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

Chapter A13

COMPUTATION OF CONTINUOUS RECORDS OF STREAMFLOW

By E. J. Kennedy

Book 3
APPLICATIONS OF HYDRAULICS

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PREFACE

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The unit of publication, the Chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises. Chapter A13 deals with the computation of continuous records of streamflow.

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TWI 1-D1. Water temperature—influential factors, field measurement, and data presentation, by H.H. Stevens, Jr., J.F. Ficke, and G.F. Smoot. 1975. 65 pages.
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TWI 3-A11. Measurement of discharge by moving-boat method, by G.F. Smoot and C.C. Novak. 1969. 22 pages.
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TWI 5-A1. Methods for determination of inorganic substances in water and fluvial sediments, by M.W. Skougstad and others, editors. 1979. 626 pages.

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[1]Spanish translation also available.

TWI 5-A2. Determination of minor elements in water by emission spectroscopy, by P.R. Barnett and E.C. Mallory, Jr. 1971. 31 pages.

TWI 5-A3. Methods for the determination of organic substances in water and fluvial sediments, edited by R.L. Wershaw, M.J. Fishman, R.R. Grabbe, and L.E. Lowe. 1987. 80 pages. This manual is a revision of "Methods for Analysis of Organic Substances in Water" by Donald F. Goerlitz and Eugene Brown, Book 5, Chapter A3, published in 1972.

TWI 5-A4. Methods for collection and analysis of aquatic biological and microbiological samples, edited by P.E. Greeson, T.A. Ehlke, G.A. Irwin, B.W. Lium, and K.V. Slack. 1977. 332 pages.

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TWI 8-B2. Calibration and maintenance of vertical-axis type current meters, by G.F. Smoot and C.E. Novak. 1968. 15 pages.

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COMPUTATION OF CONTINUOUS RECORDS OF STREAMFLOW

By E. J. Kennedy

Abstract

Records of continuous streamflow, published in the U.S. Geological Survey annual Water Data Reports for the States and territories, are computed from field data, mainly discharge measurements and recorder charts or tapes. This manual describes the computation procedures used and some details of related field operations. It was compiled mostly from unpublished Water Resource Division district manuals edited and supplemented to emphasize digital-recorder and associated computer use. Methods used primarily for graphic-recorder gaging stations and non-recording gages are also included. Reference is made to other publications for some of the more specialized or unusually complex procedures.

Introduction

Records of continuous streamflow in the U.S. Geological Survey annual Water Data Reports for the States and territories, which are also stored in various computer formats, are computed from field data, mainly discharge-measurement notes and water-stage recorder tapes or charts. This manual, in the Techniques of Water Resources Investigation (TWRI) series, describes the most commonly used computation processes. A published continuous-streamflow record consists of two parts: (1) the manuscript station description which contains statements concerning the location of the gaging station, drainage area, records available, gage details, average discharge, summary of revisions, extremes of stage and discharge, and a description of any abnormal conditions and (2) a table of daily discharges with monthly and annual statistics. Only the procedures used to compute the daily-discharge table, minimum flow, and peaks are covered herein.

The streamflow-record processing methods described in this manual have evolved under USGS leadership during the last century from a variety of methods described by Follansbee (1938) and used by a few pioneer hydrographers throughout the Western World prior to 1890. A USGS camp was established at Embudo, N. Mex., in 1889 to investigate, modify, and standardize stream-gaging methods. The Embudo work was the foundation for the present systematic stream gaging in the United States. Refinements have been added over the years as high-water measuring equipment and reliable water-stage recorders have become available, and automatic data processing (ADP) has been adapted to hydrography. Standard forms for listing and plotting the data were adapted, and general instructions for record computation were circulated. This material, combined with procedures best suited to local conditions, was described in handbooks prepared and periodically updated by several USGS districts. Selected portions of the district handbooks and other unpublished material, edited and supplemented for broader application, comprise much of this manual. All of the processes described are typical of the state-of-the-art in 1982 but may require modification to fit local conditions. Reasonable standardization of processes is recommended, but innovation and the development of improved processes are strongly encouraged.

The procedures outlined in this manual apply to field data collected by using the methods described in the other TWRI manuals in Book 3, listed at the front of this manual, and in Water-Supply Paper 2175 (Rantz and others, 1982). Hydrographers must be familiar with at least the parts of these publications and the National Water Data Storage and Retrieval System (WATSTORE) manuals (WATSTORE User's Guide volumes 1 and 5) that apply to any streamflow records they are computing. A programmable calculator is particularly useful for many of the computations involved.

The field data used to compute a station record are (1) an up-to-date field-station description giving the site details; (2) a summary of the results of all gage-checking levels that have been run at the site; (3) a list of all discharge measurements that have been made at the site; (4) the field notes describing channel conditions during the current period; and (5) the water-stage-recorder charts, punched-paper tapes, or gage observer's readings and notes for the current period. Weather records and records for nearby gaging stations are also used for most discharge records.

Record computation is usually done in eight basic steps in sequence: (1) determining the datum and gage-height corrections that apply to gage readings; (2) listing the current discharge measurements and plotting them along with relevant past measurements on an appropriate rating curve sheet; (3) developing the discharge rating; (4) computing the daily mean gage heights; (5) computing the discharge figures from the daily mean gage heights by using the discharge rating (in two steps, a primary computation and an update, for digital-recorder stations); (6) estimating the daily discharges for periods of inapplicable or missing gage-height record; (7) preparing a narrative description of the computations (station analysis); and (8) carrying out procedures to assure quality control of the records. The use of this sequence of steps prevents a revision to the work by the checker in any step from affecting the previous work.

The quality of a streamflow record at a given site and its ease of computation are closely related to the skill exercised in the fieldwork. This skill is greatly enhanced when the hydrographer has parallel office computation and field experience and by formal training and career development programs. Most record-collection work is done according to a management plan set by each district, by personnel assigned to a data-collection unit. The unit is usually directed by a hydrographer supervisor whose duties may include the scheduling of fieldwork and office work, post-field-trip debriefings for the continuous evaluation of field data, the supervision of the computation of records, career development including both on-the-job and formal training of the staff, and an annual inspection of each gaging station. Most Geological Survey offices have access to the central computer facility through a local terminal and the WATSTORE system. A growing number (in 1982) of offices also have minicomputers used to process the digital-recorder tapes, and the details of some of their procedures differ from those described in this manual. A data-collection unit's work often includes some collateral data-collection duties involving ground water, sediment, and the chemical and bacteriological quality of the streamflow; and its staff may be augmented during flood periods by personnel from other organizational units.

Field Data Requirements

The field station description contains information needed to help shape the ratings, rank major floods, investigate abnormalities in the record, and write the manuscript station description. Leveling is used to monitor gage-datum changes and to compute corrections to the gage readings. Discharge measurements are used to define the discharge rating and shift adjustments. The gage-height record, with the discharge rating and shift adjustments, is used to compute the daily discharges and peak flows.

Field-station description

Prepare a description on standard form 9-197 as soon as the gaging station is established. Use the outline and headings given in figure 1. Keep the description up to date with "pen-and-ink" changes until it becomes cluttered and must be rewritten. File superseded field descriptions for future reference. Figure 2 illustrates the recommended format for a typical description of an ordinary gaging station.

Location.--Lat-long.; land-line location (public-land surveyed states); county; distance from bridges, dams, falls, highways, tributaries, towns, etc.; and river mile or distance from mouth. How reached. Give highway routes and road logs for normal and high water access. Same information for slope station auxiliary gage.

Establishment.--Date of first record published by U.S.G.S. that is equivalent to present record, and the name of the organization that installed the gage.

Drainage area.--Size of total area, size and type of noncontributing area, source of figures, method of computation, coordination information, and name of coordinating agency

Gage.--Decription, manufacturer and type of recorder, gage heights of components (intakes, doorsills, maximum recordable stage, shelter roof, etc.), principal gage, reference gage, description and location of outside gage and other supplementary gages, unusual features of equipment, elevation (or altitude) of gage datum above N.G.V. Datum. Same information for a slope-station auxiliary gage.

History.--Brief descriptions, in chronological order by date of start of record collection, of all gages with equivalent records operated at or near the site. Include major additions or changes to the equipment.

Reference and benchmarks.--Include at least three and no more than five RM's for a base gage, no more than three for a slope-station auxiliary gage, and one for a supplementary site. Describe RM and its location fully. Show latest elevation above gage datum at the time the description is prepared and note the most permanent mark. Name and number of NGS or U.S.G.S. benchmark used for N.G.V.D. tie, its latest published or listed elevation above N.G.V.D., the adjustment or datum date, and its elevation above gage datum.

Channel and control.--Character (rock, sand, gravel, clean, vegetation prone, permanent, shifting, etc.) and alignment of channel in the gage vicinity, character of banks and stage when overflow starts on each bank, extent of overflow at a specific high stage for each bank, the character of the flood plain, and number of channels at high and low stage.

Character, type, and location of low-water and high-water controls, sensitivity to ice effect, permanency, and any special conditions.

Discharge measurements.--Location, maximum depth (gage height + ___ ft), and velocities at the best wading sections and the high-water measuring sections. Measuring conditions, anticipated accuracy, and special hazards. Location of culverts or bypass sections not evident during floods. Stage of the start of road overflow in the measuring section. Alternate high-water measuring sites, stored boats or equipment, special measuring problems or methods. For cableways; safety precautions, location, type and height of A-frames or towers, size of anchorages, length, diameter and type of cable, type of connectors (sockets, clips, etc.), unloaded sag, sag marks on A-frames, stationing, and initial point. For bridges; safety precautions, bridge occupancy limitations by police or highway officials, location, stationing details, horizontal angle coefficients. For boat ranges; safety precautions, width, permanent alignment or triangulation targets, availability of boats, etc.

Give the locations of any sites that have been used for slope-area, contracted-opening, or other indirect measurements or of sites that appear promising for the purpose.

Floods.--Narration of historic data search, (date, name of investigator, names of sources of information, nature of information, authority of informant, etc.). Interpretation of information. Include all historic floods, but only the notable ones within the period of station operation.

Point of zero flow.--Location, gage height, probable accuracy, permanency. Recommend frequency of observations.

Winter flow --Ice effect likely to be more severe or less than at other stations in the area. Why?

Regulation and diversion.--Location, description, and probable effect of dams, lakes, power plants, reservoirs, swamps, unusual land use, above or just below the station. If the station is one of several on a regulated stream, refer to the next gage upstream and describe in detail only those regulations and diversions between the gages.

Accuracy.--Anticipated accuracy, with all equipment working, for the different seasons and ranges of flow.

Cooperation.--Each agency involved, the proportion of its support (financial and technical), and the dates.

Sketch.--Page size sheet with enough detail to enable one unfamiliar with the locality to reach the station, park a vehicle, and locate principal features with minimum effort. Include gage, measuring sections, and any paths or trails used to reach them. An additional large scale sketch may be needed to illustrate an obscure site.

Photographs.--File with photographs of principal features (close view of gage and shelter, general view showing control, measuring equipment, etc., and stereo slides of the channel).

Observer.--Name, address, phone number, occupation, place where usually contacted during the day, gage duties, and rate of pay.

FIGURE 1.—Outline of a field-station description.

9-197

Station No. 05447540
Description Prepared 7-16-81
by J.C.J.

Description of Gaging Station on Mud Creek at Crisfield, Illinois

Location.--Lat 39°57′06", long 89°23′19", in NE 1/4 NE 1/4 sec. 8, T. 17N., R.3W., Logan County, Hydrologic Unit 07130009, on left bank at downstream side of county highway bridge, 0.6 mi (1.0 km) south of Crisfield 2.6 mi (4.2 km) north of Caulfield, 6 mi (10 km) downstream from Jacks Fork, and 12 mi (19 km) upstream from mouth.

The station can be reached from Crisfield at low water by driving 0.6 mi south from the courthouse. When the road is inundated during floods, the station can be reached at all stages by driving north 2.6 mi from the intersection of State Highway 54 and the county road (Elm Street) in Caulfield. There is an off-the-road parking space at the gage shelter.

Establishment.--January 15, 1970, by Corps of Engineers, U.S. Army, Rock Island District.

Drainage area.--58.7 mi^2 (145.5 km^2) measured by USGS on 7 1/2′ USGS topographic quadrangle sheets by FIABRC methods and accepted by the official coordinating agency (Corps of Engineers, Chicago Division) for inclusion in their published list of drainage areas.

Gage.--Fisher-Porter digital recorder (SN 176321, W 86429), principal gage, set to agree with an electric tape gage in a 5′-4" square concrete block house and well connected to the stream by a single 2 1/2" intake equipped with standard 3-way steam cock flushing system with hand pump (3" x 10" cylinder) and static tube. Two outside staff sections are attached to the intake headwall (3.4 to 6.65 ft) and to the face of the well (6.66 to 27.0 ft). A Type-A wire-weight gage which usually reads from 0.02 ft (at 3.4 ft stage) to .10 ft (at 17 ft stage) higher than inside stage is mounted on the downstream handrail of the bridge.

The station is equipped with a BDT (SN 18216, W86430) and a telephone (317-2264). To phone from the gage house, remove receiver and lift white plunger under the receiver before dialing. For telephone repairs and trouble shooting, call phone company - Mr. A. G. Hortz (Caulfield) 317-8120.

Pertinent elevation of gage features:

Floor of well	-1.05 ft
Intake at well	1.09 ft
Intake at outer end	1.02 ft
Cleanout doorsill	9.27 ft
Floor of shelter	26.69 ft
Maximum recordable stage	28.75
Top of instrument shelf	29.19
Top of roof (peak)	33.90

The datum of the gage is 575.18 ft above N.G.V.D. of 1929.

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History.--The gage was established using the present wire-weight gage, read twice daily by a local resident (C. M. Rouse) and operated by Rock Island District Corps personnel until it was taken over by USGS on July 1, 1972. The present recording gage was started in use on October 22, 1972. The cableway was completed in June 1974. No other gages have been operated on this stream.

Reference and bench marks.--RM-1 is a USGS gaging station tablet set in the top of the left upstream bridge wingwall. Elevation is 17.256 ft above gage datum.

RM-2 is a chiseled square in the top of the right upstream bridge wingwall. Elevation is 17.078 ft above gage datum.

RM-3 is a USGS gaging station tablet set in rock on left bank 53 ft downstream from well and 6 ft shoreward from low water edge. Elevation is 2.645 ft above gage datum.

RP-1 is the top of a 1/2" bolt set in the edge of the instrument shelf. Elevation is 21.190 ft above gage datum.

Permanent turning points (tops of 3/8" lag screw heads) are set, one in each outside staff backing, to aid in checking the accuracy of gage plate settings. A steel tape attached to the backing and adjusted for the best average agreement throughout the range of the gage plates, reads 4.498 ft at the lower TP (on sec. 0-6.75). The upper TP (sect. 6.75-27.0) reads 13.972 ft on a similarly synchronized tape.

NGS BM K-54, described in NGS list, is .5 mile north of the gage, 46.30 ft above gage datum, and 621.42 ft above NGVD of 1929.

Channel and control.--The channel is straight near the gage and its bed is gravel and loose rock which is clean except for aqueous growth during the warm months. The banks are wooded. The channel is reasonably permanent but is changed by major floods. Right bank overflow starts at 12 ft and extends about 400 ft over cultivated land at 20 ft. Left bank overflow starts at 15 ft and extends about 100 ft through wooded land at 20 ft. Control for low water is a rocky gravel riffle 50 ft downstream from the gage. The control shifts during minor rises and tends to collect leaves and debris. Grass and other aqueous growth also causes shifting. Flow is swift over the control which is affected by ice only during prolonged cold spells during low-flow periods.

Discharge measurements.--Discharge less than about 300 cfs is usually measured by wading between the gage and control where maximum depth is about 0.2 ft less than the stage. Higher measurements for stages below 5 ft can be measured at the bridge both of whose handrails are marked in 5 ft intervals from the face of the left abutment and where the maximum depth is equal to stage. Higher measurements are made from the cableway 300 ft upstream which is marked in 5 ft intervals from the left A frame and where main channel depths are about 1.5 ft plus stage. A Type A reel, protracter, puller, and 100 lb. weight are stored in a steel box at the base of the left A-frame. Flow beyond the right A-frame must be estimated or measured by wading.

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FIGURE 2.—Sample field-station description.

The cableway is articulated and has a 10 ft frame on the left bank and a 14 ft frame on the right bank. The main cable is 1-inch tramway steel, 320 ft long between sockets. Backstays are 1 1/4-inch diameter. All connections are factory-installed sockets. Unloaded erection sag is 3.2 ft. A red horizontal stripe on each frame is 3.2 ft below the pin to provide a check on unloaded sag. The car is a standup type kept locked on the left bank. Both A-frames are fenced. All components are standard USGS design.

A constricted reach of channel with minor overflow areas about 0.3 mi downstream is a good site for slope-area measurements.

Floods.--On October 12, 1972, Paul James interviewed C. M. Rouse, local resident, who has lived at the site since 1914 and whose family's knowledge of the area extends back to the settlement of the valley in 1835. Mr. Rouse pointed out the foundation of the original family residence, 1/4 mi downstream from the gage, that had a foot of water over the first floor during a flood in the summer of 1886. The 1886 flood was the highest one known to Mr. Rouse since his family settled in the area. The 1886 flood height was 28.5 ft above the water surface elevation on October 12, 1942 (1.55 ft at the gage) or about 30 ft stage at the gage site. The stream was about 3 ft over the floor of the bridge in May 1943, according to Mr. Rouse, a stage of about 27 ft, the only other major flood mentioned in local lore.

Paul James also checked the Crisfield Clarion, a weekly county paper started in 1906. News items described the flood of May 22, 1943, which washed out parts of the Crisfield-Caulfield County road, as "the highest since the big flood of August 1886" on local streams.

The above information was interpreted as follows: The flood of August 1935 reached a stage of about 30 ft, the highest known since at least 1835. The second highest known flood reached a stage of about 27 ft on May 22, 1943.

Point of zero flow.--The gage height of zero flow was 1.21 ± .04 ft on March 31, 1979. The point of zero flow moves when the control is scoured or filled by rises or ice movement. Its gage height should be measured at the time of each low-water wading measurement.

Winter flow.--Ice effect is likely to be less severe at this site than on other streams in the locality because of the swift current over the control.

Regulation and diversion.--Extreme low flow is affected occasionally by improvised and unrecorded temporary dams that form pools for pump intakes used for supplemental irrigation during droughts. About 30 stock ponds on tributaries also affect low flows. No permanent mainstream dams exist or are planned.

Accuracy.--Records for flow greater than 100 cfs should be excellent. Those for discharge less than 10 cfs should be fair. Other records should be good.

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Cooperation.--The first 2 1/2 years' operation was by the Corps of Engineers who collected and furnished the record. The USGS-Corps collaborative program paid for the gage construction and operation until June 30, 1976. The USGS-Illinois Water Survey Division cooperative program supported all operations after July 1, 1976.

Observer.--October 22, 1972 to November 30, 1976, C. M. Rouse, Star Route 17, Crisfield, Illinois, inspected the gage weekly for $10 per month. Mr. Rouse, farmer, lives in the house just south of the gage and can usually be contacted at home.

December 1, 1976 to ____________________, A. J. Rouse, Star Route 17, Crisfield, Illinois, telephone 314-6659, inspects the gage weekly for $12 per month. Mr. Rouse lives 0.2 mi north of the gage on the west side of the road, but can usually be found working in the Crisfield Hardware in Crisfield.

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FIGURE 2.—Sample field-station description—Continued.

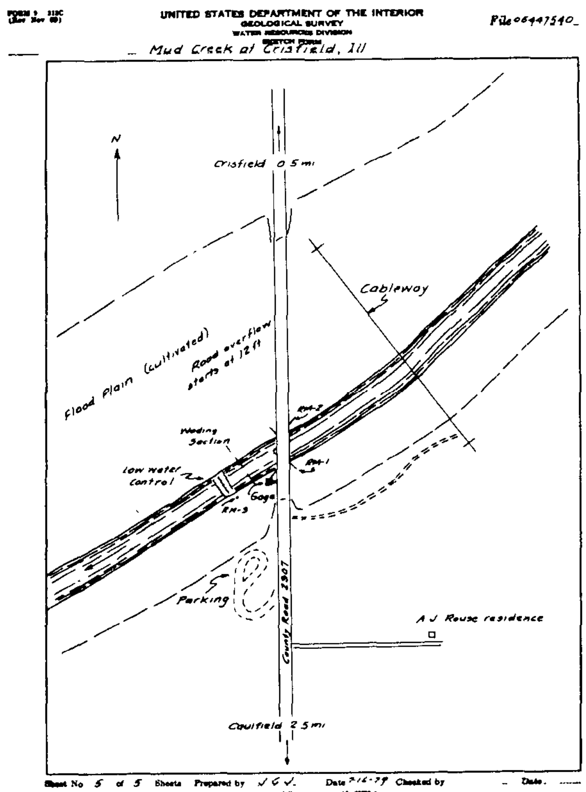


FIGURE 2.—Sample field-station description—Continued.

Gaging-station levels

A gage-supporting structure, such as a well, may settle causing the gage to read too high; or the structure may be lifted by frozen ground making the gage read too low. These and other types of gage errors may accumulate over several years and, if neglected, affect the ratings or distort the relative heights of recorded floods. The errors can be measured by running periodic gaging-station levels, with standard surveying methods and equipment, between the gage and reference marks on stable ground. Gages can be reset, or their readings can be adjusted by applying corrections based on the levels. Levels are also used to measure the elevation of the gage datum above National Geodetic Vertical Datum (NGVD) where a bench mark is within a reasonable distance (usually a few miles). Levels to NGVD are particularly desirable when there is probable need for transfer of data by profile. Examples of probable needs include (1) evaluation of risk to property in a flood-prone area; (2) design of nearby highways; and (3) development of basin models. Where levels are impractical, determine the approximate altitude of the gage from a map or with an aneroid barometer.

Gaging-station leveling is exacting work thoroughly described in the Manual for Leveling at Gaging Stations in North Carolina by Thomas and Jackson (1981), which covers scheduling of levels, precision, accuracy, instrument adjustment, adjustment of leveling errors, tabulation of results, and general concepts. Use that manual or a version of it modified to fit local conditions, for all gaging-station levels.

Manual for Leveling at Gaging Stations in North Carolina contains several examples of acceptable level-note format and tabulation of results. Figure 3 illustrates a format where the level notes are on the back side of a special form (fig. 3*B*) and the adjustments and results are on the front side (fig. 3*A*). A format similar to this is recommended, but the use of any logical and checkable method of keeping, adjusting, and listing notes is normally acceptable. The gage-checking levels are usually run to thousandths of a foot, and those for the NGVD tie are usually run to hundredths of a foot.

Tabulate the results of all complete gaging-station-level sets ever run at the site and also any partial gage checks made without levels and used to reset the principal gage. Use a format similar to that in figure 4 or the generally similar format illustrated in the Manual for Leveling at Gaging Stations in North Carolina. The tabulation is designed to be a concise history of all levels and changes to gages and will be the basis for computation of datum and gage height corrections as explained in a subsequent section of this manual. The tabulation, once prepared, is updated each year by the addition of the results of any gage-checking activities. The tabulation should be checked before it is used.

Discharge measurements

Discharge-measurement notes, ordinarily computed at the gaging-station site, require some checking before the results can be listed and used to develop the discharge rating.

A

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

STATION Mud Creek at Crisfield, Ill

DATE Nov 6, 1980 PARTY B R Jones Jr, R S Cline

ELEVATIONS OF POINTS

Object	1st Diff.	2nd Diff.	3rd Diff.	4th Diff.	Aver Diff	Elevation
RM-1						17.256
	1.858	1861			+ 1 860	
Ch bar						19.116
	2 036	2 037			− 2 036	
RM-2						17.080
	4 111	4.110			+ 4 110	
RP-1						21.190
	7 225	7.223			− 7 224	
TP-1						13.966
	9 467	~~9 462~~	9 465		− 9 466	
TP-2						4.500
	1856	1 859			− 1 858	
RM-3						2.642
RM-1						17.26
	2906	29.03			29.04	
BM-K54						46.30

WIRE WEIGHT GAGE	Found	Left
Ch Bar. Elev	19 116	19.116
Ch Bar Rd.	19.130	19.116
W.S Reads	1 42	1.41

BUBBLER DIAL or FLOAT TAPE	Found	Left
R.P. Elev.	21.190	21.190
Tape to W.S.	19.786	19.786
W.S. Elev	1 404	1 404
Gage Rdg	1 425	1.404
Corr'n	− .021	0

OUTSIDE STAFF SECTIONS

Section	Found			Left		
	R.P Elev.	R P. Read	Corr'n	R.P Elev.	R P. Read	Corr'n
0-6.7	13.996	13.972	−.006			−.006
6.8-27.0	4 500	4 498	+.002			+.002

Sheet 1 of 1 Comp. by BRJ Chk. by RSC Date 11-6-80

B

STATION	B. S.	HT. INST.	F. S	ELEVATION	REMARKS
RM-1	3.719	20.975		17.256	Gag sta marker
Ch bar	2 147	21 261	1861	19.114	Rds 19 130
RM-2	6.724	23.802	4 183	17.078	□ on rt abutm
RP-1	3 176	24 365	2.613	21.189	bolt on shelf
TP-1	1 709	15.673	10.401	13964	bolt on sec 0-6.7
TP-2	3.812	8 309	11.176	4.497	" " " 6.8-270
RM-3	9 834	12.475	5.668	2.641	bolt nr control
TP-2	11.250	15 750	7.975	4.500	
TP-1	10 254	24.216	1 788	13.962	
RP-1	2.956	24.141	3 031	21.185	
RM-2	4.252	21.327	7066	17075	
Ch bar	2673	21.785	2.215	19.112	
RM-1			4.534	17 251	
	Rerun TP-1 to TP-2				
TP-1	1 437	15.401		13.964	
TP-2			10.902	4.499	
	NGVD Tie-in levels				
RM-1	10 86	78 12		17.26	
TP-1	9.24	35.79	1.57	26.55	
2	11.54	44.47	2.86	32.93	
3	7.26	48.59	3 14	41.33	
4	6.58	50.25	4.92	43 67	
5	6.07	50.49	5 83	44.42	
BM-K54	3.92	50.24	4.17	46.32	
6	2.98	47 01	6 21	44.03	
7	.78	42 65	5 14	41.87	
8	3 15	43.65	2.15	40 50	
9	2.71	34 52	11.84	31.81	
TP-1	1.02	23 85	11.69	22.83	
RM-1			6.56	17.29	

FIGURE 3.—Gaging-station-level notes.

Water Resources Division policy prior to 1961 called for complete checking of every computation in each discharge measurement. The policy was changed as a result of a study that showed selective checking to be adequate and much less time consuming than complete checking. The currently approved practice is to check every measurement for (1) agreement between the computed mean gage height and the corrected recorded gage height or, for nonrecording stations, the observer's readings; (2) correct addition of the partial widths and discharges and agreement of the total width with the stationing of the water's edges; (3) possible error wherever the partial discharge changes substantially without a corresponding change in width, depth, or velocity; and (4) consistent relation of inside mean gage heights to outside gage readings. Check every computation in a discharge measurement that (1) varies from the rating defined by previous and subsequent measurements by more than 10 percent; (2) is the only measurement defining a substantial portion of a rating; (3) was computed by a hydrographer in the early stages of training; (4) was made during a noteworthy flood; or (5) is selected by the hydrographer in charge. Normally, less than 10 percent of the measurements for a station are completely checked.

Gage-height record

Assemble the gage-height record for the water year or other period for which the discharge record will be computed. The gage-height record, as brought in from the field, is a

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
SKETCH FORM

File 05447540

RESULTS OF LEVELS

Mud Creek at Crisfield, IL

Date	Party Chief	Reference Marks				Float Tape Gage			Wire-Weight Gage				OG Rdg.	Corr
		1	2	3	*K-54	W.S. Elev. (levels)	Gage Reading Found	Gage Reading Left	Check Bar Elev.	Ch.Bar.Rdg. Found	Ch.Bar.Rdg. Left	W.S. Rdg. as Left	3.4 to 6.6	6.7 to 27 0
9-12-76	Keller								19.12		19.12	1.46		
10-30-76	Stack	17.256	17.078	2.645		1.262		1.262	19.118	19.12	19.12	1.28	0	0
4-12-78	Krank	17.256				1.318	1.403	1.318		19.14	19.12	1.34		
8-02-78	Krank	17.256	17.076	2.647		1.214	1.216	1.216	19.119	19.12	19.12	1.23	-.01	+.02
11-06-80	Jones	17.256	17.080	2.642	46.30	1.404	1.425	1.404	19.116	19.13	19.12	1.41	-.01	0

*NGS bench mark - line 27, IL - Elev. 621.482 ft above NGVD of 1929

FORM 9-213C (Rev. Nov. 69)

Sheet No. ... of ... Sheets Prepared by ... Date ... Checked by ... Date ...

FIGURE 4.—Gaging-station-level summary.

series of 16 channel punched-paper tapes (fig. 5), graphic-recorder charts (fig. 6), or the books containing the observer's original readings of a nonrecording gage (fig. 7). Other important parts of the gage-height record include the notes concerning gage repairs and resetting, and reports of contacts with the observers of nonrecording gages that give evaluations of their work. These notes are normally written in the spaces provided on the discharge-measurement front sheets. The data-collection unit supervisor usually scrutinizes the gage-height records and discusses them with the hydrographer during the post-field trip debriefing. The evaluation includes checking that the recorded peaks agree with high-water marks, that the timer operated continuously, that the outside-inside gage relation was normal, and that any doubtful looking record has been investigated and its appearance was either satisfactorily explained or its cause was corrected. Compare the starting gage height of each tape or chart with the ending gage height of the preceding record and reconcile any differences before proceeding to the next step. At this stage of the processing, the gage-height record may require the application of certain corrections before it can be used to compute the discharge record.

Datum and Gage-Height Corrections

A correction applied to gage readings to compensate for the effect of settlement or uplift of the gage is usually measured by levels and is

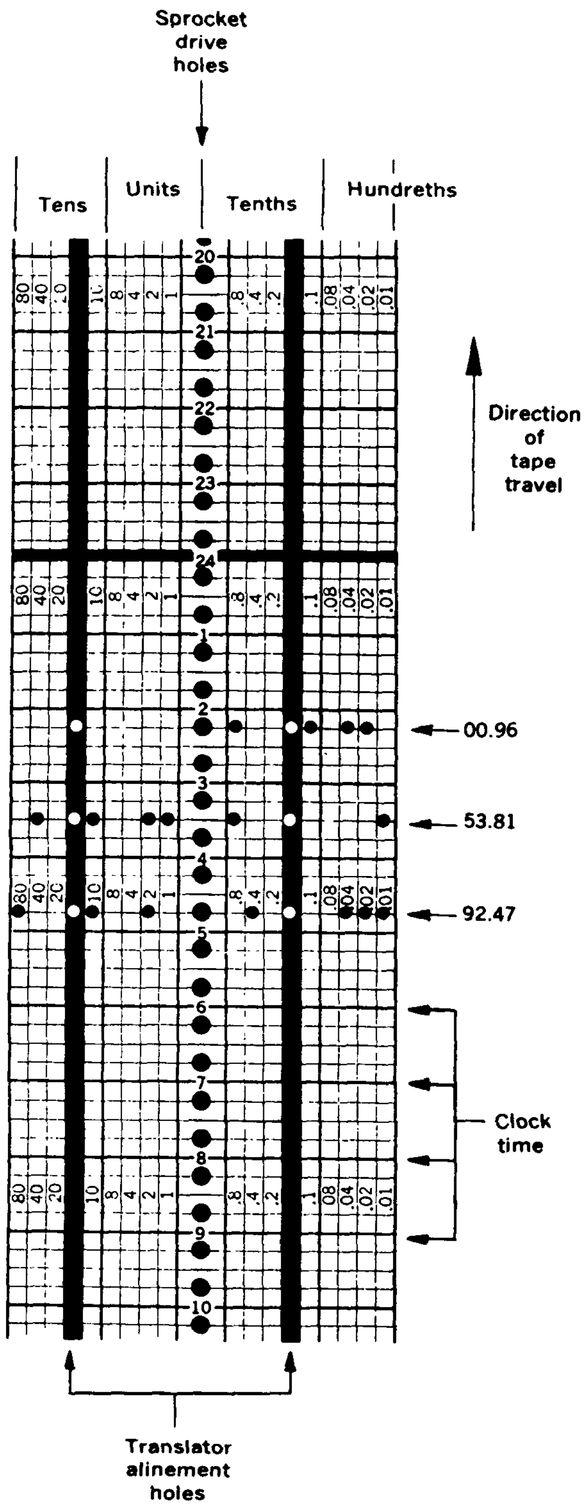


FIGURE 5.—Digital-recorder tape.

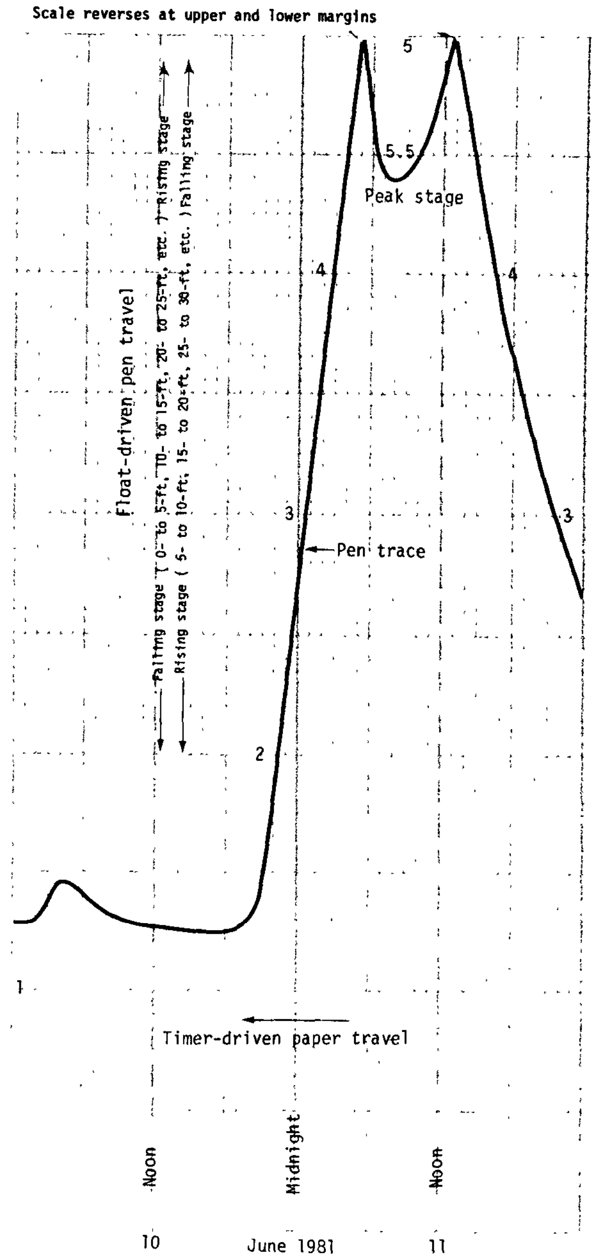


FIGURE 6.—Part of graphic-recorder chart.

called a "datum correction." A similar correction applied to compensate for a short-term occurrence (leaking float, slipped clamp, leakage or evaporation of antifreeze oil[1], and similar occurrences) is called a "gage-height correction." These short-term corrections can be measured

[1]Oil used as an antifreeze at gaging stations is limited by Section 311(b)(1) of Public Law 92-500 to those sites where there is no danger of the oil leaking into the stream system.

GAGE HEIGHTS FOR WEEK ENDING SATURDAY, May 9, 19 81

16—24204-1

Day and Date	Time	Gage Height	Mean Gage Height Obs.	Mean Gage Height Corr.*	REMARKS Follow "Instructions for Gage Observer" in the front of this book
Sun. 3	A. M. 6:40	2.68			
	P. M. 6:00	5.14			
Mon. 4	A. M. 7:30	9.35			
	P. M. 7:00	10.30			HWMk 10.3 (hand level) R.S.S.
Tues. 5	A. M. 7:30	9.50			
	P. M. 7:00	8.00			
Wed. 6	A. M. 6:15	6.20			
	P. M. 6:45	4.58			
Thurs. 7	A. M. 6:45	3.64			
	P. M. 6:30	3.13			
Fri. 8	A. M. 6:30	2.77			
	P. M. 6:30	2.50			
Sat. 9	A. M. 6:50	2.24			2.11 at 12:40 2.06 at 12:50 after debris removal
	P. M. 6:30	2.00			(SEND regular CARD today) R.S.S.

Mean Gage Ht. Computed by ---------- Date ----------

* Correction ---------- Mean Gage Ht. Checked by ---------- Date ----------

FIGURE 7.—Page of nonrecording-gage observer's book.

by levels or based on comparison of the readings of different gages. All corrections to the gage-height record are called datum corrections in automatic data processing usage.

Bubble gages and certain wire-weight gages have individual calibration errors that vary with stage and in some cases with temperature. Analysis of these errors is complex and rarely worthwhile. If calibration errors are disregarded, the rating will ordinarily compensate for them with no consequential effect on the discharge record. However, calibration error corrections may be necessary if they apply to a slope-station record or a bubble gage on a stream with very high and variable sediment concentration.

Inside each gaging-station well, one of the gages, separate from the recorder and least prone to accidental datum changes and often an electric-tape or inside-staff gage, is designated as the "reference gage." Its main purpose is to furnish occasional independent water-surface elevations to monitor the accuracy of the other inside gages. Another gage, preferably a recorder component such as the digital recorder dial or the perforated float tape that drives a graphic recorder is designated as the "principal gage." Principal gage readings determine the inside mean gage heights of the discharge measurements and are used to set the graphic-recorder pen. Bubble gage counters and the dials of digital recorders over small-diameter (3 to 6 in) wells are principal gages usually set to agree with an outside reference gage at low water when drawdown and calibraton errors are smallest. A slope station has a "base gage" similar to an ordinary gaging station and generally one "auxiliary gage" some distance away.

The sum of the datum and gage-height corrections may be applied directly to the principal gage readings, disregarded, or, with extremely unstable ratings, absorbed into the shift adjustments (gage-height adjustments used to compensate for discharge rating shifts and described in detail later). The option used depends on the magnitude of the correction, the sensitivity and permanence of the rating, and whether the corresponding gage error occurred suddenly or gradually. Corrections as small as 0.01 ft are usually applied where the low-water control is a permanent weir and zero flow occurs. If the sum of datum and gage-height corrections during the year does not exceed 0.02 ft (and the principal gage was not reset, these corrections are usually disregarded.

Corrections that are applied to principal gage readings must agree with (1) the correction used for the last day of previously computed record; (2) the corrections printed on the current year's primary computation sheet; (3) gage checks by levels or by comparison of principal gage readings to other readings; and (4) notes concerning changes made to the principal gage setting. Maintain a chronological list of corrections applicable to the principal gage in the format of figure 8. After the end of the water year, this list will become a paragraph of the station analysis, a document described in a later section of this manual. A similar list of corrections for gages other than the principal gage (reference gage, outside gages, and so forth) is optional. If the corrections are complex, plot them in a format similar to that in figure 9 and prepare the list from the graph. The list must be kept in agreement with the last correction used for previously computed record. Primary computations of current records are normally rerun from the original tapes if the datum corrections are revised, so accept the previous corrections unless they are seriously in error. Be certain that the gage-height correction changes by the same amount that the principal gage was changed and that no change in stage caused by cleaning a control or intake is mistaken for a gage resetting. When the list of datum and gage-height corrections is final, apply the appropriate correction to every principal gage reading entered on a discharge-measurement front sheet, graphic-recorder chart, or nonrecording-gage observer's book. The WATSTORE User's Guide (vol. 5) includes instructions for making the corrections to digital recorder readings.

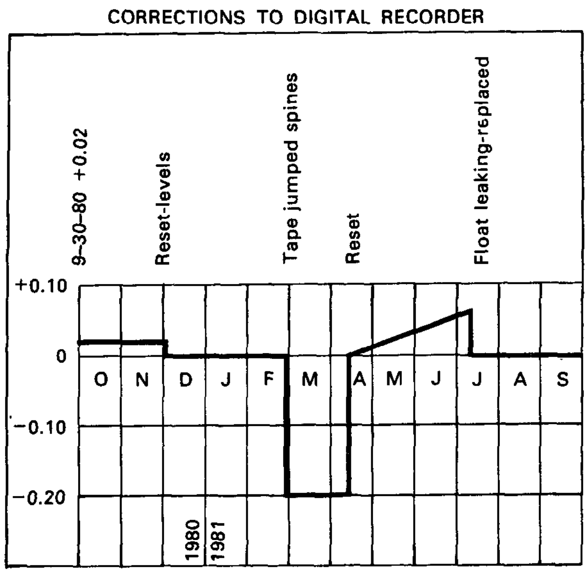
Pen corrections, to compensate for erroneous settings or lateral movement and expansion of the recorder paper, are computed on the graphic-recorder chart and are not otherwise documented. Graphic and digital recorders are

Datum and gage-height corrections.--Results of levels are summarized on an attached sheet. Based on these levels, the datum correction used on September 30, 1979, notes made when a surge chain at the recorder float was straightened, and gage-height record evidence of the most likely time that the surge chain became tangled, the following corrections were applied to digital-recorder readings:

Oct. 1, 1979 (0000 hrs)
-.02 ft
Nov. 6 (1430 hrs) Levels-gage reset
0
Dec. 11 (0330 hrs) Surge - most likely time of tangle
+.05
Jan. 3, 1980 (1415 hrs) Surge chain untangled. Ght rose .05 ft.
0
Sept. 30 (2400 hrs)

No corrections were applied to other gages.

FIGURE 8.—List of gage-height corrections.



Date	Time	Corr.
Oct. 1	0000	+0.02
Dec. 3	1115	0
Feb. 27	0200	− .20
Apr. 13	0920	0
Apr. 20	0000	+ .01
May 4	0000	+ .02
May 19	0000	+ .03
June 2	0000	+ .04
June 17	0000	+ .05
July 3	0000	+ .06
July 10	1410	0
Sept. 30	2400	

FIGURE 9.—Graph of gage-height corrections.

reset as necessary to compensate for the effect on the float when oil, used as an antifreeze, is added to or removed from the gage well. Oil-effect variations, caused by evaporation or other loss of oil, are treated as pen corrections with graphic recorders but must be included in the datum corrections that are listed and applied to digital recorder readings.

List of Discharge Measurements

The tabulation illustrated by figure 10 (form 9-207) summarizes, in a convenient form, the data pertinent to the discharge measurements made at a gaging station. The following paragraphs outline the procedure for preparing the discharge measurements for listing.

The listing can be continuous from the first measurement made at the site, with each measurement listed only once. A space is left after the last measurement in each water year, and preferably each calendar year, to separate these periods. Listing by water-year sets, starting with the last measurement of the previous water year on the top line and including the first measurement of the next year, is also satisfactory. Newly available measurements are added to the list every time an additional period of record is computed.

Arrange all of the previously unlisted discharge-measurement notes and the hydrographer's observations of no flow for the current water year in chronological order. Check the gage-height record to make certain that all measurements are on hand and be sure that the indirect measurements are included. Inclusion of the first and last observer's no-flow observation during each continuous period of no flow is optional.

Make certain that all necessary checking or rechecking has been done. Indirect measurements must be reviewed by the appropriate specialist before the results may be used. Note in particular whether the mean or weighted-mean gage height has been computed and checked for each measurement. Make sure that the measurement gage heights and the gage-height record have been based on the principal gage and that any necessary datum and gage-height corrections have been applied to both. When something was done by the hydrographer which caused the gage height to change, such as removal of debris from the control or cleaning of the intake pipes, list both gage heights and note the reason for the change under "Remarks."

Be certain that measurement gage heights and dates have been checked against the gage-height record and any discrepancies reconciled. Also, number the measurements consecutively in chronological order, including all field estimates (flow estimates made where conditions preclude standard discharge measurement techniques) and indirect measurements; observations of no flow are not numbered.

After completing the above, the measurements are listed on form 9-207. Listing not intended for typing should be done in black ink in a manner such that good, clear prints can be ob-

FORM 9-207
(Rev. 11-69)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)
DISCHARGE MEASUREMENT SUMMARY SHEET

Station No. 05447540

Discharge measurements of Mud Creek at Crisfield, Ill., during the year ending Sept. 30, 1980

No.	Date	Made by—	Width	Area	Mean velocity	Gage height	Discharge	Rating 8 Shift adj	Percent diff.	Method	Number meas. sections	Gage height change	Time	Meas. rated	Time Temp °C	GZF or Susp	Outs. Ght	REMARKS
			Feet	Sq ft	Fps	Feet	Cfs	Feet				Feet	Hr					
131	1979 Sep. 25	P.T. Spalding	18 0	12.4	.57	1.84	7 05	-04	–	.6	23	0	0 42	F	0840 14.0	1 18	Staff 1 85	Control clean
132	Oct 23	R.S. Sonds J.J Handy	16.0	16.5	1 61	2.45	26.6	–	9 +15	.6	33	-02	.58	G	1235 12.0	1.3	St 2.47	Control clean
133	Dec 4	P.T.S.	15 0	7.84	59	1 73	4.62	–	-15	.6	24	0	.42	F	0915 2.8	1.20	St 1.74	Control clean
134	1980 Jan. 8	P.T.S.	17 0	10 5	60	2 15	6 31	– ice	–	6	21	0	.33	G	0820 0	–	WWt 2.19	Complete ice cover
135	Feb. 19	J.J.H				26 60	8,760	–	0	Sl. Area	4	–	–	F	–	–	–	H W Mark on right bank 27.1 ft
136	Apr 1	R.S.S	26.0	95.2	1.65	4.99	157	-.05	-2.5	6 .2-8	23	+07	.67	F	1545 14.0	Br 30#	WW 5.06	Control 20% blocked by debris. Not changed
137	May 9	R.S.S.	18.3	16.2	.81	2.11 2 06	13.1	-05 –	– -.8	6	20	0	.50	G	1320 19 0	1.25	2.12 St 2.06	Debris removed from control. Dropped .05'
138	June 10	P.T.S.	4.5	56	43	1 35	.26	-01		.6	6	0	.17	F	0855 21.5	1 16	St 1.35	Algae blocking 50% of control area
	July 6	(A J Rouse) Observer				1 18	0										St 1.18	
	July 22	P.T.S				1 10	0										St 1.10	Heavy algae on bottom
	Aug 24	Observer				.83	0										St .83	Streambed dry
139	Sept 2	J J.H	16.0	11.5	.98	2 03	11 2	-04	–	.6	24	0	.42	G	0855 14.5	1.2	St 2.04	Algae blocking 50% of control
Beginning	1981 Water Year																	
140	Oct 14	H C Crone	16.0	8 35	.64	1.84	5 31	-08	–	6	22	0	.50	G	1550 11.5	–	St 1.85	Grass and leaves block 90% of control
141	Nov 25	J J H	10 0	2.53	.77	1.48	1 20	–	+2.6	.6	21	0	.42	G	0840 6.0	1.15	St 1.49	Control clean

Copied by R.S.S. Computed by H.C.C. Checked by P.T.S.

GPO 1972 O - 475 842

FIGURE 10.—List of discharge measurements.

tained. The following steps are used to complete the form properly.

Letter the exact name of the gaging station on the top line of each sheet used. Insert the gaging-station identification number in the space provided on each sheet.

List all measurements in chronological order, using one line for each measurement. Available measurements for the following year should be listed if they will be used in defining the current year's rating curve or shift adjustments.

Show the initials and last name of the hydrographer making the measurement the first time it appears on a page and use only the surname or initials wherever it appears again. Dittos may be used where appropriate in the "Made by" column. If more than one hydrographer was present, list the two most appropriate names.

List the water temperature in degrees Celsius and above it the "24-h" time.

If the measurement was made other than by wading, note the method used and the size of sounding weight (if used) in the "Remarks" column. Use notations such as cable 100 lb, bridge 75 lb, boat 30 lb, or optical meter. Any unusual conditions that might have some effect upon the accuracy of the measurement or upon the stage-discharge relation should also be listed under "Remarks." Use numerical remarks such as "control cross section 40% blocked by grass" rather than the less specific "backwater from grass." Any changes made to the control or intake pipes that cause a sudden gage-height change and affect the continuity of the gage-height record must be noted. Brief notes on ice conditions should be included here. The gage height of zero flow (GZF), when determined, should be listed. For indirect measurements, show a gage-height determination from the flood profile or high-water marks, if available, in addition to those obtained from inside or outside gages. Additional columns appropriate to the station may be added to the form to show such data as gage height of zero flow, outside gage height, specific conductance, etc., provided that adequate space for the "Remarks" is left. The shift adjustment and percent difference columns are left blank until the rating has been completed.

The person listing the measurements places his initials and the date near the bottom of each sheet. Each item listed on the form must be checked, and the checker adds his initials and the date to each sheet.

For each gaging station, high-water measurements above a chosen base gage height may be recorded on a separate form 9-207 and carried forward from year to year to prevent any measurement from being overlooked in future ratings. Only the date, gage height, discharge, method, and accuracy need to be listed on the supplemental sheet.

Discharge Ratings

The development of the discharge rating is one of the principal tasks in computing a discharge record. The rating is usually the relation between gage height and discharge (simple rating). Ratings for some special sites involve additional factors such as rate of change in stage or fall in a slope reach (complex ratings). A ratings manual (Kennedy, 1982), is devoted entirely to discharge ratings, simple and complex. The ratings manual also covers such fundamental rating analysis techniques such as logarithmic plotting; constructing normal and offset logarithmic scales; relating logarithmic curve shape to the gage-height offset and to GZF; using shape curves; approximating logarithmic rating curves by straight-line segments; and using digital descriptors of logarithmic rating curves. This manual covers only the development of simple ratings for reasonably stable channels and does not repeat the explanations of the fundamentals or special applications explained in the ratings manual by Kennedy (1982).

A simple rating is developed by (1) plotting the relevant discharge measurements and a shape curve on a logarithmic work-curve sheet; (2) drawing the indicated rating curve; (3) approximating the curve with a series of straight lines and determining its digital descriptors (explained in more detail later); (4) preparing a rating table from the descriptors or using the descriptors in a programmable calculator to simulate a rating table; (5) computing the variations of the discharge measurements from the rating; (6) revising the rating descriptors to obtain a better balance of the discharge measurement variations; and (7) preparing a drafted master curve sheet.

Work-curve sheets

The actual development of the rating curve is normally done in pencil on a logarithmic sheet, preferably with enough cycles so that the rating curve can be one continuous line. This worksheet may be a print of the previous year's master sheet to eliminate some plotting or a fresh sheet prepared for the purpose with a different gage-height scale offset from the one on the master sheet. The choice depends on the difference between the effective GZF and the next higher foot, or possibly half-foot, and the sensitivity of the relation between the scale offset and the curvature of the rating. A plotted logarithmic rating whose lower part is curved may require a profusion of descriptors, and if it is even slightly concave upward, it will involve scalloping. The rating curvature of a logarithmic plot is controlled by varying the scale offset. The lower end of the rating curve is straight when the scale offset is the effective GZF, concave upward when the offset is smaller than GZF, and concave downward when the offset is larger than GZF. This effect is less pronounced as the stage increases, and changing the offset by a foot has a negligible effect on rating curvature at stages above about 3 ft over GZF. In general, a print of the previous master curve is a satisfactory worksheet if the current curve can be plotted on it in one continuous line, the scale offset agrees with the previous curve's offset descriptor value, and the new rating will be straight or slightly concave downward. Otherwise, use a fresh sheet.

Figure 11 illustrates a work-curve sheet prepared from a standard form 9-279M. The discharge scale is a "normal" log scale from

0.001 ft^3/s (two additional cycles taped in place for the discharge range below 0.1 ft^3/s are not shown on figure 11) to 10,000 ft^3/s. The gage-height scale is offset by 1.2 ft, approximately the gage height of zero flow, and is convenient for plotting all gage heights below about 2.2 ft. The offset scale is too awkward for plotting higher values so they are adjusted by subtracting the scale offset from each gage-height value and can then be plotted using the "normal" log scale. Gage-height values picked off the normal scale must be increased by the offset value before use, an inconvenient procedure usually used only for worksheets.

Plot the last rating that was used for published record or the shape curve described in the rating manual on the worksheet. If a previous rating is used for the shape curve and its scale-offset descriptor is not the same as the worksheet's scale offset, consider only the part above about 4 ft on the normal scale for merging with the new curve. Minor scale-offset differences in that range have a negligible effect on the discharge values interpolated between the rating's descriptors.

Plot all relevant discharge measurements. These include the current measurements not seriously affected by ice or debris, all recent low and medium measurements that apply to the current rating, and, if used, all of those on the special list of high-water current-meter and indirect measurements. If the measurement alignment indicates that more than one rating applies at high or medium stages, use colors to distinguish the measurements that apply to each rating. If more than one rating in the near-zero-flow range is needed and shifting-control method is impractical, use a supplemental worksheet for each rating whose GZF and scale offset differs from the others. Examine any measurements that appear to vary from the general trend for errors in discharge or gage-height computation or for gage malfunction.

Draw a smooth curve that best averages the applicable measurements. If the station is new and the shape curve is a synthetic rating (slope-conveyance, step-backwater, or similar), draw the new curve generally parallel to it. Make all breaks in the slope of the new curve at the same gage heights as the breaks in the shape curve. Draw the curve only as high as the maximum recorded stage. If the shape curve is a previously used rating, merge the new curve with the shape curve at as low a gage height as the data and judgment permit. High-water ratings should include all relevant measurements, and once a high-water rating extension is made, it should be continued in use until strong supporting data indicates the need for a change. Then, the published records must be revised as necessary to reflect the revised extension. Rating extensions based only on a different hydrographer's opinion, especially extensions considered too weakly based to warrant revision of past records, should be avoided. Minor high-water extension revisions, such as the one illustrated in figure 11, require no revisions to past records. If the low-water measurements scatter due to varying amounts of aqueous growth or debris on the control, draw the curve to the right of the scatter and close to the measurements made while the control was clean. If measurement scatter reflects scour and fill at an unstable control, draw the curve near the middle of the scatter and close to measurements whose GZF is close to the scale offset used. If the lower part of the curve is concave upward, use a larger scale offset to straighten the curve or make it concave downward and avoid the scalloping described in the ratings manual. When the curve looks satisfactory, approximate it with a series of straight lines and pick off the digital descriptors (see the ratings manual). Fewer than 15 segments are adequate for most ratings, but as many as 29 can be used.

The rating is considered tentative until the percent differences and shift adjustments (discussed in greater detail later) are computed and found to be satisfactory. Graphical rating analysis, especially for high-slope rating parts, is subject to significant drafting errors. The graphically defined rating descriptors may need some adjustment to improve the balance of the percent differences. The percent differences can be computed from a rating table, described in the following section, or more conveniently by entering the descriptors in an appropriately programmed calculator. Then, the descriptors can be modified as necessary to make the rating final. The work-curve sheet is preserved for as long as it has use for future rating analysis, after which it may be discarded.

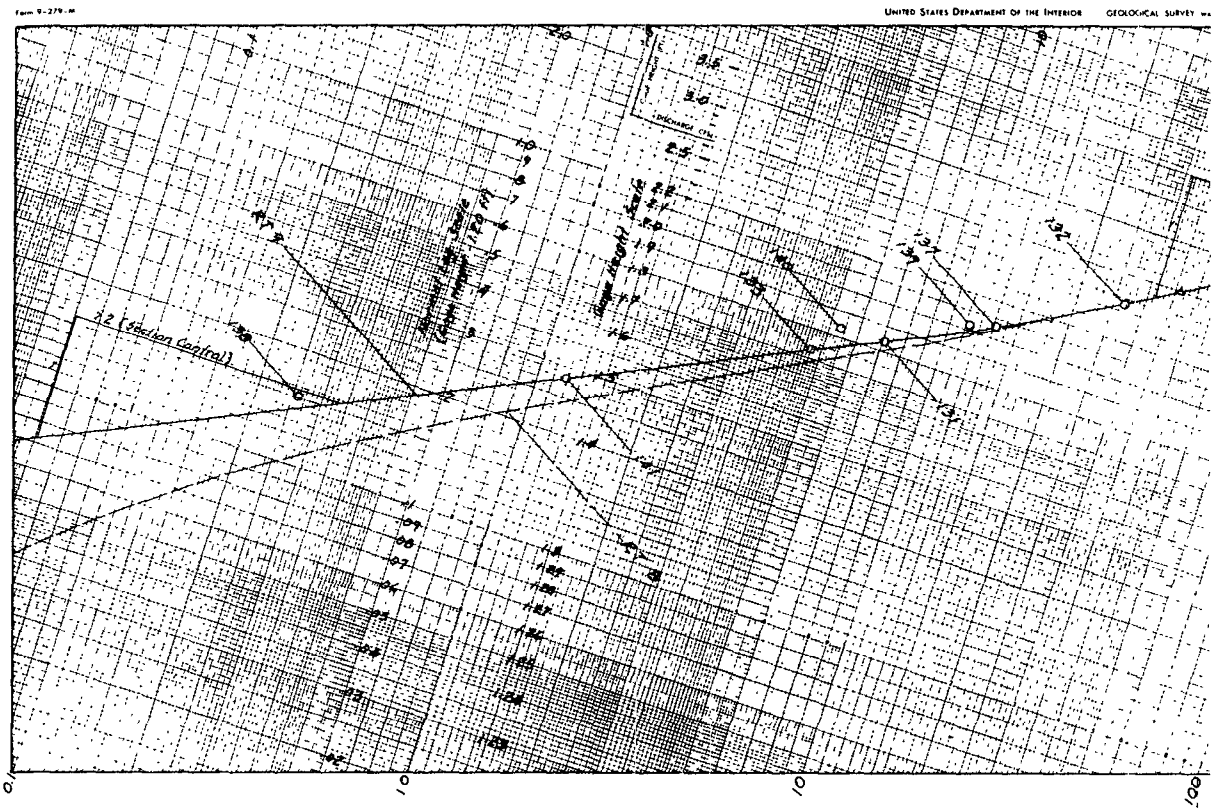


FIGURE 11.—Logarithmic work-curve sheet.

Rating tables

A rating table similar to the one in figure 12*A* (one-hundredth-foot expansion) or 12*B* (one-tenth-foot expansion) can be prepared automatically from the descriptors by using the WATSTORE "RATLIST" (automatically prepared rating tables) program. The variety of RATLIST output formats and their input requirements are described in the WATSTORE User's Guide. (vol. 1). The rating table can also be prepared manually on a standard form 9-230 from the worksheet curve. This is a time-consuming operation that produces a table with serious shortcomings for ADP use and is not normally recommended. Some programmable calculators can be programmed for logarithmic interpolation to serve as a substitute for a rating table. The necessary programs, on magnetic cards, for some handheld calculators can be obtained from USGS offices. The rating descriptors can be stored in the calculator, so that entering a gage height or discharge causes the corresponding discharge or gage height to be displayed. Descriptors in the calculator storage can be changed at will until they are satisfactory for the final table.

Rating tables are numbered chronologically by dates of use. The approximate date of the change from one rating to another is usually apparent from the dates of measurements that define each rating, and the date of the event that most likely caused the change. If the shifting-control method is used, the starting date of a rating is not critical and sometimes it can be moved to a convenient date such as the start of a water year. Enter the appropriate starting and ending dates in the space provided on the rating tables. Use of the blanks on the rating table sheet to indicate the basis for the rating and its degree of definition is recommended for stable ratings used for a year or longer and is optional for unstable ratings.

The final rating table should be checked by

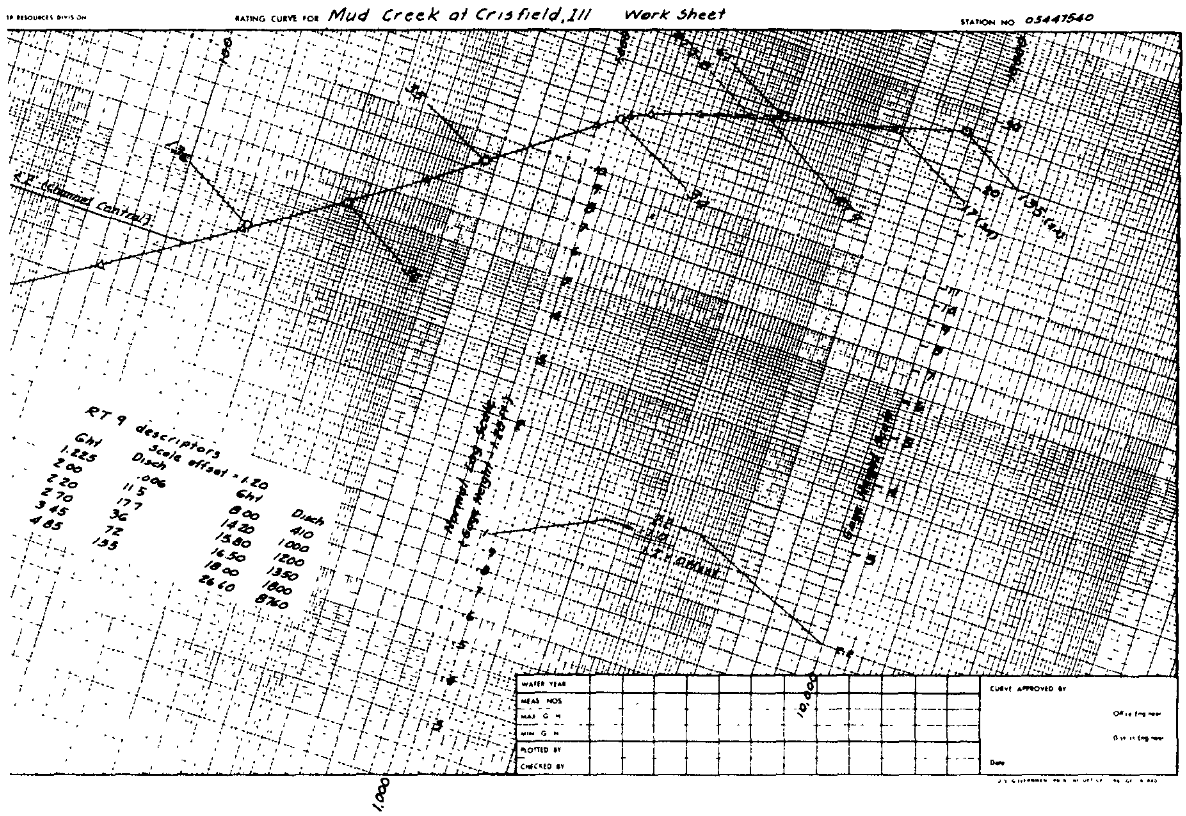


FIGURE 11.—Logarithmic work-curve sheet—Continued.

someone not involved in the original computation. Check to make certain that the correct descriptors, especially the offset, were used to prepare the table, that it covers the entire range of stage, and that the handwritten entries (dates of use, etc.) are correct and have also been entered on the previous rating table. The checker should always assure that older medium- and high-water discharge measurements are included in the rating analysis. Initials of the person doing the original computations and the checker must be shown with the dates of the work.

Percent differences and shift adjustments

At a stream-gaging station, a certain section below the gage controls the relation of gage height to discharge. This may be a rock riffle, a sand or gravel bar, a natural constricted section, a dam, weir, or flume, or it may be a stretch of the channel where the channel slope and friction of bed and banks are the controlling hydraulic parameters. When this section, called the control, is permanent or unchanging, there will normally be the same amount of water passing the gage for a given gage height. This seldom happens in nature. The sand bar, gravel bed, or drift pile that comprises the control may change during flood periods, debris may be piled on rock riffles, and aquatic vegetation, silt, and drift may accumulate in channels, on and behind dams, and in flumes.

All of these control changes are reflected in the plotting position of the discharge measurements on the rating curve. Theoretically, a new curve should be drawn following each one of these changes. However, instead of drawing new curves for each change in the stage-discharge relation, the shifting-control method is used in which a correction, called a shift

A

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION

EXPANDED RATING TABLE DATE PRINTED 08-20-81

01467150 COOPER R AT HADDONFIELD NJ TYPE LOG(SCALE OFFSET = 1.00) RATING NO 09

BASED ON ______ DISCHARGE MEASUREMENTS, NO.__________, AND ______, AND IS ____ WELL DEFINED BETWEEN _____ AND _____
FROM ________ TO ________, FROM ________ TO ________ *COMP BY _____ DATE _____
CKD. BY _____ DATE _____

GAGE HEIGHT IN FEET	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH GH
	DISCHARGE IN CUBIC FEET PER SECOND (STANDARD PRECISION)										
1.30	8.9	9.3	9.7	10	10	11	11	12	12	13	4
1.40	13	14	14	15	15	16	17	17	18	19	6
1.50	20	20	21	22	23	24	25	26	27	28	9
1.60	30	31	33	34	36	38	40	41	43	45	17
1.70	48	50	52	54	56	59	61	64	67	69	24
1.80	72	75	78	81	84	87	90	94	97	100	32
1.90	104	107	111	114	118	121	125	128	132	136	36
2.00	140	144	148	152	156	161	165	169	174	178	43
2.10	183	187	191	195	199	204	208	212	217	221	43
2.20	226	230	235	240	244	249	254	259	264	269	48
2.30	274	279	284	288	293	298	303	308	313	319	50
2.40	324	329	334	339	345	350	356	361	367	372	54
2.50	378	383	389	394	399	405	410	416	422	427	55
2.60	433	438	444	450	456	462	467	473	479	485	58
2.70	491	498	504	510	516	522	529	535	541	548	63
2.80	554	560	567	573	580	587	593	600	607	613	66
2.90	620	627	634	641	648	655	662	669	676	683	70
3.00	690	697	704	711	718	725	732	739	747	754	71
3.10	761	768	776	783	790	798	805	813	820	828	75
3.20	836	843	851	859	866	874	882	890	898	906	78
3.30	914	922	930	938	946	954	962	970	978	987	81
3.40	995	1000	1010	1020	1030	1040	1050	1050	1060	1070	85
3.50	1080	1090	1100	1110	1110	1120	1130	1140	1150	1160	90
3.60	1170	1170	1180	1190	1200	1210	1220	1230	1240	1250	80
3.70	1250	1260	1270	1280	1290	1300	1310	1320	1330	1340	100
3.80	1350	1360	1370	1370	1380	1390	1400	1410	1420	1430	90
3.90	1440	1450	1460	1470	1480	1490	1500	1510	1520	1530	100
4.00	1540	1550	1560	1570	1580	1590	1600	1610	1620	1630	100
4.10	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	100
4.20	1740	1750	1760	1770	1780	1790	1300	1810	1820	1830	100
4.30	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930	100
4.40	1940	1950	1960	1970	1990	2000	2010	2020	2030	2040	110
4.50	2050	2060	2070	2080	2090	2100	2110	2130	2140	2150	110
4.60	2160	2170	2180	2190	2200	2210	2220	2230	2250	2260	110
4.70	2270	2280	2290								

B

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION

EXPANDED RATING TABLE DATE PRINTED 08-20-81

01467150 COOPER R AT HADDONFIELD NJ TYPE LOG(SCALE OFFSET = 1.00) RATING NO 09

BASED ON ______ DISCHARGE MEASUREMENTS, NO.__________, AND ______, AND IS ____ WELL DEFINED BETWEEN _____ AND _____
FROM ________ TO ________, FROM ________ TO ________ *COMP BY _____ DATE _____
*CKD. BY _____ DATE _____

GAGE HEIGHT IN FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	DIFF IN Q PER FOOT GH
	DISCHARGE IN CUBIC FEET PER SECOND (STANDARD PRECISION)										
1.00				8.9	13	20	30	48	72	104	
2.00	140	183	226	274	324	378	433	491	554	620	550
3.00	690	761	836	914	995	1080	1170	1250	1350	1440	850
4.00	1540	1640	1740	1840	1940	2050	2160	2270			

THE FOLLOWING RATING WAS STORED ON DISK FOR FUTURE USE

DATE PROCESSED 08-20-81

STATION 01467150 RATING IDENT 09 SCALE OFFSET 1.00

POINTS STORED TEST FOR CONFORMANCE

INPUT OUTPUT POINT PERCENT DIFF

INPUT	OUTPUT
1.30	8.90
1.40	13.00
1.50	19.50
1.60	29.50
1.70	47.50
1.90	104.00
2.10	183.00
2.30	274.00
2.50	378.00
2.80	554.00
3.00	690.00
3.50	1080.00
4.00	1540.00
4.50	2050.00
4.72	2290.00

FIGURE 12.—Automatically prepared rating tables (RATLIST).

adjustment, to the curve or table is computed. Refer to the list of discharge measurements in figure 10. Two columns in the center of the form were left blank when measurements were listed. At the top of these two columns is "Rating ______" and the individual column headings are "Shift adj." and "Percent diff." Place the number of the rating table used in the space entitled "Rating ______." If a change in rating occurs between two measurements listed in the body of form 9-207, draw a heavy line across these two columns below the last measurement applying to the prior rating table and write the number of the new table just below. Compute, to one-hundredth of a foot, the gage height from the rating table which would produce the discharge shown on the measurment or as close to the measured discharge as possible. The difference between this computed gage height and the gage height of the measurement is the shift. If the computed gage height is greater than that of the measurement, the shift is plus; if it is less, the shift is minus. This should be checked with the curve according to the following criterion. If the plotted measurement is above or to the left, the shift is minus; if it is below or to the right, the shift is plus. Frequently, errors in shift, plotting of points, and location of rating curves are picked up from this check.

Percent difference is not shown on form 9-207 for measurements with shift adjustments given full weight (that is, the shift used is the actual shift indicated by the measurement to the nearest 0.01 ft). For those given less than full weight, both the shifts used and the percent differences from the rating (after application of these shifts) are shown.

A discharge measurement is subject to instrumental and sampling errors that cause a standard deviation of about 4 percent (0.6 method) or 2.5 percent (0.2 and 0.8 method) in a 25-section measurement according to a study by Carter and Anderson (1963). Additional errors that are related to the site conditions and the hydrographer's experience make the total error range of most measurements about 5 percent. For this reason, the shifting-control method is rarely used for series of measurements that plot within 5 percent of the rating curve. Therefore, one should compute actual percent differences without shifts before computing any shift adjustments. If all measurements are within 5 percent and plot on both sides of the rating, computing shifts is unnecessary except in special cases where greater refinement may be warranted. On the other hand, if a series of measurements during a year plot within about 5 percent and are all on the same side of the curve, one should consider shifting to all of them, drawing a new curve, or using the same shift throughout the year and recomputing the percentages. The hydrographer in charge normally decides whether shifts will be applied, the old rating continued in use without shifts, or a new rating drawn. Sometimes a combination of all three procedures will be used for various periods through the year; however, similar periods should be treated the same way.

To compute a percent difference, obtain the discharge for the gage height (shifted-gage height if a shift is applied but not given full weight) of the measurement from the rating table, carrying the discharge to the same number of significant figures as is listed in the "discharge" column (measured discharge) on form 9-207. Divide the difference between the measured and the table discharge by the table discharge and multiply the result by 100. Carry the difference to the nearest one-tenth of a percent.

For ice-affected measurements, record "ice" in the percent difference column. For a measurement that was disregarded, write "NOT USED" across the shift and percent difference columns. The reasons for disregarding a measurement must be valid and fully explained in the station analysis. They should be limited to such items as equipment malfunction, gross errors in width or depth, or possibly the hydrographer's inexperience. Unexplained variation from the rating is not a valid reason.

In computing shifts for measurements with rapidly changing stage (greater than 0.1 ft during measurement), see that the weighted-mean gage height has been computed correctly.

The checker verifies the arithmetic of the computed shifts and percentage differences paying particular attention to the plus and minus signs. It is very easy to err in the sign of a shift, and too often a station record must be revised after computation because shifts have been applied in the wrong direction. One method to check the sign of the shifts is to add the shift adjustment algebraically to the gage height of the measurement and enter the rating table at the adjusted gage height; if the rating discharge at that point equals the measured discharge, the shift has been computed correctly.

If the percent differences are reasonably well balanced (about as many plus as minus) and the shift adjustments are satisfactory, the rating may be considered final and ready for use in computing the record. The hydrographers responsible for analyzing and checking the rating should initial the table in the space provided. Compare the high-water part of the new rating to the prior rating to check the need for revising past records.

Master curve sheets

A master curve sheet, usually hand drawn and neatly lettered in ink on a standard form, is used for the permanent record and to make copies for field and office use. A variety of standard forms is available, large and small, logarithmic or rectangular, and combination log-rectangular. Some forms are reverse printed for ease of erasing and for superior diazo copies. Others are front printed for the best electrostatic reproduction. Figure 13 illustrates one type of master curve sheet, prepared from the figure 11 worksheet and plotted on a combination sheet (standard form 9–279–S or P). Note that the use of a 1.0-ft gage-height scale offset instead of the 1.2-ft offset used in the descriptor makes the plotting simpler. However, this change makes the curve segments between the descriptor coordinate points bend slightly. The curvature is not apparent in the parts of the rating above 10 ft³/s in figure 13 but would cause scalloping at lower flows if the 1.0-ft scale offset were used on the worksheet.

Select an appropriate standard form for the master sheet, no larger than necessary to illustrate the rating. Logarithmic sheets are best for narrow-range ratings, and combination log-rectangular sheets are usually preferable for ratings that extend down to zero flow. With a combination sheet, a log scale different from the one on the worksheet can be used for best placement of the main curve on the sheet and for scale simplicity. Some hydrographers prefer to use the normal log scales for all curves which, if used, should be prominently titled "Gage height, in feet—(offset) feet."

Choose the scales for the rectangular portion of a combination sheet to provide some overlap with the log curve and to insure that each principal grid division is a multiple of 1, 2, or 5 and not 2.5 or 4. A scale that permits GZF to be plotted is desirable.

Plot all measurements made during the water year, others that were used to define the rating, and all high-water measurements ever made at the site. Such drafting details as circle size, flag angle and length, and marginal information are matters of district or personal preference. Each measurement may be plotted only once when a log-rectangular combination sheet is used, using the log plot for measurements that fit and the rectangular plot for the rest. Additional measurement plotting on the rectangular part of the sheet is optional.

The part of the highest rating ever used for a published record at the station, that extends above the current rating, should be plotted as a dashed line to indicate the relation of the current curve to previous ratings. If a special high-water rating was prepared for flood-forecasting use by another agency, plot its curve with a distinctive line to indicate any need for updating as additional high-water measurements become available.

Identify each curve with its table number, and list the tables and their dates of use for final records (not primary computations). Tabulate the information concerning years, measurement numbers, and extremes in the spaces provided so that the criteria for omitting measurements from the plot is clear.

Manual Computation of Gage-Height Record

The computation of the gage-height record from a digital recorder is incidental to the automatic discharge record computation by an ADP program, and its discussion is included under "Computation of Discharge Record." Gage-height record computation is a separate step in