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

DEPARTMENT OF THE INTERIOR
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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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[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 It was compiled mostly from unpublished Water Resource Division district manuals edited and supplemented to emphasize digital-recorder and associated computer use.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 $\pm$ .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.

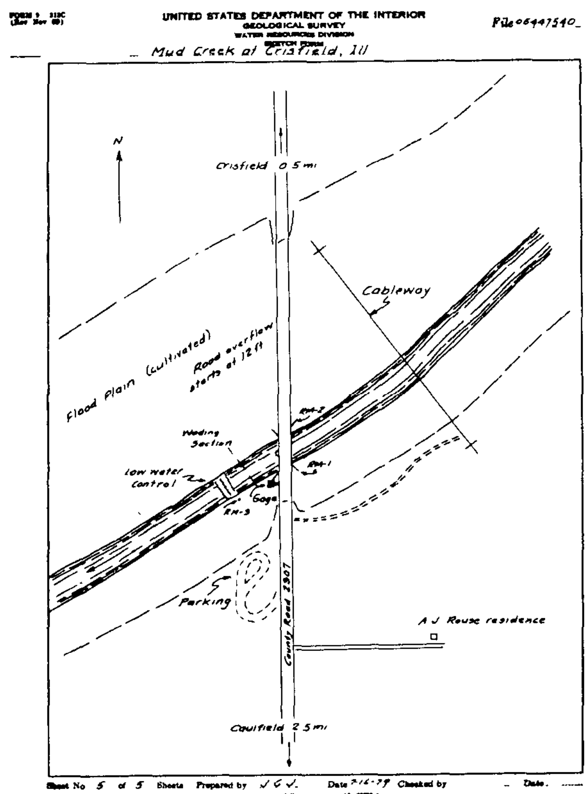


FIGURE 2.—Sample field-station description—Continued.

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	1 861			+ 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
	29 06	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 R.P Elev.	Found R P.Read	Found Corr'n	Left R.P Elev.	Left R P.Read	Left 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	13 964	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 1	Reference Marks 2	Reference Marks 3	Reference Marks *K-54	Float Tape Gage W.S. Elev. (levels)	Float Tape Gage Gage Reading Found	Float Tape Gage Gage Reading Left	Wire-Weight Gage Check Bar Elev.	Wire-Weight Gage Ch.Bar.Rdg. Found	Wire-Weight Gage Ch.Bar.Rdg. Left	Wire-Weight Gage W.S. Rdg. as Left	OG Rdg. Corr 3.4 to 6.6	OG Rdg. Corr 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. 66)

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

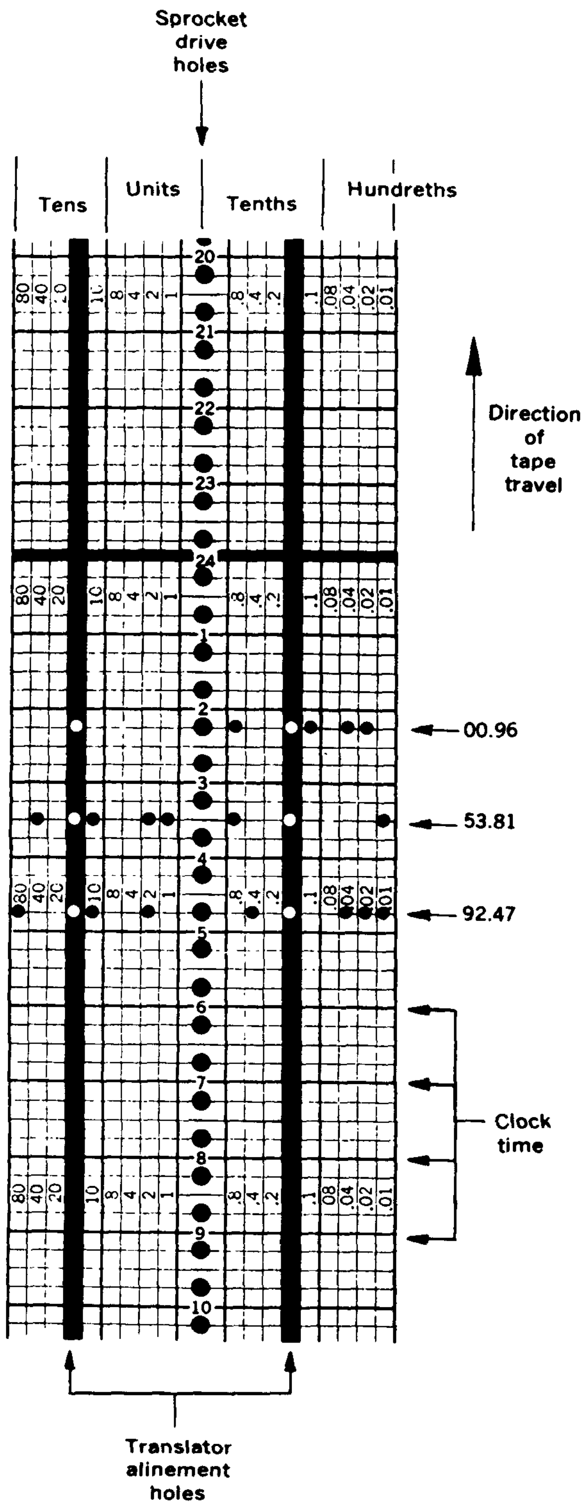


FIGURE 5.—Digital-recorder tape.

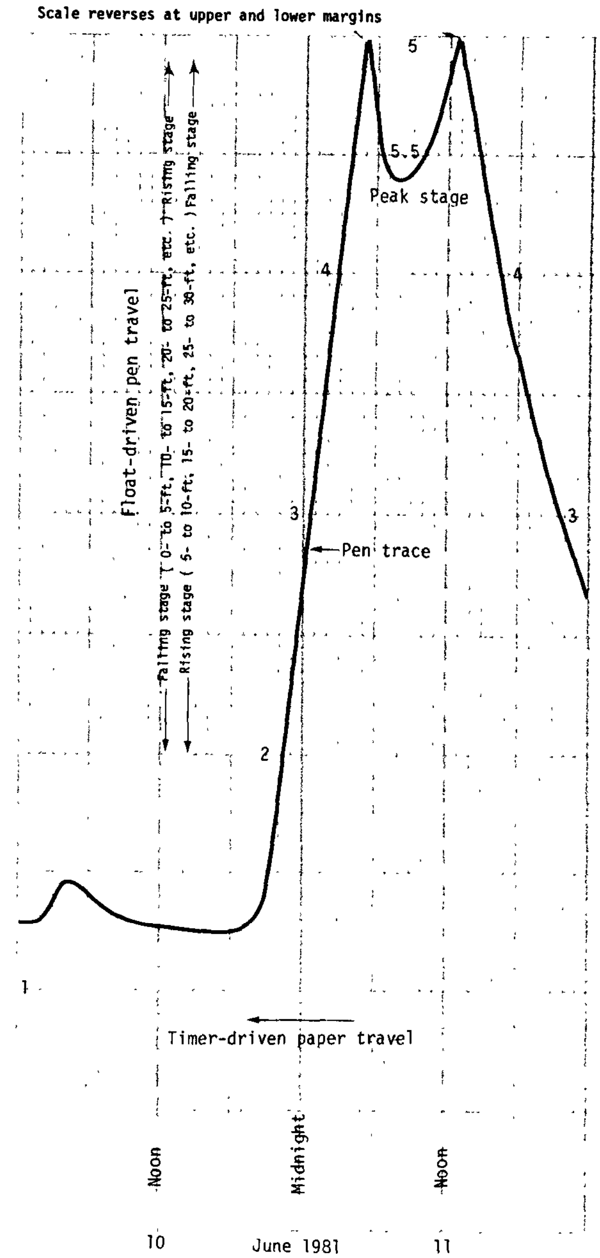


FIGURE 6.—Part of graphic-recorder chart.

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.

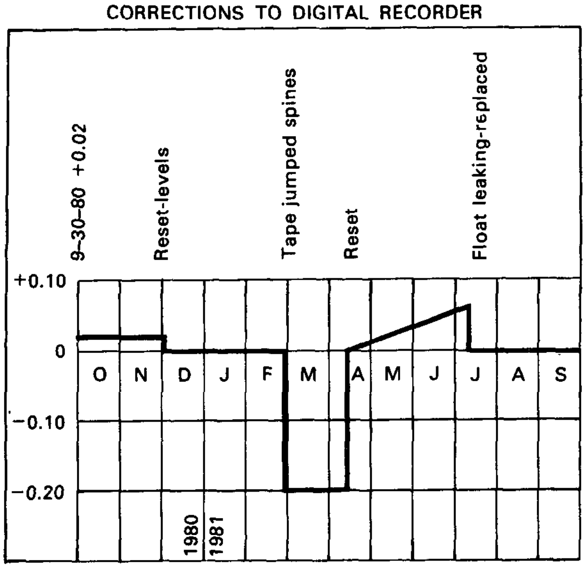
Pen corrections, to compensate for erroneous settings or lateral movement and expansion of the recorder paper, are computed on the graphic-recorder chart and are not otherwise documented. Graphic and digital recorders are

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, 19 80

No.	Date	Made by—	Width	Area	Mean velocity	Gage height	Discharge	Rating 8: Shift adj	Rating 8: 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. Hondy	16.0	16.5	1.61	2.45	26.6	–	9 +1.5	.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	–	-1.5	.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.

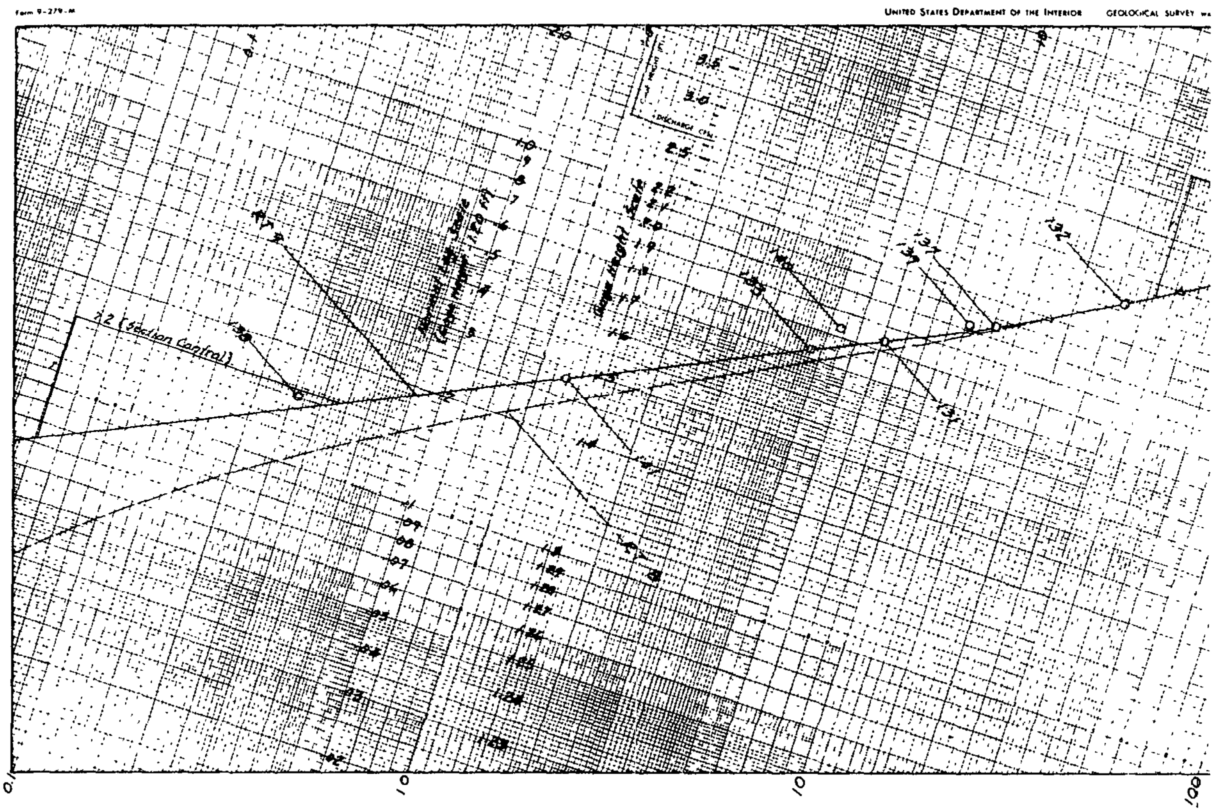


FIGURE 11.—Logarithmic work-curve sheet.

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

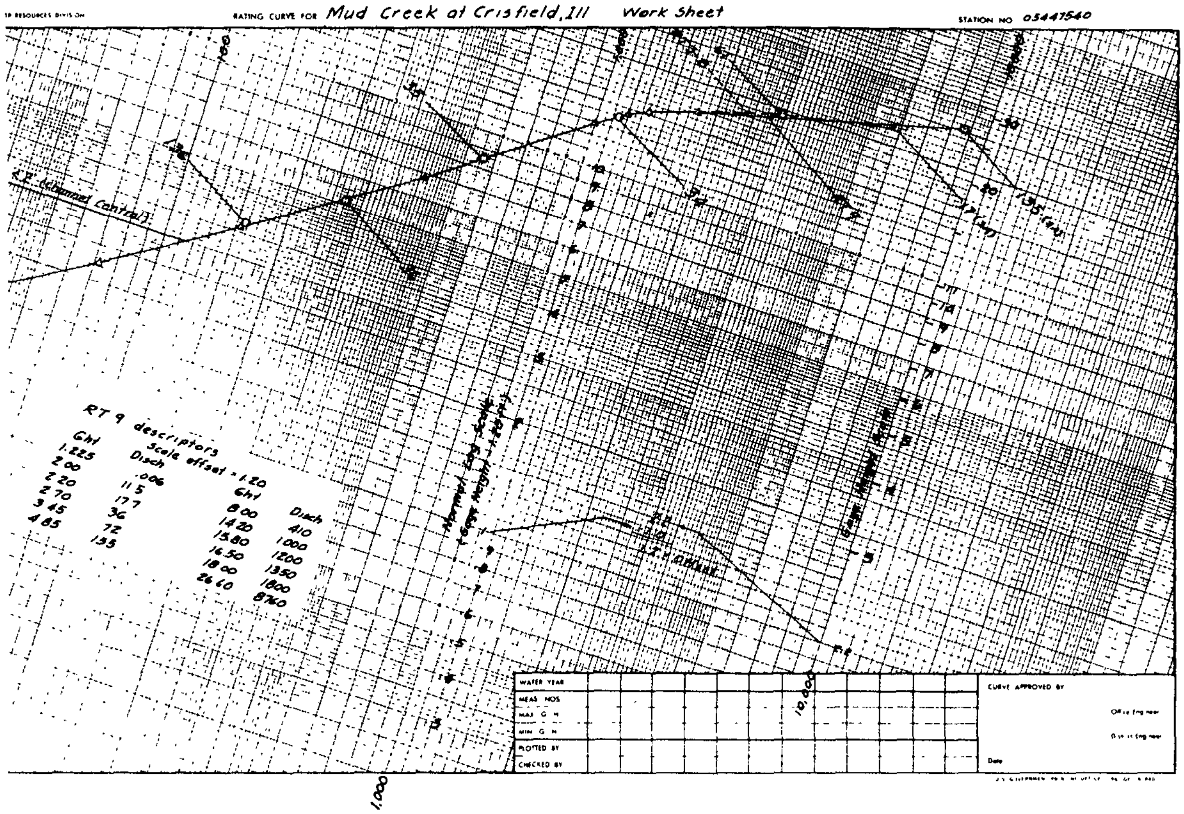


FIGURE 11.—Logarithmic work-curve sheet—Continued.

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	DISCHARGE IN CUBIC FEET PER SECOND (STANDARD PRECISION) .00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH GH
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	DISCHARGE IN CUBIC FEET PER SECOND (STANDARD PRECISION) .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	DIFF IN Q PER FOOT GH
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
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 ft^3/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

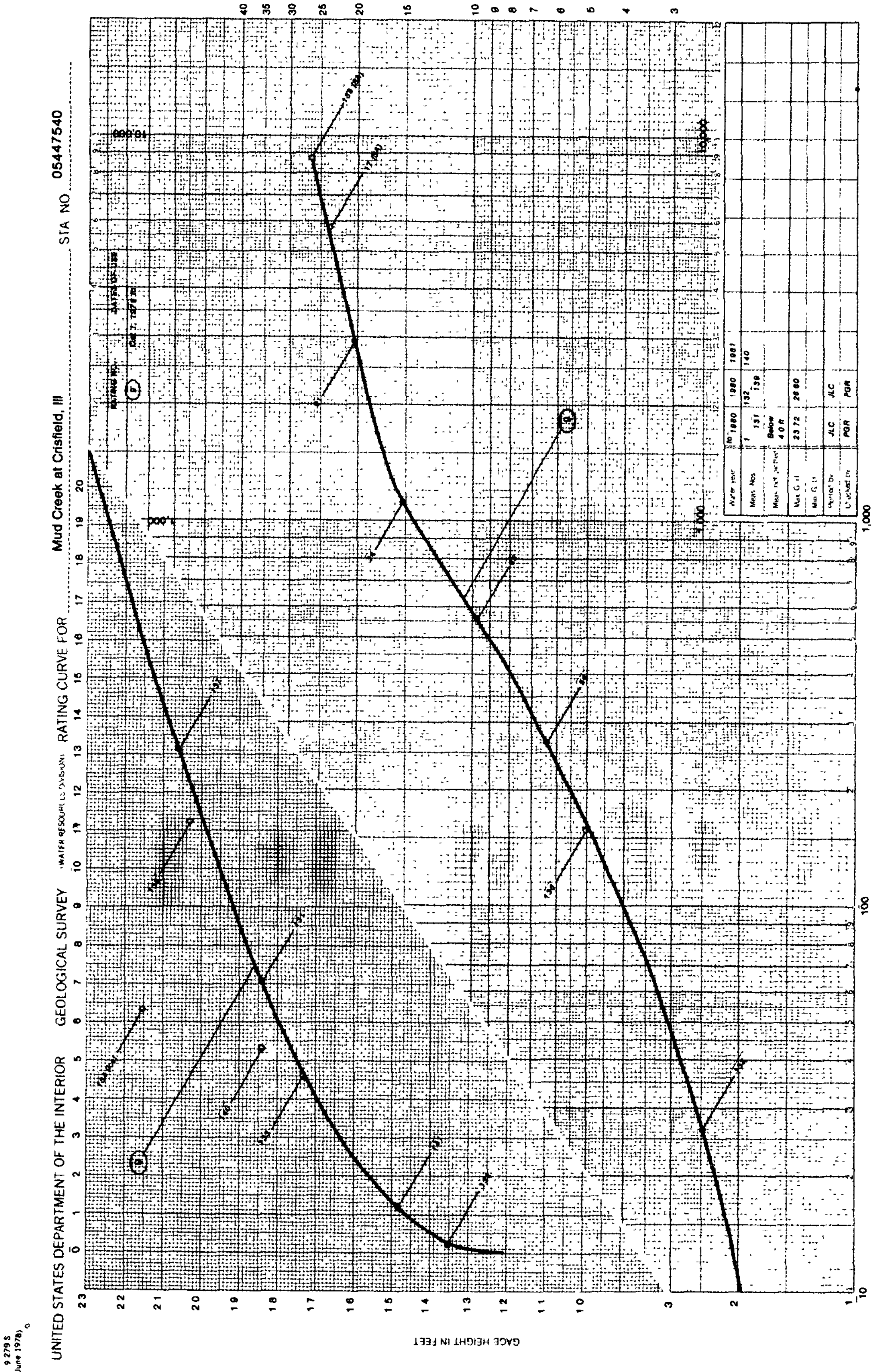


FIGURE 13.—Master curve sheet.

the manual processing of graphic-recorder and nonrecording gages and is described in this section.

Graphic recorders

The strip charts (fig. 6) are removed periodically from the graphic recorder and brought to the office for processing. Examine them for abnormalities. Compare the end of each chart segment with the start of the next segment for agreement with each other and with the discharge measurement notes. Sudden rises or falls, unless caused by local rain, should not ocucur except on a regulated stream. Sudden vertical jumps may denote clock stoppage, bubble-gage orifice movement or blockage, or unplugging of the intakes. Horizontal traces show possible intake blockage, dead batteries, electrical problems, or a bubble-gage orifice out of water. Vertical jumps or horizontal traces may also indicate faulty recorder action. If any suspicious periods are apparent, check the field notes to see if field personnel have noted an abnormal condition. Sometimes it is necessary to compare the chart with one from a nearby station to judge the reasonability of an odd-looking trace.

All notes and computations on the recorder chart must be neat, legible, aligned, and thoughtfully placed in soft black pencil to facilitate their interpretation and checking. No writing should obscure the pen trace or the reversal checks.

Dating recorder charts

Date the recorder charts by numbering each day prominently below the lower baseline of the chart on the noon line. Show the month and year on the first and last day of each month and on about every fifth day in between. Be sure the dates and gage heights on the discharge measurements agree with those on the recorder record.

Pen corrections for time

Determine and apply time corrections where necessary. Make a note on the chart at each inspection stating whether the pen-reading was correct or how slow or fast it was at that point. Inspect the record carefully where time corrections are large or erratic to be sure the clock has not stopped and restarted. Apply the time corrections to the nearest hour. Prorate corrections on a straight-line basis between gage inspections. A graphic method of distributing corrections is shown in figure 14. Simple mental arithmetic is the most rapid method for distributing small adjustments. Draw a short, heavy vertical line on the chart to indicate each adjusted midnight line, making sure to apply the corrections in the correct direction—ahead of the printed line if the pen is fast and behind it if the pen is slow. If there has been practically no range of stage during the period, small time corrections may be ignored as they would have no effect upon the figures of mean daily gage height computed from the graph.

Pen corrections for gage height

Determine the gage-height corrections to the recorder trace next. These are derived from any differences between readings of the recorder pen and the principal gage at inspections after any datum or gage height corrections to the principal gage have been applied. The corrections will usually be distributed according to time in essentially the same manner as time corrections and will be applied to figures of gage height obtained from the graph, whether instantaneous readings or mean figures for part or all of a day. An error in setting the pen at the start of a strip of chart will ordinarily be constant throughout the length of the strip; however, the total error may be increased or decreased by other factors.

It is sometimes necessary to correct recorder charts for reversal errors; that is, when the pen reverses either past the margin line or short of it. Reversal errors are caused by several things, such as expansion or contracton of the chart paper, lateral travel of the chart, incorrect setting of the pen, or mechanical error due to wear or maladjustment of the recorder. Most of these causes can be minimized by careful maintenance and servicing of the recorder, but paper expansion is a special problem related to humidity in the gage shelter. The strip-chart gradua-

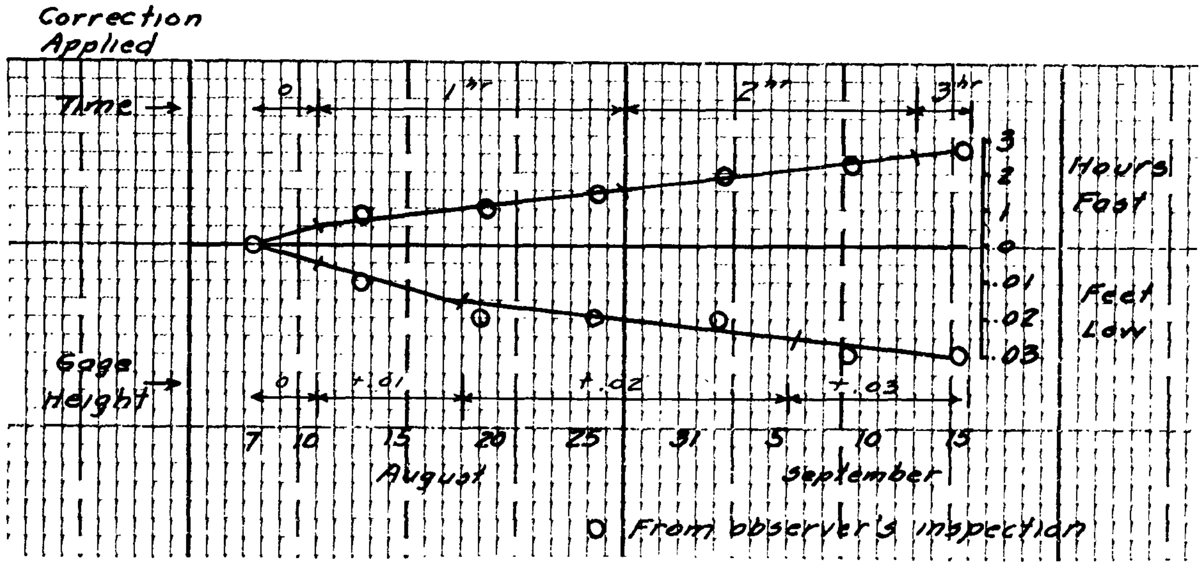


FIGURE 14.—Interpolation of pen corrections from graph plotted on recorder chart.

tions are 10 in wide when printed, 9.95 in wide in an extremely dry environment, and 10.4 in wide when the paper is completely saturated. The recorder is calibrated for a 10.00-in grid and with a perforated tape or beaded cable and splined-float wheel reverses at stages exactly 5 ft apart (10 ft apart for 1:12 ratio recorders). Reversal corrections less than 0.03 ft are normally disregarded. Larger corrections are applied to the pen readings at reversals and are prorated with stage for application to intermediate pen readings. Reversal errors are usually combined with other errors and without additional information are extremely difficult to correct. A step-reversal check, made in the field when a new strip of chart is started and again when it is removed, leaves steps whose true gage heights are known on the chart's ends. This information makes it possible to apply reversal corrections rapidly and accurately. Figure 15 illustrates a completed recorder chart affected seriously by reversal error and slightly by lateral paper travel. The step-reversal check lines at both ends of the chart strip were used to define the stage-graduated gage-height corrections applied to the recorder pen trace.

Computing mean daily gage heights

After the recorder chart has been dated and corrected, the mean daily gage heights and any other gage-height data required may be computed. Most mean daily gage heights are determined graphically by using a thin, rectangular guide made of transparent plastic about 2 by 8 in in size, through the middle of one side of which has been scribed a visible straight line parallel to the long edge. A pencil-point size hole at the center of the line is an added convenience. The plastic guide is placed over a 24-h segment of the recorder chart and moved into a position with the straight line approximately over the pen trace, so that all areas lying above the straight line and below the graph are equal to all areas lying below the straight line and above the graph. When the areas are thus balanced, the point at which the straight line intersects the noon line represents the uncorrected mean daily gage height. An example of this graphical method of determining mean daily gage height is shown for April 8, 1981, in figure 15.

List the figure of mean daily gage height thus determined on the noon line for that day, between 1 and 2 in above the base line. If a pen correction for gage height is applicable, enter it just below the uncorrected gage height, add or subtract the correction, and write the corrected gage height immediately below.

It is imperative that the recorder chart be adjusted with reference to the principal gage, the gage used for determining mean gage heights for the discharge measurements. Otherwise, it

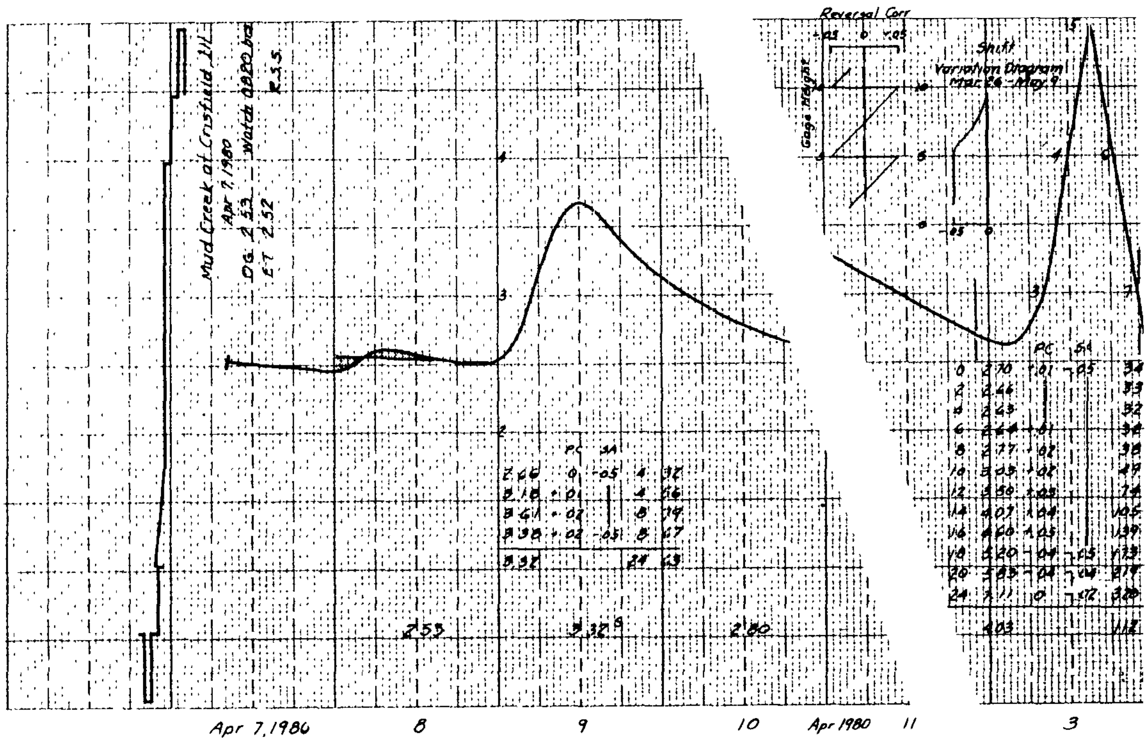


FIGURE 15.—Gage-height and discharge computations on graphic-recorder chart.

would be possible for large errors to enter into the computation of discharge. The inside float-type gage that drives the recorder is normally used as the principal gage for all graphic-recorder gage-height computations.

Allowable range in stage

The relation of discharge to gage height is nonlinear. The discharge corresponding to the mean gage height for a day of widely ranging stage is more or less than the actual discharge. If the rating curve is concave downward on rectangular paper, the mean gage height applied to it will be too low. The reverse is true for any concave upward parts of rectangularly plotted ratings.

The usual practice is to subdivide the daily gage-height graph wherever the error in the mean daily discharge produced by not subdividing would exceed 4 percent. An allowable range-in-stage table is used to determine the need for subdivision. One method of computing an allowable range-in-stage table from a rating table is first to select a gage height near the lower end of the rating table and observe the corresponding discharge. Then, by trial and error, determine the distance, in feet, equally in each direction that it is possible to move without the average of the two corresponding discharges differing by more than 4 percent from the discharge at the selected gage height. The difference between the latter two gage heights represents the allowable range of stage before subdivision is necessary. Repeat the process for as many stages as are necessary to develop a suitable table. This method was used to compute the allowable-range table in figure 17 from the rating table in figure 16.

Where shift adjustments are used, the adjusted gage heights are applied to the range table. A range table prepared from one rating can be used with a different rating as long as both have generally similar shapes and the discharges being computed are not extremely low.

Subdivided days

When a day is subdivided, it becomes necessary to determine mean gage heights for periods

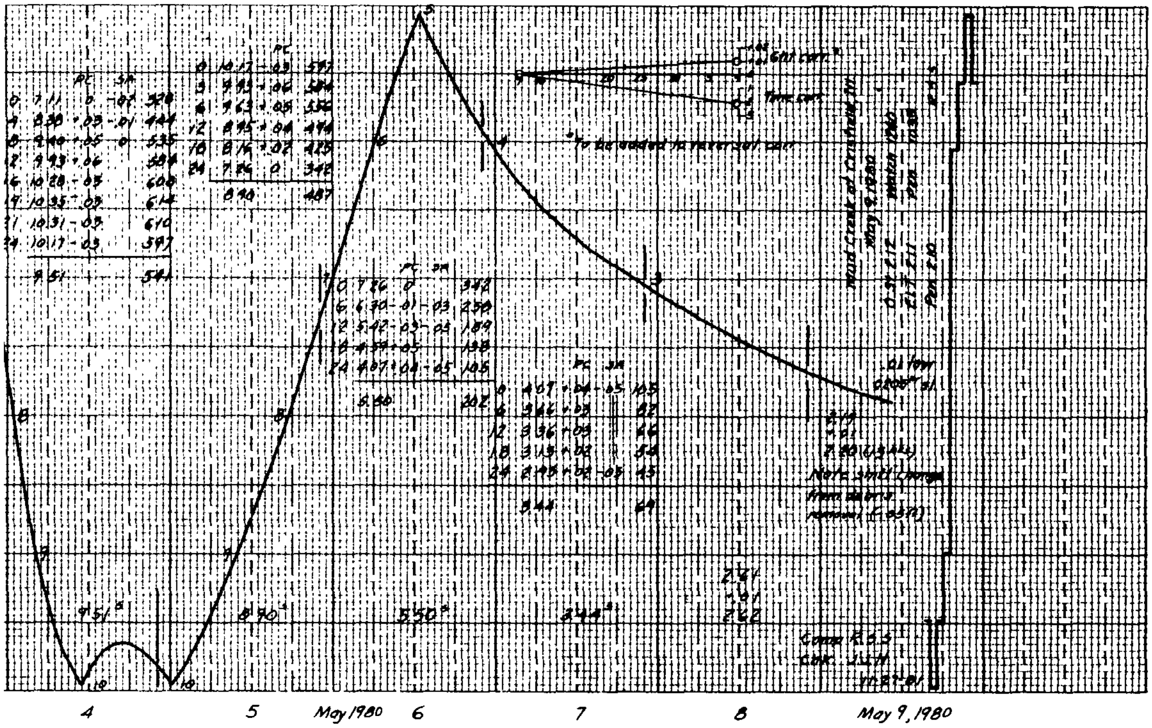


FIGURE 15.—Gage-height and discharge computations on graphic-recorder chart—Continued.

of less than 24 hours, and to combine the several figures of gage height and corresponding discharge arithmetically to obtain mean daily values. Two methods, both described in this section, are used: mean interval subdivision and midinterval or flood subdivision. Where sediment or chemical-quality computations are included, the variations in those constituents must be considered, in addition to rating curvature, for the selection of subdivision intervals.

In selecting intervals to use when subdividing gage-height graphs, a good method is to start at the lowest point on the graph and move upward as far as the allowable-rise table will permit. The length of the period can usually be rounded upward to the nearest hour lines. The periods should be in multiples of 2, 3, or 4-hours insofar as possible to simplify the arithmetic.

Computation of daily mean gage heights for subdivided days is optional but does provide a convenient means of checking discharge computations for gross errors and adequate subdivision.

Mean interval subdivision

When the mean gage height for an interval is determined graphically by averaging areas, the subdivision is known as the mean interval method. The mean gage heights for parts of days adjusted for corrections and shifts are applied to the rating table and the daily mean discharge is computed from the time-weighted values of those discharges. The method is illustrated for April 9, 1981, on the sample gage-height chart (fig. 15). Mean discharges computed by this method, using a range table to select the interval, are usually about 2-4 percent less than the true discharge unless the rating curve on rectangular paper bends upward within the stage range and causes the computed discharge to be greater than the true discharge.

With experience, the need for subdivision can sometimes be judged without a range table by considering the shape of the rating curve and the character of the recorder chart. Many rating curves have considerable curvature at the lower

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

EXPANDED RATING TABLE DATE PRINTED 09-01-81

05447540 TYPE LOG (SCALE OFFSET = 1.20) RATING NO. 9

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	DISCHARGE IN CUBIC FEET PER SECOND (EXPANDED PRECISION) .00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH GH
1.20				.009	.017	.027	.041	.057	.076	.099	
1.30	.124	.153	.184	.220	.258	.300	.345	.394	.446	.502	.437
1.40	.561	.624	.691	.761	.835	.913	.994	1.08	1.17	1.26	.79
1.50	1.36	1.46	1.56	1.67	1.78	1.90	2.02	2.14	2.27	2.40	1.18
1.60	2.54	2.68	2.83	2.97	3.13	3.28	3.44	3.61	3.78	3.95	1.59
1.70	4.13	4.31	4.50	4.69	4.88	5.08	5.29	5.50	5.71	5.92	2.01
1.80	6.14	6.37	6.60	6.83	7.07	7.32	7.56	7.81	8.07	8.33	2.46
1.90	8.60	8.87	9.14	9.42	9.70	9.99	10.3	10.6	10.9	11.2	2.9

GAGE HEIGHT IN FEET	DISCHARGE IN CUBIC FEET PER SECOND (EXPANDED PRECISION) .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	DIFF IN Q PER FOOT GH
2.00	11.5	14.4	17.6	20.9	24.4	28.0	31.9	36.0	40.2	44.6	37.7
3.00	49.2	53.9	58.9	64.0	69.3	74.6	79.8	85.1	90.5	96.1	52.6
4.00	101.8	107.6	113.6	119.7	125.8	132.1	138.5	145.0	151.6	158.3	63.3
5.00	165.1	171.9	178.9	185.9	193.0	200.3	207.6	215.0	222.5	230.1	72.7
6.00	237.8	245.6	253.5	261.5	269.6	277.6	285.8	294.3	302.6	311.1	81.9
7.00	319.6	328.4	337.1	346.0	354.9	363.9	372.9	382.1	391.3	400.6	90.3
8.00	410.0	418.3	426.7	435.1	443.5	452.0	460.6	469.2	477.8	486.5	85.2
9.00	495.2	503.9	512.7	521.6	530.5	539.4	548.3	557.3	566.4	575.5	89.4
10.00	584.6	593.7	602.9	612.2	621.4	630.8	640.1	649.5	658.9	668.4	93.3
11.00	677.9	687.4	697.0	706.6	716.2	725.9	735.6	745.4	755.2	765.0	96.9
12.00	774.8	784.7	794.7	804.6	814.6	824.6	834.7	844.8	854.9	865.1	100.4
13.00	875.2	885.5	895.7	906.0	916.3	926.7	937.1	947.5	957.9	968.4	103.7
14.00	978.9	989.4	1000	1012	1024	1036	1049	1061	1073	1086	119
15.00	1098	1111	1123	1136	1149	1161	1174	1187	1200	1221	144
16.00	1242	1263	1284	1306	1328	1350	1377	1405	1433	1462	248
17.00	1490	1520	1549	1579	1609	1640	1671	1703	1735	1767	310
18.00	1800	1841	1883	1926	1970	2014	2059	2104	2151	2198	446
19.00	2246	2295	2344	2394	2445	2497	2550	2603	2658	2713	523
20.00	2769	2825	2883	2942	3001	3061	3122	3185	3248	3311	607
21.00	3376	3442	3509	3576	3645	3714	3785	3856	3929	4002	701
22.00	4077	4153	4229	4307	4385	4465	4546	4628	4711	4795	803
23.00	4880	4966	5053	5142	5232	5322	5414	5507	5602	5697	914
24.00	5794	5892	5991	6091	6193	6296	6400	6505	6612	6719	1035
25.00	6829	6939	7051	7164	7279	7394	7512	7630	7750	7871	1165
26.00	7994	8118	8244	8370	8499	8629	8760				

FIGURE 16.—Rating table corresponding to figure 17 allowable-range table.

end; when sharp rises occur at times of low flow, even though the range in stage may not be large, the subdivided discharge may be several times the discharge obtained from the daily mean gage height. If a range table is not used, the daily mean gage heights should be computed to compare the subdivided and unsubdivided discharge to monitor the hydrographer's judgment.

Subdivision is merely manual integration. Mechanical integrators and electronic digitizers have been developed to compute the discharge for stations having large and frequent fluctuations in stage such as for those stations below power plants. However, digital recorders are usually more practical than graphic recorders for stations that require unusually frequent subdivision.

Midinterval subdivision

An alternate way to subdivide a day is to list the time and gage height at the start and end of the day and at enough intermediate times to define the variations in stage adequately. The gage-height change between intervals should be within the allowable-range table limits. The method is called "midinterval subdivision" because of the way daily values are computed. The listed value for each time is considered constant during the period starting halfway between the listed and previous listed times and ending halfway between the listed and subsequent listed times. This is the same concept used to compute discharge measurement subsection widths. Midinterval subdivision computations are laborious, especially with unequal

BASIC RELATIONS

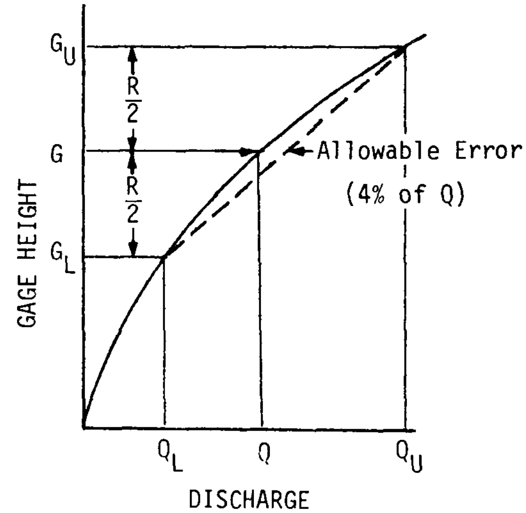
Symbols

G = Selected gage height
G_L = Gage height at lower limit of allowable range
G_U = Gage height at upper limit of allowable range
Q = Discharge at selected gage height
Q_L = Discharge at lower limit of allowable range
Q_U = Discharge at upper limit of allowable range
R = Allowable range

From graph at right

$$\frac{Q_L + Q_U}{2} = Q + 0.04Q = 1.04Q$$

$$Q_L + Q_U = 2.08Q$$



COMPUTATIONS

Selected Gage Height G	Q (from rating)	2.08Q	Widest Range with $Q_L + Q_U$ < 2.08Q					Allowable Rise $G_U - G_L$ (Feet)
			G_L	Q_L	G_U	Q_U	$Q_L + Q_U$	
1.3	0.12	0.25	1.29	0.10	1.31	0.13	0.23	0.02
1.5	1.35	2.81	1.45	.91	1.55	1.90	2.81	.1
2.0	11.5	23.9	1.8	6.1	2.2	17.7	23.8	.4
3.0	49.2	102	2.5	28.0	3.5	74.6	102.6	1.0
5.0	165	343	3.8	90.5	6.2	254	344	2.4
9.0	495	1030	6.0	238	12.0	775	1013	6.0
13	875	1820	10.0	585	16.0	1240	1825	6.0
15	1100	2290	13.5	927	16.5	1350	2280	3.0
18	1800	3740	17.0	1490	19.0	2250	3740	2.0
23	4880	10200	21.0	3380	25.0	6830	10200	4.0

ALLOWABLE-RANGE TABLE
(Listing of G_L and Allowable Rise)

Gage Height	Allowable Rise	Gage Height	Allowable Rise
1.29	0.02	6.0	6.0
1.45	.1	10.0	6.0
1.8	.4	13.5	3.0
2.5	1.0	17.0	2.0
3.8	2.4	21.0	4.0

FIGURE 17.—Derivation of an allowable-range table.

intervals or points between whole hours, but a programmable calculator can simplify the work. The sample chart (fig. 15) illustrates midinterval subdivision for May 3–7, 1981. Some hydrographers prefer to list the subdivision computations on separate sheets to avoid clutter on the recorder charts.

Flood reports and other special studies contain flow data in the midinterval-subdivision format. The computed daily figures for the special report, usually prepared after the annual report has been published, should agree exactly with the daily figures in the annual report but rarely do unless the same subdivisions were used for both. Some cooperating agencies specify midinterval subdivision for all periods of substantial flooding to avoid such discrepancies in their reports. Some hydrographers prefer the midinterval method for all subdivision despite its shortcomings for small short rises where numerous irregular time increments must be used. One common practice is to use midinterval subdivision for all high-water periods that contain a peak above a chosen base discharge and to use the simpler mean interval method for smaller rises.

Gage-height record checking

After a recorder chart is computed, each of the steps must be carefully checked. When the mean daily gage heights are computed on recorder charts, one unconsciously tends to concentrate primarily on the hundredth of a foot and gives somewhat less attention to the larger graduations. This results in fairly frequent mistakes of feet, half feet, and tenths. The primary duty of the checker should be to give particular attention to the large units and somewhat less attention to the hundredths. Approximately half of a checker's time can be saved by concentrating on the large units, because for many days this type of check can be made without using the plastic straight-line device. This procedure is not a lowering of accuracy standards but is actually a step toward better accuracy—with an attendant saving in time.

Accordingly, except for certain special studies or stations with extremely flat ratings, changes to mean daily gage heights by the checker are limited to 0.02 ft or more. Changes of 0.01 ft are not generally made because they almost invariably produce insignificant changes in discharge. There are times when there is justification for making a change of 0.01 ft; for example, if it is obvious that there was no change in discharge from one day to the next, but the computed daily gage height indicates a jog that did not occur. In other words, it is important to make those small changes if by so doing the daily gage heights are made to indicate the day-to-day trend.

Checking is done using a colored pencil to make a small dot after each checked figure or, after erasing an incorrect one, to replace it with a neat figure in the same space.

The following questions pertain to areas where errors of computation most often appear: (1) Were the "end of period" notes recorded properly? (2) Were indicated gage-height, pen, and datum corrections applied? Were they applied with the right sign? (3) Was the time correction applied? Was it applied in the right direction? (If time is slow, the line is in back of the midnight line; if time fast, it is ahead.) (4) Were corrections for reversal and mechanical errors applied properly? (5) Were the periods of reversal checked? (It is easy to compute a gage height as 4.80 (before reversal) when it should be 5.20 (after reversal).) (6) Was the mean gage height recorded to the correct foot, half foot, or tenth? (7) (Check this whenever any period of chart record looks suspicious.) Was a correct appraisal of the recorder operation used in the computation? Remember, the checker assumes all responsibility for the accuracy of the record. The checker's initial and the date are placed near the end of each chart segment.

Notes for station analysis

Notes to be included later in the "station analysis" should be written at this time. (See "Station Analysis" section.) Any changes in location or equipment should be described in the paragraph headed "Equipment." All irregularities in the gage-height record, such as clock stoppage or faulty-intake action, should be discussed and listed by dates in the "Gage-height record" paragraph.

Nonrecording gages

The observer records the gage readings, generally twice daily, in a quarterly book (one page is illustrated in figure 18) usually kept at the gage. Each week the observer copies the past week's readings on a special card and sends it to the field office. At the time of each visit, the hydrographer determines the stages of high-water marks left on the streambanks or recorded on a crest-stage gage, enters the readings made for discharge measurements in the book, and, preferably with the observer's help, determines the date of peak stages since the last inspection and reconciles any inconsistent readings. Examine the books for any abnormalities left unresolved in the field.

Computing daily mean gage heights

Enter the corrections previously listed for inclusion in the station analysis in the spaces provided in the gage books at the bottom of each left page. Compute the average of the morning and afternoon readings for days of little change in stage and enter them in the book under "Obs." Add the applicable correction, if any, to the average figure and enter the result in the book under "Corr."

Draw a stage hydrograph on a piece of graphic recorder chart for all high-water periods and other days when the mean of the two readings would not be a reasonable approximation of the daily mean. Use the same time and gage-height scales for all flood period graphs so that

GAGE HEIGHTS FOR WEEK ENDING SATURDAY, May 9, 19 80

16—24264-1

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	9 4.06		
	P. M. 6.00	5.14			
Mon. 4	A. M. 7:30	9.35	9 9.50		
	P. M. 7:00	10.30			HWMK 10.3 (hand level) R.S.S.
Tues. 5	A. M. 7:30	9.50	9 8.90		
	P. M. 7:00	8.00			
Wed. 6	A. M. 6:15	6.20	9 5.51		
	P. M. 6:45	4.58			
Thurs. 7	A. M. 6:45	3.64	9 3.44		
	P. M. 6:30	3.13			
Fri. 8	A. M. 6:30	2.77	2.64		
	P. M. 6:30	2.50			
Sat. 9	A. M. 6:50	2.24	2.17	Var. shift	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.

* Correction 0

Mean Gage Ht. Computed by RSS Date 11-24-81

Mean Gage Ht. Checked by JJH Date 11-27-81

FIGURE 18.—Computed page of nonrecording-gage observer's book.

a flood-stage hydrograph template similar to the one in figure 19 can be used to shape the graph. The template is made on recorder chart paper by tracing the shapes of previous flood-stage hydrographs that were well defined by gage readings. Given the observer's readings and the peak stage, plotted on chart paper, and with the template under the paper as a shaping guide, the best possible graph of the data can be drawn. Be sure to include the last previous low-water day on the graph.

Subdivision of days is identical to that for graphic-recorder stations, using an allowable-range table and midinterval subdivision. Figure 20 illustrates a typical graph and subdivisions.

All computations and plotting are checked in the same manner as graphic chart work. After checking, the gage-height graphs may be folded and taped into the gage-reading books for storage.

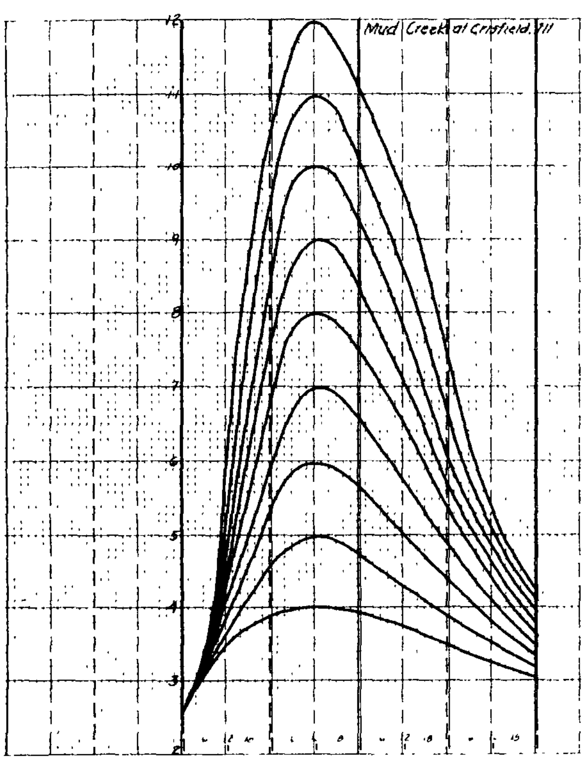


FIGURE 19.—Template for shaping nonrecording-gage graphs.

Copying gage heights on form 9-192a

Form 9-192a (fig. 21) is the basic computation sheet for stations whose discharge records are computed manually. A similar form 9-192b with extra columns for additional rating factors (fall, rate of change, and shift) is sometimes used. The form is often distributed to fill requests for data so it is carefully aligned and lettered in India ink for ozalid reproduction. The original is kept in the files as the official record, and future revisions to the published record will be noted on the original form 9-192a.

Fill in the headings in the spaces provided. Copy the daily mean gage heights from the recorder charts or gage books. If the mean gage height for a subdivided day was computed, list the figure with a lower case "s" at the left edge of the discharge column. If no mean gage height was computed, show an "s" in the center of the gage-height column.

Heavy black lines are used to indicate certain conditions. A line across the gage-height column indicates the date of a change in datum or location. A line across the discharge column shows the date of a rating change. A vertical line between the gage-height and discharge column signifies that the discharge was computed by a method other than the application of a rating to the gage height.

Check the above work. The copier's work and the checker's work are initialed and dated in the appropriate boxes. The form is then ready for the next step.

Computation of Discharge Record

Discharge records are computed by applying the gage-height record, with adjustments where the shifting-control method is used, to the applicable discharge rating. This computation is made for each instantaneous gage height from a digital recorder. For a graphic recorder or nonrecording gage, only one computation is made for each day or interval of a subdivided day. Form 9-192a is the worksheet for manual computations, and a special computer printout, the primary computation sheet, is its equivalent for

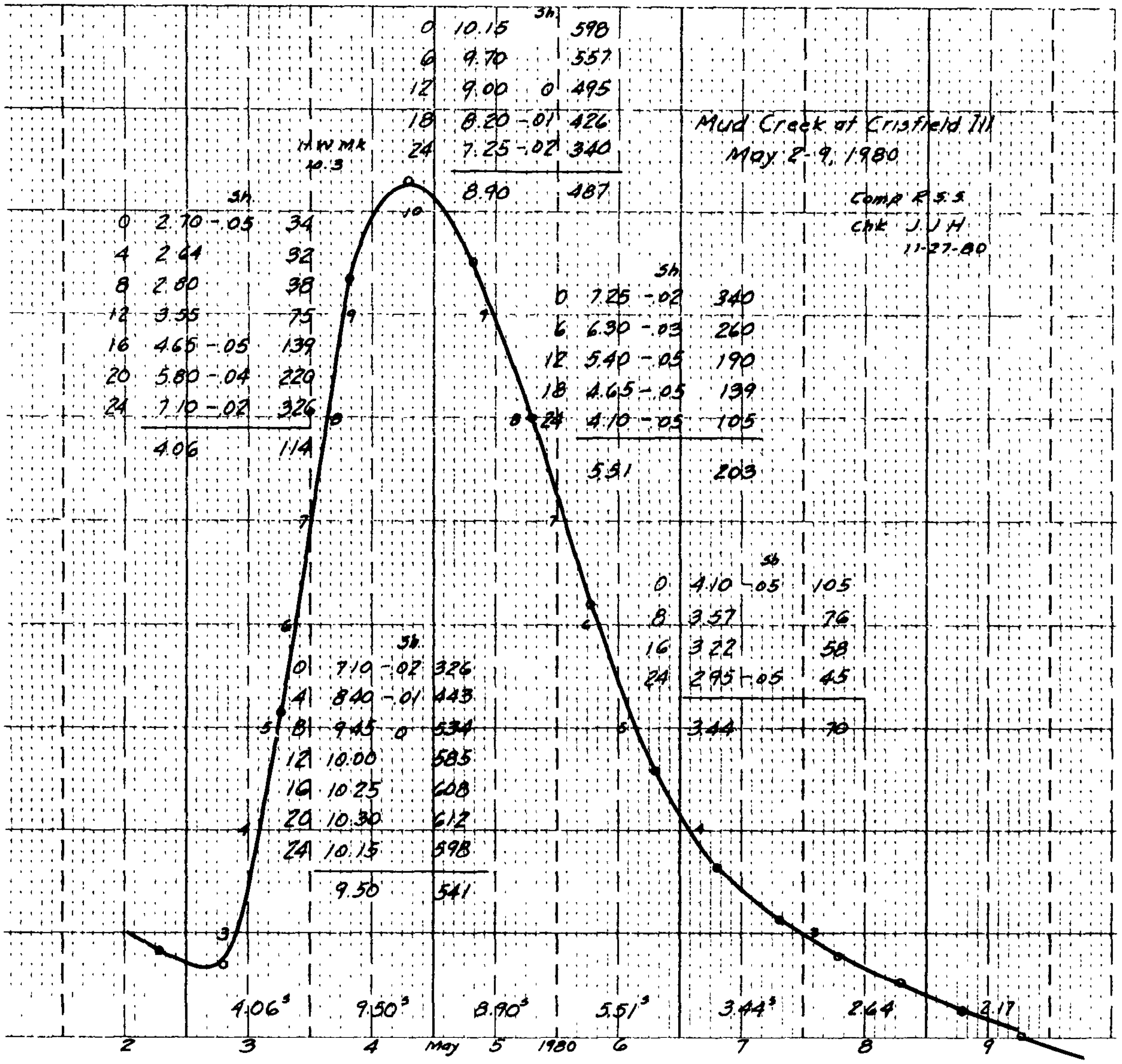
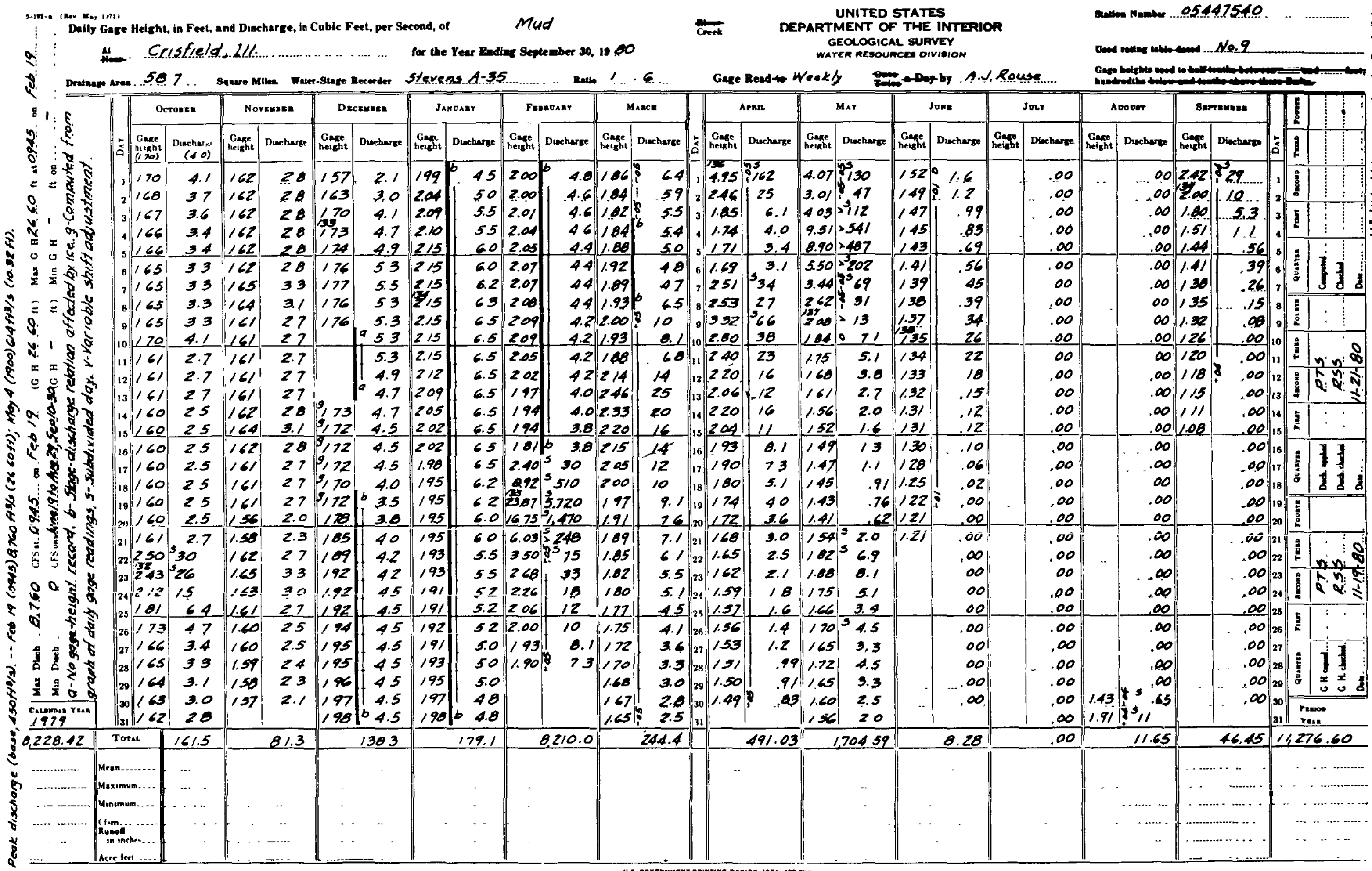


Figure 20.—Computed nonrecording-gage graph.

for ADP records. Discharge for periods of ice effect, missing gage-height record, or variable backwater is estimated or computed by using special methods.

The discharge computation for ordinary periods of record is a mechanical process except for distributing the shift adjustments. These adjustments tend to vary with time, stage, or both simultaneously, and different methods have been developed to distribute them under nearly all rating situations. After the distribution computations described in the next paragraphs have been made, the daily shift adjustments for graphic and nonrecording stations are listed on form 9–192a for nonsubdivided days (fig. 21), and those for subdivided day intervals are usually entered on the recorder charts (fig. 15) or gage-height graphs (fig. 20). The WATSTORE User's Guide contains instructions for entering manually distributed shift adjustments into the ADP system or for providing for various automatic shift distributions (constant, time varied, stage varied, or simultaneous time and stage varied) between the measurement-defined shifts.



Mud Creek at Crisfield, Ill - 1980

9-192-a (Rev. May 1971)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Daily Gage Height, in Feet, and Discharge, in Cubic Feet, per Second, of Mud Creek at Crisfield, Ill. for the Year Ending September 30, 1980

Station Number 05447540

Used rating table dated No. 9

Drainage Area 58.7 Square Miles. Water-Stage Recorder Stevens A-35 Ratio 1 : 6 Gage Read Weekly by A.J. Rouse

Day	October Gage height (1.70)	October Discharge (4.0)	November Gage height	November Discharge	December Gage height	December Discharge	January Gage height	January Discharge	February Gage height	February Discharge	March Gage height	March Discharge
1	170	4.1	162	28	157	2.1	199	b 45	200	b 4.8	186	6.4
2	168	37	162	28	163	3.0	2.04	50	2.00	4.6	1.84	59
3	167	3.6	162	28	170	4.1	2.09	5.5	2.01	4.6	1.82	5.5
4	166	3.4	162	28	173	4.7	2.10	55	2.04	46	184	b 5.4
5	166	34	162	28	174	4.9	215	60	2.05	4.4	1.88	5.0
6	165	33	162	28	176	53	215	6.0	2.07	44	1.92	48
7	165	33	165	33	177	5.5	215	6.2	2.07	44	1.89	47
8	165	3.3	164	3.1	176	53	215	63	208	44	1.93	b 6.5
9	165	33	161	27	176	5.3	2.15	65	209	4.2	2.00	10
10	170	4.1	161	27		a 53	215	6.5	209	4.2	1.93	8.1
11	161	2.7	161	2.7		5.3	2.15	6.5	2.05	4.2	188	68
12	161	2.7	161	27		4.9	212	6.5	202	42	214	14
13	161	27	161	27		a 4.7	209	6.5	197	4.0	246	25
14	160	25	162	28	g 173	4.7	205	6.5	194	4.0	2.33	20
15	160	25	164	3.1	g 172	4.5	202	6.5	194	3.8	220	16
16	160	25	162	28	g 172	4.5	202	65	181	b 3.8	215	14
17	160	2.5	161	27	g 172	4.5	1.98	65	2.40	s 30	205	12
18	160	25	161	27	g 170	4.0	195	6.2	8.92	s 510	200	10
19	160	25	161	27	g 172	b 3.5	195	62	23.87	s 5,720	197	9.1
20	160	2.5	1.56	2.0	178	3.8	195	6.0	16.75	s 1,470	1.91	76
21	161	2.7	1.58	2.3	185	40	195	60	6.03	s 248	189	7.1
22	2.50	s 30	162	27	189	4.2	193	5.5	3.50	s 75	1.85	61
23	2.43	s 26	1.65	33	192	42	193	55	2.68	33	1.82	5.5
24	2.12	15	1.63	3.0	1.92	4.5	191	5.2	2.26	18	180	5.1
25	181	64	1.61	27	192	4.5	191	5.2	2.06	12	1.77	4.5
26	173	47	1.60	25	194	45	192	52	2.00	10	1.75	4.1
27	166	3.4	160	2.5	195	4.5	191	5.0	193	8.1	172	3.6
28	165	33	1.59	24	195	45	193	50	1.90	73	170	3.3
29	164	3.1	158	23	196	45	195	5.0			1.68	3.0
30	163	3.0	157	2.1	197	4.5	197	48			167	2.8
31	162	28			198	b 4.5	198	b 4.8			1.65	2.5
Total		161.5		81.3		138.3		179.1		8,210.0		244.4

Day	April Gage height	April Discharge	May Gage height	May Discharge	June Gage height	June Discharge	July Gage height	July Discharge	August Gage height	August Discharge	September Gage height	September Discharge
1	4.95	162	4.07	130	152	1.6		.00		.00	2.42	29
2	2.46	25	3.01	47	149	1.2		.00		.00	2.00	10
3	1.85	6.1	4.03	s 112	147	.99		.00		.00	1.80	5.3
4	1.74	4.0	9.51	>541	145	.83		.00		.00	1.51	1.1
5	171	3.4	8.90	>487	143	.69		.00		.00	1.44	.56
6	1.69	3.1	5.50	s 202	1.41	.56		.00		.00	1.41	.39
7	251	s 34	3.44	s 69	139	45		00		.00	138	.26
8	253	27	262	31	138	.39		.00		00	135	.15
9	332	s 66	208	13	1.37	34		.00		00	1.32	.08
10	2.80	38	184	71	135	26		.00		.00	126	.00
11	240	23	1.75	5.1	134	22		00		00	120	.00
12	220	16	168	3.8	133	18		.00		.00	118	.00
13	2.06	12	161	2.7	1.32	.15		00		.00	115	.00
14	220	16	1.56	2.0	1.31	.12		.00		.00	111	.00
15	204	11	152	1.6	131	.12		.00		.00	1.08	.00
16	193	8.1	149	13	130	.10		.00		.00		.00
17	190	73	1.47	1.1	128	.06		.00		.00		.00
18	180	5.1	145	.91	1.25	.02		.00		00		.00
19	174	40	1.43	.76	122	.00		.00		.00		.00
20	172	3.6	1.41	.62	121	.00		.00		00		.00
21	168	3.0	154	s 2.0	1.21	.00		.00		.00		.00
22	1.65	2.5	182	s 6.9		.00		.00		.00		.00
23	162	2.1	1.88	8.1		00		00		.00		.00
24	1.59	18	175	5.1		00		.00		.00		.00
25	1.57	1.6	1.66	3.4		00		.00		.00		.00
26	1.56	1.4	170	s 4.5		.00		.00		.00		.00
27	153	1.2	165	3.3		00		.00		.00		.00
28	151	.99	1.72	4.5		00		.00		.00		.00
29	1.50	.91	1.65	3.3		.00		.00		.00		.00
30	1.49	.83	1.60	2.5		.00		.00	1.43	s .65		.00
31			156	20				.00	1.91	s 11		
Total		491.03		1,704.59		8.28		.00		11.65		46.45

Calendar Year 1979: 8,228.42 Period Year: 11,276.60

Computed PTS 11-21-80, checked RSS; PTS 11-19-80, RSS

Max Disch. 8,760 CFS at 0945 on Feb. 19 (G H 26.60 ft) Max G H 26.60 ft at 0945 on Feb. 19

Min Disch. 0 CFS on June 19 to Aug 29, Sept 10-30

a-No gage-height record. b-Stage-discharge relation affected by ice. g-Computed from graph of daily gage readings. s-Subdivided day. v-Variable shift adjustment.

Peak discharge (base, 450 ft³/s) -- Feb 19 (0945) 8,760 ft³/s (26.60 ft); May 4 (1900) 614 ft³/s (10.32 ft).

Mean / Maximum / Minimum / Runoff in inches / Acre feet

U.S. GOVERNMENT PRINTING OFFICE: 1971—489-796

FIGURE 21.—Computed form 9-192a.

The basic operations for the shifting-control method are essentially the same for ADP or manual computations.

Distribution of shift adjustments

The shift adjustments, if any, that apply at the times of discharge measurements were computed previously and listed tentatively on form 9-207 (fig. 10). The shift adjustments that apply during the periods between the measurements must be interpolated by an appropriate method before the discharge records can be computed. The method used will depend on the hydrographer's judgment considering the nature of the shifting, the frequency of measurements, and the type of channel and control.

Small shifts that change gradually may be distributed satisfactorily by inspection using mental interpolation. Larger shifts, whose variations are adequately defined by discharge measurements, warrant a more rigorous analysis with some form of graphic shift-adjustment-variation diagram. The accuracy of discharge records computed from a rating with large and erratic shifts depends to a great extent on the frequency of discharge measurements, and particularly unstable streams may need weekly or even daily measurements to define the day-to-day shift-adjustment variation.

The shift-adjustment variation between discharge measurements of unstable channels may be too great for the usual interpolation methods and a special technique may be needed. One procedure involves varying the shifts smoothly between the measurement-defined values until a smooth daily-discharge hydrograph (see "Discharge Hydrographs" section) that follows the trends indicated by the discharge measurements is obtained. A streamflow record should be computed from the data collected at the site, and, except for estimated portions, be free from the influence of other streamflow records. For this reason the use of records for other stations to distribute shift adjustments is normally avoided. If shift adjustments interpolated to produce a smooth hydrograph are above or below the range of adjustments indicated by the two adjacent discharge measurements, the discharge records for that period should be considered as estimated rather than computed and their accuracy rating downgraded accordingly.

Shift-adjustment variation diagrams

A shift-adjustment variation diagram (V diagram), a graph of the relation between shift adjustment and either time or stage, is commonly used to interpolate shift adjustments between measurement-defined values. The V-diagram shifts can be graduated with time, stage, or time and stage simultaneously either manually or as part of the ADP primary or update procedures.

When a low-water control is scoured or filled or affected by backwater from leaves, debris, or aqueous growth, the corresponding rating shift is greatest at low water and normally tapers to zero at some higher stage. This is called a stage-variable shift. If the channel is alluvial and its bed is raised and lowered by sediment being picked up or deposited, the shift variation with stage may be negligible compared to its variation with time, and the shifts are called "time variable." Most streams have shifts that must be graduated with stage while the stage graduation is changing with time.

Time-variable-shift distribution can be made manually by using a V diagram, similar to the one in figure 22, where measurement-defined shifts are plotted and curvilinear interpolations are made visually. The corresponding ADP process prorates the shift adjustments linearly between measurement-defined points, but arbitrary data points may be used to obtain other distributions.

Stage-variable-shift distribution can be made by using V diagrams similar to those in figure 23. Each diagram involves a base-rating curve (the numbered rating in effect at the time); a shift-rating curve (a rating curve drawn to fit the measurements that define the shift, usually only on the rating work-curve sheet); and the V diagram (the gage-height differences between the base curve and shift curve, plotted against stage). The shift curve should normally be drawn first with the same consideration given to its shape as would be given to a numbered

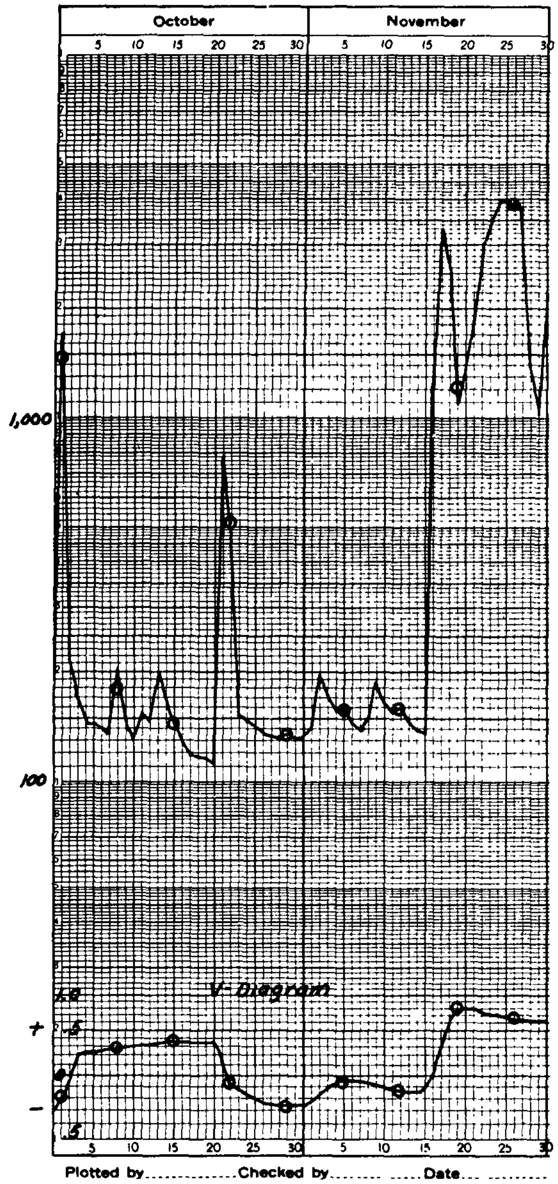


FIGURE 22.—Time-shift-variation diagram with corresponding hydrograph.

rating. The V diagram is best defined by drawing its corresponding shift curve first. The V diagrams of the type in figure 23*A*, for relatively small shifts, may be defined directly from measurement-defined shifts without drawing a shift curve, but this process is not recommended with other V-diagram types or for large shifts where it could lead to grossly misshapen equivalent ratings and dubious discharge records.

A stage-variable V diagram may be expanded, contracted, or reversed (mirror image), and the change in shape may be graduated with time. The process can be done manually or automatically to distribute shift adjustments with respect to time and stage simultaneously.

Shift adjustments varied with time only

Figure 22 illustrates a time-shift V diagram plotted below the corresponding daily hydrograph. The type of shift illustrated varies only with time, but the variation is faster at high stages than at low stages. The shift-distribution process requires a hydrograph or readable gage-height record as a guide for the shift distribution, so its greatest use is for manually computing records or updating of ADP records.

To use the process (1) plot the measurement-defined shifts on the days of measurements by using a convenient improvised shift scale; (2) connect the plotted points with a smooth curve so that no interpolated daily shift is above or below the range of the adjacent measurement-defined shifts; (3) apply the shifts from the V diagram to the daily mean gage heights (or equivalent gage heights for ADP records) and plot the computed discharges on the hydrograph; (4) look for anomalies in the hydrograph such as odd-looking rises or recessions or rising hydrographs during falling-stage periods and modify the V diagram to correct them; and, (5) for ADP records, enter the resulting V-diagram shift data in the update program described in the WATSTORE User's Guide (vol. 1). These shifts will be applied to equivalent gage heights stored in the Daily Values File and used with the appropriate rating to compute the updated mean daily discharges.

Shift adjustments varied with stage only

The use of a stage-varied-shift adjustment is equivalent to drawing a new numbered rating curve and may be preferable for temporary rating changes. The principal use for stage-shift diagrams is as one step in the process used for varying shifts with both stage and time as explained in a subsequent section.

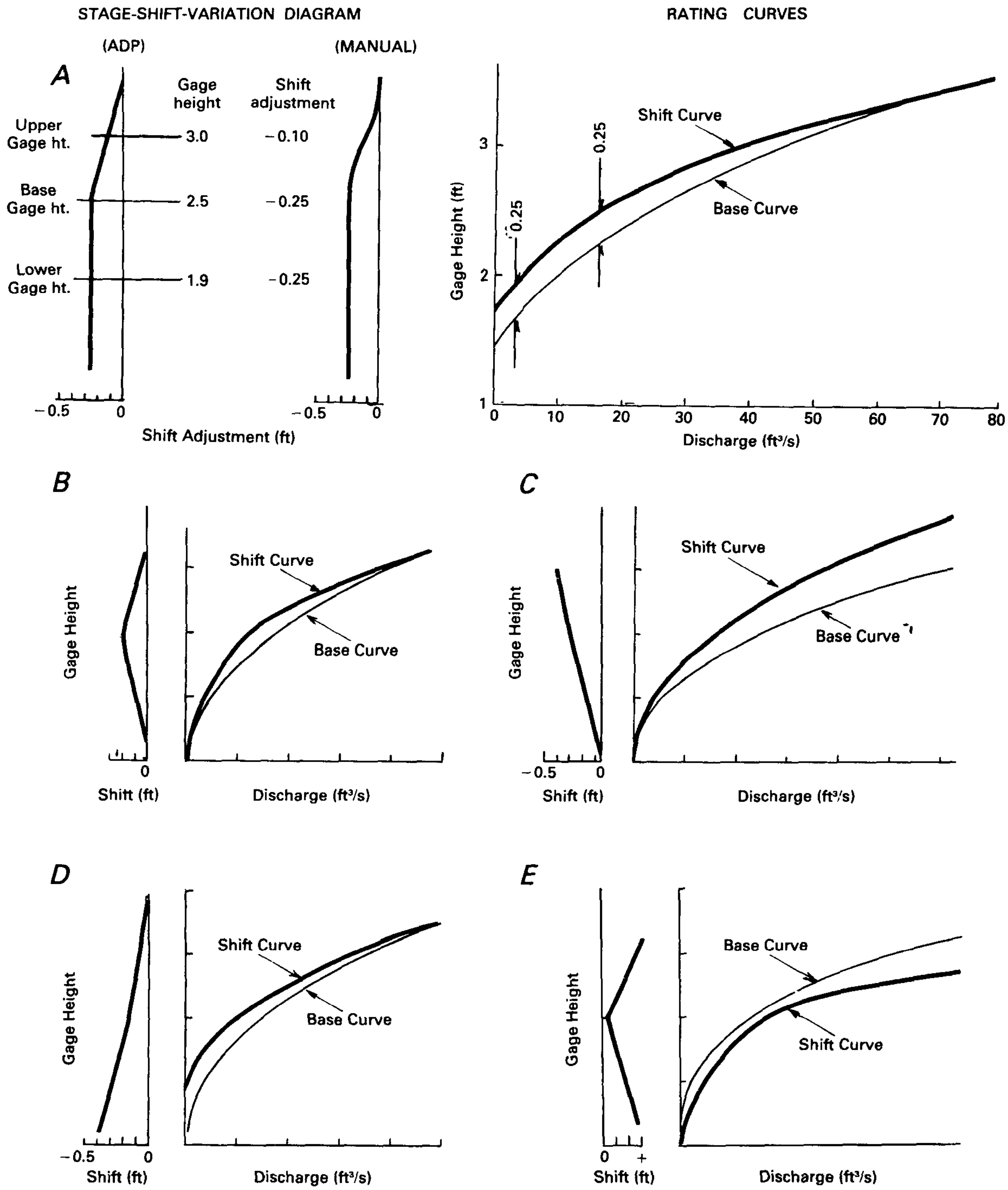


FIGURE 23.—Effect of various stage-shift-variation diagram shapes on shift-curve shape.

Figure 23 illustrates typical stage-shift V diagrams and the relations between their corresponding base curves and shift curves. The V diagrams for manual application are usually curved, but the curve must be approximated by two straight lines for ADP use (in 1982). An ADP version is defined by six descriptors; three gage heights called "upper," "base," and "lower"; and a shift adjustment corresponding to each of those three gage heights. The figure 23*A* (manual) V diagram is curved, and the ADP straight-line approximation of it has the following descriptors: upper, 3.0, -0.10; base, 2.5, -0.25; and lower, 1.9, -0.25. The upper descriptors could just as well be 3.33, 0.00, which would describe the same upper line of the diagram. The V diagrams (manual and ADP) describe a shift curve 0.25 ft above the base curve for stages below 2.5 ft that merges with the base curve at 3.33-ft gage height. The manual version can be either a graph or a table. The V diagram in figure 23*B* describes a shift curve identical to the base curve at low and high stages and above it at medium stages. The V-diagram shapes in figure 23*A* and 23*B*, in positive or negative versions, cover all ordinary rating situations. The other three shapes in figure 23 may be needed for unusual rating conditions but probably indicate an improper base-rating shape.

The gage-height difference between the shift curve and the base curve at a given stage, used for V-diagram definition, must be measured from a point at the given gage height on the shift curve to a point on the base curve directly above or below that point. Figure 24 illustrates the procedure for plotting a point on the shift curve given the gage height and the magnitude of the shift adjustment. Measuring from the point where the base curve intersects the given gage height is a frequent mistake that results in a serious error wherever the shift adjustment is large and the rating is sharply curved.

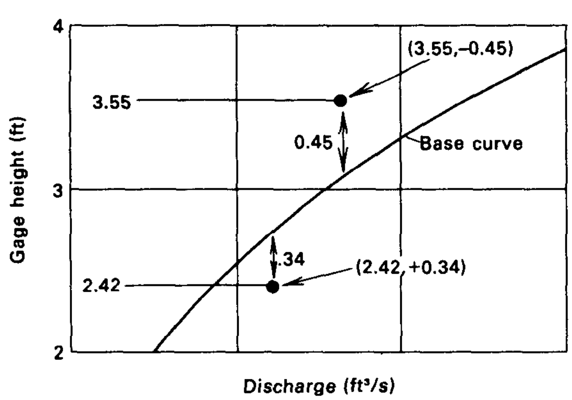


FIGURE 24.—Plotting positions of stage-shift-variation diagram points on the shift curve.

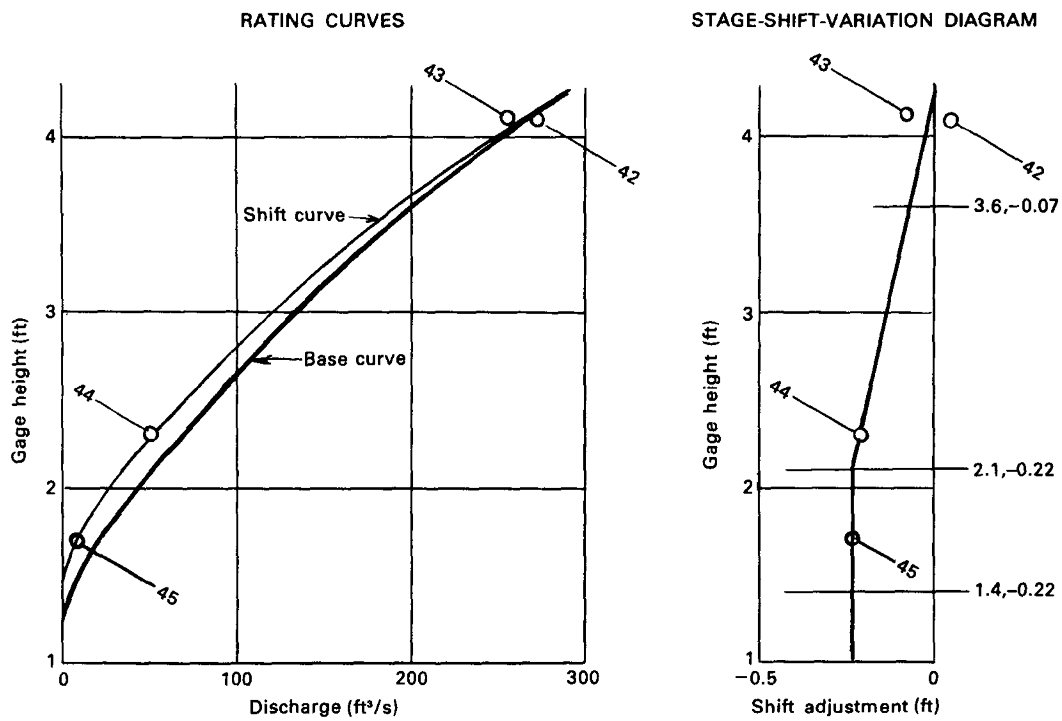
To prepare a stage-shift diagram (1), on the rating curve worksheet, mark the measurements that define the shift curve and draw the trial shift curve based on them; (2) plot the measurement-defined shift adjustments and the gage-height differences between the base and shift curves at several gage heights (fig. 25), on a rectangular grid; (3) draw a V diagram considering all of the plotted points; (4), for ADP, approximate the V diagram with two intersecting straight lines and list the three coordinate sets (gage height and shift adjustment as illustrated in figure 23*A*); (5) replot the shift curve by using the V diagram and, if the shift curve is poorly shaped, modify the V diagram as necessary to correct it; and (6) determine from the V diagram the shift adjustment applicable to each discharge measurement and recompute its percent difference if necessary.

The process is illustrated in figure 25. Note that the tentative shift adjustment listed on form 9-207 (list of discharge measurements) for a specific discharge measurement is final only if the shift curve and V diagram are drawn through that measurement's plotted points. The shift curve in figure 25 averages 42 and 43, so the originally computed shifts (+0.05 and −0.07) must be changed to the values from the V diagram (−0.02 and −0.02) that are used to compute the discharge record. The shift curve and V diagrams go through the measurement 44 and 45 values, so no revisions to their shift adjustments are necessary on form 9-207.

The coordinates of the finished V diagram are entered into the ADP system as described in the WATSTORE User's Guide. For manually computed records, the shift adjustments are taken from the V diagram or table and entered on form 9-192a or the recorder chart.

Shift adjustments varied with time and stage

One stage-shift V diagram, modified to fit the day-to-day shifting caused by changes to the control, is used to vary the shift distribution simultaneously with time and stage for primary computations by ADP or, with modifications, for manually computed records. This procedure can also be used for updating ADP records if the base and shift curves are roughly parallel. It



COMPUTATIONS

No.	Date	Gage height	Discharge	Shift adjustment computed from		% diff.
				Meas.	V-diag.	
42	May 7	4.09	273	+0.05	−0.02	+4.2
43	May 8	4.10	257	− .07	− .02	−3.8
44	June 10	2.30	53.2	− .20	− .20	– –
45	July 7	1.70	9.7	− .22	− .22	– –

FIGURE 25.—Development of a stage-shift-variation diagram.

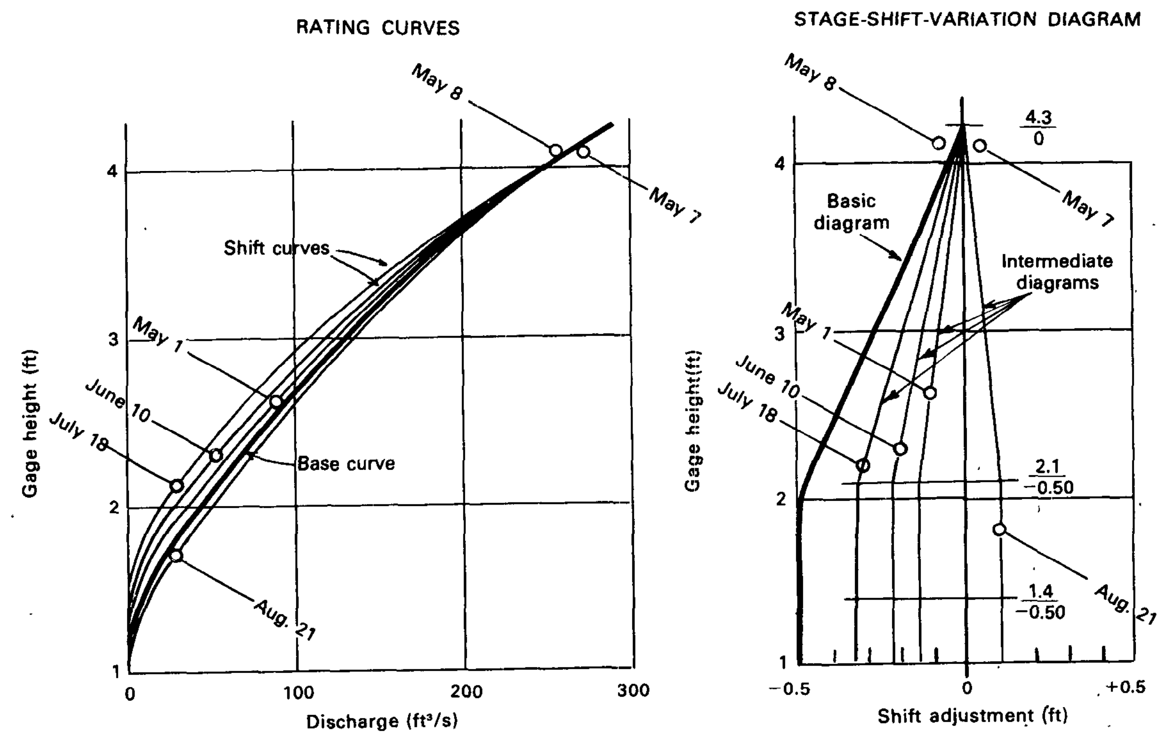
should not be used to correct the effect of an erroneously shaped base rating used for the primary computation. In that event, manual computation of the updated figures or rerunning the primary computations is necessary.

ADP procedure

The computer program details and the data input format are explained in the WATSTORE User's Guide. The data requirements, in addition to the usual material for a primary or update computation, are (1) the descriptors for a basic V diagram; (2) the dates, gage heights, and shift adjustments of most of the discharge measurements with gage heights within the V diagram range (ice measurements, disregarded measurements, and measurements outside the V diagram limits or inside but close to the limits are not used); and (3) the dates, gage heights, and shift adjustments of arbitrary data points (synthetic discharge-measurement data used to control the time-varied distribution). The program expands, contracts, or reverses one basic V diagram to generate a perfectly fitting and proportionally shaped diagram for each day of a discharge measurement or arbitrary data point. The V diagrams for the other days are interpolated, linearly with time, between the data point diagrams and are used to compute an appropriate shift adjustment for each recorded gage height.

The procedure for distributing time- and stage-variable shifts requires considerable judgment and is relatively simple for some gages and very intricate for others. One procedure for analysis of a typical distribution, suggested for the first few uses by a hydrographer with limited experience in rigorous shift distribution, is illustrated in figure 26 and outlined as follows:

1. Develop the base rating by the usual method and compute the measurement-defined shift adjustments.



COMPUTATIONS

No.	Date	Gage height	Discharge	Shift adjustment computed from		% diff.
				Meas.	V-diag.	
41	May 1	2.63	90.0	−0.10	−0.10	--
42	May 7	4.09	273	+ .05	− .02	+4.2
43	May 8	4.10	257	− .07	− .02	−3.8
44	June 10	2.30	53.2	− .20	− .20	--
45	July 18	2.13	29.6	− .30	− .30	--
46	Aug. 21	1.70	30.1	+ .10	+ .10	--

FIGURE 26.—Development of a time-varied stage-shift diagram.

2. Use the largest practical rectangular graph paper worksheet and plot the shift-prone portion of the base-rating curve on it. Also, plot the shift adjustments for the measurements to a suitable scale near the right margin.
3. Select the most appropriate V-diagram shape and the upper, base, and lower gage heights for the diagram. Base the selections on a scrutiny of the logarithmic work-curve sheet of the base rating and knowledge of the control characteristics of the stream.
4. Plot a trial basic V-diagram on the rectangular worksheet so that the diagram is outside the greatest shift adjustment and its base shift is 1.0–, 0.5–, or 0.1–ft (–0.5 ft in figure 26).
5. Draw an intermediate V diagram, a widened or narrowed version of the basic diagram, through the greatest shift (July 18 in figure 26). Plot the corresponding shift curve on the worksheet. If the shift-curve shape is unsatisfactory, revise the V diagram gage heights or shape until a satisfactory shift curve is obtained.
6. Identify any measurements, such as 42 and 43 in figure 26, that are so close to a limit of the V-diagram range that an intermediate diagram drawn through one would be unreasonable at some stages. Draw the most reasonable intermediate diagram for such a measurement and note the shift from the the diagram at the gage height of the measurement (–0.02 ft at 4.10 ft for measurement 43 in figure 26) and also the shift at the base gage height (–0.20 ft at 2.1 ft in figure 26). The base gage-height shift will be used as an arbitrary data point (see step 7), and the shift (–0.02 ft) for the measurement gage height will be used on form 9–207 (fig. 10) to compute the measurements percent difference.
7. Select arbitrary data points to modify the linear interpolation of intermediate V diagrams between the times of discharge measurements if desired. If an arbitrary data point with the same gage height and shift as the preceding or following data point is inserted, the V diagram and shift curve will be held constant between the two dates. Assuming that the gage-height record for the example in figure 26 showed rises on May 7, July 1, and August 12, arbitrary data points (May 6, 2.63, -0.10; May 8, 2.3, -0.20; June 30, 2.3, -0.20; July 2, 2.13, -0.30; August 11, 2.13, -0.30; August 30, 1.70, +0.10) could be added to the measurement-defined points. The corresponding shift distribution would be equivalent to using one shift curve for May 1–6, another for May 7 to June 30, another for July 1 to August 11, and still another for August 12–27. This would be the most logical shift distribution for a stream with a gravel control that changes only during rises. Without the arbitrary points, the time shift between measurements would be the most logical shift distribution for a sand channel. Arbitrary data points can be based on the hydrographer's judgment, the gage observer's notes, or the gage-height record appearance.
8. Enter the data for the measurement-defined shifts and arbitrary data points (omit measurements that were disregarded, ice affected, outside the V-diagram range, or too close to the V-diagram limits) as instructed the WATSTORE User's Guide.

Shortcuts in the above procedure are practical for experienced hydrographers, and other approaches, more or less detailed, may be superior for use at some stations. The procedure is designed for primary computations but can also be applied to most updates.

Manual procedure

The distribution of shifts graduated with time and stage can be made for manually computed records in much the same way as they are with ADP. A V diagram for manual use can be either curvilinear or composed of straight lines and may be either a graph or a table. The widening or narrowing of the manual version of a V diagram is done by applying a coefficient to the V-diagram shifts. The magnitude of the coefficient at the time of a discharge measurement is the measurement-indicated shift divided by the V-diagram shift. The coefficients for each day are obtained from a graph somewhat similar to the time-shift V diagram in figure 21 and are applied to the shift adjustments obtained from the basic stage-shift V diagram. The resulting shift adjustments are entered on form 9-192a (fig. 21) or on the recorder chart (fig. 15) and used to compute the daily discharges.

Figure 27 illustrates the use of coefficients to generate intermediate V diagrams to fit the individual discharge measurements.

Records from digital recorders

Digital recorder tape segments are processed individually by a "primary computation." This process converts the punched values into a listing similar to figure 28, usually called the primary computation sheet, or "PPO." The discharge figures are tentative, and the gage-height figures are usually final. The printed figures are scanned manually for evidence of equipment malfunction, edited and corrected where necessary, and used in an "update" computation to produce either a corrected record of daily discharges or, at the end of the year, the final record (fig. 29) that is used as a page of the published record.

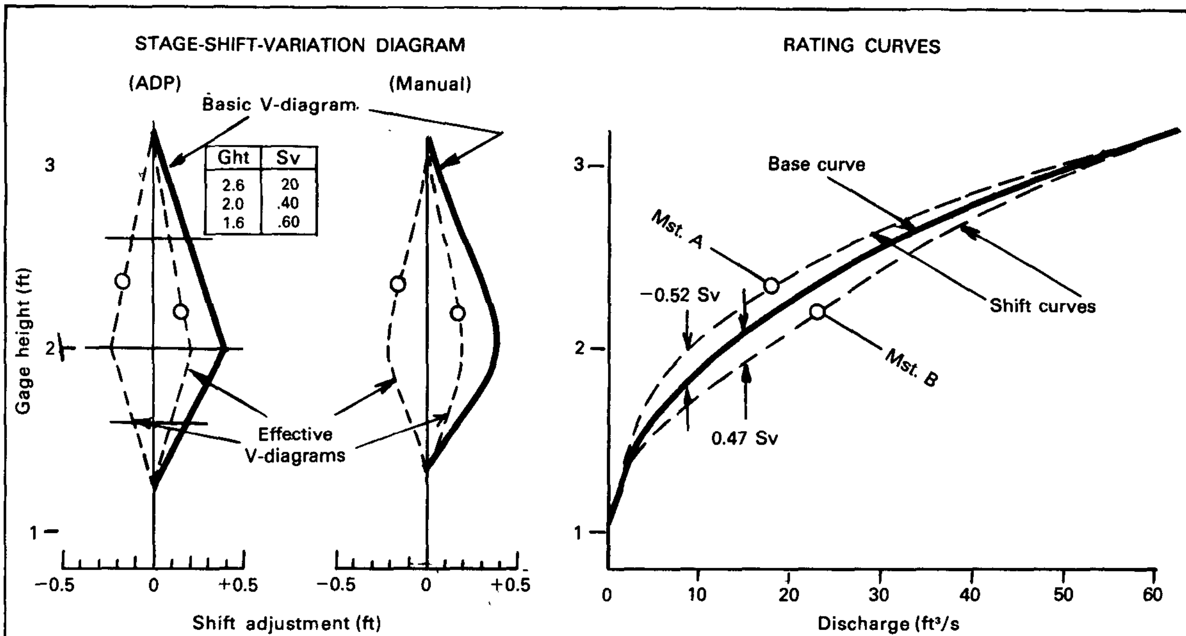
Primary computation

The punched-tape segment, rating descriptors or table, and information regarding datum corrections and shift adjustments are entered into the ADP system by using the formats prescribed in the WATSTORE User's Guide. The program applies each recorded instantaneous gage height, modified by any datum and shift adjustments, to the rating and obtains the instantaneous discharge. The average of all the instantaneous gage heights (corrected for datum error) and discharges for each day are printed (fig. 28). This procedure subdivides every day into segments one-punch interval long regardless of the range in stage. The daily mean gage heights are adjusted for the effect of subdivision, and the adjusted values are printed as "equivalent gage heights." Daily discharges can usually be revised later, without reprocessing the recorder tapes, by applying a different rating or revised-shift adjustments to the equivalent gage heights. A daily discharge computed from an equivalent gage height and revised rating is practically the same as one that would be computed by rerunning the primary computation with that rating if the revised and original rating curves (or shift curves, if used) have roughly similar shapes. The few exceptions include all days with periods of zero flow indicated by either the primary or update effective ratings and a few days where the primary or update effective ratings are practically the same at the equivalent gage height but not at other gage heights recorded during that day. Discharges for these days may be computed manually or by rerunning the recorder tapes.

A primary computation is a rapid and simple operation if the equipment functions properly, the datum correction is well defined, and the discharge rating remains stable throughout the period. Equipment problems such as faulty punching, or float tape or cable jumping its splines, make the task much more difficult. These problems can be minimized by careful field maintenance and the use of surge chains or other devices to maintain tension in the float tape while the recorder is locked for punching. The datum correction needs careful consideration before each primary computation because the only way that a subsequent change can be reflected in the printed list of gage heights is to rerun the primary computation.

A primary computation is normally made as soon as possible after the removal of the recorder tape to provide a readable gage-height record for the identification of any recorder malfunctions. The computed discharges—final, approximate, or grossly in error—will normally be stored in the WATSTORE Daily Values File until the update process. Several protection options described in the WATSTORE User's Guide are available to prevent a user from retrieving erroneous data from the daily records file.

Many primary computations can be run in such a way that the discharge figures will be useful or even final. For those few gaging stations where the discharge rating is stable and shift adjustments are not needed, the primary computation will usually generate final discharge records without any special effort. If the high and medium parts of the discharge rating are stable and the low-water part shifts only during substantial rises, use the latest



COMPUTATIONS

Meas.	Gage height	Shift adjustment (Sm)	Shift adjustment (Sv)	Coefficient (Sm/Sv)	Effective V-diagrams at gage heights		
					2.6	2.0	1.6
A	2.35	−0.15	0.29	−0.52	−.10	−.21	−.10
B	2.20	.16	.34	.47	.09	.19	.09

SYMBOLS

C=Sm/Sv=Coefficient applicable to basic V-diagram
Sm =Shift adjustment defined by discharge measurement
Sv =Shift adjustment from V-diagram

FIGURE 27.—Use of stage-shift-variation diagram coefficients to fit shift curves to discharge measurements.

rating and a time-varied V diagram as illustrated in figure 26. Change the shift pattern only during the highest rise between discharge measurements, the most logical time for a change in low-water shifts. Some ratings shift erratically at all stages. The shifting is usually more rapid during rises than during low-water periods. Interpolation of shifts with time and stage is practical for the primary computation of some such stations where weekly or more frequent measurements are made. Otherwise, the records for very unstable channels are most easily processed by using the latest rating without any shift adjusments. Then a hydrograph of the resulting discharge records, undistorted by incorrect shifts, will be used as a guide when the updating is done with final shift adjustments based on additional data (gage heights, records for other stations, hydrograph appearance, and so forth) as shown in figure 22.

The primary computation sheet, edited as will be described in the section on "updating," contains most of the information for an ADP record that form 9-192a (fig. 21) and recorder charts (fig. 15) show for a graphic-recorder station. It should be treated and preserved accordingly.

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION STATE 21 DIST 21
PRIMARY COMPUTATION OF GAGE HEIGHTS AND DISCHARGE
DATA PROCESSED 09-09-81
USE RT 15

03289500
ELKHORN CREEK NEAR FRANKFORT, KY

PROVISIONAL DATA FOR WATER YEAR ENDING SEPT. 30, 1981 TEST DIFF 0.2 PUNCH INT 60 MIN STORE PARM 00060, STATISTIC 00003
PARM 00065, STATISTIC 00003

DATE	MAX GH (TIME)	MIN GH (TIME)	MEAN GH	EQUIV GH	MEAN DISCH	SHIFT AT ADJ HR	DATUM AT CORR HR		STAGE, IN HUNDREDTHS OF FEET, AT INDICATED HOURS											
									1	2	3	4	5	6	7	8	9	10	11	12
	(1300)	(0100)						PM	252	252	252	252	252	252	251	251	250	250	250	250
5-12	2.63	2.53	2.60	2.60	178	-.13W		AM	253	258	261	263	263	263	263	263	263	263	263	262
	(0400)	(0100)						PM	262	260	259	259	258	258	258	258	257	257	256	256
5-13	2.56	2.46	2.51	2.52	154	-.14W		AM	256	255	255	255	254	254	254	254	254	254	254	253
	(0100)	(2000)						PM	252	251	251	250	249	248	247	246	246	246	246	246
5-14	2.46	2.41	2.45	2.45	135	-.14W		AM	246	246	246	246	246	246	246	245	245	245	245	245
	(0100)	(2200)						PM	245	245	245	245	245	245	243	242	242	241	241	241
5-15	2.68	2.41	2.46	2.47	140	-.14W		AM	241	241	241	241	241	241	241	241	242	242	243	243
	(2300)	(0100)						PM	243	243	243	243	243	243	245	255	263	267	268	268
5-16	2.70	2.58	2.64	2.64	191	-.13W		AM	268	270	270	269	268	268	267	266	265	264	263	262
	(0200)	(1500)						PM	260	259	258	258	258	259	262	264	266	267	267	267
5-17	2.68	2.50	2.59	2.58	174	-.13W		AM	268	268	268	266	265	264	263	262	261	260	260	258
	(0100)	(2200)						PM	257	256	256	255	254	253	252	251	251	250	250	250
5-18	2.97	2.46	2.54	2.53	161	-.13W		AM	249	249	248	247	247	246	246	247	246	246	246	246
	(2400)	(0600)						PM	246	246	246	246	246	250	263	268	276	280	264	297
A 5-19	6.71	3.84	4.98	5.05	1450	-.02W		AM	384	459	489	493	487	476	472	469	465	457	448	439
	(2400)	(0100)						PM	430	432	474	512	536	554	564	574	590	616	650	671
5-20	6.80	5.96	6.43	6.44	2700			AM	677	679	680	677	669	659	652	646	644	646	649	650
	(0300)	(2400)						PM	651	647	643	635	631	624	620	613	609	604	600	596
5-21	5.92	4.82	5.37	5.38	~~1700~~ 1710	~~-.01W~~ 0		AM	592	586	580	576	574	565	563	554	549	544	540	535
	(0100)	(2400)						PM	530	525	521	516	511	506	503	498	494	490	485	482
5-22	4.79	4.14	4.47	4.48	~~1040~~ 1090	~~-.05W~~ + 03		AM	479	475	472	468	466	463	460	458	454	454	451	448
	(0100)	(2400)						PM	445	443	440	438	434	434	429	424	421	419	416	414
5-23	4.14	3.69	3.92	3.92	~~711~~ 769	~~-.07W~~ + 04		AM	414	411	409	407	404	402	400	398	396	395	393	392
	(0100)	(2400)						PM	390	389	387	385	383	381	379	377	375	373	371	369
5-24	3.67	3.35	3.51	3.51	~~611~~ 577	~~-.08W~~ + 05		AM	367	366	363	362	360	358	357	355	353	352	351	351
	(0100)	(2400)						PM	349	348	347	346	345	343	341	340	338	338	336	335
5-25	3.33	3.08	3.20	3.20	~~386~~ 449	~~-.10W~~ + 06		AM	333	332	330	328	327	327	325	323	322	322	320	320
	(0100)	(2400)						PM	318	317	316	316	315	314	313	312	310	311	312	308
5-26	3.07	2.96	3.00	3.00	~~300~~ 376	~~-.11W~~ + 07		AM	307	306	305	304	304	303	303	302	301	301	300	299
	(0100)	(1600)						PM	299	298	297	296	296	296	296	296	296	296	296	296
A 5-27	4.06	2.96	3.30	3.34	~~441~~ 507	~~-.09W~~ + 06		AM	296	296	298	299	299	299	301	302	302	302	302	302
	(2200)	(0100)						PM	304	304	304	307	380	392	384	392	403	406	406	405
A 5-28	6.90	4.20	6.20	6.26	2510			AM	420	463	543	613	632	633	633	647	665	679	688	690
	(1200)	(0100)						PM	684	673	661	650	639	629	625	623	624	624	623	622
5-29	6.19	4.72	5.42	5.45	~~1760~~ 1770	~~-.01W~~ 0		AM	619	611	605	599	594	582	573	565	557	550	543	536
	(0100)	(2400)						PM	529	522	517	514	507	502	497	492	467	482	478	472
5-30	4.70	4.04	4.36	4.37	~~960~~ 1020	~~-.05W~~ + 03		AM	470	466	463	458	458	452	449	446	443	439	437	434
	(0100)	(2400)						PM	431	429	427	424	422	420	418	416	413	409	407	404
5-31	4.29	3.87	4.04	4.05	~~777~~ 839	~~-.07W~~ + 04		AM	403	402	399	397	395	393	391	391	391	391	390	388
	(1700)	(1300)						PM	387	392	408	423	429	429	424	418	414	412	412	413
MONTH					~~600~~			TOTAL (CFS-DAY) = ~~10600~~												
6-01	4.14	3.95	4.03	4.03	~~771~~ 828	~~-.07W~~ + 04		AM	414	414	414	414	413	412	410	408	407	404	401	399
	(0100)	(1400)						PM	397	395	395	395	395	395	395	395	395	396	397	398
A 6-02	4.80	3.99	4.46	4.47	~~1010~~ 1080	~~-.04W~~ + 03		AM	399	403	409	410	410	410	409	413	425	446	462	470
PERIOD	6.90	2.26																		

RECORDER CLOCK RUNNING 0.9 MINUTES PER DAY SLOW. RECORD ADJUSTED.

NOTE. SYMBOLS USED ABOVE HAVE THE FOLLOWING MEANINGS
A - SUCCESSIVE ADJUSTED PUNCH READINGS DIFFER BY MORE THAN THE SPECIFIED ALLOWABLE TEST DIFFERENCE
P - DAILY SUMMARY IS FOR AN INCOMPLETE DAY
R - ONE OR MORE INPUT VALUE IS OUTSIDE THE RANGE OF THE RATING IN USE
W - SHIFT IS A VALUE WEIGHTED BY DISCHARGE WHERE SHIFT VARYS WITH STAGE DURING THE DAY
% - UNIT VALUES RECORD WRITTEN

STAGE-SHIFT VARIATION DIAGRAM EFFECTIVE 81-04-20

HIGH POINT 0 SHIFT AT GH 5.5
BASE -.15 SHIFT AT GH 2.2
LOW POINT -.15 SHIFT AT GH .01

FIGURE 28.—Primary computation sheet.

Notes for station analysis

Notes to be included in the "station analysis," described in a subsequent section, should be written when each primary computation sheet is received. The datum correction paragraph notes are updated to reflect the corrections included in each set of primary computation supplementary data. Any changes in location or equipment should be described in the paragraph headed "Equipment." All irregularities in the gage-height record, such as timer failure or faulty-intake action, should be discussed and listed by dates in the "Gage-height record" paragraph. The ratings used for the primary work should be listed in the "Rating" paragraph and their adequacy described. Shift distribution and V-diagram use should be explained in the "Discharge" paragraph. The notes will be consolidated when the final update is made.

Updating

The update is a procedure that follows the primary computation and uses one or more subsequent passes of daily data through the computer to correct errors in the primary computation caused by faulty gage-height record, ice effect, erroneous shift adjustments, or datum corrections. Updated discharges can be computed manually and substituted for the primary discharges, or, for some periods, computed entirely by ADP. Preparation of data for updating is described in the WATSTORE User's Guide.

Before starting to update a period of record, which may be as short as a month or as long as a year, retrieve a hydrograph similar to the one in figure 30 from the WATSTORE Daily Values File (hydrograph details are discussed in a subsequent section) or plot one from the primary computation sheet discharges. Plot the dis-

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	12	14	54	35	30	52	263	165	166	134	40	27
2	11	26	592	25	30	49	233	172	188	144	39	26
3	11	15	343	28	30	47	203	176	210	134	38	27
4	11	14	201	30	30	47	186	166	240	122	37	27
5	11	14	146	35	33	46	168	154	265	114	36	29
6	11	14	136	38	35	44	156	147	273	107	36	33
7	12	13	119	38	38	51	146	149	252	104	35	28
8	11	11	101	40	38	60	138	165	245	98	33	27
9	11	13	92	40	42	62	133	186	237	92	33	42
10	11	14	90	41	39	74	144	199	210	86	33	39
11	11	15	114	42	36	84	159	184	186	82	33	31
12	11	14	108	43	42	84	156	170	176	77	33	29
13	11	14	330	41	38	84	151	178	170	74	33	28
14	10	15	528	41	37	82	144	199	163	70	31	27
15	10	17	406	42	35	82	139	186	151	68	33	26
16	10	16	290	40	33	86	144	176	144	76	32	25
17	9.9	11	230	39	33	107	131	174	146	66	31	25
18	10	9.9	184	37	33	147	128	176	151	63	31	25
19	9.9	7.0	154	37	34	166	128	192	156	61	31	25
20	9.9	4.0	133	36	36	184	128	226	152	59	31	25
21	9.9	3.0	122	36	39	221	122	242	152	56	32	25
22	10	3.0	112	35	43	258	118	235	149	53	33	24
23	11	5.0	101	33	49	295	114	205	144	51	29	25
24	11	8.0	93	32	57	276	109	184	142	50	36	25
25	12	15	85	33	59	260	112	170	133	48	35	24
26	11	25	80	32	58	265	138	161	128	50	31	23
27	11	33	75	31	57	265	161	158	127	49	30	22
28	11	35	70	31	55	281	168	166	127	46	28	22
29	13	52	65	30	---	304	172	163	139	44	28	22
30	14	39	60	30	---	318	172	158	136	43	28	22
31	12	---	55	30	---	298	---	159	---	41	28	---
TOTAL	340.6	488.9	5269	1101	1119	4679	4564	5541	5258	2362	1017	805
MEAN	11.0	16.3	170	35.5	40.0	151	152	179	175	76.2	32.8	26.8
MAX	14	52	592	43	59	318	263	242	273	144	40	42
MIN	9.9	3.0	54	25	30	44	109	147	127	41	28	22
CFSM	.16	.24	2.47	.52	.58	2.19	2.21	2.60	2.54	1.11	.48	.39
IN.	.18	.26	2.84	.59	.60	2.53	2.46	2.99	2.84	1.28	.55	.43
AC-FT	676	970	10450	2180	2220	9280	9050	10990	10430	4690	2020	1600

CAL YR 1977 TOTAL 10643.3 MEAN 29.2 MAX 592 MIN 3.0 CFSM .42 IN 5.75 AC-FT 21110
WTR YR 1978 TOTAL 32544.5 MEAN 89.2 MAX 592 MIN 3.0 CFSM 1.30 IN 17.57 AC-FT 64550

FIGURE 29.—Final discharge record printout.

charge measurements as colored circles on the appropriate days. The hydrograph will indicate any periods that may need attention and provide clues about the dates of rating shifts.

Assemble the primary computation sheets for the period to be updated. Check the starting and ending days against the prior and subsequent sheets for continuity or agreement with discharge-measurement notes when changes were made to the control. Scrutinize the hourly gage-height lists, especially those for days labeled "A" or "R," (fig. 28) for mispunches or incorrectly read punches. Look for sudden changes in stage or long periods of no change that could indicate recorder failure or plugged intakes. Check the discharge hydrograph for odd-looking periods (recession curve lower after a rise than before, recession faster than rise, and similar inconsistencies), and if any questionable periods are found, study the corresponding gage heights and shift adjustments to find the reason. Check the datum corrections listed on the primary computation sheet against the station analysis paragraph. See that each change (resetting) to the principal gage is reflected by a change in continuity of the punched-gage heights and that the applied correction restores the continuity and agrees with the station analysis. Resolve any minor differences by accepting the primary computation to avoid unnecessary rerunning of the tapes for the affected periods.

Decide whether the ratings and shift adjustments used for the primary computation are adequate or if updating is needed for all or part of the record. Check the shift-adjustment computations for all periods whose discharge records are acceptable. Those for other periods will not be used and need not be checked. Prepare new ratings and V diagrams (if used) for periods that will be recomputed and have them checked by another hydrographer. Try the new rating or shift adjustments by making a manual computation every 10th day or so and for about 2 days immediately before and after any periods that will be estimated.

Fill in the discharges for periods of ice effect or no gage-height record (more about these special computations later). Treat periods of particularly erratic shift-adjustment distribution as periods of no gage-height record.

When the data for the updating process (ratings, shift distributions, and substituted discharges) are ready to prepare for computer input, the final hydrograph position should be sketched in, on the basis of manually computed values for occasional days, so there will be no surprises in the final record.

Have all computations for ratings, percent differences, shift adjustments, and substituted values checked before running the update. Obtain a new hydrograph from the WATSTORE Daily Values File after the update results have been stored. Plot the discharge measurements on the new hydrograph and scan it for any mistakes that may have survived the previous checking.

After the update is complete and all figures are final, update the primary computation sheet neatly in ink as shown in figure 28. The entries should include all of the discharges changed by recomputation or substitution, the revised shift adjustments, and the gage heights from backup recorders or graphs. If any datum corrections were revised after the primary computation, rerunning the tapes is normally more convenient than manual entry of all the related changes. The edited primary computation sheet should represent the final record as published, and any figures that are formally revised in the future will be shown on this sheet.

Records from graphic recorders

During previously described operations, the form 9-192a (fig. 21) was partially completed by listing the daily mean gage heights. The subdivided-day gage heights were computed and checked on the recorder charts. The shift adjustments, if used, must be distributed and listed on form 9-192a and on the chart's subdivision tabulations. Discharge for all but the specially computed periods (ice effect, missing record, and so forth) can then be computed from the rating table and entered on form 9-192a. Discharges likely to be changed (winter months and tentative shift adjustments, for instance) may be entered in pencil, and the others may be entered directly in ink.

Discharge-measurement numbers are usually written on form 9-192a in the space for the day on which they were made, and shift adjustments may be written as shown in figure 21. The symbol "v" indicates that the shift varied during the day. Tentative figures previously penciled in are inked after they are checked and accepted as final.

Distribution of small shift adjustments, with time and stage, can be made by inspection directly on form 9-192a. Large or complex shift-adjustment distribution is best done with V diagrams and coefficients. If a new rating is started in use on October 1, a smooth transition between discharge records for the end of the previous year and the start of the current year must be maintained. One useful transition method is to treat the previous September 30 gage height and discharge as a discharge measurement. Compute the applicable shift adjustment for that day and distribute the adjustment between September 30 and the first discharge measurement of the current year.

All computations including shift-adjustment distribution, shift curves, and the subdivided days must be checked by a second hydrographer who initials and dates form 9-192a in the appropriate space. The monthly figures, except daily discharge totals, are left blank. They will be computed by ADP when the final update is made and may be copied onto form 9-192a at that time if the district considers them necessary.

Records from nonrecording gages

The process used to compute and check the discharge computations for nonrecording gages is identical to that for graphic recorders.

Discharge hydrographs

A semilogarithmic plot of daily discharges, similar to that in figure 30, depicts the day-to-day variations in discharge in an easy-to-see form, revealing some of the errors in basic data, computations, or shift distribution. It is one of the most valuable tools available for quick assessment of record consistency and is indispensable for estimating discharges for periods of ice effect or missing gage-height record. The records for several stations in an area can be compared by placing their hydrographs on a light table and shifting the individual sheets to obtain the best fit. The discharge hydrograph for a manually computed record can be plotted while the discharge figures are being computed. In this way, the effects of the shift distribution can be studied as the discharge points are plotted. An automatically plotted hydrograph of the discharge figures in the WATSTORE Daily Values File at any time can be retrieved (see WATSTORE User's Guide). Interim hydrographs, automatically plotted, of primary computation figures are particularly useful in the update process, and an automatically plotted final hydrograph is always preferable to a manually plotted version for use as the permanent file copy. Show normally computed records as a black line, estimates in color, and discharge measurements as colored circles on the final hydrograph.

National Weather Service records of daily maximum and minimum temperatures and daily precipitation are used in the discharge computations for periods of ice effect. Figure 31 illustrates one convenient format for weather records. Prints of the form provide worksheets for stations in the area of the weather station, with space to plot the winter hydrograph on a rectangular grid which is convenient for some applications.

Periods of no gage-height record

Discharge for periods of equipment malfunction or unusual stream conditions (backwater from leaves, debris, or tributaries) where the gage-height record cannot be used directly must be estimated, usually by one of the methods described in Water-Supply Paper 2175 (Rantz and others, 1982). These methods involve the use of some combination of interpolation, reconstruction of missing gage-height records, and the use of records for other stations, power plant generation records, reservoir records, and weather records. The estimated figures are entered on form 9-192a or into the ADP update process by substitution.

Periods of ice effect

The presence of ice at a stream's control causes the gage height to indicate flow greater than the actual discharge. The computation of discharge for a period when the stream was frozen is a complex and highly subjective process, different for each section of the country. Water-Supply Paper 2175 describes the freezing phenomenon in detail and explains the discharge computation methods that apply under many conditions. The figures so computed are substituted for those previously entered on form 9-192a or are included in the updating of digital recorder records.

Station Analysis

The station analysis, illustrated in figure 32, is a complete and formal discussion of the data collected for the current year. It details the amount and kind of data, its probable accuracy, and the method used for processing it. Notes for inclusion in each section should be written, by the hydrographers who actually analyzed that part of the record, when the work is done. For example, the gage-height record section notes will generally be prepared by the individuals who made the primary computations or copied the gage heights on form 9-192b, the rating section by the individuals who analyzed the rating, and so forth. The hydrographer who prepares the final update for the water year reviews these notes and writes the station analysis. The checker should always review the entire analysis carefully. It should be written clearly and concisely. Additional sections may be added to suit local needs, but the analysis must include the following six general headings:

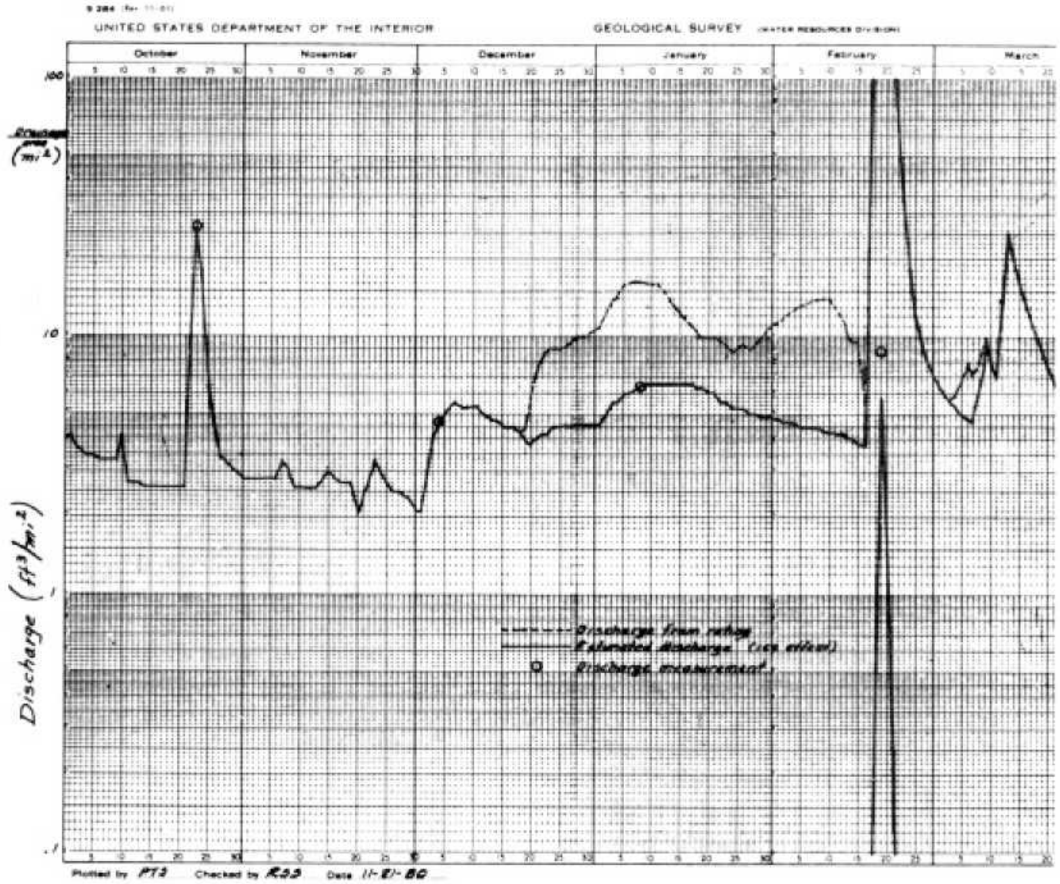


FIGURE 30.—Semilogarithmic hydrograph.

Equipment.—Start with a short statement telling the type of recorder, principal gage, and shelter. List the permanent structures outside the gage, such as outside gages, cableways and concrete controls that affect the record quality. Mention all changes in equipment and the dates.

Gage-height record.—Make a general statement about the accuracy and continuity of the gage-height record, listing all periods of missing record and the reasons for them. For a period of clock stoppage, tell if a range in stage was available or if a graph was drawn based on the observer's gage readings. List the dates for which daily gage readings are available. Mention any periods for which the record is doubtful or poor because of lagging intakes, plugged orifice, insensitive manometer, or other causes and whether the doubtful record was used. If there is more than one recorder at a station, tell which recorder was used for what period to compute the discharge record.

Datum and gage-height corrections.—Insert the gage-height correction material prepared as previously described if necessary.

Rating.—Give a brief description of the control and channel as they pertain to the current year's record. Next give the total number of measurements made during the year, their serial numbers, and the range in discharge of the measurements made during the year. Tell which were affected by ice or other unusual conditions. Explain the rest of the measurements, either individually or in groups, in terms of how they plotted with respect to the rating or ratings used during the year and why. If a new rating is drawn, state the basis for doing so. Give the reason for not drawing a new rating when one seems warranted. Explain anything out of the ordinary to help someone unfamiliar with the station to understand the situation.

Discharge.—For a digital recorder station, use a separate paragraph for a brief description of the primary computations, giving the ratings

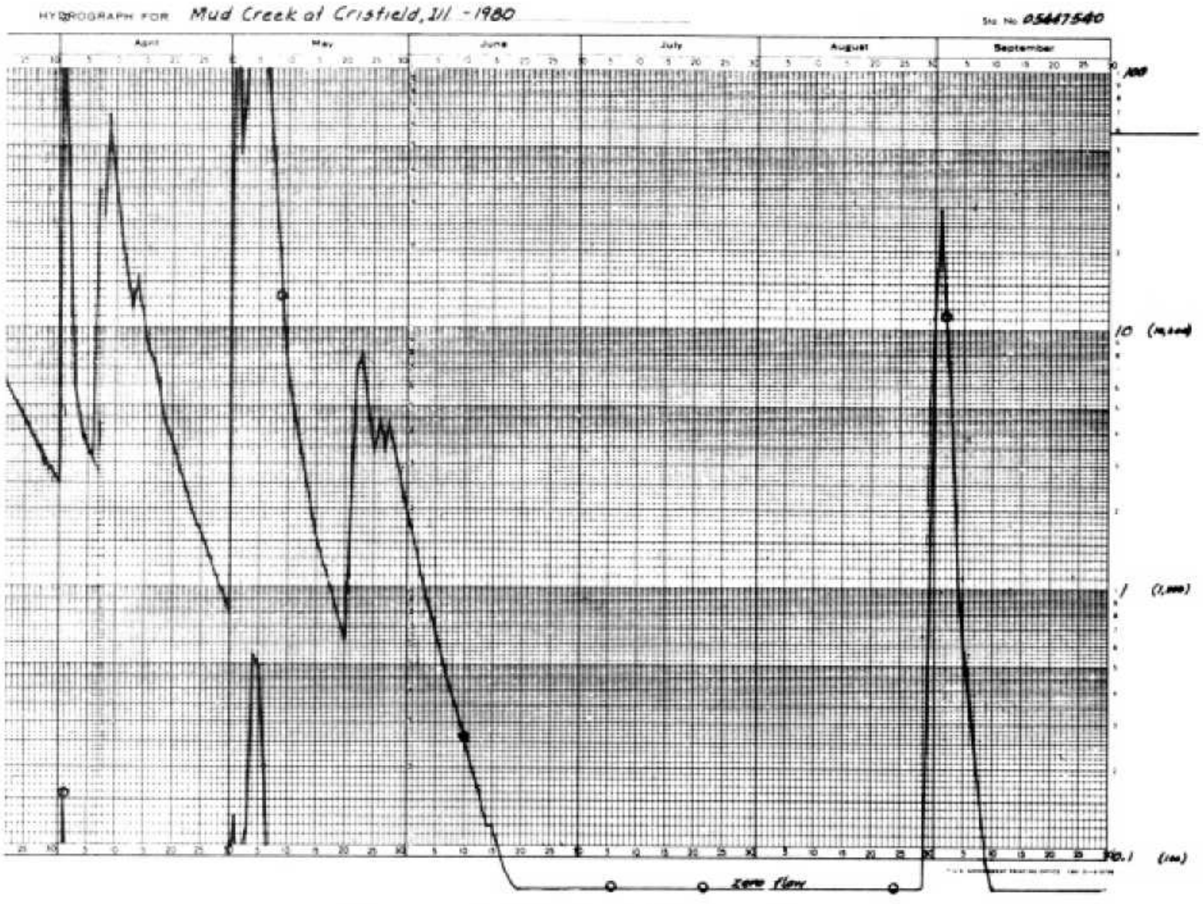


FIGURE 30.—Semilogarithmic hydrograph—Continued.

and types of shift adjustments used. Discuss the adequacy of the primary discharge records and the reasons for accepting or rejecting them as final records. In the opening sentence of the update paragraph (first paragraph for graphic recorder and nonrecording stations) state which ratings were used for the final discharge figures and their periods of use. Give the coordinates of the V diagrams used unless that information is shown elsewhere, such as on an ADP printout. List the periods for which special discharge computations (ice, missing record, or backwater) were used and give the basis for the computations. Explain all unusual features of the discharge record.

Remarks.—Give the general accuracy of the record. A rating of excellent means that about 95 percent of the daily discharges are correct within 5 percent; good, within 10 percent; and fair, within 15 percent. Poor means that daily discharges have less than fair accuracy. If some period is considerably below the rest in overall accuracy because of a lack of supporting data or because of a special method of computation, that period should be noted and rated lower in accuracy. The accuracy rating assigned in the station analysis must agree with the accuracy rating in the station manuscript.

Progress Documentation

Use some type of form to indicate the completion of each step in the record computation by a check mark, initials, or shading of an area and to ensure that the work is being done systematically and completely. The format of the sheet used depends on the type of gage and the procedures adopted by the field office to collect the data and compute the record. Figure 33 illustrates one type of progress form that can be

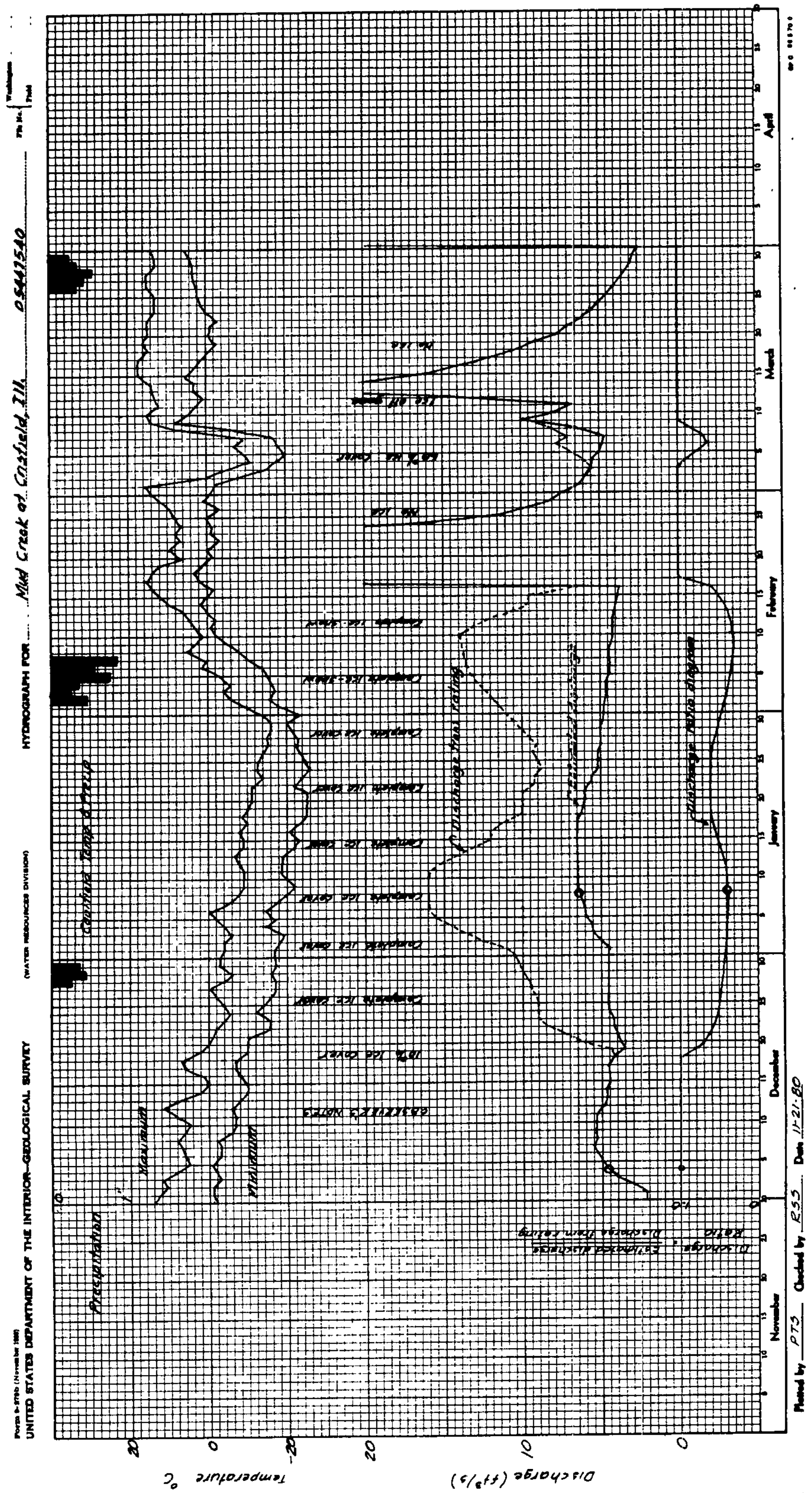


FIGURE 31.—Rectangular hydrograph and weather-record plot.

Mud Creek at Crisfield, Illinois 05447540

STATION ANALYSIS

1979-80

Equipment.--Digital recorder in 5'-4" concrete block house and well with a cableway 300 ft upstream. Local observer inspects gage weekly. No changes to equipment.

Gage-height record.--Fisher-Porter digital recorder (principal gage), checked by an electric tape (reference gage), furnished an excellent record for the entire year except for December 9-20, when the recorder was stopped by battery failure. The observer made daily electric tape readings December 14-19 and the resulting graph was satisfactory gage-height record.

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 untangled, and gage-height record evidence of the most likely time that the chain became tangled, the following corrections were applied to digital recorder readings:

October 1, 1979	(0000 hrs)		
		-.02	
November 6, 1979	(1430 hrs)		
		0	Levels--gage reset
December 11, 1979	(0330 hrs)		
		-.05	Surge--most likely time of tangle
January 3, 1980	(1415 hrs)		
		0	Chain untangled; Ght dropped .05 ft
September 30, 1980	(2400 hrs)		

No corrections were applied to other gages.

Rating.--The channel, about 20 ft wide at low flow, 120 ft wide at bankfull stage (12 ft), and 600 ft wide during floods, has stable wooded banks and a loose rock and gravel bed. The rocky gravel riffle collects debris and supports algae growth but is otherwise stable for long periods. Seven current-meter measurements (nos. 132-134, 136-139), a slope-area measurement (no. 135), and one observation of no flow were made during the year. Six additional observations of no flow were made by the observer. The measurements cover the entire range of flow during the water year.

The discharge measurements indicate that a low-water shift from last year's rating (no. 8) occurred during the September 3, 1979, rise and that the high-water portion of that rating needs minor revision in order to fit the recent slope-area measurement. Rating no. 9 was developed on the basis of the current data and is identical to rating no. 8 between 2.2 and 18 ft stages. The new rating is well defined throughout and reasonably consistent with all prior high-water ratings, so revisions to past records are unnecesary. The 1979 records for September, with the shift adjustments used agree closely with rating no. 9.

Discharge.--(Primary computations). Primary computations were run using rating no. 8, extended to 27 ft to cover the February 19 peak, with the V-diagrams shown on the primary computation sheets. All gage heights listed are final values. Most of the discharge figures were recomputed from the equivalent gage heights in the updating.

(Update). Rating no. 9 was used for the entire year. A V-diagram (2.0, -0.05; 6.0, -0.05; 8.0, 0) was used from February 19 to May 9 for stage-only distribution and from June 1 to September 30 for stage and time distribution of shift adjustments. Primary computation discharges for days whose gage heights were all between 8 and 18 ft are equivalent to those from rating no. 9 and were used without revision.

Discharge for the periods of ice effect (December 19 to February 16) was computed on the basis of one discharge measurement, gage heights, weather records and records for nearby stations.

Discharge for periods of no gage-height record (December 10-13) was estimated on the basis of weather records and records for nearby stations.

Remarks.--Records are good except those for December and January, which are poor.

Prepared	P. T. Spalding	12-1-80
Checked	R. S. Sands	12-4-80

FIGURE 32.—Station analysis.

Sta. No. ____________________

PROGRESS CHECKLIST

COMPUTATION OF DIGITAL RECORDER RECORDS

Station____ Water Year____________________________

PRIMARY COMPUTATIONS

Review disch. msts. - check ghts with tape
Review tape for continuity with previous tape
Update datum correction and apply to tape headers and meas.
List discharge msts. and remarks on 9-207
Plot disch. msts. (worksheet) - if rating is OK, skip a line
Prepare discriptors for new rating - obtain RATLIST
Compute shift adjustments and percent diff.
Prepare or update V-diagram - distribute shifts
Update station analysis notes

Transmit tapes and supplemental data - obtain hydrograph

UPDATE

Plot disch. msts. on prim. comp. hydrograph
Review levels data. Update datum correct. Rerun P.C. if necess.
Review P.C. sheets (continuity and agreement with meas.)
Review rating. If P.C. rating is satisfactory, skip three lines
Prepare new work curve sheet
Prepare descriptors for new rating - obtain RATLIST
Recompute shifts and % for update period msts.
Update old or prepare new V-diagram
Distribute shift adjustments
Rough in final hydrograph position on P.C. hydrograph
Compute ice, missing, and other special computation records
Update station analysis notes
Check the above work
Prepare station analysis final copy (typed)
Check final station analysis
Prepare master curve sheet

Transmit update material - request hydrograph
Plot meas. on new hydrograph

FINAL ASSEMBLY

Compute and list peak disch., min. disch., and aver. disch.
Prepare manuscript and annual report page copy
Check above work

QUALITY CONTROL

Prepare basin comparison (monthly records)
Check comparison

By____________________Date__________ Broad review (all records)

Intensive review with memorandum (selected records)

FIGURE 33.—Typical progress form.

used for digital recorder stations whose primary computations are run currently and updated monthly, quarterly, or annually. Equivalent forms for graphic-recorder stations are simpler, and more elaborate forms can be designed to indicate the percent completion of each record at any time.

Quality Assurance

The quality of a station record depends to a large extent on natural conditions at the site and the management practices used to obtain the best records with the available manpower and equipment. The adequacy of a record can be gaged to some extent by having an experienced hydrographer review the process used to obtain the data and compute the record. The reviewer ensures that approved methods were used throughout or that locally devised procedures were proper. All records should receive a brief review by a hydrographer not involved in the computations. A few records (5-10 percent of the total) should be thoroughly reviewed, and a memorandum of review prepared by a supervisor each year. An outside (regional, other district, or headquarters) assessment of technical operations is provided about every other year and includes a thorough review of a sampling of the gaging-station records.

Parts of most discharge computations depend on subjective judgment, especially for rating extensions, shift distribution, and estimates. Substantial errors are usually apparent from hydrographic comparison of each station record with others from the same general area. A basin comparison of monthly and annual discharges may provide a good check for major errors. Figure 34 illustrates the simplest type of basin comparison, one that can be used in a relatively humid area where the runoff from gaged areas is comparable to that from ungaged areas. A table of monthly discharges for all stations in a basin is arranged in downstream order. The monthly discharges must be adjusted for travel time between adjacent stations by advancing the downstream station period by an estimated number of days. The runoff figures (in cubic feet per second per square mile) for tributary stations are listed and those for ungaged areas are computed, listed, and underlined. If the gaging station records are free from gross errors, the underlined runoff figures will ordinarily be comparable to the other figures in the column.

The discharge of streams in arid areas does not increase uniformly downstream and may decrease in certain reaches. The gains or losses in monthly flow between stations do not indicate the reliability of records for this type of stream, and other assessments based on knowledge of the hydrology of the region must be made.

If the assessment procedure identifies the records for a very poor site as dubious, alternatives to collecting daily discharge records there should be considered.

References Cited

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Follansbee, R., 1938, A history of the Water Resources Branch of the United States Geological Survey to June 30, 1919: Washington, D.C., privately printed, 459 p.

Hutchinson, N. E., and others, 1975 (v. 1), WATSTORE User's Guide: U.S. Geological Survey Open-File Report 75-426, Reston, Va., 523 p.

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BASIN COMPARISON
(Portion of Ohio River Basin in Illinois - 1977-78 Water Year)

	Ohio River Basin	Dr. Area	Time Advance (days)	Oct.		Nov.		Water Year	
				cfs	csm	cfs	csm	cfs	csm
1	Wabash River Basin (continued)								
2	Little Wabash - Effingham	240	0	62.4	.26	34.5	.14	237	.99
3	Ungaged [4 - 2]	505		94.6	.19	142	.28	531	1.05
4	Little Wabash - Louisville	745	+1	157		177		768	
5	Ungaged [6 - 4]	386		108	.28	50	.13	277	.72
6	Little Wabash - Clay City	1131	+1	265		227		1045	
7									
8	Skillet Fk. - Iuka	208	+1	28.4	.14	87.3		181	.87
9	Horse Cr. - Keene	97.2	+1	8.1	.09	26.5		83.9	.86
10	Ungaged [11-(8 + 9)]	159		20.1	.13	56.2	.35	126	.79
11	Skillet Fk. - Wayne City	464	+2	56.6		170		391	
12	Ungaged [13 -(6 + 11)]	1507		391	.26	570	.38	1286	.85
13	Little Wabash - Carmi	3102	+4	713		967		2722	
14	Little Wabash - Carmi	3102	0	821	.27	584	.19	2722	.88
15	(continued)								

FIGURE 34.—Basin comparison of monthly and annual runoff.

Kennedy, E. J., 1982, Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water Resources Investigations, book 3, Chap. A-10 (in press).

Rantz, S. E., and others, 1982, Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175 (2 vol.,) 631 p.

Thomas, N. O., and Jackson, N. M., Jr., 1981, Manual for leveling at gaging stations in North Carolina: U.S. Geological Survey Open-File Report 81-1104, Raleigh, N. C., 36 p.

Glossary

ADP Automatic data processing used to compute the discharge records for digital recorder stations

Discharge hydrograph A semilogarithmic plot of daily mean discharges for a water year, used as a visual check of the continuity of computed discharges and a means of comparing discharges for different stations

Primary computation The ADP process normally used for the first pass of streamflow data through the computer. The recorder tape, rating, shift-adjustment-distribution instructions, and datum corrections are input. A tentative daily discharge and hourly gage-height printout are output and a discharge hydrograph is optional.

Scalloping An undesirable discharge-rating characteristic in which the straight-line segments of a logarithmic rating curve, when plotted using rectangular coordinates, billow upward between nodes at the descriptor points. The corresponding rating table has erratic discharge differences per tenth foot of gage-height difference.

Shape curve A previous rating curve, or one based on a special study, whose shape is similar to the rating curve being developed

Shift adjustment An adjustment, usually varying with time and stage, applied to gage heights in order to compensate for a change in the rating shape or position

Shifting-control method The systematic use of shift adjustments as a substitute for revised ratings

Station analysis A narrative description, in a standard format, of the gaging-station equipment, its performance, and the methods used to compute the discharge record

Update The ADP process by which discharges from the primary computation are revised by using a different discharge rating, different shift adjustments, or substituted manually computed values to compile the final discharge record.

WATSTORE User's Guide Volume 5 (record processing) and volume 1 (data files) of a set of instruction manuals regarding the format of data input to the ADP system used for discharge-record computation.