientific investigations, "sea level" is not referenced to a single vertical datum. "Mean sea level" also is not used with reference to a single datum; where used, the phrase means the average surface of the ocean as determined by calibration of measurements at tidal stations.

Abbreviations and Acronyms

AA	Price AA current meter
ADCP	acoustic Doppler current profiler
ADC	acoustic digital current meter
ADV	acoustic Doppler velocimeters
Aquacalc	JBS Instruments Aquacalc Pro Discharge Measurement Computer
C1	C1 connector
CMD	current meter digitizer
CMCsp	Hydrological Services Current Meter Counter signal processor
CSG	crest stage gage
CST	Central Standard Time
C type	Columbus type
DCP	Data Collection Platform
DGPS	global positioning system with differential corrections
dB	decibels
EDT	Eastern Daylight Time

EFN	electronic field notebook
EST	Eastern Standard Time
FlowTracker	SonTek/YSI FlowTracker Handheld acoustic Doppler velocimeter
GPS	global positioning system
HIF	U.S. Geological Survey Hydrologic Instrumentation Facility
HWM	high water mark
Hz	hertz
ISO	International Organization for Standardization
kHz	kilohertz
LEW	left edge of water
MHz	megahertz
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NWIS	U.S. Geological Survey National Water Information System
OFR	U.S. Geological Survey Open-File Report
PDA	portable digital assistant
PFD	personal flotation device
QA/QC	quality assurance and quality control
RD	Teledyne RD Instruments
REW	right edge of water
RP	reference point
RTK	real-time kinematic
RTK-GPS	real-time kinematic global positioning system
SNR	signal-to-noise ratio
SWAMI	surface water measurement and inspection
TM	U.S. Geological Survey Techniques and Methods
TRDI	Teledyne RD Instruments
TWRI	U.S. Geological Survey Techniques of Water-Resources Investigations
USGS	U.S. Geological Survey
WAAS	Wide Area Augmentation System
WRD	Water Resources Division/Discipline
WSC	Water Science Center
WSCan	Environment Canada Ministry Water Survey of Canada Agency

Definitions of Symbols

a_i	cross-section area for the *i*th segment of the *n* segments into which the cross section is divided
arctan	arctangent
b	width of the throat section (in units of distance)
b_i	distance from initial point to location i
$b_{(i-1)}$	distance from initial point to preceding location
$b_{(i+1)}$	distance from initial point to next location
d_i	depth of water at location *i*
C	coefficient of discharge

c	speed of sound (in distance per unit time)
cos	cosine of the angle alpha
°C	temperature in degrees Celsius
$CORR_{wl}$	correction (in units of distance) to subtract from the wet-line depth to obtain the vertical depth
D_{wl}	wet-line depth (in units of distance)
D_v	vertical depth (in units of distance)
	average change in stage in the reach L during the measurement (in units of distance)
	elapsed time during measurement
	computed phase difference
°F	temperature in degrees Farenheit
H	weighted mean gage height (in units of distance)
h	static head, head, elevation, or gage height (in units of distance)
IQR	interquartile range
L	length of reach between measuring section and control (in units of distance)
m	difference (in feet) between the air-line correction for the sounding position and that for the 0.8 position
n	difference (in feet) between the wet-line correction for the sounding position and that for the 0.8 position, if the depths are greater than 40 feet and the change in vertical angle is more than 5 percent
P	vertical angle (in degrees)
	ratio of the circumference to the diameter of a circle; approximately equal to 3.14159
Q	discharge (in volume per unit time)
$Q1$	25 percent of samples are less than this value
$Q3$	75 percent of samples are less than this value
q_i	discharge through partial section i, (in volume per unit time)
R	number of rotor revolutions per second
T	total time for the measurement
t_1	duration of time intervals between breaks in the slop of the gage height graph
tan	tangent
	time lag between pulses
V	velocity (in distance per unit time)
Vx	velocity (in distance per unit time) in the x direction (perpendicular to the tag line)
Vy	velocity (in distance per unit time) in the y direction (parallel to the tag line)
V	volume of water in container
v_i	mean velocity (in units of distance per unit time) of the flow normal to the ith segment, or vertical
W	average width of stream between measuring section and control (in units of distance)
W_1	weight of empty container (in units of mass)
W_2	weight of container with water (in units of mass)
w	unit weight of water (in units of mass per volume)
x	x-direction (perpendicular to the tag line) or x-component of velocity

Discharge Measurements at Gaging Stations

By D. Phil Turnipseed and Vernon B. Sauer

Abstract

The techniques and standards for making discharge measurements at streamflow gaging stations are described in this publication. The vertical axis rotating-element current meter, principally the Price current meter, has been traditionally used for most measurements of discharge; however, advancements in acoustic technology have led to important developments in the use of acoustic Doppler current profilers, acoustic Doppler velocimeters, and other emerging technologies for the measurement of discharge. These new instruments, based on acoustic Doppler theory, have the advantage of no moving parts, and in the case of the acoustic Doppler current profiler, quickly and easily provide three-dimensional stream-velocity profile data through much of the vertical water column. For much of the discussion of acoustic Doppler current profiler moving-boat methodology, the reader is referred to U.S. Geological Survey Techniques and Methods 3–A22 (Mueller and Wagner, 2009).

Personal digital assistants (PDAs), electronic field notebooks, and other personal computers provide fast and efficient data-collection methods that are more error-free than traditional hand methods. The use of portable weirs and flumes, floats, volumetric tanks, indirect methods, and tracers in measuring discharge are briefly described.

Purpose and Scope

The U.S. Geological Survey (USGS) makes tens of thousands of streamflow measurements each year across the United States and its territories. Measured discharges range from a trickle in a small ditch or stream [less than 0.01 cubic foot per second (ft^3/s)], to a flood on the Mississippi River (greater than 1,800,000 ft^3/s). Several methods are used by the USGS to make streamflow measurements. Principally, the USGS uses mechanical current meters and hydroacoustic meters [for example, acoustic Doppler current profilers (ADCPs) and acoustic Doppler velocimeters (ADVs)]. The purpose of this report is to describe the equipment and procedures used by the USGS and others for making discharge measurements, and to describe new developments in equipment and procedures. Other traditional methods of measuring streamflow include portable weirs and flumes, and volumetric, float, indirect, and tracer measurements. Relatively new developments include the use of a moving boat with the ADCP (Mueller and Wagner, 2009), the wading rod mounted ADV, electromagnetic current meters, electronic field notebooks, personal digital assistants (PDAs), and various procedural changes.

The original version of USGS Techniques of Water-Resources Investigations book 3, chapter A8 (TWRI 3–A8), by Buchanan and Somers (1969), was used as an extensive resource in the preparation of this publication because much of the equipment and techniques described by Buchanan and Somers are still applicable to current streamgaging methods. The USGS publications "Measurement and Computation of Streamflow, volumes 1 and 2," by Rantz and others (1982); "Discharge measurements using a broad-band acoustic Doppler current profiler," by Simpson (2002); "Quality-assurance plan for discharge measurements using acoustic Doppler current profiler," by Oberg and others (2005); and "Measuring discharge with acoustic Doppler current profilers from a moving boat," by Mueller and Wagner (2009), were also used extensively in the preparation of this publication. Numerous parts of this chapter were taken verbatim from Buchanan and Somers (1969), Rantz (1982), Simpson (2002), Oberg and others (2005), and Mueller and Wagner (2009), and even though some of these parts are not specifically denoted, credit is hereby given to these authors.

Definition of Streamflow

Streamflow, or discharge, is defined as the volumetric rate of flow of water (volume per unit time) in an open channel, including any sediment or other solids that may be dissolved or mixed with it that adhere to the Newtonian physics of open-channel hydraulics of water. The definition of streamflow in this chapter does not include non-Newtonian flow events such as debris flows and lahars (an avalanche of volcanic mud and water down the slopes of a volcano). Streamflow in the USGS is usually expressed in English dimensions of cubic feet per second (ft^3/s). Other common units are million gallons per day (Mgal/d) and acre-feet per day (ac-ft/d). Streamflow cannot be measured directly but must be computed from variables that can be measured directly, such as stream width, stream depth, and streamflow velocity. Even though streamflow is computed from measurements of other variables, the term "streamflow measurement" or "discharge measurement" is generally applied to the final result of the calculations.

Discharge Measurements at Gaging Stations

Procedures for making most types of current-meter [mechanical meters, electromagnetic meters, ADV meters, acoustic digital current meters (ADCs), and so forth)], moving-boat ADCP, and ADCP midsection measurements are described in the following sections. For much of the discussion of moving-boat ADCP, the reader is referenced to Mueller and Wagoner (2009). The chapter includes discussions on the selection of a measuring section, laying out the stationing for subsection verticals, width measurements, depth measurements, velocity measurements, direction of flow measurements, and recording of field notes. Additional details that pertain to instrumentation and specific types of measurements, such as wading, cableway, bridge, boat, and ice, are described in subsequent sections. Special procedures such as networks of current meters, measurement of deep, swift streams, and measurements during rapidly changing stage are also described.

Velocity-Area Method

The most practical method of measuring the discharge of a stream is the velocity-area method. Discharge is computed as the product of the area and velocity. The measurement is made by subdividing a stream cross section into segments (sometimes referred to as partial areas, sections, subareas, verticals, stations, profiles, panels, or ensembles), and by measuring the depth and velocity in a vertical within each segment. The total discharge is the summation of the products of the partial areas of the stream cross section and their respective average velocities. This computation is classically expressed by the equation

$$Q = \sum_{i=1}^{n} a_i v_i, \tag{1}$$

where Q total discharge, in cubic feet per second,
a_i cross-section area, in square feet, for the ith segment of the n segments into which the cross section is divided, and
v_i the corresponding mean velocity, in feet per second of the flow normal to the ith segment, or vertical.

Midsection Method

The current-meter midsection method of making a current-meter discharge measurement is used by the USGS and others. The method assumes that the mean velocity in each vertical represents the mean velocity in a partial rectangular area (segment). The mean velocity in each vertical is determined by measuring the velocity at one or more selected points in that vertical, as described in a later section of this chapter. The cross-section area for a segment extends laterally from half the distance from the preceding vertical to half the distance to the next vertical, and vertically, from the water surface to the sounded depth as shown in figure 1.

The cross section in figure 1 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 (segment) at location i as

$$q_i = v_i \left[\frac{\left(b_i - b_{(i-1)}\right)}{2} + \frac{\left(b_{(i+1)} - b_i\right)}{2} \right] d_i, \text{ or} \tag{2}$$

$$= v_i \left[\frac{b_{(i+1)} - b_{(i-1)}}{2} \right] d_i, \tag{3}$$

where q_i discharge through partial section i,
v_i mean velocity at location i,
b_i distance from initial point to location i,
$b_{(i-1)}$ distance from initial point to preceding location,
$b_{(i+1)}$ distance from initial point to next location, and
d_i depth of water at location i.

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

$$q_4 = v_4 \left[\frac{b_5 - b_3}{2} \right] d_4. \tag{4}$$

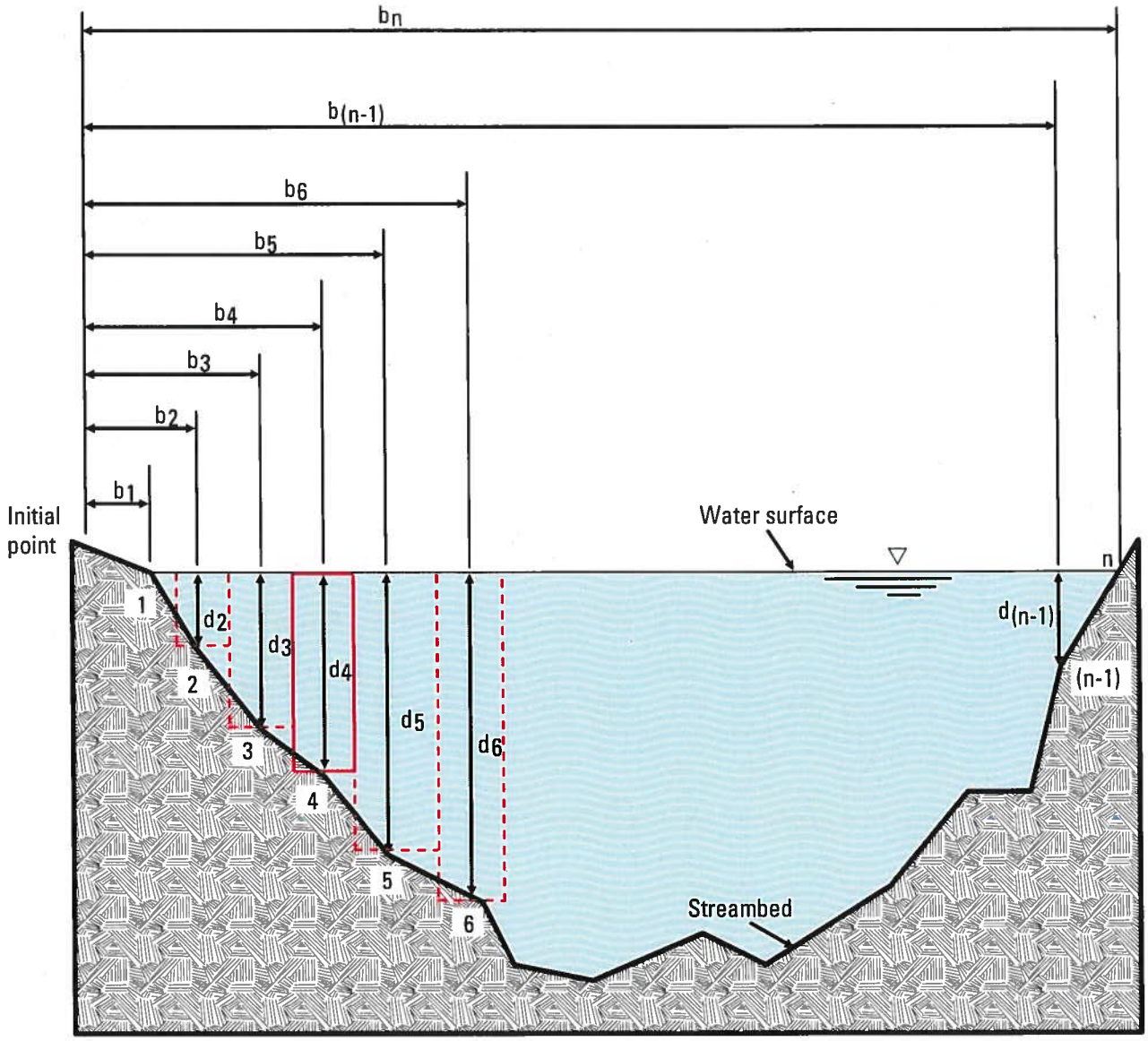
The procedure is similar when i is at an end section. The "preceding location" at the beginning of the cross section is considered coincident with location 1; the "next location" at the end of the cross section is considered coincident with location n. Thus,

$$q_1 = v_1 \left[\frac{b_2 - b_1}{2} \right] d_1, \text{ and} \tag{5}$$

$$q_n = v_n \left[\frac{b_n - b_{(n-1)}}{2} \right] d_n. \tag{6}$$

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. Equations 5 and 6 are used whenever there is water only on one side of an observation point, such as at the edge of the stream, piers, abutments, and islands. It usually is necessary to estimate the velocity at an end 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 estimated velocity is usually made as a percentage of the adjacent section.

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*A*. In the hydraulic properties reported, the summation of discharges from an ADV discharge



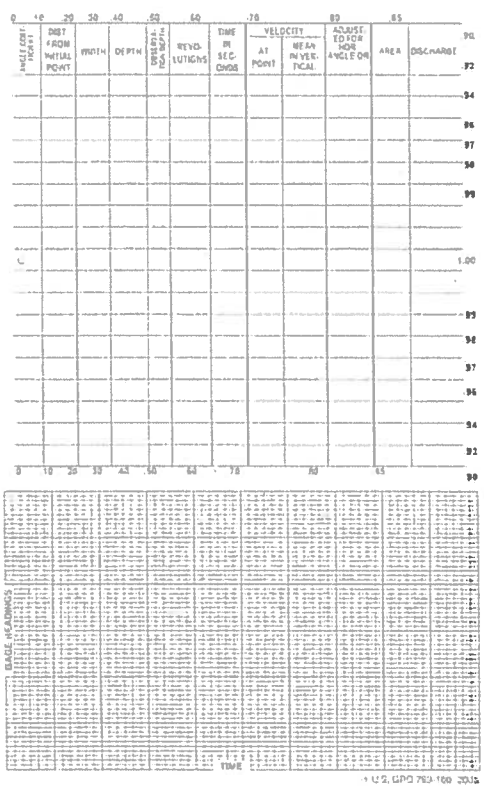
EXPLANATION

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

Figure 1. Definition sketch of the current-meter *midsection* method of computing cross-section area for discharge measurements.

measurement (fig. 2*B*) is similar to that of a current meter; however, it is designed to report the properties inherent to the ADV software and signal processing necessary to compute discharge using acoustic Doppler technology. A program written by staff in the USGS Maine Water Science Center entitled Surface Water Measurements and Inspections (SWAMI) has become common in use in the USGS with a PDA, and may be used to record discharge measurements, inspections, differential level surveys, and other field measurements (fig. 2*C*).

Included here for convenience is a typical, well-documented ADCP discharge measurement (fig. 2*D*). This measurement serves as an example of how an ADCP measurement note should be kept in the field. Further discussion of ADCP measurements can be found in subsequent sections of this chapter.



Form 9-275F (Apr. 2001)

U.S. DEPARTMENT OF THE INTERIOR
U.S. Geological Survey
WATER RESOURCES DIVISION
DISCHARGE MEASUREMENT AND GAGE INSPECTION NOTES

Meas. No. 587
Comp. by DPT
Checked by LRB

Sta. No. 01994650
Sta. Name RED CREEK NEAR LEESBURG, VA
Date OCT. 31, 2010 Party DPTURNIPSEED
Width 70 Area 144 Vel 0.51 G.H. 1.93 Disch. 73.4
Method .2&.8, .6 No. secs. 28 G.H. change -0.02 in 1 hrs
Method coef. 1 Horiz. angle coef. VARIES Susp. ROD Tags checked —
Meter Type AA Meter No. 3684 Meter — ft. above bottom of wt.
Rating used STD. No. 2 Soln. test before meas. 2:45 after FREE
Meas. plots 2.1 % diff. from rating no. 19.0 Indicated shift —

GAGE READINGS

Time		El.T.	Rec.		Inside	Outside
1310		1.94	1.94		1.94	1.92
1330					(1.94)	
1430					(1.92)	
1445		1.92	1.92		1.92	1.90
Weighted MGH					1.93	
GH correction						
Correct MGH						

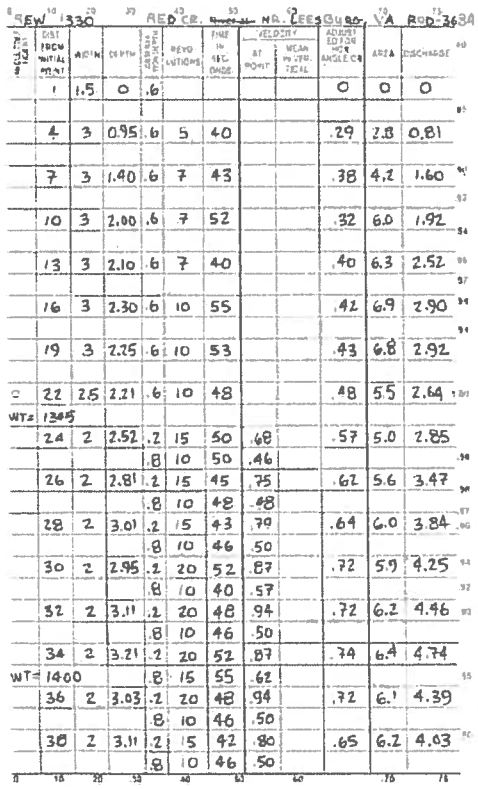
Samples collected: water quality, sediment, biological, other —
Measurements documented on separate sheets: water quality, aux./base gage other —
Rain gage serviced/calibrated —
Weather CLOUDY
Air Temp. 19 °C at 1435
Water Temp. 12 °C at 1435
Check bar/chain found —
Changed to — at —
Correct —

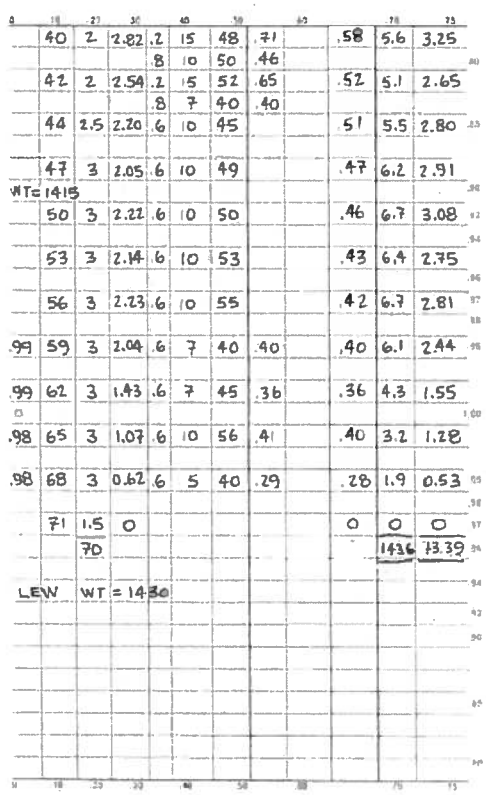
Wading, cable, ice, boat, upstr., downstr., side bridge 25 ft., ms (upstr.) downstr. of gage
Measurement rated excellent (2%), good (5%), fair (8%), poor (>8%), based on following conditions: Flow WELL DISTRIBUTED
Cross section SANDY, TRIANGULAR

Gage operating OK Record Removed NO
Battery voltage 13.7 Intake/Orifice cleaned/purged NO
Bubble-gage pressure psi: Tank — Line — Bubble rate — /min
Extreme GH indicators: max — min —
CSG checked — HWM height/ch. stick — Ref. elev. — HWM elev. —
HWM inside/outside —
Control ROCK RIFFLE, ~100 FT DS OF GAGE
CONTROL CLEAR
Remarks —

GH of zero flow = GH 1.92 - depth at control 1.61 = 0.3 ft., rated G
Sheet No. ___ of ___ sheets

A





	40	2	2.82	.2	15	48	.71		.58	5.6	3.25
				.8	10	50	.46				
	42	2	2.54	.2	15	52	.65		.52	5.1	2.65
				.8	7	40	.40				
	44	2.5	2.20	.6	10	45			.51	5.5	2.80
	47	3	2.05	.6	10	49			.47	6.2	2.91
WT= 1415											
	50	3	2.22	.6	10	50			.46	6.7	3.08
	53	3	2.14	.6	10	53			.43	6.4	2.75
	56	3	2.23	.6	10	55			.42	6.7	2.81
.99	59	3	2.04	.6	7	40	.40		.40	6.1	2.44
.99	62	3	1.43	.6	7	45	.36		.36	4.3	1.55
.98	65	3	1.07	.6	10	56	.41		.40	3.2	1.28
.98	68	3	0.62	.6	5	40	.29		.28	1.9	0.53
	71	1.5	0						0	0	0
		70								1436	73.39
LEW	WT = 1430										

Figure 2. Computation notes of: *A*, a current-meter measurement by the *midsection* method; *B*, an ADV discharge measurement; *C*, from the Surface Water Measurement and Inspection (SWAMI) form; and *D*, an ADCP discharge measurement.

9-275-x	01/24/2007	U.S. DEPARTMENT OF THE INTERIOR	Meas. No.	625
Station Number		*U.S. Geological Survey*	Comp. by	SEM
03329700		ADV Discharge Measurement Notes	Checked by	RGK

Station Name	Deer Creek nr Delphi, IN				
Date	8/18/2009	Party	SEMorlock		
Width	Area	Velocity	SNR	Gage Height	Discharge
63	51.6	1.16	32	2.08	59.8
Method		# Sections	Gage Height Change		
.6		30	-.01 in .52 hrs.		
Diagnostic Test File	Std Velocity Profile	Measured Water Temp	Weather		
P156.080509.bnk	(Y) or N or Uncertain	24.3 °F/C at 1100	Cloudy		
Raw Data File	ADV Sync'd to WT	ADV Water Temp	Wind Speed / Dir.		
03329700.WAD	(Y) at 1120 or N	73.1 °F/C at 1140	0-5/SW		
Manufacturer	Model	Serial No.	Firmware	Software	
Sontek	Flowtracker	P156A	3.3	2.20	

EST Time	Gage Readings	DCP	ETG Inside	ETG Outside	STAFF
1052		2.09	2.08	2.08	
1123	S				
1155	F				
1207		2.08	2.07	2.07	

Rating number	30
Percent from rating	3.5
Indicated shift	Ø
Rain gage serviced/calibrated	n/a
Salinity	— ppt at —
Checkbar found	na
Checkbar Changed to	— at —

Weighted MGH			
GH corrections			
Correct MGH			

Wading ~~cable, ice, boat, upstr., downstr., side bridge~~	a-t	~~ft., mi. upstr., downstr.~~ of gage	
Measurement rated	excellent (2%), (good (5%)), fair (8%), poor (>8%)	based on following conditions	
Flow	Steady and Even		
Cross section	Sand and gravel, fairly even		
Control	Sand, gravel and cobbles 100'ds clear		
Gage operating	(Y) or N	Record removed (Y) or N	Filename 03329700.log
Battery voltage	12.8 V	Intakes/Orifice cleaned/purged	Yes
Bubble-gage psi	Tank na	Line na	Bubble rate na / min
Extreme-GH indicators	Max 2.45	Min 1.87	CSG Checked (Y) or N
HWM on stick	no	Ref elev 4.32	HWM elevation na
GH of zero flow = GH	2.08	- depth at control 1.20 = .88 ft.	Rated Fair
Remarks			
		Sheet No. 1 of 2 sheets	

B

SEM

Discharge Measurement Summary

Date Generated: Tue Nov 17 2009

File Information

File Name	03329700.WAD
Start Date and Time	2009/08/18 11:23:50

Site Details

Site Name	
Operator(s)	HTM

System Information

Sensor Type	FlowTracker
Serial #	P156A
CPU Firmware Version	3.3
Software Ver	2.20

Units (English Units)

Distance	ft
Velocity	ft/s
Area	ft^2
Discharge	cfs

Discharge Uncertainty

Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.2%	1.0%
Velocity	0.6%	3.1%
Width	0.1%	0.1%
Method	1.5%	-
# Stations	1.7%	-
Overall	**2.6%**	**3.4%**

Summary

Averaging Int.	40	# Stations	30
Start Edge	LEW	Total Width	63.000
Mean SNR	32.0 dB	Total Area	51.550
Mean Temp	73.12 °F	Mean Depth	0.818
Disch. Equation	Mid-Section	Mean Velocity	1.1593
		Total Discharge	**59.7613**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	11:23	0.00	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0
1	*11:23*	*4.00*	*0.6*	*0.400*	*0.6*	*0.160*	*0.2966*	*1.00*	*0.2966*	*1.200*	*0.3558*	*0.6*
2	11:25	6.00	0.6	0.500	0.6	0.200	0.4426	1.00	0.4426	1.000	0.4426	0.7
3	*11:26*	*8.00*	*0.6*	*0.600*	*0.6*	*0.240*	*0.6266*	*1.00*	*0.6266*	*1.200*	*0.7521*	*1.3*
4	*11:27*	*10.00*	*0.6*	*0.800*	*0.6*	*0.320*	*0.7802*	*1.00*	*0.7802*	*1.600*	*1.2481*	*2.1*
5	11:28	12.00	0.6	1.100	0.6	0.440	0.9803	1.00	0.9803	2.200	2.1568	3.6
6	11:29	14.00	0.6	1.300	0.6	0.520	0.8986	1.00	0.8986	2.600	2.3362	3.9
7	11:30	16.00	0.6	1.300	0.6	0.520	0.9829	1.00	0.9829	2.600	2.5554	4.3
8	11:32	18.00	0.6	1.300	0.6	0.520	1.1299	1.00	1.1299	2.600	2.9375	4.9
9	11:33	20.00	0.6	1.300	0.6	0.520	1.2979	1.00	1.2979	2.600	3.3742	5.6
10	*11:34*	*22.00*	*0.6*	*1.100*	*0.6*	*0.440*	*0.9744*	*1.00*	*0.9744*	*2.200*	*2.1438*	*3.6*
11	11:36	24.00	0.6	1.100	0.6	0.440	1.4452	1.00	1.4452	2.200	3.1797	5.3
12	11:37	26.00	0.6	1.200	0.6	0.480	0.9862	1.00	0.9862	2.400	2.3672	4.0
13	11:38	28.00	0.6	1.200	0.6	0.480	1.0472	1.00	1.0472	2.400	2.5137	4.2
14	*11:39*	*30.00*	*0.6*	*1.000*	*0.6*	*0.400*	*0.9636*	*1.00*	*0.9636*	*2.000*	*1.9272*	*3.2*
15	11:40	32.00	0.6	1.000	0.6	0.400	0.9551	1.00	0.9551	2.000	1.9101	3.2
16	11:41	34.00	0.6	1.000	0.6	0.400	1.5469	1.00	1.5469	2.000	3.0938	5.2
17	11:42	36.00	0.6	1.000	0.6	0.400	1.4954	1.00	1.4954	2.000	2.9908	5.0
18	11:44	38.00	0.6	1.000	0.6	0.400	1.4741	1.00	1.4741	2.000	2.9482	4.9
19	11:45	40.00	0.6	0.900	0.6	0.360	1.5633	1.00	1.5633	1.800	2.8138	4.7
20	*11:46*	*42.00*	*0.6*	*0.900*	*0.6*	*0.360*	*1.3133*	*1.00*	*1.3133*	*1.800*	*2.3638*	*4.0*
21	11:47	44.00	0.6	0.800	0.6	0.320	1.6240	1.00	1.6240	1.600	2.5980	4.3
22	11:48	46.00	0.6	0.800	0.6	0.320	1.2562	1.00	1.2562	1.600	2.0096	3.4
23	11:49	48.00	0.6	0.700	0.6	0.280	1.6437	1.00	1.6437	1.400	2.3016	3.9
24	11:51	50.00	0.6	0.700	0.6	0.280	1.4249	1.00	1.4249	1.400	1.9952	3.3
25	11:52	52.00	0.6	0.600	0.6	0.240	1.2969	1.00	1.2969	1.200	1.5565	2.6
26	11:53	54.00	0.6	0.600	0.6	0.240	1.4646	1.00	1.4646	1.200	1.7577	2.9
27	11:54	56.00	0.6	0.500	0.6	0.200	1.4452	1.00	1.4452	1.000	1.4452	2.4
28	11:55	58.00	0.6	0.500	0.6	0.200	0.9639	1.00	0.9639	1.750	1.6868	2.8
29	11:55	63.00	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

01031500 - Site Visit Summary - 2009-05-20

SWAMRiver 0.1.5

Site Visit Summary

Site Number:	01031500	Site Name:	Piscataquis River near Dover-Foxcroft, Maine		
Date:	2009-05-20	StartTime:	09:13:07	EndTime:	10:48:46
Party:	LEF	Weather:	Sunny		
Comment:					

Discharge Measurement

Meas #:	872	Meas Flow:	440 cfs	Time:	10:05:48
Stage:	3.02 ft	Stage Change:	-.01 ft	Change Duration:	1.4 hrs
Qm Rated:	Fair (8%)	Base Flow:	Unspecified		
Comment:	Rated fair due to boulders encountered during QM // This was a good/fair QM.				

Channel 0 Summary

Name:	Main	Meas Flow:	440.013 cfs ()	Qm Type:	Wading
Qm Method:	Midsection	Condition:	8mm, uneven, cobbles-boulders	Vel Method:	Price AA
Horiz Flow:	Even	Vel Desc:	Steady	Sect Loc.:	Downstream 600ft. to gage
Start Point:	Left edge of water	Mtr Type:	Price AA	Mtr s/N:	ME_P450
Mtr Susp:	Top-setting wading rod	Mtr Insp B4:	true	Mtr Insp Aft:	true
Dist to Mtr:		Wt. Used:		Summary Only:	false
Total Area:	272	Total Width:	133	Mean Vel:	1.62

Stn. #	Time	Method	Coef%	Dist (ft)	Width (ft)	TotDepth (ft)	Ice (ft)	IceDepth (ft)	%Depth	Rev	Time	Adj'd Vel	Adj Vel	Area (ft²)	Discharge (ft³/s)	Com
1	09:22:56	Est'N	75	3.0	0.5	.91							0.578	0.46	0.266	--
2	09:25:36		.88	4.0	1.75	.80			.6	14	41	0.771	0.756	1.4	1.058	
3	09:28:31		1.00	6.5	2	1.20			.6	19	41	1.04	1.04	2.4	2.496	
4	09:31:07		1.00	8.0	2.75	1.32			.6	25	40	1.4	1.4	3.63	5.082	
5	09:33:27		1.00	12	4	1.63			.6	25	40	1.4	1.4	6.52	9.128	--
6	09:35:03		1.00	16	4	1.85			.6	23	41	1.25	1.25	7.4	9.25	
7	09:37:05		1.00	20	4	1.65			.6	27	41	1.47	1.47	6.6	9.702	--
8	09:39:54		1.00	24	3	2.92			.2	33	40	1.84	1.575	8.76	13.797	
									.8	24	41	1.31				
9	09:43:15		1.00	25	3	3.06			.2	38	40	2.11	1.78	9.18	16.340	
									.8	26	40	1.45				
10	09:46:30		1.00	30	3	3.14			.2	38	40	2.11	1.63	9.42	15.355	
									.8	21	41	1.15				
11	09:49:36		1.00	32	3	3.23			.2	37	40	2.06	1.755	9.84	17.269	
									.8	26	40	1.45				
12	09:52:34		1.00	36	3	3.42			.2	43	41	2.33	1.92	10.26	19.699	
									.8	27	40	1.51				
13	09:55:30		1.00	38	3	3.32			.2	42	40	2.33	1.975	9.96	19.671	
									.8	29	40	1.62				
14	09:58:34		1.00	42	3	3.24			.2	46	40	2.55	2.17	9.72	21.092	
									.8	33	41	1.79				
15	10:01:18		1.00	44	3	3.02			.2	45	40	2.50	2.195	9.06	19.887	
									.8	34	40	1.89				
16	10:04:29		1.00	48	3	3.05			.2	49	41	2.65	2.3	9.15	21.045	
									.8	35	40	1.95				
17	10:07:32		1.00	50	3	3.20			.2	51	40	2.83	2.39	9.6	22.944	
									.8	35	40	1.95				
18	10:10:30		1.00	54	3	3.12			.2	49	40	2.72	2.39	9.36	22.370	
									.8	37	40	2.06				
19	10:13:59		1.00	56	3	2.65			.2	48	40	2.66	2.28	7.95	18.126	
									.8	35	41	1.90				
20	10:17:20		1.00	60	3	2.86			.2	45	40	2.55	2.09	8.58	17.932	
									.8	30	41	1.63				
21	10:21:21		1.00	62	3	2.91			.2	46	40	2.55	2.085	8.73	18.202	
									.8	29	40	1.62				
22	10:24:08		1.00	66	4	2.62			.2	44	40	2.44	2.14	10.48	22.427	
									.8	33	40	1.84				
23	10:26:11		1.00	70	4	2.46			.6	38	40	2.11	2.11	9.84	20.762	
24	10:27:43		1.00	74	4	2.42			.6	31	42	1.65	1.65	9.68	15.972	
25	10:29:32		1.00	78	4	1.82			.6	30	41	1.63	1.63	7.28	11.866	
26	10:31:20		1.00	82	5	1.84			.6	22	44	1.12	1.12	9.2	10.304	
27	10:33:20		1.00	88	6	1.72			.6	25	40	1.4	1.4	10.32	14.448	
28	10:35:16		1.00	94	6	1.58			.6	22	41	1.2	1.2	9.48	11.376	
29	10:36:50		1.00	100	6	1.50			.6	19	40	1.07	1.07	9	9.63	
30	10:38:22		1.00	106	6	1.32			.6	18	40	1.01	1.01	7.92	7.999	
31	10:40:12		1.00	112	6	1.18			.6	15	41	0.824	0.824	7.08	5.834	
32	10:45:50		1.00	118	7	1.02			.6	8	42	0.438	0.438	7.14	3.127	--
33	10:45:26		1.00	126	5	1.58			.6	8	45	0.41	0.41	7.9	3.239	--
34	10:47:38		1.00	128	5	1.73			.6	5	44	0.268	0.268	8.65	2.318	
35	10:48:40		1.00	136	4	0			.6	0	40	0	0	0	0	--

Midsection Comments

Stn #	Comment
1	LEW
5	Behind rock
7	Top of rock
32	Left edge of sand bar.
33	Right edge of sand bar.
35	REW

C

Acoustic Profiler Discharge Measurement Notes							Filename Prefix: foxmon_ds1200_
Left Bank:	Sloping	Vertical	Other:_____			Right Bank:	Sloping Vertical Other:_____
Transect No.	Starting			Ending		Total Discharge	Notes
	Bank	Time	Distance	Distance	Time		
0	L R						Moving bed test in center of channel
1	L (R)	1249	16	69	1255	1,321	Simultaneous comparison discharge measurements
2	(L) R	1256	69	16	1301	1,358	upstream of dam
3	L (R)	1301	69				Transect aborted due to debris in river
4	L (R)	1303	69	16	1308	1,327	
5	(L) R	1309	16	69	1315	1,356	
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
Notes	All times are in CST. Measurement was made using a temporary rope-and-pulley cableway. Edge distances were measured with laser rangefinder by marking the start and ending positions on the rope and measuring the distance from edge of water to the center of the tethered boat.						

9-2754 7/1908 U.S. Department of the Interior U.S. Geological Survey Meas. No. 57 Processed by BLL Checked by KAO

Station Number 05551540 Station Name Fox River at Montgomery, IL

Date July 6, 2004 Party B.L. Loving, S.E. Anderson

Width 235 Area / Rated Area 707 Velocity 1.90 Index Vel. 1.74 Gage Height 11.74 Discharge 1,340

Gage Height Change 0.00 in 0.4 hrs. Meas. plots 4.4% diff From mtng No.: 11 Shift 0.0 ADCP Syncd to WT (Y) at 1207 or N

ADCP Mfr / Model / Frequency RDI Rio Grande 1200 Serial No. 1636 Firmware 10.14 Software WinRiver 10.06

Boat/Motor Used GPS Used Trimble AgGPS ADCP Depth 0.27 ft Diag. Test / Errors? ☑ Y or N

Compass Calib. & Eval. OceanScience Tethered Mag. Var. Mag Var Method Moving Bed?

(Y) or N 0.8 -2.4 On-site (Mode) Previous Y or (N)

Meas. Water Temp 26.5 °F / (C) at 1210 ADCP Water Temp 26.5°F (C) at 1210 Weather / Air Temp Sunny/clear 85 (F) C Wind Speed / Dir. Southerly @ 5-10 mph

Gage Readings

Time	ETG	CR10	Inside	Outside
1100	11.74	11.70		11.70
1230		11.70		±0.05
1249 (S)		11.70		
1300		11.70		
1315 (F)		11.70		
1400	11.74	11.70		11.70
				±0.05
Weighted MGH	11.74			
GH corrections				
Correct MGH	11.74			

Site Conditions

Max Water Depth 10 ft

Max Water Speed 2.5 ft/s

Max Boat Speed 1 ft/s

Water Mode 12

Bottom Mode 5

Streambed material Gravel

Salinity ppt at Checkbar found 22.41

Checkbar changed to — at —

Wading, cable, ice, boat, upstr., downstr., side bridge 1500 ft, mi. upstr. (downstr.) of gage

Measurement rated excellent (2%), good (5%), fair (8%), poor (>8%) based on following conditions

Flow Steady & uniform. Flow at edges appears to be moving in DS direction

Gross section Sand and Gravel with some mud

Control Dam is clear of debris

Gage operating (Y) or N Record removed Y or (N) Filename Telephone telemetry

Battery voltage 12.5 V Intakes/Orifice cleaned/purged No

Bubble-gage pst Tank — Line — D — / min

Extreme GH indicators Max — Min — CSG Checked (Y) or N

HWM on stick None Ref elev. 12.65 HWM elevation None

GH of zero flow = GH — - depth at control — = — ft, Rated 10.48

Sheet No. 1 of 1 sheets

D

The mean-section method used by the USGS prior to 1950 differs from the midsection method in computation procedure. Partial discharges are computed for partial sections between successive verticals. The velocities and depths at successive verticals are each averaged, and each partial section extends laterally from one vertical to the next. Discharge is the product of the average of two mean velocities, the average of two depths, and the distance between verticals. 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.

Site Selection

The first and most critical step in making a midsection current-meter or ADV measurement, or an ADCP measurement is to select a measurement cross section of desirable qualities. If the stream cannot be waded, nor high-water measurements made from a bridge, moving or tethered boat, or cableway, the hydrographer may have little or no choice in selecting a measurement cross section. If the stream can be waded or the measurement can be made from a boat, the hydrographer should look for a cross section with the following characteristics:

- There is a reasonably straight channel with streamlines parallel to each other; a stable streambed free of large rocks, weeds, and obstructions that would create eddies, slack water, and turbulence; and desirable measurement sections that are roughly parabolic, trapezoidal, or rectangular. These conditions are obviously not always possible, but remember that most current meters are rated in a still water tank by towing them through the tank at a known speed. With that in mind, these are conditions a hydrographer should seek in the field: a smooth, mirror-like water surface with steady, uniform, nonvarying flow conditions in the stream reach where the discharge measurement will be taken.
- The velocities are, for the most part, greater than 0.5 ft/s, and depths that are greater than about 0.5 ft. These conditions are not always possible to find in the field.
- The measurement section is relatively close to the gaging station control to avoid the effect of tributary and (or) intervening drainage area inflows between the measurement section and the control, and to avoid the effect of channel storage between the measurement section and the control during periods of changing stage.

It is usually not possible to satisfy all of these conditions. Select the best possible reach using these criteria and then select a cross section. For a further discussion regarding site selection when using a mechanical or other point-velocity current meter refer to Rantz and others (1982).

For convenience, special site-selection considerations for an ADCP discharge measurement are presented as follows, and further discussion of ADCP methods and instruments is presented in subsequent sections of this chapter:

- The minimum depth near the left and right edges of water at the measurement site should allow for the measurement of velocity in two or more depth cells while being close enough to minimize the estimated edge discharges.
- Make sure velocities are, for the most part, greater than 0.5 ft/s, and depths are greater than the minimum depth required by the ADCP. Although measurements can be made in low velocities, keep boat speeds extremely slow (if possible, less than or equal to the average water velocity), which requires special techniques for boat control (Simpson, 2002).
- Avoid measurement sections having local magnetic fields, especially if a moving bed is present and a Global Positioning System with differential corrections (DGPS) or the Loop Method (Mueller and Wagoner, 2006) is used. For example, during measuring, avoid overhead truss bridges, low steel-beam spans, power lines, and other sources of magnetic fields. Just as with ADCP mounts and boats, the presence of ferrous metals will result in ADCP compass errors.
- If possible, avoid asymmetric channel geometries (for example, deep on one side and shallow on the other; Simpson, 2002) and avoid cross sections with abrupt changes in channel-bottom slope. The streambed cross section should be as uniform as possible and free from debris and vegetation or plant growth.
- When using DGPS with an ADCP, avoid cross-section locations where multipath interference, such as riparian vegetation (low-hanging trees and large bushes on river or stream banks), buildings at or near the river banks, bridges, and other flow-control structures, could impede or block signals from GPS satellites.

It is usually not possible to attain all of these conditions, but site selection cannot be understated as a critical part of a discharge measurement. Select the best possible reach using these criteria and then select a cross section. For more discussion regarding site selection when using an ADCP, refer to Mueller and Wagner (2009).

Layout and Stationing of Partial Sections and Verticals in a Midsection Current-Meter Discharge Measurement

After the cross section has been selected, determine the width of the stream. For a mechanical current-meter or other point-velocity measurement, string a tag line or measuring tape for measurements made by wading, from a boat, from ice cover, or from an unmarked bridge. Except for bridges, string the line

at right angles to the direction of flow to avoid horizontal angles in the cross section. For cableway or bridge measurements, use the graduations painted on the cable or bridge rail. Next, determine the spacing of the verticals, generally using about 25 to 30 partial sections. With a smooth cross section and even velocity distribution, fewer partial sections may be used. Space the partial sections so that no partial section has more than 10 percent of the total discharge in it. The ideal measurement is one in which no partial section has more than 5 percent of the total discharge in it; this can be challenging when only 25 partial sections are used. For example, the discharge measurement shown in figure 2*A* had 6.5 percent of the total discharge in the partial section with the greatest discharge. Equal widths of partial sections across the entire cross section are not recommended unless the discharge is evenly distributed. Lessen the width of the partial sections as depths and velocities become greater. Usually an approximate or expected total discharge can be obtained from the stage-discharge curve. Space the verticals so the discharge in each partial section is about 5 percent of the expected total discharge from the rating curve. When using an electronic field notebook [such as the JBS Instruments Aquacalc Pro Discharge Measurement Computer (Aquacalc), a PDA with the Hydrological Services Current Meter Counter signal processor (CMCsp), or the SonTek FlowTracker], the expected total discharge can be entered prior to starting the discharge measurement. During the measurement, a warning message will be displayed if a partial discharge exceeds 10 percent of the expected total discharge. When using an ADV or other acoustic point-velocity instrument, make sure the instrument is appropriately aligned and plumbed to the tag line because slight variations in the alignment of the instrument can result in large errors in the measurement of point velocity. See further discussion of the use of acoustic point-velocity instruments in this chapter.

For a standard mechanical current-meter discharge measurement, the usual procedure, after selecting and laying out the section, is to measure and record at each vertical (1) the distance from the initial point, (2) the depth, (3) the meter position, (4) the number of revolutions, (5) the time interval, and (6) the horizontal angle of flow. The starting point can be either bank. The edge of water, which may have a depth of zero, is considered to be the first vertical. The hydrographer should move to each of the verticals in succession and repeat the procedure until the measurement is completed at the opposite bank.

Measurement of Width

The first measurement made in a discharge measurement is usually the determination of horizontal stationing (width) in the cross section being measured. Width needs to be measured using the proper equipment and procedures that apply to the type of measurement being made (that is, wading, bridge, cableway, boat, or ice). Details of measuring width using a variety of equipment, and under different flow conditions, are described in subsequent sections of this chapter.

The horizontal distance to any vertical in a cross section is measured from an initial point on the bank. Cableways and bridges used regularly for making discharge measurements are commonly marked at 2-, 5-, 10-, and (or) 20-ft intervals by paint marks. Distance between markings is interpolated, or measured with a rule or pocket tape. Steel or Kevlar tag lines and metallic tapes are used for measurements made by wading, from boats, or from unmarked bridges. For wide streams of about 2,500 ft or more, where conventional measuring methods cannot be used, surveying methods and Global Positioning Systems (GPS) can be used.

Tapes and Tag Lines

Tag lines used for wading measurements are usually made of either galvanized steel aircraft cord with solder beads at measured intervals, or Kevlar, which is marked with black ink and waxed to resist abrasion. A Kevlar tag line consists of a Kevlar core with a nylon jacket.

The standard arrangement of solder beads on steel tag lines is shown in table 1. The standard markings for Kevlar tag lines is one mark every 2 ft, two marks every 10 ft, and three marks every 100 ft. The standard lengths of tag lines are 300, 400, and 500 ft, but other sizes are available.

Four types of tag-line reels typically used for the steel tag lines are the Lee-Au, Pakron, Columbus type A, and the USGS Stainless Steel Tag line as shown in figure 3. The reel used for the Kevlar tag line is shown in figure 4.

Larger reels, used for boat measurements, are designed to hold up to 3,000 ft of ⅛-inch (in.) diameter steel tag line. These reels and boat measurement methods have largely been replaced by the ADCP technology. Two different types of reels still available are as follows:

- A heavy-duty, horizontal-axis reel without a brake, and with a capacity of 5,000 ft of ⅛-in. beaded tag line or 3,000 ft of $^{3}/_{16}$-in. Kevlar boat tag line, as shown in figure 5.
- A vertical-axis reel without a brake (fig. 6), and with a capacity of 1,500 ft of ⅛-in diameter steel tag line (800 ft tag lines are standard) or up to 900 ft of 3/16-in. Kevlar boat tag-line cable.

Table 1. Standard markings for steel tag lines.

Distance from initial point (zero mark), in feet	Distance between marks, in feet	Number of solder beads, or tags
0 to 50	2	1 (single bead)
50 to 100	5	1
150 to 500	10	1
0 to 50	10	2 (double bead)
50 to 450	100	2
0 to 500	100	3 (triple bead)

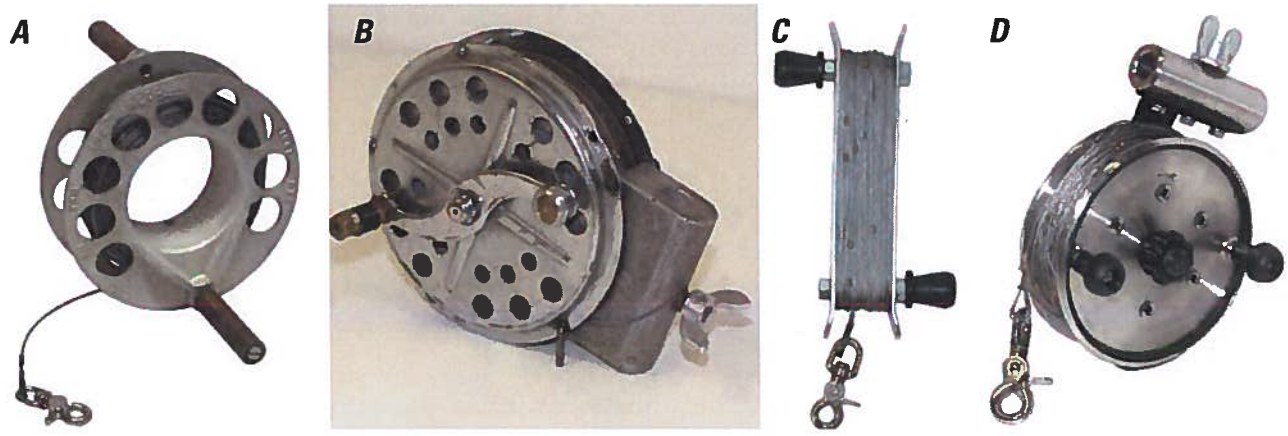


Figure 3. Type-A reels: *A*, Lee-Au; *B*, Pakron; *C*, Columbus; and *D*, USGS stainless steel tag line.

Figure 4. Kevlar tag-line reel.

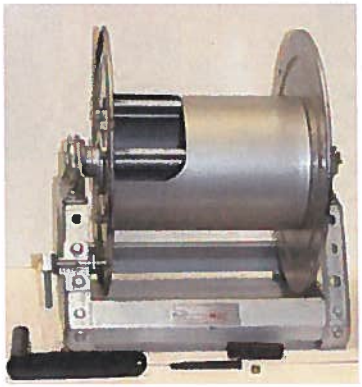


Figure 5. Horizontal-axis boat tag-line reel without a brake.

Figure 6. Vertical-axis boat tag-line reel.

Surveying Methods of Width Measurement, Surveying Level, and Electronic Total Station

For wide streams where it is not practical to string a tag line for discharge measurements from a boat, surveying methods can be used to measure stream width and stationing for measurement points. Surveying methods require the use of a surveying level, as shown in figure 7, or electronic total station instrumentation, as shown in figure 8. The procedure to determine width with a transit is used less frequently, but is described in the section of this chapter on boat measurements.

With the advent of electronic total station surveying instruments and digital surveying levels, a direct reading of the distance can be made from the digital surveying level or from the total station instrument setup point to the boat. One example of a commercially available total station instrument is shown in figure 8. Most of these instruments require a reflector target at the point where a measurement is desired (in this case the boat); however, total station instruments are also available that provide accurate measurements of distance without a reflector target. Accurate distance measurements can be made with total station instruments over distances of 1 mi or more, provided the boat can be seen and not obstructed by intervening objects.

Figure 7. Surveying level and tripod.

Figure 8. Total station surveying equipment: A, instrument and tripod and B, instrument reflector targets and surveying tape.

Global Positioning System With Differential Corrections

Measurement points can be stationed for wide streams, such as flood plains that may be several miles wide, or large tidal estuaries, with a global positioning system with differential corrections (DGPS) instrument, such as that shown in figure 9, which is a real-time kinematic (RTK) GPS base station with radio transmitter. RTK-GPS and other DGPS instruments utilize satellite telemetry from an array of satellites, and use radio triangulation to compute positions for any point on the Earth. In order to obtain the accuracy necessary for a discharge measurement, the raw GPS positions must have differential corrections applied on the basis of simultaneous readings at a base station. Most DGPS units contain built-in differential correction receivers that make automatic and instantaneous corrections. Other GPS units may use a separate receiver that attaches to the GPS unit with a cable. In either case, base station data are received by radio signal from nearby ground base stations or via communications satellites from a network of ground stations, such as the Wide Area Augmentation System (WAAS).

A surveying grade DGPS unit with capability of storing and recalling data is preferred. These units may or may not have built-in or attached differential correction receivers. If instantaneous differential corrections are not made, then use correction data obtained after the fact from a separate GPS base station to postprocess coordinate data. Various agencies collect and provide the base station data via the Internet. Coordinate data for the measurement points are downloaded from the GPS unit to a computer for postprocessing. Software is available to make the differential corrections, to compute corrected coordinates of the measurement points, and to automatically compute distances between and to plot a map of the measurement points.

Figure 9. Global positioning system with real-time kinematic (RTK–GPS) base station and radio transmitter.

Accuracy of GPS coordinates will vary depending on the type of GPS unit used and whether or not differential corrections are made. Coordinates without differential corrections can be in error by as much as ±300 ft because of various errors in the system. Obviously, this is not acceptable for discharge measurements. However, if care is taken in making observations, and then making differential corrections, errors can be reduced to as little as ±3 ft, and even less in ideal conditions. This method is acceptable for wide flood plains and inaccessible estuaries with open skies and minimal reflective surfaces, which can result in multipath errors.

Measurement of Depth

The second measurement normally made at a vertical is the stream depth. Depth should be measured using the proper equipment and procedures that apply to the type of measurement being made (that is, wading, bridge, cableway, boat, or ice). Details of measuring depth using various equipment and under different flow conditions are described in the following sections of this chapter. The water depth of a stream at a selected vertical can be measured in several ways, depending on the type of measurement being made, the total depth of the stream, and the velocity of the stream. Stream depth is usually measured by use of a wading rod, sounding lines and weights, acoustic Doppler sensor, or another sonic sounder, as described in the following sections of this chapter.

Use of Wading Rod

Use a wading rod for measuring stream depth when depth is shallow enough, or when measuring from a low footbridge or other supportive structure over the stream. Likewise, use the wading rod for measuring from ice cover for shallow depths. Wading rods can even be used from a boat if depths are not too great. The top-setting wading rod can be used for depths up to 4 ft, but greater depths can be measured with 6-, 8-, and 10-ft top-setting wading rods. The round wading rod, which is assembled with 1-ft sections, can be made up into any length, but generally is not used for depths greater than about 10 ft. Velocity of flow is also a consideration because high velocity may not allow for keeping a long wading rod in place.

Wading rods have a small foot on the bottom to allow the rod to be placed firmly on the streambed, and yet not sink into the streambed under most conditions. In sand-bottom streams, or in soft muck, it is sometimes difficult to keep the wading rod from sinking into the streambed as the weight of the rod and meter and the eroding power of the flowing water cause the foot of the wading rod to sink. The hydrographer must use care in these conditions to be sure the measured water depth, as well as the depth of the current-meter placements, are accurately based on the surface of the streambed. In some cases, the wading rod may need to be supported in some manner other than resting on the streambed.

When using a wading rod in streams with moderate-to-high velocity, there will be a velocity-head build-up of water on the wading rod. The stream depth should be based on where the surface of the stream intersects the wading rod, and not on the top of the velocity-head build-up. Wading rods are graduated in tenths-of-a-foot, and stream depths are generally measured or estimated and recorded to the nearest 0.01 ft.

Use of Sounding Lines and Weights

Water depth is measured with sounding lines and weights when the depth is too great to use a wading rod, and when measuring conditions require measuring from a bridge, cableway, or boat. This section will describe the measurement of depth when using sounding reels and handlines. It also discusses the procedures used to correct observed depths when high velocity causes the weight and meter to drift downstream.

Use of Sounding Reels

When using one of the sounding reels described in a subsequent section of this chapter, a counter or dial is used to determine the length of cable that has been dispensed. Depths are measured to the nearest 0.1 ft when using a sounding line and weight.

The size of the sounding weight used in current-meter measurements depends on the maximum depth and velocity in a cross section. A rule of thumb is that the size of the weight in pounds should be greater than the maximum product of velocity and depth in the cross section. If insufficient weight is used, the sounding line will be dragged at an angle downstream. If debris or ice is flowing or if the stream is shallow and swift, a heavier weight can be used than the rule designates. The rule is not rigid but it does provide a starting point for deciding on the size of the weight that is needed. If available, notes can be examined of previous measurements at a site to help determine the size of the weight needed at various stages.

Some sounding reels are equipped with a computing depth indicator, or spiral. To use the computing spiral, the dial pointer must be set at zero when the center of the current-meter rotor is at the water surface. After the sounding weight and meter are lowered until the weight touches the streambed, and the indicated depth should be read. The distance that the meter is mounted above the bottom of the weight should be added. For example, if a 30 C .5 (that is, a 30-pound Columbus weight is being used and the center of the meter cups is 0.5 ft above the bottom of the weight) suspension is used and the dial pointer reads 18.5 ft when the sounding weight touches the streambed, the depth would be 19.0 ft (18.5 + 0.5). To move the meter to the 0.8-depth position, merely raise the weight and the meter until the pointer is at the 19-ft mark on the graduated spiral, which will correspond to 15.2 ft on the main dial (0.8 × 19.0). To set the meter at the 0.2-depth position, raise the weight and meter until the pointer is at 3.8 ft on the main dial (0.2 × 19.0).

Tags can be placed on the sounding line a known distance above the center of the meter cups as an aid in determining depth. The tags, which are usually streamers of

different-colored binding tape, are fastened to the sounding line by solder beads or by small cable clips. Tags are used for determining depth in two ways; the following is the preferred procedure:

1. Set the tag at the water surface and then set the depth indicator to read the distance of that tag above the center of the meter cups.
2. Continue as if the meter cups themselves have been set at the water surface.
3. When the weight touches the streambed, read the depth indicator and add the distance that the meter is above the bottom of the weight to obtain the total depth.
4. Use the spiral indicator, as described above, for setting the 0.8-depth meter position. If debris or ice is flowing, this method keeps the meter below the water surface and helps to prevent damage to the meter.

This is an alternate method that is sometimes used with handlines and sounding reels: With the sounding weight on the streambed, raise the weight until the first tag below the water surface appears at the surface. If using a reel, determine the distance the weight was raised by subtracting before and after readings of the depth indicator; if using a handline, use a tape or measuring stick. The total stream depth is the sum of (a) the distance the weight was raised to bring the tag to the water surface, (b) the distance the tag is above the center of the meter cups, and (c) the distance from the bottom of the weight to the center of the cups.

Use of a Handline

Although rarely used in the USGS, handlines still provide a viable means of measuring discharge from bridges. When using a handline, unwind enough cable from the handline reel to keep the reel out of water when the sounding weight is on the streambed at the deepest part of the cross section. If the bridge is high enough above the water surface, raise and lower the weight and meter by the rubber-covered cable rather than by the bare cable.

The usual procedure for determining depths is to set the meter cups at the water surface and then lower the sounding weight to the streambed while measuring the amount of line needed to reach the streambed. Measure along the rubber-covered service cord with a steel or metallic tape or a graduated rod to determine the distance the weight is lowered. This measured distance, plus the distance from the bottom of the sounding weight to the meter cups, is the depth of water. When the meter is set for the velocity observation, stand on the rubber-covered cable or tie it to the handrail to hold the meter in place. This arrangement frees the hands to record the data.

Another method of determining depth when using a handline includes the use of tags set at a known distance above the meter. Lower the sounding weight to the streambed, and then raise the weight until one of the tags is at the water surface. Measure along the rubber-covered service cord with a steel or metallic tape or a graduated rod to determine the distance the weight is raised. The total depth of water is then the summation of (1) the distance the particular tag is above the meter cups, (2) the measured distance the meter and weight was raised, and (3) the distance from the bottom of the weight to the meter cups.

Depth Corrections for Downstream Drift of Current Meter and Weight

Where it is possible to sound but the weight and meter drift downstream, the depths measured by the usual methods are too great. Figure 10 graphically illustrates this condition. The correction for this error has two parts, the air correction and the wet-line correction. The air correction is shown in figure 10 as the distance *cd*. The wet-line correction in figure 10 is shown as the difference between the wet-line depth *de* and the vertical depth *dg*.

As shown in figure 10, the air correction depends on the vertical angle *P* and the distance *ab*. The correction is computed as follows:

$$\cos P = \frac{ab}{ad} = \frac{ab}{ac+cd} = \frac{ab}{ab+cd} \Rightarrow$$

$$ab + cb = \frac{ab}{\cos P} \Rightarrow \quad , \qquad (7)$$

$$cd = \frac{ab}{\cos P} - ab = ab\left[\frac{1}{\cos P} - 1\right]$$

where $ab = ac$

The air correction for even-numbered angles between 4 degrees and 36 degrees and vertical lengths between 10 and 100 ft is shown in table 2. The correction is applied to the nearest tenth of a foot; hundredths are given to aid in interpolation.

Use of an air correction table may be nearly eliminated by using tags at selected intervals on the sounding line and using the tags to refer to the water surface. This practice is almost equivalent to moving the reel to a position just above the water surface.

The correction for excess length of line below the water surface is obtained by using an elementary principle of mechanics. If a known horizontal force is applied to a weight suspended on a cord, the cord takes a position of rest at some angle with the vertical. The tangent of the vertical angle of the cord is equal to the horizontal force divided by the vertical force owing to the weight. If several additional horizontal and vertical forces are applied to the cord, the tangent of the angle in the cord above any point is equal to a summation of the horizontal forces below that point, divided by the summation of the vertical forces below the point.

The distribution of total horizontal drag on the sounding line is in accordance with the variation of velocity with depth. The excess in length of the curved line over the vertical depth is the sum of the products of each tenth of depth and the function $[(1/\cos P) - 1]$ of the corresponding angles. The function is derived for each tenth of depth by means of the tangent relation of the forces acting below any point.

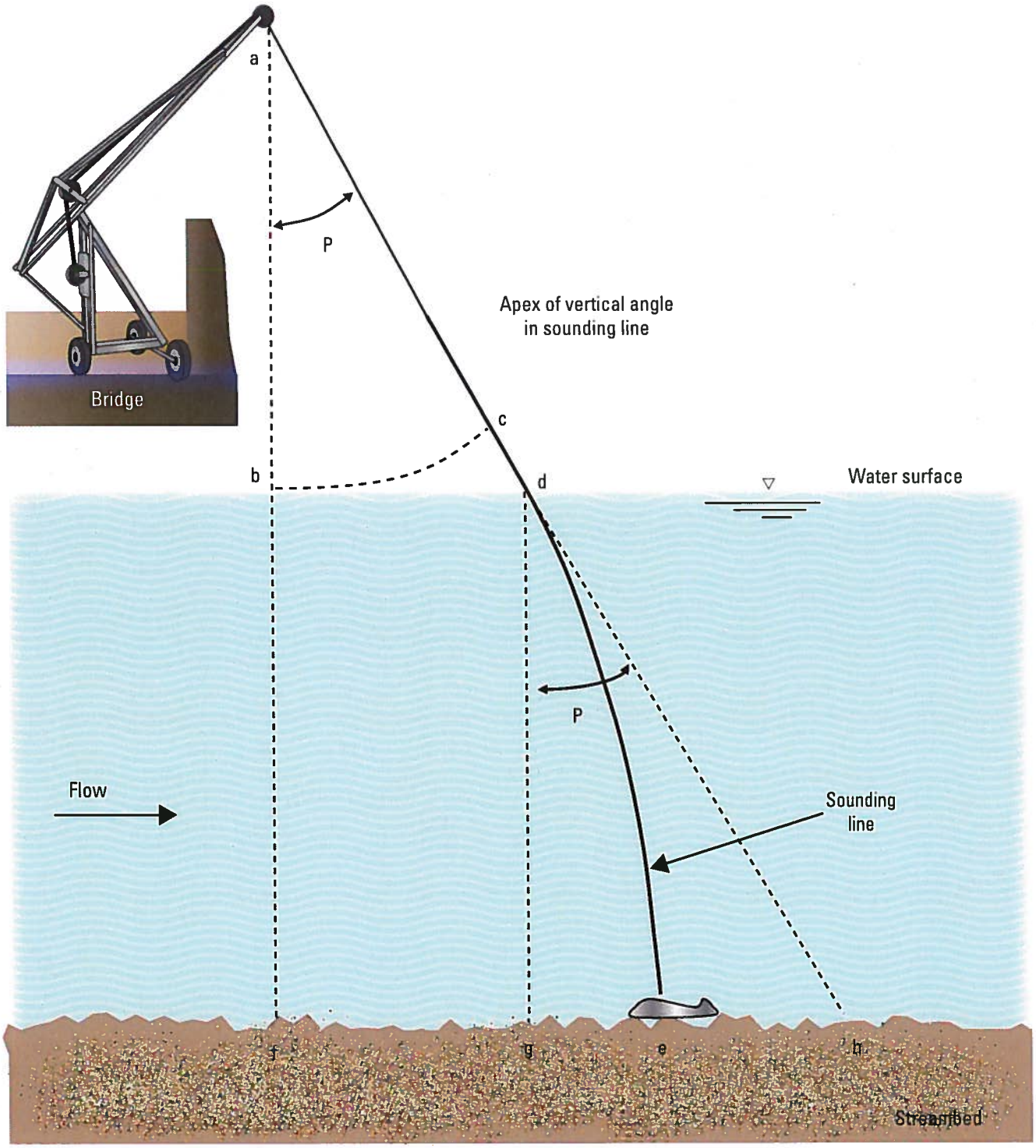


Figure 10. Position of sounding weight and line in deep, swift water.

The wet-line correction for even-numbered angles between 4 degrees and 36 degrees and wet-line depths between 10 and 100 ft is shown in table 3. The correction is applied to the nearest tenth of a foot. The wet-line correction cannot be determined until the air correction has been deducted from the observed depth.

The following assumptions were used in deriving the wet-line correction table:

1. The weight will go to the bottom despite the force of the current.
2. The sounding is made when the weight is at the bottom but entirely supported by the line.
3. Drag on the streamlined weight in the sounding position is neglected.
4. The air-line/wet-line table is generic and can be used for any size sounding weight or line, provided they are designed to offer little resistance to the current.

Wet-line corrections can also be computed with the equation below. This polynomial equation was derived by Kenneth L. Wahl (U.S. Geological Survey [ret.], Regional Surface Water Specialist, written commun., 2000) from the data in table 3, and reproduces the table values to within a few hundredths of a foot. It can be used in a field computer to quickly and easily compute wet-line corrections. With additional programming, depths and depth settings can also be computed.

$$CORR_{wl} = D_{wl} - D_v = \left(0.0004081 - 0.0001471 \times P + 0.00005731 \times P^2\right) \times D_{wl}, \quad (8)$$

where $CORR_{wl}$ the correction, in feet, to subtract from the wet-line depth to obtain the vertical depth,
D_{wl} the wet-line depth, in feet,
D_v the vertical depth, in feet, and
P the vertical angle, in degrees.

If the direction of flow is not perpendicular to the measuring section, the observed angle in the measuring line as indicated by a protractor will be less than the true angle of the line. The air correction and wet-line correction will then be too small. To correct for this, measure the horizontal angle between the direction of flow and a perpendicular to the measuring section with a protractor, or determine the horizontal angle coefficient as described in a subsequent section of this publication. The geometry of this condition is illustrated in figure 11.

If the horizontal angle of the direction of flow is called H, the observed vertical angle P, and the true vertical angle X, the relation between the angles is expressed by the equation

$$\tan X = \frac{\tan P}{\cos H}. \quad (9)$$

Table 4 gives the amounts in tenths of degrees. Add these to observed vertical angles to obtain the true vertical angles for a range of horizontal angles between 8 degrees and 28 degrees.

The conditions that cause error in sounding the depth also cause error in the placement of the meter at selected depths. The correction tables are not strictly applicable to the problem of placing the meter because of the increased pressure placed on the sounding weight by higher velocities when it is raised from the streambed. A meter placed in deep, swift water by the ordinary methods for observations at selected percentages of the depth will be too high in the water. The use of tables 2 and 3 will tend to eliminate this error in placement of the meter, and although not strictly applicable, their use for this purpose has become general.

For the 0.2-depth position, the curvature of the wet line is assumed to be negligible and the length of sounding line from the apex of the vertical angle to the weight is considered to be a straight line. The method used to place the meter at the 0.2-depth position is as follows:

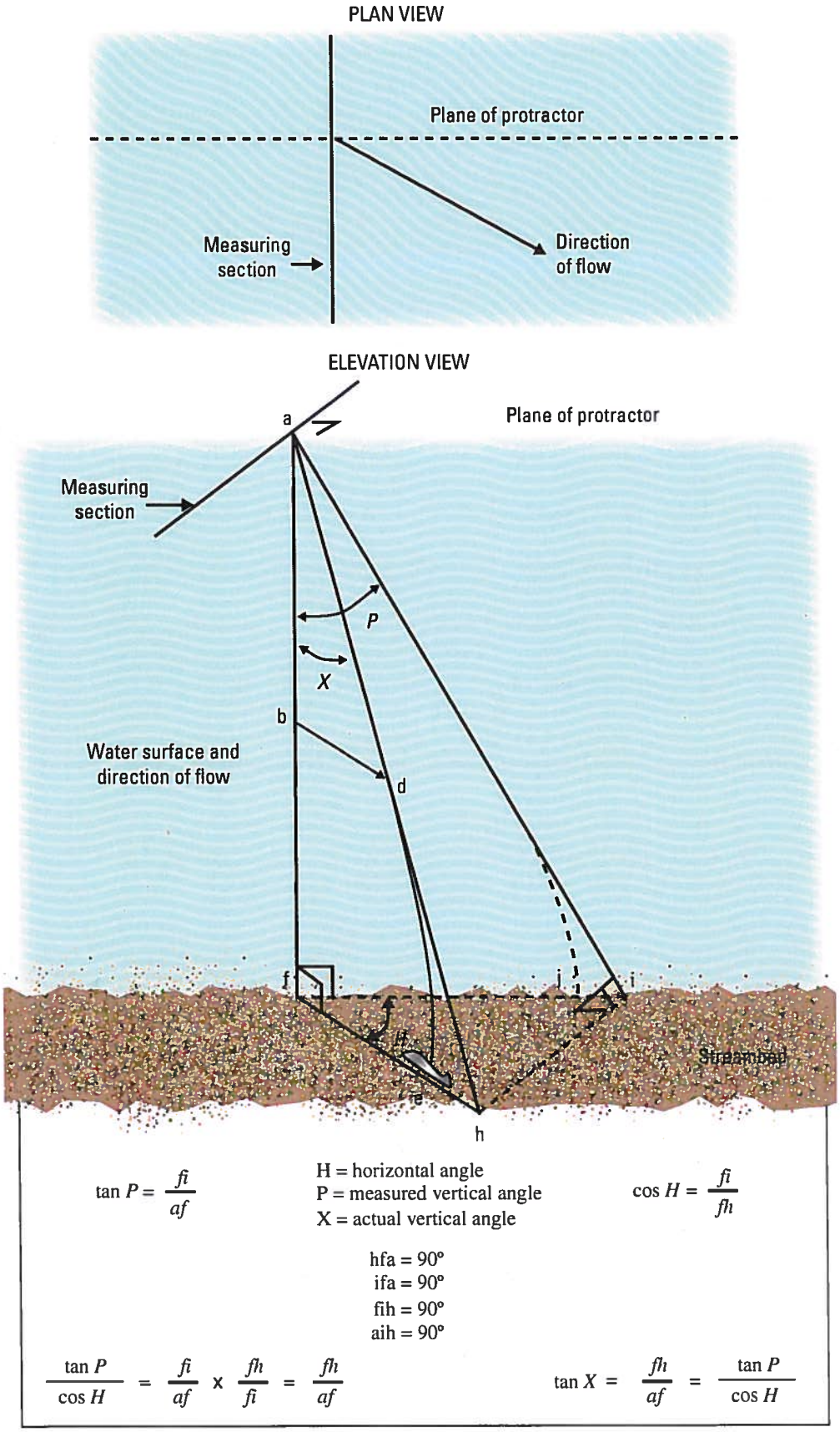
1. Compute the 0.2 value of the vertical depth.
2. Lower the meter to this depth into the water and read the vertical angle.
3. Obtain the air correction from table 2. The vertical length used to obtain the air correction is the sum of (a) 0.2 of the vertical depth, (b) the distance from the water surface to the apex of the angle, and (c) the distance from the bottom of the weight to the meter.
4. Let out an additional amount of line equal to the air correction.

Table 2. Air correction table (in feet), giving differences between vertical length and slant length of sounding line above water surface for selected vertical angles.

Vertical length (feet)	Vertical angle of sounding line at protractor																	Vertical length (feet)
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	
10	0.02	0.06	0.10	0.15	0.22	0.31	0.40	0.51	0.64	0.79	0.95	1.13	1.33	1.55	1.79	2.06	2.36	10
12	0.03	0.07	0.12	0.19	0.27	0.37	0.48	0.62	0.77	0.94	1.14	1.35	1.59	1.86	2.15	2.47	2.83	12
14	0.03	0.08	0.14	0.22	0.31	0.43	0.56	0.72	0.90	1.10	1.32	1.58	1.86	2.17	2.51	2.89	3.30	14
16	0.04	0.09	0.16	0.25	0.36	0.49	0.64	0.82	1.03	1.26	1.51	1.80	2.12	2.48	2.87	3.30	3.78	16
18	0.04	0.10	0.18	0.28	0.40	0.55	0.73	0.93	1.16	1.41	1.70	2.03	2.39	2.78	3.23	3.71	4.25	18
20	0.05	0.11	0.20	0.31	0.45	0.61	0.81	1.03	1.28	1.57	1.89	2.25	2.65	3.09	3.58	4.12	4.72	20
22	0.05	0.12	0.22	0.34	0.49	0.67	0.89	1.13	1.41	1.73	2.08	2.48	2.92	3.40	3.94	4.54	5.19	22
24	0.06	0.13	0.24	0.37	0.54	0.73	0.97	1.24	1.54	1.88	2.27	2.70	3.18	3.71	4.30	4.95	5.67	24
26	0.06	0.14	0.26	0.40	0.58	0.80	1.05	1.34	1.67	2.04	2.46	2.93	3.45	4.02	4.66	5.36	6.14	26
28	0.07	0.15	0.28	0.43	0.63	0.86	1.13	1.44	1.80	2.20	2.65	3.15	3.71	4.33	5.02	5.77	6.61	28
30	0.07	0.17	0.29	0.46	0.67	0.92	1.21	1.54	1.93	2.36	2.84	3.38	3.98	4.64	5.38	6.19	7.08	30
32	0.08	0.18	0.31	0.49	0.71	0.98	1.29	1.65	2.05	2.51	3.03	3.60	4.24	4.95	5.73	6.60	7.55	32
34	0.08	0.19	0.33	0.52	0.76	1.04	1.37	1.75	2.18	2.67	3.22	3.83	4.51	5.26	6.09	7.01	8.03	34
36	0.09	0.20	0.35	0.56	0.80	1.10	1.45	1.85	2.31	2.83	3.41	4.05	4.77	5.57	6.45	7.42	8.50	36
38	0.09	0.21	0.37	0.59	0.85	1.16	1.53	1.96	2.44	2.98	3.60	4.28	5.04	5.88	6.81	7.84	8.97	38
40	0.10	0.22	0.39	0.62	0.89	1.22	1.61	2.06	2.57	3.14	3.79	4.50	5.30	6.19	7.17	8.25	9.44	40
42	0.10	0.23	0.41	0.65	0.94	1.29	1.69	2.16	2.70	3.30	3.97	4.73	5.57	6.50	7.53	8.66	9.91	42
44	0.11	0.24	0.43	0.68	0.98	1.35	1.77	2.26	2.82	3.46	4.16	4.95	5.83	6.81	7.88	9.07	10.39	44
46	0.11	0.25	0.45	0.71	1.03	1.41	1.85	2.37	2.95	3.61	4.35	5.18	6.10	7.12	8.24	9.49	10.86	46
48	0.12	0.26	0.47	0.74	1.07	1.47	1.93	2.47	3.08	3.77	4.54	5.40	6.36	7.43	8.60	9.90	11.33	48
50	0.12	0.28	0.49	0.77	1.12	1.53	2.02	2.57	3.21	3.93	4.73	5.63	6.63	7.74	8.96	10.31	11.80	50
52	0.13	0.29	0.51	0.80	1.16	1.59	2.10	2.68	3.34	4.08	4.92	5.86	6.89	8.04	9.32	10.72	12.28	52
54	0.13	0.30	0.53	0.83	1.21	1.65	2.18	2.78	3.47	4.24	5.11	6.08	7.16	8.35	9.68	11.14	12.75	54
56	0.14	0.31	0.55	0.86	1.25	1.71	2.26	2.88	3.59	4.40	5.30	6.31	7.42	8.66	10.03	11.55	13.22	56
58	0.14	0.32	0.57	0.89	1.30	1.78	2.34	2.98	3.72	4.55	5.49	6.53	7.69	8.97	10.39	11.96	13.69	58
60	0.15	0.33	0.59	0.93	1.34	1.84	2.42	3.09	3.85	4.71	5.68	6.76	7.95	9.28	10.75	12.37	14.16	60
62	0.15	0.34	0.61	0.96	1.39	1.90	2.50	3.19	3.98	4.87	5.87	6.98	8.22	9.59	11.11	12.79	14.64	62
64	0.16	0.35	0.63	0.99	1.43	1.96	2.58	3.29	4.11	5.03	6.06	7.21	8.48	9.90	11.47	13.20	15.11	64
66	0.16	0.36	0.65	1.02	1.47	2.02	2.66	3.40	4.24	5.18	6.25	7.43	8.75	10.21	11.83	13.61	15.58	66
68	0.17	0.37	0.67	1.05	1.52	2.08	2.74	3.50	4.36	5.34	6.44	7.66	9.01	10.52	12.18	14.02	16.05	68
70	0.17	0.39	0.69	1.08	1.56	2.14	2.82	3.60	4.49	5.50	6.62	7.88	9.28	10.83	12.54	14.44	16.52	70
72	0.18	0.40	0.71	1.11	1.61	2.20	2.90	3.71	4.62	5.65	6.81	8.11	9.55	11.14	12.90	14.85	17.00	72
74	0.18	0.41	0.73	1.14	1.65	2.27	2.98	3.81	4.75	5.81	7.00	8.33	9.81	11.45	13.26	15.26	17.47	74
76	0.19	0.42	0.75	1.17	1.70	2.33	3.06	3.91	4.88	5.97	7.19	8.56	10.08	11.76	13.62	15.67	17.94	76
78	0.19	0.43	0.77	1.20	1.74	2.39	3.14	4.01	5.01	6.13	7.38	8.78	10.34	12.07	13.98	16.09	18.41	78
80	0.20	0.44	0.79	1.23	1.79	2.45	3.22	4.12	5.13	6.28	7.57	9.01	10.61	12.38	14.33	16.50	18.89	80
82	0.20	0.45	0.81	1.27	1.83	2.51	3.30	4.22	5.26	6.44	7.76	9.23	10.87	12.69	14.69	16.91	19.36	82
84	0.20	0.46	0.83	1.30	1.88	2.57	3.39	4.32	5.39	6.60	7.95	9.46	11.14	12.99	15.05	17.32	19.83	84
86	0.21	0.47	0.85	1.33	1.92	2.63	3.47	4.43	5.52	6.75	8.14	9.68	11.40	13.30	15.41	17.73	20.30	86
88	0.21	0.48	0.87	1.36	1.97	2.69	3.55	4.53	5.65	6.91	8.33	9.91	11.67	13.61	15.77	18.15	20.77	88
90	0.22	0.50	0.88	1.39	2.01	2.75	3.63	4.63	5.78	7.07	8.52	10.13	11.93	13.92	16.13	18.56	21.25	90
92	0.22	0.51	0.90	1.42	2.06	2.82	3.71	4.73	5.90	7.22	8.71	10.36	12.20	14.23	16.48	18.97	21.72	92
94	0.23	0.52	0.92	1.45	2.10	2.88	3.79	4.84	6.03	7.38	8.90	10.58	12.46	14.54	16.84	19.38	22.19	94
96	0.23	0.53	0.94	1.48	2.14	2.94	3.87	4.94	6.16	7.54	9.09	10.81	12.73	14.85	17.20	19.80	22.66	96
98	0.24	0.54	0.96	1.51	2.19	3.00	3.95	5.04	6.29	7.70	9.27	11.03	12.99	15.16	17.56	20.21	23.13	98
100	0.24	0.55	0.98	1.54	2.23	3.06	4.03	5.15	6.42	7.85	9.46	11.26	13.26	15.47	17.92	20.62	23.61	100

Table 3. Wet-line table (in feet) giving differences between wet-line length and vertical depth for selected vertical angles.

Wet-line length (feet)	Vertical angle of sounding line at protractor																	Wet-line length (feet)
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	
10	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.25	0.30	0.35	0.41	0.47	0.54	0.62	0.70	10
12	0.01	0.02	0.04	0.06	0.09	0.12	0.15	0.20	0.24	0.30	0.36	0.42	0.49	0.57	0.65	0.74	0.84	12
14	0.01	0.02	0.04	0.07	0.10	0.14	0.18	0.23	0.29	0.35	0.41	0.49	0.57	0.66	0.76	0.87	0.98	14
16	0.01	0.03	0.05	0.08	0.12	0.16	0.20	0.26	0.33	0.40	0.47	0.56	0.65	0.76	0.87	0.99	1.12	16
18	0.01	0.03	0.06	0.09	0.13	0.18	0.23	0.30	0.37	0.45	0.53	0.63	0.73	0.85	0.98	1.12	1.26	18
20	0.01	0.03	0.06	0.10	0.14	0.20	0.26	0.33	0.41	0.50	0.59	0.70	0.82	0.94	1.09	1.24	1.40	20
22	0.01	0.04	0.07	0.11	0.16	0.22	0.28	0.36	0.45	0.55	0.65	0.77	0.90	1.04	1.20	1.36	1.54	22
24	0.01	0.04	0.08	0.12	0.17	0.24	0.31	0.39	0.49	0.60	0.71	0.84	0.98	1.13	1.31	1.49	1.68	24
26	0.02	0.04	0.08	0.13	0.19	0.25	0.33	0.43	0.53	0.64	0.77	0.91	1.06	1.23	1.41	1.61	1.81	26
28	0.02	0.04	0.09	0.14	0.20	0.27	0.36	0.46	0.57	0.69	0.83	0.98	1.14	1.32	1.52	1.74	1.95	28
30	0.02	0.05	0.10	0.15	0.22	0.29	0.38	0.49	0.61	0.74	0.89	1.05	1.22	1.42	1.63	1.86	2.09	30
32	0.02	0.05	0.10	0.16	0.23	0.31	0.41	0.52	0.65	0.79	0.95	1.12	1.31	1.51	1.74	1.98	2.23	32
34	0.02	0.05	0.11	0.17	0.24	0.33	0.44	0.56	0.69	0.84	1.01	1.19	1.39	1.60	1.85	2.11	2.37	34
36	0.02	0.06	0.12	0.18	0.26	0.35	0.46	0.59	0.73	0.89	1.07	1.26	1.47	1.70	1.96	2.23	2.51	36
38	0.02	0.06	0.12	0.19	0.27	0.37	0.49	0.62	0.78	0.94	1.12	1.33	1.55	1.79	2.07	2.36	2.65	38
40	0.02	0.06	0.13	0.20	0.29	0.39	0.51	0.66	0.82	0.99	1.18	1.40	1.63	1.89	2.18	2.48	2.79	40
42	0.03	0.07	0.13	0.21	0.30	0.41	0.54	0.69	0.86	1.04	1.24	1.47	1.71	1.98	2.28	2.60	2.93	42
44	0.03	0.07	0.14	0.22	0.32	0.43	0.56	0.72	0.90	1.09	1.30	1.54	1.80	2.08	2.39	2.73	3.07	44
46	0.03	0.07	0.15	0.23	0.33	0.45	0.59	0.75	0.94	1.14	1.36	1.61	1.88	2.17	2.50	2.85	3.21	46
48	0.03	0.08	0.15	0.24	0.35	0.47	0.61	0.79	0.98	1.19	1.42	1.68	1.96	2.27	2.61	2.98	3.35	48
50	0.03	0.08	0.16	0.25	0.36	0.49	0.64	0.82	1.02	1.24	1.48	1.75	2.04	2.36	2.72	3.10	3.49	50
52	0.03	0.08	0.17	0.26	0.37	0.51	0.67	0.85	1.06	1.29	1.54	1.82	2.12	2.45	2.83	3.22	3.63	52
54	0.03	0.09	0.17	0.27	0.39	0.53	0.69	0.89	1.10	1.34	1.60	1.89	2.20	2.55	2.94	3.35	3.77	54
56	0.03	0.09	0.18	0.28	0.40	0.55	0.72	0.92	1.14	1.39	1.66	1.96	2.28	2.64	3.05	3.47	3.91	56
58	0.03	0.09	0.19	0.29	0.42	0.57	0.74	0.95	1.18	1.44	1.72	2.03	2.37	2.74	3.16	3.60	4.05	58
60	0.04	0.10	0.19	0.30	0.43	0.59	0.77	0.98	1.22	1.49	1.78	2.10	2.45	2.83	3.26	3.72	4.19	60
62	0.04	0.10	0.20	0.31	0.45	0.61	0.79	1.02	1.26	1.54	1.84	2.17	2.53	2.93	3.37	3.84	4.33	62
64	0.04	0.10	0.20	0.32	0.46	0.63	0.82	1.05	1.31	1.59	1.89	2.24	2.61	3.02	3.48	3.97	4.47	64
66	0.04	0.11	0.21	0.33	0.48	0.65	0.84	1.08	1.35	1.64	1.95	2.31	2.69	3.12	3.59	4.09	4.61	66
68	0.04	0.11	0.22	0.34	0.49	0.67	0.87	1.12	1.39	1.69	2.01	2.38	2.77	3.21	3.70	4.22	4.75	68
70	0.04	0.11	0.22	0.35	0.50	0.69	0.90	1.15	1.43	1.74	2.07	2.45	2.86	3.30	3.81	4.34	4.89	70
72	0.04	0.12	0.23	0.36	0.52	0.71	0.92	1.18	1.47	1.79	2.13	2.52	2.94	3.40	3.92	4.46	5.03	72
74	0.04	0.12	0.24	0.37	0.53	0.73	0.95	1.21	1.51	1.84	2.19	2.59	3.02	3.49	4.03	4.59	5.17	74
76	0.05	0.12	0.24	0.38	0.55	0.74	0.97	1.25	1.55	1.88	2.25	2.66	3.10	3.59	4.13	4.71	5.30	76
78	0.05	0.12	0.25	0.39	0.56	0.76	1.00	1.28	1.59	1.93	2.31	2.73	3.18	3.68	4.24	4.84	5.44	78
80	0.05	0.13	0.25	0.40	0.58	0.78	1.02	1.31	1.63	1.98	2.37	2.80	3.26	3.78	4.35	4.96	5.58	80
82	0.05	0.13	0.26	0.41	0.59	0.80	1.05	1.34	1.67	2.03	2.43	2.87	3.35	3.87	4.46	5.08	5.72	82
84	0.05	0.13	0.27	0.42	0.60	0.82	1.08	1.38	1.71	2.08	2.49	2.94	3.43	3.96	4.57	5.21	5.86	84
86	0.05	0.14	0.28	0.43	0.62	0.84	1.10	1.41	1.75	2.13	2.55	3.01	3.51	4.06	4.68	5.33	6.00	86
88	0.05	0.14	0.28	0.44	0.63	0.86	1.13	1.44	1.80	2.18	2.60	3.08	3.59	4.15	4.79	5.46	6.14	88
90	0.05	0.14	0.29	0.45	0.65	0.88	1.15	1.48	1.84	2.23	2.66	3.15	3.67	4.25	4.90	5.58	6.28	90
92	0.06	0.15	0.29	0.46	0.66	0.90	1.18	1.51	1.88	2.28	2.72	3.22	3.75	4.34	5.00	5.70	6.42	92
94	0.06	0.15	0.30	0.47	0.68	0.92	1.20	1.54	1.92	2.33	2.78	3.29	3.84	4.44	5.11	5.83	6.56	94
96	0.06	0.15	0.31	0.48	0.69	0.94	1.23	1.57	1.96	2.38	2.84	3.36	3.92	4.53	5.22	5.95	6.70	96
98	0.06	0.16	0.31	0.49	0.71	0.96	1.25	1.61	2.00	2.43	2.90	3.43	4.00	4.63	5.33	6.08	6.84	98
100	0.06	0.16	0.32	0.50	0.72	0.98	1.28	1.64	2.04	2.48	2.96	3.50	4.08	4.72	5.44	6.20	6.98	100



$$\tan P = \frac{fi}{af} \qquad \cos H = \frac{fi}{fh}$$

$$\frac{\tan P}{\cos H} = \frac{fi}{af} \times \frac{fh}{fi} = \frac{fh}{af} \qquad \tan X = \frac{fh}{af} = \frac{\tan P}{\cos H}$$

Figure 11. Sketch of geometric relationship of actual to measured vertical angle when flow direction is not normal to the measuring section.

5. If the angle increases appreciably when the additional line is let out, let out more line until the total additional line, the angle, and the vertical distance are in agreement with values presented in the air-correction table.

To place the meter at the 0.8-depth position, a correction to the amount of line reeled in must be made for the difference, if any, between the air correction for the sounding position and that for the 0.8-depth position. This difference is designated as *m* in table 5. If the angle increases for the 0.8-depth position, the meter must be lowered; if it decreases, the meter must be raised.

For the 0.8-depth position of the meter, the wet-line correction may require consideration if the depths are more than 40 ft and if the change in vertical angle is more than 5 percent. If the vertical angle remains the same or decreases, the wet-line correction (table 3) for the 0.8-depth position is less than the wet-line correction for the sounding position by some difference, designated as *n* in table 5. If the vertical angle increases, the difference in correction *n* diminishes until the increase in angle is about 10 percent; for greater increases in angle, the difference between corrections increases also. Table 5 summarizes the effect on air and wet-line corrections caused by raising the meter from the sounding position to the 0.8-depth position.

For slight changes in the vertical angle, because of the differences *m* and *n* in the air and wet-line corrections, the adjustments to the wet-line length of the 0.8-depth position are small and usually can be ignored. Table 5 indicates that the meter may be placed a little too deep if the adjustments are not made. Because of this possibility, the wet-line depth instead of the vertical depth is sometimes used as the basis for computing the 0.8-depth position with no adjustments for the differences *m* and *n*.

Use of Sonic Sounder

The sonic sounder has been used primarily for measuring depth when making a moving boat measurement and in ADCP discharge measurements, and is generally not utilized for measurements where sounding weights are used. However, it can be used in swift, debris-laden streams, where it is difficult or dangerous to lower the sounding weight and meter into the water. The sonic sounder will record the depth when the weight is just below the water surface. For moving boat measurements, the sonic sounder records a continuous trace of the streambed on a digital or analog chart. Details of the setup and use can be found in Smoot and Novak (1969). Relevant information on the use of acoustic sounders in a riverine environment is discussed in detail in Mueller and Landers (1999) and by the International Organization for Standardization (2003). For use of a sonic sounder in ADCP measurements, consult Mueller and Wagner (2009).

Table 4. Degrees to be added to observed vertical angle, *P*, to obtain true vertical angle when flow direction is not normal to measurement section.

Observed vertical angle, *P*, in degrees	Horizontal angle, *H*, in degrees					
	8 cos = 0.99	12 cos = 0.98	16 cos = 0.96	20 cos = 0.94	24 cos = 0.91	28 cos = 0.88
8	0.1	0.2	0.3	0.5	0.8	1.0
12	0.1	0.3	0.5	0.8	1.1	1.5
16	0.1	0.4	0.6	1.0	1.4	2.0
20	0.2	0.4	0.7	1.2	1.7	2.4
24	0.2	0.5	0.8	1.4	2.0	2.8
28	0.2	0.5	1.0	1.5	2.2	3.0
32	0.2	0.6	1.0	1.6	2.4	3.3
36	0.2	0.6	1.1	1.7	2.5	3.4

Table 5. Summary table for setting the meter at 0.8-depth position in deep, swift streams.

Change in vertical angle	Air correction		Wet-line correction	
	Direction of change	Correction to meter position	Direction of change	Correction to meter position
None	None	None	Decrease	Raise meter the distance *n*
Decrease	Decrease	Raise meter the distance *m*	Decrease	Raise meter the distance *n*
Increase	Increase	Lower meter the distance *m*	Decrease, then increase	[1]

[1]Raise meter the distance *n* unless the increase in angle is greater than about 10 percent, then it is necessary to lower the meter the distance *n*.

Measurement of Velocity

With point-velocity meters, after the width and depth at a vertical are measured and recorded, determine the method of velocity measurement. Normally the two-point method or the 0.6-depth method is used. Details of velocity measurement methods using various equipment and under different flow conditions are described in subsequent sections of this chapter.

Compute the setting of the meter for the particular method that will be used at that depth. For the top-setting wading rod, or the spiral-computing dial, some meter settings are self-computing. Record the meter position as 0.8, 0.6, 0.2, or another setting. After the meter is placed at the proper depth, let it adjust to the current before starting the velocity observation. With an ADV, make sure the instrument is located perpendicular to the tag line and the wading rod is plumbed (that is, vertical to the channel bed) before beginning measurement. The time required for adjustment to the undisturbed stream velocity is usually only a few seconds if the velocities are greater than 1 ft/s; however, for lower velocities, particularly if the current meter is suspended by a cable, a longer period of adjustment is needed. After the meter has become adjusted to the current, count the number of revolutions made by the rotor for a period of 40 to 70 seconds; for an ADV, this time period is typically programmed into the instrument's discharge measurement software.

If using a stopwatch to time the revolutions of a mechanical current meter, start the stopwatch simultaneously with the first signal or click, counting "zero," not "one." End the count on a convenient number given in the mechanical current meter rating table column heading. Stop the stopwatch on that count and read the time to the nearest second. Record the number of revolutions and the time interval. If the velocity is to be observed at more than one point in the vertical, determine the meter setting for the additional observation, set the meter to that depth, time the revolutions, and record the data.

When using a current meter digitizer (CMD), a personal digital assistant (PDA), or an electronic notebook such as the Aquacalc or an ADV, observe the same basic procedure for setting the meter, and for providing time for the meter to stabilize. With these instruments, however, the counting and timing of the rotor revolutions or the acoustic pulse measurement are performed automatically. The number of revolutions, time, and velocity displayed by the CMD must be transferred manually to paper field notes, whereas, these data are electronically recorded by the Aquacalc, a PDA, or an ADV. When using any of these automatic meter counting devices and a mechanical current meter, make sure that multiple counts are not occurring during measurement of slow velocity. This can sometimes be determined by visually observing the rotation of the rotor while simultaneously listening to the audible clicks or beeps from the counting device. With the ADV, instead of audible clicks, acoustic Doppler theory is applied. The ADV can sense and measure velocities much smaller than those rated and measured by mechanical meters and are not prone to the multiple count errors of the mechanical current meter.

Current meters, in general, measure stream velocity at a point. One notable exception is the ADCP. This method will be discussed in a subsequent section of this chapter; a thorough discussion of a moving boat discharge measurement using an ADCP is documented in Mueller and Wagner (2009).

The method of making discharge measurements at a cross section by using a current meter that measures point velocities requires determination of the mean velocity in each of the selected verticals. The mean velocity in a vertical is obtained from velocity observations at several points in that vertical. The mean velocity can be approximated by making a few velocity observations and using a known relation between those velocities and the mean in the vertical. The various methods of measuring velocity are: vertical-velocity curve, two-point, 0.6-depth, 0.2-depth, three-point, and surface and subsurface.

Vertical-Velocity Curve Method

In the vertical-velocity curve method, a series of velocity observations at points well distributed between the water surface and the streambed are made at each of the verticals. If there is considerable curvature in the lower part of the vertical-velocity curve, then it is advisable to space the observations more closely together in that part of the depth. Normally, the observations are taken at 0.1-depth increments between 0.1 and 0.9 of the depth. Observations are always taken at 0.2, 0.6, and 0.8 of the depth so that the results obtained by the vertical-velocity curve method may be compared with the commonly used methods of velocity observation. Observations are made at least 0.5 ft from the water surface and from the streambed with the Price AA meter, at least 0.3 ft from these boundaries with the Price pygmy meter, or at least 0.2 ft from these boundaries with the FlowTracker ADV.

The vertical-velocity curve for each vertical is based on observed velocities plotted against depth, as shown in figure 12. In order that vertical-velocity curves at different verticals may be readily compared, it is customary to plot depths as proportional parts of the total depth. The mean velocity in the vertical is obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, and dividing the area by the length of the ordinate axis.

The vertical-velocity curve method is valuable in determining coefficients for application to the results obtained by other methods, but is not generally adapted to routine discharge measurements because of the extra time required to collect field data and to compute the mean velocity. A typical vertical-velocity curve for the cross section should be measured and evaluated at all new measurement sites, and perhaps at new measurement sections if the new section is significantly different in hydraulic characteristics than the section normally used at a regular measurement site.

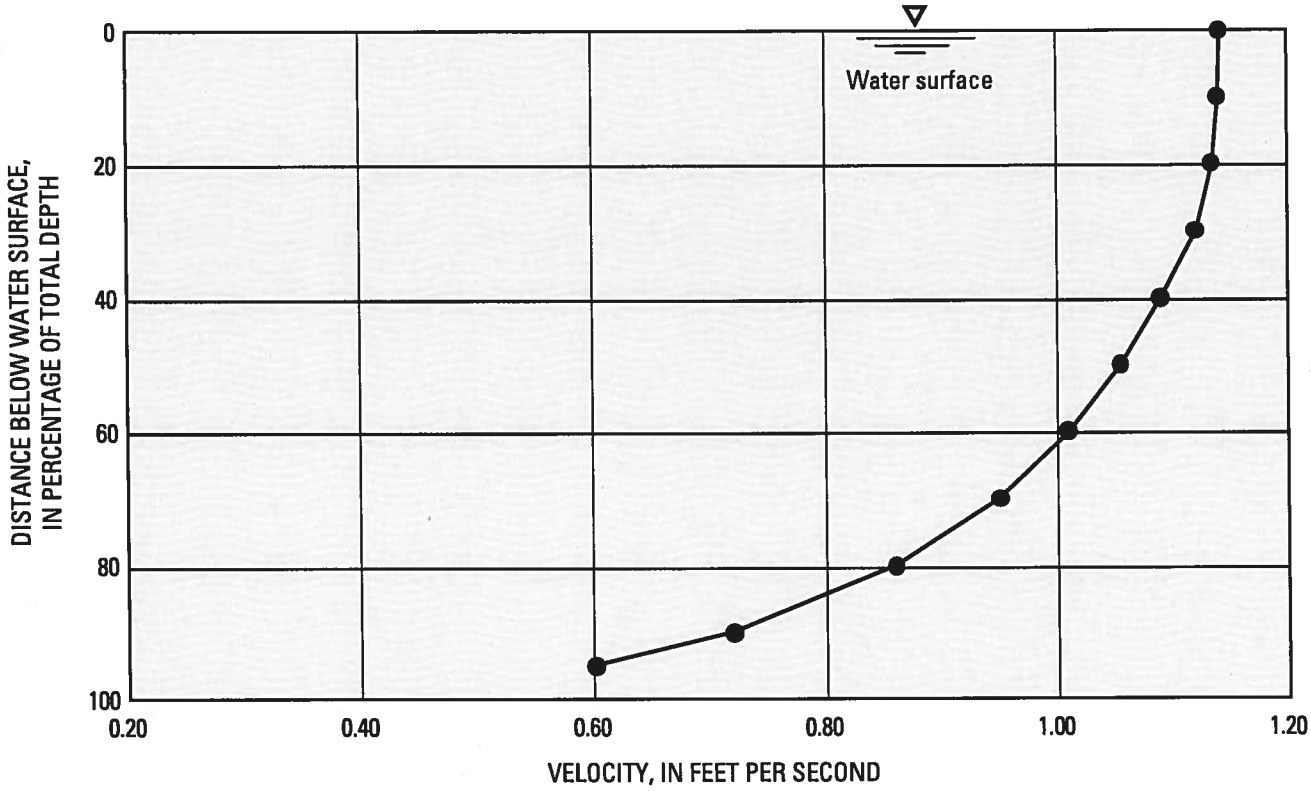


Figure 12. Typical vertical-velocity curve.

Two-Point Method

This is the preferred method for making midsection discharge measurements with point velocity meters. In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of these two observations is used as the mean velocity in the vertical. This method is based on many studies of actual observation and on mathematical theory. Experience has shown that this method gives more consistent and accurate results than any of the other methods, except for the vertical-velocity curve method. Use the two-point method for depths of 2.5 ft or greater, unless using a pygmy current meter or an ADV, in which case, this method is used in depths of 1.5 ft or greater.

With an ADV, the actual instrument has much less drag or resistance to the flow as compared to a mechanical current meter. To prevent boundary interference, avoid placing the ADV sample volume [typically 10 centimeters (about 4 in.) from the center transmitting transducer] within 2 in. from any solid boundary. This boundary condition with the ADV allows for measurement of velocity closer to the water surface and channel bed than a Price AA or to the pygmy (fig. 13). With the Price AA current meter, the two-point method is not used at depths less than 2.5 ft because the current meter would be too close to the water surface and to the streambed to give dependable results.

Six-Tenths-Depth Method

In the 0.6-depth method, an observation of velocity made at 0.6 of the depth below the water surface in the vertical is used as the mean velocity in the vertical. Actual observation and mathematical theory have shown that the 0.6-depth method gives reliable results and is used by the USGS under the following conditions:

Price AA Current Meter

1. Whenever the depth is between 0.3 ft and 2.5 ft.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. (This condition prevents the use of the two-point method.)
3. When the meter is placed a distance above the sounding weight, which makes it impossible to place the meter at the 0.8 depth. (This condition prevents the use of the two-point method.)
4. When the stage in a stream is changing rapidly and you must make a quick measurement.

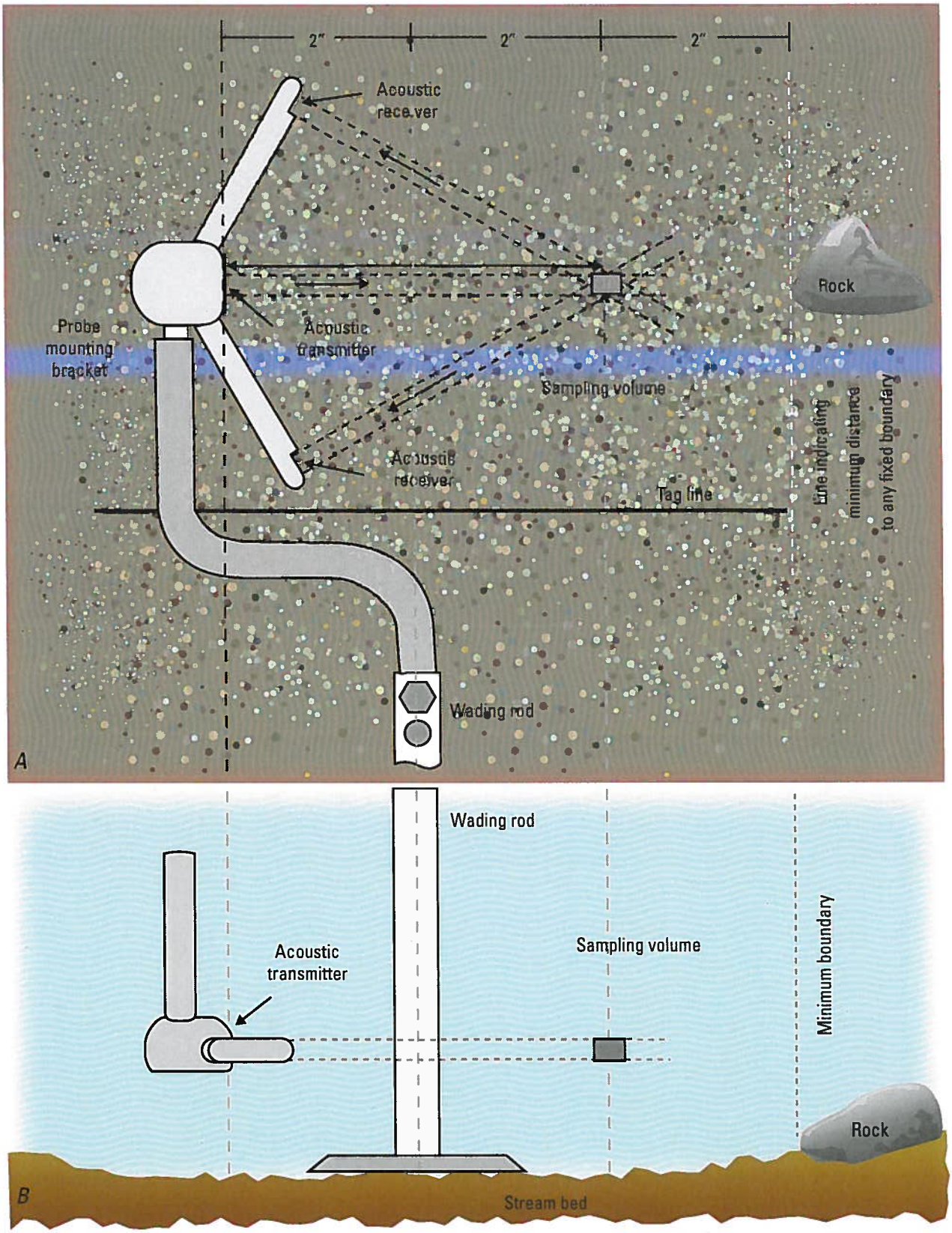


Figure 13. Schematic showing A, plan vie and B, cross section of the FlowTracker sampling volume and the proximity to a fixed boundary in the stream. (Note: Probe mounting bracket not shown.)

Pygmy Current Meter

1. Whenever the depth is between 0.3 ft and 1.5 ft.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. (This condition prevents the use of the two-point method.)
3. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Acoustic Doppler Velocimeter

1. Whenever the depth is between 0.25 ft and 1.5 ft.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. (This condition prevents the use of the two-point method.)
3. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Two-Tenths-Depth Method

The 0.2-depth method consists of observing the velocity at 0.2 of the depth below the surface and applying a coefficient to this observed velocity to obtain the mean in the vertical. It is used mainly during times of high water when the velocities are great, making it impossible to obtain soundings or to place the meter at the 0.8 or the 0.6 depth.

Use a standard cross section or a general knowledge of the cross section at a site to compute the 0.2 depth when it is impossible to obtain depth soundings. A sizeable error in an assumed 0.2 depth is not critical because the slope of the vertical-velocity curve at this point is usually nearly vertical. The 0.2 depth is also used in conjunction with the sonic sounder for flood measurements. The two-point method and the 0.6-depth method are preferred over the 0.2-depth method because of their greater accuracy.

The discharge measurement is normally computed by using the 0.2-depth velocity observations without coefficients as though each were a mean in the vertical. The approximate discharge thus obtained divided by the area of the measuring section gives the weighted mean value of the 0.2-depth velocity. Studies of many measurements made by the two-point method show that for a given measuring section, the relation between the mean 0.2-depth velocity and the true mean velocity either remains constant or varies uniformly with stage. In either circumstance, this relation may be determined for a particular 0.2-depth measurement by recomputing measurements made at the site by the two-point method using only the 0.2-depth velocity observation as the mean in the vertical. The plotting of the true mean velocity versus the mean 0.2-depth velocity for each measurement will give a velocity-relation curve for use in adjusting the mean velocity for measurements made by the 0.2-depth method.

If not enough measurements by the two-point method are available at a site to establish a velocity-relation curve, vertical-velocity curves are needed to establish a relation between the mean velocity and the 0.2-depth velocity. The usual coefficient to adjust the 0.2-depth velocity to the mean velocity is about 0.88.

Three-Point Method

The three-point method consists of observing the velocity at 0.2, 0.6, and 0.8 of the depth, thereby combining the two-point and 0.6-depth methods. The preferred method of computing the mean velocity is to average the 0.2- and 0.8-depth observations and then average this result with the 0.6-depth observation. However, when more weight to the 0.2- and 0.8-depth observations is desired, the arithmetic mean of the three observations may be used.

The three-point method is used when the velocities in the vertical are abnormally distributed [for example, the 0.2 (top) velocity is more than twice the 0.8 (bottom) velocity, or the 0.8 (bottom) velocity is greater than the 0.2 (top) velocity]. It is also used when the 0.8-depth observation is made where the velocity is seriously affected by friction or by turbulence produced by the streambed or an obstruction in the stream. If using a Price AA, the depths must be greater than 2.5 ft to use this method. If using a Price pygmy or ADV, the depths must be greater than 1.5 ft to use this method.

Surface and Subsurface Methods

Surface and subsurface methods consist of observing the velocity at the water surface or some distance below the water surface. Surface measurements may be made with the optical current meter, or by observing and timing surface floats. Subsurface measurements are made with a current meter at a distance of at least 2 ft below the surface to avoid the effect of surface disturbances. Surface and subsurface measurements are used primarily for deep swift streams where it is impossible or dangerous to obtain depth and velocity soundings at the regular 0.2, 0.6, and 0.8 depths.

Coefficients are necessary to convert the surface or subsurface velocities to the mean velocity in the vertical. Vertical-velocity curves obtained at the particular site are the best method to compute these coefficients. However, the coefficients are generally difficult to determine reliably because they may vary with stage, depth, and position in the measuring cross section. Experience has shown that the coefficients generally range from about 0.84 to about 0.90, depending on the shape of the vertical-velocity curve. The higher values are usually associated with smooth streambeds and normally shaped vertical-velocity curves, whereas the lower values are associated with irregular streambeds and irregular vertical-velocity curves.

Direction of Flow Measurements

Consider the direction of flow because the component of velocity normal to the measurement section is that which must be determined by both mechanical and acoustic Doppler point-velocity current meters. Generally, for the mechanical meter, the relation for velocity components not normal to the measuring section can be visualized in figure 14, and should be corrected using the cosine of alpha.

Flow direction is also critical with respect to an ADV, since the ADV assumes a horizontal and perpendicular plane to the flow. The hydrographer must pay close attention to the flow angle reported by the FlowTracker. Always hold the wading rod (with FlowTracker attached) perpendicular to the tag line so that the pulse generated by the transmitter is parallel to the tag line. Ideally, the tag line should be set up in the cross section to be measured so that flow is perpendicular to the tag line. Flow angle, as calculated by the FlowTracker, is defined as the direction of flow relative to the x-direction of flow, so that:

$$FlowAngle = \arctan(Vy / Vx), \quad (10)$$

where Vy is the velocity in the y direction (parallel to the tag line), and

Vx is the velocity in the x direction (perpendicular to the tag line) used to calculate discharge.

The flow angle calculated by the FlowTracker can result from two sources: (1) the flow is not perpendicular to the tag line, and (2) the flow is perpendicular to the tag line but the wading rod is not held correctly relative to the tag line, as described above. Regarding source (1), some small angles and variation in the flow angle at a site is not unusual. However, if large fluctuations of flow angles are reported, make measurements at another section with more uniform flow. Regarding source (2), holding the FlowTracker so that it is skewed at any angle relative to the tag line will result in a measurement of velocity that is biased low. Small angles do not result in significant biases, but because of these biases, users should be careful to minimize this error. If the FlowTracker is held so that it is skewed at an angle of approximately 8 degrees from the tag line, the measured velocity may be in error by as much as 1 percent (assuming that flow is perpendicular to the tag line). Large variations in flow angles may be indicative of poor or inconsistent alignment of the wading rod or poor site selection for the measurement.

In a wading measurement, if the meter used is a horizontal-axis meter with a component propeller, such as the Ott meter, the propeller should be pointed upstream at right angles to the cross section, but only if alpha is less than 45 degrees. Such a meter will register the desired component of velocity normal to the cross section when alpha is less than 45 degrees. The same procedure should be used if an electromagnetic component meter is used. These meters also measure the component of velocity normal to the measuring section. Generally, for either type of meter, if alpha is greater than 45 degrees, the component meter should be pointed directly into the current,

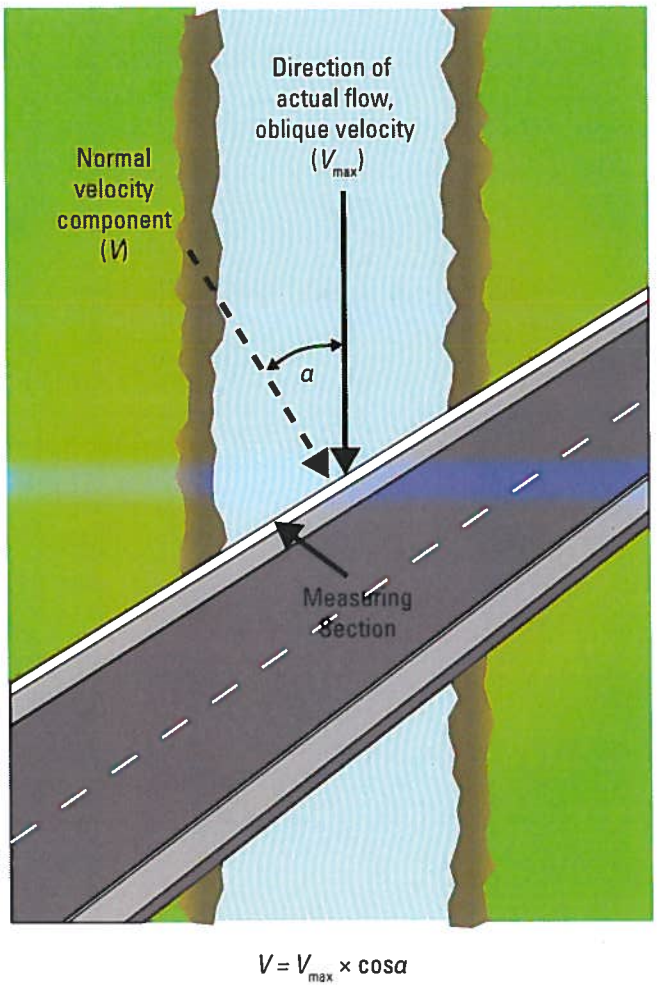


Figure 14. Velocity components when flow is not normal to measuring section.

and the horizontal angle correction should be applied as described in the following paragraphs.

Other meters on a wading-rod suspension, such as the vertical-axis Price current meter, should be pointed into the current. Any meter on a cable suspension will automatically point into the current because of the effect of the meter vanes. When the meter is pointed into an oblique current, the measured velocity must be multiplied by the cosine of the angle (alpha) between the current and a perpendicular to the measurement section in order to obtain the desired normal component of the velocity.

Either of two methods may be used to obtain the cosine of the angle alpha. In the first method, use the field note sheet that has a point of origin (o) printed on the left margin and cosine values on the right margin (see figure 2*A*). Measure the cosine of the angle of the current by holding the note sheet in a horizontal position with the point of origin on the tag line, bridge rail, cable rail, or any other feature parallel to the cross section, as shown in figure 15. With the long side of the note sheet parallel to the direction of flow, the tag line or bridge rail

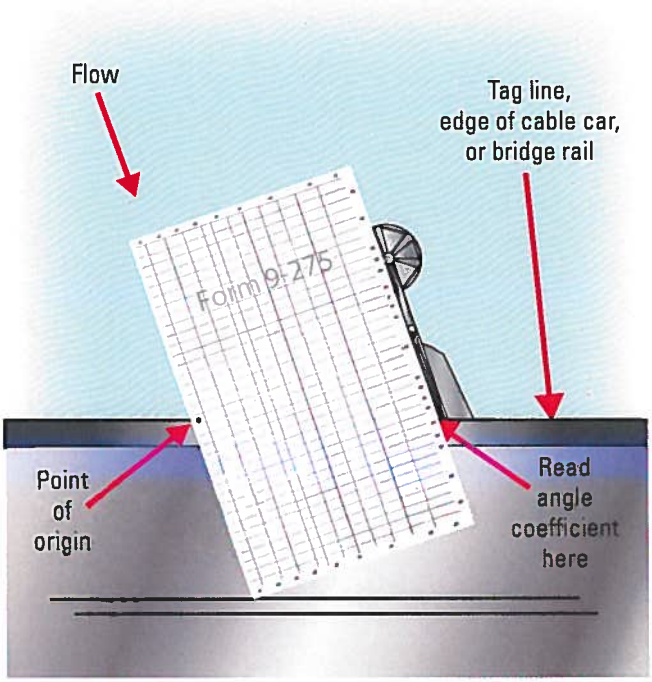


Figure 15. Measurement of horizontal angle with measurement note sheet.

will intersect the value of cosine alpha on the top, bottom, or right edge of the note sheet. The direction of the current will be apparent from the direction of movement of floating particles. If the water is clear of floating material, the edge of the note sheet is aligned parallel to the direction of movement. If no such material is available, the rather inelegant, but time-honored method of spitting into the stream can be used to discern the direction of flow. The position of the current meter may also be used if it can be seen below the water surface. Multiply the measured velocity by the cosine of the angle to determine the velocity component normal to the measurement section.

The second method of obtaining the cosine of the angle alpha involves the use of a folding rule that folds at 0.5-ft or 1-ft intervals. The rule must be graduated in hundredths of a foot and jointed every 0.5 ft or 1 ft. Extend the first 2 ft of the rule and place the 2.00-ft marker on the tag line or bridge rail, as shown in figure 16, with the rule aligned with the direction of flow. Fold the rule at the 1-ft mark so that the first foot of the rule is normal to the tag line or bridge rail. Make a reading where the 1-ft section intersects the tag line or bridge rail. That reading, subtracted from 1.00, is the cosine of the angle alpha. For example, if the reading on the rule is 0.07 ft (fig. 16), the cosine of alpha equals 0.93.

The direction of flow, as observed on the surface of the stream, may not always be a reliable indication of the direction of flow at some distance below the surface. For instance, when measuring a stream influenced by tidal fluctuations, it is possible to have flow moving downstream near the surface of the stream, and flow moving upstream near the bottom of the

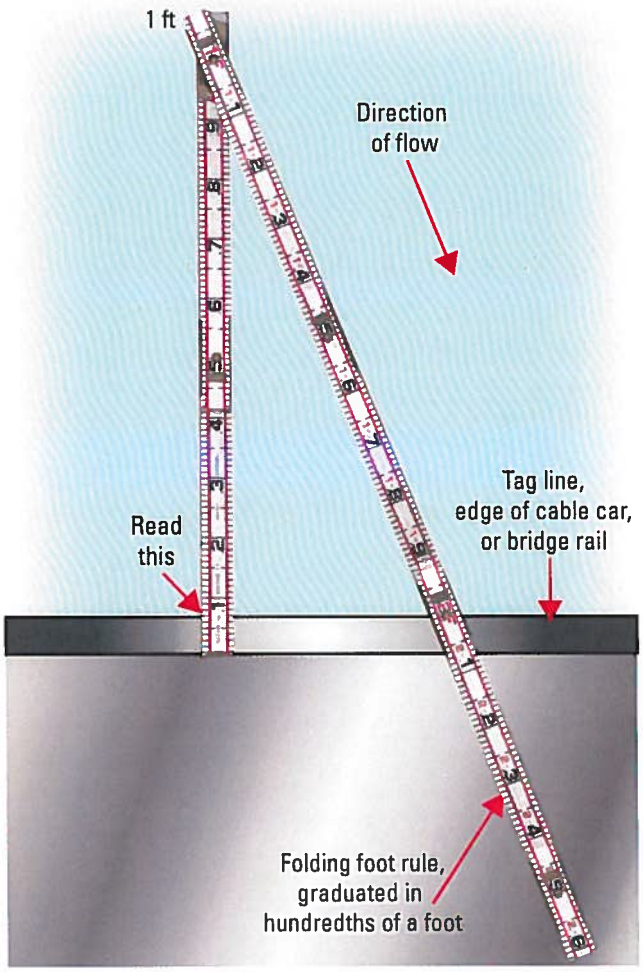


Figure 16. Measurement of horizontal angle with a folding rule.

stream. Therefore, whenever it is suspected that the direction of flow is variable at different depths, other means than those already mentioned must be used to determine the direction of flow. One such method is to use a rigid rod or pole, with a vane attached to the bottom, and an indicator parallel to the vane attached to the top. Another method is to use a sounding weight with a compass and remote readout, as described in the equipment section of this chapter. If the variation of the direction of flow in the vertical is not great, then an average value of the cosine of the angle may be used for computing the component mean velocity for the vertical. However, if the variation is considerable, then you may need to subdivide the vertical and make separate computations for each subdivision. This may require additional measurements of velocity in the vertical.

If available, an ADCP from a moving boat can be used to quickly discern multidirectional flow in the vertical and across the selected cross-section. In a tidal affected reach, an ADCP is the preferred method of measuring discharge because of its use in the measurement of three dimensional velocity through most of the water column.

Current-Meter Measurements by Wading

Current-meter measurements by wading are preferred, if conditions permit. Wading measurements offer the advantage over measurements from bridges and cableways because the hydrographer can usually chose the best of several available cross sections for the measurement. Figure 17 shows a wading measurement being made with a top-setting rod.

Use the type AA, pygmy, or ADV meter for wading measurements. Table 6 lists the type of meter and velocity method to use for wading measurements at various depths.

If a type AA meter is being used in a cross section where most of the depths are greater than 1.5 ft, do not change to the pygmy meter for a few depths less than 1.5 ft or vice versa. The Price AA meter is not recommended for depths of 1.0 ft or less because the registration of the meter is affected by its proximity to the water surface and to the streambed. However, it can be used at depths as shallow as 0.5 ft to avoid changing meters if only a few verticals of this depth are required. The type AA meter or the pygmy meter should not be used in velocities less than 0.2 ft/s unless it is absolutely necessary.

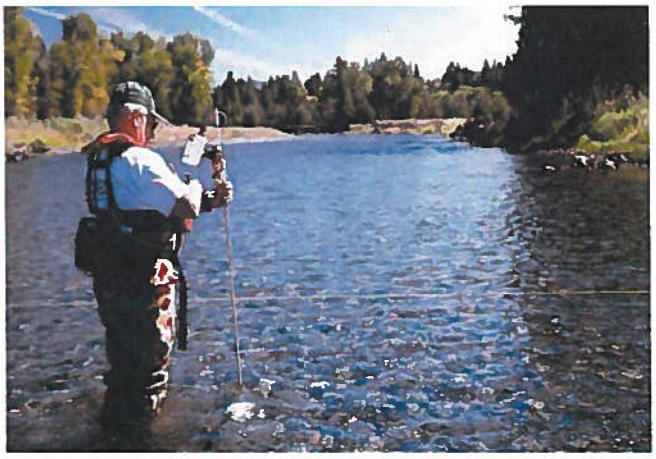


Figure 17. Wading measurement using a top-setting rod.

Table 6. Current meter and velocity-measurement method for various depths.

Depth, in feet	Current meter	Velocity method
2.5 and greater	Price Type AA	0.2 and 0.8
1.5 - 2.5	Price Type AA	0.6
0.3 - 1.5	Price Pygmy	0.6
1.5 and greater	Price Pygmy	0.2 and 0.8
0.3 - 1.5	ADV	0.6
1.5 and greater	ADV	0.2 and 0.8

It is no longer recommended to use coefficients given by Pierce (1941) for the performance of current meters in water of shallow depth and low velocities.

When natural conditions for measuring are in the range considered undependable, modify the measuring cross section, if practical, to provide acceptable conditions. Often it is possible in small streams to build dikes to cut off dead water and shallow flows in a cross section, or to improve the cross section by removing the rocks and debris within the section and from the reach of stream immediately upstream from it. After modifying a cross section, allow the flow to stabilize before starting the discharge measurement.

Stand in a position that least affects the velocity of the water passing the current meter by facing the bank, with the water flowing against the side of the leg. Holding the wading rod at the tag line, stand from 1 to 3 in. downstream from the tag line and 18 in. or more from the wading rod. Avoid standing in the water if feet and legs would occupy a considerable percentage of the cross section of a narrow stream. In small streams where the width permits, stand on a plank or other support above the water rather than in the water. Velocity bias caused by effects of the hydrographer's position can be significant. Observance of these conditions is important while using mechanical meters, ADVs, and any wading measurement where an obstacle could interfere with the natural flow conditions of the stream.

When using a Price meter, keep the wading rod in a vertical position and the meter parallel to the direction of flow while observing the velocity. If the flow is not at right angles to the tag line, measure the angle coefficient carefully. When using an ADV or other instrument that can measure the x component velocity, the instrument should be aligned more precisely with the tag line. See the discussion of FlowTracker use and flow angles in the "Measurement of Velocity" section of this chapter.

During measurements of streams with shifting beds, the scoured depressions left by the hydrographer's feet can affect soundings or velocities. Generally, place the meter ahead of and upstream from the hydrographer's body and feet. Record an accurate description of streambed and water-surface configuration each time a discharge measurement is made in a sand-channel stream.

For discharge measurements of flow too small to measure with a current meter, use a volumetric method, Parshall flume, or weir plate. Those methods are described in subsequent sections of this chapter.

Current-Meter Measurements From Cableways

The Price type-AA current meter is generally used in conjunction with sounding weights and a sounding reel when measuring discharge from a cableway, although in recent years, using an ADCP mounted to a tethered craft has become much more widespread. Stationing (for width measurements) is usually determined from marks painted on the cableway. The velocity is measured by setting the meter at the proper position in the vertical, as indicated in table 7. Table 7 is designed so that no velocity observations will be made with the meter closer than 0.5 ft to the water surface. In the zone from the water surface to a depth of 0.5 ft, the current meter is known to give erratic results.

One problem found while measuring velocities from a cableway is that the movement of the cable car from one station to the next causes the car to oscillate for a short time after coming to a stop. Wait until this oscillation has decreased to a negligible amount before counting the revolutions.

By using a method of tagging the sounding cable at convenient intervals with streamers of different-colored binding tapes, each colored streamer being a known distance above the current-meter rotor (known as using tags), the meter can be kept under water at all times to prevent it from freezing in cold air. Tags are also used in measurements of deep, swift streams. See the section of this chapter on "Measurement of depth."

If large amounts of debris are flowing in the stream, raise the meter up to the cable car several times during the measurement to be certain the pivot and rotor of the meter are free of debris. However, keep the meter in the water during the measurement if the air temperature is considerably below freezing.

During floods, there is always a danger of catching a submerged or floating object, such as a tree or log, which can endanger the sounding equipment, meter, and most importantly, the hydrographer. Always be sure that the sounding cable has been installed on the sounding reel, according to the breaking loads specified in table 8. This assures that the sounding cable will break when it reaches its end, thereby preventing a potentially serious accident where the cable car and hydrographer could be spilled into the stream. Also, for added safety, always carry a pair of lineman's side-cutter pliers while making measurements from a cableway. If the sounding cable becomes hopelessly hung and does not break, as it should, cut the sounding line to ensure safety. Sometimes the cable car can be pulled to the edge of the water and the debris can be released.

When measurements are made from cableways where the stream is deep and swift, measure the angle that the meter suspension cable makes with the vertical due to the drag. The vertical angle, measured by protractor, is needed to correct the soundings to obtain the actual vertical depth, as described in the section on "Depth corrections for downstream drift of current meter and weight."

Table 7. Velocity-measurement method for various suspensions and depths.

Suspension	Minimum depth, in feet	
	0.6 method	0.2 and 0.8 method
15 C .5[1], 30 C .5	1.2	2.5
50 C .55	1.4	2.8
50 C .9	2.2	4.5
75 C 1.0, 100 C 1.0, 150 C 1.0	2.5	5.0
200 C 1.5, 300 C 1.5	3.8[2]	7.5

[1]15 pound Columbus-type weight, 0.5 above channel bed.

[2]Use 0.2 method for depths 2.5 to 3.7 feet with appropriate coefficient (for example, 0.87 or 0.88).

Table 8. Breaking loads for Ellsworth stranded cable.

Sounding cable	Diameter, in inches	Total number of strands	Rated total breaking load, in pounds	Recommended breaking load, in pounds	Number of strands to cut	Number of strands to remain
Ellsworth 0.084	0.084	36	500	250	15	21
Ellsworth 0.100	0.100	30	1,000	500	15	15
Ellsworth 0.125	0.125	30	1,500	500	20	10

Current-Meter Measurements From Bridges

When a stream cannot be waded, a bridge may be used to obtain current-meter measurements. Many measuring sections under bridges are satisfactory for current-meter measurements, but cableway sections are usually better because they provide an unobstructed reach of the channel. In addition, cableways usually have no bridges constricting the free flow of the stream in the measuring reach.

No set rule can be given for choosing between the upstream or downstream side of the bridge while making a discharge measurement. The advantages of using the upstream side of the bridge are the following:

- Hydraulic characteristics at the upstream side of bridge openings usually are more favorable. Flow is usually smoother and there is less turbulence than at the downstream side of the bridge.
- Approaching drift can be seen and be more easily avoided.
- The streambed at the upstream side of the bridge is not likely to scour as much as at the downstream side.

The advantages of using the downstream side of the bridge are:

- Vertical angles are more easily measured because the sounding line will move away from the bridge.
- The flow lines of the stream may be straightened out by passing through a bridge opening with piers.

Using the upstream side or the downstream side of a bridge for a current-meter or ADCP measurement should be decided based on circumstances for each bridge. Consider the factors mentioned above and the physical conditions at the bridge, such as location of the walkway, traffic hazards, and accumulation of trash on piles and piers.

For an ADCP measurement with a tethered craft, unless a special rigid support for deployment or bank-operated cableway has been developed for the upstream side of the bridge, the downstream side of the bridge is usually where the ADCP is most conveniently deployed. Bridge piers can cause excessive turbulence during high streamflow, especially if debris accumulates on the piers and(or) the piers are skewed to the flow. The effect of bridge-pier-induced turbulence may be reduced when deploying an ADCP from the downstream side of the bridge by lengthening the tether to increase the distance between the bridge and the tethered boat. Close attention should be paid to the cross section to ensure that no large eddies that could cause flow to be nonhomogeneous are present. Possible alternatives to measuring off the downstream side of the bridges include using a bank-operated cableway, a rigid extension that allows the hydrographer to deploy from the upstream side of the bridge, or having personnel on each bank hold a rope or cord attached to the platform to pull the tethered boat back and forth across the river.

For a mechanical current meter measurement, use either a handline, or a sounding reel supported by a bridge board or a portable crane, to suspend the current meter and sounding weight from bridges. Depth measurements should be made as described in the section entitled "Measurement of depth." Measure the velocity by setting the meter at the position in the vertical as indicated in table 7. Keep equipment several feet from piers and abutments if velocities are high. Estimate the depth and velocity next to the pier or abutment on the basis of the observations at the nearest vertical.

If there are piers in the cross section, it is usually necessary to use more than 25 to 30 partial sections to get results as reliable as those from a similar section without piers. Piers will often cause horizontal angles that must be carefully measured. Piers also cause rapid changes in the horizontal-velocity distribution in the section.

Whether or not to exclude the area of a bridge pier from the area of the measurement cross section depends primarily on the relative locations of the measurement section and the end of the pier. If measurements are made from the upstream side of the bridge, it is the relative location of the upstream end (nose) of the pier that is relevant; for measurements made from the downstream side, it is the location of the downstream end (tail) of the pier that is relevant. If any part of the pier extends into the measurement cross section, the area of the pier is excluded. Bridges quite commonly have cantilevered walkways from which discharge measurements are made. In these cases, the measurement cross section lies beyond the end of the pier (upstream from the pier nose or downstream from the pier tail, depending on which side of the bridge is used). In that situation, it is the position and direction of the streamlines that determines whether or not the pier area is to be excluded. If the stationing of the sides of the pier when projected to the measurement cross section was not already done, the hydrographer does it at this point. If there is negligible or no downstream flow in that width interval (pier subsection), then the pier is excluded. That is, if only stagnation and (or) eddying exists upstream from the pier nose or downstream from the pier tail, whichever is relevant, the area of the pier is excluded. If there is substantial downstream flow in the pier subsection, the area of the pier is included in the area of the measurement cross section. In that circumstance, the horizontal angles of the streamlines in and near the pier subsection will usually be quite large.

Footbridges are sometimes used for measuring canals, tailraces, and small streams. Rod suspension can be used from many footbridges. The procedure for determining depth in low velocities is the same as for wading measurements. For higher velocities, obtain the depth by the difference in readings at an index point on the bridge when the base plate of the rod is at the water surface and on the streambed. Measuring the depth in this manner will eliminate errors caused by the water piling up on the upstream face of the rod. ADCP tethered boats, handlines, bridge cranes, and bridge boards are also used from footbridges.

The handline can be disconnected from the headphone wire and passed around a truss member with the sounding

weight on the bottom. This eliminates the need for raising the weight and meter to the bridge each time a move is made from one vertical to another; it is the principal advantage of a handline.

Safety is a primary consideration when measuring discharge from bridges. High-speed traffic can present a major safety hazard; in fact, it is no longer permissible to make discharge measurements from some Interstate route bridges without special permission. Observe all safety precautions, such as the use of traffic cones, traffic signs, and flag persons, that are prescribed in the USGS Water Science Center's flood plan and safety plan.

Observe the same safety precautions regarding the snagging of debris, such as floating or submerged trees or logs, as described above for cableways.

Current-Meter Measurements From Ice Cover

Discharge measurements under ice cover, as shown in figure 18, are made under the most severe conditions, but are extremely important because a large part of the discharge record during a winter period may depend on one measurement. In recent years ADCPs and ADVs have increasingly been used to make measurements from ice cover.

Select the possible locations of the cross section to be used for measurement from ice cover during the open-water season when channel conditions can be evaluated. Commonly, the most desirable measurement section will be just upstream from a riffle because slush ice that collects under the ice cover is usually thickest at the upstream end of the pools created by riffles.

The equipment used for cutting or drilling the holes in the ice is described in a previous section of this chapter.

Never underestimate the danger of working on ice-covered streams. When crossing, test the strength of the ice with solid blows using a sharp ice chisel. Ice thickness may be irregular, especially late in the season when a thick snow cover may act as an insulator. Water just above freezing can slowly melt the underside of the ice, creating thin spots. Ice that is bridged above the water may be thick but still be weak.

Cut the first three holes in the selected cross section at the quarter points to detect the presence of slush ice or poor distribution of the flow in the measuring section. If poor conditions are found, investigate other sections to find one that is free of slush ice and that has good distribution of flow. After finding a suitable cross section, make at least 20 holes in the ice for a current-meter measurement. Space the holes so that no partial section contains more than 10 percent of the total discharge. On narrow streams, it may be simpler to remove all of the ice in the cross section.

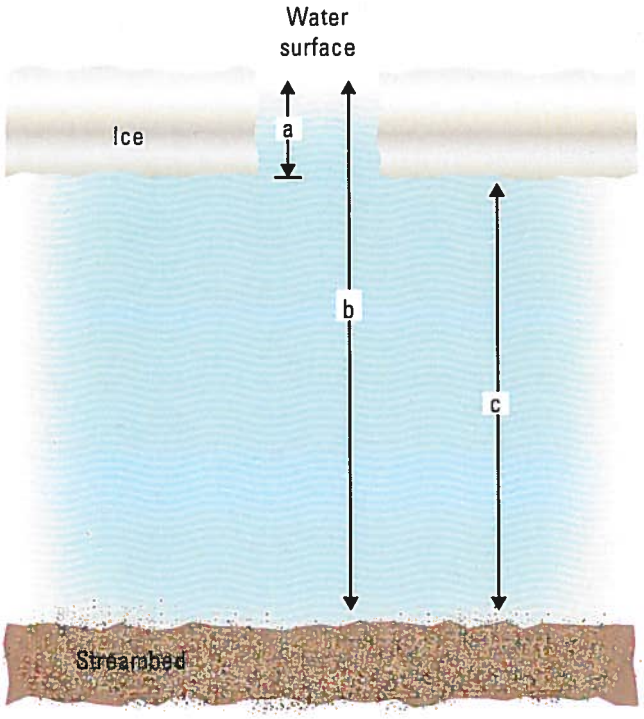
The effective depth of the water, as shown in figure 19, is the total depth of water minus the distance from the water surface to the bottom of the ice. The vertical pulsation of water

Figure 18. *A,* Ice drill being used to cut holes and *B,* ice rod being used to support current meter for a discharge measurement.

in the holes in the ice sometimes causes difficulty in determining the depths. The total depth of water is usually measured with an ice rod or with a sounding weight and reel, depending on the depth.

Measure the distance from the water surface to the bottom of the ice with an ice-measuring stick. Do not use the ice-measuring stick if there is slush under the solid ice at a hole. In order to find the depth at which the slush ice ends, suspend the current meter below the slush ice with the meter rotor turning freely. Raise the meter slowly until the rotor stops. This point is used as the depth of the interface between water and slush. After the effective depth of the water has been determined, compute the proper position of the meter in the vertical as shown in figure 19.

Use the Price winter Water Survey of Canada (WSCan) current meter yoke, with a polymer rotor, under ice cover when slush ice is present because the cups are solid and cannot become filled with slush ice; this is what happens with the cups of the regular Price meter. For situations where slush ice is not present, use the Price winter WSCan current meter yoke



a = Water surface to bottom of ice
b = Total depth of water
c = Effective depth (c=b-a)

0.2-depth setting = a + 0.2c
0.8-depth setting = b - 0.2c
0.6-depth setting = b - 0.4c

Figure 19. Method of computing meter settings for measurements under ice cover.

with regular Price metal cups. The old-style vane ice meter is no longer recommended, primarily because of its poor performance in slow velocities.

The velocity distribution under ice cover, when the water is in contact with the underside of the ice, is similar to that in a pipe, with a lower velocity nearer the underside of the ice. This is illustrated in figure 20. Use the 0.2- and 0.8-depth method for effective depths of 2.5 ft or greater, and the 0.6-depth method for effective depths of less than 2.5 ft. Define two vertical-velocity curves while making ice measurements to determine whether any coefficients are necessary to convert the velocity (obtained by the 0.2- and 0.8-depth method or the 0.6-depth method) to the mean velocity. Normally, the average of the velocities obtained by the 0.2- and 0.8-depth method gives the mean velocity, but a coefficient of about 0.92 usually is applicable to the velocity obtained by the 0.6-depth method.

When measuring the velocity, keep the meter as far upstream as possible to avoid any effect that the vertical pulsation of water in the hole might have on the meter. Eliminate as much as possible the exposure of the meter to the cold air during the measurement. The meter must be free of ice when the velocity is being measured.

If there is partial ice cover at a cross section, use the procedure described above where there is ice cover, and use open-water methods elsewhere.

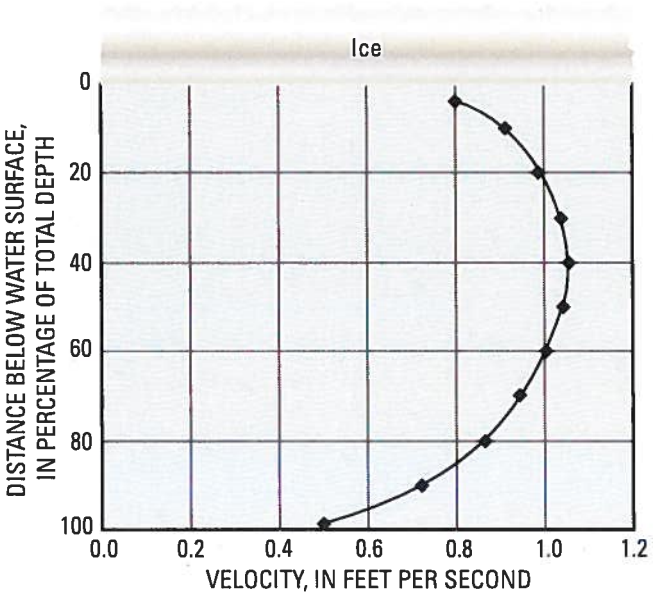


Figure 20. Typical vertical-velocity curve under ice cover.

DISCHARGE MEASUREMENT NOTES—ICE COVER

FRIO River, at Creek, near COLD HARBOR, ME METER = V-587

REW Dist. from initial point	Width	Total depth of water	W.S. to bot. ice	Effective depth	Depth of meter below water surface	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Area	Discharge
1315											
24	3	0							0	0	0
30	6	2.6	1.6	1.0	2.2	10	47	.49	.45	6.0	2.7
36	6	3.6	1.8	1.8	2.9	15	49	.69	.63	10.8	6.8
42	5	4.3	2.0	2.3	3.4	15	44	.77	.71	11.5	8.2
46	4	4.5	1.8	2.7	2.3	20	43	1.04	.84	10.8	9.1
					4.0	15	52	.65			
50	4	4.7	1.7	3.0	2.3	20	40	1.12	.90	12.0	10.8
					4.1	15	50	.68			
54	4	4.6	1.7	2.9	2.3	25	49	1.14	.94	11.6	10.9
1325					4.0	15	46	.74			
58	4	4.9	1.6	3.3	2.3	20	40	1.12	.90	13.2	11.9
					4.2	15	50	.68			
62	4	4.8	1.6	3.2	2.2	25	48	1.17	.96	12.8	12.3
					4.2	15	46	.74			
66	3.5	5.0	1.5	3.5	2.2	25	44	1.27	1.04	12.2	12.7
					4.3	15	41	.82			
69	3	5.3	1.6	3.7	2.3	25	40	1.40	1.12	11.1	12.4
					4.6	15	40	.84			
72	3	5.1	1.5	3.6	2.2	25	41	1.36	1.12	10.8	12.1
1335					4.4	20	51	.88			
	49.5									122.8	109.9

Figure 21. Part of note sheet for discharge measurement under ice cover.

A sample sheet of discharge-measurement notes under ice cover is shown in figure 21. In this measurement, the vertical-velocity curves indicate that the 0.2- and 0.8-depth method gives the mean velocity and that the 0.6-depth method requires a coefficient of 0.92.

Current-meter measurements under ice cover are frequently made with a special winter-style sounding rod, ADV or ADCP, as described in this chapter. When depths are too deep for rod suspension, use an equipment assembly mounted on runners, such as shown in figure 22. For winter conditions, the 30-pound C-type weights should be used with a special, collapsible hanger assembly (shown in figure 22) that can be passed through an 8-in. hole in the ice. A handline can also be used for making ice measurements.

Where it is impractical to use a powered ice drill, use ice chisels to cut the holes. Ice chisels are usually 4- or 4.5-ft long and weigh about 12 pounds. Use the ice chisel when first crossing an ice-covered stream to determine whether the ice is strong enough to support the hydrographer. If a solid blow of the chisel blade does not penetrate the ice, it is safe to walk on, providing the ice is in contact with the water.

Some hydrographers supplement the ice chisel with a Swedish ice auger. The cutting blade of this auger is a spade-like tool of hardened steel that can cut a hole 6 to 8 in. in diameter by turning a brace-like arrangement on top of the shaft.

After the hole is made in the ice, water will be forced up, owing to the water being under pressure from the weight of the ice. In order to determine the effective depth of the stream, use ice-measuring sticks to measure the distance from the water surface to the bottom of the ice. Measuring this distance is done using a bar about 4 ft long, made of strap steel or wood, graduated in feet and tenths of a foot and having an L-shaped projection at the lower end. Hold the horizontal part of the L on the underside of the ice and read the depth to that point at the water surface on the graduated part of the stick. The horizontal part of the L is at least 4 in. long so that it may extend beyond any irregularities on the underside of the ice.

Figure 22. Collapsible hanger assembly for used with 30- and 50-pound C-type weights, for measurements under ice (*A*, in measurement position and *B*, collapsed).

Current-Meter Measurements From Stationary Boats

Discharge measurements are made from boats where no cableways or suitable bridges are available and where the stream is too deep to wade, although ADCP discharge measurements from a moving boat, now a USGS standard operating procedure, have largely replaced this method. Personal safety is the limiting factor in the use of boats on streams having high velocity of flow.

For boat measurements whether using a mechanical meter or an ADCP, select a cross section that has attributes similar to those described in the previous section "Site selection," except for those listed in items concerning depth and velocity. There is no need to consider depth in a boat measurement because if the stream is too shallow to float a boat, the stream can usually be waded. Velocity, however, is an important concern. If velocities are too slow, mechanical current meter registration may be affected by an oscillatory movement of the boat, in which the boat (even though fastened to a tag line) moves upstream and downstream as a result of wind action. Vertical movement of the boat as a result of wave action may also affect a vertical-axis current meter. If velocities are too fast, it becomes difficult to string a tag line across the stream.

If it is feasible to use a tag line in making a boat measurement, string it at the measuring section by unreeling the line as the boat moves across the stream. After a tag line without a brake has been stretched across the stream, take up the slack by means of a block and tackle attached to the reel and to an anchored support on the bank. If there is traffic on the river, one person must be stationed on the bank to lower and raise the tag line to allow the river traffic to pass. Place streamers on the tag line so that it is visible to boat pilots. If there is a continual flow of traffic on the river, or if the width of the river is too great to stretch a tag line, other means will be needed to position the boat. Night measurements by boat are not recommended because of the safety concerns.

When no tag line is used, the boat can be kept in the cross section by lining it up with flags positioned on each end of the cross section, as illustrated in figure 23. Flags on one bank would suffice but it is better to have them on both banks. Determine the position of the boat in the cross section by using a transit or total station on the shore and a stadia rod held in the boat. Another method of determining the position of the boat is by setting a transit or total station on one bank a convenient, known distance from and at right angles to the cross-section line. The position of the boat is determined by measuring the angle α to the boat, measuring the distance CE, and computing the distance MC as shown in figure 24. A third method of determining the position of the boat is done with a sextant read from the boat. Position a flag on the cross-section line and another at a known distance perpendicular to the line. The boat position can be computed by measuring the angle β with the sextant, as shown in figure 24. Boat position can also be determined by using a global positioning system with differential corrections (DGPS). This method is especially useful on wide streams and in flood plains where other methods of determining boat position are not applicable. Unless anchoring is more convenient, the motor must hold the boat stationary while readings are being taken.

Do not take boat measurements at velocities less than 1 ft/s when the boat is subject to wave action. The up-and-down movement of the boat (and the meter) seriously affects the velocity observations. If the maximum depth in the cross section is less than 10 ft and the velocity is low, the hydrographer can use a rod for measuring the depth and for supporting the current meter. For greater depths and velocities, use a cable suspension with a reel and sounding weight. The procedure for measuring from a stationary boat using the boat boom and crosspiece is the same as that for measuring from a bridge or a cableway, as described in previous sections of this chapter.

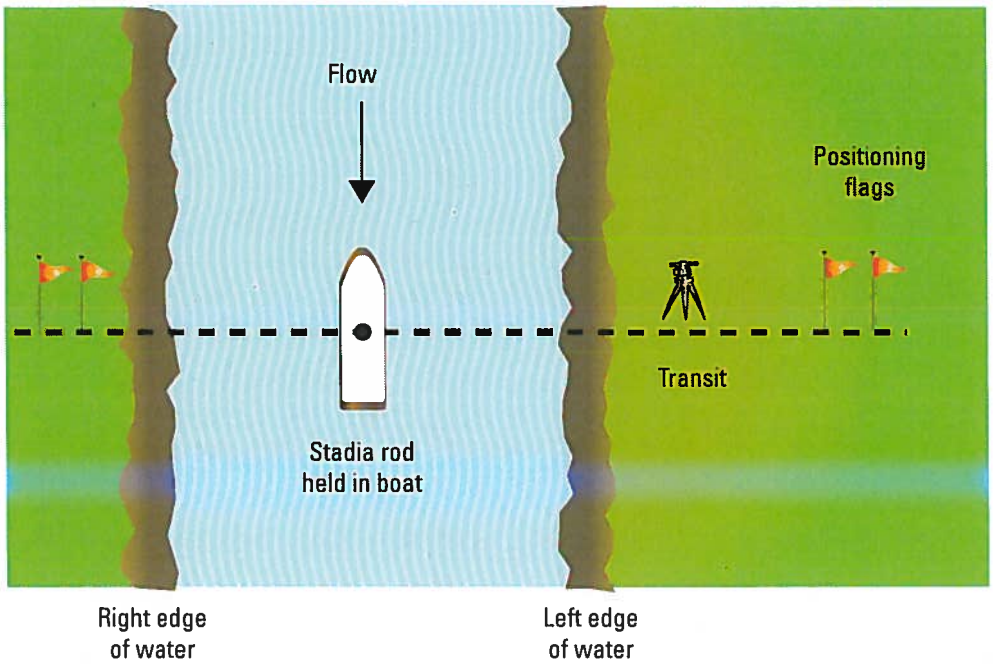


Figure 23. Determining the position in a cross section using the stadia method.

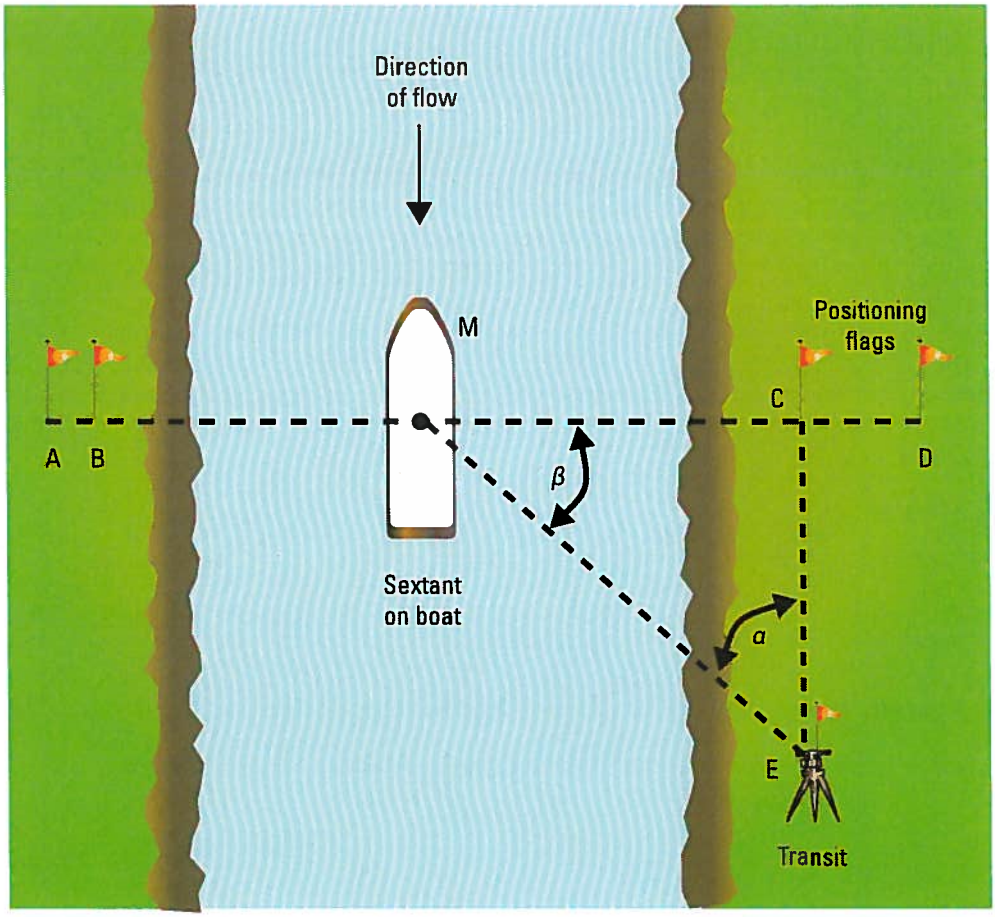


Figure 24. Determining the position in a cross section using the angular method.

Moving-Boat Measurements of Discharge

On large streams and estuaries, the midsection methods of measuring discharge are frequently impractical and involve costly and tedious procedures. There may be no facilities at remote sites. Where facilities do exist, they may be inundated or inaccessible during floods. At some sites, unsteady flow conditions require that measurements be made as rapidly as possible. Measurements on tide-affected rivers must not only be made frequently, but continually, throughout a tidal cycle. The moving-boat technique is a method of quickly measuring a large stream. It requires no fixed facilities, and it lends itself to the use of alternate sites if conditions make this applicable. Brief descriptions of three moving-boat methods are given in the following sections. It must be stated here that these methods have been almost entirely replaced by the use of ADCP discharge measurements. Details of ADCP setup and use can be found in Mueller and Wagner (2009) and subsequent section of this chapter discussing the moving boat method using an ADCP.

Manual Method, Using a Mechanical Current Meter

Smoot and Novak (1968) describe the manual moving-boat technique in detail. It is similar to the mechanical current-meter measurement in that the velocity-area approach is used to determine the discharge. The total discharge is the summation of the products of the partial areas of the stream cross section and their respective average velocities. During the traverse of a stream by boat, a sonic sounder records the geometry of the cross section, and a continuously operating current meter senses the combined stream and boat velocities.

The current meter used for a moving-boat measurement is a component propeller type, such as the Ott current meter, with a custom body made for mounting on the leading edge of a vane. The current meter and vane assembly are attached to a vertical rod and bearing assembly that allows them to rotate freely. An angle indicator is located at the top of the rod, which indicates the crab angle.

It usually takes three people to make a moving-boat measurement: one to operate the boat, one to make crab-angle observations, and one to take notes. The note keeper is responsible for recording the crab-angle observations and the current-meter pulses. Depths are recorded automatically on the sonic-sounder chart. Special computations and conversions, which are somewhat tedious, are required to determine stationing and normal mean velocities for each vertical. Discharge can then be computed similar to a standard velocity-area discharge measurement. Experience has shown that measurements obtained by the moving-boat technique compare within 5 percent of measurements obtained by conventional means.

Automatic Computerized Method, Using a Mechanical Current Meter

The automatic computerized moving-boat method is the same basic procedure as the manual moving-boat method described above, except that all readings of depth, velocity, crab angles, and boat position are automatically fed into an onboard computer. A substantial difference is that the automated moving-boat method requires only two crew members—a boat operator and an instrument operator. The manual method requires three crew members.

The automated method requires an electronic compass that provides automatic input of the crab angle. The current meter and depth sounder likewise provide automatic input of pulse rates and depth, respectively. The computer is programmed to make the conversions and computations that would normally be made manually, thereby speeding up the computation process and virtually eliminating arithmetic errors. A computed measurement is available immediately after completion of the data collection.

Moving-Boat Method, Using an ADCP

ADCPs can be used to measure unsteady, bidirectional, and other flows with nonlogarithmic velocity distributions—problems hydrologists have faced for decades. ADCPs are called profilers because they provide measurements of velocity throughout the water column. The ADCP divides the water column into depth cells (also referred to by some software and references as "bins") and reports a velocity for each depth cell; however, an ADCP cannot measure velocities near the water surface or near the bed. The length of the unmeasured zone at the water surface is a function of the draft of the instrument deployment, the effect of the transducer mechanics, and the flow disturbance around the instrument. The length of the unmeasured zone near the streambed is due to side-lobe interference, which is a function of the mechanics of transducers and the slant angle of the beams. The ADCP must be deployed below the water surface; therefore, it cannot measure the water velocity above the transducers.

Although ADCPs have no moving parts and typically require no calibration, the instruments and associated software and firmware are complex. Using quality-assurance procedures defined by Oberg and others (2005) and Mueller and Wagner (2009) will help identify potential instrument problems.

ADCPs can be mounted on either side of manned boats, off the bow, or in a well through the hull. A tethered boat can be defined as a small boat (usually less than 6.5 ft long) attached to a rope, or tether, that can be deployed from a bridge, a fixed cableway, a moving boat, or a temporary or permanent bank-operated cableway. The tethered boat should be equipped with an ADCP mount that meets all of the specifications for manned boats. Unmanned, remote-control ADCP boats are also used and allow the deployment of ADCPs where deployment with a manned boat or tethered boat may not be feasible or ideal. Similar to (but smaller than) a manned boat,

a remote-control boat has self-contained motors and a remote-control system for maneuvering the boat across the river.

The procedures for predeployment preparation, field data collection, and processing of collected data are discussed in detail by Mueller and Wagner (2009). A detailed description of how an ADCP measures velocity and computes discharge and additional details on selected topics are presented in the appendices (Mueller and Wagner, 2009).

Networks of Current Meters

In the past, occasional special measurements made by USGS hydrographers have required simultaneous velocities at several points in a cross section, distributed either laterally or vertically. For example, it may be necessary to measure a vertical-velocity profile quickly in unsteady flows and to check it frequently in order to determine the changes in shape of the vertical profile, as well as the rates of these changes. In another example, for the measurement of tide-affected streams, it is desirable to measure the total discharge continuously during at least a full tidal cycle (approximately 13 hours). The need for so many simultaneous velocity determinations (one at each vertical in the cross section) for so long a period could be an expensive and laborious process using conventional techniques of discharge measurement.

A grouping of 21 current meters and special instrumentation has been devised in the past by the USGS to facilitate measurements of the types just described. The 21 meters are connected together so that the spacing between any two adjacent meters can vary up to 200 ft. In using this method, each meter should be uniformly calibrated and have sufficient handline cable to be suspended vertically from a bridge as much as 200 ft. Revolutions of the rotors are recorded by electronic counters that are grouped compactly in one box at the center of the bank of meters. The operator, by flipping one switch, starts all 21 counters simultaneously, and after an interval of several minutes, stops all counters. The indicated number of revolutions for the elapsed time interval is converted to a velocity for each meter. The distance between meters is known, and a record of stage is maintained to evaluate depth. Prior information at the site is obtained to convert point velocities in the verticals to mean velocities in those verticals. All of the information necessary to compute discharge in the cross section is available, and is tabulated for easy conversion to discharge. If possible a concurrent ADCP discharge measurement should be completed in close proximity and time to this measurement to corroborate the results.

Discharge Measurement of Deep, Swift Streams With a Mechanical Current Meter

Discharge measurements of deep, swift streams with a mechanical current meter usually present no serious problems when adequate sounding weights are used and when floating drift or ice is not excessive. Normal procedures must sometimes be altered, however, when measuring these streams. The four most common circumstances are the following:

1. It is possible to sound, but the weight and meter drift downstream.
2. It is not possible to sound, but a standard cross section is available.
3. It is not possible to sound, and a standard cross section is not available.
4. It is not possible to put the weight and meter in the water.

Procedures are described below for use during measurements made under each of these conditions. Use procedures for items 2, 3, and 4 where there is a stable cross section. The procedure for unstable channels must be determined by conditions at each location.

Possible To Sound, but Weight and Meter Drift Downstream

For some streams, it may be possible to sound the streambed, but because of the force of high velocities, the weight and meter are carried downstream. This may be a condition for only a few verticals near the center of the stream, or it may affect many of the verticals. Make corrections to the observed depths and meter settings to account for the downstream drift. These corrections are commonly referred to as "vertical angle corrections." The procedure for computing vertical angle corrections is described in a previous section of this chapter entitled "Depth corrections for downstream drift of current meter and weight." The corrections can be computed manually, or they may be computed automatically through the use of an electronic notebook or a PDA.

Not Possible To Sound, but Standard Cross Section Available

When it is not possible to sound the streambed, use a standard cross section from previous measurements at the bridge or cableway for determining depth. Such a cross section is useful only if all discharge measurements use the same permanent initial point for the stationing of verticals across the width of the stream. There should also be an outside reference gage or reference point on the bank or bridge to which the water-surface elevation at the measurement cross section

may be referred. If these conditions are met, use the following procedure to make a discharge measurement:

1. Determine the depths from the standard cross section, based on the water-surface elevation.
2. Measure the velocity at 0.2 of the depth at each vertical.
3. Compute the measurement in the normal manner using the measured 0.2-depth velocities as though they were the mean velocities in the vertical. Apply horizontal-angle corrections, if necessary. Use depths as determined in step 1 above.
4. Determine the coefficient to adjust the 0.2-depth velocity to the mean velocity on the basis of previous measurements at the site by the two-point method. See a previous section of this chapter entitled "Two-tenths-depth method."
5. Apply the coefficient from step 4 to the computed discharge from step 3.

Not Possible To Sound, and Standard Cross Section Not Available

When it is not possible to sound the streambed and a standard cross section is not available, use the following procedure:

1. Reference the water-surface elevation before and after the measurement to an elevation reference point on a bridge, on a driven stake, or on a tree at the water's edge. It is assumed here that no outside reference gage is available at the measurement cross section.
2. Estimate the depth and observe the velocity at 0.2 of the estimated depth. The meter should be at least 2.0 ft below the water surface. In the notes, record the actual depth the meter was placed below the water surface. If an estimate of the depth is impossible, place the meter 2.0 ft below the water surface and observe the velocity at that point.
3. Make a complete measurement, including some vertical-velocity curves, at a lower stage when you can sound the streambed.
4. Use the complete measurement and difference in stage between the two measurements to determine the cross section of the first measurement. To determine whether the streambed has shifted, compare the cross section with one taken for a previous measurement at that site.
5. Use vertical-velocity curves, or the relation between mean velocity and 0.2-depth velocity, to adjust the velocities observed in step 2 to mean velocity. Apply horizontal-angle corrections as necessary.
6. Compute the measurement in the normal manner using the depths from step 4 and the velocities from step 5.

Not Possible To Put the Weight and Meter in Water

If it is impossible to put the sounding weight and mechanical current meter in the water because of high velocities and (or) floating drift, use the following procedure:

1. Obtain depths at the measurement verticals from a standard cross section, if one is available. If a standard cross section is not available, determine depths by the method explained above in the section "Not possible to sound, and standard cross section not available."
2. Measure velocities and compute discharge using an ADCP.
3. Measure surface velocities by timing floating drift, or by using an optical or other approved noncontact flowmeter.
4. Compute the measurement in the normal manner, using the surface velocities as though they were the mean velocities in the vertical, and using the depths from step 1.
5. Apply the appropriate velocity coefficient to the discharge computed in step 3. Use a coefficient of 0.86 for a natural channel and 0.90 for an artificial channel.

The optical current-meter and ADCP measurement procedures are described in previous sections of this chapter and by Mueller and Wagner (2009). The optical current meter is portable, battery operated, and requires no great skill for quick and accurate readings of the surface rate of flow. The meter is not immersed, so it does not disturb the flow, and it is in no danger of damage from floating debris or ice. In many cases, the ADCP has become the most efficient alternative to the mechanical current meter where velocities are too great; however, the ADCP also has limitations. See the previous sections of this chapter for information on velocity, depth, turbidity, and other site-condition limitations of the ADCP.

Keep in mind that just after the crest, the amount of floating drift or ice is usually greatly reduced, and it may be possible to obtain velocity observations with a current meter. These observations can help define the velocity coefficient mentioned in step 5 above.

Recording Field Notes

Field notes for a discharge measurement may be recorded on standard paper note sheets (for example, USGS Forms 9-275-F, 9-275-I, and other special field forms). With the ADCP discharge measurement, the software attached to each instrument contains digital forms for the recording of some of the field data. The USGS has developed a paper form for recording field data observed during an ADCP discharge measurement (fig. 2*D*). With a current-meter discharge measurement, field forms can be recorded using an electronic notebook, such as the Aquacalc or a Personal Digital Assistant (PDA). With an ADV measurement, there are special field forms to accommodate its specifications and details. These methods are described in more detail in subsequent paragraphs in this section. The SWAMI program with a PDA (commonly used by the USGS) can be used to record discharge measurements, inspections, differential level surveys, and other field measurements. SWAMI has an interface with the National Water Information System (NWIS), so measurements are easily uploaded to NWIS (fig. 2*C*).

Standard Paper Note Keeping for a Mechanical Current-Meter Discharge Measurement

Paper note sheets, as shown in figure 2*A*, are the traditional way to record the field observations for a mechanical current meter, ADV, or ADCP discharge measurement. Generally, for each discharge measurement, the hydrographer should record the following information, at a minimum, on the front sheet of the measurement notes (the information may vary, depending on the meter and method being used):

- Measurement number, who computed, and who checked the measurement;
- Downstream station identification number and station name (station name includes stream name and location, to correctly identify an established gaging station). For a miscellaneous measurement, record the stream name and exact location of site;
- Date of measurement and members of measurement party (initials and last name);
- Measured channel width, area, average velocity (computed as a ratio of the measured discharge/measured area), average gage height, and discharge;
- Vertical velocity method(s) of measurement, number of sections, and change in gage height during the discharge measurement;
- Measurement method coefficient, horizontal-angle coefficient, type of meter suspension (for example, rod, 100#C, and so forth) and whether tags were checked;
- Type of meter (for example, AA or pygmy), the current meter's serial number; and the elevation of the meter above the channel bottom;
- Meter rating used (for example, Standard Rating No. 2) and the most recent spin test results;
- Measurement percentage (after computed) from the existing stage-discharge rating, and the indicated shift in feet from that rating;
- GAGE READINGS: Do not erase inside this block on the front sheet. If an error is made, cross through the error and write the correct reading.
  - Start time measurement using 24-hour clock time, and record the time zone (that is, EST, CST, EDT, and so forth).
  - Record inside and outside gage, and also readings from recording devices (for example, data logger, graphic, and so forth).
  - Compute weighted mean gage height either by averaging readings, or if sufficient change in gage height occurred, by using methods for weighting gage height discussed in this chapter.
  - Compute gage-height correction caused by difference in true gage height (reference gage) and recorder or other gage that is reading incorrectly.
  - Record the correct mean gage height.
- Samples collected: Indicate type of water-quality measurements and samples [that is, water-quality, sediment, and (or) biological], and indicate if the measurements are documented on separate sheets (that is, water quality, aux./base gage, other);
- Indicate whether the rain gage (if applicable) was serviced/calibrated;
- Briefly describe the weather (for example, sunny, cloudy, rainy, cold, or other);
- Record the air temperature in degrees Celsius and the time of the reading;
- Record the water temperature in degrees Celsius and the time of the reading;
- Record the check bar reading (if a wire weight is present), time of the reading, and any adjustments in elevation made to the check bar.
- Indicate the type of measurement (wading, cable, ice boat, and so forth) and location of measurement relative to the gage (upstream, downstream, and so forth).
- Rate the measurement based on the hydrologic/hydraulic conditions in which the measurement was made [that is, excellent (2 percent), good (5 percent), fair (8 percent), or poor (more than 8 percent)].
- Flow: Document the hydraulic condition of the flow (steady, unsteady, where the flow was within the cross section, and so forth).
- Cross section: Geomorphologically describe the cross section (that is, sand, clay, cobble, and so forth), shape, presence of vegetation, and any other roughness affecting flow.

- Document if the gage is operating and whether the record was removed during this visit;
- Note the battery voltage and the cleaning of the orifice or intakes;
- If appropriate, indicate pressure readings of the nonsubmersible pressure transducer (that is tank, line, bubble-rate (bubbles/minute);
- Indicate if appropriate, readings of extreme indicators of high flow.
- Document the condition of the crest stage gage (CSG) and record the high water mark (HWM) if a reading is available on the CSG and the reference elevation.
- Record any other HWM obtained at the gage, if appropriate.
- Control conditions: Describe what and where the control of flow is for the gage pool (that is, gravel riffle about 80 ft downstream of the gage, and so forth).
- REMARKS: Use this space to document any unusual conditions in the gage reach that might affect the measurement, record, or other pertinent information regarding the accuracy of the discharge measurement and conditions that might affect the stage-discharge relation and document any observer reading or results of discussions with an observer.
- Measure the gage height of zero flow as many times a year as possible; record to the nearest 0.1 ft. Do this by recording the gage height at the gage at the time the gage height at zero flow is measured. Subtract the gage height from the depth of flow at the point the gage height at zero flow is measured and rate this measurement as good, fair, or poor.
- Fill in all items on the front sheet or mark with a dash after the measurement is completed and computed.

Mechanical Current-Meter Inside Notes

In the inside notes of a mechanical current-meter discharge measurement, identify the measurement starting point by either left edge of water or right edge of water (LEW or REW, respectively), when facing downstream, and record the time you started the measurement. If a significant change in stage is expected during the measurement, periodically record the time for intermediate verticals during the course of the measurement. If possible, synchronize this time with the recording interval of the digital recorder or data logger. Intermediate times are important because if there is any appreciable change in stage during the measurement, these recorded times are used to determine intermediate gage heights, which are then used to compute a weighted mean gage height for the measurement, as described in a subsequent section of this chapter. When the measurement is completed, record the time and the bank of the stream (LEW or REW) where the section ends.

Begin the measurement by recording the distance from the initial point to the edge of the water. Measure and record the depth, and velocity (if any), at the edge of water. Compute the width using the midsection method described in a previous section of this chapter. Proceed across the measurement section by measuring and recording the distance of each vertical from the initial point; the depth at the vertical; the observation depths as 0.6, 0.2, 0.8, and so forth; the revolutions and time for each velocity observation; and the horizontal angle coefficient if different than 1.00.

Complete all computations required for the inside notes to determine the total width, area, and discharge. Transfer these values to the front sheet and complete other items on the measurement front sheet. The measurement computations should be made, and the note sheets completed, before the hydrographer leaves the gaging station.

Erasures of original field data are not allowed. This includes items such as gage readings, distances, depths, meter revolutions, times, horizontal-angle coefficients, and other field measurements that cannot be repeated. If a variable is remeasured, and it is necessary to change the originally recorded value of that variable, cross it out and record the new measurement above or adjacent to the original. The original measurement should remain legible, even though it is crossed out. On the other hand, it is permissible to erase computed values, such as velocities, areas, widths, and discharges.

Standard Paper Note Keeping for an ADV Discharge Measurement

Paper note sheets, as shown in figure 2*B*, are the traditional method to record the field observations for an ADV discharge measurement. If using paper note keeping with an ADV for each measurement, the hydrographer should record the information, at a minimum, as if it were a mechanical velocity-meter discharge measurement, with a few variations. Indicate the filename of the infield diagnostic test performed on the ADV during the discharge measurement. Fill in all items on the front sheet or mark with a dash after the measurement is completed and computed.

ADV Inside Notes

An electronic summation of an ADV discharge measurement is produced by the ADV software. This information contains much of the information on the front sheet of the standard discharge measurement form, plus depths, widths, velocities, angles, area, and discharge. Typically ADV software does all the computations for an ADV discharge measurement. Print this output and attach it to the discharge measurement form for archival. Recent programming with personal digital assistants (PDAs) has further facilitated the collection, processing, and entry of discharge measurements into digital databases. See the sections entitled Electronic counters" and "Other electronic counters, electronic field notebooks, and personal digital assistants" for further discussion of the use of PDAs for field measurements.

Mean Gage Height of Discharge Measurements

The mean gage height of a discharge measurement represents the mean height of the stream during the period the measurement was made and is referenced to the datum of the gaging station. Just as an accurate determination of the discharge is important, so is an accurate determination of the mean gage height because it is one of the coordinates used in plotting the discharge measurement to establish the stage-discharge relation. The computation of the mean gage height presents no problem when the change in stage is small (0.1 ft or less). At gage-height changes of less than 0.1 ft, the mean gage height for the discharge measurement can be obtained by averaging the gage heights at the beginning and end of the measurement, without significant error. Measurements, however, must sometimes be made during floods or regulation when the stage significantly changes more than 0.1 ft.

To compute an accurate mean gage height for a discharge measurement, read the gage at the beginning and end of the discharge measurement, and several times during the measurement if there are significant changes. If the station is equipped with an electronic data logger or DCP that automatically records at intervals of 15 minutes or less, you can take the intermediate gage-height readings from those instruments after the measurement is completed. The hydrographer should accurately synchronize watch time and recorder time, and should record watch time for selected verticals at intervals during the discharge measurement. If the recording interval is greater than 15 minutes (that is, 30 minutes or 1 hour), intermediate gage- height readings should be obtained by reading the gage once or twice during the discharge measurement.

If the change in stage during the measurement is greater than about 0.1 ft (Rantz, 1982, suggests a change of 0.15 ft), the mean gage height should be computed by weighting the gage-height readings. In the past, the mean gage height was computed by weighting the gage readings with partial discharges from the discharge measurement. Later studies show, however, that this method tends to overestimate the mean gage height. Time weighting has also been used to compute a weighted mean gage height, but this method tends to underestimate the mean gage height. Therefore, it is recommended that both methods of weighting be used for discharge measurements having stage changes of 0.10 or more, and that an average of the two results be used for the mean gage height.

Plot the gage-height readings so that intermediate readings can be interpolated where necessary. Pay particular attention to breaks in the slope of the gage-height graph. Figure 25 illustrates a plot of gage heights for a discharge measurement. Gage heights for this measurement were determined from the stage recorder at 15-minute intervals.

In the discharge-weighting procedure, the partial discharges measured between recorded watch times are used with the mean gage height for that same time period. The equation used to compute the weighted mean gage height is:

$$H = \frac{q_1h_1 + q_2h_2 + q_3h_3 + \ldots + q_nh_n}{Q}, \qquad (11)$$

where H = weighted mean gage height, in feet,
Q = total discharge measured, in cubic feet per second = $q_1 + q_2 + q_3 + \ldots + q_n$,
$q_1, q_2, q_3, \ldots q_n$ = amount of discharge measured during time interval 1, 2, 3...n, in cubic feet per second,
$h_1, h_2, h_3, \ldots h_n$ = average gage height during time interval 1, 2, 3...n, in feet.

Figure 25 shows the computation of a discharge-weighted mean gage height. The graph at the bottom is a reproduction of the gage-height graph during the discharge measurement. To help explain the method, the discharges are taken from the current-meter measurement shown in figure 2*A*. The upper computation of the mean gage height in figure 25 shows the computation using the given formula. The lower computation was calculated using a shortcut method to eliminate the multiplication of large numbers. In this method, after the average gage height for each time interval has been computed, a base gage height, which is usually equal to the lowest average gage height, is chosen. Then, the difference between the base gage height and the average gage heights is used to weight the discharges. When the mean difference has been computed, the base gage height is added to it.

In the time-weighting procedure, the arithmetic mean gage height for time intervals between breaks in the slope of the gage-height graph is used with the duration of those time periods. The equation used to compute mean gage height is

$$H = \frac{t_1h_1 + t_2h_2 + t_3h_3 + \ldots + t_nh_n}{T}, \qquad (12)$$

where H = weighted mean gage height, in feet,
T = total time for the measurement, in minutes ($t_1 + t_2 + t_3 + \ldots + t_n$),
$t_1, t_2, t_3, \ldots, t_n$ = duration of time intervals between breaks in the slope of the gage height graph, in minutes, and
$h_1, h_2, h_3, \ldots, h_n$ = average gage height, in feet, during time interval 1, 2, 3, ..., n.

Using the data from figure 25, the computation of the time-weighted mean gage height is as follows:

Average gage height (h) in ft	Time interval (t) in minutes	$h \times t$
1.92	15	28.80
1.70	15	25.50
1.67	15	25.05
1.88	15	28.20
Totals	60	107.55

The mean gage height is computed as $H = 107.55/60 = 1.79$ ft.

In this example, there is little difference between the discharge-weighted mean gage height (1.77 ft) and the time-weighted mean gage height (1.79 ft). The average of the

ANGLE COEFFICIENT	DIST. FROM INITIAL POINT ①	WIDTH ②	DEPTH ③	OBSERVATION DEPTH	REVOLUTIONS ④	TIME IN SECONDS	VELOCITY AT POINT	VELOCITY MEAN IN VERTICAL	ADJUSTED FOR HOR. ANGLE OR	AREA	DISCHARGE
	Time	GHt.	ave. GHt.		Q		③×④				
	1330	1.94	1.92		15.31		29.40				
	1345	1.90	1.70		23.61		40.14				
	1400	1.49	1.67		20.03		33.45				
	1415	1.85	1.88		14.44		27.15				
	1430	1.92									
			Total Q = 73.39				Total = 130.14				
	MGH =		Total ③×④ / Total Q		= 130.14 / 73.39		= 1.77				

	Time	GHt. ②	ave. GHt. ③	ave. GHt. minus base ④	Q	④×⑤
	1330	1.94	1.92	.25	15.31	3.83
	1345	1.90	1.70	.03	23.61	.71
	1400	1.49	1.67	.00	20.03	.00
	1415	1.85	1.88	.21	14.44	3.03
	1430	1.92				
	Base	1.67		Total Q = 73.39		Total = 7.57
	MGH =	Base +	Total ④×⑤ / Total Q	=	1.67 + 7.57 / 73.39	= 1.67 + .1 = 1.77

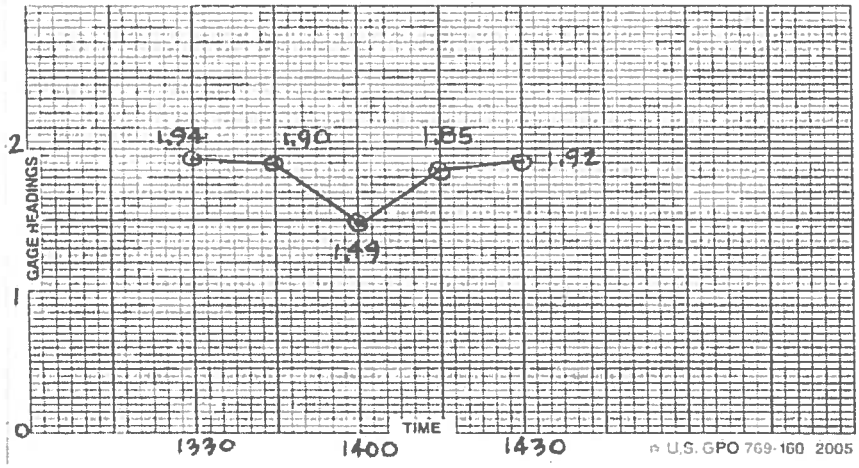


Figure 25. Graph of readings used to compute a weighted mean gage height.

two values, 1.78 ft, is the preferred mean gage height for the discharge measurement.

When extremely rapid changes in stage occur during a measurement, the weighted mean gage height is not truly applicable to the discharge measured. To reduce the range in stage during the measurement, try to reduce the time required for making the discharge measurement; however, keep in mind that shortcuts in the measurement procedure usually reduce the accuracy of the measured discharge. Therefore, measurement procedures during rapidly changing stage must be optimized to produce a minimal combined error in measured discharge and computed mean gage height. The following section of this chapter describes procedures for making discharge measurements during periods of rapidly changing stage.

Discharge Measurements During Rapidly Changing Stage

Discharge measurements during periods of rapidly changing stage are more difficult to obtain, and accuracy is often not as good as for measurements made when the stage is fairly constant. The computation of total discharge and the corresponding stage are both subject to more uncertainty when the stage significantly changes during the period of the measurement. Two procedures are suggested for shortening the time required for a discharge measurement. The first procedure is applicable more for large streams where the stage changes are usually not as great as for small streams. The second procedure is designed more for the flash-flood conditions experienced with small streams, where peaks can be of momentary duration, and where the rising and falling stage is rapid. Keep in mind that the moving-boat ADCP discharge measurement can be used during these conditions. For a more detailed discussion of procedures for using an ADCP moving-boat during rapidly changing stage, see Mueller and Wagoner (2009).

Measurements of Large Streams With Rapidly Changing Stage

During periods of rapidly changing stage in a large stream, make measurements as quickly as possible to keep the change in stage to a minimum. This will minimize discharge errors caused by the shifting of flow patterns and other variables as the stage changes, and will provide a more accurate stage computation for the measurement. To reduce the time required for making a discharge measurement, make fewer than the usual number of observations and shorten the time to make them. This is sometimes referred to as a shortcut method. Following is a list of some of the things that can be done to reduce the time:

1. Use the 0.6-depth method rather than the 0.2 and 0.8 method. If the 0.6 method cannot be used because the flow is too swift, or if debris makes it too hazardous, then use the 0.2-depth method or the subsurface method. If an optical meter is available, use surface-velocity measurements.
2. Reduce the velocity observation time to about 20 to 30 seconds. This is referred to as half-counts.
3. Only measure about 15 to 18 sections. For some conditions, even use less than 15 sections may be used.
4. Observe and record the watch time at about every third vertical. If possible, observe and record the stage once or twice during the measurement.

By incorporating the above practices, a measurement can usually be made in 15 to 20 minutes. The surface or subsurface method for observing velocities is used, then some vertical-velocity curves will be needed later to establish coefficients to convert observed velocity to mean velocity. Compute a weighted mean gage height for the discharge measurement, as described in a previous section of this chapter.

Use the determination of error in discharge measurements, as described by Sauer and Meyer (1992), to illustrate the difference in errors between the standard measurement procedure and the shortcut procedure. The results shown in table 9 are based on a firm and smooth streambed. The additional uncertainty caused by using the shortcut method is generally less than the error that can be expected from the shifting of flow patterns and other variables that may occur during periods of rapidly changing stage.

Measurements of Small Streams With Rapidly Changing Stage

A series of "instantaneous" discharge measurements can be made during flash flood conditions on small streams by rating individual subsections, or verticals. This method requires repeated observations of gage height, depth, and velocity at selected verticals during the rise and fall of the flood wave. Two procedures are described below, with the primary difference being the method of determining depth at each vertical. In the first procedure, the streambed elevation referenced to gage datum is predetermined for each selected vertical. Depth is then determined as the difference between the gage height and the streambed elevation. In the second procedure, depth is measured at the selected verticals by sounding each time velocity is observed. The first procedure is faster; however, it may not be suitable if the streambed is unstable.

The method of computing the discharge measurements is also slightly different for the two procedures. For both procedures, a rating of gage height versus mean velocity is required

Table 9. Comparison of discharge measurement error for standard and shortcut methods.

[No., number; s, seconds; ft/s, feet per second; ft, feet]

Measurement	Meter type	No. of verticals	Points in vertical	Suspension	Observation time, s	Mean velocity, ft/s	Mean depth, ft	Uncertainty percent	Measurement rated
Standard	AA	30	2	cable	50	2.50	10.0	2.3	Excellent/good.
Shortcut	AA	15	1	cable	25	2.50	10.0	5.1	Good/fair.

for each subsection, or vertical. For the second procedure, a rating of gage height versus depth is required for each vertical. The two procedures are described below.

Procedure 1—Depth Is Computed From Predetermined Streambed Elevations at Each Vertical

1. Select about 10 verticals, or subsections. For very small streams, you may use fewer verticals. Mark the selected verticals in some way so that repeated observations can be made at the same vertical each time.
2. Determine the streambed elevation referenced to gage datum for each selected vertical prior to making the series of discharge measurements. After the flood recedes, determine the streambed elevations at each vertical again to see if changes occurred during the flood. If the streambed is not stable, it will be necessary to interpolate the changes based on time and the best judgment of the hydrographer. Depth is determined at each vertical as the difference between this elevation and the gage height.
3. Take velocity observations at each vertical using the 0.6-depth method. Full counts of 40 seconds or more are recommended, but half-counts may be used if the stream is rising or falling extremely fast. If the 0.6 method cannot be used, then take velocity observations at the 0.2 depth or the subsurface depth. If an optical or other approve noncontact flowmeter is available, use it to take surface-velocity readings. For surface- and subsurface-velocity readings, it will be necessary to determine the coefficient required for converting the readings to a mean velocity. Meter positions should be based on the depth, as computed in item 2 above.
4. Make observations of other factors that would affect the computation of discharge, such as horizontal-angle coefficients.
5. Repeat the velocity and other observations at each of the selected verticals several times over the duration of the flood wave.
6. Record the watch time of each vertical measurement, and make corresponding gage- height observations frequently during the period of the flood wave.
7. Develop a rating of gage height versus mean velocity for each of the selected verticals. If surface- or subsurface-velocity observations were made, apply adjustments so that the rating represents mean velocity in the vertical. In some cases, it may be necessary to develop more than one rating for each vertical. For instance, a rating for the rising side of the flood wave, and a separate rating for the falling side of the flood wave, may be necessary.
8. Select a gage height for which a discharge measurement is to be computed. Use a standard discharge measurement note sheet for computing the discharge measurement. Enter the stationing for the edge of water and for each of the selected verticals. Enter the depths at each vertical, computed on the basis of the selected gage height minus the streambed elevation. Enter the mean velocity at each vertical on the basis of the gage height versus mean velocity ratings. Enter other adjustments, such as horizontal-angle coefficients, as observed during the observation of velocities. Compute the discharge measurement similar to a regular discharge measurement.
9. Repeat the process described in item 8 above for other selected gage heights. If the ratings of gage height versus mean velocity change, such as for rising and falling stage, then compute separate discharge measurements for the rising and falling limbs of the flood wave.

Procedure 2—Depth Is Measured by Sounding at Each Vertical

1. Select about 10 verticals, or subsections, as described in the first procedure above. For very small streams, fewer verticals may be used. Mark the selected verticals in some way so that repeated observations can be made at the same vertical each time.
2. Determine the depth for each selected vertical by sounding the streambed each time you measure a vertical. Use this method when it is possible to easily make soundings, and when there is a likelihood of streambed elevation changes caused by scour or fill during the course of the measurement.
3. Take velocity observations at each vertical using the 0.6-depth method. Full counts of 40 seconds or more are recommended, but half-counts may be used if the stream is rising or falling extremely fast. It is not likely that you will need to make surface or subsurface observations because depth soundings are possible with this procedure. Meter positions should be based on the sounded depth.
4. Make observations of other factors that would affect the computation of discharge, such as horizontal-angle coefficients.
5. Repeat the observations of depth, velocity, and other variables at each of the selected verticals several times over the duration of the flood wave.
6. Record the watch time of each vertical measurement, and make frequent, corresponding gage-height observations during the period of the flood wave.
7. Develop a rating of gage height versus mean velocity for each of the selected verticals. As described in the first procedure, it may be necessary to develop more than one rating, such as for the rising and falling sides of the flood wave.
8. Develop a rating of gage height versus depth for each of the selected verticals. If streambed changes occur during the measurements, it will be necessary to take these into account by making appropriate corrections.

9. Select a gage height for which a discharge measurement is to be computed. Using a standard discharge-measurement note sheet, enter the stationing for the edge of water and for each of the selected verticals. Enter the depths at each vertical, based on the selected gage height and the ratings of gage height versus depth. Enter the mean velocity at each vertical on the basis of the gage height versus mean velocity ratings. Enter other adjustments, such as horizontal-angle coefficients, as observed during the observation of depths and velocities. Compute the discharge measurement similar to a regular discharge measurement.
10. Repeat the process described in item 9 above for other selected gage heights. If the depth and (or) mean velocity ratings change, such as for rising and falling stage, or for streambed scour or fill, then compute separate discharge measurements for conditions before and after the changes.

Correction of Discharge for Storage During Measurement

Most discharge measurements are made at or near the gaging station and the gage control. However, at some gages, it may be necessary to make discharge measurements at a substantial distance away from the gage and (or) control. For instance, during a flood, the only place to measure may be at a bridge located some distance from the gage. Or for some sites, the low-water section control may be located at a substantial distance downstream from the gage. If a discharge measurement is made at a substantial distance from the gage control during a change in stage, the discharge passing the control during the measurement will not be the same as the discharge at the measurement section. In these situations, an adjustment must be applied to the measured discharge to account for the change in channel storage that occurs between the measurement section and the control during the period of the measurement. The adjustment for channel storage is computed by multiplying the channel surface area by the average rate of change in stage in the reach between the measurement section and the control. The equation is

$$Q_G = Q_m \pm WL\frac{\Delta h}{\Delta t}, \qquad (13)$$

where Q_G discharge going over the control, in cubic feet per second,
Q_m measured discharge, in cubic feet per second,
W average width of stream between measuring section and control, in feet,
L length of reach between measuring section and control, in feet,
Δh average change in stage in the reach L during the measurement, in feet, and
Δt elapsed time during measurement, in seconds.

Determine the change in stage at each end of the reach (that is, at the control and at the measuring section) and use an average of these two values. Generally, the gage height at the gage is used at one end of the reach, and a reference point (RP) or a temporary gage is set at the other end of the reach. The water-surface elevation at each end of the reach is determined before and after the measurement to compute Δh. If the measurement is made upstream from the control, the adjustment will be plus for falling stages and minus for rising stages; if it is made downstream from the control, it will be minus for falling stages and plus for rising stages.

An example computation for a flood measurement that was made 0.6 mile upstream from the gage (and control) during a period of changing stage is shown below:

- Measurement made 0.6 mile upstream, L = 3,170 feet.
  Average width between measuring section and control, W = 150 ft.
- Gage height at beginning of measurement, at the gage (and control) = 5.84 ft.
  Gage height at end of measurement, at the gage (and control) = 6.74 ft.
  Change in stage at gage (and control), 6.74 – 5.84 = +0.90 ft.
- Gage height at beginning of measurement, at measuring section, = 12.72 ft.
  Gage height at end of measurement, at measuring section = 13.74 ft.
  Change in stage at measuring section, 13.74 – 12.72 = +1.02 ft.

Readings taken at measuring section from a reference point before and after measurement.

- Average change in stage in the reach, Dh = (0.90+1.02)/2 = 0.96 ft.
  Elapsed time during measurement, Dt = 1.25 hours = 4,500 seconds.
  Measured discharge, Q_m = 8,494 ft^3/s.

$$Q_G = 8{,}494 - \left(150 \times 3{,}170 \times \frac{0.96}{4{,}500}\right) = 8{,}494 - 101 = 8{,}393\ \frac{ft^3}{s}, \qquad (14)$$

This discharge should then be rounded to 8,390 ft^3/s, which represents the discharge at the gage, or control.

The adjustment of the measured discharge for storage between the gage (or control) and measuring site, as described above, is a separate and distinct problem from that of making adjustments owing to variable water-surface slopes caused by changing discharge. Those adjustments are related to stage-discharge rating analysis, and are described by Kennedy (1984), and by Rantz (1982). The storage adjustment they described should be made immediately following the completion of the discharge measurement, and the resulting adjusted discharge is later used for rating analysis.

Instruments and Equipment

Point-velocity current-meter and profiler measurements are usually classified in terms of the method used to cross the stream during the measurement (that is, wading, bridge, cableway, or ice), the method used to compute the discharge, such as midsection, ADCP, flume, or volumetric, and the method used to compute the velocity (if applicable to the discharge method), such as Price AA meter, ADCP, or ADV. Instruments and equipment used in making current-meter measurements will vary, depending upon which of these measurement types are being used. Current meters, timers, and electronic and other counting equipment are generally common to all types of current-meter and profiler measurements. This section describes equipment currently used by USGS field offices.

Current Meters

A point-velocity current meter, in the context of this report, is a precision instrument calibrated to measure the velocity of flowing water in a single point or fixed volume. Several types of current meters are available for use, including rotating-element mechanical meters, electromagnetic meters, acoustic Doppler velocimeters (ADVs or FlowTrackers), acoustic digital current meters (ADCs), and optical meters.

The principle of operation for a mechanical meter is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a mechanical 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 can be determined from the meter rating.

An electromagnetic current meter is based on the principle that a conductor (water) moving through a magnetic field will produce an electrical current. By measuring this current and the resultant distortion in the magnetic field, the instrument can be calibrated to determine point velocities of flowing water.

The acoustic meter or profiler (for example, ADV or ADCP) uses the Doppler principle to determine velocities of flowing water. Acoustic meters and profilers have been developed to measure point velocities in the vertical profile of an open-channel flow, as well as multicell vertical-velocity profiles. The ADCP has been adapted for use with the moving-boat method of measuring discharge, as described by Mueller and Wagner (2009). The ADV has been developed and adapted to mount on the standard USGS wading rod to measure point velocities in a manner similar to the method for measuring velocity with a vertical-axis rotating-element mechanical meter. ADVs will be described in a later section of this chapter.

The following sections describe the various types of current meters and profilers in more detail, give advantages and disadvantages of each, and provide guidance on care and maintenance.

Current Meters—Mechanical and Vertical Axis

Historically, the most commonly used meter by the USGS to measure open-channel velocities in rivers and streams has been the vertical-axis, mechanical current meter. The original prototype for this kind of current meter was designed and built in 1882 by W.G. Price, while he was working with the Mississippi River Commission. The Price current meter has evolved through a number of different models and refinements since 1882, but the basic theory and concepts remain the same. The Price AA meter is the most commonly used mechanical current meter for discharge measurements made by the USGS; however there are other variations of this meter, such as the Price AA slow velocity, the Price pygmy, and the Price AA winter meter. The following sections describe the various Price meters in more detail, and table 10 summarizes the various configurations and recommendations for the Price current meter, Price AA low velocity, the Price pygmy, the Price AA winter yoke with polymer and metal cups, and the SonTek FlowTracker ADV.

Price AA Meter

Historically, most current-meter measurements made by the USGS have been made with the vertical-axis Price AA and the Price pygmy current meters, as shown in figures 26 and 27. The basic components of the Price AA meter include the shaft and rotor (bucket wheel) assembly, the contact chamber, the yoke, and the tailpiece. The rotor, or bucket wheel, is 5 in. in diameter and 2 in. high with six cone-shaped cups mounted on a stainless-steel shaft. A vertical pivot supports the vertical shaft of the rotor, hence the name vertical-axis current meter. The contact chamber houses the upper part of the shaft and provides a method of counting the number of revolutions the rotor makes. A reduction gear (commonly referred to as the penta gear) on the lower part of the shaft allows counting every fifth revolution of the rotor when it is activated. The penta gear is used in discharge measurements with very high velocities. Contact chambers that can be used on the Price AA meter are described in a later section of this chapter. The yoke is the framework that holds the other components of the meter. A tailpiece is used for balance and keeps the meter pointing into the current.

When placed in flowing water, the rotors of the Price current meters turn at a speed proportional to the speed of the water. For practical purposes, these current meters are considered nondirectional because they register the maximum velocity of the water, even though they may be placed at an angle to the direction of flow. Advantages of the vertical-axis current meter are:

1. They operate in lower velocities than do horizontal-axis meters.
2. Bearings are well protected from silt-laden water.
3. The rotor is easily repairable in the field without adversely affecting the rating.
4. USGS standard ratings apply to the Price AA and Price pygmy meters.
5. A single rotor serves for the entire range of velocities.

Table 10. Price current meter and SonTek ADV configurations, usages, and recommended ranges of depth (without boundary interference) and velocity.

Meter	Contact chamber	Counting method	Rating	Velocity range, feet per second[1]	Depth range, feet	Remarks
Price AA	Standard, cat'swhisker and penta gear	Headphones, CMD[2], or EFN[3]	Standard	0.2 to 12	1.25 or greater	The Price AA meter can be used as a low-velocity meter if equipped with an optic contact chamber.
			Individual	0.1 to 12		
	Magnetic	CMD[2] or EFN[3]	Standard	0.2 to 12		
			Individual	0.1 to 12		
	Optic		Standard or individual	0.1 to 12		
Price AA, low velocity	Cat's-whisker with double contact lobe on shaft. No penta gear.	Headphones, CMD[2], or EFN[3]	Individual	0.1 to 12	1.25 or greater	This is the traditional Price AA low velocity meter. An individual rating is recommended; however, a standard rating can be used if less accuracy is acceptable.
Price pygmy	Cat's whisker	Headphones, CMD[2], or EFN[3]	Standard or individual	0.2 to 4.0	0.3 to 1.5	--
Price, winter WSC[4] yoke, polymer cups	Cat's whisker	Headphones, CMD[2], or EFN[3]	Individual, with suspension device	0.1 to 12	1.25 or greater	This meter is recommended for conditions where slush ice is present.
	Magnetic or Optic	CMD[2] or EFN[3]				
Price, winter WSC[4] yoke, metal cups	Cat's whisker	Headphones, CMD[2], or EFN[3]	Individual, with suspension device	0.1 to 12	1.25 or greater	This meter is recommended for conditions where slush ice is not present.
	Magnetic or Optic	CMD[2] or EFN[3]				
SonTek FlowTracker ADV	N/A	N/A	Individual	0.003 to 13[5]	0.25 or greater	The FlowTracker has been documented by the USGS to provide velocities comparable to mechanical vertical axis current meters.

[1]Low- and high-velocity limits shown in the table are based on a small-to-moderate extrapolation of the lower and upper meter calibration limits. It is not recommended that the meters be used for velocities less than the lower limit. The velocity rating for the Price meter may allow additional extrapolation in the upper range to about 20 feet per second. The upper range of the Price pygmy meter rating may be extrapolated to about 5 feet per second. Standard errors within the meter calibration limits are less than ±5% in all cases. Standard errors in the extrapolated range of velocities are unknown, but are probably within ± 5%.

[2]Current-meter digitizer. Observe cautions for low velocities: See text.

[3]Electronic field notebook, such as Aquacalc or DMX. Observe cautions for low velocities. See text.

[4]Water Survey of Canada.

[5]Manufacturer's specification.

Price AA Meter (Slow Velocity)

In addition to the Price AA meter described above, there is a Price AA meter modified slightly for use in measuring low velocities. To reduce friction, the penta gear has been removed from this meter, and the shaft has two eccentrics making two contacts with the cat's whisker per revolution. The low-velocity meter normally is rated from 0.2 to 2.5 ft/s and is recommended when the mean velocity at a cross section is less than 1 ft/s.

Price Pygmy Meter

A miniature version of the Price AA meter is the Price pygmy meter, as shown in figures 26 and 27, which is used for measuring velocities in shallow depths. The Price pygmy meter is scaled two-fifths the size of the standard meter and has neither a tailpiece nor a penta gear. The contact chamber is an integral part of the yoke of the meter. The Price pygmy meter makes one contact for each revolution and is used only for rod suspension.

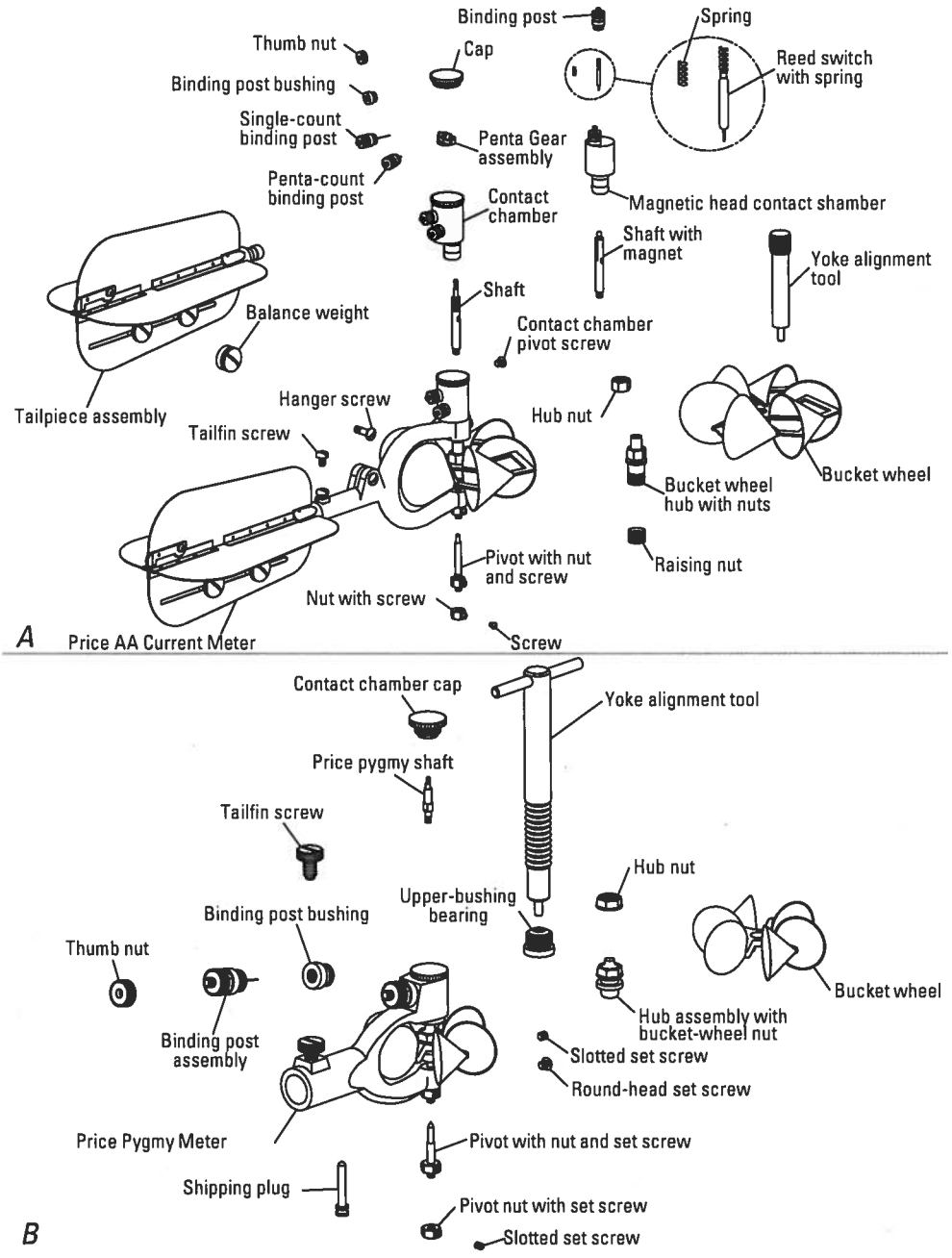


Figure 26. Assembly drawing of the *A*, Price AA current meter and *B*, Price pygmy current meter.

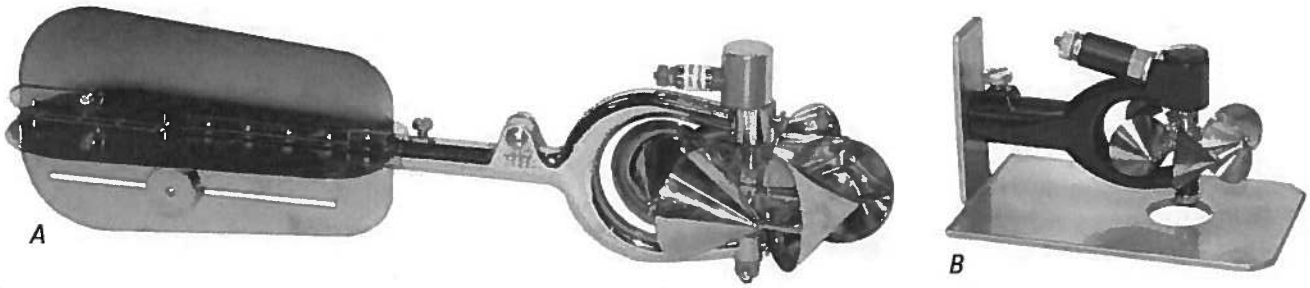


Figure 27. *A*, Price AA and *B*, Price pygmy current meters.

Price AA Winter Meter

In streams where slush ice is present, use a modified Price AA meter, as shown in figure 28. This meter is built with a WSCan winter-style yoke, and uses a polymer rotor (bucket wheel) in place of the standard metal-cup rotor. The WSCan winter-style yoke meters require an individual rating due to increased tolerances in manufacturing. The solid polymer rotor has the advantage that it does not fill with slush ice during a measurement, and the slush ice does not easily adhere to it. If slush ice is not present, alternative methods can be used, including replacing the polymer rotors with metal cups or using a pygmy meter. Regular Price AA meters with metal-cup rotors are also acceptable for slush-free conditions, if there are no problems with cutting the required larger holes through the ice. In recent years, the USGS has increasingly used ADCPs and ADVs as alternatives to the Price AA for making discharge measurements in streams where ice is present.

Figure 28. Price AA meter with winter-style yoke and polymer rotor.

Current Meters—Mechanical and Horizontal Axis

A number of mechanical current meters are available that have a propeller-, or vane-, type of rotor mounted on a horizontal shaft. These meters are used extensively in Europe and some Asian countries, but very little in the United States, and are generally not recommended by the USGS because they are not as durable as the Price current meter. Horizontal-axis current meters include the Ott (Germany), Neyrpic (France), Haskell (U.S.), Hoff (U.S.), Braystoke (United Kingdom), and Valeport. Various models of each of these are also available. As a group, horizontal-axis current meters have the following advantages:

1. The rotor, or propeller, disturbs flow less than vertical-axis rotors because of axial symmetry with flow direction.
2. The rotor is less likely to be entangled by debris than vertical-axis rotors.
3. Bearing friction is less than for vertical-axis rotors because bending moments on the rotor are eliminated.
4. In oblique currents, some of these meters (for example, the Ott meter) measure the velocity normal to the measuring section when the meter is held normal to the measuring section.
5. Rotors with propellers of different pitches are available for some of the meters, allowing measurement of a considerable range of velocity.

See figures 29, 30, and 31, respectively, for examples of the Ott, Hoff, and Valeport current meters.

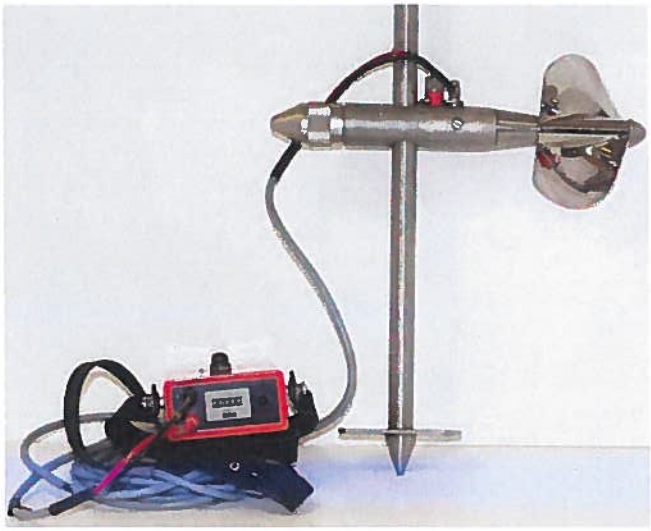


Figure 29. Ott current meter.

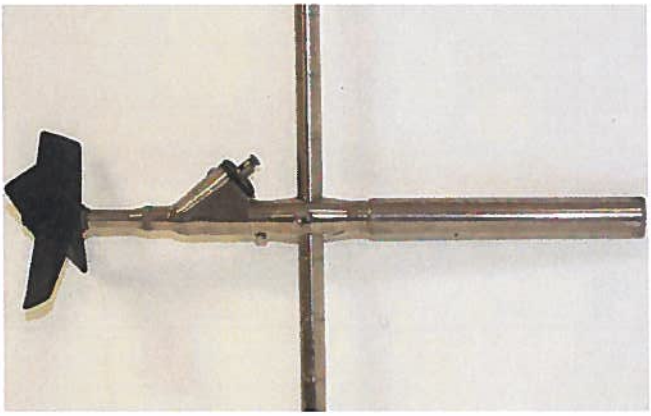


Figure 30. Hoff current meter.

Figure 31. Valeport current meter.

Current-Meter Contact Heads (Vertical Axis)

The Price current meter is normally fitted with a contact chamber that has a cat's-whisker type of circuitry used for counting the number of revolutions of the rotor. Two other types of contact chambers—the magnetic switch type and the optical type—can be fitted to the Price AA meter.

Cat's Whisker

When placed in flowing water, the rotor of the current meter turns at a speed proportional to the speed of the water. The number of revolutions of the rotor is obtained by counting electrical impulses generated in the contact chamber. An eccentric contact on the upper end of the rotor shaft wipes a slender alloy wire (cat's whisker) attached to the binding post, which closes an electrical circuit. This electrical impulse produces an audible click in a headphone or registers a unit on a counting device. Contact points in the chamber are designed to complete the electrical circuit at selected frequencies of revolution, such as twice per revolution, once per revolution, or once per five revolutions (by use of the penta gear). The penta gear, wire, and binding post provide a contact each time the rotor makes five revolutions. Figure 32 shows the contact chamber and shaft for the cat's-whisker-type chamber, with a single-count binding post.

Two types of cat's-whisker wires have been used: one is the simple bronze wire, and the other is the old type of wire with a small solder bead on the end of it. Adjust the cat's whisker for the penta gear so that it always touches the penta eccentric, even when the penta counter is not in use. Otherwise, the meter rating may be affected.

Magnetic Switch

A contact chamber housing a magnetic-type switch, as shown in figure 32, is available to replace the cat's-whisker-contact chamber. The magnetic switch is composed of glass that is 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. Two types of magnets used: (1) a bar magnet and (2) a circular magnet. If the contact chamber uses the bar magnet, it should be identified with an "A" stamped on the top surface of the chamber to indicate it has been modified. Older, unmodified contact chambers with the bar magnet were found to under-register for velocities greater than about 2 ft/s. The chambers that utilize the circular magnets fit the standard rating throughout its range.

The magnetic switch quickly closes when the magnet is aligned with it, and then promptly opens when the magnet moves away. The magnet is properly balanced on the shaft. Any type of AA meter can have a magnetic switch added by replacing the shaft and the contact chamber. The magnetic switch is placed in the contact chamber through the tapped hole for the binding post. The rating of the meter is not altered by the change.

An automatic counter, as described in a later section of this chapter, is used with the magnetic-switch contact chamber. Do not use a headphone with the magnetic head because arcing can weld the contacts.

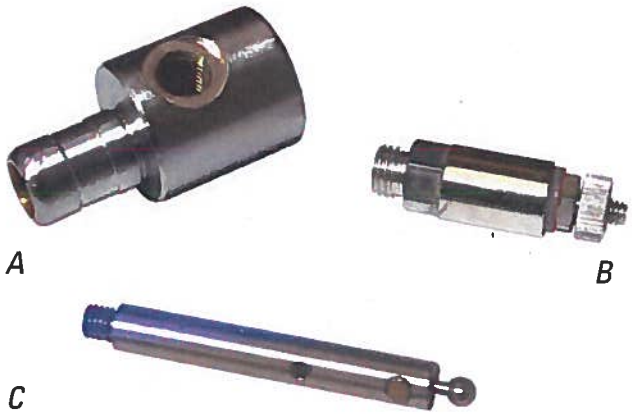


Figure 32. *A*, Price AA magnetic head current meter contact chamber; *B*, single count binding post; and *C*, shaft with magnet for magnetic heads.

Optical Head

A contact head utilizing fiber-optics technology is available for reading the pulse rate of the Price AA current meter. A special rotor containing two fiber-optic bundles is attached to the upper end of the bucket-wheel shaft. The rotation of these fiber-optic bundles gates infrared light from a photo diode to a photo transistor, creating a pulse rate that is proportional to the rotor's revolutions. The pulses are counted, stored, and then compared with a quartz crystal oscillator. This information is processed to display stream velocity on a liquid crystal readout. The display has three averaging periods selected by a rotary switch. The averaging periods range from a minimum of about 5 seconds to a maximum of about 90 seconds. The unit is powered by a 9-volt battery.

Output of pulses from the optical sensing unit can be counted by the current-meter digitizer and the electronic field notebooks described in subsequent sections of this chapter. A standard rating table based on tow-tank calibration tests at the USGS Hydrologic Instrumentation Facility (HIF) is used to convert pulse rate to stream velocity.

A special tail-fin assembly is required for the optical meter so it will balance properly when submerged. The vertical section of this tail fin is marked with the letters OAA, and the horizontal section is marked PAA.

Vertical-Axis Current-Meter Timers and Counters

The determination of velocity using a mechanical current meter requires that the number of revolutions of the rotor be counted during a specified time interval, usually 40 to 70 seconds. Several methods are available for timing and counting the revolutions, as described in the following paragraphs.

Stopwatch and Headset

For current meters having a cat's-whisker-type contact chamber, an electrical circuit is closed each time the contact wire touches the single or penta eccentric of the current meter. A battery and headphone, as shown in figure 33, are parts of the electrical circuit, and an audible click can be heard in the headphone at each electrical closure. Some hydrographers have adapted compact, comfortable hearing-aid-type phones to replace headphones. Beepers that can be heard without the headset are also sometimes used. Do not use a headset, or similar device, with the magnetic contact chamber because arcing can weld the contacts.

Measure the time interval to the nearest second with a stopwatch. Figure 33 shows the standard analog stopwatch; however, a digital wrist watch can also be used.

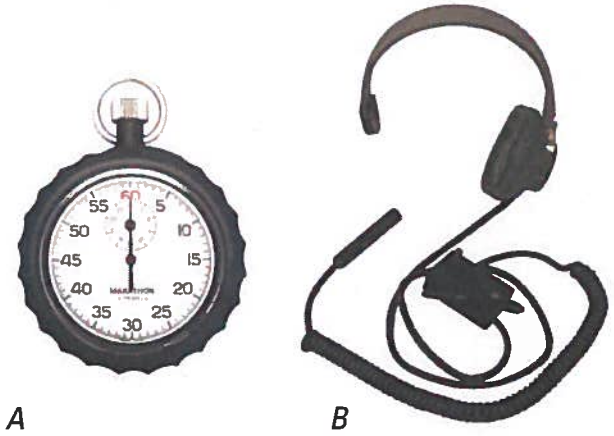


Figure 33. *A*, Analog stopwatch and *B*, current-meter headset.

Electronic Counters

Current-Meter Digitizer (CMD)

A current-meter digitizer (CMD), or automatic electronic counter, as shown in figure 34, was developed for use with the cat's-whisker-, optic-, and magnetic-contact chambers. It can be used with any of the mechanical, vertical-axis current meters, but be careful to avoid false counts when using it for low velocities when the cat's-whisker-contact chamber is used. The CMD automatically counts and displays the number of revolutions of the current-meter rotor and the elapsed time. A buzzer produces an audible signal at each contact closure, and the total counts and elapsed time are shown in the display at the completion of the velocity measurement. A coded chip can be installed in the CMD that will compute and display the velocity from the standard rating table for the particular meter being used. The CMD is powered with five rechargeable batteries, and has an adapter that can be used to attach it to the top of a wading rod.

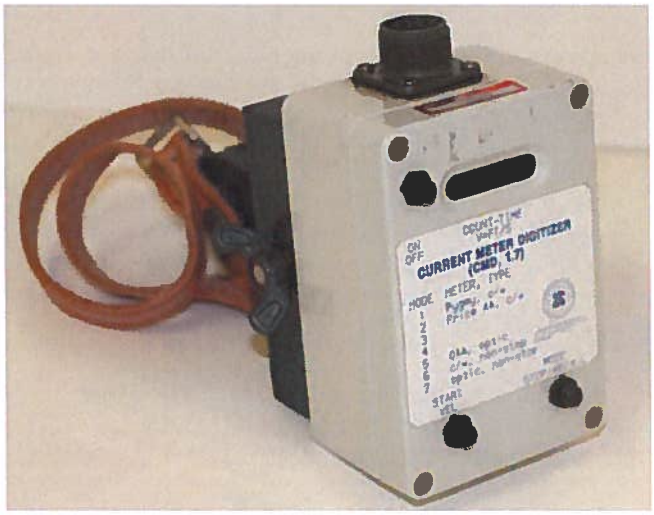


Figure 34. Current-meter digitizer.

Other Electronic Counters, Electronic Field Notebooks, and Personal Digital Assistants

Electronic counters and timers for mechanical current meters are also available in some commercially available devices. Electronic field notebooks (EFNs), such as the JBS Instruments Aquacalc Pro Discharge Measurement Computer, are designed for electronic recording of discharge-measurement data. These will be described in more detail in a later section of this chapter. Both the Aquacalc and the Hydrological Services Current Meter Counter signal processor (CMCsp) contain built-in digitizers that count and time the current-meter rotor revolutions. Built-in ratings convert the revolutions and elapsed time to velocity. Just as with the CMD described above, the EFNs should be used with caution to avoid false counts when measuring low velocities with meters equipped with a cat's-whisker-contact chamber.

The USGS is increasing development and use of personal digital assistants (PDAs) for primary data collection and processing of discharge measurements and surface-water field data. Software programs such as the Surface WAter Measurement and Inspection application (SWAMI) continue to streamline field activities by reducing the need for paper forms in the field through the development of electronic field forms written for the PDA. SWAMI, as described in previous sections of this chapter, is used in many USGS Water Science Centers, and other PDA applications and programs are continually being developed.

Care of the Vertical-Axis Mechanical Current Meter

There are a number of documents describing the care and maintenance of the vertical-axis current meters. Among these, the most important originated from the USGS and are by Smoot and Novak (1968) and by Rantz (1982), and Office of Surface Water Technical Memorandum No. 89.07 (1989) and Office of Surface Water Technical Memorandum No. 99.06 (1999). These instructions represent a long history of experience based on field use of the meters, as well as from individuals in the Office of Surface Water Hydraulic Laboratory who have repaired and adjusted current meters to calibrate them within close tolerances. A brief description of the recommended procedure for checking the condition of a current meter, and for its care and cleaning during daily field use, is presented in the next few paragraphs. For complete details, consult the above-mentioned documents.

Recommended Procedure Before, During, and After Each Discharge Measurement

1. Before each discharge measurement, make a visual examination of the meter cups or vanes, pivot, bearing, and shaft for damage, wear, or faulty alignment. Inspect the bearing surface for water. This will usually appear as a milky emulsification of oil and water on the lower bearing and pivot, and in the contact chamber. If water is found, dry the meter parts and re-oil because the presence of water will affect the performance of the meter. The lower bearing is probably the most susceptible to the entrance of water.
2. Spin the rotor to make certain it operates freely, and allow it to slowly return to a resting position. If the rotor does not turn smoothly, or if it stops abruptly, then it is a sign of some problem and it should be corrected before using the meter. Check the balance and alignment of the meter on the hanger or wading rod. Be sure that the conductor wire does not interfere with meter balance and rotor spin.
3. During measurements, check the meter periodically when it is out of the water to be sure that the rotor spins freely, and that there is no debris or other substance obstructing it.
4. After a measurement is completed, make another visual inspection as described above to ensure that nothing was damaged or caused the meter to malfunction during the measurement. If there is a problem, you may have to make another discharge measurement.
5. Timed spin tests (described later in this chapter) are not required for each discharge measurement. The visual inspection described above is preferred over timed spin tests made in the field.

Recommended Procedure After a Day of Use in the Field

1. Examine the pivot and bearing surfaces for wear and damage, especially the pivot point. The pivot should feel sharp, not rounded or dull. It should not have a burr detectable visually or with the fingernail. A magnifying glass is helpful in making this examination. If the pivot is dull or burred, replace it with a new one.
2. Clean and lightly oil the pivot, bearing, and upper shaft with current-meter oil. Do not use regular machine oil, such as "3-in-1," because it tends to become gummy when exposed to water.
3. Check and carefully adjust cat's-whisker contacts, if necessary. Cat's whiskers should be made of simple bronze wire, not beaded wire.
4. After replacing the contact-chamber cap, spin the meter to see if it is operating correctly, as previously described. A timed spin test is not required.

Recommended Procedure After Each Field Trip

After each field trip, completely disassemble, inspect, and clean current meters. Make any necessary repairs. Detailed instructions for the disassembly, inspection, and adjustment of Price AA (both standard and magnetic head) and pygmy current meters are contained in the attachments to Office of Surface Water Technical Memorandum No. 99.06 (1999). A timed spin test may also be performed after each field trip, and after meter repairs.

Inactive Current Meters

Disassemble, inspect, and clean current meters as described above, prior to storing them. If the period of storage is less than 1 year, the meter may be used without further maintenance if an inspection and a spin test indicate it is operating properly. If the meter has been in storage longer than 1 year, or an indeterminate period, complete inspection, cleaning, and adjustment before using the meter.

Spin Tests

A timed spin test, made in the field before and after each discharge measurement, is no longer a requirement as it was in the past. The visual tests as described above are adequate for checking the meter in the field. Note "OK" or "free" in the spaces on the front sheet of the discharge measurement for spin test information to indicate that the visual check of the meter was acceptable.

Perform the full-timed spin test under controlled conditions between field trips, when the meter is suspect, and before and after repairs. Place the meter on a stable, level surface to perform the spin test. There should be no wind currents or drafts that can affect the rotor spin. Sharply spin the rotor while starting a stopwatch. Stop the stopwatch when the rotor comes to a complete stop. The minimum, acceptable spin times are as follows:

All types of Price pygmy meters	0:45 seconds
All types of Price AA meters	2:00 minutes

These are considered to be absolute minimum spin times. Meters in good condition will perform substantially better.

Recordkeeping

Maintain a current-meter log to record the results of the timed spin tests for each current meter. In addition, the log should contain information that identifies the meter and rotor, a history of repairs to the meter, as well as the name of the person who checked the meter, and dates of occurrences. Figure 35 shows a recommended format for the current meter log. The current-meter log should become a permanent record and archived with other water-resources data.

CURRENT METER LOG				
Meter Type: AA Pygmy Other_____ (Circle one)		Meter No.________________		Rotor No.________________
Date	Meter User	Entry made by	Spin Time	Description of repairs, notation of disassembly, inspections, and remarks
			:	
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Figure 35. Example of a current-meter log (suggested format).

Rating of Mechanical Current Meters

In order to determine the velocity of the water from the revolutions of the rotor of a mechanical current meter, a relation must be established between the angular velocity of the rotor and the velocity of the water turning it. This relation is referred to as the current-meter rating, and is expressed in an equation or in tabular format.

The current-meter rating facility is operated by the USGS, and is located at the Hydraulics Laboratory of the HIF at Stennis Space Center, Miss. The rating facility consists of a sheltered, reinforced concrete basin 400 ft long, 6 ft wide, and 6 ft deep, commonly called the tow tank. An electrically driven car rides on rails alongside and extending the length of the water-filled basin, and carries the current meter at a constant rate through the still water. Although the rate of travel can be accurately adjusted by means of a hydraulic regulating gear, the average velocity of the moving car is determined for each run by making an independent measurement of the distance it travels during the time that the revolutions of the rotor are electrically counted. A scale graduated in feet and tenths of a foot is used for this purpose. Eight pairs of runs are usually made for each current meter. A pair of runs consists of two traverses of the basin, one in each direction, at approximately the same speed. Practical considerations usually limit the ratings to velocities ranging from 0.1 ft/s to about 15 ft/s, although the rating car can be operated at lower speeds. Unless a special request is made for a more extensive rating, the lowest velocity used in the rating is about 0.2 ft/s, and the highest is about 8.0 ft/s.

Because there is rigid control in the manufacture of the Price meter, virtually identical meters are produced and, for practical purposes, their rating equations are identical. Therefore, there is no need to calibrate the meters individually, which is a major advantage and time saver. Instead, a standard rating is established by calibrating a group of meters that have been constructed according to USGS specifications. This standard rating is essentially an average rating for the calibration group, and it is then supplied with all meters manufactured according to USGS specifications. Identicalness of meters is ensured by supplying the dies and fixtures for the construction of Price current meters to the manufacturer who makes the successful bid. Another advantage of the standard rating is that field repairs can be made to a meter without requiring that it be recalibrated. On the other hand, there are somewhat larger errors associated with the standard ratings, as opposed to the individual meter ratings. For additional details see Office of Surface Water Technical Memoranda Nos. 91.01 (1991) and 99.05 (1999).

Standard current-meter ratings are not mandatory for use with the Price meters. For some applications, it may be appropriate to use individually rated meters to avoid the additional uncertainty of the standard ratings. All winter-style meters must be individually rated with the suspension device that will be used with it.

Standard current-meter ratings, as of 1999, have been defined for the Price AA with the cat's-whisker- and magnetic-contact chambers, and the Price pygmy with the cat's-whisker-contact chamber. The standard rating for the Price AA with the fiber-optic-contact chamber was defined in 1991. These ratings are as follows:

- Price AA with cat's-whisker- and magnetic-contact chambers (Standard rating No. 2)

$$V = 2.2048R + 0.0178 \quad (15)$$

- Price pygmy with cat's-whisker-contact chamber (Standard rating No. 2)

$$V = 0.9604R + 0.0312 \quad (16)$$

- Price AA with fiber-optic-contact chamber

$$V = 2.194R + 0.014 \ (R<0.856) \quad (17)$$

$$V = 2.162R + 0.041 \ (R>0.856) \quad (18)$$

where V velocity, in feet per second (ft/s), and
R the number of rotor revolutions per second.

For convenience in field use, the data from the current-meter ratings are reproduced in tables, samples of which are shown in figures 36 and 37. In figure 36, the velocities corresponding to a range of 3 to 200 revolutions of the rotor within a period of 40 to 70 seconds are listed in the tables.

In figure 37, the velocities corresponding to a range of 3 to 350 revolutions of the rotor within a period of 40 to 70 seconds are listed in the tables. This range in revolution and time has been found to cover general field requirements. To provide the necessary information for extending a table for the few instances where extensions are required, the equation of the rating table is shown in the heading.

Meters that have been rated by means of rod suspension, and then by means of cable suspension using Columbus-type weights and hangers, have not shown significant differences in their ratings. Therefore, no suspension coefficients are needed if weights and hangers are properly used.

The preceding discussion relates primarily to the Price current meters. Other types of meters, such as the horizontal-axis meters and the electromagnetic meters, can also be calibrated in the tow tank in a similar manner as the Price meters. The HIF designed and constructed a special tow tank for testing and calibrating the acoustic Doppler point-velocity FlowTracker velocimeter. In the near future, there are HIF plans to build and operate a tow tank designed to test and calibrate ADCPs.

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

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

Figure 36. Example of a standard current-meter rating table No. 2 for Price pygmy current meters with cat's-whisker contact chamber.

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

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

Figure 37. Example of a standard current-meter rating table No. 2 for Price AA current meters with cat's-whisker and magnetic contact chambers.

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

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

Electromagnetic Current Meters

Electromagnetic current meters, with no moving parts, are commercially available for measuring point velocities. These meters are based on the principle that a conductor (in this case, water) moving through a magnetic field will produce an electric current. The velocity of the moving water can be related to the electric current produced, and the distortion created in the magnetic field. The electromagnetic meters can be accurately calibrated in a tow tank, similar to the calibration of mechanical meters; however, tests have shown that the electromagnetic meters are less accurate than the Price AA meters, especially at low velocities (less than about 0.5 ft/s). The Price AA meters also have less variance than the electromagnetic meters at all velocities. Advantages of the electromagnetic current meter are as follows: no moving parts; direct readout of velocity; and, in oblique flow, the velocity measured is normal to the measuring section when the meter is held normal to it.

Marsh-McBirney 2000

An electromagnetic current meter successfully used by the USGS for making discharge measurements is the Model 2000, produced by Marsh-McBirney. This meter, as shown in figure 38, is designed to mount on a standard round or top-setting wading rod. The meter is not designed for cable suspension.

A display meter, also shown in figure 38, shows a direct readout of the velocity. No conversion equation or table is necessary. The meter must be kept clean for accurate readings, and it is recommended that the rating be occasionally spot checked to verify that it is still accurate. This can be done in two ways. First, submerge the meter in a bucket of still water to verify the zero point of the rating. Second, place the meter in close proximity to a Price AA meter, in flowing water, to verify that it gives the same velocity reading. If there are differences, rate the electromagnetic meter again in the tow tank.

Figure 38. Marsh-McBirney Model 2000 electromagnetic flowmeter and display meter.

Ott Electromagnetic Current Meter

An Ott electromagnetic current meter is available; however, it has not been used extensively in the United States. The Ott meter, shown in figure 39, works in a manner similar to the Marsh-McBirney meter.

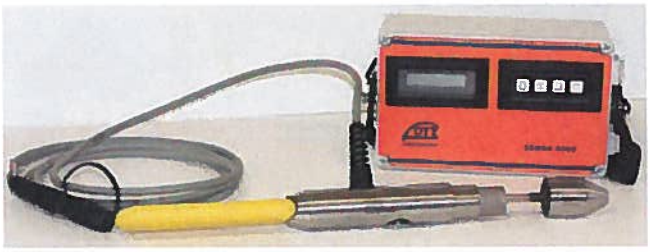


Figure 39. Ott electromagnetic current meter.

Acoustic Current Meters

Acoustic Doppler current meters, with no moving parts, are commercially available for measuring point velocities. These meters are based on the Doppler principle. The velocity of the moving water is measured using the transmitted and received signals from sound pulses reflecting off particles in the moving water column. These acoustic meters can be accurately calibrated in a tow tank, similar to the calibration of mechanical meters. Advantages of an acoustic Doppler current meter are as follows: no moving parts; direct readout of velocity; and ability to sense very low velocities less than the rated velocities in standard mechanical current meters.

Acoustic Doppler Velocimeter (ADV)

The SonTek/YSI FlowTracker handheld ADV ("FlowTracker" and "ADV" are used interchangeably in this chapter) is designed as an alternative to the Price AA and pygmy meters for wading discharge measurements. The FlowTracker operates at an acoustic frequency of 10 MHz and measures the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow. The magnitude of the phase change is proportional to the flow velocity. The phase difference can be positive or negative, allowing ADVs to measure positive and negative velocities. The FlowTracker measures the velocity at a rate of approximately 10 MHz, averages the data, and records 1-second velocity-vector data.

The maximum velocity the FlowTracker can measure is reduced when measuring flow that is not perpendicular to the transmitting transducer. The receiving transducers can measure a velocity range of only ±1.15 m/s (3.77 ft/s). A velocity component placed directly toward or away from the receiving transducers larger than 1.15 m/s (3.77 ft/s) will result in erroneous velocities. Because of the geometric arrangement of the transmitting and receiving transducers, a velocity of 4.5 m/s flowing perpendicular to the transmitting transducer face will result in the maximum velocity towards a receiving transducer of 1.15 m/s (3.77 ft/s).

The FlowTracker probe is mounted to a standard top-setting wading rod with a special offset-mounting bracket (fig. 40). This bracket is designed to locate the FlowTracker probe at the front of the wading rod, with the sampling volume

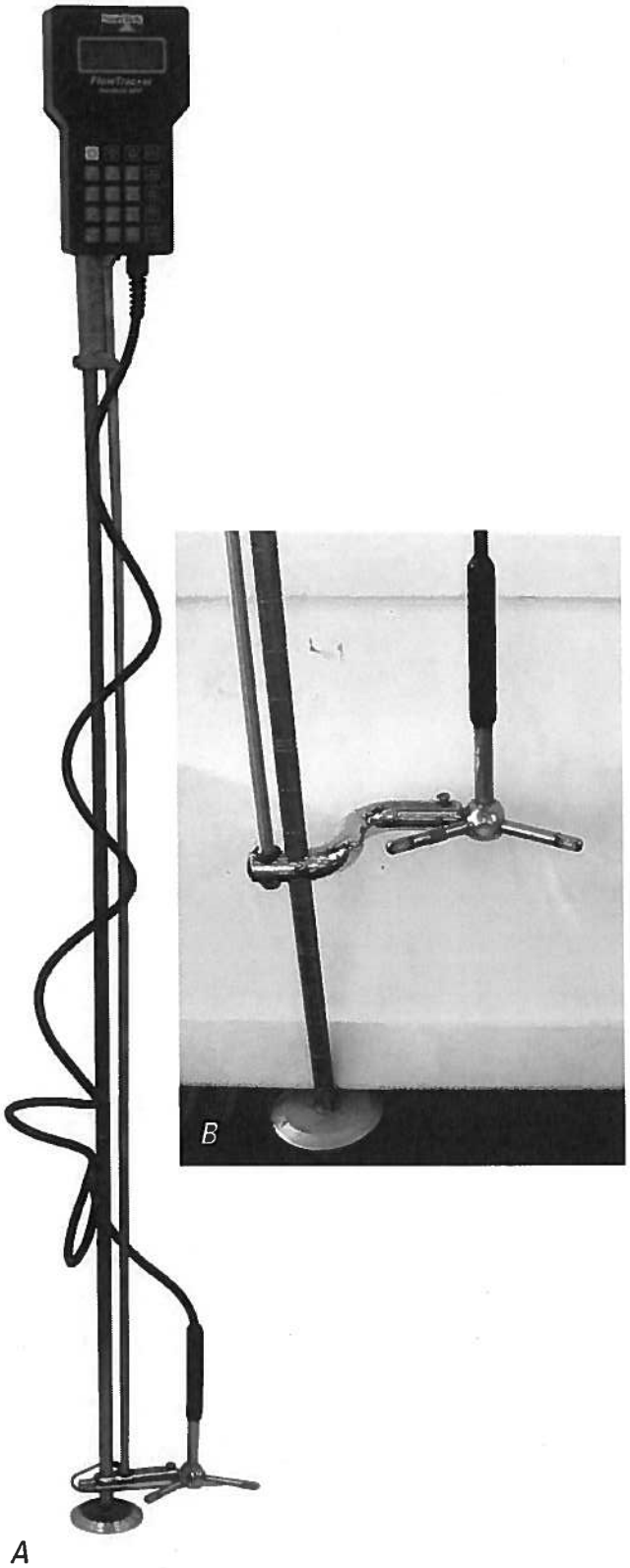


Figure 40. *A*, SonTek/YSI FlowTracker acoustic Doppler velocimeter (ADV) mounted on a standard top-setting wading rod and *B*, closer view of transmitting and receiving transducers and offset-mounting bracket.

about 2 in. (5 cm) to the right of the wading rod. Although the probe is inserted into the flow, the sampling volume is about 4 in. (10 cm) away from all physical parts of the probe, to minimize flow disturbance in the sampling volume.

FlowTrackers have several unique data-processing requirements because of their method of operation and some of the inherent limitations of the acoustic Doppler measurement technique. Unlike mechanical meters that use the momentum of the water to turn a propeller and directly measure the velocity of the water, the FlowTracker does not measure the velocity of the water. The FlowTracker measures the velocity of particles (sediment, small organisms, and bubbles) suspended in the flow, assuming that these particles travel at the same velocity as the water. Therefore, the quality of the measurement is dependent on the presence of particles within the sampling volume that reflect a transmitted signal. The FlowTracker records the signal-to-noise ratio (SNR), standard error of velocity (based on 1-second data), angle of the measured flow (relative to the x-axis of the FlowTracker probe), number of filtered velocity spikes, and a boundary quality-control flag. These velocity and quality-assurance data may be used to evaluate the measurement conditions. Few similar quality-assurance data are available for Price current-meter measurements.

Although a FlowTracker can measure within about 1.2 in. (3 cm) of a boundary, the velocity measurement might be affected by acoustic interference when the sampling volume is close to boundaries or underwater objects, even when the sampling volume is not directly on or past the boundary. At the start of each velocity measurement, if the probe detects nearby acoustic boundaries that could cause interference with the velocity measurement, a boundary adjustment is automatically made. The boundary adjustment attempts to overcome the possible interference by reducing the lag times of the acoustic signals transmitted by the FlowTracker, causing a reduction of the velocity range that can be measured. Any changes are noted in the boundary quality-control flag. Because the sampling volume is located about 4 in. (10 cm) from the transmitting transducer it can be difficult to ascertain the precise location of the sampling volume. If the sampling volume is on or past a boundary, the velocity data will be erroneous. Be careful to avoid boundaries while making measurements in depths less than 3.54 in. (9 cm), especially in channels with irregular bottoms.

Spikes in velocity data occur with any acoustic Doppler velocity sensor such as the FlowTracker. Spikes may have a variety of causes (for example, large particles in the flow, air bubbles, or acoustic anomalies). Velocity data from each FlowTracker measurement are evaluated to look for spikes. The FlowTracker spike filter is a variation on a method called "Tukey's Outlier." In this method, a histogram of each velocity component is calculated. The FlowTracker determines the lower quartile (*Q1*; 25 percent of samples are less than this value), the upper quartile (*Q3*; 75 percent of samples are less than this value), and the interquartile range ($IQR = Q3\text{-}Q1$). If the *IQR* is less than 0.015 m/s (0.049 ft/s), *IQR* is set to

0.015 m/s (0.049 ft/s). Any value less than (*Q1–2*IQR*) or greater than (*Q3+2*IQR*) is considered a spike and is not used for mean-velocity calculations.

The FlowTracker measures magnitude and direction of velocity. The operator must keep the wading rod perpendicular to the tag line so that the pulse generated by the transmitter is parallel to the tag line, regardless of flow direction. To compute discharge, the FlowTracker uses the component of velocity perpendicular to the transmitting transducer and reports the flow angle from the FlowTracker's x-axis as a quality-control value. A flow angle measured by the FlowTracker may be the result of flow that is not perpendicular to the tag line, or a wading rod that is not being held perpendicular to the tag line (operator error). Flow angles of less than 20 degrees with small variations between verticals are not unusual. Large fluctuations of flow angles between verticals, however, may indicate a poorly measured cross section. If there is angular flow, and the wading rod is oriented with the flow, the velocity used and resulting discharge would be biased high. If the flow is truly perpendicular to the cross section, but the wading rod is erroneously held at an angle, the velocity and resulting discharge would be biased low. To avoid possible errors in the measured velocities, it is important that the operator always carefully and accurately aligns the wading rod.

Signal-to-Noise Ratio (SNR)

Adequate signal-to-noise ratio is needed to obtain an accurate measurement of the flow velocity. SNR is a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the instrument. SNR is a function of the concentration and size distribution of the particles that reflect the acoustic signal. SNR is recorded for each beam with each 1-second sample. The manufacturer states that optimal SNR is 10 decibels (dB) or above (SonTek/YSI, 2002). USGS policy is that FlowTrackers should not be used for measuring discharge if the SNR for any single beam is less than 4 dB.

Speed of Sound

The accuracy of hydroacoustics instruments like the FlowTracker is dependent on an accurate speed of sound. The speed of sound is primarily a function of the temperature and salinity of the water. The FlowTracker has a built-in temperature sensor. To verify that the temperature sensor is working correctly, take an independent water-temperature measurement prior to each discharge measurement. If the FlowTracker has been stored in an environment with a different ambient temperature from the water, the probe may need to be placed in the water for a period of time, allowing it to equilibrate with the water temperature. A 5°F error in temperature will result in approximately a 1-percent bias in the measured velocity. The speed of sound is also sensitive to salinity. A 5-part-per-thousand error in salinity would result in an approximate velocity bias of 1 percent, when used in saline environments like estuaries; therefore, the operator needs to measure the salinity and input the value into the FlowTracker.

Maintenance and Care

Although the built-in QCTest is reliable for detecting issues, a BeamCheck stores more system performance data and still may be needed to evaluate the unit in more detail when there is a potential issue.

QCTests and BeamChecks

- Perform a QCTest and store it with each measurement. When a QCTest is completed as part of a measurement, it will print out on the measurement summary.
- Complete a QCTest in flowing water with the sample volume away from any boundaries.
- Perform a BeamCheck if you notice any anomalies in the QCTest. Any failures in a QCTest require a BeamCheck.
- Perform a BeamCheck after any possible physical damage (drop, and so forth), firmware upgrade, or repair.

As stated previously, the FlowTracker is an acoustic Doppler velocimeter (ADV) that has been adapted to fit on a typical USGS streamgaging wading rod, developed by the USGS in cooperation with the SonTek/YSI Inc., and is widely used by the USGS. The FlowTracker has undergone extensive testing to evaluate differences between the FlowTracker performance and vertical-axis current meters (that is, Price AA, pygmy, and so forth).

The USGS Office of Surface Water, through the HIF, has put into place a process that will check and recalibrate each FlowTracker approximately every 3 years to ensure the quality assurance/quality control of this instrument in the measurement of the Nation's surface-water resources. For additional details, see Office of Surface Water Memorandum 2010.02 (2010).

Acoustic Digital Current Meter (ADC)

Another development that is a potential alternative to the Price AA and pygmy meters for wading discharge measurements is the Ott acoustic digital current meter (ADC) (fig. 41). The Ott ADC operates with two transducers at an acoustic frequency of 6 MHz, and measures the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow. The phase measurement is restricted to ±180 degrees and uses a pulse scheme with two different time delays to resolve the phase ambiguity.

The velocity (V) is computed using the following formula:

$$V = \frac{c \times \Delta\Phi}{4 \times \Pi \times \tau}, \quad (19)$$

where V velocity (in distance per unit time),
c speed of sound in water (in distance per unit time),
$\Delta\Phi$ computed phase difference, and
τ time lag between pulses.

The Ott ADC uses a pulse-coherent technique. Transmitted pulses have a known lag time (τ). Backscatter echoes are amplified in the sensor head and then sent to the handheld display where they are digitized. A stable quartz oscillator controls the measurement sequence.

The Ott ADC has several unique data-processing requirements because of its method of operation and some of the inherent limitations of the acoustic Doppler measurement technique. Unlike mechanical meters that use the momentum of the water to turn a propeller and directly measure the velocity of the water, the Ott ADC, as with other acoustic Doppler current meters in use in the USGS and elsewhere, does not measure the velocity of the water. The Ott ADC measures the velocity of particles (sediment, small organisms, and bubbles) suspended in the flow, assuming that these particles travel at the same velocity as the

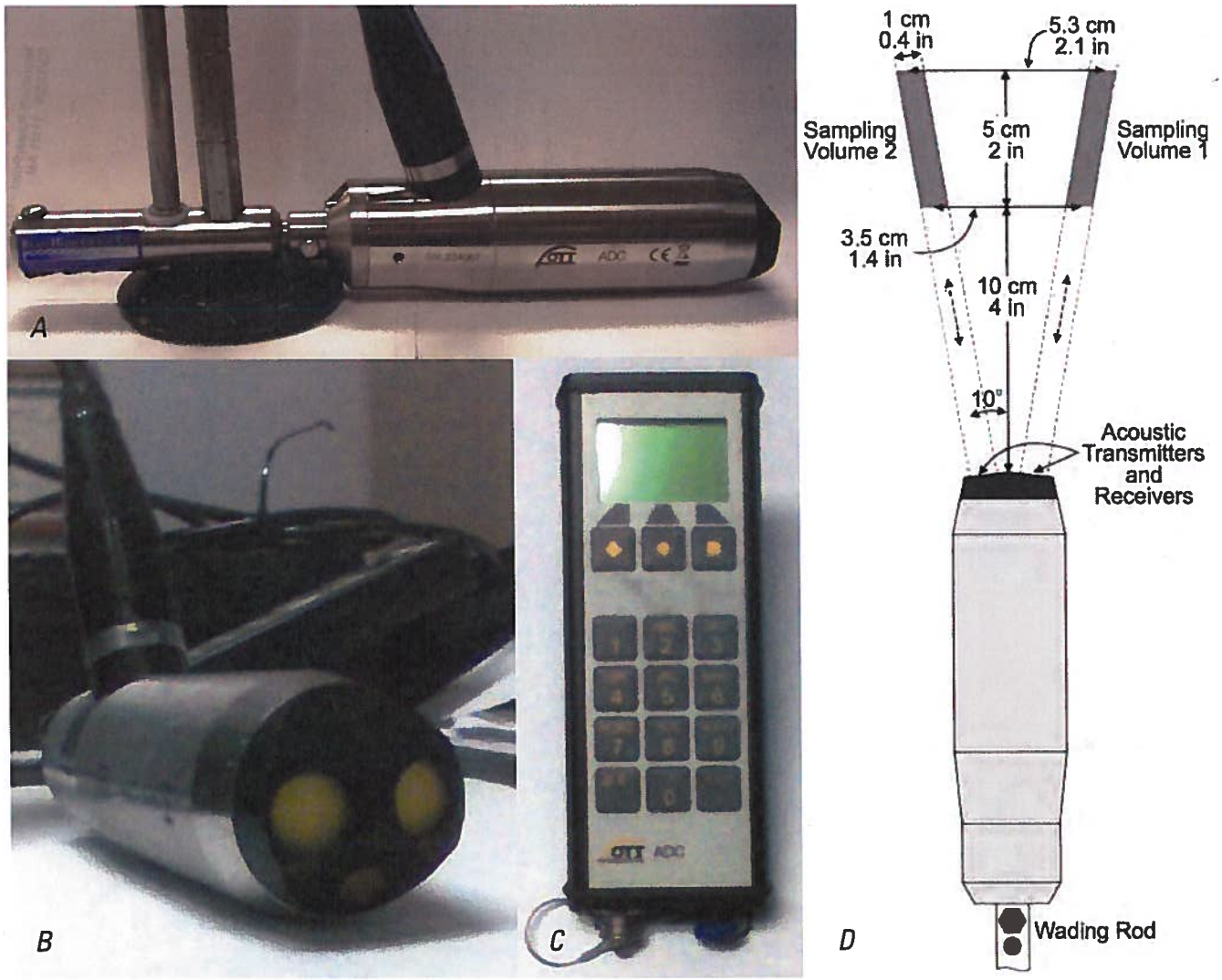


Figure 41. *A*, Ott acoustic digital current meter (ADC) mounted on a standard top-setting wading rod; *B*, closer view of transmitting and receiving transducers; *C*, ADC datalogger; and *D*, schematic of the sampling volume and transducers.

water. Therefore, the quality of the measurement is dependent on the presence of particles within the sampling volume that reflect a transmitted signal. In addition, the Ott ADC measures depth by using an absolute piezoresistive pressure cell with a range of 0 to about 16.4 ft (0–5 m). The pressure cell is located inside the probe and protected by the wading rod adapter, which is securely fastened with two screws. The hydrographer can estimate a depth without reading the top-setting rod.

Preliminary testing of the Ott ADC at the HIF indicates this technology has a lot of potential for use as an alternative to mechanical current meters.

Acoustic Doppler Current Profiler (ADCP)

The ADCP measures velocity magnitude and direction using the Doppler shift of acoustic energy reflected by material suspended in the water column, providing essentially a complete vertical profile of velocity.

Broadband, narrowband, and other pulse-to-pulse coherent ADCPs transmit pairs of acoustic pulses along a narrow beam from each of multiple transducers. As the pulses travel through the water column, they strike suspended sediment and organic particles (referred to as "scatterers") that reflect some of the acoustic energy back to the ADCP. The ADCP receives and records the reflected pulses. The reflected pulses are separated by time differences (range gating) into successive volumes called "depth cells." The frequency shift (known as the Doppler effect) is proportional to the velocity of the scatterers relative to the ADCP. The ADCP computes a velocity component along each beam, because the beams are positioned at a known angle from the vertical (usually 20 or 30 degrees) and in known horizontal orientations so that trigonometric relations can be used to compute three-dimensional water-velocity vectors for each depth cell. Therefore, the ADCP produces vertical profiles of velocity composed of water speeds and directions at regularly spaced intervals, vertical profiles of velocity, discharge profiles, and a wealth of information for a discharge measurement (fig. 42).

The Broadband ADCPs (such as the Teledyne RD Instruments Rio Grande ADCPs) use phase-coded pulses, such that many independent measurements of velocity can be made by a single Broadband pulse of the same length as a narrow-band pulse. These independent measurements are averaged to produce a velocity with a lower uncertainty than would be possible with a single measurement. Narrow-band systems (such as the SonTek/YSI RiverSurveyor S5 and M9) typically compensate for this characteristic by pinging faster (sending more pulses per second, up to 20 Hz) and reporting a velocity based on the average of many pulses with a typical velocity output of 1 Hz.

Currently, the most common main external components of an ADCP are a transducer assembly and a pressure case. Commonly, the transducer assembly consists of three to nine transducers that operate at a fixed, ultrasonic frequency, typically 300 to 3,000 kilohertz (kHz). The transducers are horizontally spaced around the transducer assembly; all transducers have the same fixed angle from the vertical, referred to as a "beam angle," that is typically between 20 and 30 degrees. The transducer assembly may have a convex or concave configuration or, in the case of the phased array, an essentially flat surface. The pressure case is attached to the transducer assembly. Examples of several different ADCPs used in the USGS are shown in figure 43.

When an ADCP is deployed from a moving boat, it is connected by cable to a power source and by cable or radio modem to a portable microcomputer. The computer is used to program the instrument, monitor its operation, and collect and store the data. For a detailed description of how an ADCP measures velocity and computes discharge, and detailed instruction in the use of ADCP technology with reference to moving boats, see Mueller and Wagner (2009).

Midsection Method With an ADCP

When an ADCP is deployed to perform a midsection method discharge measurement, most best practices used for mechanical-meter discharge measurements still apply. These practices, including site selection, are well documented in Rantz and others (1982). The midsection method with an ADCP is similar to the midsection method used for mechanical-meter discharge measurements and involves measuring the channel area and water velocities of a stream at a cross section; however, instead of point measurements of velocity, with this method, the average velocity is obtained by profiling the velocity in the water column at each section. The channel is divided into a number of vertical subsections. Most natural channels must be divided into 20 or 30 subsections to adequately characterize their irregular geometry. The depth and average velocity are measured at each subsection and are applied to a subarea whose width extends halfway to the preceding and following observation points. The area of each subsection is determined by directly measuring width and depth. The average water velocity in each subsection is estimated using the measured velocity at elected locations in the vertical. The total discharge within the stream is the sum of the individual subsection discharges.

Additional details and in-depth discussion of ADCP technology, methodology, and quality assurance and quality control can be found in USGS publications by Simpson and Oltmann (1993), in Lipscomb (1995), Morlock (1996), Oberg and others (2005), and Mueller and Wagner (2009). The ADCP method is a relatively new and evolving technology, and as a result, there are ongoing changes to the hardware, software, and firmware.

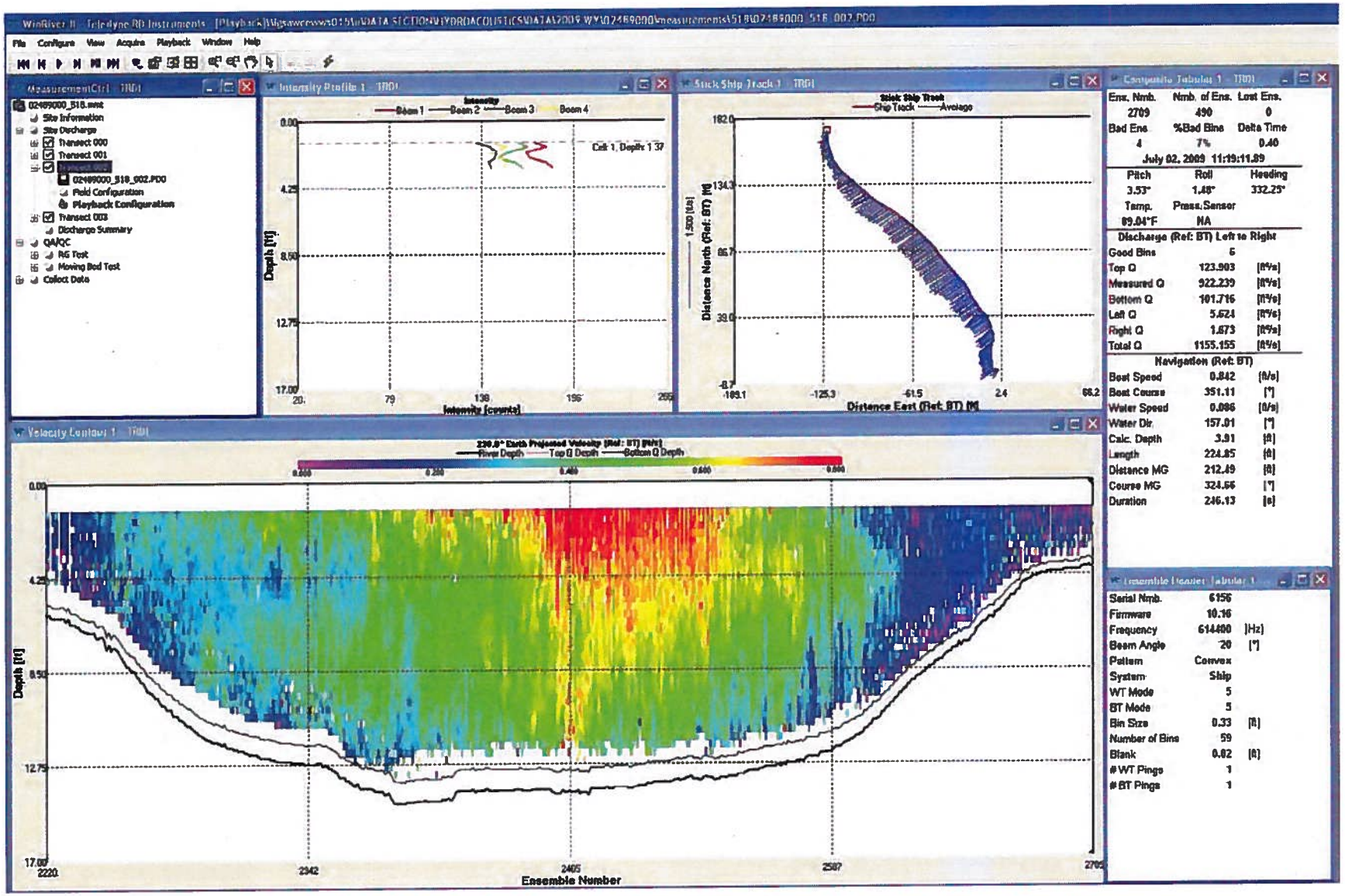


Figure 42. Screen capture of an ADCP measurement of discharge for the Pearl River near Columbia, MS (02489000).

Figure 43. Examples of acoustic Doppler current profilers (ADCPs) used to measure discharge at gaging stations; *A*, Teledyne RD Instruments 600 kHz Rio Grande ADCP; *B*, Teledyne RD Instruments 600 kHz RiverRay phased array ADCP, and *C*, closeup view of phased array transducer; *D*, SonTek/YSI RiverSurveyor S5; *E*, SonTek/YSI RiverSurveyor M9; and *F*, Teledyne RD Instruments StreamPro ADCP.

Optical Current Meters

An optical current meter, as shown in figure 44, is a stroboscopic device designed to measure surface velocities in open channels without immersing equipment in the stream. The optical current meter is used principally in measurements of surface velocity during floods when it is impossible to use streamgaging equipment that requires placement in the water, because of extremely high velocities and high-debris content in the stream. Use of this technology and other technologies, such as radar, deserves further investigation in the measurement of discharge using surface velocities.

Figure 44. Hydrographer using an optical current meter to measure surface velocity.

Sounding Equipment

Sounding (determination of depth) is commonly done mechanically; the equipment used depends upon the type of measurement being made. Measure depth and position in the vertical with a rigid rod or by a sounding weight suspended from a cable. The cable is controlled either by a reel or by a handline. A sonic sounder is also available, but it is usually used in conjunction with a reel and a sounding weight. The various equipment that can be used for sounding is described in the following paragraphs. In addition, ADCPs can sound depths using sophisticated algorithms that may have global positioning features and capabilities. Mueller and Wagner (2009) discuss ADCP sounding in more detail.

Top-Setting Wading Rods

The two types of wading rods commonly used are the top-setting rod and the round rod. The top-setting rod is preferred because of the convenience in setting the meter at the proper depth and because the hydrographer can keep his hands dry.

The top-setting wading rod, as shown in figure 45, has a ½-in. hexagonal main rod for measuring depth and a ⅜-in. diameter round rod for setting the position of the current meter.

The rod is placed in the stream so the base plate rests on the streambed, and the depth of water is read on the graduated main rod. When the setting rod is adjusted to read the depth of water, the meter is positioned automatically for the 0.6-depth method, as shown in figure 46. The 0.6-depth setting is the setting measured down from the water surface. This setting is the same as the 0.4-depth position when measured up from the streambed. When the depth of water is divided by 2, and this value is set on the setting rod, the meter will be at the 0.8-depth position from the water surface. When the depth of water is multiplied by 2, and this value is set, the meter will be at the 0.2-depth position from the water surface.

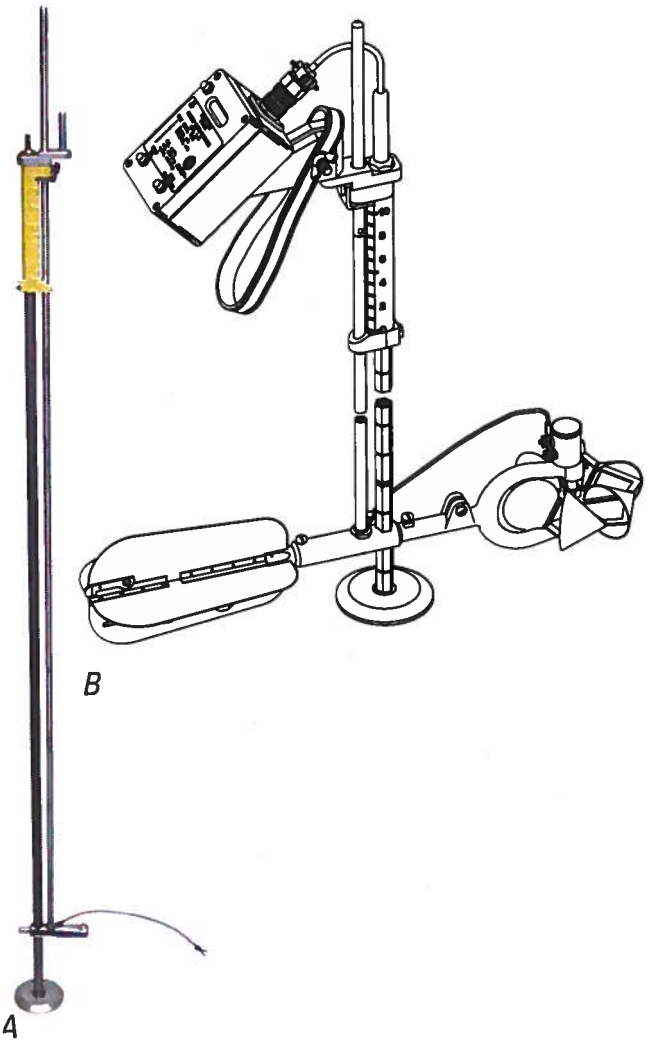


Figure 45. *A*, Top-setting wading rod and *B*, schematic of a top-setting wading rod with Price AA current meter and current-meter digitizer (CMD) attached.

Figure 46. Closeup view of setting scale on handle of top-setting wading rod.

Round Wading Rods

The round wading rod, as shown in figure 47, consists of a base plate, lower section, sliding support, three or four intermediate sections, and a rod end (not essential). The parts are assembled as shown in figure 48. The meter is mounted on the sliding support and is set at the desired position on the rod by sliding the support. The round rod can be assembled into various lengths using the 1-ft sections, and it is easy to store and transport when disassembled.

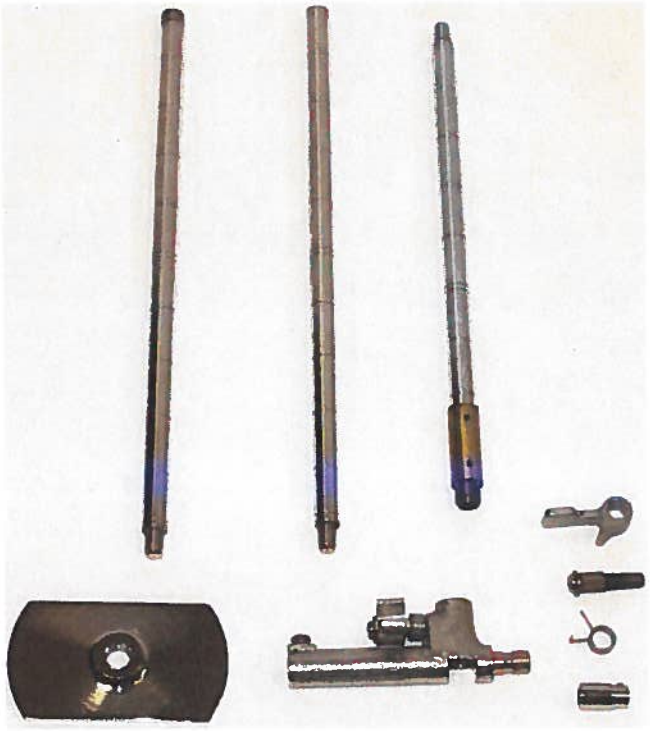


Figure 47. Parts for the round wading rod.

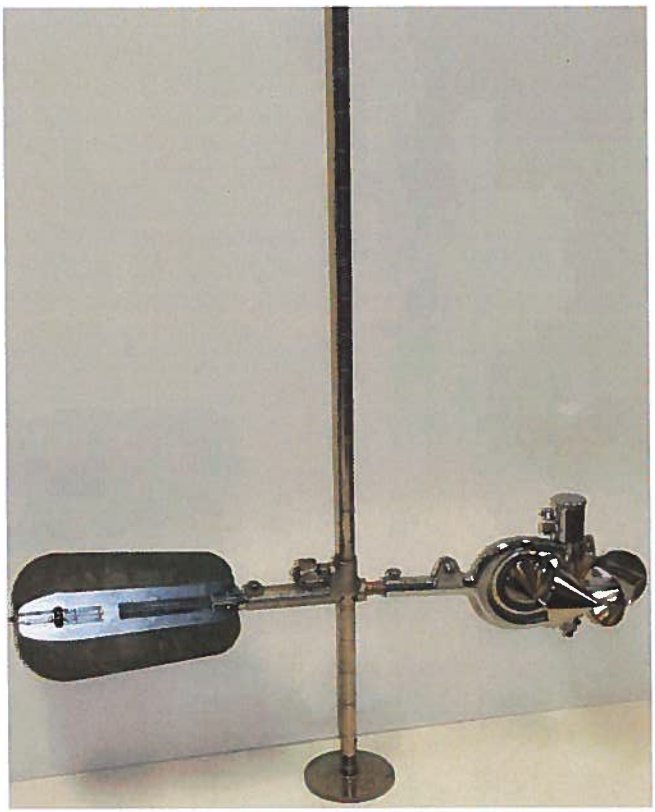


Figure 48. Round wading rod with Price AA current meter attached.

Winter-Style Suspension Wading Rods

Measurements made under ice cover should use the WSCan winter sounding rods, either in the ½- or 1-in.-diameter versions. These rods are available in sections so that the desired length can be assembled. A special foot fits the lower section, and the rods will accommodate the winter-style current-meter yoke, as shown in figure 49.

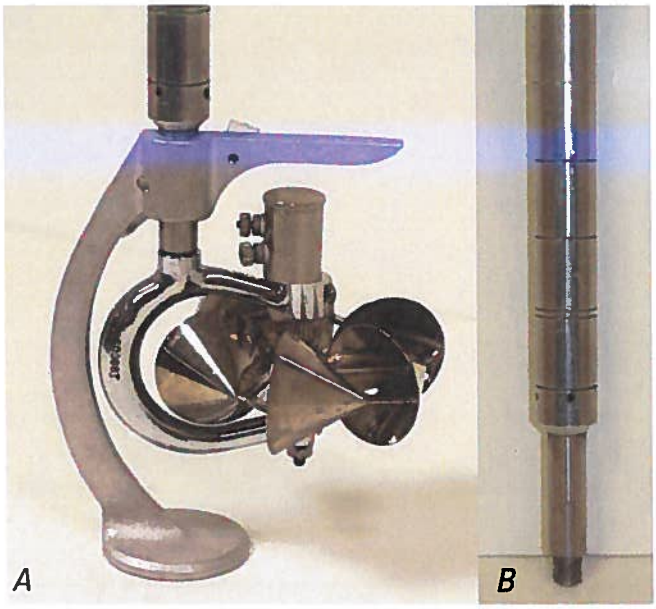


Figure 49. Water Survey Canada winter-style round 1-inch suspension rod and meter: *A*, with Price AA meter in a winter-style yoke attached and *B*, closer view of round 1-inch diameter suspension rod.

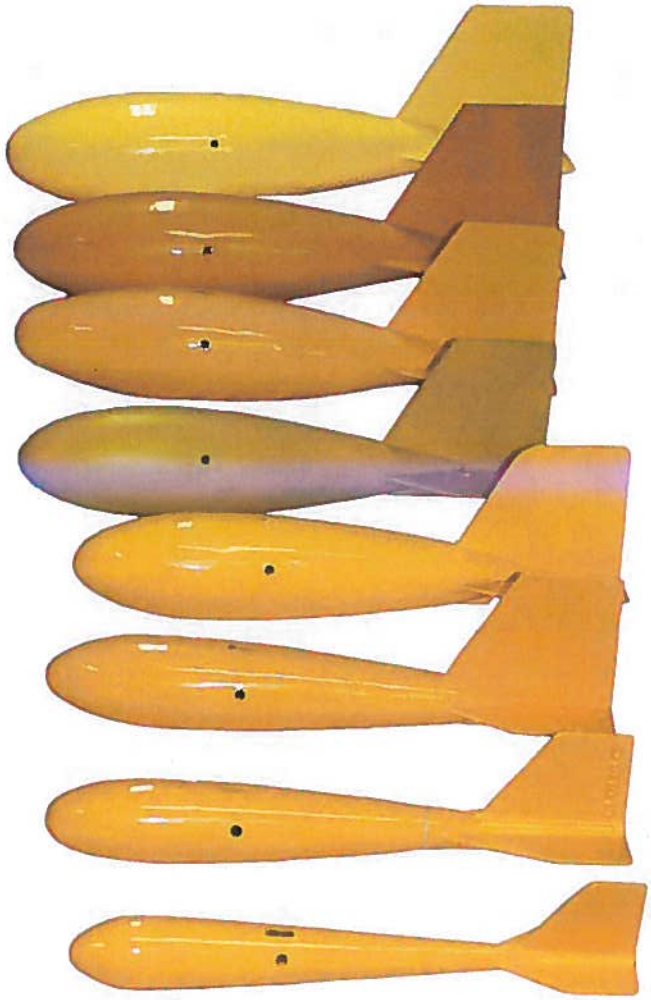


Figure 50. Columbus C-type sounding weights (15 through 300 pounds).

Sounding Weights

If a stream is too deep or too swift to wade, the current meter is suspended in the water from a boat, bridge, or cableway. A sounding weight is suspended below the current meter to keep it stationary in the water. The weight also prevents damage to the meter when the assembly is lowered to the streambed.

The sounding weights currently used are the Columbus weights, commonly called the C type, and are shown in figure 50. The weights are streamlined to offer minimum resistance to flowing water. The weights are available in 15-, 30-, 50-, 75-, 100-, 150-, 200-, and 300-pound sizes. Each weight has a vertical slot and a drilled horizontal hole to accommodate a weight hanger and securing pin.

Hanger Bars

The weight hanger is attached to the end of the sounding line by a connector. The current meter is attached to the hanger bar beneath the connector, and the sounding weight is attached to the lower end of the hanger bar.

There are three types of weight hanger bars, as shown in figure 51:

1. The Columbus or C type, ⅛ × ¾ × 12 in. (for weights up to 150 pounds);
2. Heavy weight, ⅛ × ¾ × 18 in. (for 200- and 300-pound weights);
3. Heavy weight, ⅛ × 1 ½ ×18 in. (for 200- and 300-pound sounding weights that have the slots properly extended to accommodate a 1½-in. wide hanger bar).

Figure 51. Sounding weight hanger bars and hanger pins.

The Columbus hanger bar contains three holes in order to properly position the meter. The hanger screw of the current-meter yoke is placed through the bottom hole to support the meter when a 30-pound sounding weight is used. The center of the meter cups is then 0.5 ft above the bottom of the weight. This arrangement is designated as 30 C .5, which means that a 30-pound Columbus weight is being used and the center of the meter cups is 0.5 ft above the bottom of the weight. The hanger screw goes through the middle hole when 15- or 50-pound weights are used. The designations for these arrangements are 15 C .5 and 50 C .55. The hanger screw goes through the upper hole when 50-, 75-, 100-, and 150-pound weights are used. The designations for these arrangements are 50 C .9, 75 C 1.0, 100 C 1.0, and 150 C 1.0. Each of the two heavy-weight hangers has only one hole for the hanger screw of the meter. The designations for these arrangements are 200 C 1.5 and 300 C 1.5.

Weight-hanger pins of various lengths, as shown in figure 51, are available for attaching the sounding weight to the hanger bar. The stainless steel pins are threaded on one end to screw into the hanger bar and slotted on the other.

Sounding Reels

Several different types of sounding reels are available for use with the Columbus C-type weights. In general, a sounding reel has a drum for winding the sounding cable, a crank-and-ratchet assembly for raising and lowering the weight or holding it in any desired position, and a depth indicator. Table 11 contains detailed information on each of the five most commonly used reels.

The A-pack reel, as shown in figure 52, is light, compact, and ideal for use at cableway sites a considerable distance from the highway. It can also be used on cranes, bridge boards, and boat booms.

Figure 52. A-pack reel.

Table 11. Sounding reel data.

Reel	Sounding cable	Cable diameter, in inches	Drum circumference, in feet	Cable capacity, in feet	Maximum weight, in pounds	Depth indicator	Brake	Type of operation
A-pack	Ellsworth	0.084	1	45	50	Counter	No	Hand.
Canfield	Single conductor[1]	.0625	1	45	50	Counter	No	Hand.
A-55	Ellsworth	.084 .10	1	95 80	50 100	Self computing	No	Hand.
B-56	Ellsworth	.10 .125	1.5	144 115	150 200	Self computing	Yes	Hand or power.
E-53	Ellsworth	.10 .125	2	206 165	150 300	Self computing	Yes	Power.

[1]Some Canfield reels have been converted to double-conductor cable but most of them are still used as single-conductor reels.

The Canfield reel, as shown in figure 53, is also compact with uses similar to that of the A-pack reel. The Canfield reel is not available from the HIF, and must be obtained from Leupold and Stevens Instruments, Inc.

The A–55 reel is for general purpose use with the lighter sounding weights, as shown in figure 54.

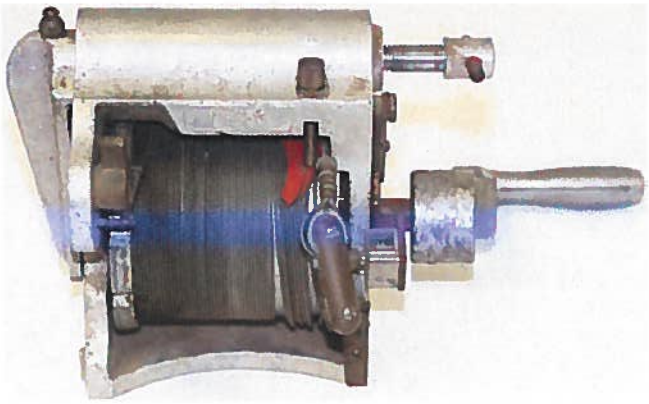


Figure 53. Canfield reel.

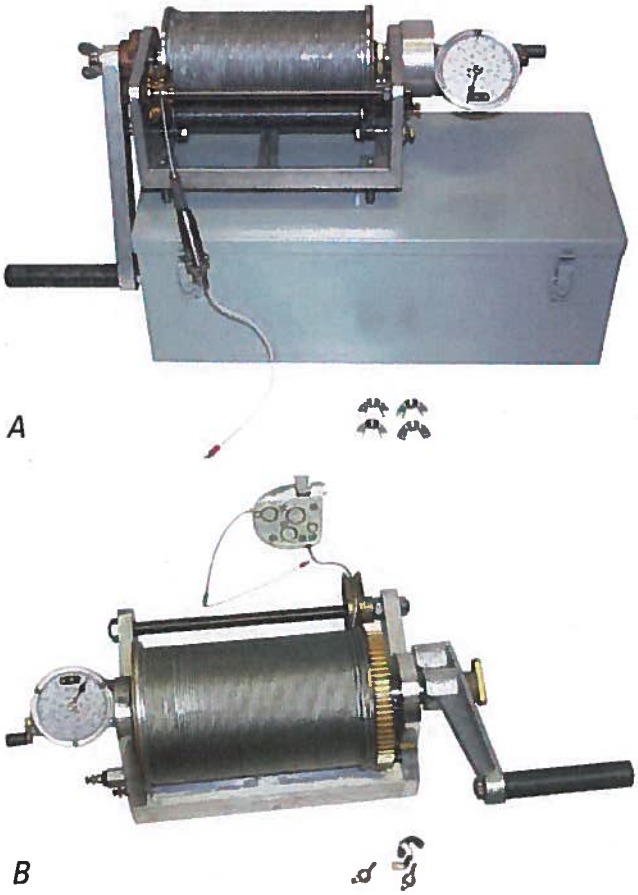


Figure 54. *A*, A–55 reel and *B*, B–56 reel.

The B–56 reel (a major modification of the B–50 reel) can handle all but the heaviest sounding weights and has the advantage that it can be used with a hand crank or power equipment, as shown in figure 54.

The E–53 reel is the largest reel commonly used for current-meter measurements. This reel will handle the heaviest sounding weights and is designed exclusively for use with power equipment. It has a hand crank for emergency use, as shown in figure 55.

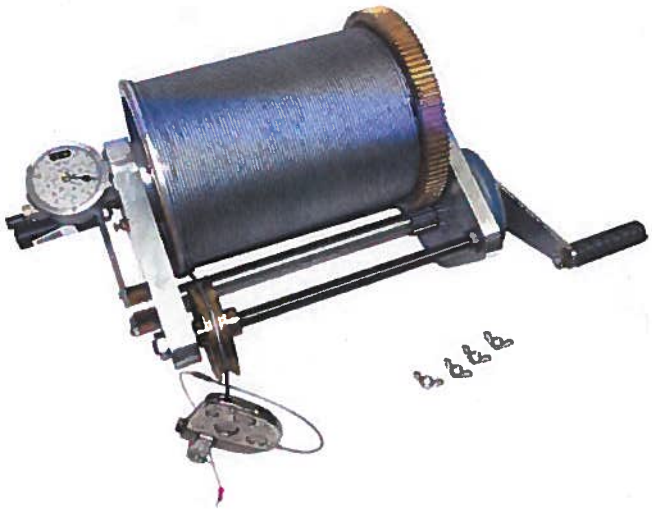


Figure 55. E–53 reel.

Sounding Cable

Ellsworth reverse-lay two-conductor stranded cable is normally used on all sounding reels, except the single-conductor Canfield reel, which uses galvanized steel aircraft cord. Ellsworth cables are normally available in 0.084-, 0.100-, and 0.125-in. diameters. It is important to use the appropriate size cable-laying sheave on the reels.

For safety purposes, when measuring floods, it is important to connect the sounding cable to the sounding reel in such a way that the cable will break in the event that heavy debris is caught and cannot be released. The cable will usually unwind (pay out) from the sounding reel until it reaches its end, at which point there is danger to the equipment and the hydrographer unless the cable is cut or breaks. Precut some of the cable strands when installing the cable on the reel so that the remaining strands will break when the load reaches a specified limit. Table 8 provides information about cable strength and number of strands to cut to provide the necessary safety margin. Complete instructions for making the cable installation are given in a HIF technical information sheet dated April 1999.

Connectors

A connector is used to join the end of the sounding cable to the sounding-weight hanger. The three types of connectors generally used are types B, C1, and pressed sleeve, as shown in figure 56. The type B connector is used with A–55, B–56, and E–53 reels. The C1 connector is used with the A-pack and Canfield reels, although the pressed-sleeve connector can be used on these reels. The pressed-sleeve connector is also used on handlines.

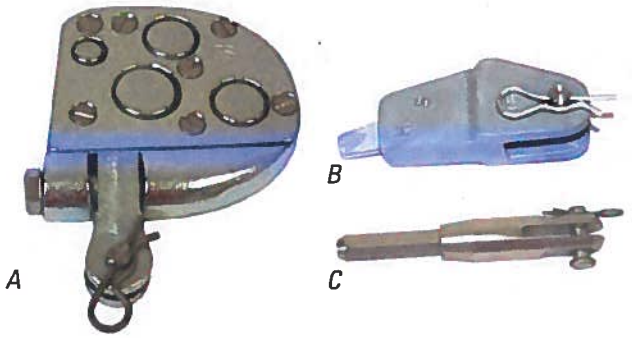


Figure 56. Connectors for attaching sounding cable to sounding-weight hanger; *A*, Type B; *B*, Type C1; and *C*, pressed sleeve.

Depth Indicators

A computing depth indicator, as shown in figure 57, is used on the A–55, B–56, and E–53 reels. The stainless-steel indicator is less than 3 in. in diameter and has nylon bushings that do not require oil. The main dial is graduated in feet and tenths of a foot from 0 to 10 ft. The depth is indicated by a pointer. Tens of feet are read on a numbered inner dial through an aperture near the top of the main dial.

The main dial has a graduated spiral to indicate directly the 0.8-depth position for depths up to 30 ft.

The A-pack and Canfield reels, shown in figures 52 and 53, are equipped with counters for indicating depths.

Figure 57. Computing depth indicator.

Handlines

A handline, shown in figure 58, is a device used for making discharge measurements from bridges using a 15- or 30-pound sounding weight. The advantages of using the handline are that it is easy to set up, it eliminates the use of a sounding reel and supporting equipment, and it reduces the difficulty in making measurements from bridges, which have interfering members, such as trusses. The disadvantages of using the handline are that there is a greater possibility of making errors in determining depth because of slippage of the handline, measuring scale, or tape, and it requires great physical exertion, especially in deep streams. Handlines can be used from cable cars, but this is not recommended because of the disadvantages mentioned above.

Ellsworth cable is recommended for handlines because of its flexibility and durability. Two-conductor electrical service cord is used between the headset connector and the handline reel.

The pressed-sleeve connector or the C1 connector is used on handlines because they are lighter in weight than the type B connector, yet strong enough for the sounding weights used with handlines.

Figure 58. Handline.

Power Unit

Power units, as shown in figure 59, are available for the B–56 and E–53 reels to raise and lower the sounding weight and meter. The power unit can be used with 6-, 12-, 18-, or 24-volt batteries.

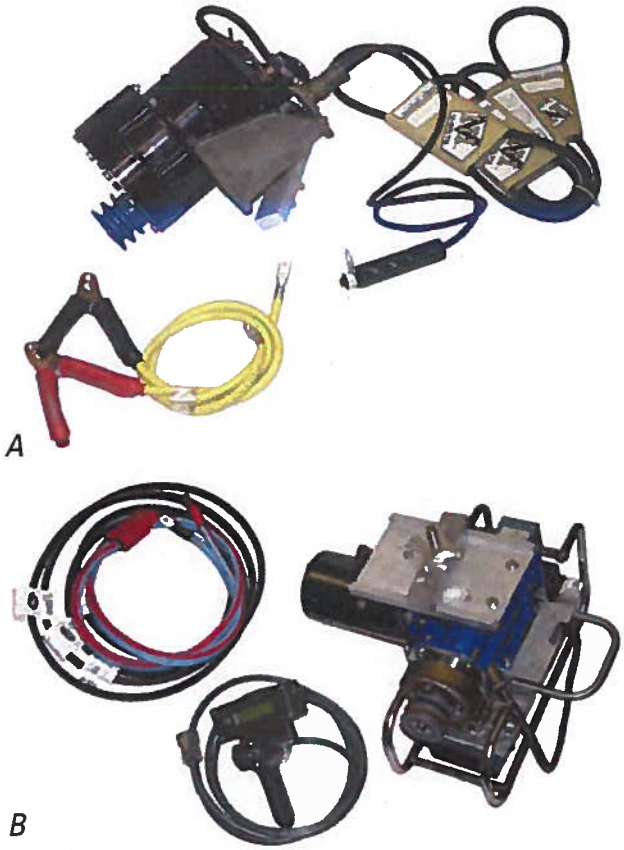


Figure 59. Power units for sounding reels; *A*, J & H Single Speed Power Drive and *B*, USGS Variable Speed Reel Drive System.

Sonic Sounder

A commercial, compact, portable sonic sounder has been adapted to measure stream depth. The sounder is powered by either a 6- or 12-volt storage battery and will operate continuously for 10 hours on a single battery charge. Three recording speeds are available—36, 90, and 180 in. per hour. Four operating ranges—0 to 60 ft, 60 to 120 ft, 120 to 180 ft, and 180 to 240 ft—allow intervals of 60 ft of depth. The sounder is portable, weighing only 46 pounds. The depth recorded is from the water surface to the streambed. The transducer has a narrow beam angle of 6 degrees, which minimizes errors on inclined streambeds and allows the hydrographer to work close to piers or other obstructions.

Measurements can be made with this equipment without lowering the meter and weight to the streambed. As soon as the weight is in the water, the depth will be recorded. The meter can then be set at the 0.2 depth, or just below the water surface where a velocity reading is obtained. Then a coefficient is applied to convert measured velocity to the mean in the vertical.

Temperature change affects the sound propagation velocity, but this error is limited to about plus or minus 2 percent in freshwater. This error can be eliminated completely by adjusting the sounder to read correctly at a particular average depth determined by other means.

Cableway Equipment

The USGS cableway provides a track for the operation of a manned cable car from which the hydrographer makes a current-meter measurement. Most cableways have a clear span of 1,000 ft or less, although a few structures have been built with clear spans approaching 2,000 ft. The design and construction of cableways are described in detail by Wagner (1995).

Cable cars provide a movable platform from which the hydrographer, sounding reel, and other necessary equipment are supported. The newer versions of these cable cars are fabricated from aluminum, and have a standard follower brake and integral-reel mounts, which will accept all standard sounding reels, including battery-powered reels. Cable cars can also be equipped with the Sandpoint type cable-car brake, which allows the cable car to be slowed or stopped. Both sitdown and standup types of manually propelled cable cars are used in streamgaging, as shown in figures 60 and 61, and have space for two people to work. Some older cable cars still in use are fabricated partially from wood, may or may not have permanent reel mounts, and may have space for only one person.

Manned cable cars are moved from one point to another on the cableway by means of cable-car pullers, as shown in figure 62. The standard car puller is an aluminum-cast handle with a snub attached. The snub, usually four-ply belting, is placed between one of the car sheaves and the cable to prevent movement of the car along the cable. A second type of puller, also shown in figure 62, is used when a car is equipped with a follower brake. A third type, the Colorado River cable-car

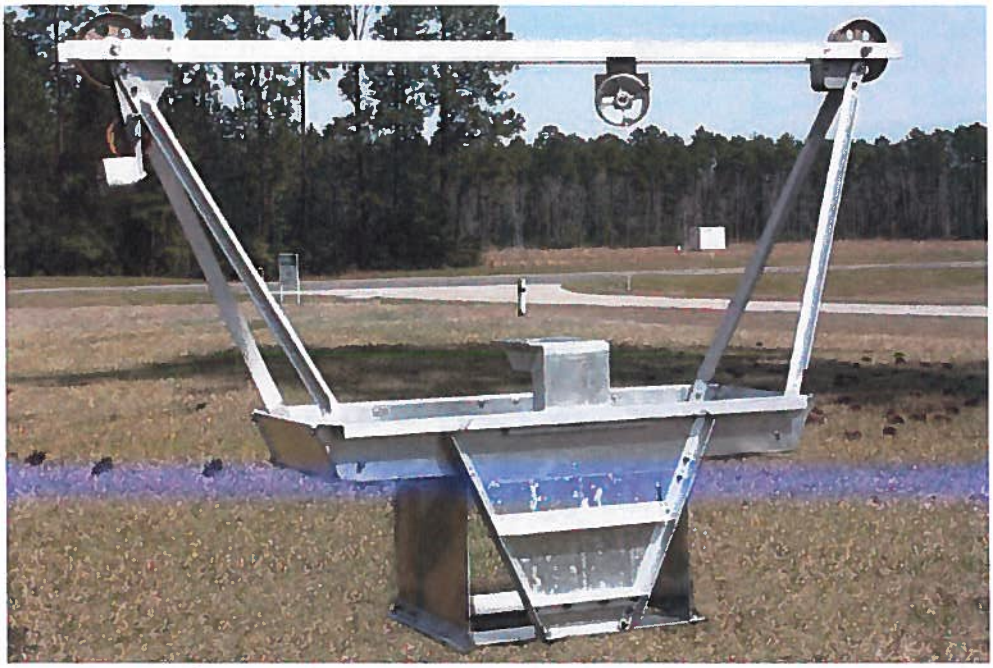


Figure 60. Sit-down cable car.

Figure 61. Stand-up cable car.

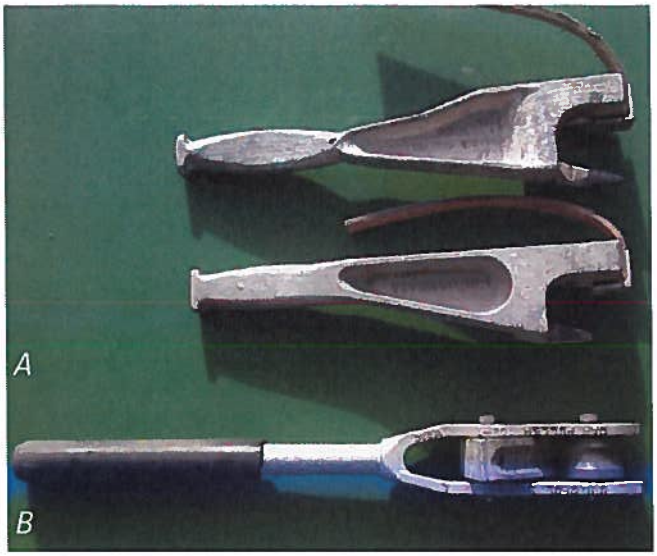


Figure 62. Cable-car pullers: *A*, with belt and *B*, with follower brake.

puller, is the same in principle as the puller used on cars equipped with a follower brake.

Power-operated cable cars, such as the battery-powered car shown in figure 63, are available for extremely long spans or other special situations where extensive streamgaging and monitoring is required. The power assist on these cable cars is also utilized to operate a type E sounding reel.

Unmanned, remotely operated cable carriages, such as the Hydrological Services Hornet, are used for discharge measurements as well as for sediment sampling. The cable carriage and sounding equipment can be remotely operated from the stream bank, as shown in figure 64. They are used in areas where it is impossible to wade, where no bridges are available, and where it is not practical to build or maintain a manned cableway.

Unmanned cableways are used more in Europe than in the United States, but are becoming more common in the United States. These bank-operated cableways have obvious benefits in safety and convenience (fig. 65). Both permanent and portable bank-operated cableways are becoming more useful in the measurement of discharge, especially for more narrow streams, generally 300 ft or less in top-bank width.

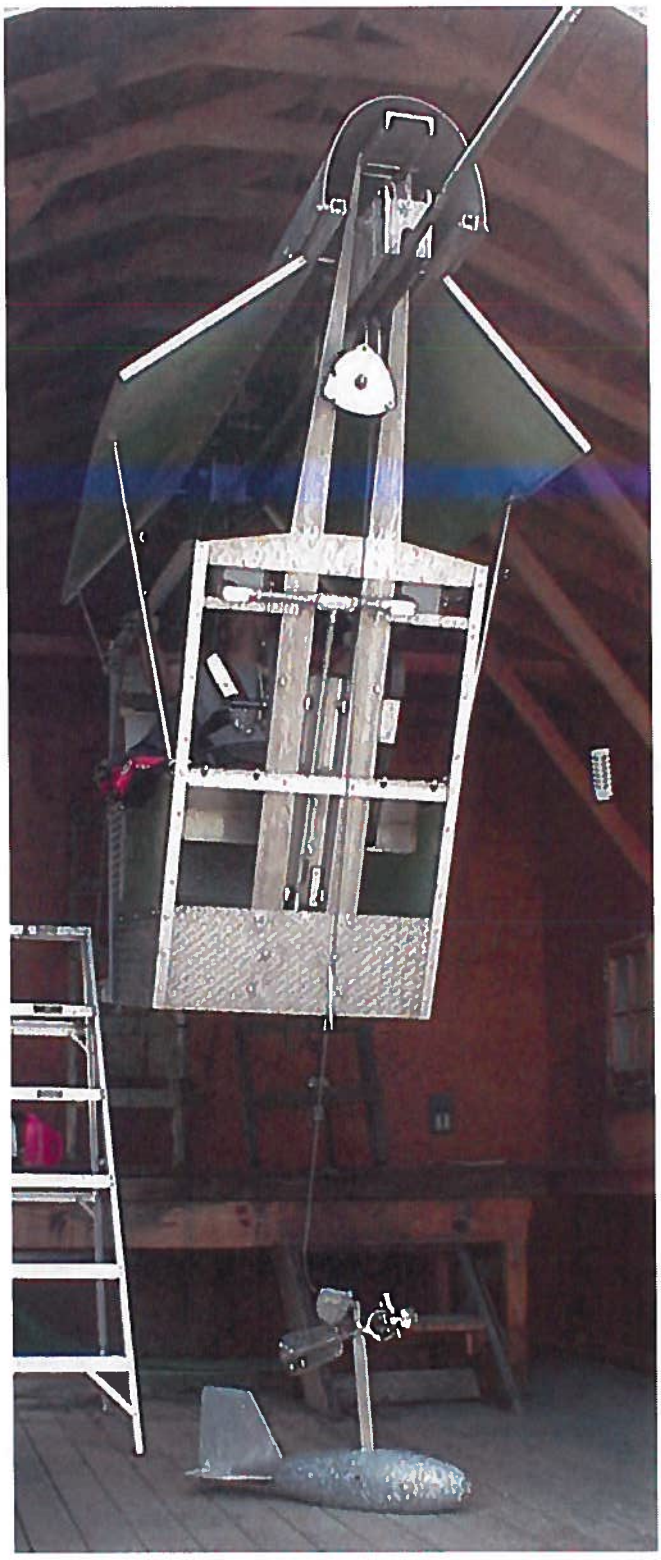


Figure 63. Battery-powered cable car.

Figure 64. Remotely operated Hydrological Services Hornet cable carriage with ADCP and trimaran used by the USGS.

Figure 65. Bank-operated cableway.

Bridge Equipment

Streamflow measurements are frequently made from a bridge. The meter and sounding weight can be supported by a handline, a bridge board, or by a sounding reel mounted on a crane. An ADCP mounted on a tethered craft can also be deployed from a bridge. Tethered ADCP craft are rapidly becoming the prevalent means of measuring discharge from a bridge.

Handlines and Bridge Boards

A handline, as described in a previous section of this chapter, is the simplest form of bridge-measuring equipment. Used extensively in the 20th century, it does not require any separate reels or handling equipment; however, it can only be used with light sounding weights, such as the 15- and 30-pound size. It also requires that depth be measured with tags, and a tape or measuring stick.

A bridge board is a portable platform made from wood or metal upon which a small reel can be mounted. Bridge boards may be used with an A-pack, A–55, or B–56 sounding reel and weights up to 75 pounds. A bridge board is usually about 6 to 8 ft long, with a sheave at one end over which the meter cable passes, and a reel seat near the other end. The board is placed on the bridge rail so that the force exerted by the sounding weight suspended from the reel cable is counterbalanced by the weight of the sounding reel. The bridge board may be hinged near the middle to allow one end to be placed on the sidewalk or roadway. Figure 66 shows a bridge board in use.

Figure 66. Measuring from a bridge with a bridge board.

Portable Cranes

Two types of hand-operated portable cranes are the type A for weights up to 100 pounds, and the type E for weights greater than 100 pounds. The type A crane mounts on a three-wheel or four-wheel base or truck, and the type E crane mounts on a four-wheel base or truck. Cranes can be easily moved by hand along the sidewalk or floor of the bridge. Figure 67 shows a type A crane mounted on a three-wheel base, and figure 68 shows a type E crane mounted on a four-wheel base.

Any of the reels described in table 11 may be used on either of the portable cranes; however, the power-driven reels (B–56 and E–53) are used only with the Type E crane. Various combinations of cranes, bases (trucks), and reels are possible.

Figure 67. Type A crane mounted on a three-wheel base.

Figure 68. Type E crane mounted on a four-wheel base.

All cranes are designed so that the crane can be tilted forward over the bridge rail far enough for the meter and weight to clear most rails and be lowered to the water. Where bridge members obstruct passage of the crane along the bridge, the weight and meter can be raised and the crane can be tilted back to pass by the obstruction.

Use cast-iron counterweights weighing 60 pounds with four-wheel-base cranes. The number of such weights needed depends upon the size of sounding weight being supported, the depth and velocity of the stream, and the amount of debris being carried by the stream.

Use a protractor on the outer end of cranes to measure the angle the sounding line makes with the vertical when the weight and meter are dragged downstream by high-velocity water. The protractor is a graduated circle clamped to an aluminum plate. A plastic tube, partly filled with colored antifreeze (ethylene glycol), is the protractor index. This tube is fitted in a groove between the graduated circle and the aluminum plate. A stainless-steel rod is attached to the lower end of the plate to ride against the downstream side of the sounding cable. The protractor will measure vertical angles from -25 degrees to +90 degrees. Figure 69 is a close-up view of a protractor mounted at the outer end of the boom.

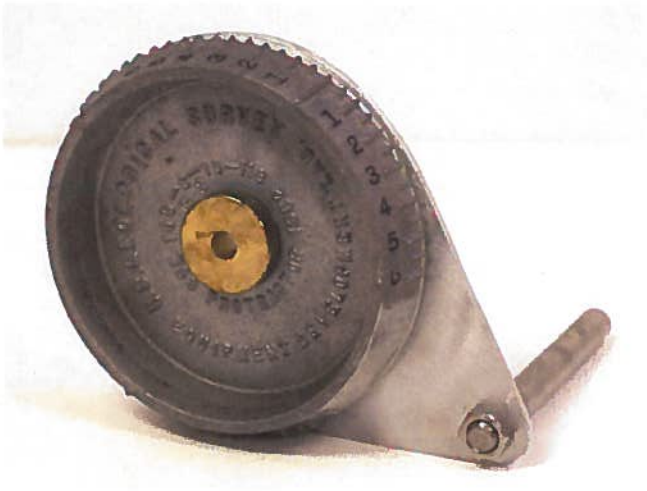


Figure 69. Protractor used for measuring vertical angles.

Power-Driven Cranes

Many special arrangements for measuring from bridges have been devised to suit a particular purpose. Vehicle-mounted cranes are often used for measuring from bridges over larger rivers, as shown in figure 70. Monorail streamgaging cars have also been developed for large rivers. The car is suspended from the substructure of bridges by means of I-beams.

Tethered Craft

The USGS, in cooperation with manufacturers, continues to test and refine tethered-platform designs for measuring streamflow. Platform specifications have been developed for

Figure 70. Vehicle-mounted, power-driven crane.

radio-modem telemetry of acoustic Doppler current profiler (ADCP) data, potential platform-hull sources have been investigated, and many hull configurations have been tested and evaluated.

Platforms, which included a variety of hull configurations, were tested for drag and stability at the USGS Hydraulic Laboratory tow tank and at a field site below a reservoir. The testing indicated that trimaran designs provided the best all-around performance under a range of conditions. The trimaran designs house the ADCP in the center hull. Waterproof radio modems that operate at 900 MHz are used to communicate wirelessly with instruments at high-baud rates.

A tethered-platform design with a trimaran hull, and 900-MHz radio modems, are commercially available from several vendors. Continued field use has resulted in USGS procedures for making tethered-platform discharge measurements, including methods for tethered-boat deployment, moving-bed tests, and measurement of edge distances. Figure 71 shows a tethered craft ADCP in wide usage in the USGS (Mueller and Wagner, 2009; Rehmel and others, 2003).

Figure 71. Measuring with a tethered ADCP, DGPS, and trimaran.

Boat Equipment

There are five basic types of boat measurements: the manual stationary boat, the manual moving boat, the automatic moving boat, the ADCP moving boat, and the remote-controlled ADCP moving boat. Equipment requirements for each of these boat measurement types are described in the following paragraphs.

Manual Stationary Boat

The manual stationary boat method uses a boat as a platform for the hydrographer and the sounding equipment. The boat is attached to a tag line or cable to stabilize it at each vertical where soundings are made. The heavy-duty tag lines required for boat measurements are described in a previous section of this chapter.

Special equipment assemblies, as shown in figure 72, are necessary to suspend the meter from the boat if the depths do not allow using rod suspension. A crosspiece spanning the boat is clamped to its sides, and a boom attached to the center of the crosspiece extends out over the bow. The crosspiece is equipped with a guide sheave and clamp arrangement at each end to attach the boat to the tag line, and makes it possible to slide the boat along the tag line from one station to the next. A small rope can be attached to these clamps so that in an emergency a tug on the rope will release the boat from the tag line. The crosspiece also has a clamp that prevents lateral movement of the boat along the tag line during readings. The boom consists of two structural aluminum channels, one telescoped within the other to permit adjustments in length. The boom is equipped with a reel plate on one end and a sheave over which the meter cable passes. The sheave end of the boom is designed so that by adding a cable clip to the sounding cable a short distance above the connector, the sheave end of the boom can be retracted when the meter is raised out of the water. The raised meter is easy to clean and is in a convenient position when not being operated.

Figure 72. Manual stationary-boat equipment assembly.

All sounding reels fit the boat boom, except the A-pack and the Canfield, which can be made to fit by drilling additional holes in the reel plate on the boom.

In addition to the equipment already mentioned, the following items are needed for making boat measurements:

1. A stable boat big enough to support the hydrographers and equipment;
2. A motor that can easily move the boat against the maximum current in the stream;
3. A pair of oars for standby use;
4. A personal floatation device (PFD) for each hydrographer; and
5. A bailing device.

Manual Moving Boat

Equipment requirements for the manual moving boat method of making a discharge measurement are described in detail by Smoot and Novak (1969); they are not described in this chapter. In summary, the manual moving-boat method requires a sonic sounder, a vane with indicator, a special current meter, and an easily maneuverable small boat. The manual moving-boat method is seldom used since the advent of the ADCP moving-boat method, which is described below.

Automatic Moving Boat

The automatic moving-boat method is similar to the manual moving-boat method, except that all readings of depth, velocity, angles, and distance are recorded automatically by onboard computer equipment. Equipment requirements are more complex in order to enable the automatic sensing and recording.

Like the manual moving-boat method, the automatic moving-boat method is seldom used since the advent of the ADCP moving-boat method.

ADCP Moving Boat

Currently, the ADCP moving-boat method is the most common moving-boat method in the USGS. All readings of depth, velocity, angles, and distance are recorded to a laptop or PDA and the discharge measurement is computed using ADCP software and input from the hydrographer.

As shown in figure 73, described in other sections of this chapter, and in depth by Mueller and Wagoner (2009), ADCP moving-boat measurement techniques have almost entirely superseded the automatic moving method.

Remote-Controlled ADCP Moving Boat

There are commercially available unmanned, remote-controlled craft with ADCPs used by the USGS and others for the measurement of discharge where a manned boat or tethered boat may not be feasible. Similar to but smaller than the ADCP moving-boat, these remote-controlled craft typically come with self-contained motors and a remote-controlled system for driving the boat across a stream or river. See Mueller and Wagner (2009) for an in depth discussion of remote-controlled ADCP moving boat discharge measurements.

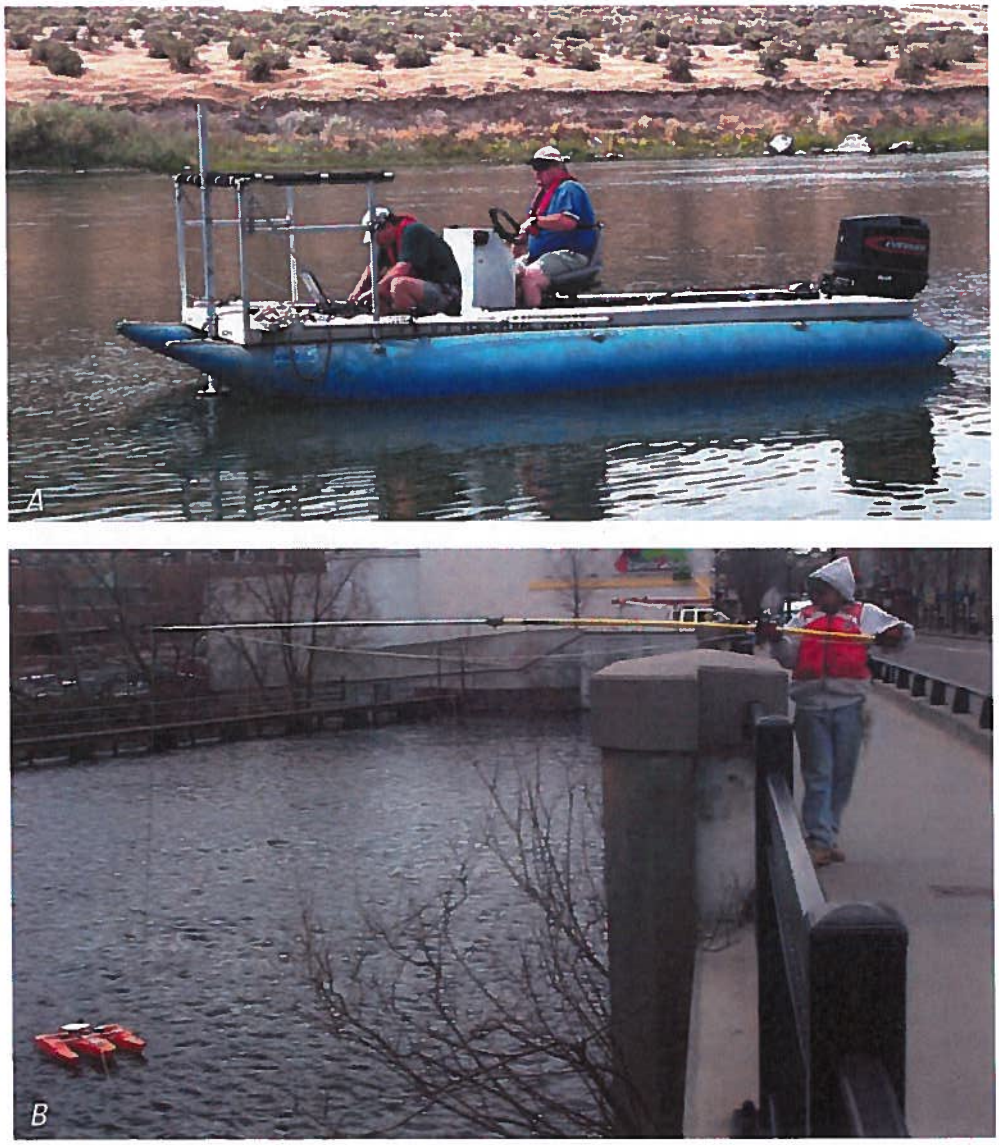


Figure 73. ADCP equipment mounted and operated on *A*, a moving boat and *B*, a tethered platform.

Electronic Field Notebooks and Personal Digital Assistants (PDAs)

Recent developments in electronics have produced commercially available electronic field notebooks (EFNs) and personal digital assistants (PDAs), designed specifically for the purpose of recording field notes while making a discharge measurement (fig. 74) . The PDAs are also designed for other field procedures, including discharge-measurement data collection and processing, station inspection, differential-level survey notes, and water-quality data collection and equipment calibration. The USGS commonly uses the Surface Water Measurements and Inspections (SWAMI) program with a PDA. The program can be used to record discharge measurements, inspections, differential-level surveys, and other field measurements. This software provides an efficient means of collecting field data (fig. 2*C*) and has been specifically designed to interface with the USGS NWIS.

The recording process is semiautomatic. Basic information and data still must be entered manually for measurements of stream depth, stationing, horizontal angle of flow, equipment, and other basic data.

EFNs automatically count meter revolutions and elapsed times, and make the conversion to stream velocity. They also assist the hydrographer with certain tasks, such as locating each subsection so that no more than 10 percent of the total flow will be included in each subsection. The notebook makes all of the measurement calculations to obtain the final discharge, and to summarize all pertinent items of the measurement.

The EFNs and PDAs can store many discharge-measurement reports. The EFN and (or) PDA reports for a discharge measurement are similar to the paper note sheets used for manual note keeping. A header, similar to the paper "front sheet," contains site information, equipment information, and a summary of measurement data. The report also contains

Figure 74. Personal digital assistants (PDAs) and electronic field notebooks (EFNs), clockwise from the top: *A*, the Trimble Juno SB PDA with GPS, Bluetooth, and Parani Serial Adapter; *B*, the Trimble Nomad 800 GL PDA with GPS and Bluetooth; *C*, the Trimble Recon PDA without GPS; *D*, the JBS Instruments Aquacalc Pro Discharge Measurement Computer; and *E*, the Hydrological Services Current Meter Counter Signal Processor with Bluetooth (CMCsp).

complete measurement data, similar to the paper "inside notes," for all of the individual subsections. In addition, the report contains various warning flags and quality-control information. Complete reports for each discharge measurement can be downloaded to a computer for viewing, printing, and other analysis.

One EFN widely used within the USGS is the Aquacalc Pro Discharge Measurement Computer (Aquacalc) by JBS Instruments. The Current Meter Counter Signal Processor (CMCsp) by Hydrological Services is used in concert with a PDA to measure discharge with a mechanical current meter, as shown in figure 74. The Aquacalc and the CMCsp will work with the cat's-whisker-, magnetic-, and optic-contact chambers on the Price current meters. As with all EFNs, care should be taken to avoid false counting of meter revolutions when measuring low velocities with mechanical meters that have a cat's-whisker-contact chamber.

PDAs are manufactured by many computer companies in the United States and abroad. Several are considered reliable and have been successfully field tested. At this writing, the PDA can interface with most of the ADCPs and electronic data loggers used by the USGS.

Miscellaneous Equipment and Personal Items

Other personal equipment and items will be needed while making discharge measurements, or when working in and around rivers, creeks, and streams. Waders or boots should be worn while making wading measurements. Waders should be loose fitting, even when allowing for heavy winter clothing.

Ice chains, as shown in figure 75, should be strapped onto the soles of boots or waders for use on steep or icy stream banks, and on rocky or smooth and slippery streambeds.

A properly fitted personal-floatation device (PFD) must be worn when working near, in, or over water. This includes while wading streams, and working on a cableway, bridge, or water retention or control structure, on ice, or in a boat.

Figure 75. *A*, Ice chains for boots and waders and *B*, Sure Grip Ice Treads for boots and waders.

Accuracy of Current-Meter Discharge Measurements

The accuracy of a discharge measurement is dependent on many factors, including the equipment used, the location and characteristics of the measuring section, the number and spacing of verticals, the rate of change in stage, the measurement of depth and velocity, presence of ice and (or) debris in the measuring section, wind, experience of the hydrographer, carefulness (or carelessness) of the hydrographer, and various conditions that can occur during the process of making the measurement. The evaluation of the accuracy of a measurement has long been a qualitative assessment that takes some or all of these factors into account. A quantitative measure of the accuracy for some discharge measurements can also be made. The following two sections of this chapter describe these methods.

Qualitative Evaluation

Every discharge measurement should be evaluated for accuracy using the qualitative method. Historically, this has been the preferred method, and the hydrographer should make this evaluation immediately after making the measurement. The evaluation should be based on the hydrographer's opinion of the accuracy of the measurement—not on how well, or how poorly, the measurement plots on the stage-discharge relation. It is difficult to provide written guidelines for making a qualitative evaluation of accuracy. A good qualitative evaluation depends mostly on the experience and training of the hydrographer. Several of the factors that should be considered by the hydrographer are as follows:

Measuring section.—Consider factors such as the uniformity of depths, the smoothness of the streambed, the streambed material (that is, smooth sand; small, firm gravel; large rocks; soft muck; and so forth), the ability to accurately measure the depth, the approach conditions, presence of bridge piers, and other conditions that would affect measurement accuracy.

Velocity conditions.—Consider smoothness of velocity, uniformity of velocity, very slow velocity, very high velocity, turbulence, obstructions that may affect the vertical velocity distribution, use of one-point or two-point method, length of counting (40 or more seconds versus half-counts), and other factors that affect accuracy of velocity measurements.

Equipment.—Consider the type of current meter used (Price AA, Price pygmy, acoustic, or electromagnetic), the type of depth-sounding equipment, and the condition of the equipment.

Spacing of observation verticals.—Use about 25 to 30 verticals for a discharge measurement, spaced so that no more than 5 percent of the total discharge is contained in each subsection. Although this is frequently difficult to attain, except in unusual cases, no more than 10 percent of the total discharge should be in a subsection. Otherwise, the accuracy will be negatively affected.

Rapidly changing stage.—Although discussed in previous sections of this chapter, this condition should also be considered when assessing the accuracy of the measurement. Using the shortcut methods previously described will result in less accurate measurements of discharge.

Ice measurements.—Making discharge measurements under ice cover is usually more difficult, and sometimes less accurate, than making open-water discharge measurements. Presence of slush ice, layered ice, and anchor ice will have adverse affects on accurate measurement of depth and velocity. Velocity distribution will be affected if the water surface is in contact with the ice. Freezing of water in the meter cups and pivot chamber may affect performance of the equipment.

Wind.—Wind can affect the accuracy of a discharge measurement by obscuring the angle of the current, or by creating waves that make it difficult to sense the water surface prior to making depth soundings. Wind can also affect the vertical-velocity distribution, particularly near the surface, and can cause vertical and (or) horizontal movement of the current meter while making a boat measurement, introducing possible error in velocity measurements.

The qualitative method of assessing the accuracy of a discharge measurement requires that the hydrographer consider all of the above items and their cumulative effect on the measurement accuracy. The front page of the discharge measurement note sheet (see figure 2) has space for describing (1) the cross section, (2) the flow, (3) the weather, and (4) any other flow conditions that relate to the accuracy. These descriptions, along with the type of equipment, number of verticals, velocity measurement method, and other measurement conditions, should provide the basis for rating the measurement as excellent (2 percent), good (5 percent), fair (8 percent), or poor (more than 8 percent).

For instance, a measurement might be rated as excellent (2 percent) if (1) the cross section is smooth, firm, and uniform; (2) the velocity is smooth and evenly distributed; (3) the equipment is in good condition; (4) the two-point velocity measurement method was used; and (5) weather conditions are good (no wind or ice). On the other hand, if several of these factors make it difficult to accurately measure depth and (or) velocity, the measurement might be rated fair (8 percent), or even poor (more than 8 percent).

As stated previously, it is not possible to provide absolute guidelines for making the qualitative evaluation of accuracy. As a general rule, the accuracy of most discharge measurements will be about 5 percent, or qualitatively a "good" measurement. This is sometimes used as the base-line accuracy, with accuracy upgraded to "excellent" when measuring conditions are substantially better than average, and accuracy downgraded to "fair" or "poor" when conditions are substantially worse than average. The qualitative-accuracy evaluation is based on the hydrographer's judgment. For more detailed qualitative-evaluation information on discharge measurements using ADCPs, see Oberg and others (2005) and Mueller and Wagner (2009).

Quantitative Evaluation

A quantitative-accuracy evaluation can be made for some current-meter discharge measurements by using the procedure described by Sauer and Meyer (1992), Herschy (1994), and the International Organization for Standardization (1997). These procedures compute the uncertainty, or standard error, using a root-mean-square error analysis of individual component errors. The component errors include errors in the measurement of width, depth, and velocity, and in computation procedures. These procedures can be used to compute the standard error for most discharge measurements made with the vertical-axis, cup-type current meter. These procedures do not apply to measurements made with other types of current meters, or other methods of making discharge measurements. Likewise, they do not apply to discharge measurements where wind, ice, boundary effects, flow obstructions, improper equipment, incorrect measuring procedures, and hydrographer carelessness are factors in the measurement.

The details of the Sauer and Meyer (1992) method are described in USGS Open-File Report 92–144, and therefore are not included in this chapter. A computer program is available to compute the standard error for individual discharge measurements, and it is recommended that this quantitative evaluation be made for each discharge measurement for which it applies. Computations using this method show that the standard error of individual discharge measurements can range from about 2 percent for ideal conditions, to about 20 percent for very poor measuring conditions. Standard errors range from about 3 percent to 6 percent for measurements having generally normal measuring conditions. The standard errors computed by this method are in close agreement with qualitative evaluations.

ADCP Discharge-Measurement Accuracy

There are many sources of error in an ADCP discharge measurement. A complete measurement is composed of the ADCP-measured channel subsection, extrapolated top subsection, extrapolated bottom subsection, and edge-estimated subsections.

The largest and most substantial subsection is the ADCP-measured channel subsection. Most errors can be greatly reduced if factors, such as moving bed, water temperature, salinity, cross-section choice, instrument configuration, and boat speed, are carefully considered and accounted for, as described in previous sections of this chapter. Software is usually provided by the manufacturer that can be used to compute the ADCP instrument error for the measured subsection.

Errors for the extrapolated top, bottom, and edge subsections will vary, depending upon the extrapolation methods and relative proportion of the total discharge represented in these subsections. Again, these errors can be kept to a minimum through proper choice of cross section and careful measurement of variables, such as ADCP transducer depth and distances from each shore to the nearest ADCP section.

Studies by Morlock (1996) and Oberg and Mueller (2007) concluded that ADCP discharge measurements can be used successfully for streamflow data collection under a variety of field conditions. In Morlock (1996), 31 ADCP discharge measurements were compared to discharge ratings defined by conventional methods for the period over which the ADCP measurements were made. These comparisons showed that 25 ADCP measurements were within 5 percent of the conventional measurements. Six of the ADCP measurements differed by more than 5 percent, the maximum departure being 7.6 percent.

The study by Morlock (1996) stated that ADCP discharge measurement error was indicated by the standard deviations of the ADCP discharge measurements. The standard deviations ranged from about 1 to 7 percent of the measurement discharges. The estimated error of each ADCP discharge measurement also was computed from formulas derived by the manufacturer of ADCPs. The computations of estimated measurement error assume that ADCP instrument- and unmeasured-subsection extrapolation errors are the main source of measurement error. The standard deviations for most ADCP discharge measurements were higher than the estimated measurement errors, indicating that significant components of measurement error were not related to the instruments; errors of this nature include temporal variations of flow. It was concluded that measurement precision can be positively affected by selection of a measurement location with minimal flow variations, and negatively affected by instrument- and boat-operation factors.

Uncertainties in Discharge Measurements

All discharge measurements, no matter how carefully made, are subject to uncertainty. The measurement uncertainty can be thought of as a quantitative measure of the dispersion of the measured discharge about the true discharge. This uncertainty arises because each measurement is subject to errors of unknown magnitude. The total uncertainty in a discharge measurement may arise from several sources, including:

- uncertainty in the measurement of the cross-sectional area, which in turn arises from the following:
  - uncertainty in measurements of width; and
  - uncertainty in measurements of depth;
- uncertainty in the measurement of the water-velocity profile, which in turn arises from the following:
  - instrument uncertainty;
  - pulsation and turbulence in open-channel flow;
  - deviation from our assumptions about the vertical-velocity distribution; and
  - uncertainty due to oblique angles in the flow velocity;
- uncertainty due to deviation from assumptions used in the computation procedures; and
- other random or systematic errors.

These component uncertainties can be combined to estimate the total uncertainty of a single discharge measurement. Where feasible, values for these component uncertainties should be estimated independently for each site.

The uncertainty is often expressed as a standard deviation. If we assume that measurement errors are normally distributed, then this uncertainty can be used to construct confidence intervals for the measured discharge value. For example, the true discharge can be expected to be within one standard deviation of the measured value at the 68-percent confidence level. At the 95-percent confidence level, the true discharge can be expected to be within two standard deviations of a single measured value.

Quality Assurance and Quality Control

It should be the goal of each hydrographer to make discharge measurements of the highest quality and with as little error as possible. As explained in other sections of this chapter there are many actions that must be performed before, during, and after the actual measuring process. In the many implicit decisions that must be made during the course of a discharge measurement, the hydrographer, through training and experience, must develop a keen sense of what is correct and incorrect through hydrologic/engineering judgment, and strive to continually take the correct course of action in making a discharge measurement. This is commonly known as quality assurance and quality control, sometimes referred to as QA/QC. Some of the QA/QC functions are implicit; that is, they are generally understood, performed automatically, and are not specifically defined in the measurement notes and sometimes must be accomplished through hydrologic/engineering judgement. Careful regard for safety, good hydrologic/engineering judgment, and observance of proper procedure are implicit functions that cannot be overstressed in making a precise and accurate discharge measurement. On the other hand, some actions are explicit, such as performing regular spin tests of current meters, or making check measurements when the first measurement may be suspect. Following are some of the QA/QC actions that should be observed for making high-quality discharge measurements. These are not all inclusive, and each hydrographer should always include and document any other actions that relate to the quality of the measurement. Additional QA/QC requirements are given in the QA/QC plan for each USGS Water Science Center.

- *Care of current meters, current profilers, and sounding equipment.*—Previous sections of this chapter describe the proper care of current meters, current profilers, and sounding equipment. Current meters are especially susceptible to damage and misalignment while in use, as well as in transit, if they are not properly protected. The hydrographer should follow all established guidelines to ensure that the streamgaging equipment, especially the current meter and (or) profiler, are in good working condition. While making a discharge measurement, the current meter should be periodically observed and checked to be sure it is operating smoothly and has not become fouled by debris, ice, or other obstructions.
- *Spin tests of current meters.*—One of the requirements for maintaining and checking current meters is a periodic, timed spin test under controlled conditions. The procedure for making a timed spin test is described in a previous section of this chapter. In addition, before, during, and after a discharge measurement, check that the rotor is turning smoothly and does not come to an abrupt stop.
- *Carefulness, good judgment, and proper procedure.*—It is the hydrographer's responsibility to apply proper procedures with care and good judgment while making streamflow measurements. These implicit functions of QA/QC should be observed at all times.
- *Computing and plotting the measurement on site.*—Compute a discharge measurement as soon as possible after it is completed. Do this at the site before leaving. If the measurement does not plot within 5 percent (or other specified percentage) of the rating curve in use, or if it is not in line with the previous trend of measurements, try to find an explanation. For instance, there may be an obvious change of the control that would explain the deviation. All such explanations should be documented in the measurement notes. If a satisfactory explanation cannot be found, then make a check measurement.
- *Making check measurements.*—If possible, while making a check measurement, select a different cross section from the original section and use a different current meter. Make the check measurement as close in time and gage height to the original measurement as possible.
- *Checking discharge measurements.*—In general, hand-computed discharge measurements are not checked for mathematical errors. Nevertheless, check measurements that do not plot within an acceptable percentage of the rating curve, or within the previous trend of measurements. Likewise, check measurements that define a significant extrapolation of the low end or high end of a rating curve. Discharge measurements recorded in an electronic notebook, such as the Aquacalc, are automatically computed and do not require checking.
- *Documentation of QA/QC.*—Document in the measurement notes, if possible, all measures taken to ensure that discharge measurements are accurate and of high quality. Some QA/QC measures require specific documentation independent of the measurement notes. For example, current-meter spin tests have specific forms that document the spin-test results and all repairs to the meter.

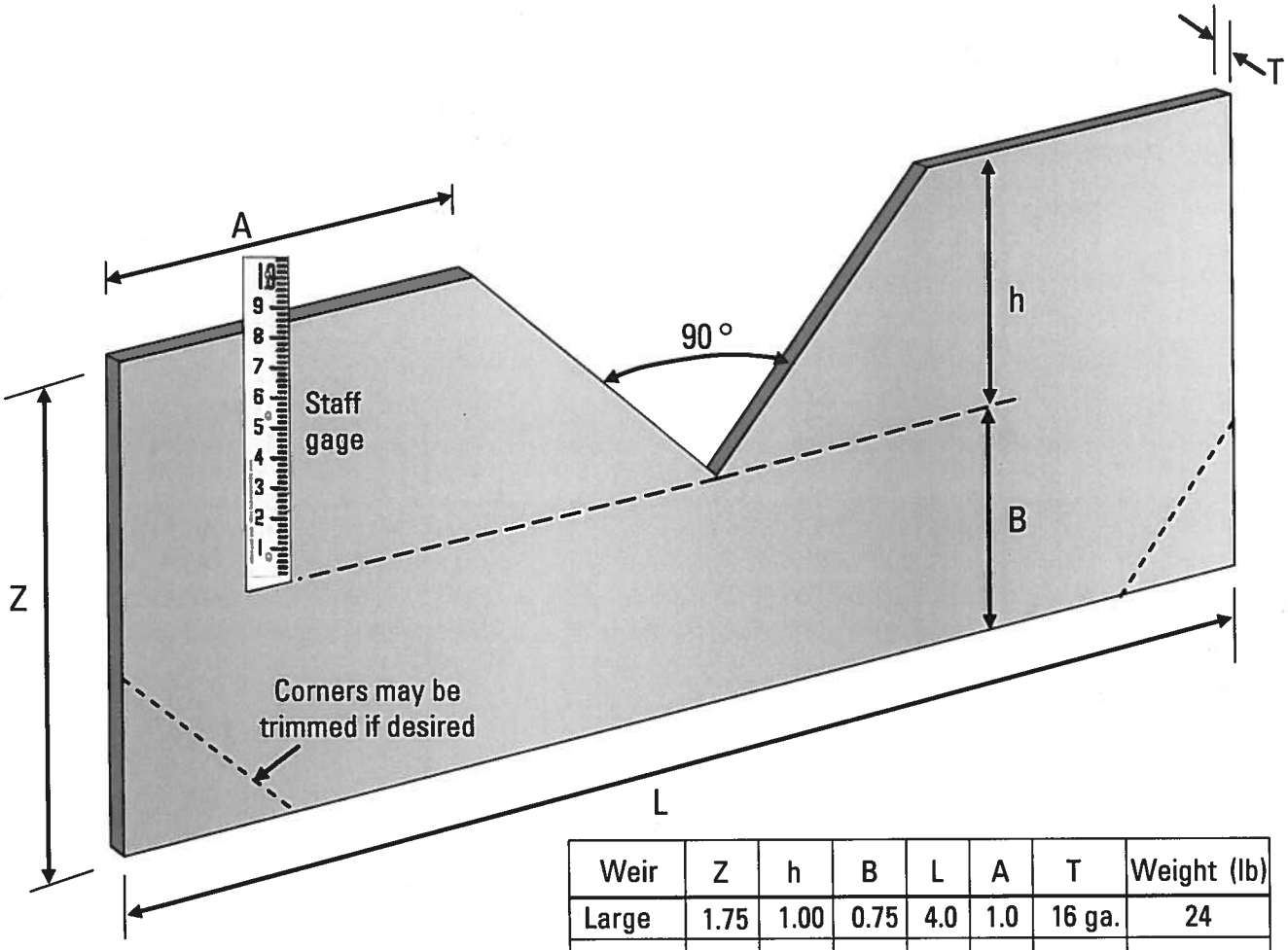
Safety Requirements

Practicing personal and overall safety is of utmost importance when working near, in, and above water. It is not the purpose of this chapter to describe all of the safety requirements; however, each hydrographer should be familiar with, and should observe, those requirements. Other documents provide the details of specific safety requirements for making wading measurements, and for working on ice, bridges, cableways, and boats. For instance, each USGS Water Science Center flood plan addresses such things as one-person versus multiple-person field parties, use of an approved PFD, and traffic control while making discharge measurements from bridges, cableway safety, and boat safety. USGS WRD Memorandum No. 99.32 (1999) provides safety guidance as it is related to discharge measurements, sampling, and other related streamgaging activities. Each Water Science Center has a safety officer and a safety plan; both should be consulted for specific safety issues.

Portable Weir-Plate Measurements

Current-meter measurements made in shallow depths and low velocities are usually inaccurate, if not impossible, to obtain. Under these conditions, a portable weir plate is a useful device for measuring the discharge.

A 90-degree V-notch weir is suitable because of its favorable accuracy at low flows. A weir made of 10- to 16-gage galvanized sheet iron will produce a free-flowing nappe, having the effect of a sharp-crested weir, and will give satisfactory performance. The thickness of the plate should vary with the size of the weir. Refer to figure 76 for recommended proportions. Decreasing the plate thickness on larger weirs will help maintain portability. The notch is cut, without sharpening, leaving a flat, even edge. Framing, in the form of small-angle irons, is required for medium and large sizes. Canvas attached on the downstream or upstream side prevents leakage under or around the weir. Eyebolts, properly placed, will secure rods driven in earth channels to stabilize the plate.



Weir	Z	h	B	L	A	T	Weight (lb)
Large	1.75	1.00	0.75	4.0	1.0	16 ga.	24
Medium	1.25	0.80	0.45	3.0	0.7	14 ga.	17
Small	0.75	0.47	0.28	2.0	0.53	10 ga.	8

Figure 76. Portable weir plate.

Attach a staff gage to the upstream face of the weir plate, with the zero point at the same elevation as the bottom of the weir notch. The staff should be far enough from the notch to be outside of the zone of drawdown, which is a distance greater than twice the head on the notch. The staff gage is used to obtain head on the weir.

The general equation for flow over a sharp-edged triangular weir with a 90-degree notch is

$$Q = Ch^{\frac{5}{2}}, \tag{20}$$

where Q discharge, in ft³/sec,
h static head, in ft, and
C the coefficient of discharge.

The weir should be rated by determining the flow volumetrically for various values of head, or by having it rated in the HIF laboratory. In the absence of a rating, a value of C of 2.47 may be used.

Flows from 0.02 to 2.0 ft³/s are measured with the large weir of figure 76. Discharges can be measured within 3-percent accuracy if the weir is not submerged. A weir is not submerged when there is free circulation of air on all sides of the nappe.

To place the plate in a sand or silt channel, only a carpenter's level and a shovel are needed. Push the weir into the streambed, and drive the rods through the eyebolts on each end to stabilize the weir. Use the level to make the top of the plate horizontal and the plate plumb. Another way to level the plate is by fastening a staff gage or level bubble to each end of the weir, where the staff gages are set at the same elevation. The plate is leveled by making the staff-gage readings identical or by using the level bubbles. Pack soil and streambed material around the ends and bottom of the weir to prevent leakage. Place canvas immediately downstream from the weir to prevent the falling jet from undercutting the streambed. Let the flow stabilize before making a measurement. Read the gage height at half-minute intervals for a period of about 3 minutes, and use a mean value in the above equation to compute the discharge. Ordinarily, one person can measure with a weir of this type. Remove the weir after you have completed the measurement.

Portable Parshall-Flume Measurements

A portable Parshall measuring flume is useful for measuring discharge when the depths are shallow and the velocities are low. The standard Parshall flume has a converging section, a throat, and a diverging section. The floor of the converging (or upstream) section is level both longitudinally and transversely when in place. The floor of the throat section slopes downward and the floor of the diverging or downstream section slopes upward. The standard Parshall flume can be used to measure discharge under free-flow conditions, as well as submerged conditions.

The flume used by the USGS is a modified version of the standard Parshall flume. The modification consists primarily of the removal of the downstream section, which reduces the weight of the flume and makes it easier to install. Because it has no downstream section, however, it can only be used to measure free-flow conditions (that is, where the submergence ratio is 0.6 or less). This can usually be accomplished by building up the streambed by a couple of inches under the level, converging floor of the flume when the flume is installed.

Free flow occurs when the ratio of the lower head to the upper head is less than 0.6. The discharge under this condition depends only on the length of crest (width of throat section) and depth of water at the upper gage. A flume that is properly constructed has an accuracy of 2 to 3 percent under free-flow conditions.

Install the flume by placing it in the channel; fill in with available channel bed or bank material around it to prevent any water from bypassing it. Use a carpenter's level to set the floor of the converging section level. Some flumes are equipped with levels attached to the braces on the flume. After the flume is in place, the streamflow is allowed to stabilize before reading the gage. After the flow stabilizes, take gage readings at about half-minute intervals for about 3 minutes. Use an average of the gage readings with the flume rating to determine the discharge. Remove the flume after the measurement is complete.

A modified 3-in. Parshall flume is shown in figure 77. This modified version is virtually the same as the standard Parshall flume except that it does not have a diverging section. The gage height, or upstream head on the throat, is read in the small stilling well that is hydraulically connected to the flow by a ⅜-in. hole.

The basic rating equation for a flume is

$$Q = Cbh^{\frac{3}{2}}, \tag{21}$$

where Q discharge, in cubic feet per second (ft³/s),
C a dimensionless coefficient of discharge that can vary with head and other factors,
b width of the throat section, in feet, and
h head, or gage height, in the converging section, in feet.

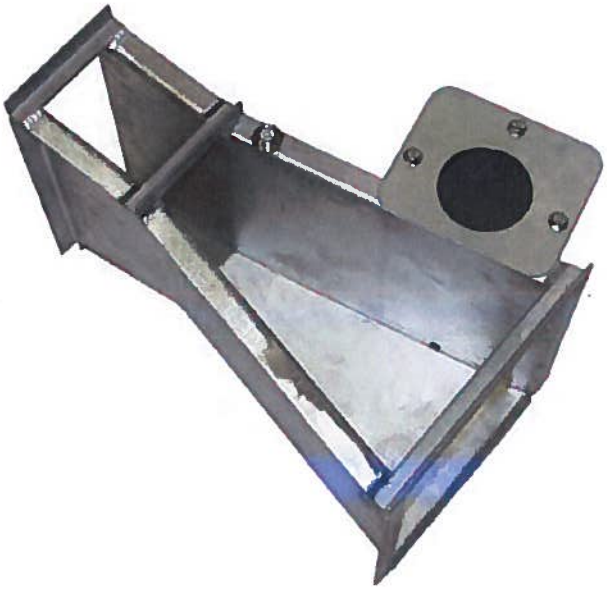


Figure 77. Modified 3-inch Parshall flume.

The rating for the 3-in. modified Parshall flume described in this section is given in table 12, and was taken from Buchanan and Somers (1969). An identical table is published by Kilpatrick and Schneider (1983), and also by Rantz (1982). The original source of this rating is unknown, but was probably based on laboratory tests. The rating in table 12 plots as a straight line on logarithmic plotting paper, and the equation for this rating was computed by regression analysis as follows:

$$Q = 1.1392h^{1.5797}. \quad (22)$$

This equation is close to one that can be derived for the 3-in. modified Parshall flume, based on the procedures given by Kilpatrick and Schneider (1983). The above equation will reproduce values of discharge precisely as shown in table 12, except for a few instances where the computed discharge deviates by 0.001 to 0.005 ft^3/s. This equation should not be used for values of gage height less than 0.01 ft or greater than 0.59 ft.

Table 12. Rating table for 3-inch modified Parshall flume.

[ft, feet; ft^3/s, cubic foot per second]

Gage height (ft)	Discharge (ft^3/s)	Gage height (ft)	Discharge (ft^3/s)	Gage height (ft)	Discharge (ft^3/s)
0.01	0.0008	0.21	0.097	0.41	0.280
0.02	0.0024	0.22	0.104	0.42	0.290
0.03	0.0045	0.23	0.111	0.43	0.301
0.04	0.0070	0.24	0.119	0.44	0.312
0.05	0.010	0.25	0.127	0.45	0.323
0.06	0.013	0.26	0.135	0.46	0.334
0.07	0.017	0.27	0.144	0.47	0.345
0.08	0.021	0.28	0.153	0.48	0.357
0.09	0.025	0.29	0.162	0.49	0.368
0.10	0.030	0.30	0.170	0.50	0.380
0.11	0.035	0.31	0.179	0.51	0.392
0.12	0.040	0.32	0.188	0.52	0.404
0.13	0.045	0.33	0.198	0.53	0.417
0.14	0.051	0.34	0.208	0.54	0.430
0.15	0.057	0.35	0.218	0.55	0.443
0.16	0.063	0.36	0.228	0.56	0.456
0.17	0.069	0.37	0.238	0.57	0.470
0.18	0.076	0.38	0.248	0.58	0.483
0.19	0.083	0.39	0.259	0.59	0.497
0.20	0.090	0.40	0.269		

Volumetric Measurements

The most accurate way of measuring small discharges is the volumetric method. This method is performed by observing the time it takes to fill a container of known capacity, or the time required to partly fill a calibrated container to a known volume. The basic equipment needed for this method is a calibrated container and a stopwatch.

Two methods can be used to calibrate the container. The first method is to add known volumes of water by increments and note the depth of water in the container. The second method is to first weigh the empty container and then add varying amounts of water to it, each time weighing the container with water, and noting the depth of water in the container. The following equation can then be used to compute the volume of water corresponding to the depth that was read:

$$V = \frac{W_2 - W_1}{w}, \tag{23}$$

where V volume of water in container, in cubic feet,
W_2 weight of container with water, in pounds,
W_1 weight of empty container, in pounds,
w unit weight of water, 62.4 lb/ft^3.

Volumetric measurements of discharge are made with two types of conditions:

- When the flow is or can be concentrated so that all of it may be diverted into a calibrated container.
- When the depth of water flowing over broad-crested weirs and dams is small and volumetric-increment samples can be obtained.

Under the first condition, measurements are made at V-notch weirs at artificial controls where all the flow is in a notch or catenary, and at places where a small earth dam can be built and all the water diverted through a pipe of small diameter. Sometimes it is necessary to place a trough against the artificial control to carry the water from the control to the calibrated container. If a small dam is built, the stage behind the dam must be allowed to stabilize before the measurement is begun. The measurement is made three or four times to ensure error-free and consistent results.

Volumetric measurements are made under the second condition by catching a segment of the streamflow with a container having a known width of opening. Samples are taken at a number of locations across the dam or weir similar to procedures used for current-meter measurements. The flow rate of each sample is increased by the ratio of the subsection width to the sampled width to obtain a discharge rate for each subsection. The total discharge of the stream is the summation of the discharge rates of each subsection.

Float Measurements

Floats have limited use in streamgaging, but they can be used where the velocity is too low to obtain reliable measurements with the current meter, or where flood measurements are needed and the measuring structure has been destroyed or it is impossible to use a meter. Both surface floats and rod floats can be used. Surface floats may be almost anything that floats, such as wooden disks, partly filled bottles, oranges, or pumpkins. Floating debris or ice cakes may serve as natural floats. Rod floats are usually made of wood and weighted on one end so they will float upright in the stream. Rod floats are sometimes made in sections so their length can be adjusted to fit the stream depth; however, they should not touch the streambed.

Two cross sections are selected along a reach of straight channel for a float measurement. The cross sections should be far enough apart so that the time the float takes to pass from one cross section to the other can be measured accurately. A travel time of at least 20 seconds is recommended, but a shorter time can be used on small streams with high velocities, where it is impossible to select an adequate length of straight channel. The edge of water for both cross sections should be referenced to stakes (or other marker) on each bank. Those points will be used at a later date, when conditions permit, to survey cross sections of the measurement reach, and to obtain the distance between cross sections. The surveyed cross sections will be used to determine the average cross section for the reach.

Float measurements may sometimes be made through a reach extending from the upstream to the downstream side of a bridge. This kind of reach may be useful where velocity is very slow and velocity observations by current meter are not reliable.

The procedure for a float measurement is to distribute a number of floats uniformly over the stream width, noting the position of each with respect to the bank. They should be placed far enough upstream from the first cross section so they attain the velocity of the stream before they reach the first cross section. Use a stopwatch to time their travel between the two cross sections. As each float passes the second cross section, note its distance.

The velocity of the float is equal to the distance between the cross sections divided by the time of travel. The mean velocity of flow in the vertical is equal to the float velocity multiplied by a coefficient that is based on the shape of the vertical-velocity profile and relative depth of immersion of the float. A coefficient of about 0.85 to 0.88 is commonly used to convert surface velocity to mean velocity. The coefficient for rod floats varies from 0.85 to 1.00, depending upon the shape of the cross section, the length of the rod, and the velocity distribution.

The procedure for computing discharge is similar to that for a mechanical current-meter measurement. The discharge in each partial section is computed by multiplying the average area of the partial section by the mean velocity in the vertical for that partial section. The total discharge is equal to the sum of the discharges for all the partial sections.

Discharge measurements made with floats under favorable conditions may be accurate to within ±10 percent. Wind may adversely affect the accuracy of the computed discharge by its effect on the velocity of the floats, especially if velocity is very slow. If a poor reach is selected and not enough float runs are made, the results can be as much as 25 percent in error.

Indirect Discharge Measurements

During floods, it is frequently impossible or impractical to measure peak discharges when they occur. Roads may be impassable; structures from which current-meter measurements might have been made may be nonexistent, not suitably located, or destroyed; knowledge of the flood rise may not be available enough in advance to allow reaching the site near the time of the peak; the peak may be so sharp that a satisfactory current-meter measurement could not be made, even with a hydrographer present at the time; the flow of debris or ice can prevent use of a current meter; or personnel limitations might make it impossible to obtain direct measurements of high-stage discharge at numerous locations during a short flood period. Consequently, many peak discharges must be determined after the passage of the flood by indirect methods, such as slope-area, contracted-opening, flow-over-dam, or flow-through-culvert, rather than by direct current-meter measurement. Detailed descriptions of the procedures used in collecting field data and in computing the discharge are given by Benson and Dalrymple (1967), Dalrymple and Benson (1967), Bodhaine (1968), Matthai (1967), and Hulsing (1967), which are in book 3, chapters Al–A5, of the USGS Techniques and Methods series. Various computer programs are available for computing the discharge for indirect measurements.

Tracer Discharge Measurements

Measurement of discharge by this method depends on determination of the degree of dilution of an added tracer solution by the flowing water. A solution of a stable tracer, such as a fluorescent dye or a radioactive chemical, is injected into the stream at either a constant rate or all at once. The solution becomes diluted by the discharge of the stream. Measurement of the rate of injection, the concentration of the tracer in the injected solution, and the concentration of the tracer at a cross section downstream from the injection point permits the computation of stream discharge. The accuracy of the method critically depends upon complete mixing of the injected solution through the stream cross section before the sampling station is reached and upon no adsorption of the tracer on stream-bottom materials. The method is recommended only for those sites where conventional methods cannot be employed owing to shallow depths, extremely high velocities, or excessive turbulence. A detailed description of the procedures and equipment used in measuring discharge by a dye-dilution method is given by Kilpatrick and Cobb (1985).

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Appendix G USGS Quality Management Plan for Environmental Projects

U.S. Geological Survey
Water Mission Area

Quality Management Plan for Environmental Projects

3 Jan 2012

Prepared For:

U.S. Environmental Protection Agency
Region VI

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Prepared By:

U.S. GEOLOGICAL SURVEY
South Central and Rocky Mountain Water Mission Areas

U.S. Geological Survey, Water Mission Area
Quality Management Plan Approval Sheet

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Date: 2/23/12

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The above signatories concur that this plan represents quality management practices within US Geological Survey Water Mission Area enters and meets the requirements for a Quality Management Plan for execution of environmental studies conducted by US Geological Survey for US Environmental Protection Agency, Region VI.

U. S. Environmental Protection Agency Region 6
Quality Management Approvals

Date: 3/5/12

Don Johnson, EPA Region 6,
Regional Quality Manager

Date: 3/5/12

Walt Helmick, EPA Region 6,
Superfund Quality Manager

iii

INTRODUCTION

It is a regulatory requirement and a policy of the U.S. Environmental Protection Agency (EPA) that all environmental programs conducted on behalf of EPA shall establish and implement effective Quality Systems. EPA policy requires that all organizational units document their Quality System in a Quality Management Plan (QMP), and submit this document to EPA for approval. Quality Systems encompass the management and technical activities necessary to plan, implement, and assess the effectiveness of quality assurance (QA) and quality control (QC) operations applied to environmental programs. The QMP is submitted to EPA, Region VI, for approval in compliance with the above-mentioned requirements. The QMP provides the general policy and procedures for the execution of environmental projects by the U.S. Geological Survey, Water Mission Area (USGS-WMA), South Central and Rocky Mountain Area (New Mexico only) which is within EPA, Region VI. Therefore, this QMP must be in agreement with the respective USGS Water Science Centers (WSC's) Quality Assurance Plan (QAP).

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ACRONYMS

ANSI	American National Standards Institute
AO	Administrative Officer
ASA	Area Science Advisor
ASQ	American Society for Quality
BASIS+	Budget and Scientific Information System Plus
DQO	Data Quality Objective
EPA	(U.S.) Environmental Protection Agency
FAR	Federal Acquisition Regulation
FBMS	Financial and Business Management System
GSA	General Service Administration
HIF	Hydrologic Instrumentation Facility
HASP	Health and Safety Plan
IDP	Individual Development Plan
IRM	Information Resource Management
IT	Information Technology
MOA	Memorandum of Agreement
NEPA	National Environmental Policy Act
NIWR	National Institute for Water Resources
NRP	National Research Program
NTC	National Training Center
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
OPM	Office of Personnel Management
PC	Project Chief
POC	Point of Contact
QA	Quality Assurance
QAP	Quality Assurance Plan
QAPP	Quality Assurance Project Plan
QC	Quality Control
QMS	Quality Management System

RA	Remedial Action
REx	Regional Executive
RMA	Rocky Mountain Area
RPD	Relative Percent Difference
SARA	Superfund Amendments and Reauthorization Act
SCA	South Central Area
SOP	Standard Operating Procedure
SPN	Scientific Publishing Network
TQM	Total Quality Management
USGS-WMA	U.S. Geological Survey-Water Missions Area
WRRI	Water Resource Research Institute
WSC	Water Science Center
WSCD	Water Science Center Director
WSCIC	Water Science Center Investigations Chief

1.0 Management and Organization

1.1 Purpose. This document provides general policy and principles for assuring the quality of data and environmental investigation products delivered to EPA, Region VI, and/or associated cooperators and partners.

1.1.1 Applicability. This QMP establishes requirements for the conduct of all environmentally related activities performed by or for the U.S. Geological Survey, Water Mission Area (USGS-WMA) South Central (SCA) and Rocky Mountain (RMA) Areas in the execution of work for and within Region VI of the U.S. Environmental Protection Agency (EPA). Several USGS-WMA offices provide services to EPA, Region VI. Figure 1 identifies the principle responsible senior staff for USGS-WMA in offices within Region VI.

1.1.2 Scope. This plan is an active working document and requires updating on an annual basis (a minimum requirement). Changes in workload, staffing, organization, and administrative guidance are reflected in each annual update. This QMP is distributed to each USGS Water Science Center (WSC) within EPA, Region VI boundaries and other USGS-WMA entities performing work in support of EPA, Region VI. A point of contact (POC) for each of these groups is included on the approval sheet on page ii. These POCs are responsible for maintaining their respective location's official QMP copy. South SCA and RMA coordinate updates and are responsible for distribution of the initial plan and updates to the POCs. The POCs will distribute the QMP within their organization and are reminded of their responsibility with each update.

1.1.3 Policy. The policy of the USGS-WMA is to deliver to cooperators and partners environmental investigation and project products that are high quality, on schedule, within budget, and conforming to the cooperator's requirements (functional, technical, aesthetic, environmental). Adherence to the following principles will contribute to achieving this policy.

- Cooperator Focused Environment. The USGS-WMA will develop and deliver products that meet the needs of its cooperators. Cooperation and open communication are established and sustained between cooperators and USGS-WMA scientists.
- Data Quality. USGS-WMA will implement its quality systems to ensure that data comply with documented standard protocols and procedures. The USGS-WMA will continue to improve the quality and usability of its long term data.

1.2 USGS-WMA Mission. To provide reliable, impartial, timely information that is needed to understand the Nation's water resources. USGS-WMA actively promotes the use of this information by decision makers to –

- Minimize the loss of life and property as a result of water-related natural hazards, such as floods, droughts, and land movement.

- Effectively manage ground-water and surface-water resources for domestic, agricultural, commercial, industrial, recreational, and ecological uses.
- Protect and enhance water resources for human health, aquatic health, and environmental quality.
- Contribute to wise physical and economic development of the Nation's resources for the benefit of present and future generations.

1.3 Organization. The USGS organization operates a number of science disciplines under the direction of the Regional Executives (REx). These disciplines include: water, biology, geology, and geography. The RExs report to the USGS Director and Deputy Director for the USGS located in Reston, Virginia (fig. 1). The RExs reside in offices in Denver, Colorado and Columbia, Missouri. The RExs manage specific areas which include the RMA and SCA. The EPA, Region VI, boundaries encompasses part of the SCA and RMA which include the following WSC offices: Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.

The RExs receive guidance and policy from the Deputy Director and staff at USGS Headquarters, Reston, Virginia, and ensures their WSCs implement and follow that guidance. REx Staff within each area perform administrative functions and manage the principle disciplines of biology, ground water, surface water, and water quality. Their responsibilities include periodic review of all aspects of WSC activities, including interpretive studies, data collection, personnel and financial resources. All USGS-WMA WSCs maintain environmental capabilities and perform a variety of data collection activities, environmental projects, and scientific research.

There are two types of programs managed at the WSC level-hydrologic investigations and data programs. The investigations program in each WSC executes scientific and environmental projects in water resources or related areas as core functions of USGS-WMA or in cooperation with local, State, or other Federal agencies. The data program consists of the collection and management of water-resources data pertinent to the mission of USGS-WMA. Area technical and managerial staff and WSC management oversee the WSC technical and project staff for program development, policy, and execution. Depending on the geography and extent of program activities, some larger WSCs may maintain program offices to support State-wide data gathering and hydrologic studies.

The USGS-WMA has established an interagency agreement with EPA to maintain a USGS-WMA liaison in the Superfund Division of EPA Region 6. The USGS-WMA liaison provides technical assistance to EPA personnel and maintains this QMP. USGS-WMA liaison for EPA, Region VI is listed below.

- Kent Becher , USGS EPA Region 6 Technical Liaison, Dallas/Fort Worth (817) 263-9545 ext. 225, (817) 253-0356 (cell)

USGS-WMA SOUTH CENTRAL AND ROCKY MOUNTAIN AREAS ORGANIZATION

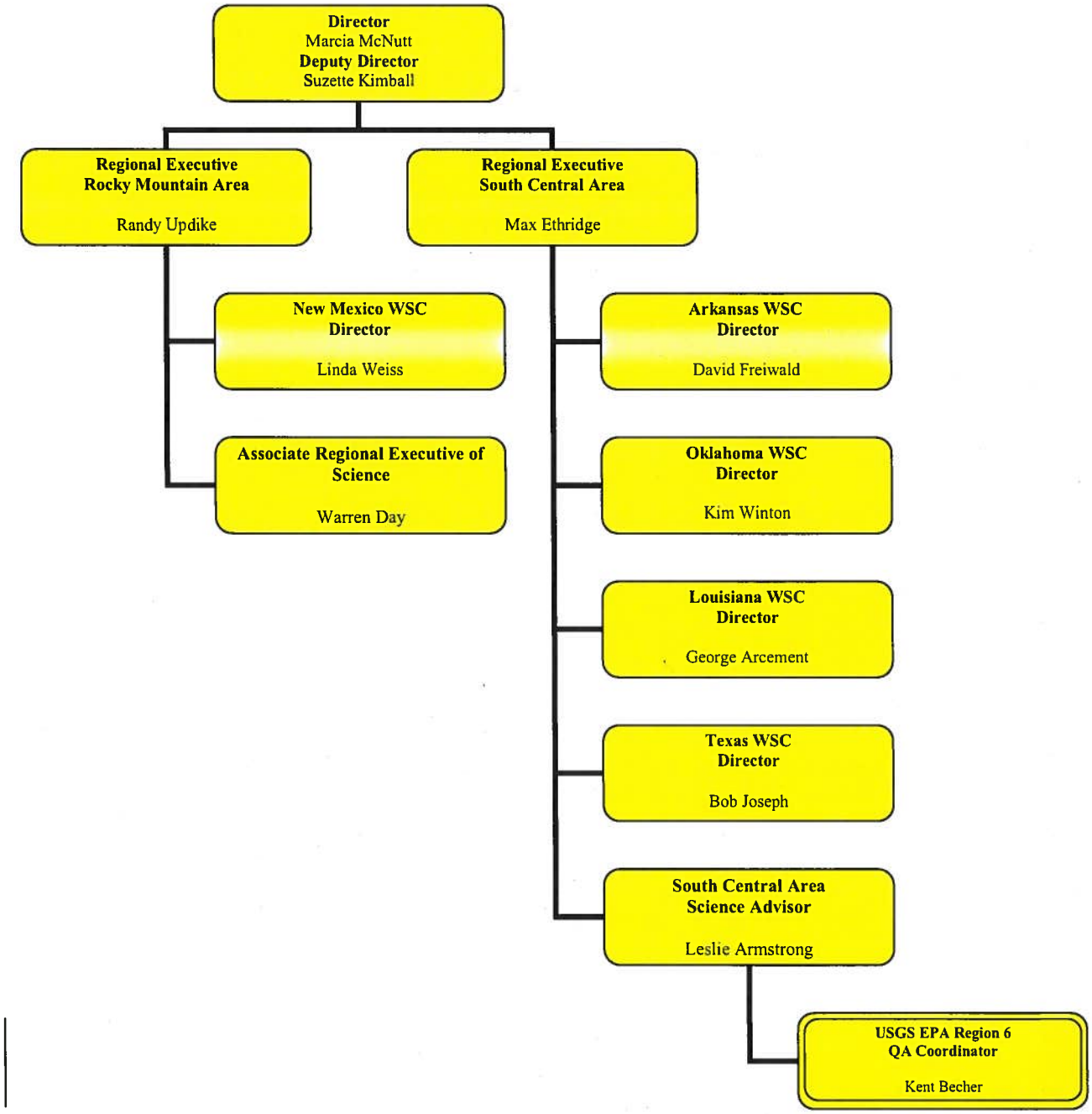

Figure 1. Organizational schematic for USGS-WMA South Central and Rocky Mountain Areas WSCs in EPA Region VI.

1.4 Roles and Responsibilities. The following sets forth the roles and responsibilities of the USGS-WMA Headquarters, Area, and WSC offices in producing and assuring that quality products and services are provided to EPA, Region VI, and /or associated cooperators and partners. In general, WSCs perform an implementation role, and Headquarters and Area offices provide QA oversight and technical assistance. All USGS-WMA staff has the responsibility to present issues to the management.

1.4.1 Headquarters. The role of the headquarters staff is to provide technical and management oversight of USGS-WMA and establish policies and guidelines for Regions and WSCs to accomplish of the mission of the USGS-WMA.

1.4.2 Area offices. The REx staff's role is to support the WSC's execution of mission by:

- Promote excellence and professionalism.
- Maintain and develop uniform technical criteria.
- Assist WSCs in resolution of technical issues
- Assist WSCs in enhancing the quality, cost effectiveness, and delivery time of environmental products and services.

Specific Area responsibilities may include review and approval of WSC project proposals and products, WSC QA programs, Quality Assurance Project Plans (QAPPs), and management of water-resource programs in keeping with the USGS-WMA Mission Statement.

Area staff may provide technical guidance to the WSCs' quality management and QC processes to ensure that:

- Mechanisms and procedures are established to enable the WSCs to produce quality products that comply with approved criteria, methods and procedures.
- WSCs plan, design, and execute projects that are relevant to the USGS-WMA mission, are cost effective and scientifically sound.
- Deliverables meet project objectives.
- WSCs develop QAPPs that provide technical detail appropriate to the complexity of the environmental system which are consistent with guidance provided. This should include documentation of QC actions, including reviews, comments, and resolution of comments.

- QA responsibilities are consistent with USGS-WMA guidelines.

The following senior staff performs key roles within Division offices to accomplish and maintain good QA:

1.4.2.1 Area Science Program Officer. QA management is carried out at the Area level by Area Science Advisor (ASA) who evaluates the quality of environmental products and processes within their WSCs by performing program assessments of the WSCs. For these assessments, the ASA provides Area review of a WSC's projects in order to evaluate the WSC's QA processes. Also, site visits are conducted to monitor the WSC's quality process. Written reports are provided to the WSC and the Region on the assessment findings, and the document is filed with permanent project documents in the WSC office and in the Area office. The ASA is independent of the WSC project activities. The ASA oversees the Area Quality Assurance Coordinator to make sure that the coordinator is working with Water Science Center QA officers in preparation of QAP and QAPPs for EPA related work activities.

1.4.2.2 Regional Executives. The RExs provide staff assistance for oversight management, technical oversight and review, and budgeting to the WSCs, utilizing the ASA to provide QA management. This includes assisting the respective WSCs in assuring quality services and products for its cooperators in accordance with the QA guidelines of the USGS-WMA.

1.4.2.3 Area Technical Staff. The technical staff of the REx consists of management experts and scientists in principle technical disciplines that provide resources to oversee and assist as needed. These technical specialists typically represent the disciplines of ground water, surface water, water quality, computer science, and reports.

1.4.3 National Water Quality Laboratory. The National Water Quality Laboratory (NWQL) is located in Lakewood, Colorado and provides routine and specialty chemical analyses to support WSC and National programs of USGS-WMA.

1.4.4 Branch of Quality Systems. The Branch of Quality Systems (BQS) is located in Lakewood, Colorado and maintains the quality-assurance/quality-control program for NWQL chemical data and for chemical analyses done through other laboratories used by USGS-WMA. The BQS mission is to monitor, assure, and improve the quality of analytical results; document field and laboratory methods; provide proficiency testing for internal and external controls; distribution and review of single and double blind samples; document potential variability and bias in analytical results; and document analytical methods used for inorganic, organic and biological constituents.

1.4.5 Region 6 Quality Assurance Coordinator. The Region 6 Quality Assurance Coordinator works with WSC QA officers in the development of QAP and QAPPs for Region 6 EPA projects. The main purpose of the coordinator is to have an

independent QA representative responsible for Region 6 QA/QC procedures that are project specific.

1.4.6 Water Science Centers. Each WSC is responsible for all QA/QC activities within their respective WSC. WSCs are responsible for controlling the quality, cost, and delivery schedule of their projects and services through the use of EPA approved QAPPs, cooperator requirements, and the WSC Quality Assurance Plans (QAP). Successful execution of quality projects requires that all functional elements and disciplines work together. Figure 2 shows the typical organizational structure of a USGS WSC. Key roles are outlined below:

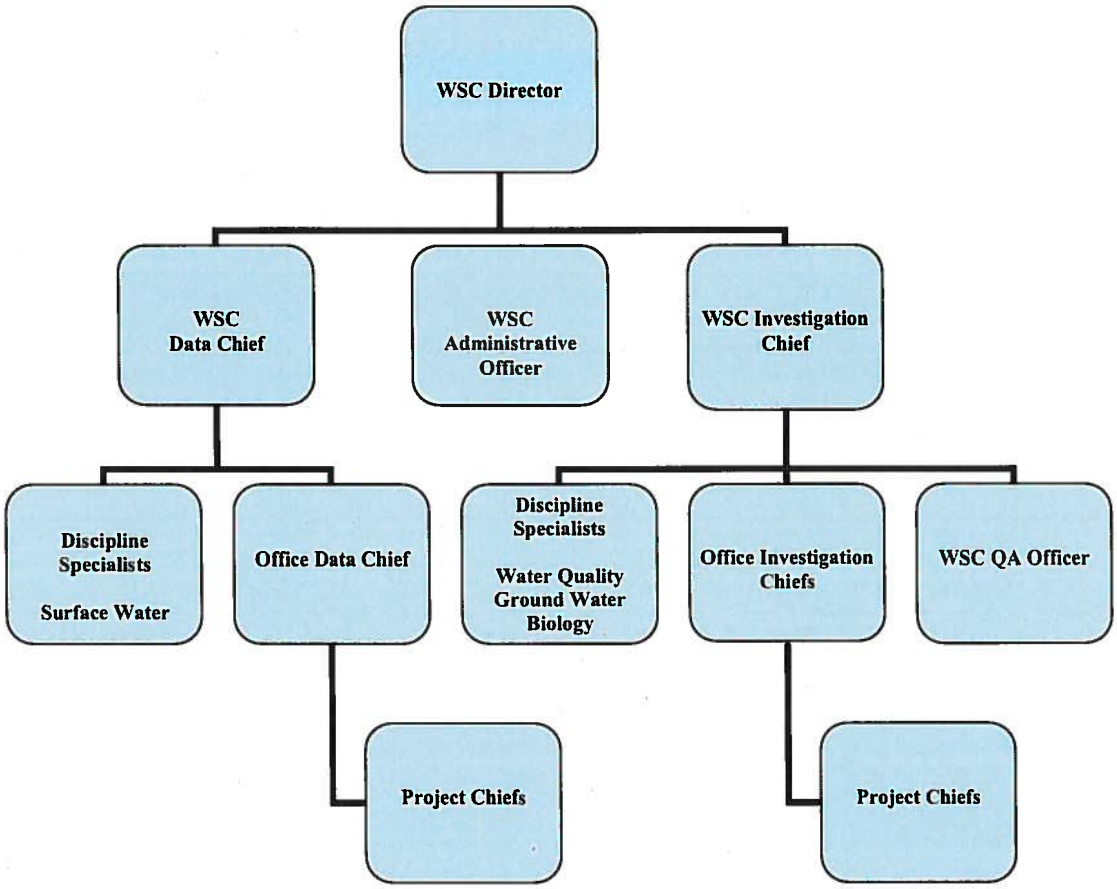

Figure 2. Generalized organizational schematic for USGS-WMA South Central and Rocky Mountain Area Water Science Centers in EPA Region VI.

1.4.6.1 Water Science Center Director. The WSCD is responsible for ensuring the actions and products of his or her staff produce the desired results such as quality, timeliness, cost effectiveness, and relevance to meeting cooperator needs.

1.4.6.2 Water Science Center Investigations Chief. The WSC Investigations Chief (WSCIC) is the WSCD assistant and monitors project QA implementation through periodic review of project activities in conjunction with the WSC QA Officer. The WSCIC is responsible to the WSCD for effective program and project management in the WSC, and supervises the individual PCs. The WSCIC is responsible for providing the resources to produce the projects and assisting in the management of projects for the WSC. The WSCIC provides continuity of leadership in developing and assessing mission and work requirements and in developing programs, plans, goals, and objectives. All project work in the WSC program is assembled under the WSCIC's oversight so that priority decisions can be made within the WSC. To assist in reinforcing integrated teamwork, the WSCIC will provide input to the WSCD concerning the performance of PCs and their contributions to project delivery.

1.4.6.3 Project Chief. The PC provides leadership to a multi-disciplined project team with responsibility for assuring that the project stays focused on the cooperator's needs and expectations and that all work is integrated and done in accordance with an approved project plan. The PC assures that the cooperator's interests are properly represented within USGS-WMA and serves as the primary point of contact between the cooperator and the USGS-WMA. Specifically, the PC keeps the WSC management and the USGS EPA Region 6 Technical Liaison apprised of the cooperator's expectations and the status of the project's progress, assists in early identification and resolution of problems, and identifies where additional resources and effort are required to meet the WSC's commitments established in the project management plan. The PC has specific project responsibility for ensuring all required QC requirements are implemented and that the resulting products are technically sound. The PC works with the WSC QA officer to make sure that all of the QC requirements are being met.

1.4.6.4 WSC Discipline Specialists. The Discipline Specialists are the lead technical staff for various disciplines appropriate to water-resources science. The Discipline Specialists are responsible for assuring WSC staff is trained in the appropriate USGS-WMA procedures and that appropriate QA/QC practices are implemented throughout the life of the project.

1.4.6.5 WSC QA Officer. The QA officer works independently of PCs to make sure that all QA activities are being followed by the PC and staff working on the project. The QA officer is responsible for the following: Serving as the focal point for QA/QC oversight of internal reviews, reviewing internal audit reports and providing comments and recommendations, ensuring the WSC QAP is implemented and followed, objectively evaluating data and performing assessments for selected projects, notifiying internal management and the Region 6 QA coordinator of QAPP deficiencies and monitoring, acts as QA liaison to EPA, participates in at least one cyle of quarterly project reviews, QAPP corrective actions, participates in all internal and external water-quality audits including review of audit reports, deals with QAPP non-conformance issues that arise, provides the final review and sign off on all QAPPs, assists in the development of QAPPs, reviews QAPP compliance reports, maintains master QAPP file (QAPPs, deficiency reports, non-conformance reports, etc.), and ensures that each project has a

Project Data Manager. Table 1-1 lists the most current QA officers for each WSC that is within the boundaries of EPA Region 6.

Table 1-1: USGS-WMA Operations Matrix within EPA, Region VI

USGS-WMA Water Science Centers in EPA Region VI	Water Science Center Office Location and Quality Assurance Officer	Program Office Location(s)
Arkansas	Little Rock Tim Kresse	Fayetteville
Louisiana	Baton Rouge Dennis Demcheck	Fort Polk; Ruston
New Mexico	Albuquerque Laura Bexfield Dianna Crilley	Carlsbad; Las Cruces
Oklahoma	Oklahoma City Mark Becker	Tulsa; Woodward
Texas	Austin Mike Canova	Corpus Christi; El Paso; Fort Worth; Houston; Lubbock; San Angelo; San Antonio; Wichita Falls

1.4.7 Collaboration. USGS-WMA networks across all organizational boundaries to draw on its strengths regardless of geographical location. Each USGS-WMA level commits itself to support project priorities and provide the necessary resources to meet commitments made to cooperators. The PC and the supporting staff foster the teamwork approach to facilitate seamless cooperator service. The PC will ensure that the direction and efforts of the team are unified, focused, and coordinated. Supporting staff shall work to deliver projects that are consistent with cooperator expectations and needs. Each member of the team keeps their respective PC informed at all times, especially of high priority or sensitive project issues including QA/QC issues.

2.0 Quality System and Description

The USGS-WMA applies QA processes and QC activities to the delivery of products and services to our cooperators to help ensure technically sound products.

- QA: An integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the client.

- QC: The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfill requirements for quality.

The USGS-WMA RMA/SCA and its respective WSCs develop and implement quality management practices, including QA for related programs and QC for various projects, that ensure that technical products meet the agreed upon requirements of the cooperator, appropriate laws, and policies. Throughout the USGS-WMA, QA systems are composed of Division management processes that together help ensure that hydrologic data and other deliverables are of the quality required for their intended use and are based on the USGS-WMA policies, procedures, and other practices. Principal elements in this Quality System are summarized below.

2.1 Quality Management Plan. This document prescribes policies and procedures for the execution of quality management activities. This plan is prepared by the USGS EPA Region 6 Technical Liaison and approved by the Regional Executives.

2.2 USGS-WMA Discipline QA Plans. Each of the principle technical disciplines in WRD have developed QA Plans that provide direction to WSC Offices on what QA/QC processes should be adhered to in order to produce data and data interpretations that are technically sound. These QA plans cover the disciplines of surface water, ground water, and water quality and are approved by the WSCD.

2.3 Quality Assurance Project Plans. In accordance with EPA requirements (EPA QA/R5), a separate Quality Assurance Project Plan (QAPP) is developed for each project undertaken by the USGS-WMA for the EPA. These plans are reviewed by the WSCD management staff and implemented following EPA approval.

2.4 WSC Reviews. All WSCs are formally reviewed on a triennial schedule by representatives of the USGS-WMA Headquarters Discipline Offices and the RMA/SCA staff. The purpose of these reviews is to evaluate all projects for adequacy of technical

approach, plans and schedule for completion, and WSC compliance with USGS-WMA discipline QA and technical policies and requirements. The results of these reviews are documented in a report to the RExs. In addition, the RMA/SCA staff performs an annual program review of WSC operations. WSC Discipline Specialists make an attempt to visit each WSC in their respective state twice a year to review projects and data.

2.5 Project Reviews. All WSC projects are reviewed quarterly. These internal reviews are conducted by senior WSC managers and typically include the appropriate Discipline Specialists and the WSCIC. These reviews assess the technical effectiveness and implementation of an individual project's progress, technical adequacy, budget, problems resolutions, adherence to project planning, and adherence to QA/QC for data gathered. Evaluating project performance produces opportunities to further improve USGS-WMA business processes, in terms of execution, productivity, cost effectiveness, timeliness, quality standards, and cooperator service. Minutes of the reviews are recorded and maintained in WSC administrative files. PCs may respond in writing as appropriate.

2.6 Technical Review of Products. USGS-WMA requires an independent technical review of all products prior to their release to the cooperator and the public. Data only products are required to have one independent review. Interpretive information products in the USGS publications series or outside publications are required to have two reviews—one of the reviews is done by a scientist from within the WSC and one by a scientist from another WSC or other USGS office.

The PC reviews the comments and responds in writing to identify any outstanding disagreements between project staff and reviewers. Disagreements are brought to the attention of the Area technical staff to facilitate resolution of those issues. If policy issues develop, it may be necessary to seek guidance from the WSCD, REx, or appropriate headquarters staff. The WSCD is responsible for the technical and policy content of all documents produced within the WSC. The author(s) documents technical issues and concerns encountered during the technical review process and documents the resolution of these issues and concerns. Files of the documentation are maintained in WSC project files. In addition, Area Technical Staff review the report and approve the report prior to processing for publication. Certain publication series require additional review from USGS-WMA Headquarters staff in Reston, Virginia. Sufficient time and resources commensurate with the complexity of the technical product are allocated to this process.

2.7 Project Proposals. Each project is managed in accordance with a project proposal. This project proposal is developed by the PC, the cooperator and the other team members. For EPA projects, the EPA Data Quality Objectives Process shall be followed to the extent applicable. http://www.epa.gov/QUALITY/qs-docs/g4-final.pdf The proposal is developed and maintained at a level of detail consistent with the size and complexity of the project. The project proposal details how the work is executed and how resources are expended. It defines the quality requirements, baseline scope, schedule, costs, and resources, including contingencies, for the project. The schedule and funding levels are realistic and reflect overall program and budget constraints and realities. It includes all project requirements including, problem statement, objectives, planning, and

other types of work performed by partners and contractors. The project proposal is considered preliminary until reviewed and approved by the Area Office.

- The quality requirements placed on each project are consistent with the risks (sensitivity, complexity, uncertainty, etc.) associated with that project and are tailored to meet cooperator requirements consistent with USGS-WMA policies. This ensures efficient use of program resources.

- All projects are periodically evaluated by the PC against the baseline requirements (quality, scope, approach, schedule, and cost) established in the approved project proposal. The PC has the responsibility to review work in progress, identify variances, and evaluate alternatives. The project team's focus for meeting project objectives is to maintain the baseline requirements in the project proposal. The PC has the primary responsibility for fiscal integrity and authority to control project funds to ensure they are used appropriately and in accordance with the project proposal. The PC, in coordination with appropriate functional elements, also is responsible for taking prompt action to correct problems identified from the project review process. Changes to the approved project proposal must be approved by WSC management, the cooperator, and the Area office, and documented in a revised proposal.

- Area staff review and approve each of their respective WSCs' project proposals for compliance with Division standards and the mission of USGS-WMA.

2.8 Data Quality Objectives (DQOs). USGS-WMA uses DQOs to formally document the desired sampling and analysis activities for EPA projects. DQOs are developed in the project proposal stage of planning and utilized to develop QAPPs.

2.9 Laboratory Data Quality Assessment. Data Quality Assessment of laboratory generated chemical data is accomplished by adherence to methodologies described in Quality Management System, U.S. Geological Survey National Water Quality Laboratory (http://wwwnwql.cr.usgs.gov/USGS_Quality.shtml)

3.0 Personnel Qualifications and Training

3.1 Personnel Qualification Requirements. As a Federal agency, the USGS must follow the Office of Personnel Management (OPM) requirements for hiring new staff. All applications are reviewed against prescribed selection criteria established for the position. These criteria are established by OPM for each position and are described in the OPM Operating Manual for Qualification Standards for General Schedule Positions. These criteria identify the knowledge, skills, and abilities required to perform the described position. In addition, the applications for all positions at the GS-13 grade level and above are reviewed by a senior management committee. This committee then identifies the best qualified individuals that have applied for the position and forwards

that list to the selecting official. Qualifications of all newly hired USGS employees are verified by the USGS personnel office.

3.2 Training. The USGS-WMA works to provide appropriate training and development opportunities to assure staff have the knowledge and skills to perform their official duties. Training needs are reviewed annually. Specific training practices and techniques are available to raise individual performance and to meet present and anticipated needs for individual knowledge, skills, and abilities. All USGS-WMA staff has Individual Development Plans (IDP) that identifies the training necessary for individual staff members to accomplish their responsibilities successfully. The USGS-WMA has developed a wide array of training courses and workshops tailored to mission needs. Staff are further encouraged and often supported financially to attend courses offered privately or at universities pertinent to an individual's career development. All formal staff training is documented and tracked through the appropriate servicing personnel office. Project specific training needs related to health and safety or to specialized technical skills are identified during project planning. The USGS-WMA meets all Occupational Safety and Health Administration requirements for health and safety training and certifications. All personnel qualification and training records are maintained by the RMA/SWA Office of Program Support.

3.3 Resource Sharing. The development of new technologies, criteria, and methods also requires a minimum technical expertise level for each discipline, depending on the extent and nature of product, service, or project accomplished by in-house personnel. Utilization of these WSC Discipline Specialists Division-wide or as instructors in USGS-WMA sponsored courses are often used to improve WSC staff capabilities. National meetings for USGS-WMA staff are held for a number of specific disciplines to exchange technical information and build knowledge of advances in the subject area. In addition, National Research Program (NRP) staff is available to the WSCs for consultation on new technologies and methods.

3.4 Individual Development Plans. It is the objective of USGS to promote the retention/development of technical expertise of WSC and Division staffs by encouraging developmental assignments, on-the-job and formal training, professional registration, participation in technical societies and conferences. IDPs are prepared and updated on an annual basis. These three-year plans identify developmental objectives (in short and long-term goals), required and recommended training, developmental assignments, and training and self-development already completed. IDPs are used to encourage continual employee enrichment and development. IDPs also are prepared at the start of a new job assignment.

4.0 Procurement of Items and Services

The procurement process in the USGS-WMA is governed by the Federal Acquisitions Regulations (FAR). In general the FARs specifies the content of the procurement document including QA requirements. The requirements and approvals vary based on the cost and complexity of the procurement. Specific application of the

FARs is described in the USGS Manual (www.usgs.gov/usgs-manual). Procurements for items and services under $3,000.00 are procured by the WSC office and are not competitively bid but are approved by the WSCD. Vendors for all procurements over $3,000.00 must be selected on cost. Based on competitive bids, the WSC office also may select vendors for procurements up to $10,000.00. The WSC can use vendors from an established source such as General Service Administration (GSA) up to $25,000. All procurements for items or services between $10,000.00 and $100,000.00 are the responsibility of the RMA/SWA Office of Program Support. Procurements over $100,000.00 are the responsibility of the Headquarters financial staff.

The degree that source evaluation and selection of a vendor is undertaken varies based on the nature, scope, and complexity of the procurement. The bid selection process includes the identification of technical criteria as appropriate for the item or service being procured. The technical criteria are established by the staff member initiating the procurement, and all procurements for technical items or services are reviewed by a technical staff member prior to issuance. When these criteria are established, bidders must address these criteria in their bid. Final payment for an item or service is based upon receipt inspection by the procuring office. For procurement of analytical services by a WSC office outside the responsibilities of the National Water Quality Laboratory, it is the policy of USGS-WMA to monitor laboratory performance through the use of QC blind samples. The Branch of Quality Systems is responsible for these tasks.

All instrumentation procured by USGS-WMA is first evaluated by the Hydrologic Instrumentation Facility (HIF) to verify that the instrument meets the specifications to perform adequately in the field. The HIF maintains a list of instruments that have been evaluated and are acceptable for field use. It is the policy of the USGS WRD that all field instruments for use in WSC operations are to be procured from the HIF. The HIF performs a receipt acceptance of the instrument prior to shipping it to the WSC. This receipt acceptance verifies that the instrument is operating correctly prior to use. The HIF also provides calibration services for a number of instruments.
Invoices are not paid until the technical staff responsible for the procurement accepts the product or service.

5.0 Documents and Records

Proper documentation is another key component of an effective QC process. Significant comments, issues, and decisions are recorded and the entire process leaves a clear audit trail. The documentation of technical reviews and other QC processes are detailed in quarterly reports submitted to the cooperator. Upon completion of the final report, the PC shall certify that the QC process for that product has been completed and that all identified technical issues have been resolved. This certification and accompanying documentation are included in the WSC project files. QA from all projects is monitored by the WSC technical staff and the PC. All project records are maintained according to the retention requirements as described in the QAPP.

5.1 Record-Keeping Procedures. Field notes, technical reviews and audits, correspondence, and other communications pertinent to project performance, data QA/QC, report reviews, and project QA are kept in a project file maintained by the WSC.

The PC may maintain some or all the records and documents for an individual active project. For inactive USGS-WMA projects records are maintained in accordance with Federal record retention requirements as interpreted by the U.S. Geological Survey Schedule Records Disposition Schedules (http://usgs.gov/usgs-manual/schedule/index.html), unless otherwise specified by the project QAPP.

5.2 Technical Guidance Documents. USGS-WMA technical memoranda and publications are used throughout USGS-WMA to promulgate directive, administrative, technical, instructional, and other types of information. Most of the memoranda and publications are coordinated with the WSCs, NRP, NWQL, and Headquarter Offices prior to finalization and issuance. The use of these memoranda and publications help aid all USGS-WMA entities are performing work in a standardized and uniform manner.

5.2.1 Updates and Revisions. When one-third or more of a publication needs updating, the publication will be revised; that is, reviewed in its entirety, reorganized as necessary, and rewritten as appropriate. When less than one-third of the publication needs updating, new pages containing the revisions will be issued to replace existing pages in the loose-leaf publication. To correct a minor error/emission, it may be more practical to just issue a single replacement page.

5.2.2 Distribution and Availability. The USGS-WMA has established an access to publications (http://infotrek.er.usgs.gov/pubs/) and technical memoranda (http://water.usgs.gov/admin/memo/) on the internet as well as notifying staff nationwide by electronic mail of significant publications. These resources ensure the most current guidance is available to all USGS-WMA entities. Printed copies of all publications are widely distributed throughout the USGS-WMA. The USGS-WMA also has libraries that provide employees electronic access to information as well as physical collections of materials. Some of the libraries are regional and serve USGS Divisions and WSCs.

5.2.3 Types of Publications and Guidance Documents. A variety of publications are used to disseminate information, policy, guidance, etc. throughout USGS-WMA. Several of these publications are listed below:

- Technical Memoranda
- Open-File Reports
- U.S. Geological Survey Scientific Investigations Report
- Professional Paper Series
- Techniques of Water-Resources Investigations
- Fact Sheets

6.0 Computer Hardware, Software and Information Technology (IT)

It is the policy of USGS-WMA to promote the widest acceptance and broadest perspective in the development of USGS-WMA information resources and to assure that data collected, analyzed, processed, and maintained on all automated data processing systems, in support of USGS-WMA programs and functions, are accurate and of

sufficient integrity to support effective quality management. It is the requirement of USGS-WMA that all complex software such as ground water models developed internally must be published through the USGS prior to use. In addition, the USGS-WMA maintains a library of published models for use by WRD personnel so that current versions of commonly used models are available on the internet (http://water.usgs.gov/software/lists/groundwater/).

IT Offices within each Region and WSC are responsible for validating and approving the requirements for the purchase and maintenance of all hardware and software. They ensure that applicable Information Resource Management (IRM) requirements and standards are met and that hardware and software are compatible with existing WSC information management systems. The majority of hardware and software purchases are of commercial off-the-shelf equipment and programs.

Budget and Scientific Information System Plus (BASIS+) is used for project and financial management for each project. Developing, defending, and maintaining budgetary data and all other information necessary to manage a project is the responsibility of the PC. Supervision of this process, along with development and maintenance of all program data and oversight of BASIS+, is the responsibility of the WSC's Administrative Officer (AO). The PC supervises the aggregation of program and project data to facilitate review and management recommendations by the WSC/RMA/SWA staff. The Department of Interior uses Financial and Business Management System (FBMS) for the Departments financial management and to meet future business needs. The system manages budgeting, project management, finance, acquisition, financial assistance, real and personal property, and reporting (including activity-based costing). FBMS gives the USGS the benefits of common processes, a common technology platform, integrated real-time data, and improved operational decision-making.

Most USGS-WMA data are stored in the National Water Information System (NWIS) data management system. It is the responsibility of each PC and WSCIC to verify that data in NWIS are correct. In cases where the data are not stored in the NWIS system electronic files or paper copies are stored in project folders.

7.0 Planning

The USGS-WMA goals for scientific applications and data gathering are to remain on schedule and within budget and without compromise to health and safety. These goals challenge Regions and WSCs to continue striving for better, safer, faster, and cost effective completion of work activities and project closeout.

7.1 Health and Safety. If required by the project, the PC develops the individual project Health and Safety Plan (HASP) on the basis of site conditions to protect personnel involved in site activities and the surrounding community. The plans address all applicable regulatory requirements in accordance to 29 CFR 1910.120(i)(2) – Occupational Health and Safety Administration, Hazardous Waste Operations and Emergency Response; 29 CFR 1926, OSHA, Safety and Health Regulations for Construction; 29 CFR 1926.65, OSHA, Hazardous Waste Site Operations and Emergency Response; U.S. EPA Occupational Health and Safety Manual. The HASP

provides site background discussions and describes personnel responsibilities, protective equipment, safety and health protocols, decontamination procedures, personnel training, emergency response contingency plan, and type and extent of medical surveillance. Accident prevention plans also are incorporated into the HASP. The plans identify problems or hazards that may be encountered and how these are to be addressed. Procedures for protecting third parties, such as visitors or the surrounding population, are also provided. The practice of field safety for all the various field activities conducted by USGS-WMA follows recommended practices detailed in the National Field Manual for the Collection of Water-Quality Data (http://water.usgs.gov/owq/FieldManual/index.html). The plans are reviewed and approved by the Regional Safety Officer. For in-house work, the WSC Safety Officer approves the plan.

7.2 Project Planning. The project planning process typically involves a number of phase-specific activities. The planning process supports efforts to prepare project specific DQO statements that meet the definition of a DQO as provided in EPA's 7-Step DQO process (EPA QA/G-4). The DQO process and the planning process are the planning tools for environmental studies within EPA's and USGS-WMA's quality management systems, respectively. As planning tools, both processes are intended to ensure data are of the type, quantity, and quality needed and that interpretations are useful for decision making in environmental actions. The planning process is a critical component of the USGS-WMA quality management system that meets the American National Standard Institute (ANSI)/ American Society for Quality (ASQ) for planning the collection and evaluation of environmental data ANSI/ASQC E4-2004, a national consensus standard for quality systems responsible for environmental data collection and environmental technology programs. Project planning typically occurs in several sequential steps or phases:

a. Phase I (Identify Project Issue or Problem)

Phase I activities bring together decision-makers and technical personnel to determine an overall project approach and identify a focus for the specific product, service, or project activities.

b. Phase II (Determine Data Needs)

Phase II activities offer guidance to assist "data users" with the detailed planning required to identify and document data needed for the current project and subsequent execution steps in the project. Phase II helps data users determine the level(s) or categories of acceptable data quality required for the intended purpose or use of every data need. The required quality of field data and analytical data to be collected is dependent on the data use.

c. Phase III (Develop Data Collection Options)

Phase III efforts of "Data Implementers" develop approaches for sampling and analysis activities that will fulfill the data needs of data users and scientists, within the constraints of the project.

d. Phase IV (Design Data Collection Program)

Phase IV activities involve selection of data-collection components that best meet the cooperator's goals for the product, service, project, etc. During this phase, the technical planning team establishes a DQO for each data need and finalizes related work plans or scopes of work. This step is used to identify the degree of QC oversight required to support the DQO's.

Some key concepts of the project planning process are:

1) Project Completion. Project completion is the successful execution of all project activities and submission of a final written product to the cooperator, often as a publication in a USGS or outside publication.

2) Cooperator's Goals. Includes identifying, understanding, and communicating to the cooperator the concept of a water-resources investigation with regard to schedule and budget constraints.

3) Project Team. Project teams consist of decision-makers, data users, scientists, technicians, and other project-specific technical specialists needed to achieve the cooperator's goal.

4) Project Objectives. Project objectives are the short- and long-term issues to be addressed and resolved in a water-resources investigation. Satisfying and resolving the project objectives with all the attendant decisions required are the purpose of all USGS-WMA investigations. Most project objectives are consequences of the environmental-resource-management issues driving the need for the investigation.

5) Project Approach. Project approach is the list of specific tasks to be performed in a timely manner to achieve the project objectives. The approach to the problem is typically well-defined in the project proposal and accompanied by a chart that lists the specific task and the time-frame for execution and completion of each task in the project approach.

6) Data Users. Data users are the technical personnel responsible for scientific evaluations that are the basis for environmental projects. Data users determine the data needs to satisfy project objectives.

7) Data Implementers. Data implementers (e.g., chemists, hydrologists, engineers, geologists, scientists, etc.) identify the sampling and analysis methods suitable for satisfying the data needs determined by the data users.

8) Data Collection Options. Data collection options are different groups of data needs and their associated sampling and analysis methods. Data collection options provide a simple mechanism to document the "basic" data needed for the current project; "optimum" data that is cost-effective and prudent to collect for future executable steps in the investigation; and any "excessive" data that others, besides the data users, impose or mandate in excess of the data needed by data users.

9) Data Quality Objectives (DQOs). "DQOs are qualitative and quantitative statements derived from the DQO process that clarify study or project objectives, define the appropriate type of data, and specify the tolerable levels of potential decision errors that are used as the basis for establishing the quality and quantity of data needed to support decisions" (EPA QA/G4). DQOs produced as a result of the project planning process meet EPA's definition (of a DQO). The DQOs documented during the planning process are project-specific statements that describe the data needed; the intended uses of the data, and the sampling and analysis methods to achieve acceptable data quality for the intended data uses. If a data user defines a probabilistic-type of data need, Steps 5 through 7 of EPA's 7-Step DQO process can be used to determine the number of samples required for the intended data uses. Application of probabilistic methods can only be accomplished when all of these three conditions exist: 1) when a precise study question is defined; 2) the cooperator and lead regulator have established tolerable limits on decision errors; and 3) the support of a qualified environmental statistician is available to work on the project.

8.0 Implementation of Work Processes

8.1 Environmental Data Collection, Verification and Validation.

8.1.1 Introduction. Collection and analysis of water-quality data within the USGS-WMA are discussed briefly in some of the sections and details of sampling protocols provided in the USGS National Field Manual (USGS, various dated). The USGS-WMA PC is responsible for initiating and coordinating the defined QA/QC activities. The project specific QAPP details the chemical data-quality management for each project and activities are implemented as described in the plan.

8.1.2 Goals of the QA/QC program. The goals of the USGS-WMA QA/QC program are to:

- Generate data of acceptable quality for the intended use.
- Satisfy the needs of the cooperator, the scientists, and the regulators.
- Generate sufficient data of known quality on the first attempt.
- Provide a historical record for potential future use.

When QA/QC is used properly, the PC can readily measure the success of the team in meeting the project-specific DQOs. The USGS-WMA QA for data-collection programs consist of activities presented in the USGS National Field Manual (USGS, various date). QC procedures for data consist of additional sampling including replicates, blanks, and matrix spikes to determine quality of data related to field procedures.

8.1.3 Chemical Data Quality Management Activities. All environmental projects require a comprehensive and multifaceted approach to QA and QC in order to achieve and document attainment of appropriate quality for the intended data usage. The PC is the focal point to ensure that chemical data DQOs are established for his or her project. The PC can use several techniques to monitor and ensure the quality of chemical data. QA/QC activities are applied by USGS-WMA on a project-specific basis to assist in generating data of known quality. These include:

- Appropriate sampling protocols.
- Field blanks, matrix spikes, and replicates.
- Sample handling QA.
- QA sample collection and field analyses.
- Field data review.
- Laboratory QA and QC.
- Review of primary laboratory data.
- Validation of data.
- Technical review of written products. Discussions of principal QA/QC activities are provided below.

8.2 Validation of Primary and QA Laboratories. In general, NWQL and supporting laboratories will obtain a BQS laboratory validation prior to field studies or

sample analysis. The USGS-WMA BQS is the lab responsible for the preparation and distribution of QA samples. The Organic and Inorganic Blind Sample Program is used by BQS to evaluate both NWQL and other laboratories supporting USGS-WMA. Results of bias and variability are available on the on the Web at (http://bqs.usgs.gov). NWQL provides limited automatic data validation consisting of logic checks on inorganic water data and holding times of samples where critical. The laboratories participate in national and international inter-laboratory performance-evaluation studies with EPA, National Water Research Institute of Canada, and National Oceanic and Atmospheric Administration.

8.3 Sample Quality Assurance.

8.3.1 Sample Handling Quality Assurance. The NWQL provides timely feedback regarding problems with sample shipments. The NWQL is responsible for checking the sample shipment including temperature, proper preservatives and correct containers. The PC or other appropriate technical personnel for the project is then notified regarding the status of the sample shipment via facsimile, electronic mail, or telephone call. All documentation pertaining to sample receipt or analysis is included in the laboratory's data report, which is emailed to the collector and the WSC contact and is stored in the sample or result comment fields in the water-quality database (QWDATA) operated under NWIS.

8.3.2 QC Sample Collection and Analysis. QC sample collection and analysis is the main tool to determine that the data generated by field activities and laboratories is technically valid and of adequate quality for the intended data usage. Based on the needs of the project, a percentage of samples are duplicated, spiked or a blank is collected. QC sample collection does not have to be performed at the same frequency or rate for all test parameters, on all matrices, during all project phases, nor for any one type of project. General considerations include:

- The data use and users as defined by the project-specific DQOs.
- The total number of samples being generated (e.g., a larger number of total samples collected may lower the percentage of QC samples needed).
- The need for statistically significant information from QC sample data.

Ideally, the USGS-WMA sample collection and analysis program is an interactive process whereby the NWQL in conjunction with the PC detect and solve problems as sampling and analysis occurs to ensure that the data generated for the project meet the project DQOs.

8.3.3 Validation of Data. Data validation is the process of data assessment as stated in accordance with EPA regional or national functional guidelines or the project QAPP or USGS-WMA guidelines. Data validation includes assessment of the whole raw data package from the laboratory.

8.4 Use of QC Samples.

The use of QC samples is a particularly powerful tool for maintenance of data quality. Having QC data for a single sampling point allows for data comparisons to be conducted. In addition, QC samples may provide unique indications about the quality of the laboratory data. The use of QC samples during the project, adds value by verifying the analytes of concern and quantifying the levels of contamination. If the environmental results and QC data are comparable, then this evaluation provides an additional level of confidence that the data are valid. If the laboratory data do not compare with the associated QC laboratory data, then this evaluation establishes bias and variability that will aid in decision making. In addition, the QC laboratory data yields information regarding the spatial heterogeneity of the data.

8.5 Data Management and Archival Process. The PC and laboratories are responsible for generating, controlling and archiving laboratory and field records for all projects. This information is maintained with a system that allows access to any documentation that affects the reported results. The PC or staff determines the quality of the data generated and submits the results into the USGS-WMA database operated under NWIS.

8.5.1 Laboratory. The laboratory prepares and retains full analytical and QC documentation that allows sample tracking from initiation to disposal. The following minimum records are stored for each project:

- Login form, chain-of-custody, and other pertinent documents received with the samples.
- Communications between the laboratory and PC.
- Any associated corrective actions.
- Laboratory data packages.
- Finalized data report.
- Laboratory log books.
- Electronic data. The laboratory also maintains a Quality Management System (QMS) and relevant SOPs for the methods performed. (See attached USGS Open File Report 2005-1263)

8.5.2 Field. Project-specific records are retained. These records may include correspondence, chain-of-custody records, field notes, and reports issued as a result of the work. These records may include documentations of equipment performance records, field log books, drilling logs, maintenance logs, personnel files, general field procedures, and corrective action reports.

8.6 Field Operations Protocol . Field methods used by USGS-WMA staff are developed by Headquarters discipline offices. Prior to final release, each proposed method goes through two independent technical reviews. The final procedural method is then approved by the Headquarters discipline Chief before it is released. All USGS-

WMA water programs follow these protocols so that data is consistent from one project to another.

8.7 Technical Review of Reports. After a draft report has been prepared, the report is reviewed for technical and editorial adequacy and policy by the senior author's supervisor. The author(s) revise the report accordingly and submit for colleague review. At a minimum, two colleague reviews (at least one from outside the originating office) are required. Colleague reviews are arranged by the supervisor, usually in consultation with the author(s). The author(s) revise the report per colleague reviews and respond in writing (e-mail is acceptable) to each reviewer, explaining how each of the reviewer's major comments were addressed. The revised report (paper copy and electronic files), colleague reviews, and copies of colleague review responses are then submitted to the WSC reports specialist. The WSC reports specialist reviews the report and either returns the report to the authors for revisions or submits the report to the Scientific Publishing Network (SPN) for editorial review, revision, and formatting for further processing. Interpretive reports (usually Scientific Investigations Reports or journal articles) are submitted (including colleague reviews and responses) to RMA/SWA for approval. Noninterpretive (data) reports (usually Data Series) are approved locally by the WSC reports specialist for the WSCD. After approval, any comments from RMA/SWA or the WSC reports specialist are resolved, and the report is prepared for Web posting or printing, or both, by the SPN. The entire process from draft report to final publication typically takes from 3 to 6 months, but the time can vary widely depending on the length and quality of the report and workloads of the reviewers and the SPN.

9.0 Assessment and Response

9.1 Project Teams. All projects are continually evaluated against the baseline requirements (quality, scope, approach, schedule, and cost) established in the project QAPP. The PC has the responsibility to review the work in progress, identify variances and evaluate alternatives. The project team's focus for meeting project execution goals is to maintain the baseline quality requirements in the project proposal. Any changes within project QAPP must be approved by the EPA or their designated approving authority. The project team participates in project reviews that are held at the Area and WSC levels to keep senior staff informed of progress, resolution of issues, and performance assessments.

9.2 WSC Project Reviews. All WSC projects are reviewed quarterly. These internal reviews are conducted by senior WSC managers and typically include the appropriate WSC Discipline Specialists and the WSCIC. These reviews assess the technical effectiveness and implementation of an individual project's progress, technical adequacy, budget, problems resolutions, adherence to project planning, and adherence to QA/QC for data gathered. Evaluating project performance produces opportunities to further improve USGS-WMA business processes, in terms of execution, productivity, cost effectiveness, timeliness, quality standards, and cooperator service. Minutes of the reviews are recorded and maintained in WSC administrative files. PCs may respond in writing as appropriate.

9.3 Regional Program Review. Each Region of USGS-WMA may annually evaluate WSC programs by reviewing individual projects and overall program for progress, technical adequacy, budget, adherence to QA/QC for data gathered, and suitability of project activities (both ongoing and proposed) for achieving the mission of USGS-WMA. These reviews may help identify system problems, trends, and improvements to the quality management and the QC process

9.4 National Discipline Reviews. For each WSC office, USGS-WMA Headquarters, specifically, the discipline offices of Surface Water, Ground Water, and Water Quality, provide reviews of projects that collect data for a particular scientific discipline in approximately three-year intervals. The national review team addresses data management, QA/QC practices, data validity, field protocols, project technical adequacy, and scientific interpretations of data. Results are compiled by the technical team leader and recommendations are submitted in a memorandum to the RH for action. The WSCD in concert with the WSCIC and PCs provide written responses to the RH, including plans to implement appropriate actions recommended by the review. The WSCD is responsible for implementation of any corrective actions required by the review. Any disagreement over the findings is referred to the next level of management for resolution.

9.5 Data Assessment. Any time data are generated, the quality of the data is assessed prior to use. The type and degree of assessment required depends upon the project DQOs. Several different levels of data assessment exist, including data verification, data review, data evaluation, and data validation.

9.5.1 Data Verification. Data verification is the most basic assessment of data. Data verification is a process for evaluating the completeness, correctness, consistency, and compliance of a data package against a standard or contract. In this context, "completeness" means that all required hard copy and electronic deliverables are present. Data verification is performed by the NWQL or contract laboratory for laboratory deliverables.

9.5.2 Data Review. Data review is the next step in the data-assessment hierarchy. Data review is the process of data assessment performed to assure data quality. Data review includes an assessment of environmental and QC data provided by the laboratory. Data review also includes examination of laboratory QC data to determine the quality of the laboratory analytical data.

9.5.3 Data Evaluation. Data evaluation is the process of data assessment conducted by PCs or their staff to determine whether the data meets project DQOs. During data evaluation, the PC uses the results of the data review as summarized to determine the usability of the data. To evaluate data, the PC utilizes the QAPP, field data collection activities, and any other data quality indicators available. The evaluation documents the potential effects of QA/QC failures on the data, and the PC assesses their impact on attainment of DQOs for the project.

9.5.4 Data Validation. Data validation is the process of data assessment as stated in accordance with EPA regional or national functional guidelines or the project QAPP or USGS-WMA guidelines. Data validation includes assessment of the whole raw data package from the laboratory.

9.5.5 Assessment of Screening Level Data. The degree of data assessment is different for screening level data than for basic data. Screening level data are typically characterized by less stringent QA/QC procedures. Assessment of screening level data consists of checking whatever QA/QC indicators are available and confirming the results with definitive analyses.

9.5.6 Data Verification and Review at Laboratory. Basic data assessment begins at the laboratory. Once the data have met the laboratory's standards, data verification is performed to determine if the data package is correct and complete. The NWQL Quality Management System describes laboratory QA/QC in detail and has been provided as additional document to this QMP in a PDF format.

10.0 Quality Improvement

An important management approach to project QA focuses on continuous process improvement. This approach is utilized with several systems within USGS-WMA to promote feedback and to assure continuous improvements in quality.

10.1 Data Quality Management. Data quality is essential to all USGS-WMA activities. The type, quantity, and quality of analytical data collected must meet all DQOs for the project. The DQO approach is used to organize key planning issues in a thoughtful sequence to ensure that the work effort will result in the type and amount of data required to determine the next course of action.

10.2 Laboratory Validation. Prior to performing project specific analysis, NWQL and any contract laboratory are required to demonstrate analytical competency through a detailed evaluation of the laboratories technical capabilities (discussed in section 8.2).

10.3 Project Reviews. Project reviews provide the management team QA of project performance for technical adequacy and timeliness.

10.4 Cooperator Surveys. The USGS-WMA occasionally solicits input from cooperators regarding performance and satisfaction. These evaluations provide valuable lessons learned and ways to improve USGS-WMA performance quality.

10.5 Employee Training. As discussed in section 3.2, it is the objective of the USGS-WMA to promote retention/development of technical expertise of Division and WSC staffs by encouraging developmental assignments, quality training, professional registration, and participation in technical societies. Attendance at scientific training workshops and seminars also provides opportunities for employee development and thus quality improvement in USGS-WMA products and services.

10.6 Partnering. Another method the USGS-WMA uses to continually seek better ways to make decisions that enable us to accomplish our scientific mission, and to generate broad support from other agencies and interests, is through partnering. Partnering involves a commitment by the participants to foster quick project implementation, improve cost-effectiveness, and improve scientific understanding of water resources needed to address environmental issues. It is a process by which two or more organizations with shared interests act as a team to remove all organizational impediments that prevent open communication within the team, to provide open access to information, and to empower working-level staff to resolve as many issues as possible. A partnering relationship enables the development of a clear sense of mission among all involved stakeholders and promotes appropriate empowerment, delegation, and assumption of responsibility.

REFERENCES

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at http://pubs.water.usgs.gov/twri9A/

ATTACHMENT A: DEFINITIONS:

Activity. An all-inclusive term describing a specific set of operations or related tasks to be performed, either serially or in parallel (e.g., research and development, field sampling, analytical operations, equipment fabrication, etc.), that in total result in a product or service.

Assessment. The evaluation process used to measure the performance or effectiveness of a system and its elements.

Audit. An independent, systematic examination to determine whether activities comply with planned arrangements, whether the arrangements are implemented effectively, and whether the results are suitable to achieve desired objectives.

Contractor. Any organization or individual that contracts to furnish services or items or perform work.

Cooperator. The owner, client, user, project manager (PM), or beneficiary of a service or product.

Data Quality Objectives (DQOs). Qualitative and quantitative statements that clarify technical and quality objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that are used as the basis for establishing the quality and quantity of data needed for support decisions.

Data Quality Objective Process. A Total Quality Management (TQM) tool, based on the Scientific Method and developed by the U.S. Environmental Protection Agency to facilitate the planning of environmental data collection activities. The DQO process enables planners to focus their planning efforts by specifying the use of the data (the decision), the decision criteria (action level), and the decision-maker's acceptable decision error rates. The products of the DQO process are the DQOs.

Data Usability. The process of ensuring or determining whether the quality of the data produced meets the intended use of the data.

Document. Any written or pictorial information describing, defining, specifying, reporting, or certifying activities, requirements, procedures, or results.

Investigations Chief. The WSC point of contact regarding QA of scientific investigations with responsibility to oversee WSC products and services.

Partnering. Partnering may be defined as "the development and sustainment of a relationship that promotes achievement of mutually beneficial goals". Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of delivered products and services. Partnering is a

voluntary relationship that builds upon the good relationship that exists among the professional participants involved in any engineering or design activity.

Program - is a group of projects, services or other activities that may be categorized by funding source, cooperator requirements or other common criteria for which resources are allocated and collectively managed.

Project. An organized set of activities within a program (products, services, etc.) intended to produce a specific expected outcome or solution to a cooperator problem or need. Cooperator, in this sense, is used in a broad manner and refers to discrete (even localized) entities, organizations internal or external to the Corps and, in some cases, the Nation as a whole.

Project Proposal. The detailed, specific plan, used to manage and control the delivery of a project from its inception to completion.

Project Chief (PC). The leader of the project team, responsible for managing the project parameters (budget, cost, safety, schedule, scope, and quality), as well as interfacing with those involved in the project process (cooperators, functional elements, government, and non-government entities).

Quality. The totality of features and characteristics of a product or service that bear on its ability to meet the properly developed stated or implied requirements of the user.

Quality Assurance (QA). An integrated system of management activities involving planning, implementation, assessment, reporting, and quality improvement that measures the degree of excellence of and insures that the system is functioning to provide the desired specified product or service.

Quality Control (QC). The overall system of technical activities that monitors the degree of excellence provided for the performance of a task that meets the agreed-upon requirements or standards of the cooperator.

Validation. The data is confirmed by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled. In design and development, validation concerns the process of examining a product or result to determine conformance to user needs. Data is accepted or approved after examining it by a qualified individual.

Verification. The data is confirmed by examination and provision of objective evidence that specified requirements have been fulfilled. In design and development, verification concerns the process of examining a result of a given activity to determine conformance to the stated requirements for that activity. Data is checked to make sure it exists or is correct by a qualified individual.

Water Science Center Director (WSCD). The program leader and authority for WSC or State operations of the USGS-WMA.

ATTACHMENT 1

Example Letter to Document Adherence to the QAPP

TO: (name)
(organization)

FROM: (name)
(organization)

Please sign and return this form by (date) to:

(address)

I acknowledge receipt of the referenced document(s). I understand the document(s) describe quality assurance, quality control, data management and reporting, and other technical activities that must be implemented to ensure the results of work performed will satisfy stated performance criteria.

_____ _____

Signature Date

Copies of the signed forms should be sent by the GBRA to the TSSWCB Project Manager within 60 days of EPA approval of the QAPP.