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Water-Supply Paper 888

STREAM-GAGING PROCEDURE

A MANUAL DESCRIBING METHODS AND PRACTICES OF THE GEOLOGICAL SURVEY

BY
DON M. CORBETT
AND OTHERS

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FOREWORD

By Nathan C. Grover [1]

The Sundry Civil Appropriation Act approved October 2, 1888, contained an item.[2]

For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation and the segregation of irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation and for ascertaining the cost thereof, and the prevention of floods and overflows, * * * the work to be performed by the Geological Survey under the direction of the Secretary of the Interior * * *.

In order to carry out this mandate, a knowledge of the quantities of water available for storage, diversion, and utilization in irrigation was needed. At that time, there were no systematic records of the flow of the streams and little knowledge of the methods that would best serve in obtaining such records; and no adequate instruments, apparatus, or equipment for collecting records of stage and discharge of streams were available. As a first and essential step in the investigation, Maj. J. W. Powell, Director of the Geological Survey established, in December 1888, a camp at Embudo, N. Mex., on the Rio Grande, where instruments and methods were studied and young men were instructed in the undeveloped art of stream gaging.

With the establishment of the Embudo camp, the Geological Survey began systematic work in collecting records of stream flow and in studying the problems related to the utilization of water for irrigation and other purposes, and this work has continued uninterrupted to the present time. Specific appropriations for stream gaging, carried first in the Sundry Civil Appropriation Act for the fiscal year 1895,[3] have been made annually. More than 4,000 stream-gaging stations are now being operated by the Geological Survey in cooperation with other Federal agencies, and with States, counties, and cities. These stations are distributed throughout the 48 States and the Terri-

[1] Chief Hydraulic Engineer (retired), Geological Survey.
[2] 25 Stat. L. 960–961.
[3] 28 Stat. L. 398.

tory of Hawaii. The field operations are conducted through 38 district offices, each of which has a district engineer in charge and a group of assistants proportional in number to the amount of work to be done.

Study of the instruments, equipment, methods, and technique involved in systematic stream gaging, which was started at Embudo, has been continued by the hundreds of engineers engaged in it, and their findings have contributed both directly and indirectly to this report. Among the reports issued by the Geological Survey that have presented various aspects of the development of the art of stream gaging are the following Water-Supply Papers:

64. Accuracy of stream measurements, by E. C. Murphy. 1902. 99 pp., 4 pls.
94. Hydrographic manual of the United States Geological Survey, by E. C. Murphy, J. C. Hoyt and G. B. Hollister. 1904. 76 pp., 3 pls.
95. Accuracy of stream measurements (2d, enlarged edition), by E. C. Murphy. 1904. 169 pp., 6 pls.
150. Weir experiments, coefficients, and formulas, by R. E. Horton. 1906. 189 pp., 38 pls.
180. Turbine water-wheel tests and power tables, by R. E. Horton. 1906. 134 pp., 2 pls.
187. Determination of stream flow during the frozen season, by H. K. Barrows and R. E. Horton. 1907. 93 pp., 1 pl.
200. Weir experiments, coefficients, and formulas (revised), by R. E. Horton, 1907. 195 pp., 38 pls.
337. The effects of ice on stream flow, by W. G. Hoyt. 1913. 77 pp., 7 pls.
371. Equipment for current-meter gaging stations, by G. J. Lyon. 1915. 64 pp., 37 pls.
868–A. Investigations of methods and equipment used in stream gaging, part 1, Performance of current meters in water of shallow depth, by C. H. Pierce. 1941. pp. 1–35, pls. 1–27.
868–B. Investigations of methods and equipment used in stream gaging, part 2, Intakes for gage wells, by C. H. Pierce. 1941. pp. 37–75, pls. 28–31.

In recent years, reports on special phases of stream-gaging activities have been issued as mimeographed circulars under the general title "Equipment for river measurements." These circulars have been issued in small editions and, like the earlier water-supply papers, most of them are no longer available for distribution. Developments in instruments, equipment, and practices are reported and discussed currently in the Water Resources Bulletin, a mimeographed pamphlet that is issued periodically for the official use of engineers of the Geological Survey.

At a conference of district engineers held in January 1930, the development of a field manual was discussed, and its preparation was subsequently authorized by the Director. Attempts were made over a period of several years to obtain a draft through the efforts of individuals who were fully occupied with other work. Finally, in 1934, steps were taken to make Don M. Corbett, then an assistant hydraulic engineer, available for part-time service in preparing the manuscript for the manual. He drew upon all sources of information, including published and unpublished reports and suggestions by district engineers and others. He brought to the task 10 years of personal experience in field and office in four Geological Survey districts. In 1935 he completed a draft of the manual, which was mimeographed and distributed in that year to all engineers of the Water Resources Branch of the Geological Survey with a request for criticism and suggestions. As Mr. Corbett could no longer be made available, C. H. Pierce, senior hydraulic engineer, was assigned to the responsible and exacting task of revising the manuscript, utilizing the many suggestions received.

This manual is far more than a compilation and adaptation of information previously published in scattered reports, as it embodies the results of the work of many engineers who have been active in all sections of the country over a period of many years. It presents the technique that has stood the test of experience under a wide variety of conditions as it has been applied by skilled engineers who have been constructively critical and have not hesitated to modify, abandon, or propose substitutions for any precedure that seemed to be unsatisfactory.

The report has been prepared primarily for use in the training of young engineers for work in the Geological Survey. During 1938, 1939, and 1940 the number of new engineers added to the organization averaged 85 a year. The work of training these young men represents an undertaking that warrants the furnishing of the best possible facilities. The report will serve also to systematize, stabilize, and improve the work of stream-gaging as a whole. In a far-flung field organization it is not easy to obtain consistency in methods and results among many groups that perform their work without frequent contacts with each other. The report will be useful also in connection with the training of students in the engineering colleges—an activity in which the Geological Survey is much interested because it must recruit its personnel from such students. It will also serve as an aid to practicing engineers who may be called upon to measure and record the flow of streams, as it contains much new and valuable information not to be found elsewhere in engineering literature.

The information given relates to both the science of the flow of water in open channels and to the art of measuring and recording river discharge. Because the technique followed is perhaps as important as the instruments and equipment utilized, much attention is given to the details of the field procedures that have been found to yield the best records of river flow.

In stream gaging, as in all other engineering activities, over-all costs are important, especially so when the funds available are inadequate for the work to be done, as has always been the situation in connection with the systematic recording of river discharge by the Geological Survey. The instruments, equipment, and procedures have been developed, therefore, with a view to obtaining reliable records at a minimum cost. Since the greatest elements of cost are those of salaries and traveling expenses, including subsistence, all field instruments and equipment are designed for operation by one man or, at most, by two men.

The report is limited in its scope to the field side of stream gaging, and except for the office work related directly thereto, it does not discuss the many office practices that are fully as important as the field activities in their relation to the collection, computation, and publication of records of stream flow.

In an activity that is current, it must be understood that there will be continuing improvements, and even as this report goes to press it is probably not strictly up to date, because of changes made in instruments or procedures since the latest revisions were made in the manuscript. It can be said, however, that the methods and practices described herein represented, in general, the best used by the Geological Survey at the time the report was prepared.

STREAM-GAGING PROCEDURE

A MANUAL DESCRIBING METHODS AND PRACTICES OF THE GEOLOGICAL SURVEY

By Don M. Corbett and others

INTRODUCTION

Water is a requisite of both plant and animal life. Its availability in usable form defines the limits within which human activities can be carried on, because the growth of cities and towns, the production of food supplies, the maintenance of transportation facilities and other public utilities, and the operation of many industries depend upon the availability of suitable supplies of water.

In its unending cycle between the clouds and the surface of the earth, water follows many courses. Precipitation, if in sufficient amount, produces surface runoff in stream channels, but not all of the total precipitation appears in surface runoff because a large part enters the ground directly or returns to the atmosphere either by evaporation or by transpiration. In its journey to the sea, water may follow courses below the surface of the ground or it may flow in surface channels. In general, there is much intermingling and interchange of surface and subsurface waters.

Systematic studies of the water resources of the United States have been made by the Geological Survey, United States Department of the Interior, for more than 50 years, and a vast amount of valuable information has been collected and made available by publication in more than 900 water-supply papers. The investigations have included measurements of the flow of streams, studies of the quantity and availability of ground water, chemical analyses to determine the quality of water with respect to its use in agriculture and industry, surveys of river channels and valleys, studies of power production, and collection of other data needed in determining the best methods of utilizing water resources. With the increase in growth and population of the country, the problems of providing adequate water supplies and of controlling the flow of streams to prevent damage and to promote utility have become increasingly difficult; and the demand for reliable information has become more insistent with each succeeding year.

Measurements of the flow of streams, investigations of underground currents and artesian wells, and determinations of the available water supplies of the United States were begun by the Geological Survey in 1888 in connection with special studies relating to the irrigation of the public lands. Systematic records of stream flow at more than 7,800 places in the United States, including Alaska and Hawaii, have been obtained by the Geological Survey. These records of stream flow usually extend over long periods of time and include determinations of the daily flow of the stream at the place of measurement. The data thus obtained are used in the administration of water rights, in studies in hydraulics and hydrology and in engineering studies related to the design, construction, and operation of hydraulic structures; to domestic, industrial, livestock, and irrigation water supplies; to the design of hydroelectric power plants; to litigation involving the determination of water rights; and to stream pollution, flood control, navigation channels and locks, drainage of agricultural lands, sanitary and storm sewers for urban areas, railway and highway bridges, road drainage, and erosion-control structures and practices.

In July 1941 more than 4,000 river-measurement stations were being maintained by the Geological Survey in cooperation with Federal bureaus, with nearly all of the States, with the Territory of Hawaii, and with many counties, municipalities, and other organizations.

The greatly increased usefulness in recent years of the results of the water-resources investigations of the Geological Survey and its resulting increased personnel have led to a pressing need for a manual on stream-gaging procedure. In recognition of this need, the district engineers during their conference in 1930 recommended that the committee on field methods prepare a preliminary draft of a field manual. In the conference in 1931 further consideration and approval was given to the project. Preparation of the complete text of the field manual extended over a period of several years. As the manual received the attention of many of the engineers of the Geological Survey, the descriptions of methods and procedure are representative of the general practice of the Geological Survey in measuring and recording the flow of streams.

ADMINISTRATION, PERSONNEL, AND ACKNOWLEDGMENTS

The entire project of writing the manual on stream-gaging procedure was under the administrative direction of Nathan C. Grover, Chief Hydraulic Engineer, and C. G. Paulsen, Chief, Division of Surface Water.

The committee on field methods, which prepared the preliminary draft of the manual in accordance with the recommendations of the district engineers in conference in 1930, consisted of E. D. Burchard, chairman, M. H. Carson, J. J. Dirzulaitis, H. E. Grosbach, A. B. Purton, and M. R. Stackpole.

In 1934 the assignment of expanding the preliminary draft into the complete manual was given to Don M. Corbett who carried the work forward until the spring of 1938, when he was assigned to other duties. C. H. Pierce then undertook the completion of the manuscript.

Parts of the manuscript were prepared, or reviewed and revised, by other members of the Water Resources Branch, as follows: The section on "Measurements of rivers that are deep and swift" by G. C. Stevens; the sections on "Slope-stage-discharge relations at gaging stations affected by variable slopes," "Variable slopes due to backwater," "Variable slopes caused by changing discharge," and "Variable slopes caused by backwater in conjunction with changing discharge" by M. C. Boyer; and the section on "Instruments and miscellaneous equipment" by A. H. Frazier.

At various stages in the preparation of the manual, the manuscript had the benefit of review and revision by the district engineers of the Water Resources Branch.

ORGANIZATION FOR WATER-RESOURCES INVESTIGATIONS

WATER RESOURCES BRANCH

The Geological Survey is divided into five branches—Geologic, Topographic, Water Resources, Conservation, and Alaskan. Water resources are investigated by the Water Resources Branch, which is subdivided into five divisions. The part of the work relating to measurements of river discharge comes within the activities of the Division of Surface Water, whose work is in many ways closely connected with the work of the other divisions of the branch. The various types of investigations conducted by the divisions of the Water Resources Branch are discussed below.

Division of Surface Water.—The Division of Surface Water measures the flow of streams at selected stations in the 48 States, the District of Columbia, and the Territory of Hawaii. At these stations not only is the flow of water measured, but records of stages and other data are collected. A stream-flow measurement station on Antietam Creek near Sharpsburg, Md., is shown in plate 1. The Division of Surface Water operates through 38 district offices with a district engineer in charge of the work in each district. In general, the districts are limited to single States, although a few districts include two or more States or parts of States. In river basins that cross State boundaries, the work is efficiently and economically coordinated among the districts concerned.

Division of Ground Water.—The Division of Ground Water investigates those waters that lie below the surface in the zone of saturation, from which wells and springs are supplied. That division studies the source, occurrence, quantity, and head of these waters; their conservation; their availability and adequacy for domestic, industrial, irrigation, and public supplies and for watering places for livestock and desert travelers; and devises methods of constructing wells and recovering water from them and of improving springs. Each year surveys are made of selected areas where problems of water supply are acute, and the results of the surveys are made available to the public.

Division of Quality of Water.—The Division of Quality of Water makes chemical analyses of water from surface and underground sources with reference to its suitability for both industrial and agricultural uses and for such domestic use as is not related to questions of health, so far as such use is affected by the dissolved mineral matter.

Division of Power Resources.—The Division of Power Resources studies and reports on water-power resources, collects and compiles information regarding not only the capacities of water wheels in water-power plants in the United States of 100 horsepower or more, but also the records of power production.

Division of Water Utilization.—The Division of Water Utilization investigates problems that are related to the utilization and control of the waters of streams and issues reports on floods and water utilization; interprets records of stream flow; and performs such administrative work as relates to supervision and investigation of those activities of the field organization of the branch that pertain to power projects of the Federal Power Commission and of the Department of the Interior.

ADMINISTRATION AND OPERATION

Under the Director of the Geological Survey, the Chief Hydraulic Engineer is the administrative officer of the Water Resources Branch. The operation of the district and field offices of the Division of Surface Water is supervised by the chief of that division, who is responsible for the procedure used in collecting records of stream flow and who assists the Chief Hydraulic Engineer in administrative matters pertaining to that work. The Division of Surface Water cooperates with the other divisions of the Water Resources Branch and with many bureaus of other departments in obtaining stream-flow information needed in connection with the work of those divisions and bureaus. The work in each district is under the direction of a district engineer, who has charge of the details of the work in his district and is responsible for the selection of the sites; and for the establishment, construction, and operation of river-measurement stations; and also for the analysis and compilation of records for publication. The district engineer is the contact officer between the Geological Survey and the Federal, State, and municipal officials who cooperate in obtaining records of stream flow at stations in his district.

PERSONNEL

Appointments to the staff are made from lists of eligibles certified by the Civil Service Commission. Vacancies in the higher grades are nearly always filled by promotion of experienced persons selected from the lower grades; therefore new appointments, especially in the professional and scientific services, are usually made in the lowest, or entrance, grades. A position may be filled by transfer from another Government agency if the applicant's request for transfer is approved by such agency and by the Civil Service Commission and if the qualifications of the applicant meet the requirements of the work. A vacancy may be filled by the reinstatement of a former employee if the person is eligible for reinstatement under Civil Service rules and regulations. A vacancy may occur because of promotion, resignation, transfer, or death, or because of an increase in the work of any district or branch division.

RECRUITING OF PERSONNEL

College and university graduates who have established Civil Service eligibility provide the normal sources of supply for professional and scientific personnel in the Geological Survey. These graduates may acquire experience in other kinds of work before receiving an appointment in the Geological Survey. If this is not extended for too long a time it is helpful in broadening their outlook on general problems.

Some educational institutions provide training in water-resources investigations so that men preparing for this type of work have an opportunity there to apply theoretical hydraulics to practical problems. Instructors in such colleges welcome the opportunity to have a representative of the Geological Survey address their students on the subject of hydrography. These personal contacts, which engage the interest of the students in the work of the Water Resources Branch, may result in an increased number of high-grade eligibles on the Civil Service lists from which the Survey replenishes its personnel.

TRAINING OF PERSONNEL

New appointees to engineering positions in the Geological Survey serve a probational period of 1 year, during which time their services may be terminated if they are not found satisfactory. New appointments must be made at the lowest salary in the grade, which is usually the junior grade. The new appointee is normally assigned first as an assistant to an experienced man, under whose close supervision he obtains practical experience in the highly specialized technique of stream gaging.

Much of the routine field work is done by engineers traveling alone, with no assistance except such as they may obtain locally. The newly appointed junior engineer is preferably given instruction by more experienced engineers and acquires some field experience while acting as an assistant before he is given the responsibility of independent field work. In order to insure the best possible instruction for each junior engineer upon his introduction to the work to which he has been assigned, it is desirable that the district engineer supervise the instruction personally and that he arrange for one of his ablest assistants to give such technical advice and instruction as may be most helpful to the appointee in becoming acquainted with the details of his work. This instruction should include details in connection with the work to be performed at gaging stations. Instruction received by an assistant while observing the methods used by an experienced man, supplemented by his own experience when doing similar work under the direction of his superior, will make a deep and lasting impression. This personal instruction might well continue throughout a field trip covering all the gaging stations likely to be visited by him on his first unsupervised trip. If the trip does not include the different conditions which prevail at low and high water, for which different methods might be used, it should be repeated when those conditions do prevail.

An engineer engaged in this work should be able to adapt himself readily to the various local conditions that may prevail as he moves from place to place. These conditions vary not only in different districts but also in different parts of the same district. Some of the districts are so large that it is expedient to divide them into two or more areas with a group of engineers assigned to each area. After an engineer becomes thoroughly acquainted with the conditions in one area, he may be assigned to another area and there obtain experience of value in supplementing that previously obtained. These changes in assignment within a district ordinarily can be made by the district engineer to the mutual advantage of all concerned, as they not only provide wider experience for the men assigned to the work, thereby developing their resourcefulness and initiative, but they also bring the accumulated experience of several men to each problem of an area.

Although essentially the same methods are used in all districts, the application of those methods to the great variety of conditions in different sections of the country results in variations in the work that require engineers able to meet new situations and new problems as they arise. Therefore a broad and well-rounded experience that can best be acquired by service in several districts is always beneficial in developing well-trained and efficient engineers.

Many helpful suggestions in regard to contacts with the public can be given to a junior engineer by those who are familiar with the local customs. As the Geological Survey is a service organization it should not be necessary to enlarge upon the importance of courteous conduct. A mere suggestion that each engineer has his share of responsibility in maintaining the good will of the public toward the organization he represents should serve to direct his attention to the importance of creating a favorable impression.

The scientific aspects of the work should never be overlooked. The engineer employed in obtaining basic stream-flow data should realize that he is also a scientist engaged in research and that these data, or deductions from them, may be used in establishing fundamental laws in hydraulics and hydrology as well as in more immediate engineering problems.

Above all else, the young engineer should be imbued with loyalty to his work and to the organization of which he is a part. He is one unit among many units engaged in the same undertaking. Confidence in his superiors and loyalty to their programs will carry him through many difficulties and enable him to use his talents to the best advantage.

GENERAL PROCEDURE

In a program for obtaining systematic records of stream flow, the technical work may be classed under three major heads: (1) establishing and constructing stream-flow measurement stations; (2) operating and maintaining those stations; and (3) computing, compiling, and preparing stream-flow data for publication.

Before a stream-flow measurement station is constructed, a general reconnaissance is made in order that a suitable site for the gage may be selected. This reconnaissance is facilitated by an examination of topographic maps or such other maps of the area as may be available. Tentative sites for the gaging stations may be indicated on the maps, each site being subject to critical examination, and to rejection if the physical characteristics of the stream channel at and near it are unfavorable.

Consideration should be given to the channel characteristics in the vicinity of each proposed site with particular reference to the hydraulic conditions necessary for maintaining a fixed and permanent relation between stage and discharge at the gage. The selection of a suitable cross section of the stream for use in making discharge measurements and the proper placing of the gage with respect to the measuring section and to that part of the channel which controls the stage-discharge relation are of special importance. As the suitability of a particular site with respect to the hydraulic requirements for a gaging station may vary with different stages of the stream, it is desirable that information be obtained in regard to the hydraulic conditions prevailing at times of low, medium, and high stages. If time and opportunity do not permit examinations at various stages, and if the engineer must make his selection of sites for gages from information obtained at one stage, he should give consideration to the probable changes in conditions that might prevail at other stages before making his selection.

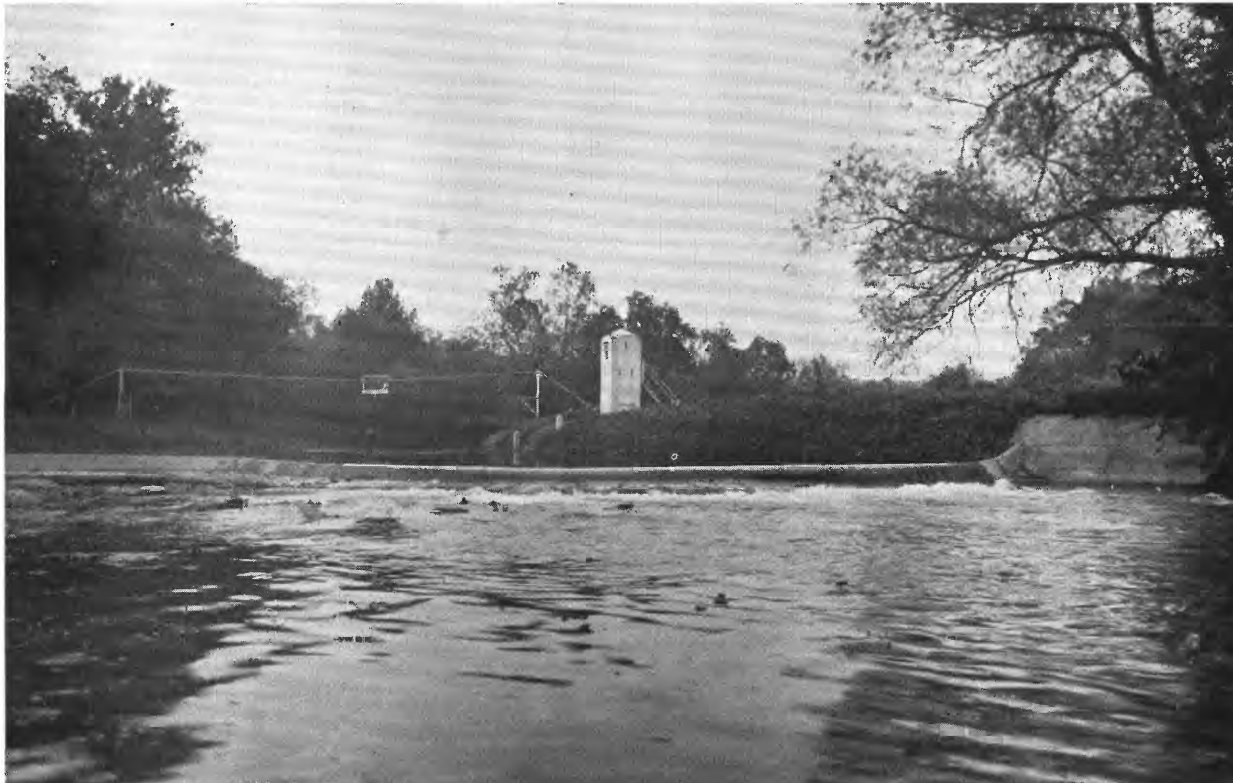
The construction of stream-flow measurement stations includes all the work pertaining to installation of the staff gages, building of the gage wells and shelters, erection of cableways and structures from which discharge measurements are made, improvement of the channels and control sections, and placing of reference marks and other items of permanent equipment. Structures typical of those generally used at stream-flow measurement stations are shown in plate 1.

Operation and maintenance work begins with the completion of the construction of the station. It involves collecting basic stream-flow data and comprises most of the routine activities of the field organization when it is away from field headquarters.

The data are computed and compiled in the district offices. This work includes the analysis of all discharge measurements; the development of rating curves defining the relation between stage and discharge; the computation of mean daily, monthly, and annual rates of flow; and the preparation of descriptions of the stations to accompany the tables of discharge. Reviewing and assembling the data for publication in water-supply papers of the Geological Survey are functions of the reviewing section of the Division of Surface Water in the office at Washington, D. C.

RECORDS OF STAGE

The stage or gage height of a stream is the height of the water surface above a chosen datum corresponding to the zero of the gage. An accurate record of stage is one of the essential factors in determining river discharge, and it provides basic data necessary for computing the rates and quantities of flow for any period of time. An



STREAM-FLOW MEASUREMENT STATION ON ANTIETAM CREEK NEAR SHARPSBURG, MD.

engineer assigned to field work should recognize the obvious fact that a record of discharge can be no more accurate than the record of stage upon which it is largely based.

METHODS OF OBTAINING GAGE-HEIGHT RECORD

Gage heights may be obtained either from direct observations on a nonrecording gage or by the use of a mechanically operated recording instrument and are classed either as observed gage heights, which consist of gage readings made by individuals, or recorded gage heights, which are those obtained by means of a recording instrument.

OBSERVED GAGE HEIGHTS

A record of observed stages consists of one or more daily readings of the height of the water surface as indicated by a nonrecording gage. Where such a record is used in determining mean daily discharge a sufficient number of observations should be made each day to assure a satisfactory record of stage from which the mean daily discharge can be computed. A record of this kind usually consists of two daily readings with additional observations made during floods and periods of large or rapid variations in stage, although for a stream not affected by diurnal regulation and where changes in stage occur very slowly one daily reading may suffice. The frequency with which the gage can be read depends to a large extent on the availability of a gage observer, the distance he must travel to reach the gage, and the compensation that can be made for the work. A Geological Survey type-A wire-weight gage used in obtaining observed records of stage is shown in plate 2, *A*.

A record of observed stages is kept in a gage-height book (Geological Survey form 9–175) provided for that purpose. The book contains sufficient space for a 3-month's record of stage observed twice daily and such additional information as may be obtained by the observer. The name of the gaging station and the date for each day during the 3 months' period is entered in the proper places in the book before it is issued to the observer. For each day of the period, spaces are provided for two observations of stage, for the time of each observation, and for remarks pertinent to the accuracy and significance of the observations.

The accuracy and sufficiency of an observed record of stage depends largely upon the capability and faithfulness of the observer as well as upon the number of readings each day. The ever-present personal or human element is probably the greatest single factor with which the field engineer must contend in obtaining an accurate and reliable observed record of stage, because the observations and records are made by persons of varying intelligence, carefulness, and faithfulness and not by mechanical instruments.

RECORDED GAGE HEIGHTS

A record of recorded stages is obtained by the use of a mechanically operated recording instrument known as a water-stage recorder. This instrument may be designed either to produce a graphic record of the rise and fall of the water surface with respect to time or to print or otherwise indicate the stage at definite time intervals. Of these two types of records, the graphic record is generally accepted as being both more accurate and more usable.

The record produced by a water-stage recorder largely eliminates the personal element that always prevails in an observed record and provides the refinement that is necessary for a high degree of accuracy. A water-stage recorder in operation in a concrete shelter over a 5-foot square gage well at the gaging station on the Rahway River at Springfield, N. J., is shown in plate 2, *B*.

OBSERVERS

Gage observers are employed for obtaining records of stage either by directly observing nonrecording gages or by attending to the operation of water-stage recorders.

Availability.—In many places little or no choice in the selection and employment of gage observers may make it necessary to employ the person living nearest the gage, as he may be the only individual reasonably available. If a choice is possible, it is good practice to interview first the person on whose property the station is situated. If that person, or someone else connected with the property, is interested in the work and appears to be competent, it is better to employ him than another person who must trespass in order to perform the duties, thus avoiding potential trouble with the property owner as well as possible embarrassment to the Survey.

The necessity for daily observations at definite hours, eliminates as gage observers many persons who are profitably employed otherwise. Therefore the selection may be limited to comparatively few persons even where the gaging station is in a thickly populated area.

Trustworthiness.—The observed record of stage should be accurate and reliable, which is possible only if the observer is competent, faithful, trustworthy, and has a full understanding of the need for accurate observations. These characteristics are not always obvious when the individual is first interviewed but are usually encouraged by proper contact and instruction. On the other hand, a capable and honest observer may become careless and unreliable if the engineer fails to show proper interest in his work. Some observers whose capability and honesty were doubted at the time of their employment have rendered excellent and faithful service as a result of tactful and diplomatic efforts of the field engineer.

Discontent and laxity of the observer can generally be avoided if, at the time of his employment, he is given definite instructions as to his duties and the compensation he is to receive. It is a good policy to issue instructions, either personally or by correspondence, with consideration and diplomacy, and thus avoid as much as possible any inference that the supervision of the work is to be conducted in an arbitrary manner.

It is desirable for the observer to realize that there are ways of detecting errors in gage readings. If he is shown that inconsistencies in gage readings may be discovered by comparison with records at other gaging stations on the same stream or on other streams in the vicinity, he is likely to be more careful in his work and less apt to think that he can "estimate" the gage height without actually reading the gage.

Duties.—The character of the observer's duties varies with the type of the gage-height record required. For an observed record of stage the duties are specific. They consist mainly of the careful reading of the gage and the proper recording of the readings. In addition the observer is required to assist in keeping the gage in good condition and to report promptly to the office any trouble that he cannot correct. For example, at times he may need to remove such small amounts of mud, debris, or ice as interfere with his accurate reading of the gage.

The instructions in each gage-height book must be followed by the observer if his duties are to be performed most satisfactorily. The gage-height book should either be kept in a compartment in the gage box at the gaging station or taken by the observer to the gage at the time of each reading so that the record may be entered at the moment the observation is made. The observer should be careful to record each gage reading, with the time, date, and remarks related thereto, in the proper columns. Recording these data elsewhere for later entry, or trusting to memory, should always be avoided. If for any reason the observer is unable to read the gage, he should leave the spaces blank in the gage-height book except for a note stating that no reading was obtained. If he employs someone to attend to his duties, a note to that effect should be made under "remarks."

If a rise and fall in stage has occurred between visits and if the highest stage reached by the river can be seen from the high-water mark on the gage, the gage height of such a high stage with the probable time of its occurrence should be recorded under "remarks" for the day. Information on conditions that affect the height of water at the gage, such as the forming or breaking of log jams, the growth of grass in the channel, or the collection of logs and debris on the control, is of value to an engineer using the record and should be noted by the observer. Statements regarding the weather, the approximate amount of precipitation (whether rain or snow), and the trend of river stage at the time of the observation (whether rising, falling, or stationary) should be made. During winter the observer should describe the condition of the river below the gage, or at the riffle or rapids controlling the ordinary stage-discharge relation, by stating whether the channel is open, partly open, or frozen over; whether there are ice jams above, below, or on the riffle; and whether ice is anchored to the bed at the riffle or floating in the stream. If the stream at the gage is covered with ice the observer should record the stage of the water surface and not the height of the top or bottom of the ice.

At the end of each week the observer should copy on a card (Geological Survey form 9–176) the week's data from his gage-height book and mail the card to the district office, thus providing the office with an up-to-date record of the stage of the stream. At the end of the 3-months' period for which the gage-height book was issued the observer should sign the book and mail it to the district office.

The duties of the observer at a station equipped with a water-stage recorder are so exacting that they must be performed by the field engineer if a capable observer is not available. In several districts where the stations are so situated that they can be visited frequently by an engineer, it has been found economical and practicable to operate well-equipped gaging stations without the use of observers. In other districts experience has shown that every reasonably accessible gaging station should be visited by an observer at least once a week in order to insure continuity of the records. Improved highways and transportation facilities have made it possible in many sections for a field engineer to visit gaging stations frequently and to perform the essential duties more efficiently than the ordinary observer. Modern water-stage recorders installed with adequate gage wells and shelters require less frequent attention than older types of recorders.

Manipulation of a water-stage recorder by an observer who has no knowledge of its operations may result not only in additional work for the field engineer but also in the loss of valuable records. Instructions to the field engineer in regard to his duties at a gaging station also apply to the observer for those duties that he must perform.

Upon the completion by the observer of those duties that are directly related to the operation of the water-stage recorder, a summary of the results obtained should be recorded on the inspection card

(Geological Survey form 9–176–C), which outlines specifically those duties that should be performed on each visit to the gaging station. The card is then signed and sent to the district engineer.

Compensation.—Observers, like all other individuals earning a livelihood, expect compensation for the work they do, even though it may require but a few minutes of their time each day. The compensation of each observer should be based on the amount of work he has to do and the distance he must travel to reach the gaging station.

MEASUREMENT OF DISCHARGE

The discharge or rate of flow of a stream is the quantity of water flowing past a cross section of the stream in a unit of time. The unit in which discharge is usually expressed is cubic foot per second, which is contracted into second-foot. A second-foot of water is defined as the quantity flowing through a cross section 1 square foot in area at a velocity of 1 foot per second. The procedure of measuring the area of a cross section of a stream and the velocity of flow past the section is known as the velocity-area method of measuring discharge. The product obtained by multiplying the area of the cross-section by the velocity constitutes a discharge measurement for that area.

The velocity of water may be measured either directly or indirectly, depending on the method employed. A direct method consists in observing the rate of travel of a float or a chemical placed in the stream. An indirect method consists either in the measurement of the slope of the water surface from which the velocity is computed by means of a slope-velocity formula or in the use of an instrument to measure the velocity of flow within a selected section. Discharge measurements are classified according to the method used in measuring velocity.

The detailed collection of stream-flow records needed in a well-arranged investigation of water resources has become practicable through the development of methods and equipment for accurately measuring the velocity of water in open channels. In the following discussion the merits of several of the more generally accepted methods are reviewed and considered with respect to the adaptability and application to general stream-gaging procedure.

CURRENT-METER MEASUREMENTS

A velocity-area measurement of discharge in which the velocity is measured by an instrument known as a current meter is a current-meter measurement.

In making a current-meter measurement, the total area of the cross section at the place of measurement is divided into small or partial sections and the area and the mean velocity of each is determined separately. The small sections are each bounded by the water surface, the stream bed, and two imaginary vertical lines, called verticals. Each vertical, therefore, being a common dimension for two adjoining sections, fixes the point at which observations of depth and velocity are made. Sufficient velocity observations are made to establish the mean velocity in each of the two verticals forming the side boundaries of a section, and the velocities in the two verticals are then averaged to determine the mean velocity in the section. The product of the mean velocity thus obtained and the area of the section, which in turn is the product of the distance between the two verticals and the mean of their depths, is the discharge in the section. The sum of the discharges in all the partial sections is the discharge of the stream.

The specific procedure followed in making a current-meter measurement depends on the method selected for use in determining the depth and the mean velocity in the vertical, the manner in which the meter is suspended, and the type of structure or support from which the measurement is made.

TYPES OF DISCHARGE MEASUREMENTS

Discharge measurements are made in various ways and therefore may be said to be of different types, depending on the kind of support used by the engineer in crossing the stream and the manner in which the current meter is held in the desired position in the water. The specific procedure for each type of discharge measurement is described below. Factors affecting the accuracy of measurements of the different types are discussed on pages 65 to 76. The meter and sounding equipment are described on pages 168 and 197. Stop watches, note forms, angle charts, and other items of equipment are assumed to be available.

WADING MEASUREMENTS

Before making a wading measurement, the engineer should examine various cross sections in the vicinity of the gage to find the one most suitable for this type of measurement. With the measuring section selected and the equipment assembled. the next step is to span the measuring section with a tag line at right angles to the direction of the current. As this cannot always be done with respect to angularity throughout the width of the stream, it may become necessary to measure and record the amounts by which the angles formed by the current with the tag line at some of the measuring points deviate from 90°. Any unnecessary deviation should be avoided by careful placing of the line. While placing the tag line, the engineer should obtain a general idea of the proper spacing of verticals by observing the total width of the section and the character of the stream bed.

After the tag line is placed, the actual discharge measurement is begun. A wading measurement in progress at the gaging station on Patuxent River near Burtonsville, Md., is shown in plate 3, *A*. The edge of the water in reference to a marker on the line and also the bank from which the measurement is started (whether left or right bank, looking downstream) are recorded. The rod is then placed in a perpendicular position in the first selected vertical and the depth observed. If the depth in the vertical is 1.5 feet or greater, the two-point method should be used. If the depth is less than 1.5 feet the method used will depend largely upon the type of current meter, the depth of the water, and the roughness of the stream bed.

The performance of current meters in water of shallow depths has been investigated by the Geological Survey at the National Hydraulic Laboratory of the National Bureau of Standards. The results indicate that the 0.6-depth method should be used for depths between 0.5 foot and 1.5 feet and that the 0.5-depth method should be used for depths less than 0.5 foot.

It appears that coefficients other than unity may be necessary for current-meter measurements in very shallow depths for two reasons: First, the distribution of velocity in a vertical may be such that the actual velocity at the point of observation is not the mean for the vertical as, for instance, an observation at 0.5 of the depth; and second, the registration of the current meter may be affected by its proximity to the water surface or the stream bed. Sometimes the errors from those two sources may be of opposite sign and therefore compensating. Under other circumstances the errors may be of the same sign, or may be predominantly of one sign, and therefore not compensating. As a result of the investigations mentioned above, coefficients have been determined for use with observations of velocities in shallow depths.[1]

In wading measurements the engineer should stand in a position that least affects the velocity of the water passing the current meter. Field and laboratory studies conducted by the Hydraulic Laboratory Committee of the Geological Survey indicate that the position of the engineer least affecting the accuracy of a discharge measurement by wading may be described as follows: With the meter rod at the tag-line and facing the bank with the water flowing against the side of his leg, the engineer should stand from 1 to 3 inches downstream from the tag-line and 18 inches or more from the meter rod. If facing the left bank, he will naturally hold the meter rod with his

[1] Pierce, C. H., "Performance of current meters in water of shallow depth": U. S. Geol. Survey Water-Supply Paper 868–A, pp. 1–35, 1941.

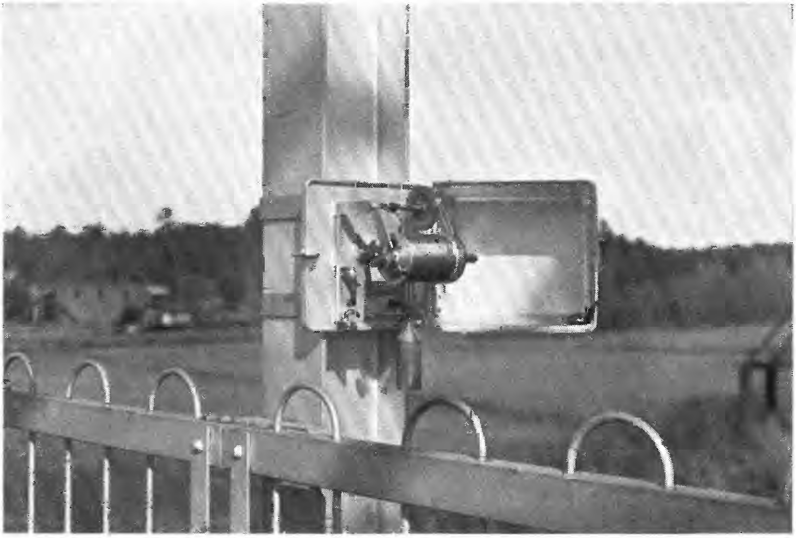
left hand; if facing the right bank he will hold it with his right hand. The results of the investigation show that no coefficient for position need be applied if this position is used. The engineer can maintain a standing position 18 inches or more from the meter rod with a reasonable degree of comfort and at that distance can also give proper attention to the current meter.

Care should be taken to keep the rod in a vertical position and the meter parallel to the direction of flow while the velocity is being observed. If the flow is not at right angles to the tag-line, the amount by which the angle deviates from 90° or the angle coefficient for that difference should be recorded. This angle coefficient, which is the cosine of the angle of difference, may be determined by the use of an angle chart or a protractor held in proper alinement with the tag-line while the "angle-coefficient line" that corresponds most nearly to the direction of the flow is being observed on the chart or protractor. Upon completion of the necessary observations at the first measuring point, a similar procedure is followed successively at each of the remaining verticals.

If the velocity at the edge of the water is not zero, it is customary to estimate this velocity as a percentage of the velocity measured at the first vertical or measuring point. In order that no appreciable error may be introduced into the total measurement as a result of such estimates, care should be taken to space the verticals so that the flow in the section bordering the edge of water is extremely small in comparison with the total flow. Furthermore, it should be kept in mind that the vertical-shaft cup-type meter tends either to underregister or to overregister when used close to a vertical wall or bank where the velocity is nonuniform, the direction of deviation depending on whether the bank or wall is to the right or left of the meter, looking downstream.

CABLEWAY MEASUREMENT

A measurement of discharge may be made from a cableway with the meter and weight suspended either from a hand-line or from a reel assembly. The use of a reel assembly with a type-B gaging car on a cableway at the gaging station on the Licking River at Toboso, Ohio, is shown in plate 3, *B*. A hand-line used from a type-A gaging car is generally operated over a sheave placed on the side of the gaging car near the end opposite the operator (see pl. 1). A scale, marked in feet and tenths, attached to the side of the gaging car and in direct alinement with the sheave, materially assists in measuring the depths and in placing the meter in position in the vertical. If a type-B gaging car is use, the hand-line may be operated over the end sheave and the depths measured with a graduated scale.



A. TYPE-A WIRE-WEIGHT GAGE.

B. WATER-STAGE RECORDER IN OPERATION ON RAHWAY RIVER AT SPRINGFIELD, N. J.

A. WADING MEASUREMENT ON PATUXENT RIVER NEAR BURTONSVILLE, MD.

B. MEASUREMENT FROM CABLEWAY ON LICKING RIVER AT TOBOSO, OHIO.

A reel assembly may be used from either the type-A or the type-B gaging cars. In the type-A gaging car, in which the operator works from a sitting position, the reel assembly is operated most satisfactorily if the rack on which it is mounted is placed at right angles to the sides of the car. In this arrangement the axis of the drum is at right angles to the cableway. In the older type-B gaging car, in which the operator works from a standing position, the reel assembly is mounted on the upstream side of the car with the axis of the drum parallel to the cableway. The improved type-B car has an end sheave, and the reel assembly is mounted so that the axis of the drum is at right angles to the cableway. Provision for easily mounting the reel assembly is essential in the construction of either type of gaging car.

If the observations of depth and velocity do not necessitate the consideration of the vertical angle (see p. 45), the specific procedure in measuring from a cableway may, in general, be considered the same for both the hand-line and the reel assemblies. This procedure is as follows: Identify the edge of the water in relation to the initial point or zero marking, which is usually at one of the structures supporting the cableway, and the record the bank (whether left or right, looking downstream) where the measurement is started. The meter and weight are lowered at the first vertical until the horizontal axis of the meter is flush with the water surface; they are then lowered until the weight touches the bed of the stream, during which procedure the amount of line let out is measured. If the bed of the stream is composed of stable material, the weight may be again raised and lowered a short distance to determine irregularities in the profile of the section at that point. If there is a difference in the two observations, the mean is usually accepted. If, however, the stream bed consists of mud or shifting sand and silt, the depth should be noted the instant the weight touches the bed, as repeated churning with the weight may cause a scour that will result in an unduly large observation of depth. To the part of the depth thus measured, the distance from the bottom of the weight to the horizontal axis of the meter must be added to obtain the total depth.

Some engineers prefer to use the bottom of the weight instead of the axis of the meter as an index for determinations of depth. Where the suspension cable of the current meter makes a considerable angle with the vertical line from the point of suspension to the water surface, commonly called the vertical angle, and where floating drift is present in the measuring section, there is a recognized advantage in this method; but where a vertical angle and floating drift are not present, the swerving and swinging of the meter will be materially

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reduced if the weight is submerged, and consequently a more accurate measurement of depth will be obtained, particularly if the cableway is far from the water surface.

After the depth is measured and recorded, the observations of velocity are made. With the weight at the stream bed after the measurement of depth, the most convenient procedure is to raise the current meter first to the 0.8-depth position for an observation there, and then to bring it to the 0.2-depth position for the observation at that place. In computing the distance that the current meter is to be raised, the distance from the meter to the bottom of the weight must be taken into consideration. In working from a cableway, the velocity observation should not be started until the cable and car have ceased oscillating.

The two-point method, in which velocities are measured at 0.2-depth and at 0.8-depth, should be employed wherever the depths will permit. The minimum depth at which this method may be used in cableway measurements depends on the position of the meter with respect to the bottom of the weight. If the horizontal axis of the meter is placed 0.5 foot above the bottom of the weight, the minimum depth in which this method can be used is 2.5 feet. For the 0.7-foot position of the meter, the minimum depth is 3.5 feet; for the 1.0-foot position, 5 feet. The 0.6-depth method should be used where the depth in any vertical will not permit the use of the two-point method; except that in very shallow water where depths are less than 0.5 foot the 0.5-depth method may be preferable.

If the angle made by the current with the cableway deviates from 90°, the correction for this angle may be determined from an angle chart, a protractor, or an indicator operated from the side of the gaging car by observing the "angle-coefficient line" which coincides with the direction of flow. The direction of flow may be detected by observing particles of drift that pass the measuring section near the measuring line or by noting the position of the meter when it is placed just beneath the surface of the water. The latter practice is preferable, and is reliable provided the velocities are great enough to overcome any torsional force that the twist of the measuring line may exert on the meter. When observing passing drift, note carefully that the particles under observation are not affected by action of the wind. In the absence of floating drift when the surface is fairly smooth, the angle coefficient may be observed by bisecting the wake produced by the meter cable. The wake is usually identified by two small ripples that make an acute angle with the measuring line at the apex.

After the completion of the above procedure in the first vertical, each successive vertical is treated in like manner until the stream has been crossed.

If there is floating drift at or below the surface, it may be necessary to raise the meter for inspection or cleaning after the depth is measured and before the velocity observations are completed. After such an interruption of the routine procedure it may be desirable to measure down from the water surface when placing the meter for the velocity observations. With this change in procedure from that used in placing the meter from the bottom upward, care should be taken to see that the meter is lowered the computed distance below the water surface.

An emergency may arise in using a hand line where the available weight is insufficient to obtain reliable measurements of depth in the usual manner. Under those circumstances the line and weight may be cast upstream and a fairly accurate measurement of depth obtained with the line pulled taut when the weight is on the bottom of the stream directly beneath the cableway.

A measurement is sometimes required in a section of shallow depth that cannot be waded because of a soft stream bed. In making a measurement from a cableway under such conditions, it may be necessary to place the meter below the weight in order to obtain a 0.5-depth or 0.6-depth observation. If the meter is used in that position great care must be used in placing it so that it will not come in contact with the bed. Under these circumstances the measurements of depth should be made either with the meter removed and before the observations of velocity are begun or by means of an auxiliary weight and line.

Although it is desirable to adhere to specific procedure in measuring depths and velocities, departures are sometimes permissible. For example, in streams that are comparatively free of drift and in which a vertical angle is not involved, the tag-line method may be used to advantage in measuring the depth and in placing the current meter. The tag-line method may be used also when the vertical angle must be considered, provided the angle does not change when the index tag is brought to the water surface (see p. 56). However, before adopting any method that apparently tends to simplify a generally accepted practice, the engineer should first assure himself that his proposed departure from customary methods will not affect the accuracy of his measurement.

BRIDGE MEASUREMENT

On some rivers subject to overflow, the only places where the total flow at flood stages can be measured are at highway or railroad bridges where the roadway embankments restrain the flow to channels under the bridges. During flood stages, when the use of a cableway is impracticable, it may be necessary to utilize the bridge in measuring the discharge. It is, of course, desirable that the bridge should be normal to the current and that the cross section of the channel beneath the bridge should be reasonably uniform. Old pier footings, piling, and other obstructions left in the channel after the completion of the bridge may sometimes seriously impair the accuracy of measurements made at bridge sections. Bridge piers in the measuring section are particularly objectionable where the piers make large angles with the direction of flow.

A discharge measurement is rarely made from a bridge as quickly and conveniently as from a cableway. The necessity of dividing the area into a larger number of sections because of bridge piers and greater irregularity in the stream bed, the inability to observe floating drift if working from the downstream side of the bridge, the greater possibility of damage to the meter, and the interference of bridge members are some of the factors that make a bridge measurement difficult and undesirable.

The downstream side is generally preferred in measuring from a bridge, as the direction of flow on that side often appears to be more nearly normal to the structure. The tendency for the meter line to move away from the lower bridge members affords a better opportunity for measuring the vertical angle of the meter line, if any is present. This tendency also largely eliminates the continual contact of the line with the bridge members, which cannot be avoided on the upstream side.

Either a hand line or a reel assembly may be used from a bridge in essentially the same manner as from a cableway. In the use of a hand line assembly from a bridge, it is generally more convenient to lower the sounding weight first to the bed of the stream and measure the depth by raising the meter and weight from the bottom to the surface This procedure reduces to a minimum the contact of the meter line with the bridge members.

If a weight heavier than 30 pounds is required, it is customary to use a crane-and-reel assembly, the reel being mounted on a crane designed to clear the handrail of the bridge and to guide the meter line beyond any interference with bridge members. The crane is attached to a movable base for convenience in transferring the equipment from one measuring point to another. The use of such equipment in making a bridge measurement at the gaging station on Rillito Creek near Tucson, Ariz., is shown in plate 4, *A*. Another somewhat heavier type of crane with hand reel that is sometimes used for measurements of the overflow sections of the Mississippi River at Vicksburg, Miss., is shown in plate 4, *B*. If the depths and velocities require weights greater than 200 pounds, the crane-and-reel equipment is usually mounted on a power-driven truck, the motor of which is arranged to operate the reel as well as the truck. A power-driven truck carrying crane-and-reel equipment used at the gaging station on the Mississippi River at Memphis, Tenn., is shown in plate 5, *A*. If the current deviates from the 90° angle with the bridge, the angle correction may be best obtained by placing the angle chart or protractor against the handrail and reading the angle coefficient in the same manner as for cableway measurements.

For measurements of canals, tailraces, and small streams, foot bridges are sometimes designed and built to provide facilities for making discharge measurements by use of the rod suspension. Where the depths and velocities do not permit the use of a standard wading rod, a special rod may be designed, or a stay-line and wire arrangements may be employed to hold the rod and meter in place. Although for low velocities the procedure may be the same as for a wading measurement, it is often advisable at higher velocities to measure the depth in the following manner: For each selected vertical a point is established on the bridge. With this point as an index, the distance to the water surface is measured by lowering the rod until the base plate touches the water. The rod is then lowered to the bottom of the channel, and the rod reading is again noted at the index point. The difference in readings is the depth of water in the vertical. Measuring the depth in this manner tends to eliminate errors that may be caused by the piling up of water on the upstream face of the rod.

BOAT MEASUREMENT

Measurements of discharge from a boat are generally made by the Geological Survey only on those rivers that may be readily spanned by a temporary cable of sufficient strength to hold the boat in position while the observations are being made. The equipment used will depend largely on the size and character of the stream, the frequency with which discharge measurements are to be made, and the availability of a suitable boat. The boat should have a flat bottom, should be at least 15 feet long, and should be heavy enough to dampen the effects of the action of waves. The temporary cable used to span the measuring section must serve as a means of holding the boat in position and also of measuring the width of the stream. This cable should be wound on a reel that can be conveniently operated from the stern of a boat to pay out the cable as the boat is propelled across the stream.

A hand-line or reel assembly operated from a boom is most adaptable for measuring the depth and velocity from a boat, although where the depths are shallow and the bed of the stream is uniform and smooth, the depths may be measured with a rod. The boom should extend upstream beyond the bow of the boat a sufficient distance to eliminate any possible effect of the boat on the velocity of the water at the meter. It is preferable that the boom be so designed as to permit the use of a Geological Survey type of sounding reel, although reels of special design may be developed for use on individual streams where boat measurements become general practice. In general, the equipment should be of such nature that a boat measurement may be made by one engineer with the aid of not more than one helper. Equipment used in the St. Paul district of the Geological Survey in making boat measurements of the Mississippi River is shown in plate 5, *B*.

Although one particular assembly of boat equipment may not be adaptable for all types of streams and conditions, the equipment specified in the following list may be considered as typical for use with river spans of 1,000 feet or less and for velocities up to 5 feet per second. Deviations from this list of equipment may be necessary because of specific local conditions. Assuming that a boat is available and that an engineer has the usual current-meter outfit, the following additional equipment is necessary:

1. A demountable tag-line reel and support carrying about 1,300 feet of $\frac{3}{32}$-inch 19 wire galvanized aircraft-strand boat cable graduated into 10-, 50-, and 100-foot intervals by solder marks using one, two, and three marks, respectively.

2. A pair of lightweight double blocks and tackle with a parallel jaw or a winch to be used in taking up the slack in the boat cable. With the latest design of tag-line reel, the slack can be taken up by means of the reel crank.

3. A hand ax, sledge, stakes, and a short length of rope for use in anchoring the boat cable.

4. A boom consisting of a single beam constructed either of an oak timber reinforced along the sides by angle irons or of two structural aluminum channel shapes, one telescoped within the other to permit adjustments in length. This boom is equipped with a bronze sheave at the far end and must be of sufficient length to reach from a cross beam attached to the gunwales of the boat to a point at least 3 feet beyond the bow.

5. A cross beam, preferably constructed of structural aluminum angle shapes or channels, for attachment to the gunwales of the boat near the center. This cross beam should be provided with a base to permit the ready mounting of the measuring reel. It may be provided also with a guide sheave at each end under which the boat cable is passed. A combination boom and cross beam has been designed as part of the standard equipment for boat measurements.

6. Sufficient J-bolts or C-clamps to attach the cross beam to the gunwales of the boat and the boom to the cross beam.

7. A sounding reel of the type described on pages 205–206 or a specially designed reel equipped with the necessary length of measuring line.

The recommended procedure in making a boat measurement is as follows: After the measuring section has been selected and the necessary equipment taken to the site, substantial anchorage to which the boat cable can be temporarily attached must be provided. If a tree or other object is not available near the edge of the water for an anchorage, an iron pin of the proper length and size may be driven into the ground. To stretch the cable, the free end is fastened to the anchorage on one bank. The boat reel assembly is placed in the stern of the boat with the cable leading off the top of the reel. As the boat is propelled across the stream the cable is paid out. As the cable is paid out, the boat should be headed somewhat upstream so that the opposite bank may be reached at the desired point or slightly above it. If the cable is allowed to unreel easily it will fall to the river bottom practically at right angles to the current. When the bank is reached, the reel and support are taken ashore and the cable tightened by means of a block and tackle, or by the use of the reel and reel crank, until the cable clears the water by 6 to 12 inches. In preparation for the measurement the boat is placed under the boat cable with the bow upstream. The cross beam is then attached to the boat, and the boat cable is passed through the guide sheaves on the cross beam. These guide sheaves may be two J-bolts installed in an inverted position at each end of the cross beam, or two C-clamps attached directly to the gunwales opposite each other. Usually there is sufficient friction between the cable and guides to hold the boat in position while the observations are taken. By placing the boom over the forward gunwale slightly to one side of the stem at the bow, the operator may more easily observe the meter.

With the equipment assembled in this manner the procedure followed in making the measurement is essentially the same as for cableway measurements, and sufficient weight can generally be used to eliminate the vertical angle. The two most common factors contributing to the inaccuracy of a boat measurement are the upstream and downstream movement of the boat, which is caused by variable wind or nonuniform velocity of the water, and the vertical movement of the boat, which is caused by wave action. Inaccuracies in measurements of velocity resulting from the upstream and downstream oscillation, which is usually rather uniform, may be overcome by taking velocity observations over a longer period, or by starting and stopping the velocity observations at the same point in the oscillation. Upstream or downstream wind may destroy the uniformity of this oscillation and also create enough wave action to produce vertical movement. This vertical movement, in addition to making observations of depth more difficult and less reliable, may also affect the accuracy of the velocity observations, especially those taken with types of meters affected by vertical motion. For this reason, boat measurements should not be attempted when the velocity of the wind is more than 15 miles an hour.

On navigable streams the boat cable should be fastened so that it may be readily lowered to the bed of the stream. This is usually accomplished by releasing the tension through either the block and tackle or the reel crank. The boat cable should be well tagged so that approaching boats can see it. Where these precautions have to be taken an additional helper may be desirable or necessary to operate the cable.

MEASUREMENT THROUGH ICE COVER

A measurement of discharge may be made through ice cover if the ice is of sufficient thickness to support the engineer safely and if no open water measuring section is available. In some situations it may be necessary to measure the flow for a part of the distance across the channel in open water and the remainder through ice cover. This procedure should be limited to those channels that can be waded as the surface ice may be thin and unsafe where such conditions exist.

The equipment used for a measurement through ice cover must include, in addition to that used for open-water measurements, tools for cutting holes through the ice and for measuring its thickness and hangers to permit such changes in the suspension of the meter as may be found necessary. A shovel and an ice chisel or an axe are most commonly used for cutting holes. The shovel is used principally for clearing away surface snow and for removing chips of ice from the hole during the process of cutting. The use of either an ice chisel or an axe is a matter of preference where the surface ice is thin, but for a thickness of ice greater than 1 foot an ice chisel is indispensable. If a suitable ice chisel cannot be purchased, one can be constructed by a blacksmith from an ordinary steel bar. It should be at least 4 feet long, should be looped at one end to permit easy gripping, and should weigh at least 14 pounds. The blade should be wedge-shaped and drawn out to a section about 1/4 inch in thickness and 3 inches in width. The blade must be tempered so that it can be ground to a keen edge and readily sharpened with a file or stone. The edge should be sharpened on one side only and the cutting surface kept straight. To assist in keeping the lower part of the hole free from ice chips, the lower 6 inches of the chisel may be so bent back that the cutting edge is not more than 3/16 of an inch to the rear of the chisel above.

A scale about 4 feet long, graduated in feet and tenths and having an L-shaped projection at the lower end, is generally used for measuring the thickness of the ice and the distance from the water surface

A. BRIDGE MEASUREMENT WITH TYPE-A CRANE AND TYPE-A REEL ON RILLITO CREEK NEAR TUCSON, ARIZ.

B. HEAVY CRANE AND HAND REEL FOR BRIDGE MEASUREMENT.

A. POWER-DRIVEN TRUCK CARRYING CRANE AND REEL FOR BRIDGE MEASUREMENT, USED ON MISSISSIPPI RIVER AT MEMPHIS, TENN.

B. EQUIPMENT USED IN BOAT MEASUREMENTS.

to the bottom of the ice. For use in a newly cut hole, the horizontal part of the L should be at least 4 inches long so that it may extend beyond any irregularities on the under side of the ice. If the holes are used for subsequent measurements, the lower edges may become so rounded that the horizontal part of the L should be about 1 foot long for reliable determinations of thickness of ice.

The holes cut through the ice should be elliptical, with the major axis of the ellipse parallel to the current, and should be no larger than is necessary to permit the raising and lowering of the meter. For most efficient cutting, the worker should strike with the chisel so that as many of the chips as possible will fly clear of the hole. This can be best accomplished if the worker cuts with the blade slightly inclined toward the center of the hole as he makes the first cuttings around its circumference, and with the blade inclined toward the outer edge of the hole as he makes the second round of cuttings. The groove thus completed will be several inches deep and comparatively free from chips of ice. The solid central part can then be jarred loose, usually in one piece, by striking it a wedging blow with the chisel. This procedure is repeated until the bottom of the ice is reached, although special care is required to complete the cutting before an appreciable amount of water is admitted into the hole. The entrance of the water may be largely prevented by cutting the last groove to a uniform depth just above the bottom of the ice and striking the center part with a sharp blow to loosen it. The remaining pieces of ice will float to the surface and may be easily pushed aside with the chisel or shovel.

It is usually advisable to chop the first hole through the ice in the middle of the measuring section and then proceed to the quarter points. This practice may lead to the detection of slush ice and so enable the engineer to investigate another section if necessary before much time and effort have been expended. On small streams where measurements of velocity are desired at many points close together, the ice may be removed from the entire measuring section, thus materially reducing the vertical pulsation of water that sometimes occurs at holes cut through ice cover.

A measurement through ice cover may be made by either a rod, a hand-line, or a reel suspension. A meter supported on a rod may be used satisfactorily where depths are shallow and temperatures such that ice will not readily form in the meter bearings when the meter is removed from the water (see pl. 6, *A*). If the temperatures are subfreezing and if the regular wading assembly is used, it is better practice to keep the meter at a fixed position on the rod throughout the measurement, say at a point 0.5 foot above the base plate. If the surface of the ice or water is used as an index point, the meter may be placed at the proper position in the vertical for velocity observations without removing it from the water until it is transferred to the next vertical. If the meter is retained in the fixed position on he rod, the assembly may, in the absence of the L-shaped scale, be used for determining the thickness of the ice and the distance from the water surface to the bottom of the ice.

A small portable reel assembly mounted on a tripod, stand, or sled in such a manner that the weight and meter can be raised and lowered directly over the hole in the ice is useful in making this type of measurement. Reel and sled equipment used in making discharge measurements of the Mississippi River at St. Paul, Minn., through ice cover is shown in plate 6, *B*. The tripod or stand should be collapsible and have adjustable legs by which its height and spread may be regulated. These features of design assist in making the equipment readily transportable. A hand-line assembly may be conveniently used if the hand-line consists wholly of rubber covered cable and if the velocities are such that reliable soundings are obtainable with a 15- or 30-pound sounding weight. When either the hand-line or reel suspension is used during subfreezing temperatures, the observations of depth and velocity in a vertical may be obtained without exposing the meter to the atmosphere once it has been placed in the water. This may be accomplished by tagging the measuring line at a known distance above the horizontal axis of the meter and by using this point as an index for measuring the depth and for placing the meter.

The two-conductor system as used in making open-water measurements of discharge is generally employed with satisfactory results in measuring through ice cover with either a hand line or a reel assembly. Satisfactory results may also be obtained with the single-conductor system if the ground wire is placed in running water while the observations of velocity are being made. Some difficulty may be experienced with the single-conductor system if there is a layer of frazil or anchor ice (p. 69) under the surface ice, unless the ground wire extends into the running water.

After holes have been cut and positions of the verticals established, observations of depth and velocity are started. The thickness of the ice and the distance from the water surface to the bottom of the ice are measured at both the upstream and the downstream ends of the hole. If the measurements differ, the mean of the two measurements is recorded. The total depth of the water is then measured, and from this depth the distance from the water surface to the bottom of the ice is subtracted to obtain the effective depth. If there is a layer of frazil or anchor ice below the surface ice, its thickness must also be determined. The lower limits of the layer are found by raising the meter upward from the bottom of the stream until it fails to register any velocity. The distance from the meter in this position to the top of the water surface is measured and subtracted from the total depth to obtain the effective depth.

The method selected for measuring the velocity will depend on the type of meter suspension used and the effective depth. If the effective depth is 2.0 feet or more and the meter is supported on a rod, the two-point method should be used. If the meter is suspended from a line and is placed 0.5 foot above the bottom of the sounding weight, the two-point method should be used for all depths of 2.5 feet or greater. Where the two-point method is not practicable, the velocity observation may be taken at either 0.5-depth or 0.6-depth, and coefficients may be applied to reduce the observed velocity to the mean in the vertical, these coefficients being less than unity. The results of experiments by the Geological Survey[2] show that for velocities under ice cover, the average coefficient for a 0.5-depth observation is about 0.88 and for a 0.6-depth observation about 0.92. Wherever practicable it is advisable to establish the coefficient by defining one or two vertical velocity curves in sections where there is sufficient depth below the ice.

The procedure of placing the meter for velocity observations will be simplified if the percentage depth is determined from the bottom upward regardless of the type of suspension used. The distance that the meter must be raised when the weight or the base plate of the rod is on the bottom is computed by multiplying the effective depth by the desired percentage depth above the bottom and by subtracting from the figure thus obtained the distance from the horizontal axis of the meter to the bottom of the rod or weight.

In subfreezing temperatures where the stage is likely to remain reasonably constant during the measurement, it is advisable to complete all correlated steps in the procedure, such as the determination of distances between verticals, the measurement of depths, and the preparation of forms for notes, before making the velocity observations. In this manner, inconveniences caused by the formation of ice in the meter bearings and the collection of frazil in the meter cups will be appreciably reduced.

The vertical pulsation of water in the holes cut in the ice must be given careful attention in determining depths and velocities. Pulsations of half a foot or more are not uncommon and may cause appreciable error if they are not carefully observed and averaged. Because of pulsations the meter should be held as far upstream as possible when the velocity is being observed. Where pulsations are large,

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[2] Barrows, H. K., and Horton, R. E., Determination of stream flow during the frozen season. U. S. Geol. Survey Water-Supply Paper 187, 92 pp., 1907.

inaccuracies in depths and placement of meter may be reduced by using, as an index, the top of the ice or a rod placed across the hole; or, if the depths are shallow, the L-shaped scale may be used to measure the effective depths directly. It is desirable to observe the revolutions of the current meter over a longer period of time than is usual in open water measurements.

GENERAL PRECAUTIONS

Experience has shown that the following precautions will increase the accuracy of discharge measurements by eliminating sources of error.

Test the meter immediately before and after each discharge measurement by submitting it to a spin test in quiet air. For use in velocities of less than 1 foot per second, the meter should have an initial spin test of at least 2 minutes and should slow down gradually in coming to a stop. Only in streams of high velocity or in streams heavily laden with sand and silt is it advisable to use a meter with a spin test of less than 1 minute.

The current meter should be inspected at frequent intervals. As meters hold to their ratings only when operating freely, it is essential that they be kept in good operating condition at all times.

The cross section of the stream at the place of measurement should be divided into a sufficient number of partial sections so that the measusements of depth will develop an accurate profile of the bed and so that the measurements of velocity may be made close enough to each other for an accurate determination of velocity in each of the partial sections. Where the velocity is not uniformly distributed, a larger number of sections will be needed than where uniformity prevails. The number of necessary verticals will depend therefore upon the roughness of the bed and the variations in the velocities (see p. 68).

The stop watch used in timing velocity observations should be checked frequently, as accurate timing is obviously essential.

In slow and irregular velocities, if the stage is not changing rapidly, observe the revolutions of the current meter over a longer period of time than usual.

SUSPENSION OF CURRENT METER AND MEASUREMENT OF DEPTH

Measurement of depth at each of the selected verticals in the measuring section is essential, both in determining the area of the cross section and in the correct placing of the meter. The method used in measuring depth depends largely on the manner in which the meter is suspended or supported. The depth must be the true vertical distance from the surface of the water to the bed of the stream.

Measurements of depth and velocity at each vertical are usually made in successive operations. For this reason the following discussion not only includes the various methods of suspending the meter and measuring the depths but also describes briefly the assembly of the equipment for each type of meter suspension.

ROD SUSPENSION

The determination of depths and velocities by a current meter supported on a graduated rod is restricted generally to measurements made by wading; to measurements made from complete ice cover where depths and velocities are not excessive; to measurements made from a boat; and to measurements made in canals, flumes, and narrow streams that are spanned by footbridges placed just above the surface of the water. The rod suspension cannot be used where the velocity is so great that the rod and meter cannot be held in position by the engineer. A rod 4 or 5 feet long attached to a base plate is used for the ordinary wading measurement. The base plate largely prevents the rod from sinking into the stream bed or from entering narrow crevices in the bed that are not representative of the general profile of the measuring section, and thus it eliminates certain tendencies to obtain soundings that are too large. The rod may be round, half an inch in diameter, in one piece or made up of 1-foot or 1½-foot sections joined together. Flat rods of various designs are used also (see pl. 26, *B*). The current meter, with a sliding support inserted between the tailpiece and the meter, is mounted on the rod. Care must be taken to observe that the bucket wheel rotates in a horizontal plane at right angles to the rod. This sliding support is so designed that when unclamped it can be easily moved along the rod, and when clamped it will hold the meter firmly at the desired position.

Occasionally there are places where mud or shifting sand at the measuring section makes it impossible to rest the base plate of the rod on the bed of the stream, or where the collection of ice on the rod is sufficient to interfere with the placement of the meter. For these conditions it may be necessary to dispense with the base plate and to hold the rod in position by hand, first clamping the meter at a selected position on the rod.

Revolutions of the current-meter rotor are electrically indicated through a telephone head set (p. 207) connected to two small insulated wires of suitable length, one leading to a binding post on the head of the meter and the other to the attachment cap on top of the rod or to the hanger screw on the meter. A small dry battery is introduced into the circuit to provide current for actuating the telephone receiver, but satisfactory results can be obtained without this battery.

Depths are measured by reading the position of the water surface on the rod when the base plate rests on the bed. In high velocities the water will tend to pile up on the upstream face of a rod and to draw down on the downstream face, so that the observations of depths may be in error if this fact is not given proper consideration. Under this condition, the accuracy of the measurement of depth may be increased by standing at one side of the meter and viewing the rod across and at right angles to the direction of flow and by observing the position of the water surface on the side of the rod. For very small depths it is advisable to slide the meter clear of the water before the sounding is made in order to eliminate surface disturbance caused by the current-meter bucket wheel. Although the smallest graduation on the rod is one-tenth of a foot, shallow depths should be read to half-tenths or hundredths of a foot if the smoothness of the measuring section will permit. A folding rule graduated to hundredths of a foot is convenient for measuring shallow depths.

HAND-LINE SUSPENSION

The current meter and sounding weight are generally suspended from a hand-line if accurate soundings are obtainable with a 15- or a 30-pound weight. This procedure is adaptable for measurements made from a bridge, a cableway, a boat, or ice; but its use is limited to small depths and comparatively low velocities. If vertical angles are too large to be neglected and if the required weight is more than can be conveniently manipulated by hand, hand-line suspension should be replaced by reel suspension.

A hand-line consists of joined sections of two types of cable, one section for use above the surface of the water and the other sections for use below. For ease in handling, the upper part is a rubber-covered cable about 3/8-inch in diameter, which contains two insulated copper strands. The underwater part is usually a strong, flexible wire cable about 1/10-inch in diameter, which is used to reduce to a minimum the resistance offered to the moving water. The cable has an insulated copper core for use with the two-way electrical circuit. A small reel where the two sections are joined permits adjustment of the underwater part to the depth of the stream. This reel also provides a means of electrically connecting the two cables. Occasionally a square knot is used to join the cables, but it provides no means for readily adjusting the underwater length. At the upper end of the hand-line the copper strands are attached to the terminals of a connection plug, which permits ready connection to the telephone head set. The hanger, to which the meter and sounding weight are fastened, is discussed below, as are also the small connector that joins the measuring line to the hanger and the manner in which the meter is electrically connected to the measuring line.

REEL SUSPENSION

The practicable assembly for measuring high velocities and great depth is a current meter and sounding weight suspended from a reel and line. This type of suspension is convenient and simple and utilizes sounding weights that are too heavy for use on a hand-line.

A reel suspension is most commonly used from a cableway or bridge, although it is adaptable for measurements made from a boat or an ice cover. Suitable apparatus for supporting the reel and for guiding the measuring line must be provided for each of these types of measurements.

A typical reel assembly consists essentially of a drum of known diameter, around which the measuring line is wound; of a counter calibrated to the diameters of the drum and cable for measuring the depths; and of a crank and brake with which to operate the reel. These parts may be assembled and supported on a base in a portable unit. The measuring line is a small metal cable, the diameter of which depends on the strength needed. It has an insulated copper-strand core, which makes possible the completion of a two-way electrical circuit. A small connector fastened to the lower end of the cable provides for its attachment to the weight hanger. Before the line is fastened to the connector the end of the copper-strand core is freed so that it may be readily joined to another small insulated wire strand of sufficient length to reach the binding post on the meter.

A typical hanger from which the sounding weight and meter are suspended is designed to permit the placement of the current meter in certain definite positions relative to the bottom of the sounding weight. These positions, depending on the type of hanger used, are such that when a 15-pound sounding weight is used the horizontal axis of the meter is 0.5, 0.7, 0.9, or 1.0 foot above the bottom of the weight; when a 30-or 50-pound weight is used the axis of the meter is 0.7, 0.9, or 1.0 foot above the bottom of the weight; and when a 75-, 100-, or 150-pound sounding weight is used the axis of the meter is 1.0 foot above the bottom of the weight.

SINGLE-CONDUCTOR SYSTEM WITH HAND-LINE OR REEL SUSPENSIONS

Although a two-conductor electrical system is generally used with either a hand-line or reel assembly, a single-conductor system that includes a ground return may be adaptable for emergency or general practice. In an emergency the two-conductor system can be converted into a single-conductor system by electrically insulating the weight hanger from the measuring line and electrically connecting the measuring line to the binding post on the meter head. If the single-conductor system is used in general practice, the measuring line may be the same as used for the two-conductor system, or it may be a smaller wire cable or strand without the insulated copper core.

If the single-conductor system is used from a cableway the electrical circuit may be completed through the cable, provided the anchorages are well grounded. The battery and head-set assembly must then have an extension consisting of two insulated wires, one leading from the measuring line to the battery and head-set assembly and the other from this assembly to the cableway. A battery clip or small thin sheet of lead or zinc attached to the end of the wire that is to contact the cableway facilitates the completion of the circuit. In some situations a short piece of copper wire permanently attached to a cable-car hanger bolt will suffice if the bolt is insulated from the reel. The battery clip or sheet of metal, when gripped about the cableway by hand, will make a satisfactory contact if the cableway is free from paint and rust; otherwise the wire used to ground the circuit should be attached by means of a sharp instrument that will insure a good contact. A small radio ground clamp with a pointed setscrew is convenient for this purpose. If the return circuit cannot be completed through the cableway, a ground attached to the battery and head-set assembly and extending beneath the surface of the water may be substituted. A piece of copper or zinc fastened to the submerged end of this line is usually needed to improve the ground.

In using a single-conductor system from a bridge the return circuit is commonly made with the ground line as mentioned above, although sometimes it is possible to complete the circuit through a metal handrail or drain pipe effectively grounded. Bridge measurements by this system should be made from the downstream side to avoid possible short circuits from interfering bridge members. The wire used to contact the handrail or drain pipe should also be attached to a sharp instrument so that any rust or paint on the surface may be easily penetrated. If the metal, particularly on the handrail, cannot be reached without marring its surface, a wire the length of the bridge and grounded at the ends can be used to complete the circuit.

The successful application of the single-conductor system when using a battery as a source of electrical current depends largely on the depth of the stream and the chemical composition of the water. As the leakage in the electrical circuit increases with the depth of water, the identification of the revolutions made by the rotor of the current meter becomes more difficult with increasing depth. Basic or acidic water assures better conductivity than relatively pure water. At times this system may yield favorable results without a dry cell; but a dry cell in the circuit is recommended, with the polarity reversed when necessary, as explained below.

A. CURRENT METER SUPPORTED ON A ROD.

B. REEL AND SLED EQUIPMENT USED ON MISSISSIPPI RIVER AT ST. PAUL, MINN.

DISCHARGE MEASUREMENT THROUGH ICE COVER.

ELECTRICAL HOOK-UP WITH DRY CELL ELIMINATED

Without a dry cell in the circuit, the source of electromotive force may be considered as a wet voltaic cell in which the meter assembly, or a part of it, acts as one electrode; a trailing piece of metal, ground cable, or insulated part of the meter assembly acts as the other electrode; and the river water acts as the electrolyte. This method was developed by the Geological Survey in its Montana district and was later used in its California district, where B. C. Colby and H. M. Orem conducted extensive experiments on its adaptability, with the meter supported on a rod, by a hand line or by a reel, using either the two-conductor or the single-conductor system. It was found that the current in the wet voltaic cell, for a given hook-up and depth, has a definite direction, which may be the same or the opposite of that supplied by the dry-cell battery. As the condition of a wet voltaic cell is also in effect when a dry cell is used in a single-conductor system, it is desirable that the dry cell be connected so as to aid and not oppose the wet call action. In some single-conductor hook-ups there is a definite but narrow zone in which no meter signals will be heard. This may occur either with or without a dry cell in the circuit.

In studying the action of the wet voltaic cell alone with various hook-ups it was found by Colby and Orem that the current through the telephone receiver reversed as the meter was lowered from the top to the bottom of the stream, and around the point of reversal was a zone of weak signals. A strength of signal that does not vary appreciably with depth can be had by increasing the size of the zinc electrode by attaching an insulated piece of zinc to the back of the sliding support or by using an insulated meter tailpiece constructed of zinc, these additions to the zinc electrode being connected to the galvanized suspension cable above the insulator on the meter hanger. The hook-up for this arrangement, except the head-set assembly and the use of an additional wire to connect the insulated hanger or tailpiece with the measuring line, is the same as for the single-conductor system.

A convenient head-set assembly for this hook-up, which is adaptable to rod, hand-line, or reel suspension, is as follows: A 7-foot length of small rubber-covered two-strand extension cable is connected with the head-set and the insulation removed from the free ends for about 6 inches. These free ends are made into terminals by coating one end with solder and attaching the other to a small galvanized or zinc battery clip.

When this telephone assembly is used with rod suspension one of the loose terminals is attached to the binding post of the meter contact chamber and the other is clipped to an insulated tailpiece or to the sliding support. The electrolytic action between the battery clip and the meter assembly will usually produce sufficient current to give satisfactory signals. If at times it is found necessary to strengthen the signals, this can be done by resetting the battery clip or by fixing a strip of zinc around the insulated sliding support to provide additional electrode area. The battery-clip electrode and insulation are placed behind the rod on the meter assembly so that there will be negligible interference with the flow past the meter.

When this assembly is used with hand-line or reel suspension from a bridge or cableway, the loose terminal of the telephone cable is fastened to the terminals of the hand-line or to the frame of the sounding reel. If the usual two-conductor rubber-covered cord is used for a hand-line, it is convenient to twist the two strands together and attach them to a battery clip, which in turn may be clamped to the loose terminal of the head-set cable. The battery-clip terminal of the head-set cable is then fastened to the best available ground, which is usually the cableway or handrail. For this purpose it is desirable to have about 3 feet extra of insulated cable, stripped of insulation at one end and attached to a battery clip at the other, for use as an extension from the sounding reel or as a ground wire when a direct contact is made with the cableway or metal bridge rail.

MEASUREMENT OF VELOCITY

In determining the mean velocity in a section used in making a discharge measurement, the mean velocity normal to the measuring section must be measured at each vertical. This is done with the current meter by measuring the velocity at specific points in the vertical. The number and position of the selected points with reference to the total depth identifies the method used in measuring the velocity.

After the current meter is placed at a selected point in the vertical it should be permitted to become adjusted to the current before the observation of velocity is started. The time required for such adjustment is usually only a few seconds if velocities are reasonably high. In low velocities, particularly if the current meter is suspended by a cable, this adjustment may require a minute or more. The failure of the operator to wait for full adjustment may lead to inaccurate results.

The number of revolutions made by the rotor of the current meter is ordinarily observed over a period of 40 to 70 seconds except for velocities less than 1 foot per second, in which a longer run is usually taken. Observation of time to the nearest half-second is usually sufficient. The observed number of revolutions and the corresponding time are converted into velocity in feet per second by use of a rating table for the current meter.

VERTICAL VELOCITY-CURVE METHOD

In the vertical velocity-curve method a series of velocity observations at points well distributed between the surface of the water and the bed of the stream is made at each of the selected verticals. If there is considerable curvature in the lower part of the vertical velocity curve, as indicated by the intervals between revolutions of the current-meter rotor, it is advisable to space more closely the observations in that part of the depth. The velocities measured in each vertical will, when plotted against depth, define the vertical velocity curve from which the mean velocity in that vertical can be determined. In order that vertical velocity curves at different stations may be readily comparable, it is customary to plot the curves with proportional parts of the depth as ordinates. Typical vertical velocity curves at stream-flow measurement stations are shown in figure 1.

Studies of vertical velocity curves made under widely different hydraulic conditions show that their shapes usually correspond to part of a parabola, the axis of which is parallel to the surface of the water, coincides in general with the filament of maximum velocity, and is generally between the surface and one-third of the depth. The velocity decreases gradually upward from the axis to the surface and downward nearly to the bottom, where the change becomes more rapid as a result of the friction and turbulence produced by the bed. For the same mean velocity and different depths of water, the curvature of the vertical velocity curve decreases as the depth increases. For the same depth and different velocities, the curvature increases as the velocities increase.

In making observations of velocity for constructing vertical velocity curves, three of the points selected for observations should be at distances below the surface equal to 0.2, 0.6, and 0.8 of the total depth, so that the results obtained by the vertical velocity curve method may be compared directly with those obtained by the two-point and 0.6-depth methods. Observations made near the surface should always be checked, because irregularities in the movement of the water are likely to occur in that part of the vertical and because the current meter is erratic in its action if it is only partly submerged. Velocity observations at points in the vertical frequently give erratic results, owing to pulsations and surges affecting the distribution of velocities.[3] These pulsations or surges vary the velocity of the water in cycles ranging

[3] Murphy, E. C., Accuracy of stream measurements: U. S. Geol. Survey Water-Supply Paper 95, pp. 28–32, 1904.

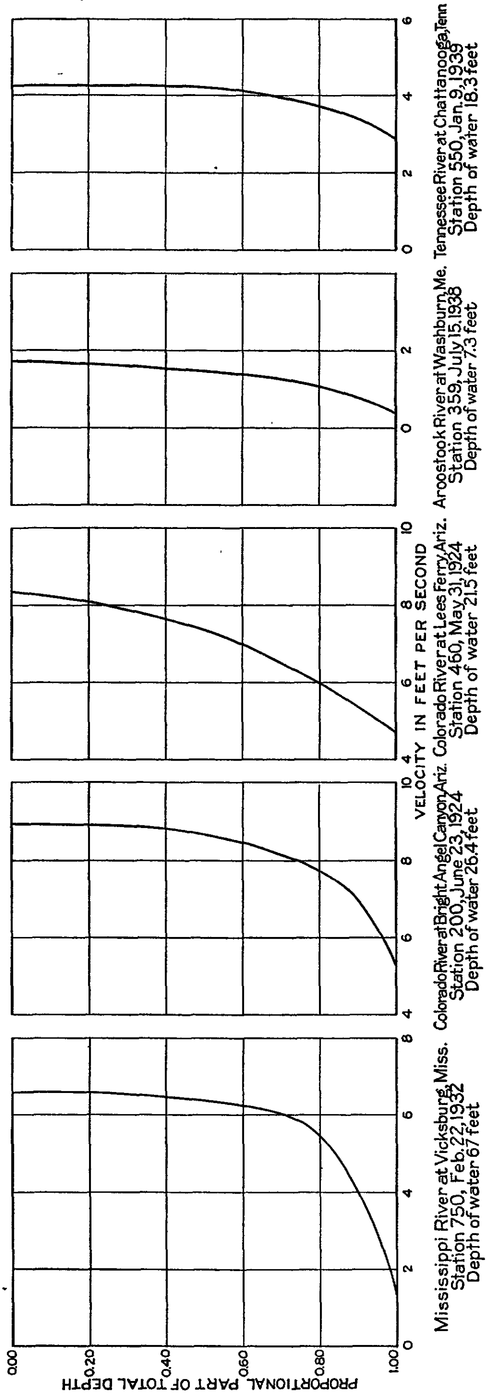

FIGURE 1.—Typical vertical velocity curves.

from a few seconds to several minutes, depending on the nature of the stream. To obtain a reliable vertical velocity curve under such conditions, it is necessary either to run each velocity observation long enough to average the effects of the pulsation and surge or to determine the velocity limits of the cycles. These limits may be approximated either by taking several short velocity observations while the meter is at one position in the vertical or by increasing the number of observation points in the vertical while decreasing the time required for each observation, so that two or more velocity readings are obtained within the same phase of the cycle at two adjacent depths. Although either of these procedures may result in reducing the probable accuracy of an individual velocity observation, the information thus obtained is useful in systematically weighting the individual velocity determination when constructing the vertical velocity curve.

In constructing the vertical velocity curve the velocity observations are plotted with the velocities as abscissas and depths below the water surface as ordinates. The mean velocity is determined from a smooth curve drawn as nearly as possible through the plotted points. With a sufficient number of velocity observations available to define a velocity curve for each vertical, the discharge may be determined by plotting on a graph of the cross section the velocities at different depths as indicated by the vertical velocity curves. Lines of equal velocity are then drawn and the areas between them are measured by means of a planimeter. The sum of the products of the area and the average velocity for each area is the discharge in the section. This method of determining discharge is described in textbooks on hydraulics.

The vertical velocity-curve method is valuable in determining coefficients for application to the results obtained by other methods. The method is not generally adapted to the making of routine discharge measurements, chiefly because the apparently increased precision thus obtainable may be more than offset by errors resulting from changes in stage during the longer period of time needed for making such measurements.

TWO-POINT METHOD

In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of these two observations is taken as the mean velocity in the vertical.

The two-point method is based on many studies of actual observations and also on the theory that the vertical velocity curve corresponds to part of a parabola with axis horizontal at the point of highest velocity, for which it may be mathematically demonstrated that the average of the velocities at 0.2114 and 0.7886 of the depth is equivalent to the mean velocity.[4] Studies of many vertical velocity curves made for different depths, velocities, and conditions of stream bed support this theory. Experience has shown that this method gives more consistent and accurate results than any of the other methods, except the vertical velocity curve method when it is used under measuring conditions of constant stage and steady flow. Because of the support given the two-point method by both theory and practice, it is generally used by the Geological Survey in current-meter measurements of discharge.

There are, however, a few situations where correct results are not obtainable by the use of the two-point method. One situation relates to the use of the vertical-shaft cup-type current meter, which underregisters near the surface and near the bed of the stream, so that for shallow depths a coefficient greater than unity may be required, as shown by Pierce.[5] The coefficient may vary with both depth and velocity. With the cup-type meter it is generally not advisable to use the two-point method in depths of less than about 2.0 feet unless a coefficient is applied. Occasionally, conditions, may necessitate the application of a coefficient less than unity to obtain the correct discharge, as for example in deep water immediately above a dam where the measuring section is sloping upward. Before any coefficient is applied, however, its applicability should be thoroughly established by vertical velocity curves for the entire range of conditions covered by the measurement or by such other data as are available.

SIXTH-TENTHS-DEPTH METHOD

In the 0.6-depth method an observation of velocity is made in each of the selected verticals at 0.6 of the depth below the surface. This method is based on the theory that the vertical velocity curve corresponds to part of a parabola with the maximum abscissa within the upper third of the ordinate representing the depth. On this basis, the mean abscissa lies between 0.58 and 0.67 of the depth below the surface. If the maximum abscissa is in the upper fourth of the measured depth, the 0.6-depth ordinate is very nearly the mean. Although a large percentage of velocity curves that have been studied indicate that the mean velocity in the vertical is at approximately 0.6 of the depth below the surface, experience on

[4] Pardoe, W. S., Methods of stream gaging: *Eng. News*, vol. 75 p. 889, 1916; Liddell, W. A., Stream gaging, pp. 39–40, 1927; Hoyt, John C., The use and care of the current meter as practiced by the United States Geological Survey: Am. Soc. Civil Eng. Trans., vol. 66 (1910), p. 97 and 110 (discussion by H. K. Barrows).

[5] Pierce, C. H., Performance of current meters in water of shallow depth: U. S. Geol. Survey Water-Supply Paper 868–A, pp. 35, 1941.

certain streams, particularly those of great depths or with smooth beds, has shown that the results obtained by this method tend to be slightly greater than those obtained by the two-point method. Under those circumstances it is possible that the maximum abscissa for several of the selected verticals in the measuring section may be more than one-fourth of the depth below the surface. Laboratory investigations of performance of current meters in water of shallow depth indicate that vertical-axis cup-type current meters when used at 0.6 of the depth give results that are too small (requiring coefficients greater than unity) for velocities of 0.3 foot per second and less and also where depths are 0.5 foot or less.

Although the 0.6-depth method generally gives fairly satisfactory results, nevertheless as the variations of individual observations may be somewhat greater than those shown by the two-point method it is used by the Geological Survey only if the two-point method is found impracticable because of insufficient depth or for other reasons such as a rough stream bed or aquatic growth.

TWO-TENTHS-DEPTH METHOD

The 0.2-depth method consists of an observation of velocity in each of the selected verticals at 0.2 of the depth below the surface and is used only when the depths, velocities, or other causes do not permit the use of the methods previously described. The depth is obtained from a standard profile of the measuring section or, if the cross section is not permanent, from soundings made before the velocity observations are taken or as soon thereafter as possible. Discharges are determined in the following manner: The measurement is computed by using the 0.2-depth velocity observations without coefficients as though each was a mean in a vertical. The approximate discharge thus obtained (called for convenience the 0.2-depth discharge) divided by the area of the measuring section gives the weighted mean value of the 0.2-depth velocity. Studies of many measurements made by the two-point method show that for a given measuring section the relation between the mean 0.2-depth velocity and the true mean velocity either remains constant or varies uniformly with the stage. In either case this relation may be determined for a particular 0.2-depth measurement by recomputing measurements made at the site by the two-point method to obtain the observation values of the 0.2-depth discharge and the mean 0.2-depth velocity. The plotting of the true discharge and the 0.2-depth discharge as coordinates for each measurement will give a discharge-relation curve, and the plotting of the mean velocity and the mean 0.2-depth velocity as coordinates will give a velocity-relation curve.

These curves may be extended to determine the true discharges corresponding to the 0.2-depth discharge either by reading directly from the discharge-relation curve or by multiplying the true mean velocity obtained from the velocity-relation curve by the area of the measuring section.

It has been found that many of these relation curves are practically straight lines passing through the point of origin, thus showing an approximately constant relation between the 0.2-depth values and the true values of mean velocity and discharge. However, where backwater or overflow conditions affect the flow or where the distribution of the flow changes decidedly with the change in stage, the discharge-relation curve may give a more accurate extension. If the measuring section shifts materially and if the velocity distribution is not seriously disturbed by change in stage, an extension of the velocity-relation curve may be the more reliable. It is therefore advisable to plot both these relation curves and select for extension the one more nearly approaching a straight line.

Results obtained by this method are reliable provided the discharge relation and the velocity relation do not change materially between the time of definition of the curves and the time when the measurement is made. The relation curves for shifting channels should be checked frequently by data obtained from measurements made by the two-point method.

The 0.2-depth method may be advantageously used under conditions where high velocity, floating ice or debris, or inadequate measuring equipment makes it impracticable to obtain reliable velocity observations at 0.8 of the depth; also at times when the stage is changing so rapidly that it is desirable to complete a measurement in as short a time as possible. This method is generally considered superior to the subsurface method because the relation between the mean 0.2-depth velocity and the mean velocity is usually more nearly constant and more easily determined than the relation between the mean subsurface velocity and the mean velocity. It is also useful in studying the accuracy of a measurement made by the two-point method, especially if the uncertainty relates to the 0.8-depth observations. The method should not be used if the depths are so small as to bring the meter close to the surface of the water. Appreciable errors in velocity because of uncertainty in regard to placing the meter at the exact 0.2-depth position are not likely to occur, even if soundings are roughly determined, because most vertical velocity curves for depths where this method might be required show little curvature in the vicinity of the 0.2-depth point. The results obtained by this method are considered more reliable than those based on coefficients determined by vertical velocity curves occasionally made at the station.

THREE-POINT METHOD

In the three-point method the velocity observations, which are made at 0.2, 0.6, and 0.8 of the depth below the surface, combine the two-point and the 0.6-depth methods. In this method the 0.2- and 0.8-depth observations may first be averaged and the result averaged with the 0.6-depth observation or, if it is desired to give more weight to the mean of the 0.2-depth and 0.8-depth observations, the arithmetical mean of the three observations may be used. The two-point method is considered more reliable than the 0.6-depth method; therefore, in using the three-point method it is probable that additional weight should be given the mean of the 0.2-depth and 0.8-depth observations to the extent of using the arithmetical mean of the observations at the three points. The method is used principally for comparison with other methods, although its use may be desirable if velocities appear to be abnormally distributed in a vertical or if the 0.2-depth observation is near the surface and the 0.8-depth observation is made in that part of the depth where the velocity is seriously affected by friction or by turbulence produced by the stream bed. The method is based on the assumption that the mean velocity obtained by the two-point method alone is too small and by the 0.6-depth method alone is too great, and that an average of the results obtained by the two methods represents more nearly the true value. Its use is recommended only for unusual conditions where other methods are not entirely applicable.

SUBSURFACE METHOD

In the subsurface method a velocity observation is made in each of the selected verticals at a uniform depth below the surface. This depth should be at least 2 feet below the surface and preferably at a greater depth for deep, swift streams in order to avoid the effect of surface disturbances. The measured velocity must be multiplied by a coefficient to reduce it to the mean velocity in the vertical. Whether this coefficient should be applied to each velocity observation or to the computed discharge for the measurement would depend upon information obtained from vertical velocity curves. If the vertical velocity curves are well distributed across the section and show variable coefficients, a higher degree of accuracy will be obtained if the coefficients are applied separately to each measured velocity by using the coefficient deemed most applicable to each vertical. If the coefficients are fairly uniform, an average coefficient can be applied to the total discharge. It should be kept in mind that these coefficients are likely to vary with the stage, depth, and position in the measuring section.

As it is generally difficult to determine accurately the exact coefficients for use with the subsurface method, results of high accuracy cannot be expected by this method. It should be employed only where it is impracticable to obtain reliable soundings or where the 0.2-depth method is not adaptable.

INTEGRATION METHOD

In the integration method the current meter is lowered and raised at a uniform rate in each of the selected verticals in the measuring section. The number of revolutions is timed over two or more complete cycles, and the result when converted into velocity is the mean velocity for the vertical. This method may give accurate results if sufficient care is used in its application. However, as vertical movement of a vertical-shaft cup-type meter affects the motion of the rotor to some extent, the method is not recommended for general use. In order that the vertical movement of the meter shall not seriously affect its rotation, the rate at which the meter is raised and lowered must be limited to a small percentage of the average velocity of the water. The integration method requires additional precautions on the part of the engineer and possibly additional assistance, which are added reasons why it is not particularly adaptable to routine stream gaging. Its only use by the Geological Survey is for purposes of comparison.

ONE-POINT CONTINUOUS METHOD

In the one-point continuous method the velocity is measured continuously at a point in a selected vertical with a current meter which is provided with a recording apparatus. The position of this point, which varies with the depth, should be in the region of the higher velocities and should be between 0.3 and 0.6 of the depth below the surface to insure the best results. This measured velocity is averaged, usually for 24-hour periods, and a coefficient is applied to obtain the average mean velocity for the period.

The coefficient to be used in obtaining the mean velocity is determined from discharge measurements made at different rates of flow at the section in which the recording current meter is placed. The revolutions registered by the recording current meter are observed for the actual time of each discharge measurement and converted into average velocity in feet per second for the period of observation. The coefficient is then computed by dividing the mean velocity obtained from the discharge measurement by the average velocity measured by the recording meter in the selected position. The coefficient may vary for different rates of flow if the distribution of velocity in the measuring section changes materially. Where such a condition prevails, a velocity-relation curve is developed by plotting the mean velocity for the discharge measurement as the ordinate and the average velocity measured at the selected point as the abscissa.

The accuracy obtained by this method may be of a high order, but its adaptability is so limited that its use is restricted to places where the discharge is largely a function of the slope and where the variation in stage is relatively small, such as in some canals, tailraces, flumes, and lake outlets. The coefficients or velocity-relation curves used in this method can generally be defined easily and accurately, and a record of the revolutions made by the recording current meter can be obtained either by an electrically-controlled counter or by graphs made on a time chart. In the application of this method the operator must be sure that the recording current meter is always placed at the selected depth, that it is kept free of algae and floating debris, and that its mechanical operation is uniformly maintained. This method has been used by the Boston district of the Survey in determining daily discharge at the outlet of Lake Winnepesaukee at Lakeport, N. H.

MEASUREMENTS OF STREAMS THAT ARE DEEP AND SWIFT

Measurements of depth and velocity of streams that are both deep and swift require additional precautions and special equipment. Accurate determinations of depth and of mean velocity in the verticals are of primary importance in obtaining an accurate measurement of discharge because the discharge is the product of the area and the velocity; so an error in the measurement of either would result in a corresponding error in the discharge measurement. Those parts of the cross section that have the greatest depths and velocities usually carry the major part of the total discharge, and it is in those sections that accurate soundings are most difficult to obtain.

Improvements in cable cars, booms, reels, sounding weights, and suspension lines have increased the accuracy and efficiency of stream-measurement work, particularly on streams of high velocity and great depth. There is, however, a practical limit to the extent to which the difficulties caused by high velocities and great depths can be overcome by the use of the available equipment, and when that limit has been reached under the usual methods of operation, other methods must be used to increase the accuracy of soundings and the precision of placement of the current meter.

In rivers of high velocities and great depths where the current meter and weight drift downstream from the vertical, the accuracy of the measurement may be increased by measuring the angle made between the line and the vertical and by applying corrections to the indicated depth to offset the effect of the inclination of the line above the water surface and the effect of curvature of the line between the surface and the weight. Thus it is possible not only to obtain a more accurate determination of depth but also to place the meter more nearly in the desired position. The use of tags or markers placed at known intervals on the measuring line will expedite measurements in comparatively deep water under certain conditions.

In streams of high velocity and comparatively shallow depth the use of stay-line equipment will be of assistance in measuring the depth and in placing the meter.

MEASUREMENT OF DEPTH

Measurements of depth made by the usual methods are too large if the depth and velocity are such as to cause the weight and line to drift downstream from the vertical. The downstream drift of the weight and line will place the weight downstream from the vertical when it reaches the river bed, causing the sounding line to be curved from the water surface to the weight and to be inclined above the surface. The length of line under water is therefore greater than the vertical depth, and the measured line includes the effect of the inclination of the line above the water. The excess in length of the curved line over the vertical depth is indicated by the vertical angle made by the line at or above the water surface, and the excess in apparent depth caused by inclination of the line above the water is a function of the same angle and the vertical distance between the surface and the point of suspension of the line. Therefore the vertical angle of the line at or above the surface and the vertical distance from the surface to the point of suspension of the line must be measured as additional observations in the process of obtaining a correct measurement of depth.

The error that may occur in such a measurement of depth is illustrated in figure 2, which shows the position of a sounding weight and line where the depth and velocity are such as to cause the equipment to drift downstream. The error consists of two parts if the structure supporting the equipment is not at the water surface. If the index on the measuring reel is read when the sounding weight is at the surface (*b*) and then read again when the weight is at the river bottom (*e*), the distance (*ce*) represents the amount of line let out by the reel during the process of lowering the weight from the surface to the river bottom. This distance (*ce*) may be called the observed depth. The error in the observed depth consists of (1) the distance (*cd*) above the water, and (2) the difference between the wet line depth (*de*) and the vertical depth.

The correction above the water surface (*cd* on the diagram), commonly called the air correction, depends upon the vertical angle of the line and the height (*ab* on the diagram) of the apex of the vertical angle above the surface. This correction is obtained by using the exsecant of the vertical angle. Computed figures for this correction for even-numbered angles between 4° and 36° and vertical heights between 10 and 100 feet are shown in table 1. To apply this table, the vertical angle and the height of the apex of the angle above the water surface at different stations along the cableway

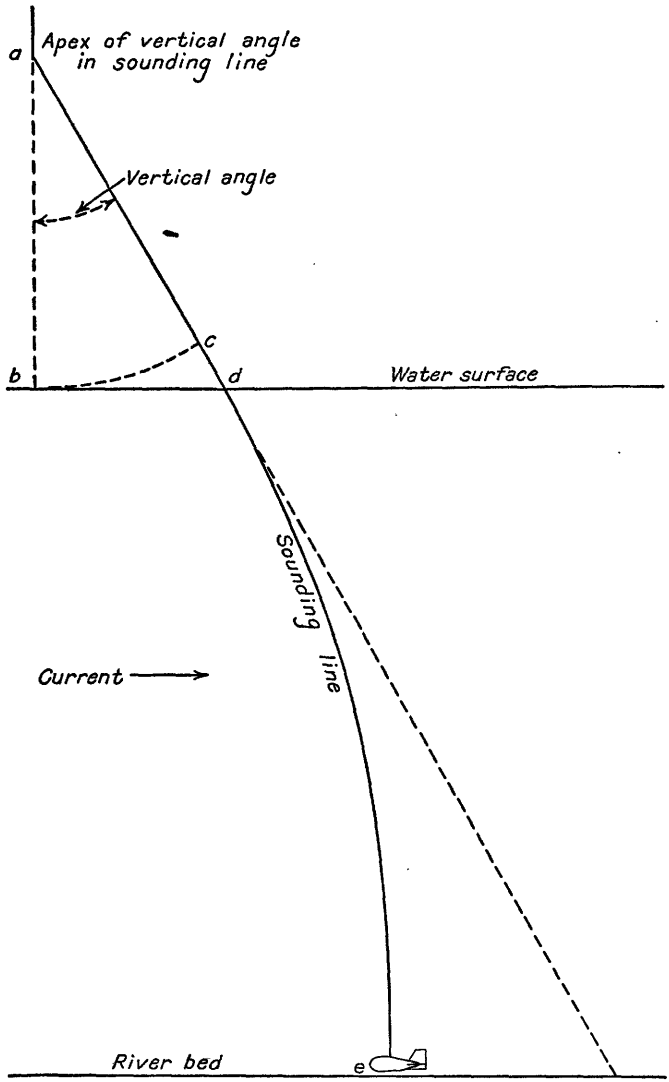

FIGURE 2.—Position of a sounding weight and line in deep, swift water. See text for explanation of letters.

or the bridge must be known, but the error will be small if the height is determined to the nearest half-foot. The corrections shown in tables 1 and 2 need be applied only to the nearest tenth of a foot; hundredths are given to aid in interpolation for odd degrees and lengths of line.

TABLE 1.—*Air-correction table, giving difference, in feet, between vertical length and slant length of sounding line above water surface for vertical angles between 4° and 36°*

Vertical length (feet)	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	Vertical length (feet)
10	0.02	0.06	0.10	0.15	0.22	0.31	0.40	0.51	0.64	0.79	0.95	1.13	1.33	1.55	1.79	2.06	2.36	10
12	.03	.07	.12	.19	.27	.37	.48	.62	.77	.94	1.14	1.35	1.59	1.86	2.15	2.47	2.83	12
14	.03	.08	.14	.22	.31	.43	.56	.72	.90	1.10	1.32	1.58	1.86	2.17	2.51	2.89	3.30	14
16	.04	.09	.16	.25	.36	.49	.64	.82	1.03	1.26	1.51	1.80	2.12	2.48	2.87	3.30	3.78	16
18	.04	.10	.18	.28	.40	.55	.73	.93	1.16	1.41	1.70	2.03	2.39	2.78	3.23	3.71	4.25	18
20	.05	.11	.20	.31	.45	.61	.81	1.03	1.28	1.57	1.89	2.25	2.65	3.09	3.58	4.12	4.72	20
22	.05	.12	.22	.34	.49	.67	.89	1.13	1.41	1.73	2.08	2.48	2.92	3.40	3.94	4.54	5.19	22
24	.06	.13	.24	.37	.54	.73	.97	1.24	1.54	1.88	2.27	2.70	3.18	3.71	4.30	4.95	5.67	24
26	.06	.14	.26	.40	.58	.80	1.05	1.34	1.67	2.04	2.46	2.93	3.45	4.02	4.66	5.36	6.14	26
28	.07	.15	.28	.43	.63	.86	1.13	1.44	1.80	2.20	2.65	3.15	3.71	4.33	5.02	5.77	6.61	28
30	.07	.17	.29	.46	.67	.92	1.21	1.54	1.93	2.36	2.84	3.38	3.98	4.64	5.38	6.19	7.08	30
32	.08	.18	.31	.49	.71	.98	1.29	1.65	2.05	2.51	3.03	3.60	4.24	4.95	5.73	6.60	7.55	32
34	.08	.19	.33	.52	.76	1.04	1.37	1.75	2.18	2.67	3.22	3.83	4.51	5.26	6.09	7.01	8.03	34
36	.09	.20	.35	.56	.80	1.10	1.45	1.85	2.31	2.83	3.41	4.05	4.77	5.57	6.45	7.42	8.50	36
38	.09	.21	.37	.59	.85	1.16	1.53	1.96	2.44	2.98	3.60	4.28	5.04	5.88	6.81	7.84	8.97	38
40	.10	.22	.39	.62	.89	1.22	1.61	2.06	2.57	3.14	3.79	4.50	5.30	6.19	7.17	8.25	9.44	40
42	.10	.23	.41	.65	.94	1.29	1.69	2.16	2.70	3.30	3.97	4.73	5.57	6.50	7.53	8.66	9.91	42
44	.11	.24	.43	.68	.98	1.35	1.77	2.26	2.82	3.46	4.16	4.95	5.83	6.81	7.88	9.07	10.39	44
46	.11	.25	.45	.71	1.03	1.41	1.85	2.37	2.95	3.61	4.35	5.18	6.10	7.12	8.24	9.49	10.86	46
48	.12	.26	.47	.74	1.07	1.47	1.93	2.47	3.08	3.77	4.54	5.40	6.36	7.43	8.60	9.90	11.33	48
50	.12	.28	.49	.77	1.12	1.53	2.02	2.57	3.21	3.93	4.73	5.63	6.63	7.74	8.96	10.31	11.80	50
52	.13	.29	.51	.80	1.16	1.59	2.10	2.68	3.34	4.08	4.92	5.86	6.89	8.04	9.32	10.72	12.28	52
54	.13	.30	.53	.83	1.21	1.65	2.18	2.78	3.47	4.24	5.11	6.08	7.16	8.35	9.68	11.14	12.75	54
56	.14	.31	.55	.86	1.25	1.71	2.26	2.88	3.59	4.40	5.30	6.31	7.42	8.66	10.03	11.55	13.22	56
58	.14	.32	.57	.89	1.30	1.78	2.34	2.98	3.72	4.55	5.49	6.53	7.69	8.97	10.39	11.96	13.69	58

60	.15	.33	.59	.93	1.34	1.84	2.42	3.09	3.85	4.71	5.68	6.76	7.95	9.28	10.75	12.37	14.16	60
62	.15	.34	.61	.96	1.39	1.90	2.50	3.19	3.98	4.87	5.87	6.98	8.22	9.59	11.11	12.79	14.64	62
64	.16	.35	.63	.99	1.43	1.96	2.58	3.29	4.11	5.03	6.06	7.21	8.48	9.90	11.47	13.20	15.11	64
66	.16	.36	.65	1.02	1.47	2.02	2.66	3.40	4.24	5.18	6.25	7.43	8.75	10.21	11.83	13.61	15.58	66
68	.17	.37	.67	1.05	1.52	2.08	2.74	3.50	4.36	5.34	6.44	7.66	9.01	10.52	12.18	14.02	16.05	68
70	.17	.39	.69	1.08	1.56	2.14	2.82	3.60	4.49	5.50	6.62	7.88	9.28	10.83	12.54	14.44	16.52	70
72	.18	.40	.71	1.11	1.61	2.20	2.90	3.71	4.62	5.65	6.81	8.11	9.55	11.14	12.90	14.85	17.00	72
74	.18	.41	.73	1.14	1.65	2.27	2.98	3.81	4.75	5.81	7.00	8.33	9.81	11.45	13.26	15.26	17.47	74
76	.19	.42	.75	1.17	1.70	2.33	3.06	3.91	4.88	5.97	7.19	8.56	10.08	11.76	13.62	15.67	17.94	76
78	.19	.43	.77	1.20	1.74	2.39	3.14	4.01	5.01	6.13	7.38	8.78	10.34	12.07	13.98	16.09	18.41	78
80	.20	.44	.79	1.23	1.79	2.45	3.22	4.12	5.13	6.28	7.57	9.01	10.61	12.38	14.33	16.50	18.89	80
82	.20	.45	.81	1.27	1.83	2.51	3.30	4.22	5.26	6.44	7.76	9.23	10.87	12.69	14.69	16.91	19.36	82
84	.20	.46	.83	1.30	1.88	2.57	3.39	4.32	5.39	6.60	7.95	9.46	11.14	12.99	15.05	17.32	19.83	84
86	.21	.47	.85	1.33	1.92	2.63	3.47	4.43	5.52	6.75	8.14	9.68	11.40	13.30	15.41	17.73	20.30	86
88	.21	.48	.87	1.36	1.97	2.69	3.55	4.53	5.65	6.91	8.33	9.91	11.67	13.61	15.77	18.15	20.77	88
90	.22	.50	.88	1.39	2.01	2.75	3.63	4.63	5.78	7.07	8.52	10.13	11.93	13.92	16.13	18.56	21.25	90
92	.22	.51	.90	1.42	2.06	2.82	3.71	4.73	5.90	7.22	8.71	10.36	12.20	14.23	16.48	18.97	21.72	92
94	.23	.52	.92	1.45	2.10	2.88	3.79	4.84	6.03	7.38	8.90	10.58	12.46	14.54	16.84	19.38	22.19	94
96	.23	.53	.94	1.48	2.14	2.94	3.87	4.94	6.16	7.54	9.09	10.81	12.73	14.85	17.20	19.80	22.66	96
98	.24	.54	.96	1.51	2.19	3.00	3.95	5.04	6.29	7.70	9.27	11.03	12.99	15.16	17.56	20.21	23.13	98
100	.24	.55	.98	1.54	2.23	3.06	4.03	5.15	6.42	7.85	9.46	11.26	13.26	15.47	17.92	20.62	23.61	100

The correction for excess in length of line below the water surface is obtained by the method for determining the true depth of a sounding from the wet-line depth and vertical angle of the line at the water surface, described by F. C. Schenehon,[6] who was formerly assistant engineer in charge of discharge measurements of Niagara River. The method depends on an elementary principle of mechanics: if a known horizontal force is applied to a weight suspended on a cord, the cord takes a position of rest at some angle with the vertical, and the tangent of the vertical angle of the cord is equal to the horizontal force divided by the vertical force due to the weight. If several additional horizontal and vertical forces are applied to the cord, the tangent of the angle in the cord above any point is equal to a summation of the horizontal forces below that point, divided by the summation of the vertical forces below the point.

In applying the above principle to conditions of measurements of depths of flowing water it is assumed that with a properly designed sounding weight the horizontal pressure on the weight in the comparatively still water near the bottom can be neglected. The distribution of total horizontal water pressure along the sounding line is made in accordance with the variation of velocity from surface to bottom. The excess in length of the curved line over the vertical depth is the sum of the products of each tenth of depth and the exsecants of the corresponding angles derived for each tenth of depth by means of the tangent relation of the forces acting below any point.

Table 2, which is taken from Shenehon's report,[7] shows corrections for even-numbered angles between 4° and 36° and wet-line depths between 10 and 100 feet. Corrections for wet-line depth of 100 feet are numerically equal to percentage correction for any depth.

The corrections from table 2, which may be called the water-correction, cannot be ascertained until the air correction has been deducted from the observed depth and the wet-line depth obtained by means of table 1. The air correction is zero when the apex of the vertical angle is at the water surface. The air correction may be nearly eliminated by using tags or markers at selected intervals on the sounding line. This practice is almost equivalent to moving the reel to a position just above the surface and gives a measurement of wet-line depth with small error. The vertical angle of the line at or above the surface must be measured so that the wet-line depth may be reduced to vertical depth by use of table 2.

[6] Shenehon, F. C., in Lydecker, G. J., Survey of northern and northwestern lakes: Ann. Rep. Chief of Engineers, 1900 U. S. Army, pt. 8, Appendix III, pp 5329–5330, 1900.

[7] Shenehon, F. C., op. cit., p. 5330.

The following points concerning the method for determining the vertical depth of the water from the wet-line depth and vertical angle of the line at or above the surface should be kept in mind by users of the method:

1. The weight and line are such that the weight will go to the bottom despite the force of the current.

2. The sounding is made when the weight is at the bottom but entirely supported by the line.

3. Horizontal pressure on the weight when in the sounding position is neglected.

4. The table is general, not for any particular line or wire or sounding weight, provided they are designed so as to offer little resistance to the current, as the vertical angle is a function of the resistance offered by the line and weight.

The correction tables show the amount and rate of variation of the corrections. In each table, for a given vertical angle, the corrections vary directly as the distance—either the distance above water or the wet-line distance. Also in each table, for a given distance, the corrections vary approximately as the squares of the vertical angles. The correction tables show also that, for a given angle, the air and water corrections are about equal when the distance above water is about one-third of the vertical depth. For many gaging stations at which the distance above water is equal to or greater than the depth, air corrections will be necessary for depths and velocities not requiring water corrections.

Soundings made in deep, swift water sometimes have been reduced to vertical depths by applying the cosine of the vertical angle to the measured depth. If the measured depth is the wet-line depth the method will give results that are too small. The reason for this statement is evident from the diagram in figure 2. If the meter line under water continued to the bottom at the same angle as at the surface, the cosine method would give true depth if applied to the wet-line depth, but the wet-line depth (*de*) is shorter than the straight continuation of the line; therefore, application of the cosine of the angle to the wet-line depth gives too small a depth. The error is compensated to some extent if the cosine is applied not to the actual wet-line depth but to the observed depth, which is greater than the wet-line depth by the amount *cd*. As the compensating effect increases with the distance between reel and water surface, it follows that for a certain distance between reel and water surface an application of the cosine to the observed depth (measured at the reel) will give the true depth. For a greater distance, the cosine method will indicate depths that are too large; for a lesser distance, depths that are too small.

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TABLE 2.—*Wet-line table, giving difference, in feet, between wet-line length and vertical depth for vertical angles between 4° and 36°*

Wet line depth in feet	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	Wet line depth in feet
10	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.25	0.30	0.35	0.41	0.47	0.54	0.62	0.70	10
12	.01	.02	.04	.06	.09	.12	.15	.20	.24	.30	.36	.42	.49	.57	.65	.74	.84	12
14	.01	.02	.04	.07	.10	.14	.18	.23	.29	.35	.41	.49	.57	.66	.76	.87	.98	14
16	.01	.03	.05	.08	.12	.16	.20	.26	.33	.40	.47	.56	.65	.76	.87	.99	1.12	16
18	.01	.03	.06	.09	.13	.18	.23	.30	.37	.45	.53	.63	.73	.85	.98	1.12	1.26	18
20	.01	.03	.06	.10	.14	.20	.26	.33	.41	.50	.59	.70	.82	.94	1.09	1.24	1.40	20
22	.01	.04	.07	.11	.16	.22	.28	.36	.45	.55	.65	.77	.90	1.04	1.20	1.36	1.54	22
24	.01	.04	.08	.12	.17	.24	.31	.39	.49	.60	.71	.84	.98	1.13	1.31	1.49	1.68	24
26	.02	.04	.08	.13	.19	.25	.33	.43	.53	.64	.77	.91	1.06	1.23	1.41	1.61	1.81	26
28	.02	.04	.09	.14	.20	.27	.36	.46	.57	.69	.83	.98	1.14	1.32	1.52	1.74	1.95	28
30	.02	.05	.10	.15	.22	.29	.38	.49	.61	.74	.89	1.05	1.22	1.42	1.63	1.86	2.09	30
32	.02	.05	.10	.16	.23	.31	.41	.52	.65	.79	.95	1.12	1.31	1.51	1.74	1.98	2.23	32
34	.02	.05	.11	.17	.24	.33	.44	.56	.69	.84	1.01	1.19	1.39	1.60	1.85	2.11	2.37	34
36	.02	.06	.12	.18	.26	.35	.46	.59	.73	.89	1.07	1.26	1.47	1.70	1.96	2.23	2.51	36
38	.02	.06	.12	.19	.27	.37	.49	.62	.78	.94	1.12	1.33	1.55	1.79	2.07	2.36	2.65	38
40	.02	.06	.13	.20	.29	.39	.51	.66	.82	.99	1.18	1.40	1.63	1.89	2.18	2.48	2.79	40
42	.03	.07	.13	.21	.30	.41	.54	.69	.86	1.04	1.24	1.47	1.71	1.98	2.28	2.60	2.93	42
44	.03	.07	.14	.22	.32	.43	.56	.72	.90	1.09	1.30	1.54	1.80	2.08	2.39	2.73	3.07	44
46	.03	.07	.15	.23	.33	.45	.59	.75	.94	1.14	1.36	1.61	1.88	2.17	2.50	2.85	3.21	46
48	.03	.08	.15	.24	.35	.47	.61	.79	.98	1.19	1.42	1.68	1.96	2.27	2.61	2.98	3.35	48
50	.03	.08	.16	.25	.36	.49	.64	.82	1.02	1.24	1.48	1.75	2.04	2.36	2.72	3.10	3.49	50
52	.03	.08	.17	.26	.37	.51	.67	.85	1.06	1.29	1.54	1.82	2.12	2.45	2.83	3.22	3.63	52
54	.03	.09	.17	.27	.39	.53	.69	.89	1.10	1.34	1.60	1.89	2.20	2.55	2.94	3.35	3.77	54
56	.03	.09	.18	.28	.40	.55	.72	.92	1.14	1.39	1.66	1.96	2.28	2.64	3.05	3.47	3.91	56
58	.03	.09	.19	.29	.42	.57	.74	.95	1.18	1.44	1.72	2.03	2.37	2.74	3.16	3.60	4.05	58

60	.04	.10	.19	.30	.43	.59	.77	.98	1.22	1.49	1.78	2.10	2.45	2.83	3.26	3.72	4.19	60
62	.04	.10	.20	.31	.45	.61	.79	1.02	1.26	1.54	1.84	2.17	2.53	2.93	3.37	3.84	4.33	62
64	.04	.10	.20	.32	.46	.63	.82	1.05	1.31	1.59	1.89	2.24	2.61	3.02	3.48	3.97	4.47	64
66	.04	.11	.21	.33	.48	.65	.84	1.08	1.35	1.64	1.95	2.31	2.69	3.12	3.59	4.09	4.61	66
68	.04	.11	.22	.34	.49	.67	.87	1.12	1.39	1.69	2.01	2.38	2.77	3.21	3.70	4.22	4.75	68
70	.04	.11	.22	.35	.50	.69	.90	1.15	1.43	1.74	2.07	2.45	2.86	3.30	3.81	4.34	4.89	70
72	.04	.12	.23	.36	.52	.71	.92	1.18	1.47	1.79	2.13	2.52	2.94	3.40	3.92	4.46	5.03	72
74	.04	.12	.24	.37	.53	.73	.95	1.21	1.51	1.84	2.19	2.59	3.02	3.49	4.03	4.59	5.17	74
76	.05	.12	.24	.38	.55	.74	.97	1.25	1.55	1.88	2.25	2.66	3.10	3.59	4.13	4.71	5.30	76
78	.05	.12	.25	.39	.56	.76	1.00	1.28	1.59	1.93	2.31	2.73	3.18	3.68	4.24	4.84	5.44	78
80	.05	.13	.25	.40	.58	.78	1.02	1.31	1.63	1.98	2.37	2.80	3.26	3.78	4.35	4.96	5.58	80
82	.05	.13	.26	.41	.59	.80	1.05	1.34	1.67	2.03	2.43	2.87	3.35	3.87	4.46	5.08	5.72	82
84	.05	.13	.27	.42	.60	.82	1.08	1.38	1.71	2.08	2.49	2.94	3.43	3.96	4.57	5.21	5.86	84
86	.05	.14	.28	.43	.62	.84	1.10	1.41	1.75	2.13	2.55	3.01	3.51	4.06	4.68	5.33	6.00	86
88	.05	.14	.28	.44	.63	.86	1.13	1.44	1.80	2.18	2.60	3.08	3.59	4.15	4.79	5.46	6.14	88
90	.05	.14	.29	.45	.65	.88	1.15	1.48	1.84	2.23	2.66	3.15	3.67	4.25	4.90	5.58	6.28	90
92	.06	.15	.29	.46	.66	.90	1.18	1.51	1.88	2.28	2.72	3.22	3.75	4.34	5.00	5.70	6.42	92
94	.06	.15	.30	.47	.68	.92	1.20	1.54	1.92	2.33	2.78	3.29	3.84	4.44	5.11	5.83	6.56	94
96	.06	.15	.31	.48	.69	.94	1.23	1.57	1.96	2.38	2.84	3.36	3.92	4.53	5.22	5.95	6.70	96
98	.06	.16	.31	.49	.71	.96	1.25	1.61	2.00	2.43	2.90	3.43	4.00	4.63	5.33	6.08	6.84	98
100	.06	.16	.32	.50	.72	.98	1.28	1.64	2.04	2.48	2.96	3.50	4.08	4.72	5.44	6.20	6.98	100

PLACEMENT OF CURRENT METER

The accuracy of a measurement of discharge depends upon the correct determination of the mean velocity in the vertical, and this determination requires the placement of the current meter at selected positions in the vertical depth. The conditions that cause a measurement of depth to be in error when made by the usual methods would also affect the placing of the meter at selected positions in the vertical. A current meter placed in deep, swift water by the usual methods for observations at selected positions in the depth will be too high in the water, and the amount of error in placement increases rapidly with increases in the vertical angle. That part of the error due to inclination of the line above the water surface may be corrected by use of the air-correction table. The water-correction table for use in measurements of depth is not strictly applicable, however, to the determination of the vertical distance to an intermediate position.

The assumptions upon which the water-correction table is based are listed on page 49. The assumption that horizontal pressure on the weight when in the sounding position is neglected is based both on the fact that the sounding weight is in the zone of minimum velocity and on the supposition that it is so shaped as to offer very little resistance to the current. If the weight is raised above the bottom it is subjected to higher velocities, the pressure on the weight is increased, and the vertical angle of the line at the surface will change with any change in the total pressure on the equipment that is under water. The position and shape of the sounding line, if the weight is above the bottom, will therefore not be identical with those shown in figure 2 for the sounding position. As the water-correction table was computed for a weight and line, it is not strictly applicable for a sounding made with a current meter and weight. As the meter is placed about a foot above the weight, it is in a zone of higher velocity than the weight, and because of its shape it offers more resistance to the current.

Correction tables for placement of the current meter for velocity observations have not been prepared, as it is apparent that they would be specific and not general in their application. It is evident, however, that the use of the air- and water-correction tables prepared for use in measurements of depth will tend to reduce the error in placement of the meter for velocity observations, and, although they are not strictly applicable, their use for this purpose has become general in measurements of rivers that are deep and swift.

The two-point method for determination of mean velocity in the vertical, which is in general use, requires observations at 0.2 and 0.8 of the depth. If the use of correction tables is needed, the meter is usually placed by measuring down from the water surface for the

0.2-depth position and by measuring up from the bed of the stream for the 0.8-depth position. Inaccurate placement of the meter for the 0.2-depth position will result in less error than for the 0.8-depth position, as the velocity near the upper position usually varies less rapidly. It is obvious that letting out a length of line equal to 20 percent of the vertical depth for the 0.2-depth position and reeling up the same amount for the 0.8-depth position will not place the meter at the desired positions unless consideration is given to the amount of line involved in the air and water corrections.

For the 0.2-depth position the water correction is negligible as the wet line is practically a straight line. The amount of line to be let out, however, in addition to 20 percent of the vertical depth, is somewhat more than the air correction corresponding to the vertical angle and a distance equal to the height above water. This amount of line, including the air correction, may be determined from the air-correction table by using the vertical angle, observed when line equal to 20 percent of the vertical depth has been let out, and a distance equal to the sum of the height above water and 20 percent of the vertical depth. If the angle increases appreciably when the additional line is let out, more line must be let out until the total additional line, the angle, and the vertical distance are in agreement with figures in the air-correction table. For the 0.2-depth position the wet line depth instead of the vertical depth is sometimes used as the basis for the setting. Its use is assumed to result in placing the meter at the desired depth without additional corrections for change in vertical angle.

In the placing of the meter for the 0.8-depth position, a correction to the amount of line reeled in must be made for the difference, if any, between the air correction for the sounding position and the air correction for the 0.8-depth position. This difference is designated as *c* in the summary below. If the angle increases for the 0.8-depth position, the meter must be lowered; if it decreases, the meter must be raised. The angle is an indication of the total pressure on the equipment. If the angle does not change when the meter and weight are moved from the sounding position to the 0.8-depth position, the increased pressure on the meter and weight has been compensated by the removal of pressure on the line, because a shorter length of line is subjected to the action of the current when the meter is moved to the 0.8-depth position.

For the 0.8-depth position of the meter the water correction may require consideration if the depths are more than 40 feet and if the change in vertical angle is more than 5 percent. As the wet-line depth when the meter is in the 0.8-depth position is less than when it is in the sounding position, it is obvious from table 2 that, if the vertical angle remains the same or decreases, the water correction for the 0.8-depth position is less than the water correction for the sounding position by some difference designated as c^1 in the summary below. If the vertical angle increases, the difference c^1 between the water corrections diminishes until the increase in angle is about 10 percent; for greater increase in angle the difference between corrections increases also.

The effect on the air and water corrections caused by raising the meter from the sounding position to the 0.8-depth position, and the resulting effect on the corrections for the 0.8-depth position are summarized below.

TABLE 3.—*Summary of effect on air and water corrections caused by raising the meter from the sounding position to the 0.8 depth position*

Change in vertical angle	Air correction		Water correction	
	Direction of change	Correction to meter position	Direction of change	Correction to meter position
None.	None.	None.	Decrease.	Raise meter the difference c^1.
Decrease.	Decrease.	Raise meter the difference c.	Decrease.	Raise meter the difference c^1.
Increase.	Increase.	Lower meter the difference c.	Decrease then increase.	Raise meter the difference c^1.

The difference c^1 will decrease with increase in angle and will change sign when increase in angle has become about 10 percent. Beyond that point the correction to the meter position (because of water correction) requires lowering the meter the difference (c^1) between the sounding and the 0.8-depth water corrections.

For slight changes in the vertical angle the adjustments that must be made to the wet-line length because of the differences c and c^1, in the air and water corrections, in order to obtain the correct position of the meter for the 0.8-depth observation, are small and usually may be ignored. Inspection of the summary table given above indicates that the meter may be placed a little too low in the water if the adjustments are not made. Because of this possibility, the wet-line depth instead of the vertical depth is sometimes used as the basis for the 0.8-depth position with no adjustments for the differences c and c^1 in the air and water corrections, respectively.

For all positions of the current meter, the distance between the center of the meter and the bottom of the weight must not be ignored if the bottom of the weight is used as the index in the measurement of depths.

PROCEDURE

The procedure generally followed in making observations and corrections for depth and for velocity positions in discharge measurements of rivers that are deep and swift has been developed from experience acquired at various river-measurement stations. The equipment for such work includes reels, booms, depth indicators or counters, and protractors for indicating the vertical angles. After the equipment has been assembled and tested, the routine procedure is as follows:

1. Place the gaging car or the reel and boom equipment in position at the station on the cableway or bridge at which the observations are to be made. Measure and record the vertical distance from the water surface to the apex of the vertical angle.

2. Place the bottom of the sounding weight at the water surface and set the counter or depth indicator to read zero. Lower the sounding weight to the bed of the stream. Read and record the observed depth and vertical angle when the sounding weight is at the bed of the stream but entirely supported by the sounding line. With the aid of the correction tables compute and record (1) air correction, (2) wet-line depth, (3) water correction, (4) vertical depth, (5) 0.2 of vertical depth.

3. Raise the meter from the sounding position a distance equal to 0.2 of the vertical depth minus the distance from the meter to the bottom of the weight. This places the meter approximately at the 0.8-depth position if the vertical angle has not changed and if the depth and angles are not sufficient to cause an appreciable change in the water correction. If the vertical angle has increased, the meter must be lowered the difference between the air corrections for the 0.8-depth position and the sounding position; if it has decreased, the meter must be raised the difference between the air corrections. If the depth and angles are sufficient to cause an appreciable change in the water correction, an adjustment on this account will be necessary.

4. Observe and record data for velocity at the 0.8-depth position.

5. Raise the meter from the 0.8-depth position until the counter reads 0.2 of the vertical depth plus the distance from the meter to the bottom of the weight. Note the new angle for this position. From the air-correction table, find the proper correction for this angle and a vertical distance equal to the height above the water plus 20 percent of the vertical depth, and lower the meter an amount equal to this correction. This places the meter approximately at the 0.2-depth position unless the vertical angle increases appreciably. If the angle increases, additional line should be let out until the amount of line in excess of 20 percent of the vertical depth, the angle, and the vertical distance are in agreement with the air-correction table.

6. Observe and record data for velocity at the 0.2-depth position. In work on streams carrying drift and fine debris in suspension, the procedure may need modification. Accumulation of debris on the line increases the angle progressively as the accumulation increases, and it requires that the sounding be made as rapidly as possibile and that the meter and weight be brought to the surface immediately after the sounding for inspection and cleaning and protection from large drift. During the time required for a velocity observation at a given point, the accumulation of debris on the line may cause the meter to rise above the selected depth of observation. To compensate for this condition, the vertical angle must be observed constantly and the necessary additional amounts of line must be let out.

TAG-LINE METHOD

The tag-line method of measuring depth and placing the meter consists essentially in using index tags or markers fastened to the meter line at known distances from the meter or bottom of the weight. The tags, which may be streamers of different colors fastened on the meter line by solder beads, small cable clips, or adhesive tape, should be easily identified and should remain fixed in position. A narrow strip of inner tube tightly stretched in a double turn around the cable makes a satisfactory marker. After the weight touches the stream bed the depth of water is determined by drawing up the meter line enough to measure the depth of the first tag below the water surface and adding to that depth the known distances of this tag above the bottom of the weight. In the placing of the meter for a velocity observation, the tag nearest the selected depth is used as a reference point in raising or lowering the meter to the desired depth.

The tag-line method is considered advantageous in the measurement of deep water with low or moderate velocities, as it eliminates the necessity for measuring a large part of the wet line and thereby avoids the necessity for raising the weight of the surface at each sounding. It permits the placing of the meter in the correct position for a velocity observation with less effort and greater speed. The current meter remains below the surface, where it is not so likely to encounter floating debris or ice. The method is used more frequently with hand-line equipment than with a reel assembly, although it may be used with either; and it is particularly useful in freezing temperatures, as it avoids exposing the meter to the cold air.

The tag-line method may be used where there are vertical angles in the sounding line, although certain precautions must be observed. The air correction for sounding and placing of meter is eliminated if the measuring equipment is supported at the water surface. The use of the tag-line method will reduce the air correction to a negligible amount if the vertical angle does not change when an index tag is raised to the water surface. The method, however, cannot be considered as equivalent to moving the meter-line support to the water surface, as the support, if at the water surface, would be in a fixed position; whereas with the support above the water the intersection of the line with the surface is free to move upstream and downstream, and therefore the length of line in the water may increase or decrease. If the vertical angle increases when the index tag is brought to the surface the difference in the air correction for the two angles must be added to the observed depth to obtain the wet-line depth. If the angle decreases, the difference must be subtracted. The wet-line depth thus obtained must be corrected to vertical depth by use of the water-correction table. These corrections should all be taken into consideration, especially if the stream is deep and swift. The use of adequate sounding weights will ordinarily eliminate the necessity for corrections.

Differences between air-corrections due to movement upstream or downstream of the intersection of the line with the water surface are of consequence only when they are such percentage of the vertical depth as to affect the accuracy of the sounding or the placing of the meter. It is therefore essential that users of this method become familiar with the magnitude of possible errors in order to know its limitations. It should be noted that the height above water of the support of the equipment is a significant factor, as the air correction varies directly with the height and approximately with the square of the vertical angle. The procedure for making discharge measurements by the tag-line method with corrections for vertical angles is essentially similar to that described on page 54.

STAY-LINE EQUIPMENT

Measurements of shallow streams with high velocities may be made with increased accuracy by the use of a stay-line. The stay-line wire or cable is erected parallel to the measuring section and should be about the same height above water as the cableway or bridge from which the measurements are made. It should be far enough upstream from the measuring section so that the angle made by the stay-line with the water surface will not be greater than about 30°. The stay-line cable carries a traveling pulley, to which is attached a swivel pulley. The stay-line, which is attached to the meter hanger above the meter, passes through the swivel pulley and then to the operator or the bridge or cableway. A small wire of high strength should be used for the part of the stay-line in the water. A strong cord or small rope that will pass over the pulley readily should be used above the water.

To obtain the best results with the least effort and in the shortest time, make the soundings by measuring down from the water surface, and place the meter for velocity observations by measuring up from the bottom.

A stay-line is most useful at measuring sections where the structure from which measurements are made is at a considerable height above the water, where the water is comparatively shallow, and where the velocities are high. Under these conditions its use eliminates the necessity for measuring the vertical angles made by the meter line and the application of air corrections. It eliminates also errors that might be caused by the downstream drift of the meter and weight into a section not equivalent to that at the measuring section.

The principal error in the use of a stay-line occurs when depth and velocity are sufficient to cause curvature in the meter line when the sounding weight and meter are brought into the vertical plane of the measuring section by tension in the stay-line. If the use of a larger sounding weight will not reduce the error in the observed depth to a negligible amount, the use of a stayline is not recommended. Errors due to curvature in the meter line, where a sounding is made with the use of a stay-line equipment, cannot be removed by means of the water-correction table as the assumptions on which that table is based do not apply.

HORIZONTAL ANGLES

If the direction of flow is not perpendicular to the measuring section, the angle in the measuring line as indicated by the vertical-angle protractor will be less than the actual angle in the line. The corrections to air line and wet line based on the observed angle will be too small; consequently incorrect measurement of depth and incorrect placement of meter will result. The horizontal angle between the direction of flow and a perpendicular to the measuring section may be measured from the gaging car or from the bridge with angle charts or protractors prepared for that purpose.

If the horizontal angle of the direction of flow may be called H, the measured vertical angle P, and the actual vertical angle X, the relation between the angles may be expressed by the formula

$$\tan. X = \frac{\tan. P}{\cos. H}$$

Angles P and H are measured, and therefore angle X may be derived from the equation.

Table 4, which gives the amounts, in tenths of degrees, to be added to observed vertical angles to obtain the actual vertical angles for a range of horizontal angles between 8° and 28°, has been computed from the relation between the angles H, P, and X.

TABLE 4.—*Amounts to be added to observed vertical angles to obtain actual vertical angles*

Observed vertical angles	Horizontal angles					
	8°	12°	16°	20°	24°	28°
8°	0.1	0.2	0.3	0.5	0.8	1.0
12°	.1	.3	.5	.8	1.1	1.5
16°	.1	.4	.6	1.0	1.4	2.0
20°	.2	.4	.7	1.2	1.7	2.4
24°	.2	.5	.8	1.4	2.0	2.8
28°	.2	.5	1.0	1.5	2.2	3.0
32°	.2	.6	1.0	1.6	2.4	3.3
36°	.2	.6	1.1	1.7	2.5	3.4
40°	.2	.6	1.1	1.8	2.6	3.5

Applicability of the table will depend on the degree of refinement with which the vertical angle is observed. No additions to the observed vertical angle are necessary for any vertical angles below 20° if the refinement is 1° and if the horizontal angles are below 12°. If the refinement is 2°, the limits are 24° in the vertical angle and 20° in the horizontal angle.

RECORDING OF DATA

To systematize the recording and computing of data pertaining to current-meter measurements, the Geological Survey uses a series of standard forms on which data are recorded and computed.

Form 9–275.—Form 9–275, shown in figure 3, is used for all open-water discharge measurements where the observations are not corrected for vertical angles. It contains 13 columns, each with a heading explanatory of the data to be inserted. On the left margin are the angle coefficients referred to on page 72. The position of the vertex of the angle is indicated by the small circle on the right margin. When this form is used it is common practice to utilize two horizontal lines for recording the observations and calculations made at each vertical, regardless of whether the two-point or the 0.6-depth method is used. Such procedure permits the recording of data for 12 verticals on one sheet, avoids possible confusion of notes, and allows sufficient space for recording any miscellaneous observations that may be necessary. Data in the following order are recorded on the upper of the two horizontal lines, beginning at the left margin of the sheet: (1) Distance from the initial point to the vertical, (2) angle coefficient or cosine of the angle between the direction of flow and the normal, (3) depth in the vertical, (4) actual depth at which the first observation of velocity is taken, (5) revolutions of the rotor of the current meter, (6) time over which these revolutions are observed, (7) calculated velocity at the point of observation, and (8) mean velocity in the ver-

9-275
January 1935

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

Date__________, 19___ DISCHARGE MEASUREMENT NOTES

____________________ River, at ____________________

Dist. from initial point	Angle coef-fi-cient	Depth	Depth of ob-serva-tion	Rev-olu-tions	Time in sec-onds	Velocity: At point	Velocity: Mean in ver-tical	Velocity: Mean in section	Area	Mean depth	Width	Discharge

No. ________ of ________ Sheets. Comp. by ________________ Chk. by ________

U. S. GOVERNMENT PRINTING OFFICE 6—7682

FIGURE 3.—Discharge-measurement notes, form 9–275.

tical. If a second observation of velocity is taken in the same vertical the actual depth, revolutions, and time observations are recorded in ther proper spaces on the second line, followed by calculations of velocity at the second point of observation as follows: (9) Mean velocity in the section, (10) area, (11) mean depth, (12) width, and (13) discharge. If but one observation of velocity is taken, the second line is used only for recording the calculations of mean velocity in the section, area, mean depth, width, and discharge. The time at which an observation in a specific vertical is completed is noted in the first

9-275a
(February 1940)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

Date ________________, 19____ No. of Meas. ________

CURRENT METER NOTES—ICE COVER

________________ River, at / Creek, near ________________

Dist. from initial point	Thickness of ice / W. S. to bot. ice	Total depth of water / Effective depth	Depth of meter below water surface	Revolutions	Time in seconds	Velocity: At point	Velocity: Mean in vertical	Velocity: Mean in section	Area	Mean depth	Width	Discharge
TOTALS.												

No.______of______Sheets. Comp. by__________ Chk. by__________ Make notes on back.

U. S. GOVERNMENT PRINTING OFFICE 16—15074

FIGURE 4.—Current-meter notes, ice cover, form 9–275a.

column directly below the figure designating the distance from the initial point. To identfy the bank at which the measurement is started or finished, the letters "L. E. W." or "R. E. W.", signifying the left edge of water or the right edge of water and followed by its distance from the initial point, are written in the first column at the beginning and end of the measurement. Each sheet should be dated and identified to avoid confusion of notes. To obtain consistency in computatons, calculations should be carried to three significant figures except below 1, where hundredths is sufficient. If the figure following the last significant figure is 5, it should be either dropped or added to make the preceding figure even.

Form 9–275a.—All observations pertaining to the measurement of discharge under ice cover are recorded on form 9–275a (see fig. 4).

This form is essentially the same as form 9–275 except that the angle coefficient column is omitted and the "Depth" and "Depth of observation" columns are replaced by three columns headed "Thickness of ice," "Total depth of water," and "Depth of meter below water surface." The system of note keeping is also the same except for the data tabulated in the three columns mentioned. In the "Thickness of ice" column, the thickness of ice is recorded in the upper space and the distance from the water surface to the bottom of the ice in the lower space. In the "Total depth of water" column, the total depth is recorded in the upper space and the effective depth, which is the depth of the water beneath the ice, is recorded in the lower space. In the column headed "Depth of meter below water surface," the actual computed figure showing the position of the meter is recorded.

If the top of the ice, or a rod placed across the hole, is used as an index for measuring the depths, the distance from the index to the bottom of the channel may replace the total depth of water in the "Total depth of water" column, and the distance from the index to the bottom of the ice may replace the thickness of ice in the "Thickness of ice" column. The figures recorded in the column "Depth of meter below water surface" should, in this case, identify the position of the meter with respect to effective depth.

Form 9–275b.—Where an open-water measurement requires consideration of the vertical angle, form 9–275b is used. This form, shown in figure 5, is an expansion of form 9–275, with seven columns replacing the two columns headed "Angle coefficient" and "Depth." These additional columns provide space for tabulating the following data: Distance above water surface, vertical angle, observed depth, air correction, wet-line depth, water correction, and vertical depth.

Form 9–275c.—Form 9–275c, shown in figure 6, serves as the first sheet for each discharge measurement and contains a complete list of headings showing necessary data that must be collected and tabulated if the measurement is to be of maximum value. The column headings are self-explanatory, and no measurement of discharge should be considered complete until all information indicated by the column headings has been obtained and entered in the spaces provided. All entries of data should be made directly on this form immediately upon their observation and not recorded elsewhere to be transferred at a later date. Those headings that do not apply to the particular measurement should be deleted so as not to leave any inference that the information may have been overlooked. The substitution of initials for names, the abbreviations of names of places, and the record of the date by figures should be avoided.

Form 9–275d.—Form 9–275d (see fig. 7) is used for compiling general information indicated by the topics listed at the top of the sheet

9-275-b
(February 1940)

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

DISCHARGE MEASUREMENT NOTES

TWO-TABLE METHOD

U. S. GOVERNMENT PRINTING OFFICE 16—13835

Date ______________ No. of Meas. ______________
Meter No. ______________ Reel Coefficient ______________
Type of suspension ______________
Size of line ______________ Notes by ______________

	Distance from initial point	Distance above water surface	Vertical angle	Observed depth	Air correction	Wet-line depth	Water correction	Vertical depth	Depth of observation	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	VELOCITY Mean in section	Area	Mean depth	Width	Discharge
85																		
97																		
96																		

Computed by ______ Checked by ______ No. ______ of ______ Sheets.

FIGURE 5.—Discharge-measurement notes, two-table method, form 9–275b.

9-275 c
(July 1935)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

DISCHARGE MEASUREMENT NOTES

Meas. No. ....
Checked by ....
Date ....

....

Date ...., 19...... Party ....

Width .... Area .... Vel. ...... G. H. .... Disch. ....

Method .... No. secs. .... G. H. change .... in ...... hrs. Susp. ....

Method coef. .... Hor. angle coef. .... Meter No. .... Susp. coef. ....

GAGE READINGS				
Time		Recorder	Inside	Outside
	Start			
	Finish			
Weighted M. G. H.				
G. H. correction				
Correct M. G. H.				

Date rated .... Used rating for rod .... susp. Meter .... ft. above bottom of wt. Tags checked ....

Spin before meas. .... after ....

Meas. plots ...... % diff. from .... rating

Wading, cable, ice, boat, upstr., downstr., side bridge .... feet, mile, above, below gage, and ....

Chain, wire, found ...., changed to .... at ....

Correct length ....

Levels obtained ....

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions: Cross section ....

Flow .... Weather ....

Other ....

Gage ....

.... Record removed .... Intake flushed ....

Observer ....

....

Control ....

....

Remarks ....

....

....

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

U. S. GOVERNMENT PRINTING OFFICE 6—7440

FIGURE 6.—First sheet of discharge-measurement notes, form 9–275c.

and is the basis of the field report to be prepared by the engineer at the time of his visit to the station. If the data relate to a discharge measurement, the form is attached as the final sheet of notes concerning the measurement; if they have no reference to a discharge measurement they are filed with other data pertaining to the station.

9-275 d
(Sept. 1927)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

Date ...., 19..... No. of Meas. ....

SUPPLEMENTARY DISCHARGE MEASUREMENT NOTES

....

Enter on this form ample notes in regard to the following:

1. Accuracy of measurement; 2, gage; 3, observer; 4, bench marks; 5, gage-height corrections; 6, adjustments to total discharge; 7, station equipment; 8, channel, control, and point of zero flow; 9, rating, backwater; 10, diversions, regulation; 11, records; 12, cooperation.

....

....

....

....

No. of sheets 6—6226 U. S. GOVERNMENT PRINTING OFFICE: 1929

FIGURE 7.—Supplementary discharge measurement notes, form 9–275d.

FACTORS AFFECTING THE ACCURACY OF MEASUREMENTS

For accurate and reliable measurements of discharge, especially in natural stream channels, a knowledge of many factors is essential in addition to the specific procedure followed in making a discharge measurement. The wide variety in the character of streams, in climatic conditions, both seasonal and regional, and in behavior of the measuring equipment when used under various circumstances gives rise to many problems which may affect the specific procedure of the work.

USE AND CARE OF EQUIPMENT

Accuracy in measurements of discharge can be expected only when the equipment is properly assembled, adjusted, and kept in good condition. The current meter and stop watch, in particular, must receive the best of care and protection, both when in use and when being transported, as they are the two most delicate and sensitive elements of the measuring equipment.

The current meter necessarily receives a certain amount of hard usage that may result in damage, such as a broken pivot, chipped bearing, or bent shaft, any one of which may cause the meter to underregister. Observations of velocities near bridge piers and abutments, soundings taken at sections having irregular and uncertain profiles with the meter attached to the measuring line, and the presence of floating drift or ice probably include the greatest hazards to the meter equipment. Floating drift and ice, under careful observation, can usually be seen in time to allow the removal of the equipment from the water. Occasionally a measurement is so valuable that considerable hard usage of the equipment is justified. After such usage each part of the current meter should be thoroughly examined.

Damage to measuring equipment during transportation is generally due to careless packing or negligence in protection. A standard case is provided for use in transporting the current meter and the several small and more delicate articles of equipment. Pivots, bearings, contacts, and other extra parts carried into the field should be carefully packed. The stop watch should always be carried in a container that provides protection against dampness and sudden jarring. The headset assembly should be packed carefully to avoid accidental short circuits, which may discharge the battery. If several sounding weights are to be carried, a box should be used with a separate compartment for each weight, and the compartments should be arranged and fitted so as to protect the weights from flattening and scarring. Other articles, such as sounding reels and waders, should always be carried in separate cases. The means for transporting more bulky equipment, such as cranes and reels, will vary with the type of conveyance used. Transportation of equipment in assembled form from one gaging station to another is one of the most common sources of damage and too often results in a loss rather than a saving of time. An engineer who takes pride in the care and protection of his measuring equipment will find himself amply repaid for the extra time and effort that may be required to maintain it in the best possible condition.

SELECTION OF MEASURING SECTION

The selection of the section at which to measure discharge should be given ample consideration, when measuring either in open water or through ice cover. Although this phase may have been given careful study during reconnaissance prior to the establishment of the gaging station, nevertheless changes in channel conditions may occur from time to time which necessitate the selection of other sections, especially for low-water measurements.

If results of the discharge measurement are to be accurately related to the flow at the gage during the time of measurement, it is essential that the place of measurement should be near the gage. Only where it is known that there is no appreciable difference between the discharge at the gage and at the measuring section during the time of measurement, or where there is some reliable means by which the difference may be determined, is it permissible to have the measuring section far from the gage. The characteristics of the measuring section may differ from those of the section controlling the stage at the gage, and they need to remain permanent only during the time required for making the measurement. Inasmuch as a measuring section must meet certain requirements, it is not uncommon to select several sections to be used for wading measurements at different stages.

The ideal open-water measuring section is perpendicular to the direction of the flow and should be in a stretch of the stream where the bed and banks are uniform. Accurate measurements are most easily made if the minimum velocity at any one vertical is not less than 0.5 foot per second and the depth of the water is sufficient to permit the use of the two-point method. Such a section is not always found in natural streams, but reliable and accurate results of measurement are obtainable at measuring sections showing considerable departures from the ideal if the engineer uses proper precautions and good judgment in choosing the cross section and in operating the current meter and if he makes sufficient observations of velocity to assure a representative mean velocity for each part of the section.

Sections for measurements through ice cover should have the same general characteristics as good open-water sections. On streams where ice cover is anticipated, these sections should be selected during the open-water season and their positions indicated by markers that will not be obliterated by ice and snow. Prior selection of the section will enhance the accuracy of the determination of the discharge under the ice, as the distribution of velocities under ice cover and in open water is very similar. If the general distribution of velocity in the ice-covered section is different from that for open-water conditions, it will have resulted from the pressure caused by the rigidity and weight of the ice. A previous knowledge of the cross section will assist in finding the edges of flowing water and in spacing the holes in the ice so that the discharge measured between verticals in each part of the area will be in proportion to that measured in open water.

The section directly under a cable or bridge used for open-water measurements may be used at some stations for measuring through ice cover, although when measuring through the ice at a bridge it is generally advisable to select a cross section far enough upstream or downstream from the open-water section to avoid the disturbing influence of the piers. Because the anchor ice and frazil from which slush ice is formed collect more thickly in the upstream part of an ice-covered reach, the most favorable ice-covered section is just above a place of open water.

SPACING OF VERTICALS

Appreciable errors may result in determining both the area and the mean velocity if the verticals in the measuring section are not properly spaced. With regard to measurements of depth, these verticals should be so spaced that the error involved in determining the area becomes negligible if the part of the profile of the section between two successive verticals is assumed to be a straight line. With regard to velocities, the verticals should be so spaced that the average of the mean velocity in any vertical and that in the preceding or following vertical will represent the mean velocity in the section between the verticals. Usually where the profile of the measuring section is very irregular the velocities are irregular, and more verticals are necessary for an accurate measurement of discharge. Only where the velocity appears to be well distributed and where the profile of the cross section is reasonably regular and smooth is it desirable to space the verticals at equal intervals throughout the measuring section. In some deep channels the surface velocities may appear to be fairly uniform, but irregularities in the bed of the stream may require irregular spacing of verticals in order to define accurately the profile of the cross section. If the stream bed is irregular it is generally advisable to measure the velocity in each of the corresponding verticals, as the velocities near the bed may be affected by the irregularities in the profile.

Besides the effect of distribution of velocity and the character of the bed at the measuring section upon the number of verticals required, the number varies with the depth and width of the stream. Because of these differences and because a few measuring sections are divided into two or more channels, no fixed rule can be made as to the exact number of verticals required for a measurement. Even where the stream is confined to one channel and the stream bed and velocities are reasonably uniform, no definite rule can be followed except that the verticals should be so spaced as to disclose the real shape of the bed and the true mean velocity of the flowing water. The verticals may be as much as 15 or even 20 feet apart in a smooth channel 400 feet wide and perhaps as much as 40 feet apart in a 1,000-foot channel. The channel should be devided into 20 or more parts except for very small streams, where a somewhat smaller number may be sufficient if the distance between verticals becomes less than 1 foot. The division is generally made so that there will be not more than 10 percent, and preferably not more than 5 percent, of the discharge between any two verticals.

MEASUREMENT OF DEPTH

The accuracy of a measurement of discharge in any section depends as much on the correct determination of depth as it does on the accuracy of measurements of velocity. Inasmuch as the discharge is a product of area and velocity, any error in the area as a result of an incorrect measurement of depth will produce a corresponding error in the discharge. This error would affect the determinations of areas and discharges in the two adjoining sections.

Inaccuracies in soundings are most likely to occur in those sections having great depths and high velocities where the engineer is unable to measure the vertical depths directly. As those sections generally carry the larger part of the total discharge, it is essential that methods of measuring be used which will either eliminate this source of error or reduce it to a negligible amount.

ICE IN MEASURING SECTION

In regions of subfreezing temperatures, surface ice, frazil, or anchor ice may form during each winter. Ice in the measuring section adds to the difficulty and inconvenience of making discharge measurements, and as frazil or anchor ice it tends to reduce the accuracy of the measurements. The accuracy can be considered equal to that of open-water measurements only where there is surface ice alone and where it serves as a support from which to measure.

Surface ice ordinarily forms first at the edges of the stream and gradually proceeds toward midstream until the stream is spanned. The ice cover forms last in that part of the stream where the velocities are highest because agitation by the current breaks away many small crystals of ice as rapidly as they form.

The surface ice during the period when it is breaking up should not be used as a support for the engineer. Floating cakes of ice are as great a menace to meter equipment as any other type of drift, and accurate determinations of depth and velocities are always difficult when such ice is present.

Frazil is ice in fine elongated needles, cubical crystals, and thin sheets, formed at the surface of the stream when the disturbances of the water caused either by high velocities or by wind are too great to permit the formation of ordinary surface ice. It never forms under an ice cover but may be carried under it by the current as a mass of floating slush.[8] Anchor ice, which resembles frazil ice, forms between sunset and sunrise on the stream bed and attaches itself to boulders and other objects. It is rarely found at great depths but forms

[8] Barnes, H. T., Formation of anchor ice and precise temperature measurements: Am. Soc. Mech. Eng. Trans., vol. 26, pp. 558–583, 1905.

rapidly and in large quantities in shallow streams where the bed is rough. During the daytime, particularly when there is sunshine, anchor ice may break loose, rise to the surface, and merge in the frazil.

Measurements through ice cover at a section containing frazil or anchor ice should be made only as a last resort because of the unavoidable inaccuracies in determining both the velocities and the effective depths. The fine particles of ice are likely to collect in and about the rotor of the meter and thereby retard it enough to cause underregistration. If the thickness of the frazil or anchor ice is taken as that part of the depth in which the current meter indicates no velocity, the assumed effective depth may be too small because of the effect of the ice on the free operation of the rotor.[9]

FREEZING TEMPERATURES

Freezing temperatures not only add to the discomfort of the engineer while operating the meter but may cause serious errors in velocity determinations if the meter is used after ice has formed in the bearings and contact chamber. In making a discharge measurement at subfreezing temperatures, the engineer, once he has put the meter into the water, should expose it to the air only when absolutely necessary. If the measurement is made through ice cover, the meter should be moved from one vertical to another in the minimum time and should be kept under water as much as possible during the measurement. The formation of ice on the meter equipment may be minimized by making the soundings without attaching the meter and by computing all meter settings before the meter is put into the water. When the meter must be removed temporarily from the water, the rotor should be permitted to revolve for a short time after it is again submerged before the revolutions are recorded, as the river water with a temperature above freezing will tend to thaw any ice that may have formed in the bearings. If the rotor is so sealed with ice that it ceases to turn, the meter should be thoroughly dried by a fire or heated with warm water before it is again used.

TURBULENT FLOW AND TURBULENCE

Turbulent flow is that type of flow in which any particle of water may move in any direction with respect to any other particle and in which the loss in head is approximately proportional to the second power of the velocity. The range in depth, velocity, and viscosity of the water in natural streams is generally within those limits in which turbulence occurs. Where the condition of flow is such that the water

[9] Hoyt, W. G., The effect of ice on stream flow: U. S. Geol. Survey Water-Supply Paper 337, pp. 24–30, 1913.

is considerably agitated by cross-currents, boils, and eddies, the accuracy of the velocity observations obtained by a current meter, regardless of the type used, may be affected to some extent. However, many comparisons and tests have shown that unless these disturbances of flow are pronounced, the errors will be small and mostly negligible. Because of the inaccuracies due to excessive turbulence, engineers of the Geological Survey generally specify that sites for stream-gaging stations shall be so selected that current-meter measurements can always be made in water comparatively free from cross-currents, boils, and eddies.

The nature of errors caused by excessive turbulence depends largely upon the type of current meter used and to some extent upon the method of suspension. It is generally accepted that a vertical-shaft cup-type current meter if used with rod suspension will overregister in water of excessive turbulence and that a horizontal-shaft propeller-type meter will underregister under those conditions. Some experiments have shown that the over-registration of vertical-shaft cup-type meters in turbulent water approximately equals the underregistration of certain horizontal-shaft propeller-type meters. Although the available information on this subject is far from conclusive, it suggests that the degree of accuracy is enhanced if two measurements are made under the same conditions—one with a cup-type meter known to overregister and the other with a propeller-type meter known to underregister by about the same amount—and the results averaged. Such a procedure has been practiced in several districts in the measurement of flow in flumes, tailraces, and other channels where the effects of excessive turbulence cannot be avoided. The results thus obtained have been found to compare favorably with results obtained by other methods.

ANGLE OF CURRENT

The angle of current, as applied to stream-gaging procedure, is the difference between 90° and the angle made by the current with the bridge or cableway. To eliminate errors introduced by such angles it is necessary either to convert the width between two measuring points into the width normal to the current, or to obtain the component of the velocity normal to the measuring section. The method by which this angle is corrected depends on the type of current meter used. A vertical-shaft, cup-type meter, if supported on a rod, will tend to measure the full velocity in the direction in which the water is moving and not in the direction represented by the horizontal axis of the meter. Experiments have shown that the angle between the current and the axis of the meter must exceed 25° before any appreciable error is introduced in the meter registration as a result of the disturbance created by the meter yoke. This characteristic of the cup-type meter permits some departure of the horizontal axis from the direction of flow without serious error. The horizontal-shaft propeller-type meter when supported on a rod tends to measure only the component of the current parallel to the axis of the meter; therefore the meter must be held in line with the direction of flow if corrections are to be made for angularity. The horizontal axis of either type of meter suspended from a cable will take the direction of the current if no torsional effect is caused by the suspension cable and if the flow is comparatively free from excessive turbulence.

If it is necessary either to correct the width between two measuring points to the width normal to the current or to obtain the component of the velocity normal to the measuring section, this width or velocity must be multiplied by the cosine of the angle made by the current with the normal to the section. Several methods may be used in correcting for the angle of current, such as the use of an angle chart or specially devised angle indicator, on which are shown directly the cosines of the angles; or a direct measurement of the angle may be made by a protractor. To eliminate the use of a separate angle chart, angle coefficients have been printed on discharge-measurement form 9–275 (see fig. 3). The points representing these coefficients are spaced along the left margin of the sheet with the vertex of the angle at the right margin and are so arranged that the form itself can be used as an angle-correction chart by holding the vertex parallel to the measuring section and noting the coefficient that corresponds most satisfactorily with the direction of current.

The angle protractor is of notebook size and is constructed on transparent celluloid. Lines representing the angle coefficients appear symmetrically along both margins of the protractor and are drawn so that the lines representing the lesser coefficients are nearest the base of the protractor. When this protractor is used to measure a counterclockwise angle, the right corner is held in position on an object parallel with the measuring section and the protractor rotated until the right edge coincides with the direction of flow. The angle made by the protractor with the parallel object is the angle of current and can be read directly on the left margin. For a clockwise angle, the left corner of the protractor is held in position on the object parallel with the measuring section, the left edge is brought to coincide with the direction of flow, and the angle of current is read along the right margin of the protractor. A special device known as the Veatch angle-of-current coefficient-indicator, described on page 208, is especially adaptable for use when measuring from a cable car or with a crane and reel.

If no angle chart, protractor, or indicator is available, or if their use is inconvenient, the angle of current may be determined in the following manner: Hold a tape parallel to the direction of flow with a foot mark on a line or object parallel to the measuring section and with the next foot mark at a fixed point. The tape is then pivoted about the fixed point until it is at right angles to the measuring section and the new distance between the fixed point and the line or object parallel to the measuring section is observed. If the tape is graduated in tenths and hundredths of a foot, the new observed distance will be the cosine of the angle of current. The procedures used in these methods of correction for the angle of current are based on the assumption that the angle observed on the surface of the water is representative of the one prevailing throughout the vertical. A further assumption is that vertical angles cause no effect on the observation of the horizontal angle.

EFFECTS OF PIERS, PILING, AND EDDIES

Where there are piers, piling, or eddies in the measuring section, the procedure of measuring becomes more difficult, and the possibilities of error are increased in determining both the cross-section area and the mean velocity. The volume of water that would ordinarily flow through the space occupied by a pier or pile must pass the measuring section in adjacent openings. In order that these adjacent openings may carry the additional flow, either the cross-section area or the mean velocity in the open section, or both, must be increased. If the bed of the channel is subject to scour, it is possible that the area in the open section may be sufficiently increased by scour of the bed so that the additional flow may pass without any material increase in mean velocity. In any event, the distribution of the velocity will be affected for some distance out from the obstruction. The distance from the pier or pile to the point in the open section where the distribution of the velocity is least affected is dependent upon the character of the stream bed, the depth and velocity of the water, the size and shape of the piers and piling, and the distance between them.

Where a pier is free of drift and where the velocities are sufficiently slow to permit depth and velocity observations close to the structure, there is every reason to expect accurate results if additional verticals are used and properly spaced. If turbulence about the pier is so pronounced that making reliable velocity measurements within several feet of the pier is impracticable, estimates must be made to complete the measurement. Every effort should be made to define the profile of the cross section up to the pier by sounding without the meter as a part of the assembly, as changes in depth because of scour of the channel bed may be greater near the pier than in any other part of the channel. In velocity measurements that are made close to a pier where the turbulence is excessive, the meter, if suspended by a cable, will tend to drift from the vertical toward the thread of greatest velocity. Consequently, large errors may result if such velocity determinations are used without consideration of the adjacent velocities. A common method of estimating velocities near a pier is to measure the velocity up to a point on each side of the structure where there is no visible effect on the velocity distribution, then to plot the mean velocity in each vertical with respect to its position in the measuring section, and to base the estimates of velocity at the pier on the normal trend of the mean-velocity line extended to the pier. A study of the trend of mean-velocity lines developed for several measurements made at different stages is helpful in increasing the accuracy of estimates made in this manner. In these estimates the engineer should assure himself that the affected area about the pier contains no back eddy or negative flow.

The effects from piles, which are usually cylindrical, should be considered when measuring the discharge in overflow areas where the velocities are usually lower than in the main channel and where shifts in the bed are less likely to occur. With extremely low velocities and in the absence of drift lodged against the piling, the water will flow around each pile in streamline fashion with little or no effect on the distribution of velocity in the open section. Consequently, if the piles are spaced several feet apart and if the velocity observations are made from the upstream side and midway between the piles accurate results will probably be obtained by including the area of the piling in the area of the cross section. If the distribution of velocity at a point midway between the piles is in any way affected by their presence, the area of the piles should be taken into consideration and the total or a part of such area deducted from the area of the cross section. Whether to include or to deduct the area of the piling is therefore a problem requiring careful consideration for each measurement in which piles are involved. An eddy causing a reversal of the direction of flow within the measuring section may, for practical purposes, be likened to a cylindrical roller having a vertical axis. If it may be assumed that the eddy is a rotating cylinder having concentric or excentric rotation with the upstream flow equal to the downstream flow within the revolution, it may be treated as if it were dead water. It is possible, however, that the downstream velocity on one side of the cylinder may be greater than the upstream velocity on the other side, and an effort should be made to determine the net downstream velocity within the area containing the eddy. Soundings should be taken in the eddy for use with the estimates of the net downstream velocity in completing the estimates of discharge.

VERTICAL AND HORIZONTAL MOTION OF METER

A current meter suspended from a cable is not held rigidly in position and so occasionally may have vertical and horizontal motion. The effects of this motion are similar to those applied to the meter when it is used for integrating the velocity. Various tests have indicated that if a vertical-shaft cup-type meter is used, suspended from a cable, the effect of the motion can safely be neglected only when the rate of the vertical or horizontal motion is a small percentage of the velocity of the water. Therefore, it is essential that the meter, if suspended from a cable, shall be steady while the velocity is being observed.

When the meter is moving backward and forward in line with the current, the normal result is for the registration of the rotor to increase when the movement is upstream and to decrease when the movement is downstream. The effect of each complete cycle will, therefore, be of a compensating nature and the velocities thus measured will be nearly equal to the true velocity if each observation includes one or more complete cycles.

INSUFFICIENT WEIGHT ON CURRENT METER

A current meter suspended from a cable is likely to meander if it is insufficiently weighted to hold it in position. One source of error thus introduced is due to the tendency of the meter to integrate the normal velocity along an arc lying in the plane of the measuring section and therefore to indicate velocities that are higher than those at the selected point in the vertical. When the meter swings downstream it operates nearer the surface, where velocities are generally higher than they are at the desired position. The above conditions, combined with others not generally recognized, make it difficult to estimate the effects of the use of insufficient weight except that in general the indicated velocities are probably too large.

WIND

It is generally recognized that severe wind precludes accurate current-meter measurements, as either upstream or downstream wind may seriously affect the movement of the water near the surface. Strong wind of long duration in the same direction may also affect the stage-discharge relation at the gage. This fact should be taken into consideration in comparing results of discharge measurements made at different times; therefore it is desirable that a statement with respect to direction and intensity of wind should be given under "Remarks" on the first sheet of the current-meter notes, form 9–275c. (See fig. 6.) The wind may affect the accuracy of a measurement both by causing abnormal variations in velocity and by agitating the water surface. Wind action may abscure the angle of current and may interfere with the 0.2-depth velocity observations in shallow water.

Measurements made from boats or cableways, besides being subjected to the influences just mentioned, are often affected by the action of wind against the structure supporting the measuring equipment. This action increases the tendency of the meter to meander from its correct position in the vertical. Long lengths of exposed measuring cable subjected to the uneven pressure of the wind may also affect the performance of the current meter.

DRIFT AND AQUATIC GROWTH IN CHANNEL

The effect of floating drift on the accuracy of the discharge measurement depends to a large extent on the nature and size of the drift. Large drift, such as logs, and tree branches, may necessitate haste in making observations in order to avoid the loss of measuring equipment and may thereby cause uncertainties in the observations of both depths and velocities. There is the possibility that fine drift, collecting about the shaft and in the bearings of the meter, may seriously affect its operation; and the accumulation of drift on the measuring line during the time required to make the velocity observation, with the resulting increased pressure of the water on the additional area, tends to raise the meter out of its true position. The presence of aquatic growth in the measuring section not only may interfere with the operation of the meter but may also seriously affect the distribution of velocities, particularly near the bed of the stream. A meter used in making discharge measurements when drift and aquatic growth are present should be inspected frequently and given spin tests of performance.

MEAN GAGE HEIGHT FOR A DISCHARGE MEASUREMENT

The mean gage height for a discharge measurement is one of the coordinates used in plotting the measurements that establish the discharge rating curve. An accurate determination of the mean gage height for a measurement is therefore as important as an accurate measurement of the discharge in providing the basic data for determining the stage-discharge relation.

The gage height for a discharge measurement should always be referred to the gage that is used in obtaining the records of stage. At stations having auxiliary gages, the stages indicated by those gages should also be recorded.

Before beginning a discharge measurement, the gage height should be observed and any available information as to changes in stage that are likely to occur before completion of the measurement should be given proper consideration. An inspection of the recorder graph, if the station is equipped with a water-stage recorder, or a second reading of a nonrecording gage after a short interval of time might give an indication of probable changes in stage. It is inadvisable to make a discharge measurement at a time of rapidly changing stage such as frequently occurs on some streams subject to power operation. If it appears that a large change in stage is about to occur, it may be desirable to postpone the measurement until the flow becomes stabilized. Changes in stage downstream from a dam at which power is developed may exist for some time after a steady flow is obtained at the dam. Discharge measurements at times of high water usually must be made during a rising or falling stage, and it then becomes necessary to determine the mean gage height for the measurement. A rising or falling stage is common on natural streams, although the amount of change during the time required for a measurement may not be great enough to necessitate more than minor adjustments in the results, except for measurements on power-regulated streams and on any streams during times of rapidly changing stage caused by storm run-off.

In measuring discharges during constant or nearly constant stages, there is ordinarily no difficulty in deciding on the gage height that corresponds to the measured discharge. The observed gage heights at the start and finish of the measurement, and the time when those gage heights are observed, should be recorded in the proper places on form 9–275c (see p. 62). If the change in stage is 0.1 foot or less, and if the measurement has progressed continuously from start to finish, the mean gage height ordinarly can be taken as the arithmetical average of the two observations. If a considerable change in stage has occurred or if a major part of the measured discharge relates more closely to one than to the other of two observed stages, the proportional parts of the measured discharge and the stages to which they more nearly relate should be taken into consideration by computing a weighted mean gage height. Additional observations of stage between the times of starting and finishing the measurement may be necessary if there is very much change in stage or if surge or wave action appears to affect the accuracy of the observations. These additional observations and the times they are made should be recorded on form 9–275c; the time of each such observation should be recorded also in the first column of form 9–275 (p. 59), on the line immediately below the record of the velocity observation last made before the gage was read. The services of a gage reader may be necessary for obtaining records of stage during measurements at stations where the gage is nonrecording, the observations of stage to be made at regular intervals of time, say every 15 or 20 minutes. If a graph of gage heights is to be developed from an observer's readings of a nonrecording gage or if the engineer depends upon the water-stage recorder for a graph of gage heights during the measurement, he should record the time by his watch on form 9–275 at least once every half hour or for every page of his notes. From these data the observations of stage can be weighed in proportion to the discharge measured between each two gage-height observations or between selected points on the stage graph. This method of computing a weighted mean gage height is generally satisfactory if the changes in stage are not excessive. It is customary to plot a graph of the stage during the measurement on a sheet of field-note-size cross-section paper, either by plotting the observed gage readings or by making an enlarged copy from the water-stage recorder. There is usually room on this sheet for the actual computations in obtaining the weighted mean gage height; the sheet should then be numbered and attached to the notes for the discharge measurement. If a copy of the recorder graph is made in the field for computing a weighted mean gage height, it should be checked in the office by comparison with the original chart after the chart is available there.

Discharges as measured in the several partial sections during changes in stage may also be adjusted so as to obtain a computed discharge corresponding to a constant stage. In this method of adjustment any stage between the start and finish of the measurement may be selected as the stage of the measurement, and the discharges measured in the several sections can then be adjusted to correspond to that stage. However, it is preferable that the stage selected be intermediate between the start and finish of the measurement and approximately a mean stage for the time of the measurement. To adjust the partial discharges to those that would have been measured at the selected stage, multiply each measured partial discharge by the ratio of the total discharge at the selected stage to the total discharge at the stage of the partial discharge. An approximate rating curve may be used in this adjustment. The sum of the adjusted partial discharges may be used as the adjusted discharge of the measurement corresponding to the selected stage. One of the basic assumptions underlying the method of adjusting the discharge is that for the range of stage and discharge during the measurement the partial discharges in the several partial sections of the channel remain in the same proportion to each other. A second assumption is that the rate of change in stage is approximately constant during the measurement. The successful application of this method depends largely on the closeness with which the actual conditions approach these two assumptions. Somewhat greater refinement may be made in this method by the use of individual rating curves for the partial sections in adjusting the partial discharges.

If a discharge measurement is made at a considerable distance from the gage during a period of rising or falling stage, the discharge passing the gage at the time the measurement is made will not be the same as the discharge at the measuring section because of the effects of channel storage between the measuring section and the gage. A correction for the channel storage may be applied to the measured discharge by adding to or subtracting from the measured discharge a quantity equal to the product obtained by multiplying the area of the water surface between the measuring section and the gage by the rate of change in stage expressed in feet per second. If the measurement is made below the gage, the correction will be plus for rising stages and minus for falling stages; if made above the gage, it will be minus for rising stages and plus for falling stages. The mean stage at the gage for the time of measurement is the gage height to be used with the adjusted discharge obtained by this method.

If under the same conditions, it is desired to make a time adjustment in order to find the gage height corresponding to the measured discharge instead of adjusting the discharge to correspond to the gage height at the time of the measurement as described above, the procedure is similar and consists of dividing the correction for the channel storage, which is in second-feet, by the rate of change of discharge at the gage in second-feet per hour. In applying the time adjustment, subtract the time-interval correction from the observed time at the gage if the measurement is made either below the gage on a rising stage or above the gage on a falling stage; and add the time-interval correction to the observed time at the gage if the measurement is either below the gage on a falling stage or above the gage on a rising starge.

The methods described above do not adjust the measurement for abnormal discharge due to an abnormal slope that is caused by rapidly rising or falling stages. They are, however, fairly statisfactory methods of adjustment for the effect of channel storage between the measuring section and the gage, if it can be assumed that there is no inflow or outflow because of the area between the two places and if the channel is fairly uniform in width and is without break in the slope of the water surface between the gage and the measuring section so that the same rate of change in stage is applicable throughout the distance.

The proper coordination of the gage height and the discharge because of the amount of change in stage is a separate and distinct problem from that of making adjustments due to variable slopes that are caused by changing discharge; therefore the relation of stage to discharge at the time a measurement is made should be determined before adjustments due to variable slopes are made.

SPECIAL METHODS

Situations may arise where it is not practicable to use a current meter, and it then becomes necessary to determine the discharge by other methods. For example, the determination of the discharge of a flood that has already passed, leaving the marks of its crest stages as the only tangible data with which to work, requires special methods. A flood may be in progress with no structure available from which a current-meter measurement can be made, or a flood measurement may be made in part by a current meter and completed by some other method. The engineer may be called upon to use a current meter for verifying the discharge as measured by a weir, orifice, flume, or other calibrated device and for assisting in the determination of coefficients applicable to such structures. In order that the engineer may meet these situations and others as they arise, he should be familiar with several of the generally recognized methods of determining discharge.

WEIRS

Measuring weirs are devices for determining the flow of water from measurements of the head or depth of water flowing over the crest. Weirs generally consist of a rectangular, triangular, trapezoidal, or other notch over or through which the water must pass. It corresponds to an artificial control for which the discharge rating may be made in a laboratory. If a laboratory rating for a weir is to be used in the determination of discharge without an actual calibration in place after construction, it is essential that the shape, crest, setting, and channel conditions for the weir used in the measurements should conform with those used in the laboratory.

The weir structure extends across the stream in the form of a dam, usually at right angles to the direction of flow. The top of a weir is referred to as the crest; the weir section is the cross section of the nappe taken in the vertical plane of the weir crest; and the depth of the water on the crest (measured just above the draw-down curve and referred to the height of the crest) is the head. A weir so designed that the nappe touches only the upstream edge of the crest is called a "sharp-crested weir," whereas a weir having breadth of crest that is contacted by the water is known as a "broad-crested weir." A weir having a crest that extends entirely across the channel of approach is known as a "suppressed weir;" a weir having a crest that does not extend entirely across the channel is known as a "contracted weir."

Weir measurements must include the observational data indicated in the formula used in computing the discharge over the particular type of weir. These data generally include the following: Head on the crest; length of crest and shape of the section; angle of side slopes, if any; nature of crest, whether sharp or broad and, if broad, the shape and width; height of crest above bed of channel; number of end contractions; width and depth of the approach channel; and the velocity of approach.

Permanent weirs are used by the Geological Survey as measuring devices on some small streams whose channels do not have suitable sections for accurate current-meter measurements. Care must be exercised to insure that the weir conforms in every respect to that for which the weir formula and coefficients were determined. Common sources of errors in the use of weirs as measuring devices are attributable to such conditions as leakage, inadequate channel of approach, inaccurate readings of the head, and improper setting or construction of the weir. The fact that a weir is constructed in exact accordance with a model tested in the laboratory is not complete assurance that the results obtained will be reliable, because conditions that prevailed at the time of construction are not necessarily permanent. Weirs usually require some attention to keep their crest free from debris. It is advisable, whenever possible, to verify the discharge computed by weir formula by occasional discharge measurements made by current-meter or other methods. Tables computed from formulas for various types of weirs have been published in a report of the Geological Survey [10] and in textbooks on hydraulics.

SLOPE AREA

The slope-area method of measuring the discharge of a stream consists of the determination of three basic factors: first, the area of the average cross section of a longitudinal reach of channel of known length; second, the slope of the water surface or the slope of the energy gradient in the same reach of channel; and third, the character of the stream bed so that a suitable roughness factor may be chosen. When these factors are known, the mean velocity of the stream may be computed by the Chezy formula $V=C\sqrt{RS}$. In this formula V represents the mean velocity in feet per second, S the slope or energy gradient, R the hydraulic radius in feet, and C a coefficient depending principally on the roughness of the stream bed and the hydraulic radius. The product of the velocity thus obtained and the area of the average cross section will be the discharge.

If the mean velocity does not remain constant from point to point along the reach of channel, the surface slope will not coincide with the energy gradient, and for those conditions the energy gradient should be used in place of the surface slope for the value of S in the Chezy formula. Therefore, whenever there is any appreciable difference in the areas of the cross sections within the reach, the surface slope, as measured, must be modified by the change in velocity head to obtain

[10] Horton, R. E., Weir experiments, coefficients, and formulas: U. S. Geol. Survey Water-Supply Paper 200, 195 pp., 1907.

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the energy gradient as the value of S. Since the velocity varies inversely as the area of the cross section, and the velocity head varies with the square of the velocity, the following formulas may be used to determine the value of S:

$$(1) \quad S_e = S_m + \frac{V_1^2 - V_2^2}{2gL}$$

$$(2) \quad S_e = S_m - \frac{V_2^2 - V_1^2}{2gL}$$

In the above formulas S_m represents the measured value of S, S_e the energy gradient, V_1 the mean velocity corresponding to area A_1 of the cross section at the upper end of the reach, V_2 the mean velocity corresponding to the area A_2 of the cross section at the lower end of the reach, L the length of the reach, and g the acceleration due to gravity. If V_1 is larger than V_2 formula (1) is used; if V_2 is larger than V_1 formula (2) is used. If the velocity at a downstream section is less than that at an upstream section and there is a transformation of kinetic energy into potential energy, it is customary to assume the actual recovery to be 50 percent of the theoretical recovery.

Of the two measurable factors S and R in the Chezy formula, the determination of S requires the greater precision. This factor is expressed by an abstract number computed by dividing the difference in feet of the heights of the water surface or energy gradient at the ends of the selected reach of channel by the length in feet of the reach. The differences in heights of the water surface from which the slope or the energy gradient may be computed are measured by means of gages or from reference marks, all of which are referred to a common datum. If the channel is straight and comparatively narrow and the slope of the water surface essentially uniform, a gage at each end of the reach is usually sufficient. In some reaches it may be advisable to have gages placed on the banks opposite the primary installations, or if information is desired regarding the uniformity of the slope or gradient line, gages may be placed at various strategic points along the reach. The gages should be protected from wave action and should be read simultaneously when determining differences in heights of the water surface. The length of reach that is required depends upon channel conditions, and as a fairly uniform slope or gradient is a prerequisite, it may be necessary to select shorter reaches than otherwise would be chosen. Seldom is it advisable to select a reach less than 1,000 feet long and, wherever possible, the reach should be of sufficient length to provide a difference of 1 foot or more in height of the water surface between the upper and the lower ends.

In determining the average area and the hydraulic radius for a reach of channel, enough cross sections should be measured to obtain representative averages. One such determination may suffice for an artificial channel of uniform cross section, whereas in a natural stream, variations in the channel may necessitate several measurements of the cross section at carefully selected points along the reach before reliable averages can be determined.

The formulas developed by Kutter and by Manning are those most commonly used for determining the coefficient C. Except for the inclusion of the factor S in the Kutter formula, the two formulas are practically identical. As examination of Kutter's formula shows that surface slopes greater than 0.0003 do not materially affect the value of C, it may be considered that for any stream having a slope greater than 0.0003, the formula that is used is largely a matter of choice. These formulas, with R and S representing the same factors as in Chezy's formula, and with n representing the roughness factor of the stream bed, are shown below. According to Kutter's formula

$$C=\frac{41.65+\frac{1.811}{n}+\frac{0.00281}{S}}{1+\left(41.65+\frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

In Manning's formula

$$C=\frac{1.486}{n}R^{1/6}$$

The accompanying table of values of n for canals and ditches and for natural streams, prepared by R. E. Horton,[11] is of assistance in selecting the value of n for use in either Kutter's or Manning's formula. Good judgment is essential in selecting the values of n and each of the factors affecting the coefficient must be given individual consideration.

TABLE 5.—*Values of n for canals and ditches and for natural streams* [1]

Surface	Condition of stream bed			
	Best	Good	Fair	Bad
Canals and ditches:				
Earth, straight and uniform	0.017	0.020	[2] 0.0225	0.025
Rock cuts, smooth and uniform	.025	.030	[2] .033	.035
Rock cuts, jagged and irregular	.035	.040	.045	------
Winding sluggish canals	.0225	[2] .025	.0275	.030
Dredged earth channels	.025	[2] .0275	.030	.033
Canals with rough, stony beds, weeds on earth banks	.025	.030	[2] .035	.040
Earth bottom, rubble sides	.028	[2] .030	.033	.035
Natural stream channels:				
1. Clean, straight bank, full stage, no rifts or deep pools	.025	.0275	.030	.033
2. Same as (1) but some weeds and stones	.030	.033	.035	.040
3. Winding, some pools and shoals, clean	.033	.035	.040	.045
4. Same as (3), lower stages, more ineffective slopes and sections.	.040	.045	.050	.055
5. Same as (3), some weeds and stones	.035	.040	.045	.050
6. Same as (4), stony sections	.045	.050	.055	.060
7. Sluggish river reaches, rather weedy or with very deep pools	.050	.060	.070	.080
8. Very weedy reaches	.075	.100	.125	.150

[1] As used by Horton.
[2] Values commonly used in design.

[11] Horton, R. E., Some better Kutter's coefficients: Eng. News, vol. 75, pp. 373 and 863, 1916.

Another method that has been used by engineers of the Miami Conservancy District of Ohio [12] in selecting the proper roughness coefficient is as follows:

The coefficient 0.025, which is applicable for a smooth uniform, straight channel in gravel, free from vegetation or other obstructions, is selected as a base figure. This coefficient may be increased 20 percent or more by irregularities in the wetted perimeter, irregularities in cross section, or the presence of vegetation. It may be increased 10 percent or more by curvature in alinement or by obstructions in the channel. By using this method of adjustment, a coefficient should be obtained that is applicable to the conditions in the channel reach.

Further assistance in the selection of n may be obtained by examining the results of actual determinations of coefficients of roughness by Ramser.[13]

The slope-area method, or modifications of it, may be used in measuring flow where there are such variations in the surface slope that the relation of stage to discharge is not stable. This condition may occur in natural streams where the stage is affected by backwater; also in artificial channels such as canals, flumes, and tailraces. In most situations where the slope-area method can be used successfully, the hydraulic conditions are such that good current-meter measurements can be made. If a suitable section is available, a series of current-meter measurements will assist not only in establishing a stage-slope-discharge relation but will also provide information from which C in Chezy's formula or n in Kutter's or Manning's formula may be derived.

One of the most important uses of the slope-area method in Survey work is for the determination of a flood discharge after the flood has passed.

FLOATS

The float method of measuring velocity consists of observing the time required for a floating body to traverse a course of known length and noting its position in the channel. This floating body may be a specially designed surface float, a subsurface float, a rod float, a tube float, or selected pieces of drift or ice cakes floating with the current.

A surface float is designed to move with the same velocity as the surface water. Because of its lightness, this type of float may be very sensitive to air disturbances. It indicates only the velocity of water at the surface; consequently a coefficient must be applied to the observed surface velocity to obtain the mean velocity in the

[12] Houk, I. E., Calculation of stream flow in open channels: Miami Conservancy District Tech. Repts., part 4, p. 143, 1918.

[13] Ramser, C. E., Flow of water in drainage channels; the results of experiments to determine the roughness coefficient n in Kutter's formula: U. S. Dept. Agr. Tech. Bull. 129, p. 102, November 1929.

section. The proper coefficient is selected with considerable uncertainty.

A subsurface float consists of a submerged float attached to an indicating surface float by an adjustable line. In channels having a uniform longitudinal section for which the position of the mean velocity in the vertical is known, this type of float will measure directly the mean velocity if the submerged float is placed at the correct position. Allowances should be made for the accelerating effect of the connecting line and the surface float.

Tube and rod floats are designed to measure directly the mean velocities in the paths traveled by them, but they must not be permitted to touch the bed. Except for longitudinal sections having smooth beds and uniform depths, neither of these types will register the effect of the slower moving water near the bed of the stream; therefore a coefficient less than unity will be necessary for reducing the velocity so observed to the mean velocity in the section.

Selected pieces of drift or ice cakes will indicate velocity more reliably than the ordinary surface float. The results are comparable to those obtained with the floating tube or rod if used where coefficients are required. Floating ice cakes and heavy drift comprising logs and trees that are largely submerged hold their courses well against surface disturbances and if observed at a sufficient number of points distributed across the width of the stream will give a fairly accurate measure of the surface velocity. The surface velocity so measured requires the use of a coefficient to obtain the mean velocity.

If the hydraulic conditions are such as to insure good measurements by the float method, equally good or better results are generally obtainable with the current meter if its use is practicable. The float method is used by the Geological Survey only in measurements of flood discharge where excessive velocities, depths, and floating drift prohibit the use of a current meter.

VENTURI METER

The venturi meter consists essentially of a venturi tube and some form of indicator which, when properly calibrated, will register the discharge past a constriction in the tube. The principle of the venturi tube was stated by J. B. Venturi in 1797 and was first applied by Herschel[14] to the measurement of the flow in pipes in 1887. In its practical application the venturi meter consists of a closed conduit that is gradually contracted to a throat. This contraction is generally followed, although not necessarily, by a gradual enlargement to the original size. The principle by which the velocity is determined is

[14] Herschel, Clemens, The venturi water meter: Am. Soc. Civil Engr. Trans., vol. 17, p. 228, 1887.

based on Bernoulli's theorem that the energy head at any section in a flowing stream is equal to that at any other downstream section plus the intervening losses. The constriction or throat in the tube converts a part of the pressure head at a point just above the constriction into velocity head at the throat, thus creating a difference in pressure head at those respective points and providing the index by which the velocity and the corresponding discharge may be computed. This difference in pressure head is measured by means of two piezometers, one connected to the section in the pipe above the constriction and the other to the section at the throat. Owing to friction losses which occur between the two sections, a coefficient must be used depending upon the diameter of the tube, the material used in its construction, and the velocity of the water. This coefficient does not differ greatly from unity and in properly constructed tubes made of clean cast iron will range from 0.97 to 0.99. When this coefficient and the difference in pressure heads are known, the discharge may then be computed by the following formula:

$$Q=C\frac{A_1A_2\sqrt{2g(h_1-h_2)}}{\sqrt{A^2_1-A^2_2}}$$

where Q equals discharge, A_1 the area of section above contraction, A_2 the area at throat, h_1 the pressure head at section A_1, h_2 the pressure head at section A_2, and g the acceleration due to gravity.

In the construction of the venturi tube the length of the converging part usually ranges from 2 to 2½ times the diameter of the main pipe, and the area at the throat from ¼ to ¹⁄₁₆ that of the pipe. Such dimensions will produce a velocity at the throat ranging from 4 to 16 times the velocity at the entrance of the tube. For specific values of C, A, and A_2, a recording device may be so designed that it will give a continuous record of discharge. The design of the tube should be such that the velocity at the throat will be not less than 3, or more than 40 feet per second if accurate results are to be obtained from the recording device.

The venturi meter is recognized as an accurate means of measurement and is used extensively for measuring the outflow from reservoirs. One of its advantages is that it will measure water heavily laden with silt or impurities. Owing to the absence of wearing parts, this meter is not subject to a changing coefficient. Venturi meters are not ordinarily used by the Geological Survey, but discharge records obtained by their use are occasionally published in the Survey's water-supply papers.

PARSHALL MEASURING FLUME

The Parshall measuring flume, formerly known as the improved venturi flume and later named after Ralph L. Parshall, its inventor and principal developer, is designed for the purpose of measuring water in open conduits. It consists essentially of a contracting inlet, a parallel-sided throat, and an expanding outlet, all of which have vertical side walls. The inlet has a level floor; the throat a floor which slopes downward; and the outlet a floor which slopes upward. The crest is the downstream end of the level floor, and its length is the distance between the vertical walls of the throat. Two gages are used—one in the side wall of the contracting inlet at a point two-thirds the distance from the crest to the upper end and the other placed slightly upstream from the lowest point of the floor in the throat. Both gages are on the same side of the flume and are referred to the crest as the common datum. Because of the depression in the throat floor, negative readings on the throat gage may occur under certain conditions.

There are two general conditions of flow through the flume, namely, the condition when the water at the throat gage is lower than the crest, and the condition when the water at the throat gage is higher than the crest. Laboratory tests have shown that the discharge under either condition may be closely approximated by formulas if the head registered by the throat gage does not exceed 70 percent of that registered by the inlet gage. Within this limitation, the length of the crest and the head registered by the inlet gage are the only observations necessary in computing the discharge, the throat gage being used only as an index of the percentage of submergence of the crest. Dimensions, capacities, formulas, tables, plans and specifications, laboratory tests, and other information regarding the Parshall measuring flume have been published by Parshall.[15]

Although the Parshall flume was designed primarily for measuring the discharge in ditches and canals where it is essential to keep the loss of head at a minimum, it may be used as a low-water control section for measuring small streams where the use of a current meter is impracticable. A small portable flume without the expanding outlet has been satisfactorily used by the Survey in the measurement of small flows. Flumes of different design or construction from those for which laboratory calibrations are available should be calibrated before they are used as measuring devices.

SUBMERGED ORIFICE

The submerged orifice is the constricted part of a structure used for measuring the discharge in open channels. The structure is placed

[15] Parshall, R. L., The improved venturi flume; Am. Soc. Civil Eng., Trans., vol. 89, pp. 840–880, 1926; Measuring water in irrigation channels: U. S. Dept. Agr. Farmers' Bull. 1683, pp. 8–17, January 1932; Parshall flumes of large size: Colo. Agr. Coll. Exp. Sta. Bull. 386, 55 pp., May 1932; and The Parshall measuring flume: Colo. Agr. Coll. Exp. Sta Bull. 423, 84 pp., March 1936.

in the stream so that all the flowing water will pass through the constricted opening, which must be completely submerged by the tail water. The discharge through a submerged orifice may be computed by the formula $Q = c_q\, a\sqrt{2gh}$, where Q is the discharge, a the area of the orifice, h the effective head, which is the difference in the water surface elevations of the head and tail waters, g the acceleration due to gravity, and c_q the coefficient of discharge. In this formula c_q is a coefficient to correct for omission of factors that cannot conveniently be measured individually but are known to exist. Numerous experiments have been made to determine this coefficient for different forms of orifices under different heads, and in general they show that c_q is greater for low heads than for high heads, greater for rectangular orifices of unequal sides than for square orifices, and greater for square orifices than for circular ones. The usual range of the coefficient c_q is from 0.59 to 0.63 or more; an average value of 0.61 is frequently used for standard submerged orifices.

The submerged orifice is used mostly in measuring the discharge in locks, waterways, tide gates, and canals, where the available head is limited. Its use causes only a small loss in head and the results are considered accurate, if the orifice is properly installed and the conditions under which it is designed to function are maintained throughout its use. A negligible velocity of approach, complete orifice contractions, and an effective head large enough to minimize any error involved in its determination are essential factors in obtaining accurate results. Streams laden with silt and sand may be subject to variation in the velocity of approach because of deposition in the forebay upstream from the orifice. Although the submerged orifice is seldom used as a measuring device by the Geological Survey, it is sometimes used on irrigation projects and Survey engineers are frequently called upon to check its operation.

CHEMICAL METHODS

If the measurement of the velocity or discharge involves the introducing a chemical into the stream the procedure is known as a chemical method of measuring discharge. Although several such methods have been devised, the two most frequently used are the salt-velocity and the salt-dilution methods, both of which, properly applied, have been found by numerous experiments to give highly accurate results under favorable conditions. One of the factors limiting their use is the expense involved, particularly on large streams.

Salt velocity.—The salt-velocity method of measuring discharge devised by Professor C. M. Allen in collaboration with E. A. Taylor[16]

[16] Allen, C. M., and Taylor, E. A., The salt velocity method of water measurement: Am. Soc. Mech. Eng. Trans., vol. 45, p. 285, 1923.

is based on the fact that salt in solution increases the electrical conductivity of water. In measuring the discharge by this method the salt solution is admitted under pressure, usually through pipes leading to a group of pop valves placed throughout the section to insure immediate distribution of the solution. Two wires fastened to each of the pop valves in such a manner as to contact the salt solution the instant it is ejected constitute electrodes at each valve. These electrodes are connected as a group to a galvanometer which records, with respect to time, the change in electrical conductivity of the water. A second group of electrodes installed at a known distance downstream is also electrically connected to the recording galvanometer. The time of transit of the salt solution between the two sets of electrodes is obtained from the graph.

The graph produced at the upper section is usually rectangular in shape, whereas that for the lower section rises sharply to a peak and then slowly tapers off on a curve tangent to the constant conductivity line. The time required for a slug of salt solution to traverse the distance between the two groups of electrodes is determined from the graph by defining the centers of the areas of the two parts above the constant conductivity line. These center-of-area points correspond to the position of the center of gravity of the solution as it passes each group of electrodes. The volume of water in the reach between the two groups of electrodes, divided by the time of transit of the solution, gives the discharge directly. This method has been successfully applied to open conduits with constant cross section, although it is more generally used in determining the flow in closed conduits.

Salt dilution.—The salt-dilution or titration method of determining discharge consists of adding a concentrated solution of salt to a stream and, by analysis, determining its dilution after it has had sufficient time to become uniformly distributed throughout the stream. The solution is added at a constant rate during the time the samples are taken, and no measurements of area or distance are necessary. The weight of salt that passes in each second at the point where samples are taken must equal the combined weights of salt ordinarily carried by the stream and the salt added in concentrated solution. This may be expressed by the formula $WX+W'X'=(W+W')X''$. In this formula the constituent parts have the following meanings:

W = Weight of water discharged per second.
W' = Weight of salt solution added per second.
X = Percentage (by weight) of natural salt already in stream.
X' = Percentage (by weight) of salt in concentrated solution.
X'' = Percentage (by weight) of salt in sample after mixing.

This method is particularly applicable for determining the flow of turbulent streams where accurate current-meter measurements are difficult to obtain, as the turbulence materially assists in mixing the salt solution with the water. It has been used extensively in measuring the flow of small mountain streams in Europe. This method and the design of a portable tank for injecting the salt solution have been described by Rouse.[17]

CONTRACTED OPENINGS

Where a stream passes through a contracted opening having a cross section less than the normal area of the channel, a part of the potential head is converted into velocity head. As a result of this conversion, the water surface drops rather suddenly at the entrance of the contracted opening. This drop may be increased slightly in passing through the opening if the minimum cross section in the opening is below the entrance. Water flowing in such a manner represents a condition similar to the flow through a venturi meter or a Parshall flume, and in accordance with Bernoulli's theorem, which states that the sum of the pressure head, friction head, and velocity head is a constant, the following formula applies:

$$Q=kA\sqrt{2g\left(H+\frac{V^2}{2g}-h_f\right)}$$

In this formula Q equals the discharge in feet per second, k the coefficient of contraction, A the area of the contracted opening in square feet, H the drop in the water surface, in feet, $\frac{V^2}{2g}$ the head in feet due to velocity of approach, and h_f the loss in head in feet, due to friction. In determining A, the section having the highest velocity should be chosen and those parts of the section eliminated which do not contribute to the flow. If the entrance to the contraction has sharp edges or square corners, a coefficient of contraction k, ranging from 0.90 to 0.95, should be applied to the area. The surface drop H is best determined by defining a longitudinal profile of the surface slope for a length of channel extending through the contraction to points a short distance above and below. Two lines may then be drawn, one representing the average slope of the stream above the dropoff and the other the average slope below the dropoff. If there are standing waves in the contracted section or below it, their effect must be eliminated in obtaining the average slope of the water surface below the contraction. The vertical difference in the positions of these lines when both are extended to the most contracted part of the cross section will be the value of H to use in the formula. If the head $\frac{V^2}{2g}$ represented by the velocity of approach is not readily obtainable from the observed data, a value for V may be assumed and used in determining Q. By divid-

[17] Rouse, Hunter, Research Institute for hydraulic engineering and water power: Am. Soc. Mech. Eng., Trans., Hydraulic Section, p. 39, May 15, 1932.

ing Q thus determined by the area of the cross section of the approach channel, a new value for V will be obtained which can be used in computing a new Q. Successive approximations of this nature will finally satisfy both the equation and the relation $Q=V A$, where A is the area of the approach channel. The only serious uncertainty in employing the contracted opening method under favorable conditions lies in the determination of the friction head h_f. However, where the contraction is short and unobstructed and the surface drop amounts to 1 foot or more this factor has a relatively small influence on the final results except in the case of high velocities where it is desirable to make a deduction covering the loss of head due to the additional friction. As frictional resistance increases nearly as the square of the velocity, the additional friction slope may be calculated for a reach of channel equal in length to the contracted section plus the surface drop. The average velocity in this length may be taken as the mean of the velocity of approach and the velocity in the most contracted section, or, better still, it may be taken as equal to the square root of the average of both the square of the velocity of approach and the square of the velocity in the most contracted section.

This method of computing discharge in open channels is occasionally used in determinations of flood discharge.[18] It is also of assistance in computing the size of openings for prospective bridge structures.

VELOCITY-AREA METHOD

The velocity-area method of determining flood discharge is useful in extending the discharge curve beyond the point where it is defined by discharge measurements. This is accomplished by establishing the area curve up to flood stage for the regular high water measuring section, and by also extending the velocity curve to the same stage by estimates based on a thorough study of the flow characteristics for the individual stream. The product of the values of area and velocity selected from their respective curves at given stages gives the corresponding values of discharge. In establishing the area and velocity curves, all available determinations of area and velocity from discharge measurements made at the high-water measuring section are plotted to the same scale of gage heights and each curve is developed up to, or slightly beyond, the point where it is defined by measurements. The areas for high stages are computed from the cross-section profile of the measuring section. The extension of the velocity curve above the point of definition by measurements is based on studies of flow characteristics, such as the slope of the stream bed or water surface; the presence of contractions, bends, dams, and vegetal

[18] Houk, I. E., Calculation of flow in open channels: Miami Conservancy District Tech. Repts., pt. 4, pp. 53–59, 262–272, 1918.

growth; the possibility of backwater from downstream tributaries; the extent of overflow areas; and the depth of water on such areas.

The successful application of this method requires a thorough analysis and careful appraisal of fundamental flow factors and a knowledge of the channel conditions at the river-measurement station, especially in regard to the manner in which the width and depth of the channel vary with changes in stage, also the factors affecting changes of velocity with changes of stage, such as rapids or falls, which may tend to increase velocities, or contractions of channel downstream from the gage, which may tend to decrease velocities. The cross section of the channel at flood stage, including all overflow and bypass channels, should be determined by instrumental surveys. Pertinent conditions, such as backwater from lower tributaries and changing influences of contracted sections of the channel below, must be visualized and their effects appraised as accurately as possible from available information.

The conditions most favorable for the accurate extension of a rating curve consist of well-defined rapids or riffles below the station at all stages and a uniform increase of channel cross section as the stage increases, without abrupt changes in area or addition of overflow channels—in other words, a general uniformity of those channel conditions which control the stage and discharge relations at the gage. The construction and study, in connection with other data, of a curve showing the relation of a product of the area of the channel cross section multiplied by the square root of the mean depth $(A\sqrt{d})$ to the corresponding stage has often proved helpful in the extension of rating curves. The logarithmic plotting of stage and discharge may also be helpful in making the extension. In this method the stage and discharge are both plotted on logarithmic scales. The observed stages, or gage heights, are adjusted to conform to the physical conditions of the site, usually by the addition or subtraction of a constant corresponding to the gage height of zero flow. For example, at a river-measurement station with a riffle control of uniform elevation across the channel the gage height of zero flow should be subtracted from each observed gage reading before it is plotted on a logarithmic scale. The graph of the relation thus developed usually tends to be a straight line or a very flat curve.

Radical changes in downstream conditions that control the velocity or stages, or abrupt increases in the area of channel cross section such as result from overflow banks, may interfere seriously with the reliable application of these methods of analysis. In general the results thus obtained are about as likely to be too large as too small. Notwithstanding the application of the best available knowledge and experience, the results obtained by extension of the rating curve may be subject to considerable error, especially if the extension is carried far beyond the range defined by current-meter measurements. Results obtained by this method should therefore be used with appropriate caution.

COMPUTATION OF DISCHARGE OVER DAMS

It is generally recognized that records of stage at dams afford one of the most reliable means of determining flood discharge for places on rivers where current-meter ratings are not available. For a dam having a uniform section similar in shape to the section of a dam for which the rating or discharge coefficients are known, it is generally possible to convert records of stage into records of discharge with a good degree of accuracy by satisfying the general formula.

$$Q=CLH^{3/2}. \qquad (1)$$

In this formula Q is the discharge in second-feet; C, the coefficient for the dam; L, the length of the crest in feet; and H, the total head in feet. The total effective head is the sum of the pressure head h_p and the effective velocity head h_v.

$$h_v=\alpha\frac{V^2}{2g}\sin\theta. \qquad (2)$$

$$H=h_p+\alpha\frac{V^2}{2g}\sin\theta. \qquad (3)$$

In the above formulas, V is the average velocity in the approach channel, θ is the angle between the crest of the dam and the direction of the current, and α is a correction factor due to unequal distribution of velocity. The value of α in an unobstructed stream has an approximate range of 1.1 to 1.4, but back of a dam or other obstruction it may be 2.0 or more.

In the practical application of the basic formula (1), the accuracy of the results depends largely on the selection of the proper coefficient C for the particular dam involved. Values of C have been determined by experiments for dams and models of different shapes and it has been found that, in general, C varies with the head. Discharge measurements in the vicinity of the dam would be helpful in determining values of C for the heads at which the measurements are made. Care should be taken to see that the flow on which C is based is sufficiently large to reduce to a minimum the effect of viscosity, capillarity, and surface tension upon the coefficient. The effect of these factors on C is greatest when the depth of the crest is small. Material assistance in the selection of values of C may be obtained from the results of experiments already published by the Geological Survey.[19]

[19] Horton, R. E., Weir experiments, coefficients, and formulas: U. S. Geol. Survey Water-Supply Paper 200, 195 pp., 1907.

The velocity of approach in the channel above a dam may be determined by trial solution, using the fundamental formula $Q=AV$, in which Q equals discharge, A equals the cross-sectional area of the channel of approach, and V the velocity. The discharge Q, for first trial, is usually approximated by solving the base formula (1). After a satisfactory figure for the velocity of approach has been obtained by a sufficient number of these trial approximations it is then converted into velocity head by formula (2).

In determining flood discharges from records for dams it is often found that the observed depth of the water over the dam exceeds stages for which ratings or coefficients are available. Because of the large variations in coefficients used in formulas with the three-halves power of the head, there may be considerable uncertainty in regard to the proper coefficients to use for high heads, even though the coefficients for low heads are fairly well established. For such situations it is often helpful to recast formula (1) where C is a variable so as to obtain the formula

$$Q=KLH^n \qquad (4)$$

in which both K and n are constant for the same dam but n may be slightly greater or less than the three-halves power. The results of laboratory experiments [20] for the determination of C may be investigated for the purpose of ascertaining the discharge equations of the various models when expressed in formula (4). Those data, if plotted logarithmically, generally define a straight line or a very flat curve. The derivation of the numerical equation is simple where the logarithmic plotting produces a straight line, as the value of Q when $H=1$ ($\log H=$zero) represents the coefficient K, and the exponent n is the tangent of the angle between the straight line and the axis of $\log H$.

The application of this method has been described by Martin [21] and Pierce.[22]

CALIBRATION OF WATER WHEELS AND VALVES, GATES, AND SLUICES

The demand for records of discharge at specific places occasionally necessitates the calibration of water wheels and valves and the determination of discharge through gates and sluices as a means of determining all or a part of the total flow. In this procedure the following major factors must be considered: (1) the period during which each unit is in operation; (2) the extent of the opening for each unit; (3) the head and tail water elevations (or the head on the center of pressure is case the tail water is below the opening) for

[20] Horton, R. E., op. cit.

[21] Martin, W. F., Discharge measurements and formulas for some large overflow dams: Eng. News, vol. 64, pp. 321–325, Sept. 29, 1910.

[22] Pierce, C. H., Am. Soc. Civil Eng. Trans., vol. 94, pp. 826–829, fig. 27, 1930.

each period of operation of the unit; and (4) the method to be employed in calibrating the individual unit. If the unit is automatically operated a recording gage connected to the operating mechanism in some instances can be used to record graphically both the changes in the opening with regard to time and the extent of the corresponding opening. For a water wheel or valve, the extent of opening is usually expressed in percentage of the total. If the openings are not automatically controlled, a log should be kept by the operator in which the above information is recorded. If the gates are automatically controlled and subject to frequent change, the record of the operating head is best determined by means of two water-stage recorders—one on the tailrace and the other on the forebay. The graph produced by the tailrace gage will usually reflect almost instantaneously the changes in the unit openings and may be used for checking the time determined by other means.

In calibrating an individual unit a series of discharge measurements is made covering the range of openings and for each measurement the mean operating head is determined. In order to develop a curve applicable to the individual unit under operating conditions, the head, as measured for each discharge measurement, must be changed to a common head and the corresponding discharge computed. This may be accomplished by direct proportion based on the fact that the discharge varies as the square root of the head. In plotting this relation it is the usual practice to show the extent of opening as the ordinate and the discharge for the common head as the abscissa. To facilitate the application of this curve a rating table may be computed showing the discharge in cubic feet per second for each opening for a series of operating heads. The number of different operating heads selected in this series will depend upon the total range of operating head and the accuracy desired in the computations; where several units are in operation each unit should be calibrated in a similar manner. Check measurements should be made from time to time to determine any changes that may have taken place.

In calibrating the units of a hydroelectric power plant it is generally desirable to establish a relation between discharge and the power output. This may be done by determining the average output of each unit during the period of the discharge measurement. The effective head must be known, and each discharge measurement should be made while the units are running at or near constant load. For best results, efficiency ratings should be made for the individual units and for the combinations of units as ordinarily used. After these relations are established, the kilowatt-hour output for the day may be used as an index in comparisons of records at nearby gaging stations on the same stream and in computations of discharge for periods when the stage-discharge relation is affected by ice or the gage-height record is missing. Where a record of power output is used for computations or comparison of discharge, it must be known that the units are carrying the total flow of the stream during the period involved or, if water is being discharged through sluice gates or over the dam, the amount of such discharge must be known and added to the discharge through the turbines.

VOLUMETRIC METHOD

The volumetric method of measuring discharge is considered the most accurate of all methods with the possible exception of weighing. It consists either in observing the time required to fill a container of known capacity, or in determining the rate at which a calibrated tank or reservoir will fill. The volumetric method may be used advantageously in measurements of small flows in the calibration of weirs and artificial controls. A modification of this method has been used in measuring the discharge over broad-crested weirs and dams where the depths are small and the flow is otherwise unmeasurable. The equipment for these measurements consists of a diverting box, a leader pipe, and a calibrated tank. The diverting box may be made of sheet metal and should be about 6 inches high by 9 inches wide, with an opening of about 2 feet at the upper end. If the depth of water at the place of measurement is greater than about 0.2 foot, the width of the oppening should be correspondingly less; for a depth of 0.5 foot the width should not exceed 2 inches. The lower end is equipped with a 6-inch downspout to which is fastened a 4-inch leader pipe connecting the diverting box and the calibrated tank. The downspout is constructed so that it will divert the water away from the tank while the diverting box is being adjusted. To allow the water to pass into the diverting box without leakage or waste, and to avoid any effect from obstruction of the flow, the open end of the diverting box is placed at the downstream edge of the crest of the weir or dam just below the lip. After the equipment has been properly arranged and the flow through the diverting box has become stabilized, the water is allowed to flow into the calibrated tank for a definite length of time, or until the tank is filled, and a record is made of the quantity of water that is collected and the corresponding time. The equipment is then moved to other sections of the weir or dam, where similar measurements are made. The number of observations that are necessary will depend upon the shape of the crest and variations in the depths and velocities. Measurements at several places along the crest will determine the discharge at those places so that the discharge at intermediate points may be determined by interpolation. If the crest is level, and the flow appears to be uniformly distributed throughout the total width, only a few measurements may be necessary.

The use of this method has limitations. Its adaptability will depend upon the type of dam and the distance from the crest to the apron on which the calibrated tank must rest. The nature of the equipment and the method of operation is inadequate for measuring flows where the depth on the crest is greater than about 0.5 foot. This method of measurement, with equipment similar to that described above, has been used by engineers of the South Charleston district of the Geological Survey.

DETERMINATION OF DISCHARGE BY ADJUSTMENTS FOR GAIN OR LOSS IN STORAGE

Where the capacity, gain or loss in storage, and discharge releases from a reservoir are known, the runoff above the outlet of the reservoir may be computed in the following manner: Ascertain the change in contents in the reservoir during the 24 hours by entering the capacity table with the reservoir gage heights at the beginning and end of the day; convert the gain or loss in storage into second-feet and add or subtract this figure (depending on whether the storage has increased or decreased) to the observed outflow discharge. To determine the yield of a drainage basin accurately by this method it is desirable that water-stage recorders be established on the reservoir and below the outlet, that a stage-discharge relation be developed to determine the outflow discharge, and that an accurate capacity table be prepared for the reservoir. The amount of evaporation from the water in the reservoir should be taken into consideration if the area of the reservoir is large and it is desired to compute the natural yield of the drainage area. In adjusting discharge on a daily basis it will be necessary at times to make slight adjustments for the effects of wind on the reservoir stages. Ordinarily this effect may be detected by careful observation of the graph of reservoir stages.

LABORATORY MODELS

Where the characteristics of all the elements establishing the stage-discharge relation at a gaging station are known, it is possible to reproduce similar conditions in a model built to scale for laboratory study so that, by observing the performance of the model under different rates of flow, a discharge-rating curve that is representative of field conditions may be developed for the entire range in stage. Although this method has been used in some of the districts of the Geological Survey, the expense and extensive studies that are involved has limited its application to those regions where the

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discharge of small mountain streams is extremely valuable for domestic and irrigation purposes and where the development of high-water ratings by other methods is impracticable.

DETERMINATION OF FLOOD DISCHARGE

Measurement of flood flows require special methods which are not as well developed and understood as the methods used in measurements at ordinary stages. Many streams rise and fall so rapidly that the time is insufficient for current-meter measurements at high stages. Means of transportation and communication may fail during floods so that engineers cannot reach those places where measurements of flood flows need to be made, or the value of an engineer's opportune arrival at the time of crest stage may be nullified by the presence of floating debris or by the destruction of the bridge or cableway from which measurements are usually made, so that a current-meter measurement of discharge may be impracticable, if not impossible. Therefore, with no direct measurements available, it may be necessary to determine flood flows by means of surveys and information obtained after the flood has passed. As the accuracy of such determinations will depend largely upon the accuracy of the surveys and the extent of the information that can be obtained, the field work must be done as soon after the flood as practicable.

Before beginning the field work, a thorough reconnaissance of the stream or streams in the flood area is made to find the points at which determinations of flow are possible. As high-water marks are obliterated very quickly, any available marks should be fixed by surveys or referenced by markers until surveys can be made. Each determination of flood discharge is a distinct hydraulic problem requiring for its solution not only a thorough knowledge of the principles involved but also sound judgment in the selection of suitable sites and methods to be used. Careful and logical analyses of the situation and of the information obtainable will generally produce consistent and satisfactory results, even where the conditions may at first appear to be unfavorable. It is generally desirable to determine the maximum discharge by two or more different methods or, failing in that, by means of two separate and independent sets of observations. Careful notes containing complete details of field data and observations, together with good photographs, are necessary.

The methods commonly used by the Geological Survey in determination of flood discharge are described under appropriate headings in the following pages.

EXTENSION OF RATING CURVE

The satisfactory determination of flood discharge at a gaging station by extension of the rating curve requires that the rating curve shall have been developed by actual measurements to a stage where the differences between successive rates of change in discharge with respect to change in stage have become fairly constant. The conditions of the channel that are most favorable for an accurate extension of the rating curve consist of well-defined rapids or riffles below the gage at all stages and a uniform increase of channel cross section as the stage increases, with no abrupt changes in area or addition of overflow channels. The extensions made by the following methods should be checked against each other and a comparison should be made with the results obtained by other methods of determining the discharge.

Extension on logarithmic paper.—The rating curve may be extended by plotting on logarithmic paper the measured discharges against effective gage heights or heights above the stage of zero flow. If the stage of zero flow is not known, it may be determined approximately by an examination of the lower part of the rating curve, or by cut-and-try methods to find the constant that must be applied to the observed gage heights to cause the higher discharge measurements to tend to plot in a straight line or a very flat curve. With an appropriate knowledge of the factors that affect the stage-discharge relations, the rating for a channel not subject to overflow may be extended to higher stages, but such extensions should, if possible, be verified by comparisons with results obtained by other methods.

Extension by d–Q'.—In the d–Q' method of extension, the mean depth d is plotted on logarithmic paper against Q', which is the average discharge per foot of width. The line through the plotted points may be extended to the value of d corresponding to the cross section in the channel at the crest stage. The discharge is the product of Q', and the surface width W of the channel at the crest stage. This method appears to be reliable under favorable conditions but lacks extensive verification for long extensions under varied conditions of channel and is not well adapted to irregular channels or those subject to overflow.

Extension by studies of areas and velocity.—In extensions of areas and velocities, the area of cross section is plotted against gage height to define an area curve. This area curve may be accurately defined by surveys to the highest desired stage. The average velocity in the section as determined for each discharge measurement is similarly plotted against gage height. For channels not subject to overflow, the velocity curve generally approaches a straight line at high stages, and reasonably good extensions may be made by the use of judgment and experience. The discharge for the flood stage is computed as the product of the area and velocity from the extension of the two curves. In the application of this method consideration should be given to the existence of a definite relation between the stages at the gage and stages at the measuring section.

Extension of discharge as a function of $A\sqrt{d}$.—In the extension of the discharge curve as a function of $A\sqrt{d}$, the product of the area and the square root of the mean depth is plotted against measured discharge, the values of A and $\sqrt{d}$ having been determined from the area of the cross section. A line through the plotted points may be extended to the value of $A\sqrt{d}$ for the desired stage. This method is applicable if the extension above actual discharge measurements is not too great, and if the shape of the channel at floor stages is similar to that at which discharge measurements were made.

SLOPE-AREA METHOD

The slope-area method, the application of which has been described,[23] requires the use of a formula, generally in the basic form of $V=C\sqrt{RS}$, in which the factors R and S are evaluated from measurements in the field after the flood has subsided. The coefficient C, which includes the effect of the roughness of the channel, may be evaluated by various formulas, the Manning formula generally being preferred (p. 157).

Selection of reach.—Selecting a favorable reach of river channel for determination of discharge by the slope-area method does much to improve the accuracy of the results. The following factors should be considered:

1. The channel should be as nearly straight as can be obtained.
2. The reach should not be too long, as conditions of uniformity generally decrease as the length increases, but it should be of sufficient length for satisfactory determination of the fall within the reach.
3. Uniformity of cross section and slope is desirable; reaches should be avoided in which the area of cross section of channel increases downstream or in which there are adverse bottom slopes. Channels having overflow areas should be avoided, if possible.
4. The banks of the channel should be free from trees, brush, and other obstructions.
5. The bed and banks of the channel should be stable and not subject to erosion or deposition during the flood.
6. The high-water marks should be sufficient in number and in definition for the accurate determination of the crest stage.
7. The effect of the movement or deposition of debris is minimized by using a reach in which the channel is relatively narrow, with the area decreasing downstream, so that the velocity increases throughout the reach.

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[23] Dalrymple, Tate, and others, Major Texas floods of 1936: U. S. Geol. Survey Water-Supply Paper 816, pp. 11–15, 1937.

Survey.—At each site where the discharge is to be determined by the slope-area method, a survey is made by stadia, plane table, or other means, the survey including the high-water marks on each bank through the slope reach and for a considerable distance above and below it. A profile of the high-water marks so obtained may be plotted in the field and studied with respect to the uniformity of the indicated surface slopes. These marks show the crest stage or define a line very nearly parallel to the water surface of the crest stage. Two or more cross sections of the channel are surveyed, these cross sections being taken at places where the intervening slopes on both banks are uniform, thus insuring as nearly as possible uniform or constant hydraulic conditions. If the cross sections vary in area, it is essential that the change in area be small or at least that the change be gradual. The position of the bed at the time of the maximum discharge should be determined carefully, especially for streams having beds subject to scour during floods and subsequent deposition of fine materials. Streams with very steep slopes may have satisfactory reaches above weirs and dams that have filled to the crest with sediment and thereafter acted as stabilizers of the channel. High-water marks on the ground where wave action and surge are at a minimum are generally more reliable than marks in bushes and trees. Notes are made respecting the character of the bed and banks of the channels and any other conditions that may be pertinent to the particular measurement. Photographs are taken to show channel conditions and to help in the selection of the coefficient of roughness n.

Office procedure.—The data obtained by the surveys are plotted and from those data sheets tabulations are made of the essential factors entering into the computations of the flood discharge. Partial examples of procedure have been published by the Geological Survey [24] and contain the following data:

1. Map or sketch to scale, showing the channels and the positions of the high-water marks.
2. Longitudinal profile showing positions of the high-water marks from which the water surface slope of the stream is to be determined.
3. Cross sections of the channels.
4. Computations of the area and hydraulic radius of the cross section of each individual channel into which the total area of the channel cross section in the reach may have been subdivided.

It is customary to divide a reach into several channels if the relative conveyance capacities of the different parts of the cross section differ because of different values of the hydraulic radius and the coefficient of roughness. In determining the wetted perimeter of a channel in

[24] U. S. Geol. Survey Water-Supply Papers 773, p. 250; 798; 799; 800; 816; 844.

a subdivided reach, it is customary to neglect that portion which is common to the adjacent channel or channels, unless there is a well-defined line of demarcation between the channels such as might be caused by a dense line of trees or division of the channel. Profiles of high-water marks and sections of slope-area reach used in computations of flood discharge on the Concho River near San Angelo, Tex., have been published.[25]

Assumptions and computations.—A value of the coefficient of roughness n is selected corresponding to the condition of the channel. The values of n may differ for the different parts of the cross section into which the channel may be divided. Pertinent information on the value of n for streams of less than 15,000 second-feet may be found in a report by Ramser.[26] If the flow in any reach is not uniform, the velocity head must be considered and the slope adjusted to a value representing the energy grade line. If the velocity at a downstream section is less than that at an upstream section and there is transformation of kinetic energy into potential energy, it is customary to assume the actual recovery to be 50 percent of the theoretical recovery.[27] Variations in this percentage may be warranted by variations in conditions. This correction is simple and easily made if the flow is confined to one channel. Where a reach is divided into two or more channels with different values of n and different hydraulic radii, the weighted velocity head for the section is determined by an adaptation of equations given by O'Brien and Hickox [28] and by Dalrymple. An example of a slope-area discharge determination of 580,000 second-feet, showing in detail all assumptions and computations, is given also by Dalrymple.[29]

CONTRACTED-OPENING METHOD

The contracted-opening method involves the computation of the discharge from measurements of the drop in water surface in a short contracted section, such as the opening between bridge abutments. Under those conditions the discharge may be computed by the formula

$$Q=kA\sqrt{2g\left(H+\frac{V^2}{2g}-h_f\right)}$$

where Q=discharge in second-feet;

k=coefficient of contraction, to be applied if the water moves around a sharp corner in entering the contracted section;

[25] Dalrymple, Tate, and others, op. cit., fig. 3, p. 14.

[26] Ramser, C. E., Flow of water in drainage channels—the results of experiments to determine the roughness coefficient n in Kutter's formula: U. S. Dept. Agr. Tech. Bull. 129, 101 pp., November 1929.

[27] Freeman, J. R., Regulation of the Great Lakes, p. 303, 1926; and Stevens, J. C., Varied flow in open channels of adverse slope, discussion: Am. Soc. Civil Eng. Trans., vol. 102, p. 669, 1937.

[28] O'Brien, M. P., and Hickox, G. H., Applied fluid mechanics, p. 271; Dalrymple, Tate, and others, op. cit., p. 15.

[29] Dalrymple, Tate, and others, Major Texas floods of 1935: U. S. Geol. Survey Water-Supply Paper 796–G, pp. 252–256, 1939.

A = area, in square feet, of the most contracted section;
H = surface drop, in feet, at the entrance to the contracted section;
V = velocity of approach, in feet per second;
h_f = head loss, in feet, due to friction.

The contracted-opening method was used to compute the discharge of Dry Creek near San Angelo, Tex., for the flood of September 17, 1936.[30]

Selection of the contracted opening.—Contracted openings suitable for use in the computation of discharge are generally those between bridge abutments. In the selection of a contracted opening the following factors are considered:

1. Alinement of the opening with the channel.
2. Shape and condition of the approach channel.
3. Position and definition of the most contracted section in the opening.
4. Length of the contracted section.
5. Stability of the opening during the flood.
6. Quality and quantity of the high-water marks.
7. Amount of drop in the opening.
8. Probable accuracy of the definition of the draw-down curve.

Survey.—At each site an instrumental survey is made of the structures and the high-water marks on each bank for a considerable distance above and below the opening, so as to define the average slope above the drop, the draw-down curve, the lowest part of the trough in the contracted section, the standing wave, and the slope below the drop. Cross sections are measured in the approach channel, in the most contracted part of opening, and in such other places as may appear to be significant. High-water marks are selected with the same care as for the slope-area method. Notes are made of conditions at and near the opening and at other points pertinent to the computation; also at the entrance, especially at bridge openings, with reference to the selection of the coefficient k. Photographs are taken of the opening, the approach channel, and the channel immediately below the contracted section. Dalrymple[31] shows a map, profiles of high-water marks, and sections used in the computation of the flood discharge of Dry Creek near San Angelo, Tex.

Office procedure.—The field data are plotted and then serve as a basis for maps, profiles, and computation sheets. The map or sketch should be to scale and should show the layout of structures, channels, and high-water marks. A longitudinal profile should show the high-

[30] Dalrymple, Tate, and others, Major floods of 1936; U. S. Geol. Survey Water-Supply Paper 816, p. 17, 1937.
[31] Idem, fig. 4, p. 16.

water marks from which the position of the water surface is determined. This profile is essential for the development of the draw-down curve. The position of the contracted opening must also be shown. Cross sections of the channel of approach and the contracted section must be prepared. Computations must be made of the area and hydraulic radius of the cross section of each individual channel into which the total area of the channel cross section in the reach may have been subdivided.

Assumptions and computations.—The selection of the coefficient of contraction k that is to be applied if the water moves around sharp corners in entering the contracted section is largely a matter of judgment and experience. It is generally assumed that the coefficient k is not less than 0.90.[32] If the transition from the approach channel to the contracted section is gradual, with no abrupt projections or sharp corners, the coefficient k may be nearly unity. The velocity head may be determined from cross sections of the approach channel. The head loss due to friction h_f may be computed by first assuming an approximate value of h_f and subtracting that value from the total head, then computing the friction loss for the length of the contracted section.[33] If the computed value of h_f differs materially from the assumed value, a second computation may be made.

FLOW OVER DAM

The method of computing the flow over a dam involves also the determination of the flow over or through the appurtenant structures.

Selection of dam.—On some rivers dams are so many miles apart that little choice is offered in the selection of one, but so far as practicable the following factors should be considered:

1. Angle of dam with channel. A dam that makes an angle of 90° with the direction of flow in the upstream channel is preferable, as the formulas ordinarily used in computing discharge over dams are generally developed for this condition.

2. Alinement of crest of dam. For the best results, the crest should be straight and at the same height throughout the entire length.

3. Approach and get-away conditions. The approach channel should give a uniform distribution of flow in a direction perpendicular to the dam crest. It is desirable that the downstream channel should have sufficient capacity so that the water below the dam will not rise higher than the crest.

4. Velocity of approach. The theoretical correction formulas for the effect of velocity of approach may not always correspond to the

[32] Houk, I. E., Calculation of flow in open channels: Miami Conservancy District Tech. Rept., pt. 4, p. 264, 1918.

[33] Idem, p. 56.

actual conditions. Therefore, it is desirable that the channel above the dam should be deep enough to give a low velocity of approach. The kinetic energy head $\frac{V^2}{2g}$ should be very small as compared with the observed head h.

5. Stability of crest of dam during flood. Many dams carry flashboards during the greater part of the year and uncertainties may exist as to their height or the times of their removal. Dams without flashboards or other obstructions to the crest should be selected, if possible.

6. Selection of representative coefficients for the discharge over the dam and through sluices or wasteways. Consideration should be given to the shape of the crest to ascertain if it is similar to other dams for which the discharge coefficients are known.

7. Extent of submergence of the dam by backwater. As the submergence may have considerable effect on the discharge, information should be obtained regarding the heights of water below the dam at times of known stages above the dam.

8. Uniformity of cross section of crest. Irregularities in the shape or height of the crest would require additional computations and might cause considerable error if not taken into consideration.

9. Flow over bulkheads, past the ends of the dam, through gates, wheels, flumes, and other appurtenant structures. Information should be obtained regarding these various conditions in order that the discharge may be computed.

Survey.—A survey at the dam is made by stadia, plane table, or other means as a basis for a map showing the dam and all the appurtenant structures, such as bulkheads, canals, gates, intakes, and wasteways of all kinds. High-water marks (see p. 98) are located, studied, and shown on the map for both sides of the river for distances of several hundred feet above and below the dam. In many flood computations the high-water marks above the dam are used not only to determine the static head on the dam but also to determine the slope of the water surface in the approach channel, from which the velocity of approach is computed. The high-water marks below the dam may be used to determine the amount of submergence of the dam and the general downstream conditions. The length, height, and cross section of any structure over which the water flowed and the sizes and positions of all gates, openings, orifices, and sluices for which the discharge is to be computed are also determined. The size, shape, slope, and position of channels through which water may have bypassed the dam are studied. One or more cross sections are surveyed above the dam for the determination of the velocity of approach. Weirs and dams in streams of very steep slopes may become filled to the crest with sand, gravel, and other material and at times may lose their identity as weirs and act merely to stabilize the channel, with a velocity of approach greater than the critical velocity for the weir or dam. The usual methods of computing the flow over a dam may not be applicable under those conditions, and the possible use of other methods should be considered.

The details of the structures should be noted in connection with the selection of coefficients for use in formulas for the computation of the flow. It is necessary that the shape of the crest of the dam, especially the upstream part of the crest, should be accurately determined in order that the proper value of the coefficient C may be selected. The possibility that the nappe jumps clear of the structure so that the dam functions as a sharp-crested weir should be investigated. If the shape and height of the crest is uniform throughout the entire length, a discharge measurement of the flow over the dam at a fairly high stage will make possible a determination of the coefficient C for that stage, and the coefficient thus determined can be used as a guide in selecting the value of C for higher stages.

It is necessary to ascertain whether flashboards were on the dam at any time during the flood and, if so, their condition during and immediately after the flood. It is also necessary to know the positions, dimensions, and heights of any old dams, cofferdams, or other structures that may be in place immediately above the dam, as such structures may have a decided effect on the flow. Photographs should be taken of all the structures and of the channels above and below the dam.

Office procedure.—The field data are plotted and are then used as a basis for maps, profiles, and computation sheets. A map or sketch to scale should show the layout of structures and channels with the relative positions of high-water marks. A longitudinal profile should show the important structures and the high-water marks from which the flood profile is to be determined. Cross sections of the channels and of the structure through or over which the water flowed must be made. Computations must be made of the area and the hydraulic radius of each section or channel which may be used in the determination of flow.

Assumptions and computations.—For a dam having a uniform section similar in shape to the section of a dam for which the rating or discharge coefficients are known, it is generally possible to convert records of stage into records of discharge with a good degree of accuracy by satisfying the general formula

$$Q = CLH^{3/2} \qquad (1)$$

In this formula Q is the discharge in second-feet, C the coefficient for the dam, L the length of the crest in feet, and H the total head in feet.

As the total effective head is the sum of the pressure head h_p and the effective velocity head $h_v \sin \theta$ where θ is the angle between the crest of the dam and the direction of the current, the formula may be written as

$$h_v = \alpha \frac{V^2}{2g} \sin \theta \qquad (2)$$

and

$$H = h_p + \alpha \frac{V^2}{2g} \sin \theta \qquad (3)$$

where V is the average velocity in the approach channel section and α is a correction factor due to unequal distribution of velocity. The value of α in an unobstructed stream has an approximate range of 1.1 to 1.4, whereas back of a dam or other obstruction it may be as much as 2.0 or more.

Wherever necessary, allowance is made for submergence of the crest by water in the channel below the dam. If the submergence of sharp-crested weirs is less than about 15 percent of the total head, the discharge is not sensibly affected. Broad-crested and round-crested weirs are probably not sensibly affected by submergence up to about two-thirds of the total head. Information regarding the selection of coefficients for dams and for submerged weirs obtained from experiments have been published by the Geological Survey.[34]

The flow over highway and railroad embankments is considered as analogous to the flow over dams, and values of the coefficient C to be used under those conditions may be selected from experimental data of Yarnell and Nagler.[35]

Formulas for computing the flow through sluice gates, flumes, penstocks, wheels, and other appurtenant structures are discussed in numerous engineering publications.

OTHER METHODS

Critical-depth method.—The critical-depth method is applicable where there is available an exceptionally good natural or artificial control over which it is reasonably certain that flow has taken place at critical depths. Points of critical-depth control may occur at or near changes in bottom slope, upstream from which the bottom slope is less than is necessary to maintain uniform flow at the critical depth, and downstream from which the bottom slope is greater than is necessary to maintain such flow.

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[34] Horton, R. H., Weir experiments, coefficients, and formulas: U. S. Geol. Survey Water-Supply Paper 200, 195 pp., 1907.

[35] Yarnell, D. L., and Nagler, F. A., Flow of floodwater over railway and highway embankments: U. S. Dept. Agr., Bur. Public Roads, Public Roads, vol. 11, pp. 30–34, April 1930.

Surveys of sites for the determination of flood flows by the critical-depth method are similar to those for slope-area reaches, with special attention to the cross section of the control at which it is assumed that flow had taken place at critical dephs.

Field data are plotted and data sheets are prepared in a manner similar to that used in the slope-area method. Discharges are computed by use of equations adapted from those given by King, O'Brien, Hickox, and others.[36]

This method should be used with caution as it is difficult to determine if flow actually occurred at critical depth through the control section.

Timing of flood drift.—The velocity is sometimes determined by observations of drift if a current meter is not available or its use is impracticable. Velocities are observed in as many different parts of the channel as possible by timing the travel of drift over a known distance. Drift that is largely submerged should be selected for timing. The average velocity is computed from the observed velocities by the use of suitable coefficients. The discharge is determined as the product of the average velocity and the area of the cross section, which is either known or is measured after the flood.

Flood formulas.—With the increasing knowledge of flood flow characteristics and studies made possible by discharge data collected at gaging stations, the use of flood formulas is gradually receiving greater consideration as a practicable means of estimating and predicting both the crest discharge and the total discharge of a flood. No general formula yet derived is of universal application. Flood formulas can be properly modified and intelligently used only by special studies of the conditions at the particular place. The formulas vary in their method of application and with the nature of the results desired. Some formulas are based on the assumption that a relation exists between the peak discharge and the total discharge of the flood, whereas others are established on the basis of a relation between storm precipitation and river discharge. A formula may be devised to indicate the maximum peak that can be expected for the runoff from a given drainage basin, or it may be so arranged as to show the probable frequency of floods of certain magnitudes. Therefore, in the selection of a flood formula, consideration should be given to the nature of the problem and the character of the information that is desired.

Exhaustive studies of various flood formulas and illustrations of the use of existing stream-flow records in connection with flood predictions, together with tabulations of flood records and references to

[36] King, H. W., Handbook of hydraulics, 3d ed., p. 385, 1939; O'Brien, M. P., and Hickox, G. H., Applied fluid mechanics, 1st ed., p. 278, 1937; Dodge, R. A., and Thompson, M. J., Fluid mechanics, pp. 241–254, 1937.

numerous sources of information regarding floods and flood formulas, have been made by the Geological Survey.[37] Reference should be made to them for specific information regarding flood formulas.

FLOW CHARACTERISTICS IN OPEN CHANNELS

The characteristics of flow of natural streams seldom, if ever, satisfy the conditions of steady and uniform flow that are generally assumed in deriving theoretical formulas of flow in open channels. Steady flow may be approximated if the requirement that the flow does not change with respect to time is not too rigid or if the time is made relatively short. Artificial channels and canalized rivers may contain short reaches where the flow is nearly uniform during periods of steady flow, although generally there are variations in channel alinement, cross sections, slopes, and friction factors which interrupt the continuity of uniform flow.

Formulas developed for uniform and steady flow have been adapted in some instances to the measurement of flow in natural channels by the determination of conveyance factors, or by the development of curves of relation which served to combine the results of actual measurements and theoretical assumptions. These adaptations have been helpful in obtaining records of stream flow under circumstances where the usual methods of procedure could not be followed.

The methods ordinarily used by the Geological Survey in recording river discharge are based on the determination of the relations of stage to discharge at the places where discharge records are obtained. River stages may be observed with simplicity and exactness, and the discharges corresponding to the river stages may be readily determined from the stage-discharge relation if that relation is known.

STAGE-DISCHARGE RELATION

The stage-discharge relation at a stream-gaging station is usually determined experimentally from measurements of discharge and observations of the corresponding stages. For dams, weirs, and some types of structures described under "Artificial controls" (see p. 117), the stage-discharge relation for some conditions may be represented by theoretical equations or by curves of relation developed in laboratories. However, these theoretical relations and laboratory ratings should be verified by the results of field measurements before they are accepted and used in the determination of discharge.

In order to have a definite and enduring stage-discharge relation, the channel must have certain physical features capable of regulating

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[37] Jarvis, C. S., and others, Floods in the United States, magnitude and frequency: U. S. Geol. Survey Water-Supply Paper 771, 497 pp., 1936.

or stabilizing the flow past the gage to such an extent that for a given stage of the water surface the discharge past the gage will always be the same. This relation of stage to discharge is usually controlled by a section or reach of the channel below the gage known as the station control, which eliminates the effect of all other downstream conditions on the velocity of flow at the gage. The station control may be either natural or constructed and may consist of a ledge of rock crossing the channel, a boulder-covered riffle, an indurated bed, an overflow dam, or any other physical feature capable of maintaining a fairly stable relation between the discharge and the water height at the selected point above it. A natural control at the gaging station on the Smith River near Bristol, N. H., is shown in plate 7, *A*. A control may be either complete or partial. A complete control is independent of all downstream conditions in governing the stage-discharge relation and is in full effect throughout the entire range in stage. A partial control may, by itself, govern the stage-discharge relation only for a part of the range in stage that is encountered, although when acting in conjunction with other controlling elements it may become an essential part of a complete control; the term "complex control" is sometimes applied to a control of this kind. The term "section control" is used in referring to a complete or partial control where the elements that govern the stage-discharge relation are situated in a comparatively short length of the river channel as compared with "channel control," where the stage-discharge relation is governed by the slope, dimensions, and frictional resistances of the river channel over a considerable distance.

From the above explanation of the principle of controls it appears that if the reactions from the elements which create a stage-discharge relation are to be thoroughly understood, the term "control" must be properly defined with respect to the functions it performs and the stages for which it is effective. It should also be remembered that a control includes all the physical features of the channel which hydraulically determine the stage of the river at a given point for a certain rate of flow. If the control is of the partial or complex type it includes the resistance offered by the river bed and banks for a considerable distance downstream. In general, the distance that may be considered as forming part of such a control varies inversely with the slope and increases as the stage of the river rises. This tendency for the control to extend farther downstream with increases in stage has a direct bearing on the stage-discharge relation, and the introduction into the control of new downstream features may cause reversals in curvature of the rating curve for the station. Under exceptional conditions, such as a constricted section of channel below the gage, the reach including the control may, in effect, become shorter as the stage increases. For rivers having flat slopes the control at high stages may extend so far downstream as to introduce backwater complications which do not exist at lower stages. From consideration of these relations it is apparent that all the conditions affecting the velocity of flow past the gage must be included as parts of the control.

For a control to be complete in its effectiveness in establishing a definite stage-discharge relation it is obvious that for a given discharge both the relations of slope to stage and slope to discharge must remain constant, as also must the coefficient representing the channel conditions for the reach extending from the gage to the lower end of the control. Although the condition of steady flow for which the constant relations of slope to stage and slope to discharge would be applicable is rarely if ever found in natural streams, it is true nevertheless that the sites selected for the position of gages and controls for most of the gaging stations now operated by the Geological Survey are such that the variation in discharge for a given stage, due to variations in slope, velocity, or channel conditions during the period of time involved, is so small that for all practical purposes the effects resulting from the variation is negligible.

The station rating curve should be a smooth curve parabolic in shape, preferably without reversals in curvature. If there is to be no abrupt change in the slope of the rating curve, the rate of increase in stage corresponding to a given rate of increase in discharge should be reasonably consistent throughout the range of stage. Abrupt changes in the profile of the control and submergence of the control are two conditions that are most likely to cause deviations from this requirement.

PERMANENT CONTROLS

A permanent control, complete in its effect, retains all its original effective physical characteristics, including its position with respect to the datum of the gage, its distance downstream from the gage, and the condition of the stream bed between the gage and that part of the channel which controls the stage-discharge relation. A control satisfying these requirements will assure a permanent stage-discharge relation at all time when the conditions of slope remain the same. The fact that a generally recognized permanent control, such as a dam or ledge, may appear to have eliminated all effects from downstream conditions, or that a change in its original physical features is not readily apparent, is no complete assurance that the stage-discharge relation has remained unchanged. For instance, the velocity of approach may have changed because of scouring or deposition of sediment in the channel immediately upstream from the control, leakage within or under the control may have varied in amount, or the elements controlling the height of the water in the reach downstream from the control may have changed and created a more rapid rate of submergence of the permanent low-water control. These changes in conditions are not readily observed, but their occurrence may materially change the stage-discharge relations. It should be emphasized that, regardless of how stable and permanent a control may appear, it is always possible that the stage-discharge relation may change; but the nature of the change may be such as to be overlooked during an ordinary inspection of the controlling elements. The fact that the appearance as well as the effectiveness of the control may change from time to time as the stage of the river changes sometimes leads to a misinterpretation of the actual conditions. On the other hand, some of the physical characteristics of a control may appear to have changed, yet the nature of the change may be such as not to include those elements which materially affect the stage-discharge relation. Positive assurance that a change has not occurred in the stage-discharge relation is attainable only through the results of discharge measurements. The shape of the rating curve based on discharge measurements covering the entire range in stage generally reveals or assists in explaining the flow characteristics at the gaging station.

If the station control on a stream having a large range in stage is not formed by a dam or ledge producing several feet of fall, it is possible that the elements forming the control for low stages may be entirely different, both in nature and position, from those effective at higher stages, and that the control for low stages may be entirely submerged at times of high water. If the low-water control consists principally of a low dam, riffle, or other obstruction producing a similar effect, it may be considered as partially submerged as soon as the flow begins to show the effect of additional controlling elements. The stage at which the low-water control loses part of its effectiveness is generally indicated by a change in curvature of the rating curve. Streams having steep slopes and high velocities may have the same stretch of channel effective in controlling the stage-discharge relation for low stages as for high stages. In general, the controls which normally function for low stages are easily recognizable and may be readily distinguished from those functioning for high stages, although there may not always be a clear-cut demarkation between the two sets of conditions.

LOW-WATER CONTROLS

A low-water control usually consists of a natural ledge or riffle in the stream bed, a contraction of the channel, or an artificial structure such as a dam or weir, which causes a break in the slope of the water surface so that the effects of all downstream conditions at low-water stages are eliminated. Occasionally it may consist of a stretch of channel with an indurated bed of comparatively steep slope where the velocity at low stages maintains a permanent relation of stage to discharge. A section suitable for use as a control, whether natural or artificial, usually has a small forebay which extends a short distance above the gage. If a definite stage-discharge relation is to be maintained, this forebay must have a constant capacity for a given stage and should have enough depth to produce a reasonably low velocity of approach.

Changes in the velocity of approach which may occur because of changes in the cross section of the channel above the control have an immediate effect on the stage-discharge relation, and the possibility of such changes should be carefully considered in the selection of the site. Variations in the slope of the water surface between the gage and the control for a given discharge of the stream also will affect the stage-discharge relation; the effects of these variations in slope can be minimized, however, by placing the gage fairly close to the control. A low-water control begins to lose its effectiveness when the downstream stage rises to a height above the lowest point on the control, although the accompanying increase in stage above the control, if the increase in stage is caused by an increase in discharge, will tend to offset the effects of the submergence. However, if the discharge continues to increase, the downstream stage will rise faster than the upstream stage until a condition is finally reached where the control is said to be "drowned out."

A natural low-water control may consist of a ledge, a riffle, or a reach of channel, each condition producing the necessary fall or break in the water surface in a manner distinguishable from the others. In the ledge type of control, because of its short longitudinal profile, the fall is usually abrupt and similar to that produced by an artificial dam. Although the profile of its cross section may be very irregular, for all practical purposes the upper end of the tail-water reach below the control may be considered as retaining one position, namely, that of the downstream face of the ledge.

Information in regard to the effectiveness of a low-water control and the possible effect of submergence of the control on the stage-discharge relation may be readily obtained for the ledge type of control by installing an auxiliary gage at the upper end of the tail-water reach at the downstream face of the ledge, this gage being set to the same datum as the station gage. When the gage-height of zero flow is known, and is used as the basis for comparative observations at the gages above and below the control, the observations of the heights of

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the water surfaces at the two gages will show the amounts of submergence for various stages and the stage at which the control loses its effectiveness. The amount of submergence is usually expressed as the ratio of the water-surface height below the control to the water-surface height above the control, both of which are referred to the gage height of zero flow as the point of zero height.

The riffle type of control differs from the ledge type in that the fall is produced gradually over a reach of channel. The transverse profile of the cross section is likely to be very irregular and may change from place to place throughout the reach. The longitudinal profile instead of showing an abrupt fall may extend several hundred feet downstream at a small slope. The first complete break in the slope at the upper end of the riffle indicates the position of the upstream lip of the control and the point where the control is most effective in maintaining the stage-discharge relation. For this type of control the upstream end of the reach below the control changes position with the height of the water surface. As the stage in the downstream reach rises, the longitudinal profile of the control shortens, and when the water-surface slope of the downstream reach becomes the same as the water-surface slope in the channel above the riffle, the submergence of this type of control becomes complete. Some effects from the controlling elements downstream from the riffle usually appear while this type of control still retains several feet of its effective channel length. A determination of the particular stage at which submergence first begins can be made by means of observations of stages downstream from the riffle after the height of the point of zero flow has been established.

The channel type of low-water control is conspicuous because of the apparent lack of those elements that cause a decided break in the slope of the water surface downstream from the gage. If a definite stage-discharge relation can be developed for a control of this type, it is generally due to the slope in the water surface that is produced by the frictional resistance of the stream bed. The bed and banks for this reach of channel are not necessarily of a permanent nature if the effect on the stage-discharge relation for any change in their physical features is compensated by a change of opposite effect at some other point within the reach. A fair approximation of the stage of zero flow for this type of control may be obtained by determining the height of the lowest point in the profile of the cross section at the gage.

Because of irregularities that usually exist in the cross section of the ledge or riffle types of natural low-water controls there is always a possibility that the determination of the stage of zero flow may not be given the consideration that is needed, especially if a high degree of accuracy for extremely low discharges is desired. For these types of controls, the height of the lowest point on what appears to be the upstream lip of the control is ordinarily accepted as being the point of zero flow. This assumption is sufficiently accurate for most practical purposes if there are no narrow depressions or crevices in the cross section. If there are crevices, and especially if the velocity through them is slow, there is a possibility that the bottom of the deepest crevice may not be representative of the stage of zero flow, which actually may be determined by some higher point downstream. For stations where discharges below 10 second-feet are to be recorded to tenths and hundredths of a second-foot, situations of the above nature require more than ordinary consideration if the degree of accuracy indicated by the fractional part of a second-foot is to be justified. As the low-water part of the rating curve is particularly sensitive to small errors, if expressed as percentages, enough measurements should be made at low stages to define accurately the station rating curve and to afford assurance that no change has occurred in the stage-discharge relation.

SENSITIVENESS OF LOW-WATER CONTROLS

The sensitiveness of a control should generally be given greater consideration for low discharges than for high discharges. If a control is termed "sensitive," it is indicated that for any change in flow a rather quick response to the change is reflected at the gage and that a relatively large increase in stage is produced by a small increase in discharge. A nonsensitive control usually differs from a sensitive control in that its width is great in relation to the depth of flow over the crest, but it is possible that the lack of sensitiveness may be caused by an abnormally high velocity of approach. In the selection of a site for a gaging station or for the construction of an artificial control, it is desirable that the sensitiveness of the control as well as the shape of the probable rating curve should be considered. Gage heights are usually recorded to hundredths of a foot; therefore a change in stage of 0.01 foot should not represent more than about 2 percent of the total flow if the control is to be regarded as sensitive.

SUBMERGENCE OF LOW-WATER CONTROLS

The term "submergence" used in connection with a low-water control refers to the loss of effectiveness in stabilizing a stage-discharge relation because of an increase in the depth of water at the downstream side of the control. The amount of submergence may be expressed as a ratio of the height of the water surface at a point in the tail-water below the control to the height of the water surface at the gage if both water surfaces are higher than the point of zero flow and the point of zero flow is the common datum. "Submergence" may occur in any one of three conditions: first, where the water surface in the tail-water has risen just above the point of zero flow and submergence begins; second, partial submergence, which may include any particular degree of submergence expressed in percentage; and third, complete submergence, where the water surface in the tail-water reach has risen high enough to smooth out the break in slope caused by the control and the relation of stage to discharge is then governed by channel conditions downstream from the low-water control. The effectiveness of the control in maintaining permanent stage-discharge relations is dependent on the conditions of submergence of the control.

The degree of submergence that may occur before the depth above the control becomes appreciably affected largely depends upon the shape of the control. In general, a sensitive low-water control will stand a much higher degree of submergence than a non-sensitive control. Tests made by the Geological Survey at the National Hydraulic Laboratory of the National Bureau of Standards show that for certain types of artificial controls built so that the low-water flow passes through a deep notch, there may be a submergence of 90 percent without increasing the depth of water on the control more than about 5 percent above the depth that would have occurred under free-fall conditions. A control that has a very wide crest and is designed so that a hydraulic jump occurs after the water leaves the control has been found to be very effective in maintaining the stage-discharge relation for high stages of tail water.

Occasionally it is observed that the stage-discharge relation as defined by discharge measurements remains fairly stable for the entire range in stage except for a small part of the range at medium stages, for which the measurements plot erratically. An examination of the conditions at those stages will usually reveal that the low-water control is subject to submergence and the greatest irregularity in the plotting of measurements occurs at the higher percentages of submergence of the low-water control. A possible explanation for this situation is that the stage-discharge relation for the tail-water flow had not been completely stabilized for the higher degrees of submergence of the low-water control which occurred at the times of the discharge measurements, and the effects of somewhat unstable conditions were reflected at the gage. Thus, if a measurement made under these conditions plots to the left of the curve, the water in the reach downstream from the gage is higher than it is for another measurement of the same discharge which plots to the right of the curve. Consistency in the curve of plotted measurements above the stage of submergence of the low-water control indicates that the hydraulic conditions have become stabilized by means of a control farther downstream.

ARTIFICIAL CONTROLS

Artificial controls are structures built in a stream channel to stabilize the stage-discharge relation and thereby simplify the procedure of obtaining accurate records of discharge. They may be low dams, broad crested weirs conforming to the general shape and height of the stream bed, or flumes similar in design to the Parshall flume. A Trenton-type artificial control at the gaging station on Rahway River at Springfield, N. J., is shown in plate 7, *B*. The adverse effects of unstable conditions due to shifting bed or banks, the formation of ice in winter, progressive growth of aquatic vegetation during the summer, and other phenomena which at times affect the stage-discharge relation at low stages may generally be eliminated or alleviated by the construction of an artificial control. The structure is seldom designed to function as a complete control throughout the entire range of stage, as generally it is impracticable to build it high enough to eliminate the effects of downstream conditions at high stages unless there is a steep fall below the gage. If the downstream slope is flat, so that with an increase in discharge the water below the control rises faster than the water above it, the control may be complete in its effect only for low and medium stages.

Although the artificial control is usually constructed in the form of a dam or a weir, it is seldom if ever desirable to attempt the use of a weir formula as its rating. The rating for each station should be determined by a current meter or other method of measuring discharge. The conditions or facilities for the accurate measurement of small streams and the measurement of the low-water flow of larger streams often may be improved by the use of artificial controls.

DESIGN OF ARTIFICIAL CONTROLS

In the design of artificial controls the following four major points should be considered: first, the shape of the structure should permit the passage of water without creating undesirable disturbances in the channel above or below the control; second, the structure must be of sufficient height to eliminate the effects of variable downstream conditions; third, the profile of the crest of the control should be designed so that a small change in discharge at low stages will cause a measurable change in stage, and the relation of changes in stage to changes in discharge should produce a rating curve of a shape that may be extended to peak stages without serious error; and fourth, the control should have structural stability and should be permanent. The artificial control should be self-cleaning and not subject to obstruction by debris and ice, or to deposits of sand, gravel, or silt in its immediate vicinity, either upstream or downstream.

Each artificial-control structure should be designed in accordance with the conditions at the particular site where it is to be built. It is, therefore, not practicable to standardize the designs except as to general principles. The width of the stream and its profiles, both upstream and downstream; the nature of the bed; the flow characteristics, especially for maximum and minimum stages; and the probable minimum flow of the stream should be considered before deciding upon the width and profile of the crest. Various types of artificial controls have been designed and constructed by engineers of the Geological Survey. A typical design of the Trenton type of artificial control is shown in figure 8. Artificial controls of the flume or Parshall type may be used to advantage in ditches and canals of comparatively small range in stage and of little fall.

On some streams where the beds are continually shifting and permanent foundations are not available, it may be desirable to stabilize the beds by means of low structures that conform to the general profiles of the beds. Artificial controls of this type have served satisfactorily in several districts of the Geological Survey. By giving proper attention to the shape of the structure, both longitudinally and transversely, an acceptable degree of sensitiveness may be developed that will result in a well-proportioned rating curve with respect to increments of stage for increasing rates of change in discharge.

It is essential that an artificial control should be structurally permanent, with a definite and fixed relation between the height of the structure and the zero of the gage. The possibility of excessive seepage under or around the control should be considered and the necessary precautions taken for its prevention by means of sheet piling or concrete cut-offs and adequate abutments.

HIGH-WATER CONTROLS

The definite positions of high-water controls, with the possible exception of artificial dams or natural waterfalls, are in general more difficult to recognize than those of low-water controls; and because of their complex nature, at many sites considerable investigation is necessary to understand fully the characteristics of the controlling elements. The usual high-water control consists of a group of elements which ordinarily include one or more of such channel features as an abrupt bend in the channel, a contraction of the bed and banks, or a series of riffles. Occasionally one of these channel features may be so effective that, for practical purposes, it can be considered the principal element of the control. A rather pronounced break in the slope accompanied by a large increase in velocity makes this particular situation comparatively easy to recognize. If a thorough reconnaissance for some distance below the gage does not reveal any pronounced channel

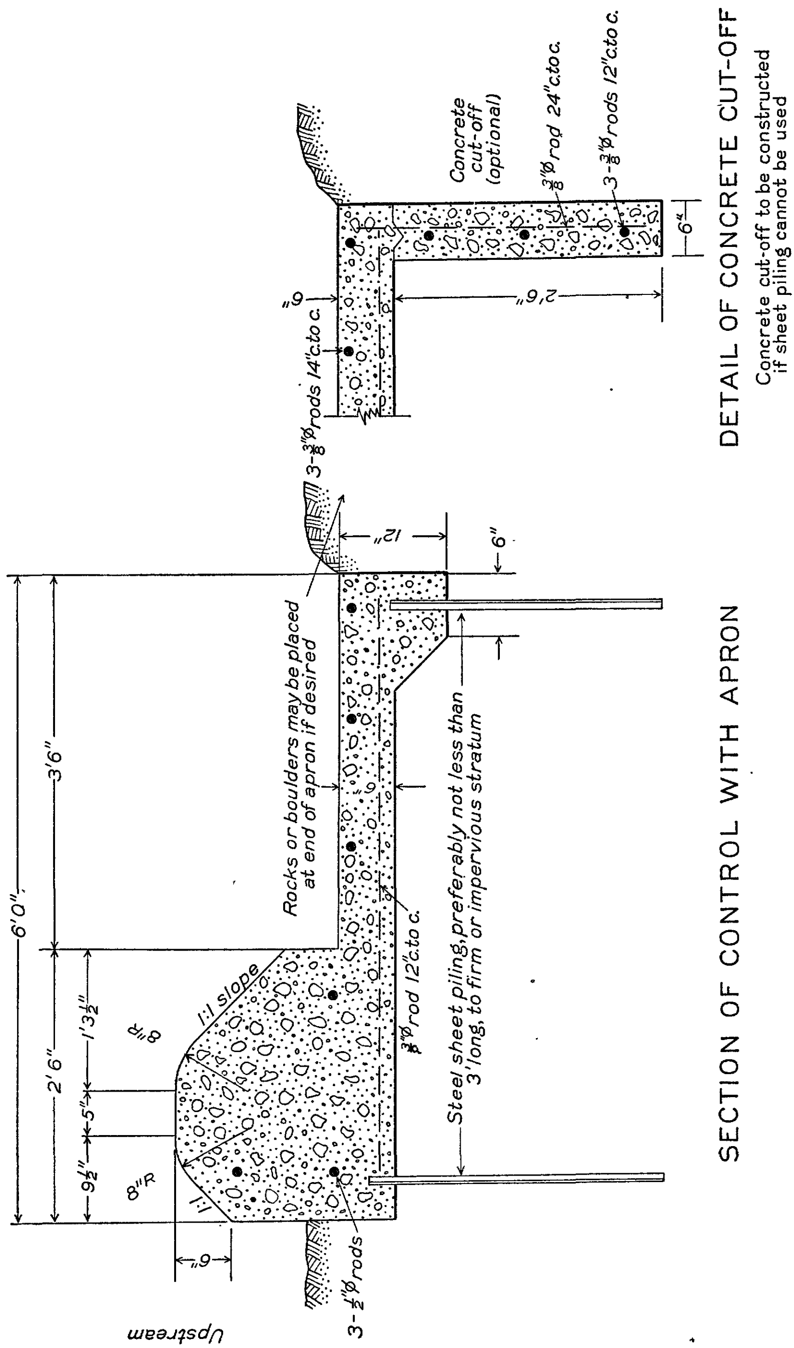


FIGURE 8.—Typical design of the Trenton type of artificial control.

characteristic which acts as the principal controlling element and if discharge measurements indicate that there is a stable stage-discharge relation, the flow past the gage is considered satisfactorily channel controlled.

Although it is impossible to determine accurately the degree of effectiveness of each major channel feature and its part in controlling the stage-discharge relation, a knowledge of its existence and position with respect to the gage, together with a general idea of its possible effectiveness, will be of value both in analyzing the plotting of discharge measurements and in extending a rating curve beyond the point where it is defined by measurements.

Dams.—A dam constructed to develop power, divert water for irrigation, or improve navigation is rarely acceptable as a control, except possibly for medium and high stages. Usually the crests of such structures are wide, flat, and non-sensitive, and the various by-passes and diversions may be so effective that they do not maintain consistent stage-discharge relations at low stages. If at high stages the flow carried by any diversion is small in comparison with the total flow over the dam and the amount of such flow can be determined and if the dam is sufficiently sensitive as a control under those conditions of flow, the structure may be utilized as a high-water control provided there are other means of maintaining stage-discharge relations for the low-water flow. Occasionally it is possible to place the gage above a riffle or a decided break in the surface slope a short distance above the upper end of the pool created by a dam at low water. Such a riffle or break in surface slope may stabilize the stage-discharge relation for low and possibly medium stages; for higher stages the flow over the dam may be large enough to establish a satisfactory relation of stage to discharge. Any diversions through canals or water wheels should be taken into consideration in the computation of discharge. Such a combination of controls is particularly apt to cause a reversal in the rating curve, and care must be taken in making extensions beyond measurements, especially within the zone of the possible reversal. The extent to which a dam will eliminate the effects of changes in slope due to rising or falling stages will depend on the distance between the dam and the gage; the length of the pool must be comparatively short if those effects are to be eliminated. The installation of a gage near enough to a dam to be affected by the height of the pool is especially undesirable if the flow passing the dam is wholly or partly controlled by the operation of water wheels, gates, or sluices or if the height of the water in the pool varies from time to time because of the use of flashboards on the dam.

A. NATURAL CONTROL ON SMITH RIVER NEAR BRISTOL, N. H.

B. TRENTON-TYPE ARTIFICIAL CONTROL ON RAHWAY RIVER AT SPRINGFIELD, N. J.

If a gage is placed above a body of water impounded by a dam, the effects of backwater from the dam and the stage at which it occurs at the gage should be investigated with respect to the following conditions: first, sensitivity of the control for the low-water stage-discharge relation; second, the possibility of a reversal in curvature of the station rating curve; and third, the possibility of a transition from a stage-discharge relation to a slope-stage-discharge relation.

Contractions.—A natural or artificial constriction in the channel of some natural streams is an important element in controlling the stage-discharge relation at high stages. Although it seldom is the only element of a high-water control, a constriction may be such a major controlling feature as to govern the shape of the high-water part of the rating curve and to a large extent eliminate the effect of changes in slope due to rising and falling stages. The most common constrictions are those formed by railroad or highway bridges where the abutments and fill at the approaches to the bridge restrict the passage of the water to the openings under the bridge. The reduction in the area of the cross section results in an increase in velocity through the bridge openings and may cause an appreciable difference in stage between the upstream and downstream sides of the bridge. Similar conditions may occur at natural contractions, such as a canyon gorge or a narrows in a river valley. The controlling effect of a contraction is similar to that of a Parshall-flume type of low-water control, except that it is impossible to measure the degree of submergence. If the surface drop due to the contraction amounts to 1 foot or more it is probable that the contraction is the major control factor, and under those circumstances consistent estimates of flood discharge may be obtainable by the "contracted-opening" method of computing discharge (see p. 90).

Contractions have a marked effect on the shape of the rating curve and consideration should be given to the position of the gage, whether above, below, or in the drawn-down reach. The high-water part of a rating curve will generally be more sensitive, have a steeper slope, and approach more nearly a straight line if the gage is above a contraction than if it is below one, especially if the channel has an appreciable increase in width below the contraction and the flow is not retarded by other contractions farther downstream. On large streams, especially those having flat slopes, a knowledge of the nature of contractions below the gage will assist materially in extending the rating curve above the point where it is defined by discharge measurements. This knowledge will also assist in analyzing the results of discharge measurements, especially if measurements at high stages indicate a reversal in the rating curve.

The shape of a rating curve for a gage placed at a section within the reach of draw-down may be similar to that of the curve for a gage in a section just above the contraction, but the curves may differ in position with respect to gage height by an amount approximately equal to the difference in water-surface heights at the respective sections.

Bends in channel.—An abrupt bend in the channel will produce an effect on the high-water flow of a stream similar to that caused by a contraction. When water is in motion its natural direction of flow is in a straight line. As it approaches a bend in the channel the tendency will be for it to flow straight across the channel to the outside bank, where the flow is deflected by the resistance of the bank. The centrifugal force will cause a superelevation in water surface along the outer bank. If the bend is abrupt, the flow along the outer bank may be deflected in such a manner as to produce a cushion of water which may move the high velocities away from the bank. Therefore, as the flow approaches the bend, the transverse profile of the water surface changes from a horizontal to an inclined line, indicating a drop in water surface along the inside bank and a rise along the outside bank. At the lower end of the bend the average gradient of the water surface will be restored to the normal gradient for the channel. At this point the surface slope, which was increased along the inside bank above and through the bend, becomes smaller and so creates a region of low velocity. The flow at the lower end of the bend along the outside bank will no longer pile up, and as a result the gradient there will decrease to the average gradient of the stream. Thus a bend, like a channel contraction, reduces the effective conveyance capacity of the channel and becomes a major controlling element if the breaks in the surface slopes are of an appreciable amount. Some channels below the gage meander in a series of more or less gradual bends which assist in stabilizing the flow and the stage-discharge relation at the gage. Where a bridge is built at or near a bend in the channel, both the bend and the contraction at the bridge may be major factors in producing a high-water control. Studies of flow at river bends have been made by several engineers.[38]

Channel controls for high stages.—If there is no contraction, abrupt bend, or obstruction in the channel causing an appreciable break in the surface slope for a considerable distance below the gage, the flow may be considered as controlled by the resistance of the bed and banks of the channel. For this condition a large number of minor controlling elements of various kinds may combine to stabilize the flow conditions effectively. If a stream does not have a steep slope and a correspondingly high velocity, it is desirable that the elements forming the high-water control should be situated within a distance of a few hundred

[38] Vogel, H. D., Thompson, P. W., Blue, F. L. jr., and others in Civ. Eng., vol. 3, No. 5, pp. 266–268, May 1933, and vol. 4, No. 5, pp. 258–260, May 1934.

feet below the gage in order that the effects of variable slopes produced by changing stage may not complicate the stage-discharge relation.

Controls for high stages generally consist of more than one major controlling element, although it may not be possible to determine even approximately the part performed by each element in controlling the stage-discharge relations. The gaging station on the Merrimack River below Concord River, at Lowell, Mass., exemplifies a combination of elements forming the control at high stages, and illustrates the manner in which the characteristics of the rating curve can be explained from a knowledge of the channel conditions. A reconnaissance survey of the river indicated that a riffle just above an abrupt bend immediately downstream from the site under consideration for the gage created an average fall of about 3 feet and appeared to be a satisfactory control for low stages. From the lower end of the riffle to a point about 10 miles downstream the low-water flow is pooled by a dam. For low and possibly medium stages there was little doubt as to the existence of stable stage-discharge relations, but for high stages it appeared probable that the riffle would be submerged and therefore lose its effectiveness as a control and that the long stretch of pool between the gage and the dam might cause the stage-discharge relation to be affected by variable slopes. However, a gage was established a short distance above the riffle and an excellent high-water rating was defined by measurements made on both rising and falling stages which showed no appreciable effect from variable slopes (see fig. 9). The reason for this stabilized condition during high stages was apparent when the effect of various channel features between the dam and the gage was observed during flood flows. For a short stretch of channel both above and below the gage and extending through the low-water control, it was observed that the average width during high stages was somewhat less than the width of the channel for a large part of the distance between the riffle and the dam, 10 miles downstream. It was also found that instead of the riffle drowning out as was expected, a decided break in the slope was maintained throughout flood stages. Furthermore, at a distance of about 2 miles below the bend a decided narrowing of the valley restricted the flow to such a small area that the velocities within this reach were much greater than the velocities above and below this contraction, thereby creating a decided break in the surface slope. Therefore, as a result of these investigations, it became possible to identify the high-water control for this station as consisting principally of a riffle and bend in the channel immediately below the gage, a natural contraction about 2 miles below the gage, and a dam about 10 miles below the gage, all of which combined in establishing effective stage-discharge relations for high stages.

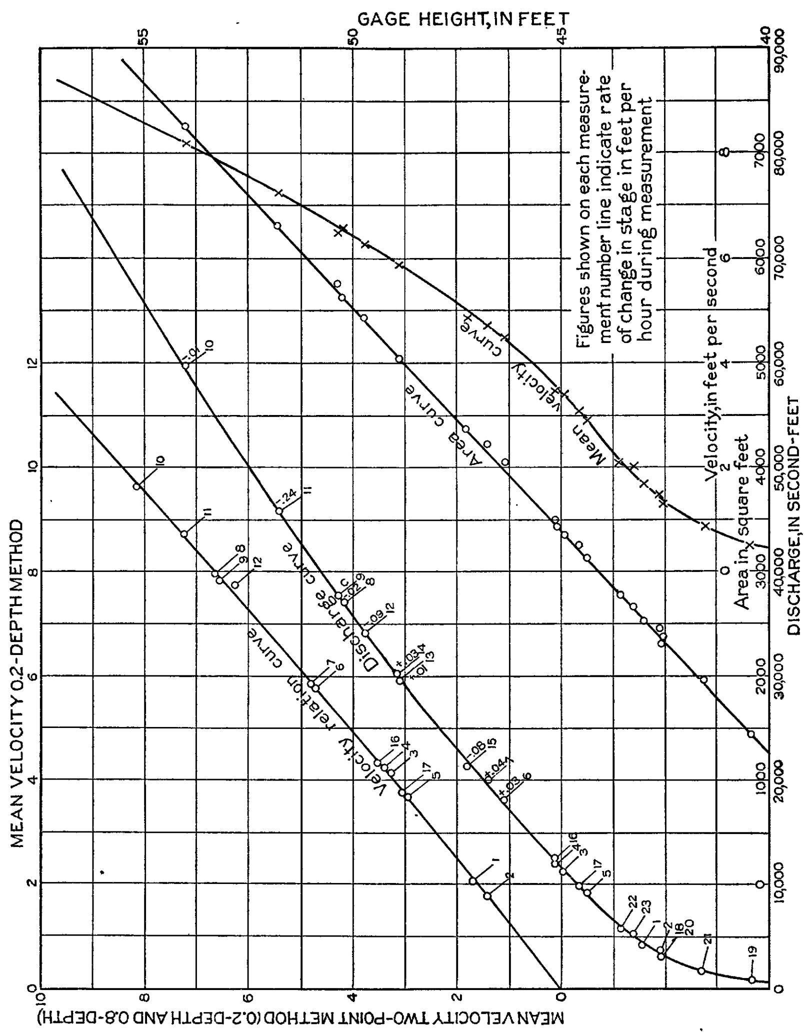


FIGURE 9.—Rating curves for Merrimack River below Concord River at Lowell, Mass.

This particular channel control, which is typical of many similar controls, illustrates two major factors relating to high-water controls: first, the results that would be obtained were not fully apparent from a first examination of the site, and only from high-water discharge measurements could the actual situation be known; and second, it indicates the manner in which a bend or contraction of the channel may be effective in stabilizing the stage-discharge relation at high stages, as here these elements almost entirely eliminated the effects of variable slopes which undoubtedly would have existed had either the bend or the channel restriction been lacking.

The riffle, which formed the low-water control described above, was found to be somewhat unstable and unsatisfactory in maintaining permanent stage-discharge relations for low stages because of changes in the gravel deposits on the riffle. However, these changes did not appear to affect the stage-discharge relation for high stages, which is additional evidence of the effectiveness of the contraction and bends in the channel in maintaining a permanent high-water control.

SHIFTING CONTROLS

The term "shifting control" as ordinarily used in connection with measurements of river discharge refers to that condition where the stage-discharge relations do not remain permanent but vary from time to time, either gradually or abruptly, because of changes in the physical features that form the control for the station.

A stage-discharge rating curve will retain its original shape only so long as the elements that form the control retain their original physical characteristics or as long as the changes in characteristics are compensating with respect to their effects on the stage of water at the gage. The effect of a shift in the control must generally result, therefore, in a change in the stage for a given discharge or, conversely, in a change in the discharge shown by the standard rating for a given stage. Furthermore, if conditions such as vegetal or aquatic growths, accumulations of ice, or the confluence of tributary streams which tend to disturb the permanency of the stage-discharge relation are considered as the causes of changes in stage, any changes in stage-discharge relations due to shifting controls may be treated as though they were the direct result of scour or fill, or other normal changes in the physical characteristics of the bed or banks of the stream. The frequency of such changes and the magnitude of their effects are generally dependent upon the climate, physiographic, geologic, vegetal, and soil conditions within the valley through which the stream flows; and the situations are often so complex that it is impossible to foresee the changes that may occur in the stage-discharge relation at a gaging station.

An example of changes in the stage-discharge relation is shown by the shifts that occurred in the rating curve for the station on the Merrimack River at Lowell, Mass. Subsequent to the development of the curve shown in figure 9, the channel was dredged for the purpose of increasing its capacity for flood discharge. The effects of cutting out the channel by dredging and the effects of coffer dams used during the progress of the work are shown in plate 8.

Effect of scour.—Low-water controls are more likely to be affected than high-water controls by scour or erosion of the stream bed or banks at the riffle or in the reach of channel controlling the stage-discharge relation. The effect of scour or erosion of the control will appear in the discharge-rating curve as a shift to the right of the previous curve, indicating an increase in discharge capacity over that previously found at the same stage. The low-water part of a rating curve may be materially changed as a result of scour, and no change may be apparent in the higher part of the curve because the additional controlling elements that come into effect at high stages are effective in retaining the previous relation between stage and discharge. If the station has a channel control and a radical change has occurred in the bed or banks below the gage, the change in the stage-discharge relation possibly may extend over the entire range of stage, and there may be some degree of parallelism between the old and new rating curves. However, this condition does not generally occur, and the situation where the scour has affected the stage-discharge relation for low stages only is the more common. The actual position of the stage-discharge rating curve after a scour has occurred can be determined only from discharge measurements made subsequent to the scour.

Effect of fill.—The effect of fill on the control is opposite to that of scour. A decrease in the discharge for any given stage will be apparent as long as the fill on the control is effective. The curve representing the new stage-discharge relation will be at the left of the original curve and its shape will depend upon the nature and shape of the control and the extent and distribution of the fill. A uniform distribution of the fill over the entire width of a control effective for all stages would result in a parallel shift similar to a lowering of the gage datum. The effect of fill on a low-water control will be drowned out when complete submergence takes place, thus causing a convergence of the curves for high stages similar to the convergence due to scour at the control.

Low-water controls that are subject to scour and fill usually involve a series of rating curves spreading out generally fanwise at the lower end and converging for stages above the beginning of submergence of the low-water control. Some of the causes of scour and fill in a stream bed have been investigated by Troxell and Peterson.[39]

Shifts in the channel above the control.—Changes in the channel near the gage or between the gage and the control may, under some circumstances, affect the velocity of the water passing the gage and the control. The banks may slough away, thus increasing the width of the channel, or the bed may scour or fill. However, if such changes do not extend through the particular reach of channel that controls the conditions of flow at the gage, the only effect on the stage-discharge relation will be that brought about by changes in the velocity of approach as a result of the change in the area of the cross section or the slope of the channel. The sensitiveness of the control may be increased by the sloughing of the banks or the scouring of the channel because the greater storage capacity of the forebay above the control would result in a lower velocity of approach for a given stage. If there is fill between the gage and the control, the decrease in the storage capacity of the forebay may increase the velocity of approach so as to increase the discharge for a given stage, thereby changing the stage-discharge relation.

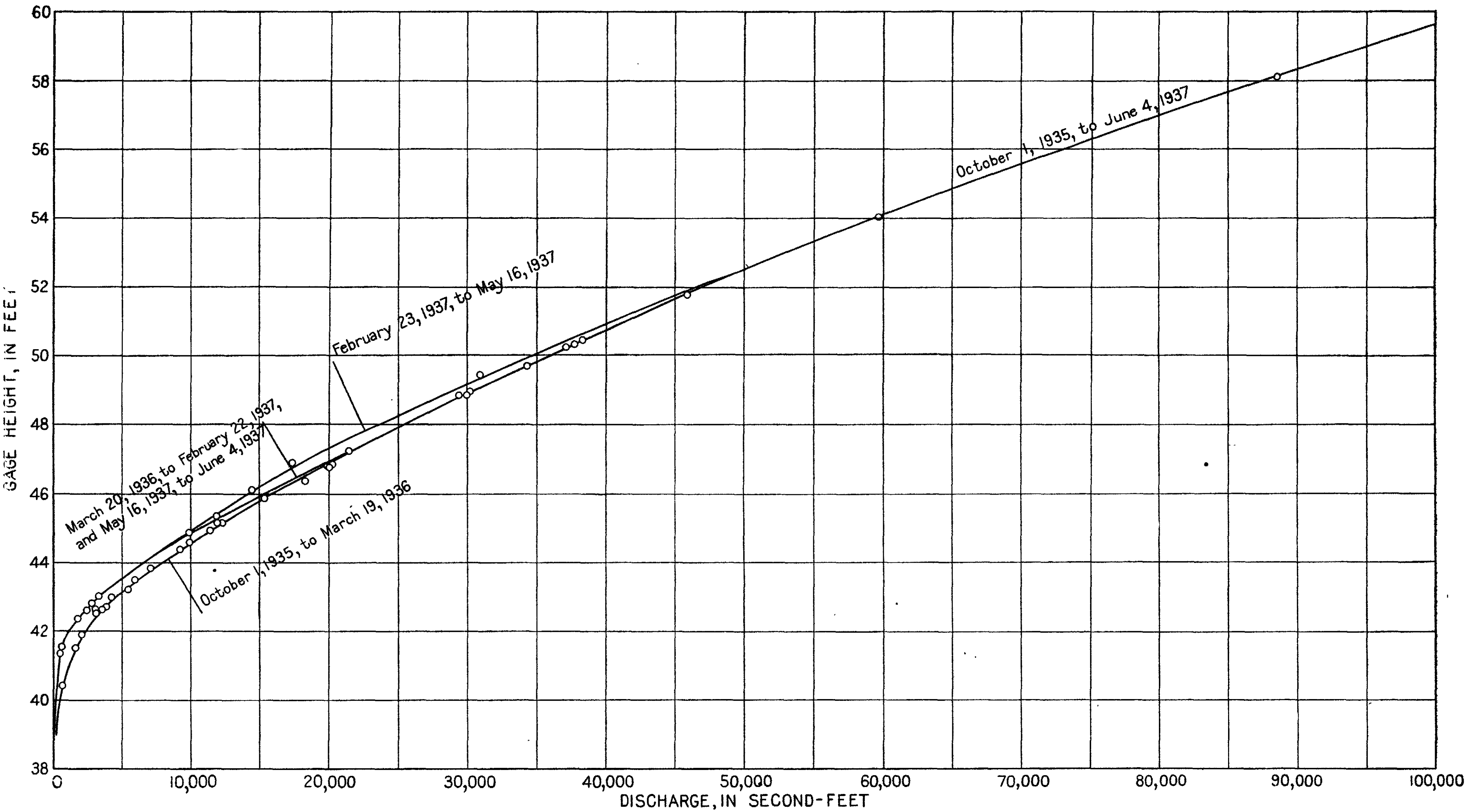
Overflow.—Streams having large overflow areas that include one or more high-water channels present many complications with respect to those elements that determine the stage-discharge relation. For streams of that type the difficulties in obtaining reliable records of discharge are especially great at the time when overflow begins during rising stages and again at the time when overflow ends during falling stages. Therefore, the overflow areas and channels should be investigated with respect to their controlling elements, especially if it appears that they may carry a large part of the total flow of the stream. Generally a shift in the overflow areas and channels that causes a change in the stage-discharge relation is caused by changes in the natural physical condition. For example, the velocities in the overflow area may be materially increased if an area, originally wooded, has been cleared for cultivation. Also, there probably would be a change in the high-water stage-discharge relation if the openings in a highway or railroad embankment that formed a major controlling element were changed so that the total area of the openings was materially increased or decreased.

A knowledge of the characteristics of the overflow areas and of the individual channels in those areas is of value in the analyses of discharge measurements that are made at times of overflow. A profile of the measuring section including all overflow areas and channels might

[39] Troxell, H. C., and Peterson, J. Q., Flood in La Cañada Valley, California, January 1, 1934: U. S. Geol. Survey Water-Supply Paper 796–C, pp. 74–80, 1939.

indicate that overflow channels would begin to fill with water at certain stages; yet if it is not definitely known that a velocity of flow occurs when these areas and channels begin to fill, the shape of the discharge-rating curve might be changed too abruptly. Under some circumstances, overflow channels may fill to several feet of depth as a result of seepage from the main channel without any flow in the overflow channel. Therefore the use of a profile of the cross section as the only guide in changing the shape of the curve may be misleading. The total area of the cross sections of all the overflow channels sometimes may be used with an estimated velocity to determine the magnitude of the change in the slope of the rating curve. Here again, if no definite information is available regarding the velocities in the overflow areas, the extension of the curve beyond the highest discharge measurements may be subject to considerable error. Occasionally it may be practicable to establish separate ratings for the discharge in the overflow areas and the flow in the main channel. The discharge in the overflow area may then be added to the discharge in the main channel for the same stage to obtain the total discharge at the station. This procedure may be helpful in extensions of the highwater part of the station rating curve.

Effect of ice on the stage-discharge relation.—Ice at the control may affect the normal stage-discharge relations in amounts varying with the quantity of ice and its nature, whether surface ice, frazil, or anchor ice. Ice may also affect the stage-discharge relation if it forms a jam in the channel below the control sufficient to cause submergence of the control, or if it forms or collects between the gage and the control in sufficient amounts to cause additional resistance to flow, thus changing the slope of the water at the gage. The magnitude of the effect of ice on the stage-discharge relation—the backwater caused by ice—may be determined by measuring the discharge, observing the corresponding stage, and computing the difference between the observed stage and the stage for the measured discharge corresponding to the open-water stage-discharge rating curve. Such a procedure is based on the assumption that the open-water control remains permanent with respect to its physical features during the time when the stage-discharge relation is affected by ice. This assumption is generally true for streams of fairly stable beds and banks except for such scouring as may occur during the period of ice break-up, which is generally accompanied by high stages and correspondingly high velocities. Complete ice cover at the control and for some distance upstream may, in some instances, produce a closed conduit in which the characteristics of flow are different from those that prevail in a normal open-water channel.



CHANGES IN STAGE-DISCHARGE RELATION AT STATION ON MERRIMACK RIVER AT LOWELL, MASS.

Ice cover increases the frictional resistance to flow by the additional resistance introduced by the surface of the ice that is in contact with the flowing water. Also, the increase in the length of wetted perimeter causes a reduction in the hydraulic radius. As a result of these changes in the hydraulic conditions, a greater effective slope is needed for the same discharge. Many studies have been made to determine the effect of ice on the open-water rating of a stream that is completely covered with ice for long reaches of channel except for a short distance at the rapids or riffle of the low-water control. These studies have shown in general that if the gage is located reasonably close to the control the presence of ice cover above or below the open control has little if any effect on the open-water stage-discharge rating. However, when the channel is partly or completely covered with ice at the control, the amount of backwater for a given stage will increase with the amount and thickness of ice and with the amount of snow on top of the ice which may, by its weight, cause additional displacement of water.

Ice may form so gradually that there may be little to indicate the time when the stage-discharge relations begin to be affected. On the other hand, there may be a decided rise in stage caused by an ice obstruction; or a sharp drop in stage, which may be caused in part by the impounding of water in the form of ice and in part by the channel storage above the gage at places where ice has retarded the flow, may be the first intimation that the stage-discharge relation is affected. On small streams in which a large part of the winter flow is derived from groundwater, it is not uncommon for the minimum flow of the year to occur just after the first extremely cold period, when the discharge from ground water is temporarily checked. Under such conditions when water is being impounded above the gage in the form of ice and channel storage, a period of extremely low flow may occur, which will usually be followed by a partial recovery. If a continuous record of the stage is made by a water-stage recorder, a steeper slope of the graph on a falling stage than on a rising stage usually indicates that the stage-discharge relations is affected by ice.

Of the three varieties of ice—surface, frazil, and anchor—surface ice is the most common, and its effect is evident at more gaging stations than either of the other two. Although the different kinds of ice often occur in combination, each one by itself will produce the same general effect on the stage-discharge relation, namely, an increase in stage above that of normal open-water conditions. The major stream-gaging problems that result from any form of ice relate to the amount of backwater and its variation from day to day and the length of time when the stage-discharge relation is affected.

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Studies of the formation of ice and its effects on the collection of stream-flow records have been made by Barrows and Horton [40] and by Hoyt.[41]

Vegetal and aquatic growths.—Aquatic growths on the control and vegetal growth along the banks and in the overflow areas will affect the capacity and the coefficient of roughness of the channel and therefore the stage-discharge relation, by amounts that will vary with the stage and the season. These growths are generally greatest in polluted streams that carry large quantities of organic waste. Aquatic growths at the control may have greater effects on stages at low discharges than at high discharges and except for their seasonal characteristics, the effects will resemble in many respects those produced by fill or scour. In northern regions the effects, if any, from aquatic growths in rivers are generally noticeable during late May, increase gradually until the early part of July, then remain fairly constant until late October, and then diminish rapidly after the first subfreezing temperatures. In milder climates the effects may begin earlier in the spring and last until later in the fall. A knowledge of this general sequence of conditions is not sufficient for the determination of discharge without additional supporting data, including discharge measurements made at frequent and regular intervals of time. Abnormally low temperatures may retard aquatic growths, and high temperatures later in the spring and early summer may increase them. Floods or high velocities may remove part or all of the effect of backwater from such growths either by flattening them out or by cutting them entirely away from the bed. In some chemically polluted streams aquatic growths may thrive during periods of high discharge when the chemicals are diluted but may die at times of lower discharge when the pollution is more concentrated.

Vegetal growths along the banks within the reach of channel that forms the control will tend so to decrease the effective area of the cross section as to become noticeable, especially at high stages. The presence of vegetal growths in the overflow areas will have a similar effect, particularly if the flow over such areas is controlled by elements not applicable to the main channel.

SLOPE-STAGE-DISCHARGE RELATIONS AT GAGING STATIONS AFFECTED BY VARIABLE SLOPES

The stage-discharge relations for conditions of steady flow at a section in an open channel are fixed if the channel is stable and if the slope corresponding to a given stage is always the same. Under

[40] Barrows, H. K., and Horton, R. E., Determination of stream flow during the frozen season: U. S. Geol. Survey Water-Supply Paper 187, 93 pp., 1907.

[41] Hoyt, W. G., The effects of ice on stream flow: U. S. Geol. Survey Water-Supply Paper 337, 77 pp., 1913.

these conditions, if a stage-discharge rating has been developed the discharge may be determined from an observation of stage without specific information as to the slope corresponding to that stage. For conditions other than steady flow, or if the slope is not always the same for a given stage, it is necessary to consider the slope of the water surface in evaluating the stage-discharge relations.

Variable slopes that affect the flow in open channels are caused by backwater, by changing discharge, or by backwater in conjunction with changing discharge, and each of these conditions requires a special method in obtaining records of discharge.

The development of a mathematical equation for the relations of slope, stage, and discharge for conditions of variable slope at a gaging station involves the use of a general equation of steady flow with uniform velocity in the form

$$V = KR^{a}S_{e}^{\rho} \tag{1}$$

in which V is the velocity, considered as uniform throughout the cross section, K is a measure of the channel resistance, R is the hydraulic radius, considered a measure of channel shape, S_e is the slope of the energy gradient, regarded as the rate at which a given volume of water loses energy as it moves downstream, ^{a} is an exponent expressing the effect of channel shape, and $^\rho$ is an exponent of the slope of the energy gradient. The development of the method involves the general equation of unsteady flow in open channels which may be expressed in the form

$$-S_e = \frac{\delta z}{\delta x} + \frac{\delta(\alpha V^2)}{\delta x(2g)} + \frac{1}{g}\frac{\delta V}{\delta t} \tag{2}$$

In this general equation of unsteady flow, S_e is the slope of the energy gradient as defined above, $\frac{\delta z}{\delta x}$ is the slope of the water surface (later referred to as S_s), $\frac{\delta(\alpha V^2)}{\delta x(2g)}$ is the increment of slope due to the velocity head, and $\frac{1}{g}\frac{\delta V}{\delta t}$ is the increment of slope due to the acceleration head, each at the same instant of time.

In those practical problems of determining flow in open channels that require the application of equation (2), the increment of slope due to the acceleration head $\frac{1}{g}\frac{\delta V}{\delta t}$ is, in general, so small with respect to the slope of the energy gradient plus the increment of slope due to the velocity head that its effect may be neglected.

Equation (2), written in the form of differentials with the acceleration-head increment of slope omitted, becomes

$$-S_e = S_s + \frac{d(\alpha V^2)}{dx(2g)} \tag{3}$$

This is the equation for steady, nonuniform flow in an open channel. The slope of the water surface S_s is considered positive in the downward direction and the velocity-head increment is considered positive if the velocity is increasing in the direction of flow. Figure 10 shows the slope and energy relations in an open channel.

Equation (1) may be modified to include the area of the cross section from the relation $Q=AV$, so that the equation becomes $Q=AKR^aS_e^p$, which may be written in the form

$$AKR^a=\frac{Q}{S_e^p} \tag{4}$$

The term AKR^a contains only parameters of the cross section, which are independent of all other conditions, and is a constant at a given

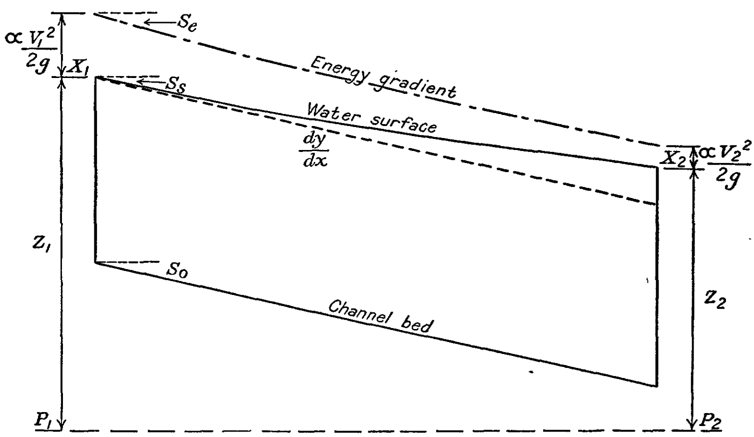


FIGURE 10.—Slope and energy relations in an open channel.

stage except that the friction coefficient K possibly may vary slightly with changes in slope. It is an index of the capacity of a channel to carry water under the theoretical condition of unit slope and is designated by Bakhmeteff [42] as the conveyance of a stream. The discharge at a given stage and condition of energy slope when divided by that slope raised to an appropriate power will define a parameter of channel capacity at that stage. In other words, if at a given stage two discharges Q_1 and Q_2 occur at different times with the corresponding energy slopes S_{e1} and S_{e2} their relation may be expressed by the equation:

$$\frac{Q_1}{Q_2}=\frac{S_{e1}^p}{S_{e2}^p} \tag{5}$$

VARIABLE SLOPES CAUSED BY BACKWATER

Backwater is that condition of stream flow in which the velocity for steady flow gradually diminishes downstream and is manifested

[42] Bakhmeteff, Boris A., Hydraulics of open channels, p. 13, 1932.

by the peculiar characteristic slope of the water surface in the direction of flow, which is always less than the surface slope that would occur if backwater was not present. It may be argued that there is some backwater at nearly every gaging station on a natural stream. This may be true for the gaging stations situated above constrictions, such as narrow reaches of channel; or artificial structures, as dams, weirs, or locks; but the backwater effects need not be considered unless they are so changeable that they produce material variations in the slope at the same stage.

Slope is an inherent element in determining the shape of the rating curve for every gaging station. For a gaging station affected by variable backwater, slope must be treated separately because at any stage differences in backwater will vary the slope, with consequent effects on the discharge at that stage. The discharge for a gaging station so affected can be determined only by consideration of slope as an essential element in the slope-stage-discharge relation.

In practical river hydraulics the slope of the water surface under backwater conditions may be ascertained from observations of stage on gages set to the same datum and placed so far apart that the difference in readings will show the fall in the reach with an accuracy that will not be affected appreciably by the ordinary errors in gage readings. If both gages are set to the same datum, the fall divided by the length of the reach is a measure of the slope of the water surface. It might be supposed that the slope determined by this means would be an accurate measure of the water-surface slope, but certain practical conditions that may prevail in any natural channel may have a material effect on the relation of the slopes determined by this means to the true slope of the water surface. These conditions are described as follows:

First, the water surface in any reach affected by backwater is not a plane surface between points in the reach, as sinuosity of the channel will produce variations in the height of the water surface, both across and along the reach; variations in channel cross section and the effects of backwater also tend to produce curvature of the water surface. The slope determined from observed difference in stages is that of a chord connecting the water-surface elevations at points at the ends of a reach. It may not represent the slope of the water surface at either end of the reach, but may be parallel to a line that is tangent to the water surface at some point in the reach.

Second, no reach of a natural stream selected for the determination of slope is completely uniform. The area of the cross section may vary considerably from point to point in the reach, but more important is the effect that shoals, riffles, rapids, or bends on the stream channel within the reach may have on the slope of the water surface, as well as on the energy gradient. In some places there may be a section control for some conditions of flow, so that below a certain stage backwater effects at the lower gage will not be transmitted completely through the reach. Under such conditions the chord between the water-surface stages at the ends of the reach will have no significance in connection with the determination of the actual slope of the water surface.

Third, the positions of the gages at the ends of the reach with respect to the physical features of the channel may have a material effect on the recorded gage heights and hence on the indicated slope. For example, if one gage is on the inside of a rather sharp bend and the other on the outside of a similar bend, the slope computed from records of stages at those gages may be widely different from the actual slope of the water surface. Also, if one gage is attached to a bridge pier where draw-down around the pier affects the recorded stages in amounts that vary with the velocity past the pier and the other gage is on the bank or at a section of different velocity conditions, the records obtained therefrom may not be true indices of the slope. There may be a draw-down effect on the intake pipe to a gage well so that effects similar to those described above may be produced. It is essential that precautions be taken to eliminate any effects that may change the relation between the recorded gage heights and the stages which they are supposed to represent. For intake pipes, this may best be accomplished by the attachment of suitable devices for the elemination of draw-down, several of which have been designed by the Geological Survey.

Fourth, both gages may not be set to exactly the same datum, the difference in datum possibly being a large percentage of the total fall if the fall is very small. The slope determined from gages not set to the same datum would not indicate the true water-surface slope, but would include in it the quantity $\frac{y}{L}$, in which y is the difference in datum and L the length of reach. This quantity would be positive or negative, depending upon the relative datums of the gages.

Fifth, the rates at which the water surface will fall in different sections in a natural stream are determined by the characteristics of the sections as expressed by the values of A, K, and R. Variations in these values affect the slope of the water surface within and above the sections at which such variations occur and tend to modify the effects of downstream conditions. If the upper gage is used as the basis of reference for determining adjustments for variable backwater effects, the magnitude of the necessary adjustments is generally less than if the lower gage is used, and the plotting of the measurements is more consistent. The nonuniformity of the reach may be such that under certain conditions of flow a section control in the reach prevents the effects of backwater from reaching the upper gage. Under those circumstances the relation between stage and discharge at the upper gage would not be affected by any variation in the backwater conditions below the section control.

VELOCITY-HEAD INCREMENT TO SLOPE

The velocity-head increment to slope corresponding to the term $\frac{d}{dx}\frac{(\alpha V^2)}{(2g)}$ in equation (3) is a quantity that, under certain conditions, may represent an appreciable percentage of the measured surface slope, and its omission may involve a sizable error in the determination of discharge. A study of the effect of the velocity head was made in connection with the analysis of the slope-stage-discharge relations for the Tennessee River at Chattanooga, Tenn. (See p. 141). The percentage relations between the velocity-head increment and the slope of the water surface as obtained from that study are given in table 6.

TABLE 6.—*Slope of the energy gradient, Tennessee River at Chattanooga, Tenn.*

Discharge in second-feet	Surface slope [1]	Velocity-head increment [2]	Slope of the energy gradient	Percent increase over surface slope
20,000	0.000057	−0.0000005	0.0000565	−0.1
36,000	.000061	−.0000019	.0000591	−3.1
55,000	.000071	−.0000020	.0000690	−2.8
75,000	.000083	−.0000034	.0000796	−4.1
111,000	.000100	−.0000029	.0000971	−2.9

[1] Fall, in feet, between Meadow Lake and Citico Bar divided by 11,200 feet, the length of reach.
[2] The average velocity at the lower end of the reach was greater than at the upper end.

From the above table it appears that the velocity-head increment to slope is not a large percentage of the slope of the water surface at this station. It might, however, be greater for conditions at other places. The velocity at each end of a slope reach should be investigated with respect to its amount and distribution and the effect of the distribution of velocity upon the velocity-head correction factor α.[43] The results of such a study would determine whether the velocity-head increment must be included in the analysis of the slope-stage-discharge relations for the reach.

RELATION BETWEEN DISCHARGE AND FALL

As may be seen from pages 133–134, the fall in a reach of a natural channel is not a direct measure of the slope of the water surface

[43] For discussion of the factor α *see* King, H. W., Handbook of hydraulics, 3d ed., pp. 260–263, 1939.

because of the effects of (1) curvature of the water surface, (2) non-uniformity of the channel, (3) position of the gages, (4) possible errors in datum, and (5) channel characteristics. However, the slope S_e as expressed in equation (5) may be considered as a function of the fall in a reach, so that the equation of relation becomes

$$\frac{Q_1}{Q_2}=\text{function}\frac{F_1}{F_2} \tag{6}$$

in which the falls are the differences in the heights of the water surface at the ends of the reach. If the velocity-head increment $\frac{\alpha V^2}{2g}$ is large enough to warrant consideration, it should be added to each observed fall.

Examination of equation (6) by the application of field data indicates that the relation between the ratio of two discharges at a given stage and the ratio of the corresponding falls is in the form of an exponential equation which can be expressed graphically by a curve. It has been found that, for some conditions, equation (6) may be represented by the equation $y=x^b$ in which y represents the discharge ratios, x the fall ratios, and b is a constant. Substituting $\frac{Q_1}{Q_2}$ for y and $\frac{F_1}{F_2}$ for x in the equation $y=x^b$, with the assumption that the second discharge Q_2 is for the unit fall 1.00, and then solving for the second discharge, the equation becomes

$$Q_2=\frac{Q_1}{F_1{}^b} \tag{7}$$

For those conditions where equation (7) is applicable, it has been found that the exponent b varies over a comparatively narrow range but seldom is exactly 0.5 as sometimes assumed.

Inasmuch as equation (6) does not always reduce to the simple form of equation (7), the evaluation of equation (6) by the aid of graphical methods simplifies the procedure. Those stations within the range of limitations which permit the relation to be solved by the application of equation (7) will have a curve of relation between the discharge ratios and the fall ratios that is parabolic in form and passes through the origin of coordinates. Other stations may have curves of relation which are equally applicable to the solution of the problem of slope-stage-discharge relations but are not as readily adapted to simple mathematical expression, possibly owing to the conditions discussed on pages 133–134.

CURVES OF RELATION

Slope reaches are either of uniform slope or of nonuniform slope. A uniform slope reach is one through which the parameters of channel, A, K, and R are reasonably uniform and any backwater condition at the lower end of the reach is to some extent transmitted through the entire reach. In a nonuniform slope reach, A, K, or R may vary considerably throughout the reach, so that under some conditions of stage and flow the backwater effects that are present at the lower end will not pass entirely through the reach but are stopped at the section control, at which point there is a break in the slope.

As stated in the preceding pages, the discharge at a given section of a stream channel is a function of the two factors stage and fall. If it is possible to produce two curves of relation for that channel, one between stage and discharge for fixed conditions of fall and one between discharge ratios and fall ratios in accordance with the equation (6), the fall-stage-discharge relations for the stream can then be completely defined. It is possible to develop these relations graphically with little more knowledge of the mathematics involved than is necessary for the use of the ordinary stage-discharge relation. The following is a step-by-step outline of the method of determining the relations between discharge and stage and between discharge ratios and fall ratios as has been discussed by Boyer.[44]

The first step in the development of these relations is to plot all discharge measurements in the ordinary manner, using discharge and stage as coordinates, the stage at the upper gage generally being used, although under some circumstances an average of the stages at the upper and lower gages may give more satisfactory results. Opposite each measurement as plotted, indicate the fall at the time of the measurement. An examination of the discharge measurements plotted in the above manner will indicate one of two characteristics, as follows:

A definite stage-discharge relation may not be apparent. It will, however, be possible to draw by inspection a curve conforming to some constant value of fall (hereafter designated as F_c) throughout most of the range of stage. This curve is essentially a contour curve of equal fall and will be designated as the constant-fall curve. From a practical standpoint, the curve of 1-foot fall is most convenient. The approximate position of this curve for the first trial may be determined by application of equation (7) with the exponent b of 0.5. As the use of the 0.5 exponent is approximate, it is necessary to develop graphically the curve of relation between discharge ratios and fall ratios, and to recompute the constant-fall discharge on the

[44] Boyer, M. C., Determining discharge at gaging stations affected by variable slope: Civil Engineering, vol. 9, p. 556, 1939.

basis of this relation rather than on the 0.5 exponent. Each discharge measurement will plot to the left or right of this curve, depending upon whether the fall for the measurement is less or greater than that selected for the curve. This curve of constant fall determines the values of discharge and fall to be used in equation (6), which may be written

$$\frac{Q_m}{Q_c} = \text{function}\,\frac{F_m}{F_c} \tag{8}$$

in which Q_m is the measured discharge, Q_c is the constant-fall discharge at the same stage, F_m is the fall corresponding to the measured discharge, and F_c is the selected constant fall.

A definite stage-discharge relation will be apparent as defined by the measurements that generally plot farthest to the right, if the reach is nonuniform. These measurements define a condition of least backwater, which means that as the backwater decreases, accompanied by an increase in fall through the reach, a section control in the reach becomes active and for that condition all measurements will line up on a curve—the curve for the stage-discharge relation at the upper gage with respect to the control. If equation (6) is to be applied to stations of this kind, it will be necessary to develop a curve of relation between the stage and the fall at which backwater just begins for that stage, rather than for a constant fall. The fall as expressed by this curve is the so-called normal fall; it is designated F_n, and the corresponding discharge from the curve of least backwater is called the normal discharge, which is designated Q_n. All discharge measurements will plot on the curve of least backwater, or to the left of it.

The curves of relation between stage and discharge and between stage and fall for the condition of least backwater are used in defining the relations in equation (6), which may be written

$$\frac{Q_m}{Q_n} = \text{function}\,\frac{F_m}{F_n} \tag{9}$$

The second step in the application of equation (8) or (9) is to compute for each discharge measurement the discharge ratio and the fall ratio. These ratios are $\frac{Q_m}{Q_c}$ and $\frac{F_m}{F_c}$ if the reach is uniform, or $\frac{Q_m}{Q_n}$ and $\frac{F_m}{F_n}$ if the reach is nonuniform.

The third step is to plot the discharge ratios as ordinates and the fall ratios as abscissas and to draw an average curve among the points so plotted. By means of this curve of relationship adjust each measured discharge to the corresponding constant-fall or normal-fall discharge by dividing each measured discharge by the factor for the discharge ratio as determined from the curve for the corresponding fall ratio. Plot these adjusted discharges against stage. It may be found that a slight reshaping of the stage-discharge curve will be necessary on the basis of the adjusted discharge measurements. Therefore, if necessary, redraw the stage-discharge curve to obtain a better average of the adjusted measurements and recompute and replot the discharge ratios against the fall ratios. If the stage-discharge curve for a nonuniform reach is not a smooth curve, some reshaping of the normal fall curve may be necessary. One or two trials will produce smooth curves, both for stage against discharge for the selected constant value of fall or the normal fall and for the relation between the discharge ratios and the fall ratios. These curves are fundamental for this method of determination of the discharge at gaging stations affected by backwater.

Constant-fall stage-discharge relation.—If all the discharge measurements in a uniform channel affected by backwater could be made under the same condition of fall, the resulting curve for the stage-discharge relation would be a curve for a constant fall. As such a procedure is not possible where there is backwater, it is necessary to construct the curve of constant fall by interpolation between the falls that were observed at the times when measurements were made.

Normal-fall stage-discharge relation.—The normal-fall stage-discharge relation defines the stage-discharge relation at the upper gage for conditions of least backwater. When no backwater is present the station may be operated by means of the normal-fall stage-discharge relation with no adjustment. As backwater effects reach the upper gage, the section control becomes submerged and adjustment for the backwater effects must be made. The fall at which the submergence begins is different for each stage, hence the necessity for the additional curve of relation between stage and fall for the beginning of backwater. The condition that the fall is a variable with stage instead of a constant, as is the case for uniform reaches, necessitates the consideration of variation of fall with stage in the application of equation (6).

Discharge-fall relation.—The curve of relation between discharge ratios and fall ratios is a graphical representation of the functional relation expressed in equation (8) or (9). It includes the effects of variations in the velocity-head increment, nonuniformity of the water surface in the reach, and other unknown factors which may be present.

The curve of relation between the discharge ratios and the fall ratios must pass through the point at which each is unity. It need not, however, pass through the origin if the gages are not set to the same datum or if there is a break in the bed slope. If the gages are at the same datum and there is no break in the bed slope, other causes, such as a draw-down or piling up of water at the gage or bridge piers, or the effects of bends in the channel, may distort the shape of the curve.

Effects of channel conditions.—If the physical conditions of the channel in the reach remain constant with respect to time, the curves of relationship between stage, fall, and dischange should not change. However, if changes in the frictional resistance of the channel, changes in area, or changes in hydraulic radius occur in the reach, such changes will be reflected in the fall-stage-discharge relations. Shifts occurring in the channel below the reach will be reflected by changes in the fall of the reach and in the stage; but as the fall and stage automatically adjust themselves to such shifts, the curves of relation will remain unchanged unless, as indicated above, such shifts occur within the reach itself.

If shifts occur within the reach, their effects will be reflected by a scattering of plotted measurements with respect to both the stage-discharge and discharge-fall curves. However, they may be treated as gage-height shifts in the usual manner by determining the departure, in feet, of the adjusted discharge measurement from the constant-fall stage-discharge, or normal-fall stage-discharge curves.

It is desirable to review the data at appropriate times to detect the possibility of rating-curve shifts, especially for stations where changing backwater conditions do not continuously affect the upper gage. Under such conditions and with unstable control conditions within the reach, there is always the possibility of low-water shifts; however, with proper precaution and adequate discharge measurements, the shifts may be detected and the necessary changes made in the ratings.

Effects of difference in datum.—If there is a difference in the datums of the gages and if the relations between stage, fall, and discharge are being determined for a reach having uniform slope by use of the curve of constant fall and application of equation (8), this difference will be absorbed in the curves of discharge-fall relation, but it may not be possible to express the discharge-fall relations in simple mathematical terms.

If the relations between stage, fall, and discharge are being determined for a reach having nonuniform slope by use of the curve of least backwater and the application of equation (9), it is essential that both gages be set to the same datum, as the normal fall varies with stage and the ratio of the observed falls at different stages will not bear a constant relation to the ratio of the true falls as determined by correcting for differences in datum.

Effects of fluid turbulence.—The foregoing analysis of the slope-stage-discharge relations is predicated on the assumption that turbulence is completely developed in the stream and that all the energy of the flowing water is being dissipated in that manner. Under some extreme conditions of small fall and low discharge, it is possible that turbulence may not be fully developed and viscous forces may predominate, in which event the relation between discharge ratios and fall ratios may be a family of curves of equal discharge instead of a single curve. However, the practical difficulties involved in accurately determining the discharge and the fall through such a reach are so great that data of sufficient accuracy for definite evaluation of this condition are not yet available.

PRACTICAL APPLICATION OF THE CURVES OF RELATION

Several gaging stations now operated by the Geological Survey are affected by backwater. Some of these stations have uniform reaches and some have nonuniform reaches. Records obtained at some of these stations have been selected for the purpose of explaining the practical application of methods described in the preceding pages.

TENNESSEE RIVER AT CHATTANOOGA, TENN.

The upper gage at the station on the Tennessee River at Chattanooga, Tenn., is designated the Meadow Lake gage. A water-stage recorder is installed in a concrete well and shelter on the right bank, 2,700 feet below the mouth of South Chickamauga Creek, 3.0 miles downstream from Chickamauga Dam, and 36.5 miles upstream from Hales Bar Dam. Gage heights are referred to an inside float gage. Auxiliary gages include inside and outside staff gages. A static tube is provided on each intake.

The lower gage at this station is the Citico Bar gage. A water-stage recorder is installed in a concrete well and shelter on the left bank, 11,240 feet downstream from the Meadow Lake gage. The gage heights are referred to an inside float gage. Auxiliary gages include inside and outside staff gages. A static tube is provided on each intake. Discharge measurements are made by boat opposite the Meadow Lake gage or the Citico Bar gage, or from the Walnut Street Bridge 6,090 feet below Citico Bar. The channel is curved in the vicinity of each gage, although it is practically straight between them. Each gage is on the outside of a bend. The relative position of the gages is shown in figure 11.

The width and depth of the channel are fairly uniform throughout the reach with no abrupt change in the area of the cross section except at Citico Bar, where the bed rises about 5 feet. Therefore, the reach may be considered as being essentially uniform. Careful inspection by boat through the reach does not reveal the presence of any shoal other than that at Citico Bar, nor is there any appreciable contraction of the channel. The bed of the stream is covered with coarse hard-packed gravel, sand, and clay, and is not subject to change except possibly at extremely high stages. The banks are covered with a fairly dense growth of brush and large trees.

Backwater and variable slopes at this station at low stages are caused by the operation of turbines and flashboards at Hales Bar

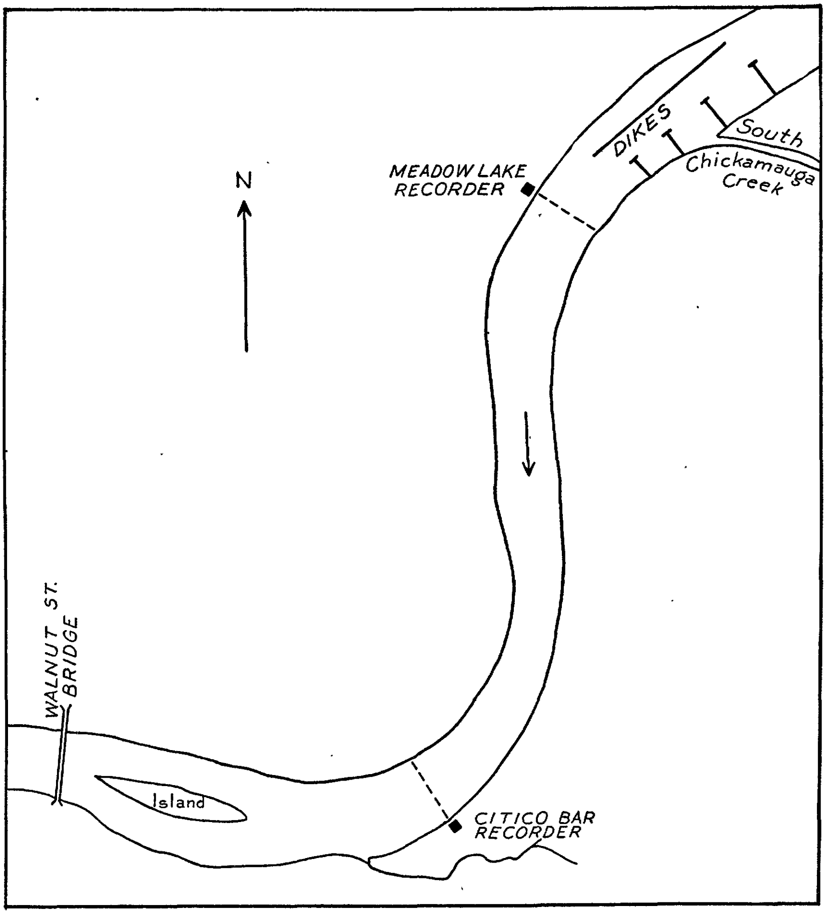


FIGURE 11.—Gages on Tennessee River at Chattanooga, Tenn.

Dam. This is a low dam which becomes submerged at extremely high stages so that the backwater effects from it are negligible under those conditions.

The curves of relation between stage and discharge and between discharge ratios and fall ratios for this station have been developed by means of the constant-fall curve in accordance with equation (8). The plotting of the discharge measurements with the fall indicated beside each measurement, and the trial curve for a constant fall of

1.00 foot, are shown in plate 9. The plotting of the adjusted discharge measurements and the curve of relation between discharge ratios and fall ratios are shown in plate 10.

TENNESSEE RIVER AT GUNTERSVILLE, ALA.

The upper gage at the station on the Tennessee River at Guntersville, Ala., is a water-stage recorder installed in a well attached to the downstream face of the pier at the left end of the main-channel span of a highway bridge. The lower gage is a water-stage recorder installed on the right bank, 43,700 feet below the upper gage and 3,300 feet above the Guntersville Dam.

The channel conditions in this reach are reasonably uniform and the sinuosities are approximately of the same nature as those of the Tennessee River at Chattanooga, Tenn. Backwater is caused by the Guntersville Dam. The curves of relation for this gage are shown in plate 11. It will be noted that the curve of relation between the fall ratios and the discharge ratios does not pass through the origin of the coordinates and therefore cannot be represented by a simple form of parabola having its vertex at the origin. This condition may be due to the gages at the ends of the reach not being set exactly to the same datum, or to a break in the surface slope between the two gages. There is also the possibility that the upper gage, which is on the downstream side of a bridge pier may be affected by the draw-down past the pier.

The possibility that the positions of the gages may have an effect on the curves of relation is brought out by a study of the fall-discharge relations at this station. If one or both of the gages in a reach are so placed that the gage heights recorded by them are distorted by conditions such as draw-down around a bridge pier or past an intake pipe, by superelevation of the water on the outside of a bend, or by depression on the inside of a bend, the falls determined from those records may be seriously affected. Conditions of that kind should be given consideration in the operation of a station. The fact that such effects have not always been recognized may have been the reason for mediocre success in the application of theoretical equations under some circumstances.

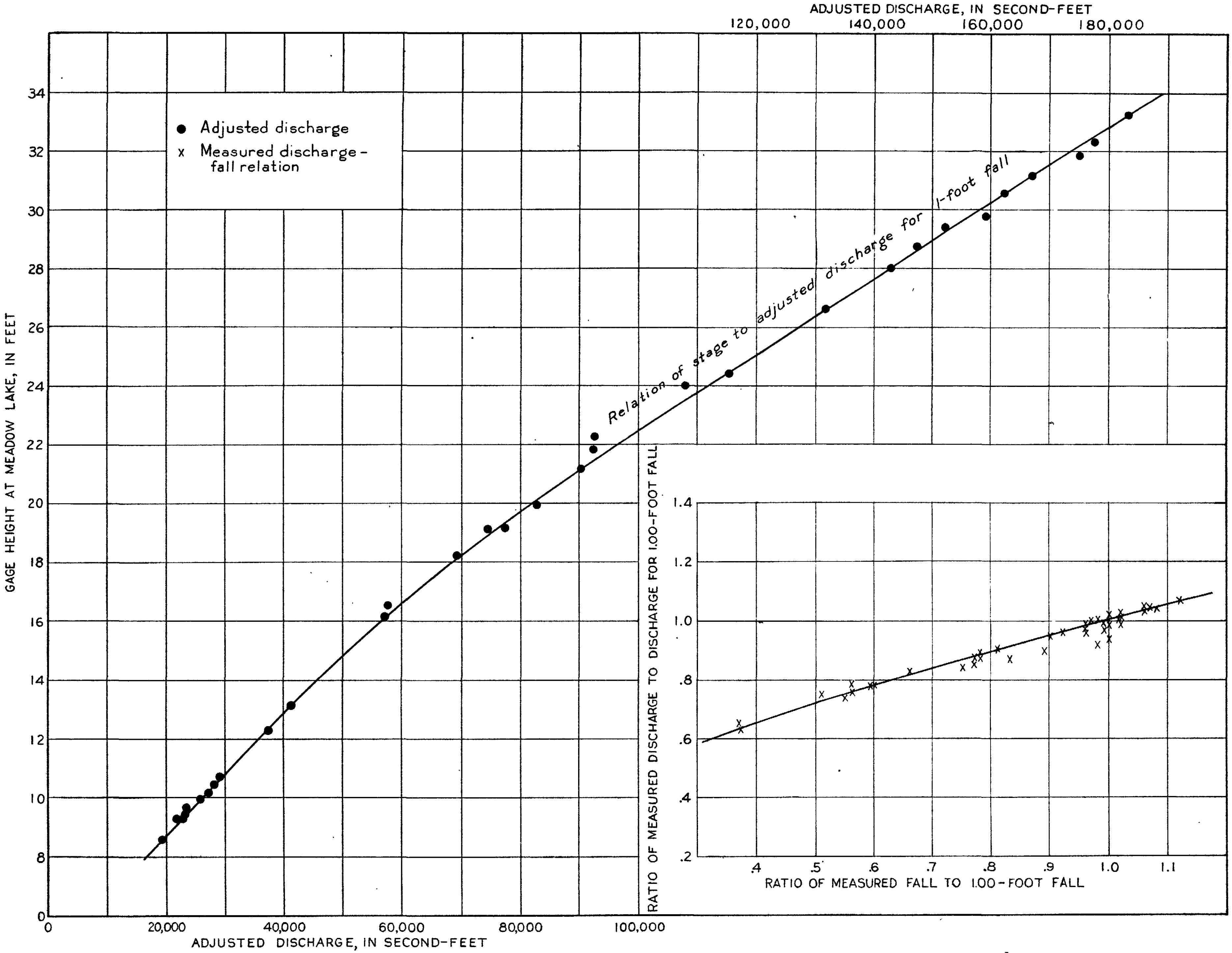
OHIO RIVER AT METROPOLIS, ILL.

The upper gage at the station on the Ohio River at Metropolis, Ill., is a water-stage recorder installed on the downstream side of a pier of the railroad bridge at Metropolis. The lower gage is a water-stage recorder installed on the right bank, 2,600 feet upstream from Dam 53, a navigation lock and dam, and 95,000 feet downstream from the upper gage. Both gages are at the same datum as determined by levels to bench marks of the Corps of Engineers, United States Army.

In the channel between Metropolis and Dam 53 are two large gravel bars, known as the Grand Chain Rapids and the Little Chain Rapids. Prior to 1929, when Dam 53 was completed, the flow over the bars was swift and the depths were shallow during low-water periods, so that navigation was difficult. The present pool has increased low-water depths of the river at sections other than the canalized parts of the channel to about 9 feet, and likewise has increased the width and the total area of the cross sections in all parts of the reach. The plan and profile of the reach are shown in plate 12. The upper part of the diagram shows the plan of the river in the reach. The hatched areas represent that part of the river bottom over which the depth of water is less than 9 feet when Dam 53 is operating and the pool is at normal level, which is 290 feet above mean sea level. The central part of the diagram is a profile of the river bottom for approximately the lowest third of the width at each section. The plan and profile show the degree of nonuniformity of the reach, particularly the bed profile. This marked nonuniformity is reflected in the variation in the average velocity from point to point in the reach, those variations naturally affecting the slope of the water surface and the energy gradient. The variations in average velocity are shown by the curve at the bottom of the diagram. The velocity was computed from areas determined on the basis of soundings by the Corps of Engineers, United States Army, at sections in the reach for a discharge of 50,000 second-feet with the pool at normal operating level.

There are three possible sources of backwater at this station. First, the operation of Dam 53 for navigation, which is the most prolific source of backwater, affects the stage-discharge relation for all discharges below about 250,000 second-feet. The effects are most serious for discharges below 100,000 second-feet and under those conditions Dam 53 at times creates such extreme backwater that the fall in the 95,000-foot length of reach is only 0.28 foot. High stages of the Mississippi River is the second source of backwater. Such stages caused 7 feet of backwater in June 1938 for a discharge of 166,000 second-feet in the Ohio River. The third source of backwater is the return of overbank flow from areas along the channel. This has considerable effect, particularly for discharges above 300,000 second-feet, but is infrequent and occurs only during periods of extreme floods, such as the flood of January 1937.

As indicated above, the reach for this station is nonuniform and the relations between fall, stage, and discharge must be determined by means of equation (9), the curves of relation between stage and



CURVES SHOWING RELATIONS OF STAGE TO CONSTANT-FALL DISCHARGE AND DISCHARGE RATIOS TO FALL RATIOS, TENNESSEE RIVER AT CHATTANOOGA, TENN.

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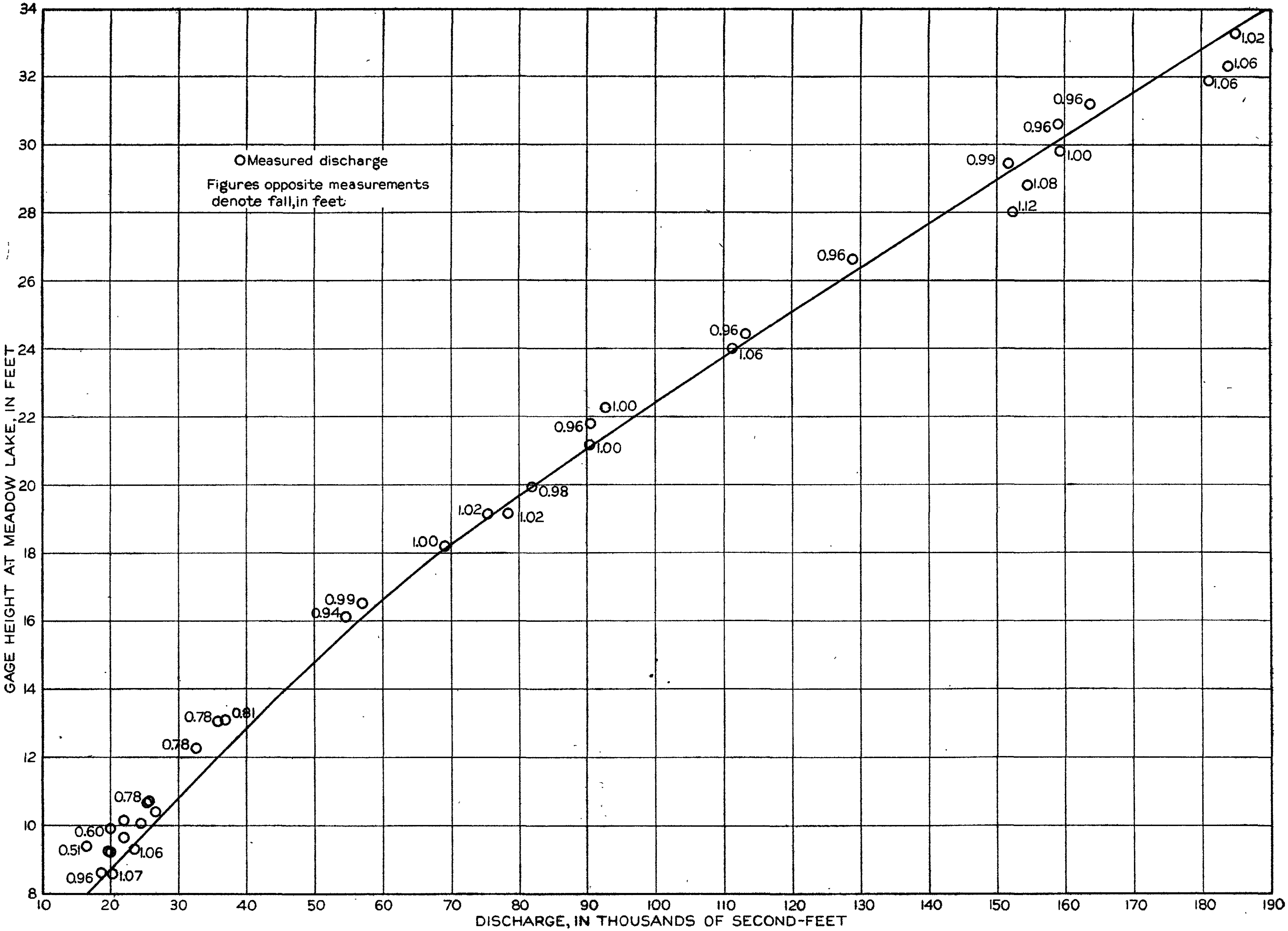
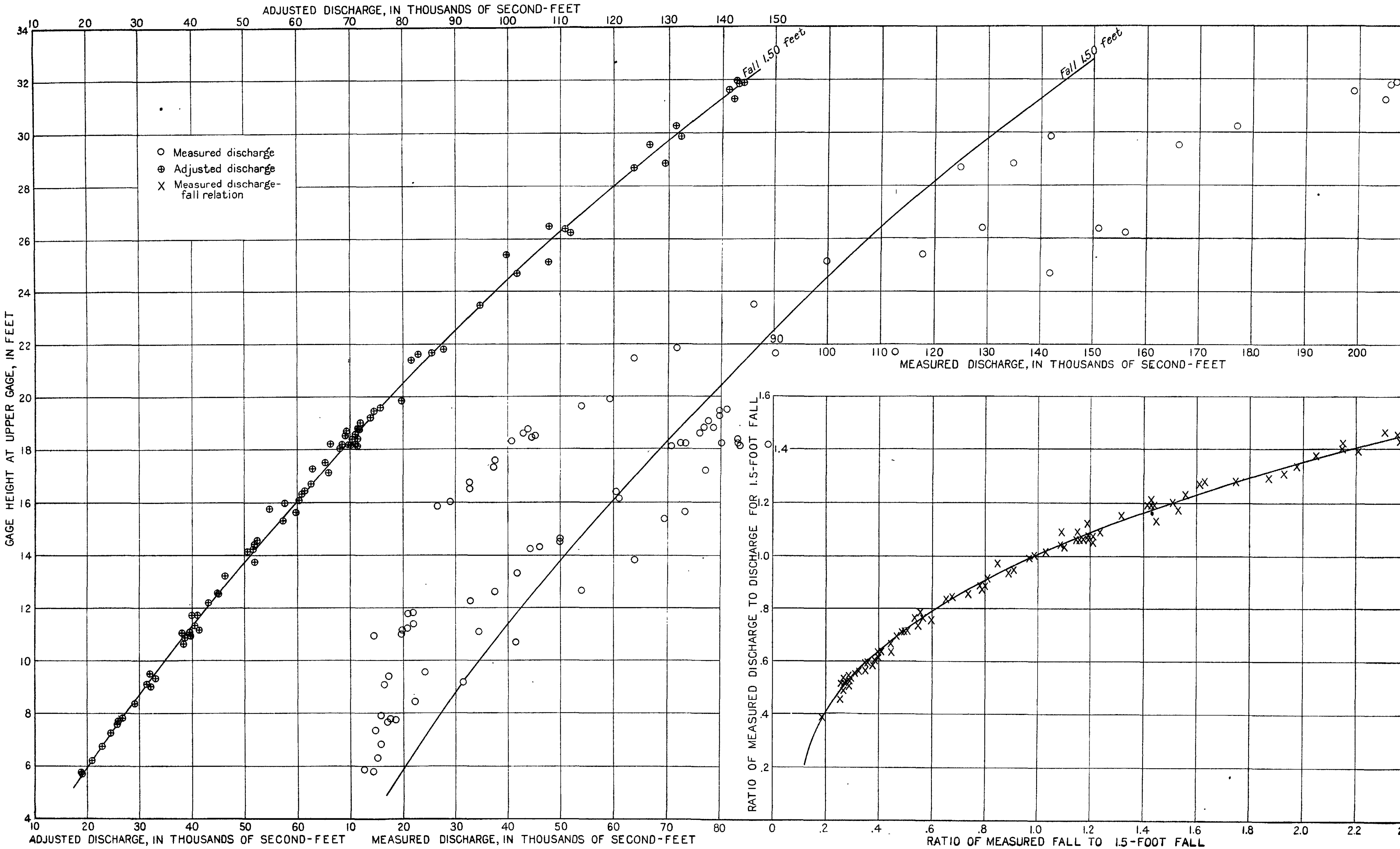
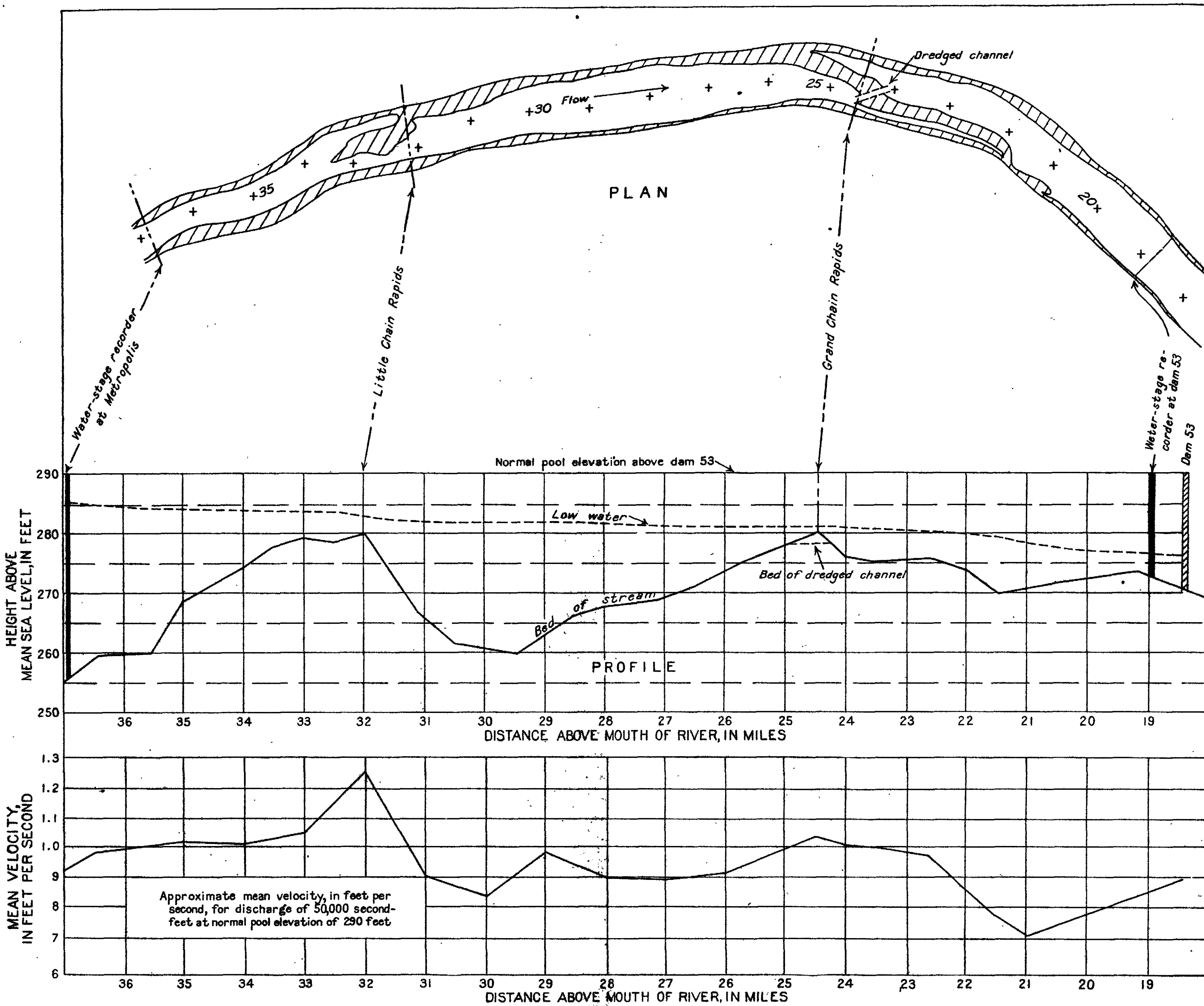


CURVES SHOWING RELATIONS OF STAGE TO DISCHARGE, TENNESSEE RIVER AT CHATTANOOGA, TENN.



CURVES SHOWING RELATIONS OF STAGE TO DISCHARGE AND DISCHARGE RATIOS TO FALL RATIOS, TENNESSEE RIVER AT GUNTERSVILLE, ALA.



PLAN AND PROFILE OF OHIO RIVER IN THE VICINITY OF METROPOLIS, ILL.

Prepared from flood-plain charts of United States Engineer Office, Louisville, Ky., 1929-30. The diagonally ruled areas on the plan are those over which the depth of water is less than 9 feet when dam 53 is at normal operating level.

normal discharge and between stage and normal fall, and discharge ratios and fall ratios. The curves of relation between stage and normal discharge and between stage and normal fall at this station are shown in plate 13. The plotting of the adjusted discharge measurements and the curve of relation between discharge ratios and fall ratios are shown in plate 14.

KOOTENAI RIVER NEAR COPELAND, IDAHO

Three gages are operated in the fall reach for the station on the Kootenai River near Copeland, Idaho. The gage to which the discharge measurements are referred is a water-stage recorder near Copeland, about midway of the reach. The measurements are made at this section. Other water-stage recorders are at Klockmann Ranch above Copeland and at Port Hill below Copeland. The distance between the upper and lower gages is 179,000 feet, or nearly 34 miles. The fall-stage-discharge relations apparently are not affected by draw-down or other local conditions attributable to the position of the gage. The gages are at the same datum as determined by levels to bench marks of the United States Coast and Geodetic Survey.

The Kootenai River is a sinuous stream flowing in a mature valley over a deep deposit of alluvial material. The total curvature in the reach is equivalent to several complete circles. There are no appreciable variations in the type of bed and bank material in the reach and no pronounced shoals or rapids which might act as controlling elements. Levees have been constructed on each bank for several miles along and beyond the slope reach. These levees have an appreciable affect on the slope-stage-discharge relations at high stages as observed by the changes in these relations at times of occasional breaks in the levees.

Backwater effects at this station are caused by changes in the stage of Kootenai Lake, 48 miles downstream from the Copeland gage; these effects extend for many miles because of the extremely flat gradient of the stream. The operation of a power dam about 60 miles below the head of the lake and about 108 miles below the Copeland gage may cause changes in backwater throughout the reach. The distances given are in miles along the river. The curves of relations for the gaging station near Copeland with a constant fall of 4.0 feet are shown in plate 15. The curves are prepared in a manner similar to those for the Tennessee River at Chattanooga, Tenn., except that the relations between the discharge ratios and the fall ratios are plotted to logarithmic scales. Examination of the relations indicates that they may be represented very closely by the simple mathematical equation

$$\frac{Q_1}{Q_2}=\left(\frac{F_1}{4.00}\right)^{0.6}$$

which is the same as equation (8) with the proper figures substituted.

The conditions at this station are unusual in several respects. First, the gage to which the ratings are referred is approximately midway of the reach through which the fall is determined, whereas the records of fall are obtained from two other gages, one at each end of the reach. Second, the fundamental assumption in the theoretical application of equation (2) to the problems of backwater is that there is a complete interchange between potential and kinetic energy. In other words, losses in kinetic energy due to retardation of flow as the discharge progresses downstream are assumed to be totally absorbed by the increases in potential energy. The sinuosity of this stream is such that a great loss of energy may occur from the continual change in the direction of flow, so that the kinetic-energy factor may be of minor importance. Third, because of the very flat slopes and low velocities the turbulent condition of flow may not be fully developed and therefore the exponent to slope in the general mathematical equation of flow (1) may be greater than 0.5. The experimental determination of 0.6 as the value of the exponent in the fall-discharge relations for this station is in agreement with this assumption.

DETERMINATION OF DISCHARGE

After having determined the curves of relation between fall, stage, and discharge by the above described methods, there still remains the problem of determining discharge for a unit of time by the mechanical operations of converting observations of stage at the ends of a reach into figures of discharge. This may be accomplished either by arithmetical or graphical methods. The arithmetical method requires the use of rating tables and the multiplication of certain factors. The graphical method consists of reading the figures of discharge from a chart.

ARITHMETICAL METHOD

Before applying the arithmetical method to the determination of discharge at stations where fall-stage-discharge relations are affected by backwater it is necessary to prepare rating tables. These rating tables of stage-discharge relations are prepared in the usual manner for the constant-fall discharge relations and the normal-fall discharge relations as follows:

For a uniform reach, prepare a table of relation between fall ratios and discharge ratios. As the fall ratios are determined by using constant fall as the divisor, fall may be used directly in place of fall ratio, thus eliminating the necessity of reducing each observation of fall to a fall ratio.

For a nonuniform reach, prepare a table relation between stage, fall, and discharge ratios. This is a three-dimensional table prepared from the curve of relation between discharge ratios and fall ratios. Table 7 shows part of the range of stage and fall for the Ohio River at Metropolis, Ill. The table should be of sufficient scope to adequately cover all conditions of stage and fall.

After the tables are prepared the procedure is as follows: First, enter the table of stage and discharge for the observed gage height at the upper gage or gage of reference and determine the constant-fall or normal-fall discharge; second, enter the table of fall and discharge ratios (for a constant-fall rating) or the table of stage, fall and discharge ratios (for a normal-fall rating) and determine the factor by which the constant-fall or normal-fall discharge is to be multiplied to give the actual discharge.

The arithmetical method of discharge determination has one advantage in that the checker can duplicate the figures arrived at by the computer. This is particularly helpful if the checker is not thoroughly familiar with the details of computation. Also, if the station is undergoing shifts with respect to time, such shifts may be treated as gage-height shifts in the ordinary manner before entering the table of stage and discharge.

TABLE 7.—*Relation between stage, fall, and discharge adjustment factor, Ohio River at Metropolis, Ill.*

Gage height (feet)	Normal fall (feet)	Applicable factors for designated fall in feet														
		0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	3.5	4.0	5.0	6.0
13	5.33	0.360	0.456	0.52	0.58	0.61	0.65	0.68	0.71	0.74	0.78	0.83	0.88	0.91	0.97	1.00
14	5.19	.365	.462	.53	.58	.62	.65	.69	.71	.74	.79	.84	.88	.91	.98	1.00
15	5.05	.372	.468	.54	.59	.62	.66	.69	.72	.74	.79	.85	.89	.92	.99	1.00
16	4.91	.377	.474	.54	.59	.63	.67	.70	.73	.75	.80	.86	.89	.93	1.00	1.00
17	4.78	.382	.480	.55	.60	.64	.67	.70	.73	.75	.81	.87	.90	.94	1.00	1.00
18	4.65	.384	.486	.56	.61	.65	.68	.71	.74	.76	.82	.88	.91	.95	1.00	1.00
19	4.54	.394	.493	.56	.61	.65	.69	.72	.74	.77	.83	.88	.91	.95	1.00	1.00
20	4.42	.405	.50	.57	.62	.66	.70	.73	.75	.78	.84	.89	.92	.96	1.00	1.00
21	4.31	.410	.50	.57	.62	.66	.70	.73	.75	.78	.84	.89	.93	.97	1.00	1.00
22	4.21	.415	.51	.58	.63	.67	.71	.74	.76	.79	.85	.90	.94	.98	1.00	1.00
23	4.13	.420	.51	.58	.63	.67	.71	.74	.76	.79	.85	.90	.94	.98	1.00	1.00
24	4.08	.425	.52	.59	.63	.68	.71	.75	.77	.80	.86	.91	.95	.99	1.00	1.00

GRAPHICAL METHOD

Having established the curves of relation between fall, stage, and discharge, it is a simple matter to produce any desired combination of relations between gage heights at the end of the reach and the discharge; or between the gage height at the upper end of the reach, the fall, and the discharge.

A series of curves for equal stages at the lower gage corresponding to different values of fall may be constructed, these curves being plotted against the upper gage heights as ordinates and the discharge as abscissas as shown by the broken lines in plate 16. These curves afford a simple method of determining the discharge graphically, as it is necessary only to enter the graph with the upper gage height as the ordinate, proceed horizontally until the proper value of the lower gage height is reached, and then read downward to the discharge. Such a series of curves has one objection in that the curves of equal gage height tend to become horizontal with low discharge and small fall, which conditions make it difficult to read the discharge with the necessary degree of refinement unless curves are constructed for small increments of the lower gage height.

Another method is to construct a series of curves of equal fall for stages at the upper gage, plotting the curves with gage heights at the upper gage as ordinates and the discharge as abscissas as shown by the full lines in plate 16. These curves involve one more step—the computation of fall—before they can be used. They possess, however, an advantage in providing for more accurate readings of the discharges for low flows and extreme conditions of backwater.

The needs and requirements of the particular problem should govern the choice of the particular type of curves of relation that are constructed. However, it is essential that these curves be first constructed by the methods outlined above and not constructed as a family of curves by simply plotting each discharge measurement with the corresponding fall, or gage height. The reasons for this are that a very large number of discharge measurements covering all the range of conditions would be required to fully develop a family of curves; and if progressive channel shifts occur, they are generally very difficult to detect in a family of curves, although they may be easily seen on a single curve.

DEVELOPMENT OF DISCHARGE HYDROGRAPH

A discharge hydrograph developed by either the arithmetical or the graphical method described above is one of the most practical means of determining daily discharge for a station affected by backwater. The hydrograph may be developed from computations of discharge for short intervals of time, using falls obtained from the records of stage at the ends of the reach. The figures of discharge are plotted with the discharge as the ordinate and time as the abscissa.

The scale for the ordinates of the discharge graph should be so large that the average discharge for the day can be determined from the graph with a good degree of accuracy, and enough discharge figures should be determined to establish accurately the shape of the discharge graph. It has been found by experience that falls determined by simultaneous readings cannot be used at some stations because of the effects of rapid regulation. Use of average falls for periods of time ranging from 2 to 24 hours will be necessary to smooth out the effects of regulation. The intervals selected for subdividing will depend on the accuracy desired and the rapidity and frequency of the fluctuations. If there is only a small change in the fall between the two gages, one or possibly two computations of the discharge in a 24-hour period are generally sufficient. If the fall is changing rapidly, as indicated by changes in stage on the gage height graphs, a larger number of computations of discharge will be necessary. The number of computations required can readily be determined by inspection of the recorder graphs and by selecting points that will define the changes in curvature of the discharge graph.

After the discharge graph is constructed, the daily discharges can be readily determined by the method of balancing areas. This method of determining daily discharge for stations affected by backwater will facilitate computations because it does not require the computation of mean daily gage heights for either of the gages, it eliminates the necessity of subdividing variations in fall, and it affords a ready means of detecting any necessary adjustments in daily discharge which may become apparent as the discharge graph is being constructed. Plotting of the discharges of actual measurements in conjunction with the computed discharges will serve as a check on both the computed discharge and the station rating.

NORMAL-FALL METHOD

The normal-fall method was one of the first of the so-called slope methods.[45] It consists of the development of a "normal" discharge rating corresponding to F_n, the "normal" or average difference in water-surface stages between two gages over a period of time, by means of the equation $\frac{Q_n}{Q_1}=\sqrt{\frac{F_n}{F_1}}$ where Q_n represents the "normal" or theoretical discharge for the "normal" or average fall F_n, and Q_1 represents the discharge at another time when the fall is F_1. The value of F_n may be arbitrarily assumed, but to make the ratio $\frac{F_n}{F}$ as nearly unity as possible, F_n is taken as the average fall in the reach. The equation of relation used in this method is identical with equation (8) except that the functional relationship is assumed to be parabolic with an exponent of 0.5.

A variation of this method is that in which the relation between stage and fall is developed for different stages and the "normal" fall F_n corresponding to a given stage is used in the above equation. The stage-fall relation is determined by plotting the fall for each dis-

[45] Hall, M. R., Hall, W. E., and Pierce, C. H., A method of determining the daily discharge of rivers of variable slope: U. S. Geol. Survey Water-Supply Paper 345, pp. 53–65, 1915.

charge measurement against stage and drawing a smooth curve averaging the points. The measured Q_1 is reduced to the corresponding "normal" discharge by means of the "normal" fall as determined from this curve rather than by use of a constant value of fall representing average conditions of fall with respect both to time and stage.

In the so-called unit-fall method a modification of the normal-fall method was made by assuming that $F_n=1.00$, so that $Q_n=\frac{Q_1}{\sqrt{F_1}}$. In this form it came to be known as the unit-fall method.

STAGE-RATIO METHOD

The so-called stage-ratio method has been used with some success in the determination of discharge at gaging stations in the Ohio River and the Tennessee River Basins. The application of this method to the computation of the discharge of the Tennessee River at the Gilbertsville dam site, Gilbertsville, Ky., has been described by Rutter, Graves, and Snyder.[46] In this method the ratios of the gage heights at the ends of a channel reach are used as criteria of the effects of backwater in the reach. The curves necessary for the application of this method are developed as follows:

1. The ratio of the gage heights (to the same datum) at each end of a reach for each discharge measurement is determined and designated as the gage ratio, GR:

$$GR=\frac{\textit{Gage height at upper end of reach}}{\textit{Gage height at lower end of reach}}$$

2. All discharge measurements are plotted against the stage at the upper end of the reach in the usual manner, and a rating curve is drawn in a position lower in stage than any of the discharge measurements but as nearly parallel to them as possible. The curve thus constructed is known as the effective-gage-height discharge curve.

3. The ratio of the gage height from the effective-gage-height discharge curve and the observed gage height for each discharge measurement is determined. This is known as the stage ratio, SR.

$$SR=\frac{\textit{Effective gage height}}{\textit{Observed gage height}}$$

4. The stage ratio SR is plotted against the gage ratio GR for each discharge measurement and an average curve drawn through them. The points may depart rather widely from this curve, but by using the curve as a basis a new stage ratio SR may be determined for each

[46] Rutter, E. J., Graves, Q. B., and Snyder, F. F., Flood routing; Am. Soc. Civil Eng. Proc., vol. 64, pp. 291–310, February 1938.

measurement and the corresponding new effective gage height computed and plotted on the effective-gage-height discharge curve. On the basis of these points a new effective-gage-height discharge curve may be drawn.

5. By a repetition of steps 2 to 4, smooth curves may be developed for effective gage height plotted against discharge and stage ratio plotted against gage-height ratio.

SELECTION OF GAGING STATIONS ON STREAMS AFFECTED BY VARIABLE SLOPE

Length of reach.—The length of reach between the two gages used in obtaining records of stages should be such that ordinary errors occurring in the determination of gage heights at a gaging station will not be more than a negligible part of the total fall in the reach. It is apparent that the greater the fall the shorter the reach that is necessary. The reach should not be unduly long because of possible variations of channel section or because of inflow from tributaries. On the assumption that the possible error in gage readings at each gage might be 0.01 foot, the maximum error in observations of fall would be 0.02 foot. This would allow a maximum error of 4 percent if the minimum fall was 0.5 foot, which would be about the allowable of error. In the fall reach of the Kootenai River near Copeland, Idaho, falls as low as 0.5 foot have been recorded in a distance of 179,000 feet.

Type of reach.—The type of reach that is selected will depend upon the characteristics of the stream. If the stream is similar in general configuration and profile to the Tennessee River at Chattanooga, Tenn. (p. 142), a fairly uniform reach may be available. If the stream is broken in longitudinal profile it may be similar in type to the Ohio River at Metropolis, Ill. (see pl. 12). The stream profile should be carefully studied to ascertain if there are any abrupt changes in slopes. If there is a pronounced change in the slope, this condition may act as the controlling element at those times when the backwater does not extend throughout the reach.

Selection of reach.—The channel reach between the gages should be as far above the source of backwater as is practicable in order to utilize the greatest possible amount of fall. Even though the upper gage at times may be above the influence of backwater, the fall relations may be established by the methods outlined for the Ohio River at Metropolis, Ill. The reach should be so selected that there are no large tributaries entering between the gages. Reaches subject to the return of water from overbank flow at high stages should be avoided if possible, also shifting channel conditions and sharp bends in the reach.

Sharp bends should be avoided, as the bends are usually undergoing erosion on the outside of the curve and deposition on the inside.

Position of gages.—In the selection of sites for the gages, particular attention should be given to local conditions. If it is necessary to place a gage on a bridge pier, the stilling well for the gage should be connected with the river in such a manner as to eliminate the effect of draw-down around the pier so far as possible. Also, if the velocity at the intake pipes causes draw-down in gage wells in the stream bank, suitable intake devices should be installed to eliminate this effect. Both gages should, if possible, be similarly placed with respect to bends in the streams in order to avoid the possibility of distorted water-surface falls caused by the piling up or depression of the water on the outside or inside of the bends. Both gages should be water-stage recorders unless the effects of variable slopes are ephemeral and relatively unimportant.

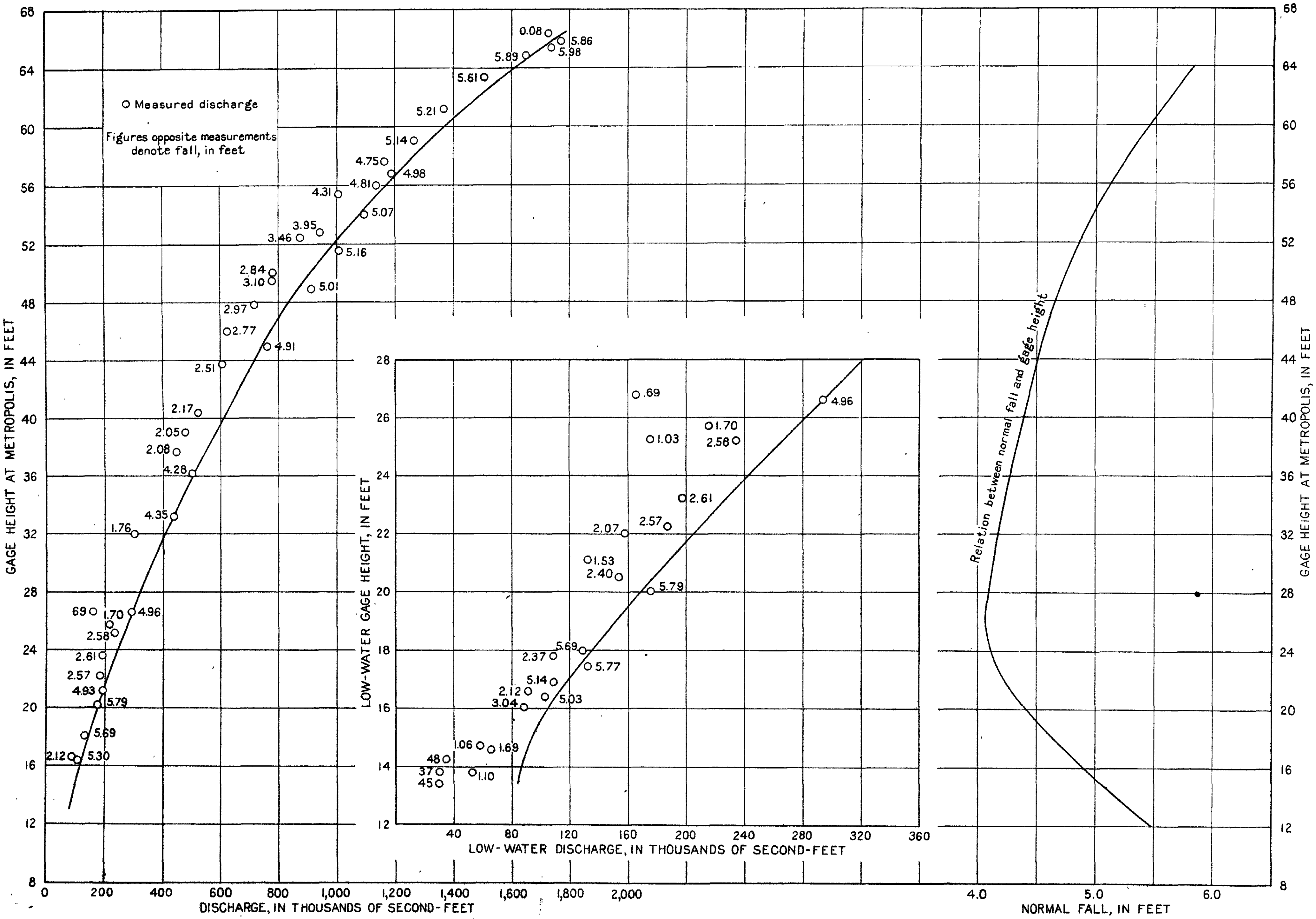
In establishing a gaging station on a stream having a section control at low stages, the upper gage should be placed as close as possible to the control, as its nearness to the control greatly reduces the effects of changing discharge. It should be remembered that the effects of changing discharge are greater for flat slopes than for steep slopes and greater for low velocities than for high velocities.

VARIABLE SLOPES CAUSED BY CHANGING DISCHARGE

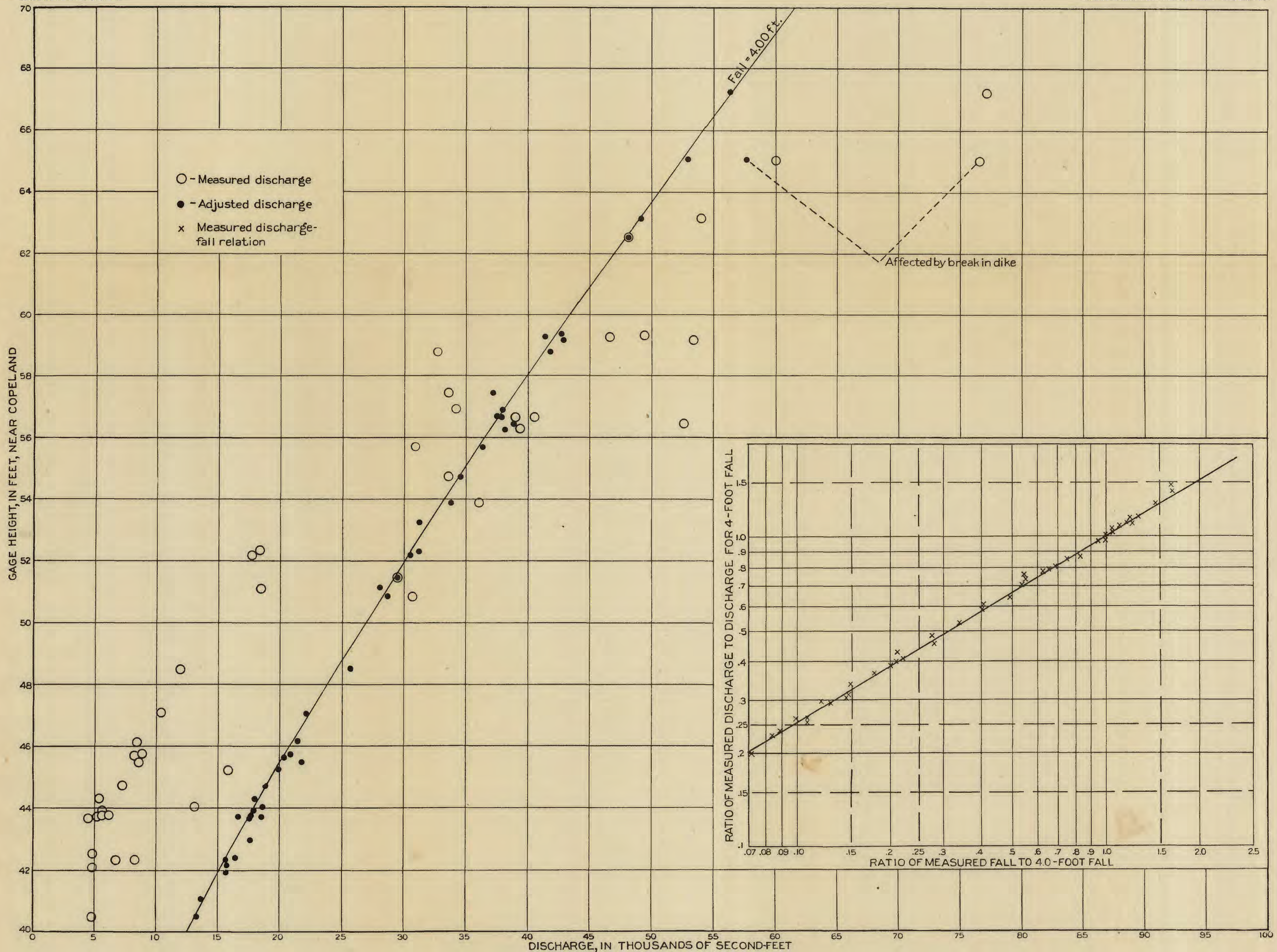
If the discharge is changing with respect to time the stage-discharge relations at a section in an open channel will be affected by one or more of three factors: (1) Increase or decrease in the slope of the water surface from the slope corresponding to steady flow conditions, (2) the conversion of discharge into or out of channel storage, or (3) the return of overbank flow. Under these conditions the discharge measurements made at times of changing discharge must be adjusted in order to correlate them with discharge measurements made during steady flow when a curve of the stage-discharge relation is developed. It is also necessary to have a means of computing the discharge under conditions of changing stage at a station where the stage-discharge relations have been developed for conditions of steady flow.

ADJUSTMENTS USING SLOPE AS A FACTOR

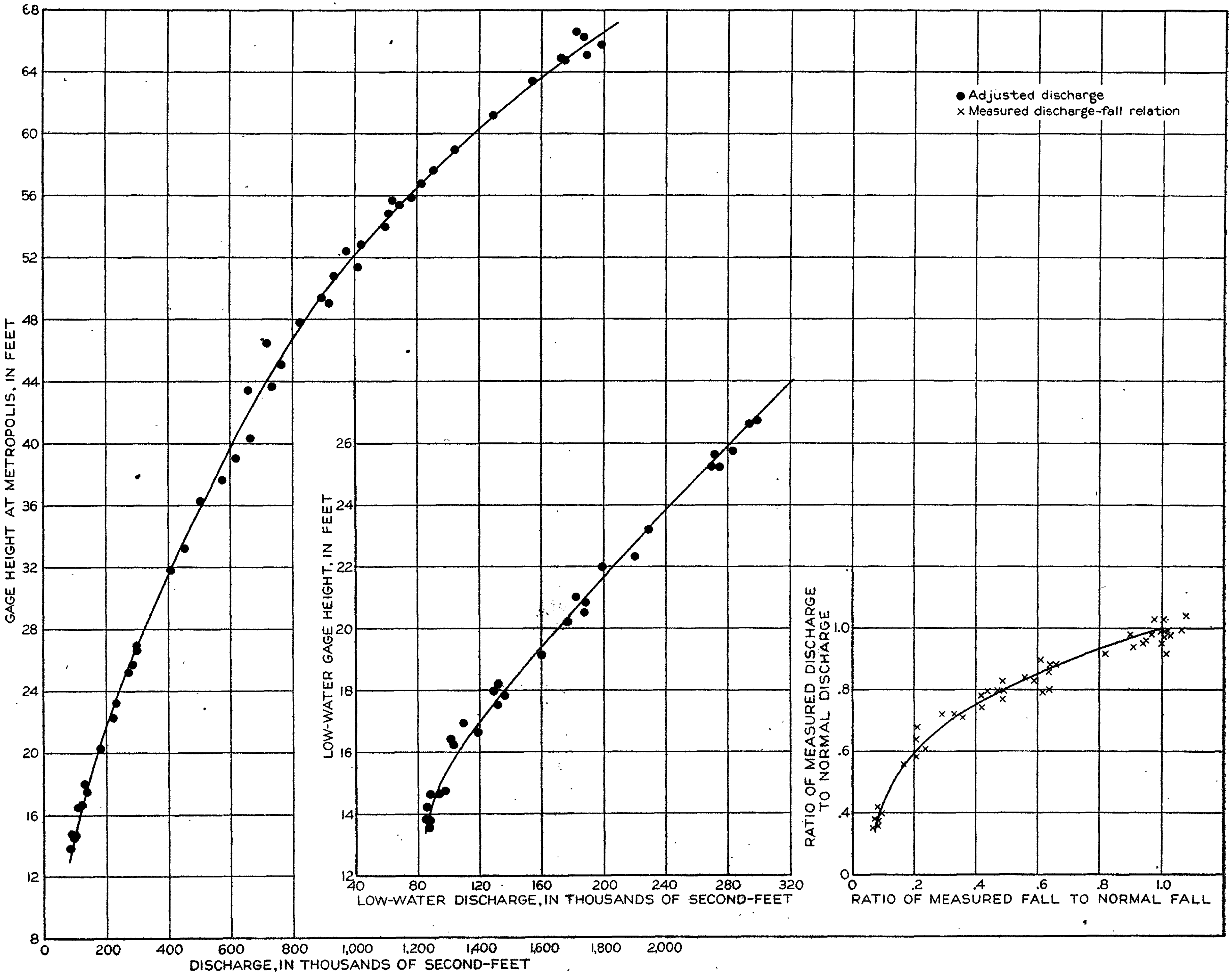
If the stage-discharge relation at a stream section in a channel-controlled reach is affected under changing discharge conditions by the variation of the slope of the water surface but not by changes in channel storage or by return of overbank flow, an approximate adjustment of the discharge Q_m for the changing-discharge condition to the equivalent discharge Q_c for a condition of constant discharge at the same gage height may be made by consideration of the slope of the water



CURVES SHOWING RELATIONS OF STAGE TO DISCHARGE AND STAGE TO FALL, OHIO RIVER AT METROPOLIS, ILL.

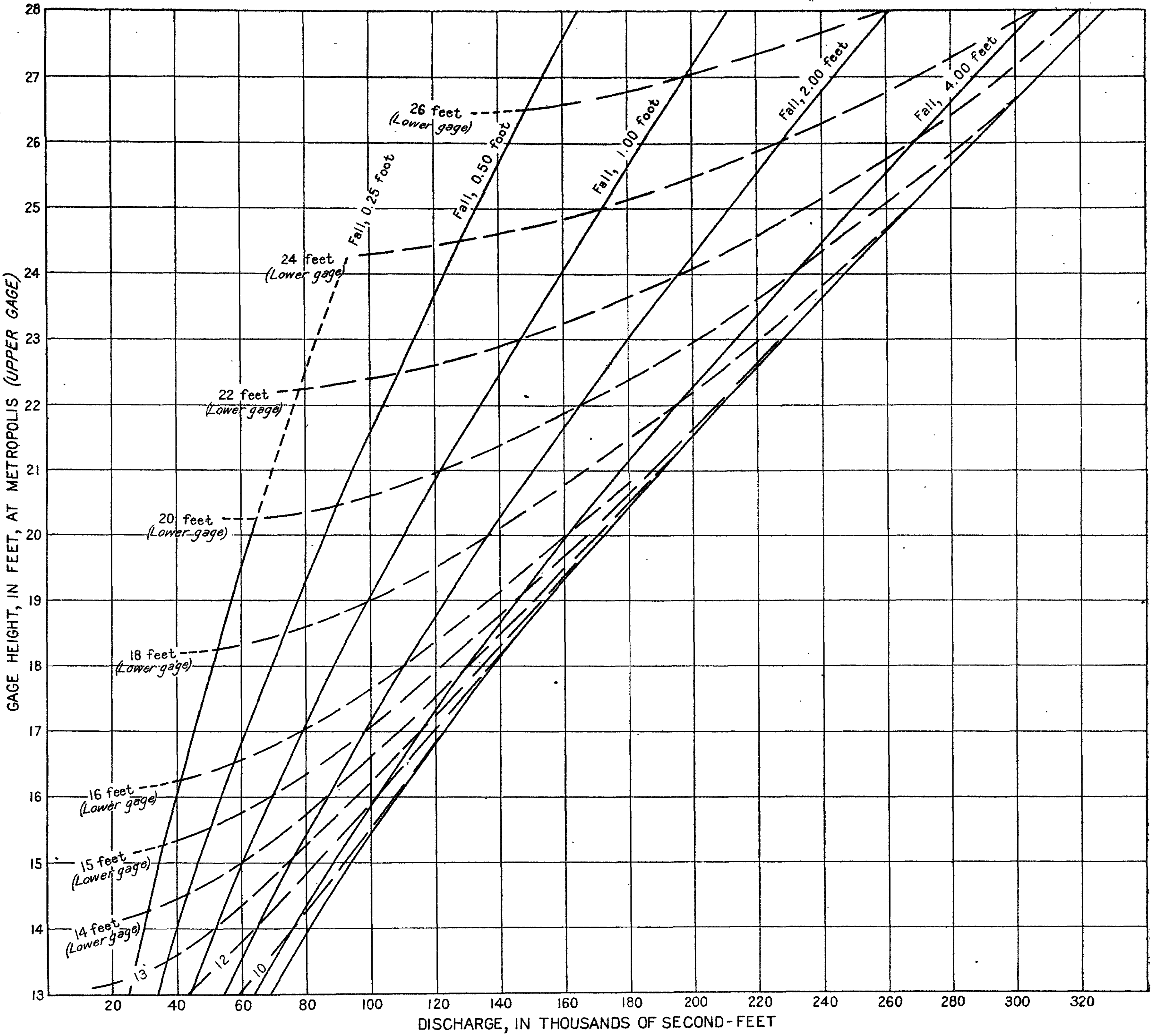


CURVES SHOWING RELATIONS OF STAGE TO CONSTANT-FALL DISCHARGE AND DISCHARGE RATIOS TO FALL RATIOS, KOOTENAI RIVER NEAR COPELAND, IDAHO.



CURVES SHOWING RELATIONS OF STAGE TO NORMAL DISCHARGE AND DISCHARGE RATIOS TO FALL RATIOS, OHIO RIVER AT METROPOLIS, ILL.

452509—42 (Face p. 152) No. 2



CURVES OF EQUAL FALL, OHIO RIVER AT METROPOLIS, ILL.

452509—42 (Face p 152) No. 4

surface, the velocity of the flood wave, and the rate of change of stage in accordance with the following equation:

$$\frac{Q_c}{Q_m}=\frac{\sqrt{S_c}}{\sqrt{S_c+\frac{1}{U}\frac{dh}{dt}}} \tag{10}$$

in which S_c is the slope of the water surface under constant discharge conditions, U is the velocity of the flood wave, and $\frac{dh}{dt}$ is the rate of change of stage, which is positive if the stream is rising and negative if it is falling.

This method requires the determination of the slope of the water surface under constant-discharge conditions by observations of gage height at the ends of the reach and also an estimate of the velocity of the flood wave.

Equation (10) will be recognized as the Jones formula[47] for the adjustment of discharge measurements made under conditions of changing discharge, except that in equation (10) the flood-wave velocity U has been substituted for the surface velocity $\frac{V}{N}$. The slope term S_c must be evaluated for conditions of constant discharge by observations on gages at the ends of a reach.

If a second gage has not been installed for the purpose of evaluating the slope of the water surface, the adjustment of discharge may be made in equation (10) by substituting the slope of the energy gradient S_e at the time of the discharge measurement for the slope of the water surface S_c. The equation then becomes

$$\frac{Q_c}{Q_m}=\frac{\sqrt{S_e-\frac{1}{U}\frac{dh}{dt}}}{\sqrt{S_e}} \tag{11}$$

which may also be written in the form

$$\frac{Q_c}{Q_m}=\sqrt{1-\frac{1}{US_e}\frac{dh}{dt}} \tag{11a}$$

The slope of the energy gradient S_e for use in the above equations may be computed by means of one of the common formulas of flow, such as the Manning formula. Equation 11a is the so-called Wiggins' formula[48] for the adjustment of discharge measurements made under conditions of changing stage. The application of this method is described on page 160.

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[47] Jones, B. E., A method for correcting river discharge for a changing stage: U. S. Geol. Survey Water-Supply Paper 375, pp. 117–130, 1916.

[48] Developed in 1925 by W. C. Wiggins, who was at that time a junior engineer in the Geological Survey.

Velocity of the flood wave.—The equations of adjustment for the effect of changing discharge contain the velocity of the flood wave U as an essential element. The magnitude of U must be determined before any equation for adjustment for the effect of changing discharge can be applied correctly.

Relative to the velocity of gravity waves in open channels, Rouse [49] states:

A gravity wave, in particular, is a most complex phenomenon, and a rigorous analysis must give due regard to boundary resistance and velocity distribution, channel slope, and the nonhydrostatic distribution of pressure resulting from curvature of the liquid filaments. The relative magnitudes of these several factors will vary considerably with the boundary conditions, and the net result can only be a complex case of unsteady motion no matter how the problem is approached. Countless efforts have been made—in particular by Boussinesq—to treat each such influence as an individual problem. Even then only approximate solutions of the separate cases have been obtained, and their combination has remained quite out of the question.

According to Moots [50] the velocity of a flood wave may have at least three interpretations: (1) The velocity interpreted as the rate of movement of the discontinuities in the first derivatives at either the beginning or the end point of the wave (2) The velocity as the rate of pregression of the wave's peak or maximum height; (3) The velocity as the virtual movement of a constant flow or stage height.

So far as application to problems of changing discharge is concerned, the shape of the flood wave which accompanies changing discharge can generally be assumed to be constant with respect to time, as its rate of change is so slow that the effect of such change may not be detected because of the limits of accuracy of the data. With respect to problems of changing discharge only two forms of wave transmission need be considered, the first of which is the virtual velocity of a wave with constant velocity in a uniform channel, expressed by the equation

$$U_u = \frac{dA}{dQ} \tag{12}$$

and known as the Seddon principle; [51] the second is the velocity of a wave of translation of small height in a pool [52] in which d is the mean depth of the section:

$$U_t = \sqrt{gd} \tag{13}$$

Equation (12) is the mathematical expression for the velocity of a flood wave in a uniform channel. From examination of the various empirical formulas [53] for the mean velocity in a natural channel it

[49] Rouse, Hunter, Fluid mechanics for hydraulic engineers, p. 377, 1939.
[50] Moots, E. E., A study in flood wave: Iowa Univ., Studies in Eng., Bull. 14, p. 130, 1938.
[51] Seddon, J. E., River hydraulics: Am. Soc. Civil Eng. Trans., vol. 43, pp. 179–243, 1900.
[52] O'Brien, M. P., and Hickox, G. H., Applied fluid mechanics, p. 299, 1937.
[53] Horton, R. E., Seddon's and Forcheimer's formulas for crest velocity of flood waves subject to channel-friction control: Am. Geophys. Union Trans., pp. 374–382, 1938.

appears that the velocity of the flood wave U_u is between 1.3 and 1.7 times as great as the corresponding mean velocity V_m. Experience seems to indicate that the most probable value is about 1.3; therefore, for purposes of practical application it will be considered that in a uniform channel

$$U_u = 1.3\ V_m \tag{14}$$

Although natural channels are seldom uniform, yet at times when the flow in a channel is well above low water and in the region of high water, it is probable that minor channel irregularities are drowned out and the channel may be considered as being practically uniform. Under such conditions, equation (14) will give the velocity of a flood wave with reasonable accuracy. Natural channels generally contain shoals, rapids, or constrictions which become controlling sections at some stages and create pools above them through which the slope may be practically zero. Under those conditions, a disturbance initiated at the upper end the pool, such as a changing discharge, will pass through the pool and over the control in much the same manner as a wave of translation with a velocity as given by equation (13).

Little has been done with respect to actual field observations of the rate of travel of flood waves at gaging stations affected by changing discharge. Because of the lack of definite data it is necessary to make certain assumptions in order to adjust discharge measurements made under conditions of changing discharge to the equivalent discharge for steady flow. It is apparent that neither equation (13) nor (14) may be used throughout the entire range of stage at a gaging station to evaluate the rate of travel of a flood wave, as such use may produce figures of adjusted discharge, particularly at low stages, that are entirely disproportionate. An examination of data for several gaging stations has led to the derivation of an empirical equation which makes allowance for the factors mentioned above by weighting them with respect to slope. This equation is

$$U = 1.3 V_m \frac{S_c}{S_o} + \left(1 - \frac{S_c}{S_o}\right)\sqrt{gd} \tag{15}$$

in which S_c is the constant-stage slope for the stage at which the discharge measurement was made, S_o is the slope which the stream tends to approach at high stages, V_m is the mean velocity at the representative cross section, and d is the mean depth at that section. As this is an empirical equation and must be considered as only an approximation, the mean velocity and mean depth for the discharge measurement may be used for V and d unless there is a decided difference between the measuring section and the representative section. The slope figures are obtained from the curve of slope plotted against stage for conditions of steady flow.

The meaning of equation (15) is, in effect, that if there is high water and the slope S_c for the stage of discharge measurement equals the slope S_o for high discharges, the second term is zero and $U=1.3V$; if there is a pool condition and S_c is zero, the flood-wave velocity becomes $U=\sqrt{gd}$; and if the discharge is between the pool condition and the completely uniform channel condition the flood-wave velocity is between the values corresponding to those conditions. If the slope S_c tends to become less as the discharge increases, do not use equation (15) but assume that the channel is essentially uniform and that equation (14) applies.

Reference is made above to the representative cross section of a gaging station. Frequently the discharge measurements are made from a bridge or cableway which is at a contracted section of the stream and the area, mean depth, and velocity at the place of measurement may not be truly representative of the average conditions in the channel. For some stations it may be necessary to develop a representative cross section of the reach in order to define representative values of the velocity and the hydraulic radius or the mean depth. The velocity and mean depth for each discharge measurement should then be recomputed on the basis of this average or representative cross section before they are used in the above formulas.

ADJUSTMENTS USING CHANNEL STORAGE AS A FACTOR

At some gaging stations discharge measurements appear to be affected by changing slope resulting from changing discharge, when in reality they are affected by channel storage. The discharge measurements may have been made at some distance away from the gage (p. 79), or the gage may be in a large pool some distance upstream from the section control which forms the pool. In either instance each discharge measurement should be adjusted to the equivalent discharge at the gage or at the section control by means of the equation

$$Q_m - Q_g = WLC\frac{d\,h}{d\,t} \tag{16}$$

in which Q_m is the measured discharge, Q_g is the discharge at the gage or section control, W is the average width of stream, L is the length between the sections at which Q_m and Q_g are determined, C is a constant relating the rate of change of stage $\frac{d\,h}{d\,t}$ to its equivalent effect in the reach. The constant C is generally close to unity.

If a sufficient number of discharge measurements are available to define a curve of relation between stage and discharge for constant-discharge conditions, Q_g may be obtained from this curve and the channel parameter WLC computed for each measurement made under conditions of changing discharge. If channel storage is the dominant factor in the stage-discharge relation the result will be a smooth curve.

RETURN OF OVERBANK FLOW

The effects of the return of overbank flow are the direct result of changing discharge when water leaves the stream channel and pours out over the banks during rises that exceed bankful stage and returns to the channel during falling stages, creating backwater. The effects are so complicated by changes in bank characteristics during the year, the absorptive capacity of the soil and its ability to release water, and other factors, that no simple treatment of the problem is possible with a single gage and studies of rate of change of stage. One method is to make a sufficient number of measurements during each overbank rise to define a loop curve of stage-discharge relation; another method is to install an auxiliary gage and treat the station as a backwater problem. The latter method is to be recommended. The reach chosen for determination of the fall-stage-discharge relations should be as free as possible of overflow areas, because any marked difference in discharge at the ends of the reach upsets the analysis that uses fall as a factor.

RÉSUMÉ OF EQUATIONS

For the benefit of those who are interested in the equations themselves and not in the manner in which they are derived, the following brief résumé is given of the equations used in adjustments for changing discharge.

Gaging stations with two gages.—The equation of adjustment is

$$\frac{Q_c}{Q_m}=\frac{\sqrt{S_c}}{\sqrt{S_c+\frac{1}{U}\frac{dh}{dt}}} \tag{10}$$

in which S_c is obtained from the slope-tage relation determined on the basis of slope observations during periods of constant stage. The velocity of the flood wave U is evaluated by means of equation (15).

Gaging stations with one gage.—At gaging stations having only one gage the equation of adjustment is

$$\frac{Q_c}{Q_m}=\sqrt{1-\frac{1}{US_e}\frac{dh}{dt}} \tag{11a}$$

The slope of the energy gradient S_e may be computed from one of the ordinary formulas, the Manning formula

$$V=\frac{1.485}{n}R^{2/3}S_e^{1/2} \tag{17}$$

probably being the easiest to apply. In this formula the value of n, the coefficient of roughness for the channel, must be selected on the basis of experience and knowledge of the channel reach. Pairs of discharge measurements at approximately the same stage, one on a rising stage and the other on a falling stage, will aid in evaluating n.

In the evaluation of S_e from equation (17) the work may be simplified by using the relation

$$S_e=\frac{(nV)^2}{2.2082R^{4/3}} \tag{18}$$

for which values of the fraction $\frac{1}{2.2082R^{4/3}}$ have been published.[54]

For the determination of the slope S_e a series of diagrams may be prepared for different values of n in the Manning formula. In these diagrams the mean velocity in feet per second and the hydraulic radius in feet are used as coordinates and a family of curves for the slope S_e is developed for each selected value of n. If the diagrams are prepared on logarithmic paper, for each value of n there will be a series of parallel lines for the values of S_e. The use of diagrams is not necessary, as the value of S_e from equation (18) may be substituted directly in equation (11a). The velocity of the flood wave U is evaluated by means of equation (15).

ADJUSTMENT OF DISCHARGE MEASUREMENTS

Adjustments of discharge measurements made under conditions of changing discharge are primarily for the purpose of correlating those measurements with other measurements made under conditions of steady flow in developing a curve of the stage-discharge relation. The methods used in these adjustments also serve to determine the effects of the rate of change of stage on the stage-discharge relation used in the computation of discharge. Four methods of determining adjustments to discharge measurements made under conditions of changing discharge are given herein. Each method, except the Jones method, has been applied to a series of measurements for the Tennessee River near Scottsboro, Ala. The gage height, the measured discharge, the rate of change of stage in feet per hour and the average velocity and hydraulic radius at the measuring section, which is a representative cross section of the river in the vicinity of the gage, for 25 discharge measurements at that station are given in table 8.

Before applying any of the methods it is desirable to plot the discharge measurement against stage in the usual manner, indicating beside each measurement the rate of change of stage in feet per hour. It may be helpful to indicate a falling stage by lines leading upward from the plotted point to the measurement number and a rising stage

[54] King, H. W., Handbook of hydraulics, 3d ed., p. 309, 1939.

by lines leading downward from the plotted point to the measurement number.

TABLE 8.—*Discharge measurements of the Tennessee River near Scottsboro, Ala.*

Measurement No.	Gage height (feet)	Measured discharge (second feet)	Rate of change of stage (feet per hour)	Hydraulic radius (feet)	Mean velocity (feet per second)
20	26. 28	247, 000	−0. 008	20. 4	4. 75
31	24. 36	215, 000	−. 007	18. 7	4. 56
30	24. 19	216, 000	+. 032	18. 3	4. 64
21	23. 30	202, 000	+. 119	17. 1	4. 61
32	23. 22	188, 000	−. 084	17. 5	4. 25
16	22. 50	180, 000	+. 013	16. 4	4. 23
33	19. 39	131, 000	−. 176	22. 2	3. 98
54	18. 74	132, 000	−. 069	21. 4	4. 16
53	18. 61	136, 000	+. 058	21. 5	4. 29
37	16. 85	124, 000	+. 056	19. 7	4. 31
55	15. 64	96, 500	−. 196	18. 6	3. 53
34	14. 91	91, 000	−. 197	17. 8	3. 49
36	14. 73	107, 000	+. 140	17. 6	4. 18
39	13. 96	95, 800	−. 053	17. 0	3. 86
35	11. 26	79, 200	+. 128	14. 4	3. 79
56	11. 29	68, 200	−. 160	14. 4	3. 26
42	10. 76	73, 200	−. 008	13. 9	3. 64
50	9. 44	59, 300	−. 058	12. 7	3. 24
57	8. 52	53, 200	−. 063	11. 7	3. 17
61	7. 38	45, 200	+. 016	10. 4	3. 01
59	6. 46	40, 100	+. 010	9. 45	2. 95
19	5. 09	31, 400	−. 006	8. 25	2. 66
45	4. 54	28, 800	+. 105	7. 78	2. 59
22	3. 98	25, 000	−. 003	7. 18	2. 45
24	2. 04	14, 800	−. 011	5. 43	1. 93

JONES METHOD

The Jones method [55] was developed for application at gaging stations equipped with two gages. This method uses an equation of relation between constant discharge and changing discharge at the same stage which is practically identical with equation (10). The application of this method is as follows: Construct a stage-slope curve from observations of stages at gages at each end of the reach under conditions of steady flow, and from this curve determine the slope S_c of the water surface corresponding to the stage of each discharge measurement. Compute the velocity of the flood wave U by means of equation (15), using in that equation the slope S_c for the measurement, the S_o for high stages, and the mean velocity V_m and the mean depth d as computed for the discharge measurement from a representative cross section. After computing the velocity of the flood wave U, substitute the computed value in equation (10) and solve for the constant-stage discharge Q_c. If the slope of the water surface has

[55] Jones, B. E., A method of correcting river discharge for a changing stage: U. S. Geol. Survey Water-Supply Paper 375, pp. 117–130, 1916.

not been evaluated by observation of gage heights at the ends of the reach, the slope of the energy gradient S_e for discharge measurements made under conditions of constant discharge may be computed and plotted against stage. Figures for S_e may then be substituted for S_c in equation (10). This is an adaption of the Wiggins method, described below.

WIGGINS METHOD

Gaging stations operated by the Geological Survey on streams affected by changing discharge are generally not equipped with auxiliary gages to determine the slope. W. C. Wiggins modified the Jones equation so as to use the slope of the energy gradient for a discharge measurement instead of the slope of the water surface under the conditions of constant discharge, the slope of the energy gradient being computed from one of the formulas for flow in open channels. The equation which he developed was similar in form to equation (11). The procedure in applying equation (11) is the same as for equation (10) as outlined above, except that the slope of the energy gradient S_e for each discharge measurement is substituted for the slope of the water surface S_s, and a stage-slope curve is not developed. The slope of the energy gradient S_e is computed by use of the Manning formula as given in equation (17) and (18).

Proper evaluation of the slope of the energy gradient is probably the most important step in application of the Wiggins method. A figure for the friction coefficient n is selected, and the discharge measurements adjusted by application of equations (11), (15), and (17). If discharge measurements have been obtained at approximately the same stages for both rising and falling stages, or if several measurements covering the same range in stage for rising and falling stage have been obtained, the adjustments to the measured discharges should bring the adjusted measurements into agreement if the proper value of n has been used. In this connection it should be noted that n may be expected to vary somewhat for different stages between low water and bankfull stage. If the selected value of n results in adjustments that are consistently too large or too small, a different value of n should be selected and the adjustments recomputed until a value of n is found which gives the most consistent results. Similar sets of trial computations may be necessary if the measurements are all made under falling stages and cover a sufficient range of stage so that the consistency of the adjustments may be considered as a check on the selected value of n. Adjustments of discharge measurements on the Ohio River at Wheeling, W. Va., by the Wiggins method are shown on plate 17.

On some streams subject to very rapid rises in stage it is practically impossible to obtain discharge measurements on rising stages. On many streams of that nature the only discharge measurements that are obtainable at medium and high stages are affected by changing discharge and are necessarily made during falling stages. The Wiggins method is particularly valuable for the adjustment of discharge measurements under such conditions, although care should be used in the selection of n.

An examination of the data given for the Tennessee River near Scottsboro, Ala., given in table 8, shows that the computed slope of the energy gradient S_e for constant discharge is practically a constant throughout the range of stage, and as S_e at high stages approximately equals S_o, for practical purposes $\frac{S_e}{S_o}$ is unity, and the solution of equation (15) gives the velocity of the flood wave as 1.3 times the mean velocity of the discharge measurement. The value of n was found to be 0.020. The adjusted figures of discharge by the Wiggins method are given in the table on page 163.

BOYER METHOD

If a sufficient number of discharge measurements have been made under conditions of both rising and falling stages at a gaging station, solution of equation (10) may be made by graphical methods devised by Marion C. Boyer, without the necessity of computing the velocity of the flood wave or computing or observing the slope. By dividing the numerator and denominator of the second member of equation (10) by S_c and inverting, the equation reduces to the form

$$\frac{Q_m}{Q_c}=\sqrt{1+\frac{1}{US_c}\frac{dh}{dt}} \qquad (10a)$$

From a study of the plotting of the discharge measurements against stage in the usual manner it is possible to construct a curve of the approximate stage constant-discharge relation from which the constant discharge Q_c may be determined for each discharge measurement. The measured discharge Q_m and the rate of change of stage $\frac{dh}{dt}$ (expressed in feet per hour for convenience) are known, and by substition of these figures in equation (10a) the term $\frac{1}{US_c}$ is computed. The term $\frac{1}{US_c}$ for each measurement is plotted against stage and a curve drawn to average the points. From this curve

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of relation each discharge measurement is adjusted by determining the value of $\frac{1}{US_c}$ for the measurement and solving for the relation between the constant discharge and the measured discharge as expressed by equation (10a).

Application of the Boyer method to a series of discharge measurements made on the Ohio River at Wheeling, W. Va., is shown on plate 17.

It will be found that for discharge measurements made during small rates of change of stage, such as 0.10 foot per hour or less, the value of $\frac{1}{US_c}$ is seriously affected by small inaccuracies in the measurement of discharge. For this reason it is desirable to compute the term only from measurements having rates of change of stage greater than 0.10 foot per hour. A considerable variation in the position of the curve of relation between stage and the term $\frac{1}{US_c}$ will have a relatively minor effect on the adjustment of a discharge measurement, this effect decreasing as the rate of change of stage becomes smaller.

Adjustments of discharge by the Boyer method for discharge measurements at the station on the Tennessee River near Scottsboro, Ala., are given in table 9.

LEWIS METHOD

An approximate method devised by Douglas D. Lewis for the solution of equation (10) is based on the results obtained from the analyses of the data for several gaging stations which indicate that the factor $\frac{1}{US_c}$ is very nearly a constant for a considerable range of stage, so that equation (10a) may be written as

$$\frac{Q_m}{Q_c}=\sqrt{1+K\frac{dh}{dt}} \tag{10b}$$

This equation gives a direct relation between the discharge ratios and the rate of change of stage, independent of stage. The discharge ratio is evaluated for each measurement and is plotted against the rate of change of stage; a curve is then drawn to average the points. Because of the possible variation in the factor $\frac{1}{US_c}$ with stage, this curve may indicate only an approximate relation between the discharge and the rate of change of stage, although in many instances it appears to be sufficiently accurate for the purpose for which it is used. The discharge measurements are adjusted by determining the relation between the constant-stage discharge and the measured discharge for the corresponding rate of change of stage directly from the curve. The application of the Lewis method to discharge measurements of the Tennessee River near Scottsboro, Ala., is shown in plate 18 which indicates the relation between the discharge ratios $\frac{Q_m}{Q_c}$ and the rate of change of stage developed in accordance with this method. The curve drawn through these points is that obtained by solving equation (10b) with the constant $K=1.00$. It has been found that the term $\frac{1}{US_c}$ is practically a constant over most of the range of stage, and therefore the Lewis method has considerable merit in its ease of application.

The following table gives the adjusted discharge for measurements of the Tennessee River near Scottsboro, Ala., corresponding to the data contained in the table on page 159, as adjusted by the Wiggins, Boyer, and Lewis methods.

TABLE 9.—*Adjusted discharge, in second-feet, for measurements of the Tennessee River near Scottsboro, Ala.*

Measurement No.	Measured discharge	Adjusted discharge		
		Wiggins method	Boyer method	Lewis method
20	247, 000	247, 000	247, 000	247, 000
31	215, 000	215, 000	215, 000	215, 000
30	216, 000	214, 000	214, 000	213, 000
21	202, 000	196, 000	195, 000	191, 000
32	188, 000	193, 000	193, 000	196, 000
16	180, 000	179, 000	179, 000	179, 000
33	131, 000	147, 000	141, 000	144, 000
54	132, 000	136, 000	136, 000	137, 000
53	136, 000	132, 000	133, 000	132, 000
37	124, 000	121, 000	121, 000	120, 000
55	96, 500	112, 000	107, 000	108, 000
34	91, 000	115, 000	101, 000	101, 000
36	107, 000	102, 000	100, 000	100, 000
39	95, 800	98, 000	98, 500	98, 500
35	79, 200	75, 700	74, 400	74, 600
56	68, 200	75, 800	74, 800	74, 500
42	73, 200	73, 200	73 200	73, 200
50	59, 300	61, 200	61, 200	61, 100
57	53, 200	54, 900	54, 900	55, 000
61	45, 200	44, 800	44, 800	44, 800
59	40, 100	39, 900	40, 100	39, 900
19	31, 400	31, 400	31, 400	31, 400
45	28, 800	27, 400	27, 600	27, 400
22	25, 000	25, 000	25, 000	25, 000
24	14, 800	14, 800	14, 800	14, 800

DETERMINATION OF DISCHARGE

The accuracy of the determination of discharge at a gaging station during a period when the stage-discharge relation is affected by changing discharge is dependent upon the determinations of the relations between stage, rate of change of stage, and discharge. If these relations have been determined, the discharge for a unit of time may be computed by the application of any of the methods used in the adjustment of discharge, the process being the reverse of that outlined above for the adjustment of discharge measurements, and consists of the determination of Q_m when Q_c, the stage, and the rate of change are known.

JONES METHOD

The Jones method was developed on the assumption that two gages would be operated in a reach, the slopes corresponding to constant gage to be determined by observations on these gages. Because of the marked lack of uniformity of most natural channels, slopes determined by that means might be considerably in error. For that reason and also because of the additional expense necessary to operate an additional gage, it seems that one of the other methods described herein may be better adapted to the practical problem of determining discharge.

WIGGINS METHODS

In solving equation (11) for Q_m it will be necessary to know the slope of the energy gradient S_e corresponding to the velocity at the time of the changing discharge. An approximate value of V for use in equation (18) can be determined by plotting velocities against stages for discharge measurements and determine the relation between stage, rate of change in stage, and velocity.

The diagrams mentioned on page 158 are helpful in the computation of the discharge for a unit of time during a period of changing discharge, as they give the graphical solutions of equation (11) and (18). Application of the Wiggins method is rather complicated in this reverse procedure.

BOYER METHOD

The term $\frac{1}{US_c}$, equation (10a), is a factor for reducing the rate of change of stage to its equivalent effective rate, which figure is added to or subtracted from unity, depending on whether the stage is rising or falling; and the square root of the resultant figure is the relation between the discharge for constant stage and the discharge at the same stage for a condition of changing stage. In the application of this method two rating tables are prepared, one of stage and constant discharge and the other of stage and the term $\frac{1}{US_c}$. To compute the discharge during changing stage it is necessary to determine the constant discharge Q_c for the gage height from the first rating table, then find the value of the term $\frac{1}{US_c}$ for that gage height from the second table, and compute the effective rate by the product of the term $\frac{1}{US_c}$ and the rate of change, $\frac{dh}{dt}$, add this effective rate to or subtract it from unity depending on whether the stage is rising or falling, take the square root, and multiply the constant discharge Q_c by this figure, thereby obtaining the discharge Q_m for the condition of changing stage. A three-dimensional table of stage, rate of change of stage, and the adjustment factor may easily be prepared.

LEWIS METHOD

In the Lewis method the relation between constant discharge and the discharge for a condition of changing stage is obtained directly from the curve of relation between this ratio and the rate of change of stage.

DEVELOPMENT OF DISCHARGE HYDROGRAPH

A discharge hydrograph may be developed from a water-stage recorder graph by any of the above methods by computation of discharges for certain instants, using the gage height and the rate of change of stage. The figures of discharge are plotted with the discharge as the ordinate and the time as the abscissa. In developing the discharge hydrograph it should be remembered that because of the effect of the increasing discharge the peak discharge occurs a little before the peak stage.

The scale of ordinates of the discharge graph should be large enough so that the average discharge for the day can be determined from the graph with a good degree of accuracy and a sufficient number of instantaneous discharges should be determined so that the shape of the discharge graph may be accurately established. The number of computations required can readily be determined by inspection of the recorder graphs and by selecting points that will define the changes in curvature of the discharge graph. The daily discharge is computed from the discharge hydrograph by the method of balancing areas.

This method of determining daily discharge for stations affected by changing discharge will facilitate computations in that it does not require the computations of subdivisions according to rate of change of stage and it affords a ready means of detecting necessary adjustments in daily discharge that may become apparent as the discharge graph is constructed. Plotting of the discharges of actual measurements in conjunction with the computed discharges will serve as a check, both on the computed discharge and on the stage-discharge relation.

Each gaging station should be studied to determine under what conditions and for what rates of change of stage it is necessary to apply adjustment factors in determining the discharge. If it is found that for some stages there are rates of change of stage that give figures of discharge materially different from the constant-stage discharge at the same stages, the periods during which these stages and rates of change of stage occur should be subdivided and computed on the basis of partial discharges which include the effects of changing discharge for the rates of change applicable to the various parts of the day. Rapidly rising stages, even though generally of shorter duration than falling stages, may show much greater effects of changing discharge than falling stages because the rate of change is usually much greater for rising than for falling stages. The computed discharge may be seriously in error unless the effects of rising and falling stages are recognized.

VARIABLE SLOPES CAUSED BY BACKWATER IN CONJUNCTION WITH CHANGING DISCHARGE

Natural streams are continuously changing in discharge, the discharge rarely remaining constant for any considerable period of time. Usually at gaging stations affected by backwater the effects of changing discharge may be absorbed in the slope or fall as determined by simultaneous readings on gages at the ends of a reach.

Although the effects of changing discharge in connection with backwater may usually be absorbed in the slope determinations, the slope-stage-discharge relations become very complex if the backwater is itself undergoing changes with respect to time. For example, a rapidly rising river to which a stream is tributary will diminish the flow of the tributary stream at a section within the backwater influence, and may at times so decrease the flow at such a section as to cause a reversal in the direction of flow. As the river falls the flow at a section will be materially increased by the release of channel storage above the section. Discharge measurements of the tributary stream made under those conditions will show less discharge for a rising stage and more for a falling stage—the reverse of the effect created by the passage of a flood wave. Evidence of this effect may be obtained from simultaneous observations on gages at the ends of a reach, but none of the methods outlined above for gaging stations affected by variable slopes are strictly applicable under these conditions. If it is necessary to operate a gaging station within the zone of influence of changing backwater, the only satisfactory solution is by means of an adequate number of discharge measurements to define completely the effects of the changes and the use of two recording gages for obtaining continuous records of the stages from which the slopes may be determined. Discharge measurements should be made as close to the center of the reach as practicable to reduce the effects of channel storage during changing stages. If a section is not available near the center of the reach measurements should be made toward the upper end rather than toward the lower to take advantage of the greater velocities in the region of least backwater. The effects of changing backwater conditions on the flow of a tributary stream generally are of short duration, and the periods of time requiring the use of the special methods would not be long.

INSTRUMENTS AND MISCELLANEOUS EQUIPMENT

The development and improvement of equipment, especially the current meters and weights used in discharge measurements and water-stage recorders used in obtaining records of stage, have resulted in greater accuracy of the records and undoubtedly have contributed more to the progress of the surface-water investigations of the Geological Survey than any other single factor. During the development period, attention was first directed toward improvements in current meters; this was followed by the development and improvement of water-stage recorders and current-meter weights.

With the beginning of stream-flow investigations by the Geological Survey in 1888 it was recognized that no current meter at that time had been developed which was satisfactory for use in river measurements under the wide range of conditions that must be successfully met. Several different types of current meters were used during the early part of the work, and the vertical-axis cup-type meter was finally selected as the type best adapted to the wide range of field conditions. Improvements were made in the design of the cup-type current meter as a result of experimentation and field experience until the needs of the Survey for a general-purpose current meter were reasonably well satisfied.

The urgent need of greater accuracy in the records of river stages became evident, and in about 1903 the development of water-stage recorders was begun. This development eventually provided the means whereby previous deficiencies in gage-height records could be overcome. By 1914 water-stage recorders were in use at 325 of the 1,741 gaging stations operated by the Geological Survey,[56] and on June 30, 1940, there were 3,181 stations so equipped in a total of 3,910 stream-flow-measurement stations.

The need for more accurate soundings and for placing and holding the current meter in a definite position in deep swift water led to the development of heavier weights and suitable apparatus for handling

[56] Pierce, C. H., Conditions requiring the use of automatic gages: U. S. Geol. Survey Water-Supply Paper 375, p. 131, 1916.

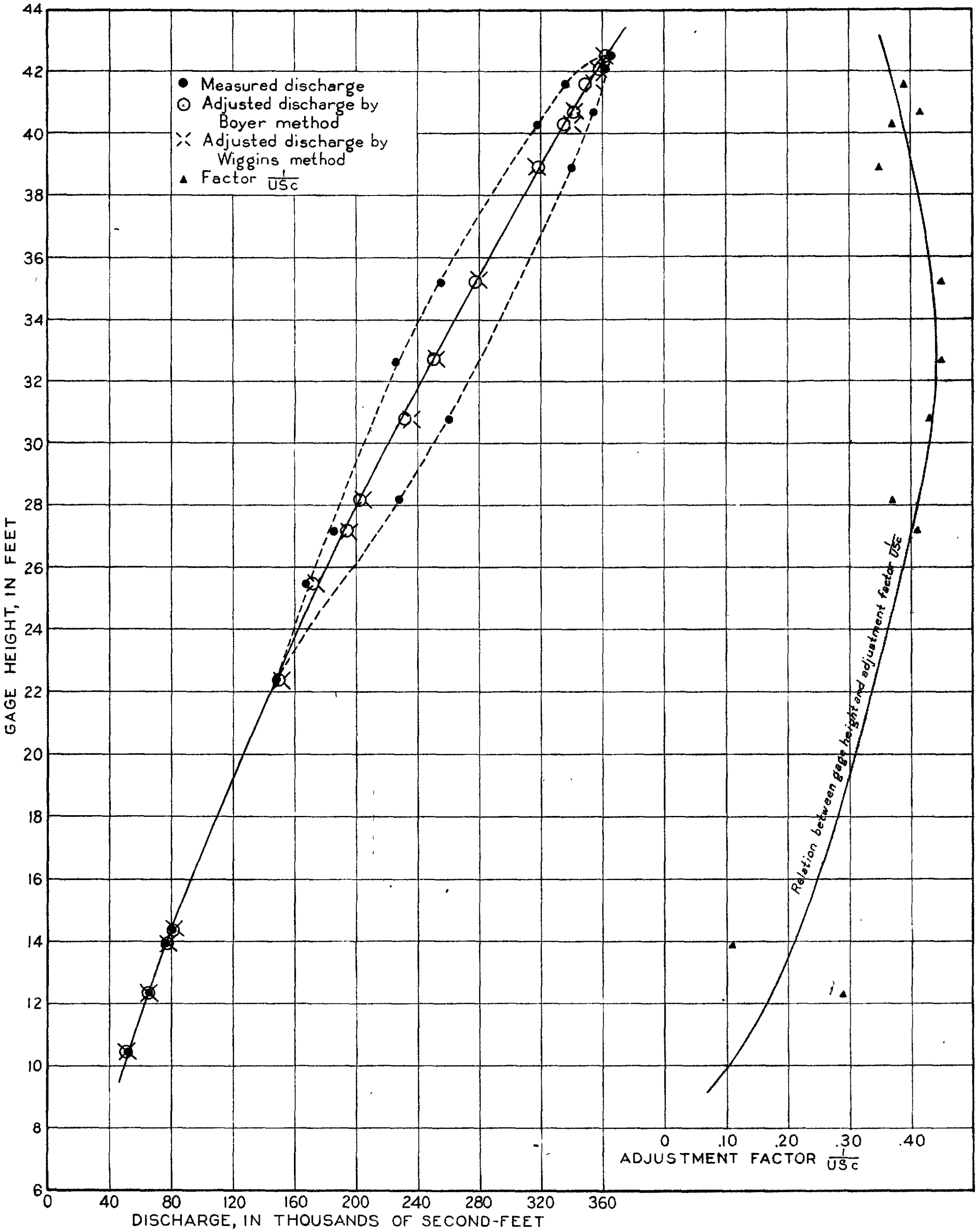
them. Descriptions of the design and construction of these articles of equipment are given in the following pages.

Records of river stages and measurements of depths, widths, and velocities are the basic data for the determination of stream-flow. Inasmuch as the accuracy of the data depends largely on the performances of the current meters, the sounding equipment, and the water-stage recorders which are used in the work, many improvements to those instruments and equipment have been made, and it is to be expected that the improvements will continue, especially as new and more exacting uses for stream-flow records make the accuracy requirements more rigid.

CURRENT METERS

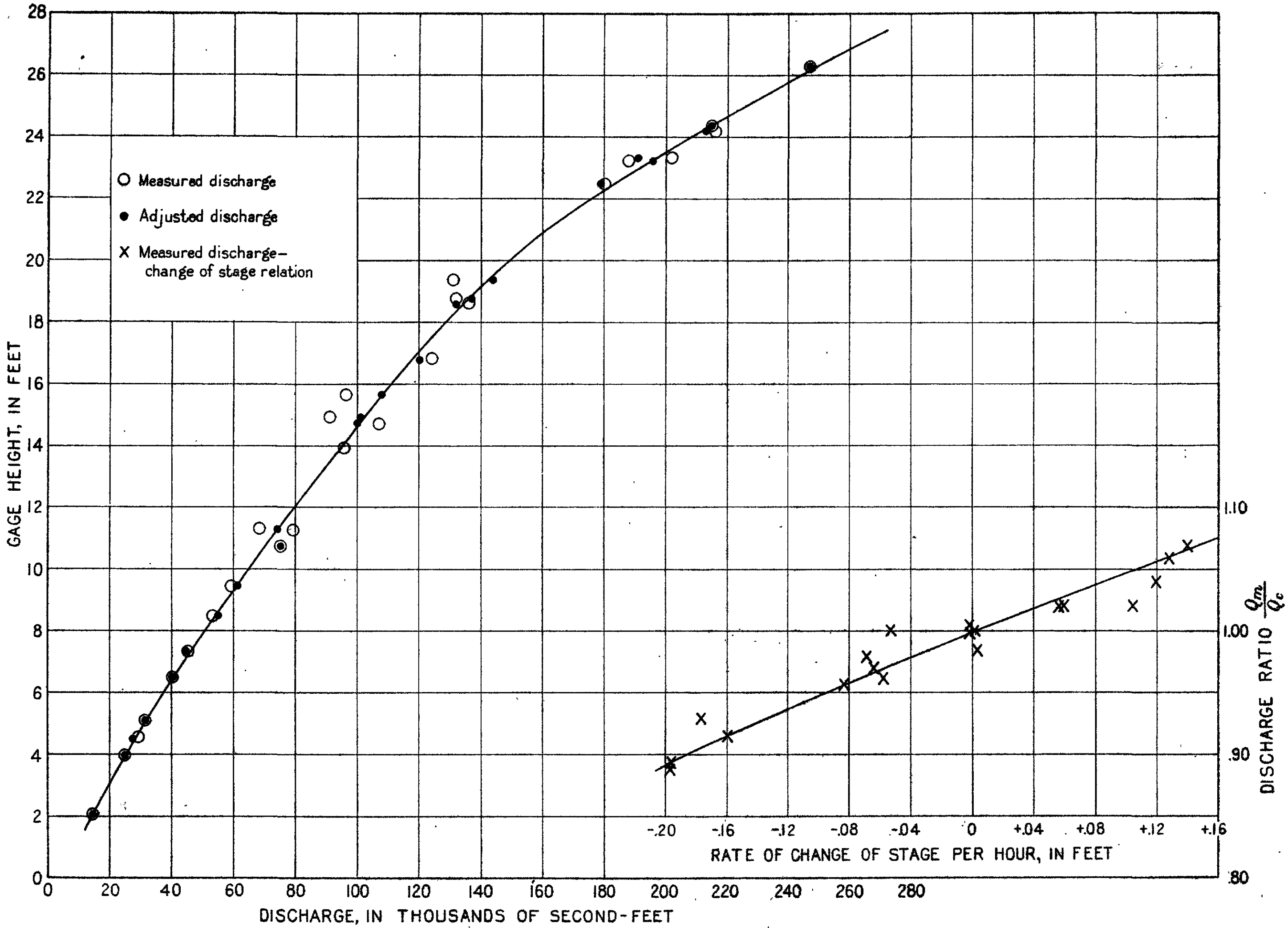
A current meter is an instrument used to measure the velocity of flowing water. It contains, as one of its essential parts, a set of cups or vanes which rotates about a central axis by the action of the moving water, the rate of rotation having a definite relation to the velocity of the water. By placing a current meter at a point in a stream and ascertaining the number of revolutions of the cups or vanes in a known interval of time, the velocity of the water at that point can be determined from the calibration of the meter. The first current meter of which there is record was the simple float wheel used by Borda and by Dupuit in the later part of the 18th century.[57] This meter contained no provision for determining the number of revolutions of the float wheel except by visual observations, and its use was confined to measuring surface velocities. Woltmann, a waterworks inspector of Hamburg, Germany, modified this meter in 1790 by including a gear mechanism for recording the number of revolutions made by the wheel so that it could be used beneath the water surface. The gear mechanism was engaged with the revolving wheel at the beginning of each observation and disengaged at the end of the observation by means of a cord operated by the observer. It was necessary to remove the instrument from the water upon the completion of each run in order that the data for computing the number of revolutions might be read from the gear wheels. Lapointe subsequently arranged the recording apparatus so that it could be read without removing the meter from the water. Various modifications and improvements were made to the current meter, although the horizontal axis was generally retained. Baumgarten in 1847 designed a meter having four helicoidal blades. During the next few years Saxton, Laignel, and others made further contributions to its development, but it was not until about 1860 when D. F. Henry,

[57] Henry, D. F., On the flow of water in canals and rivers: Jour. Franklin Inst., 3d ser., vol. 62, p. 167, 1871.



ADJUSTMENT OF DISCHARGE MEASUREMENTS FOR CHANGING DISCHARGE, OHIO RIVER AT WHEELING, W. VA., DURING THE PERIOD MARCH 14–27, 1905.

452509—42 (Face p. 168) No. 1



ADJUSTMENT OF DISCHARGE MEASUREMENTS FOR CHANGING DISCHARGE, TENNESSEE RIVER NEAR SCOTTSBORO, ALA.

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an assistant in the Lake Survey, invented an electrical recording device which replaced the mechanical registering dials, that the meter attained sufficient sensitiveness for accurate work. This improvement largely overcame the excessive friction which previously had been objectionable. Following the work of Henry, two distinct types of current meters came into use. These were the vertical-axis cup-type meters developed by Ellis and Price and the horizontal-axis propeller-type meters developed by Amsler, Stoppani, Haskell, Henry, Ritchie, Fteley, Ott, and Hoff.

The earliest use of current meters in America was in connection with investigations on the Mississippi River which were begun in 1850 by Humphreys and Abbot.[58] A ship's log and a meter devised by Saxton were used in that work, but with little success. The first successful use of the current meter in measuring river discharge was in connection with studies on the Connecticut River conducted by Gen. T. G. Ellis in 1871.[59] In the course of these studies Ellis made a series of measurements with an electrical meter devised by himself after experimenting with a Woltmann meter equipped with an electrical recording device. Many of the difficulties which had to be overcome in the development of a meter suitable for general use were first discovered in this series of measurements.

GENERAL REQUIREMENTS IN DESIGN OF CURRENT METERS

The ideal current meter should satisfy two theoretical requirements: first, the rotor of the meter should respond instantly and consistently to any changes in velocity; and second, the meter should register only those components of velocities that are perpendicular to a vertical plane across the channel at the measuring section. The quickness with which a rotor of a cup-type current meter responds to changes in velocity depends upon the friction in the bearings, the relative pressures against the cups on the opposite sides of the bucket wheel, the symmetry of the bucket wheel, and the underwater moment of inertia of the bucket wheel. Similar conditions relate to the vane-type meters with the exception that the pitch of the vanes determines the magnitude and the effectiveness of the forces acting in the direction of rotation. Modern current meters generally meet the first requirement satisfactorily. The second requirement as yet has not been fully met because of the complications in designing an instrument to register correctly the normal component of velocity under conditions of excessive turbulence.

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[58] Humphreys, Capt. A. A., and Abbot, Lieut. H. L., Physics and hydraulics of the Mississippi River: Corps of Topog. Eng., U. S. Army, Prof. Paper 4, pp. 221–285, 1861.

[59] Report of the Chief of Engineers for the year 1875, part 2, pp. 300–373.

Uncertainties in the registration of current meters under unfavorable conditions of turbulence have long been recognized, and the practice has been adopted of making careful selections of cross-sections of streams for current-meter measurements so as to avoid sections where the current meter could not be expected to yield accurate results.

In addition to the theoretical requirements of a current meter, those of a practical nature also must be considered. Some of the more important practical considerations are (1) durability, so that no part is so delicate as to make the meter unsuitable for general use; (2) simplicity in construction so that it may be easily taken apart, cleaned, and reassembled without affecting its performance; (3) simplicity in operation so that it may be readily used by a person working alone under a wide range of conditions; (4) small resistance to the pressure of the water in order that the current meter may be kept in the desired position in the measuring section; (5) adaptability for use in silt- and debris-laden streams; (6) effectiveness in warding off floating debris without damage to the instrument; (7) adaptability for use with either a rod or a cable suspension; and (8) ability to maintain a constant rating even though field repairs may have been made to the rotor and other parts.

TYPES OF CURRENT METERS

Current meters having horizontal axes with propeller-shaped rotors and those having vertical axes with cup-type rotors have been experimented with extensively to determine their respective advantages and disadvantages. Although many characteristics of different current meters are still unknown, the experiments and investigations thus far conducted are conclusive in one respect, namely, that current meters of either the horizontal- or vertical-axis type when carefully designed and constructed, and when used under favorable conditions, will measure accurately the velocity of flowing water. Several designs of horizontal-axis propeller-type current meters are shown in plate 19.

Among the reasons why the Geological Survey prefers the vertical-axis cup-type current meter are the following: (1) the vertical-axis meters will generally operate at lower velocities than the horizontal-axis meters, and the accuracy and consistency of vertical-axis meters is equal to that of horizontal-axis meters in high velocities; (2) by placing the bearings of the vertical-axis meters in air pockets it is possible to eliminate largely the entrance of silty water to those parts, whereas an equally satisfactory method for eliminating silty water from the bearing surfaces of the horizontal-axis meters has not yet been brought to the attention of the Survey; (3) meter cups which become dented or slightly bent may be repaired readily in the field, and the relation between the velocity of the water and the rate of rotation of the bucket wheel will not be seriously affected; whereas the effects of slight damage to the rotor of a horizontal-axis meter may seriously affect its rate of rotation, and the proper repair of such damage generally requires considerable skill; (4) the bucket wheel of a vertical-axis meter is relatively slow-moving, and a single rotor serves for the entire range of velocities ordinarily found in stream gaging. In contrast, the vanes of a horizontal-axis meter must be at a considerable angle (or pitch) to the current in order to assure consistent and accurate performance in low velocities. The same rotor when used in high velocities revolves too fast for use under field conditions. Consequently, two or more interchangeable rotors having vanes at different angles are occasionally required to cover the range of velocities encountered in a single measurement of discharge.

The use of ball bearings to reduce friction in either type of meter is considered impracticable unless those bearings can be completely isolated from silty water. The wear of the bearings is of minor importance as compared with the changes in the calibration of a meter caused by silt in the bearings and with the difficulty encountered in removing silt from ball bearings under field conditions.

Because of their general use by the Geological Survey and other governmental agencies, the various models of the Price current meter will be discussed in considerable detail.

The Price current meter.—The Price current meter was devised in the early part of 1882 by W. G. Price, a civilian engineer of the Mississippi River Commission, who utilized the principle of the bucket wheel mounted on a vertical axis as previously devised by General Ellis. The new feature in the design of the meter made by Price, and that on which he placed the greatest stress, was the air pocket to prevent the accumulation of silt in the pivot bearing. The meter was equipped with an electric revolution-indicating device apparently adapted from the telegraphic current meter used by Henry.[60] The current meter designed and constructed by Price in 1882 is shown in plate 20, *A*.

The Price acoustic meter.—Following the design and manufacture of the large Price meter, another model known as the acoustic meter was developed. This meter utilizes a 6-cup bucket wheel 5 inches in diameter, surmounted by a contact chamber. It is mounted in a yoke that is attached to a hollow rod. Inasmuch as this meter is not designed for cable suspension, no tailpiece is provided. It is

[60] Henry, D. F., op. cit., p. 167.

adapted for measuring velocities of flow either by wading or from a platform or bridge immediately above the water surface. Every tenth revolution of the bucket wheel is indicated by the sound of a mechanically operated hammer striking a metal drum in a contact chamber. The sound is transmitted from the acoustic chamber above the meter through the hollow rod, thence through a rubber tube and earpiece to the operator.

The small Price current meter.—When stream-flow investigations were undertaken by the Geological Survey in 1888, engineers of the Survey began experimenting with the various types of current meters at that time available to find one that could be used under the wide variety of field conditions. As a result of these investigations, Survey engineers about 1896 developed a meter containing certain features of the Price acoustic and the large Price electric meters. This type of meter, which was called the small Price, has since been used by the Survey almost exclusively because of its adaptability to general stream gaging.

The small Price current meter probably has been used more extensively and has been subjected to more investigation than any other type of current meter. As a result of this extensive investigation and because of the natural advantages afforded by the type, the small Price has been perfected in its details and is now better suited to general use than any other meter so far developed. It is light and yet strong, sensitive yet durable. It will measure with a high degree of accuracy velocities ranging from 0.1 foot per second to more than 15 feet per second. It is easily repaired, can be quickly taken apart for cleaning and oiling, and can be quickly reassembled without change in rating. It can be used by a person working alone from a cableway, bridge, boat, or ice cover or by wading. No other current meter known to the engineers of the Geological Survey satisfies so completely all these conditions. The type-A small Price current meter now in general use by the Geological Survey is shown in plate 20, *B*.

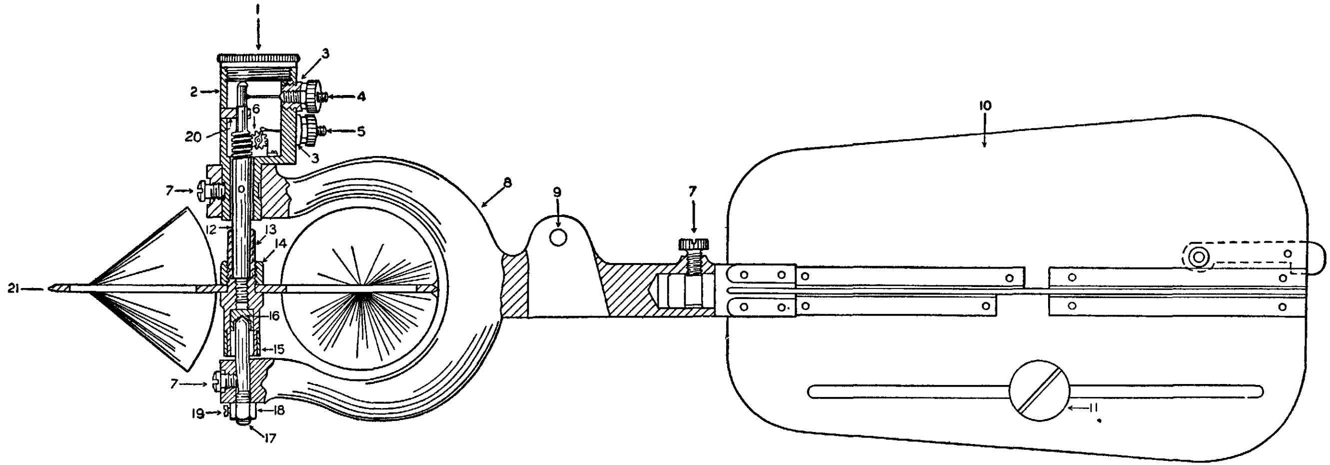
Modifications in the design of the small Price current meter have been made from time to time as years of additional experience have showed the need of improvements. As a result of these modifications, six different types have been developed in addition to the original small Price. The original small Price was designated by the manufacturer the 617-type meter and was designed to produce one electrical contact for each revolution of the bucket wheel. Later, about 1907, the 621-type was developed, which introduced the penta contact feature (one electrical contact for each 5 revolutions of the bucket wheel). A meter with interchangeable single-contact and penta-contact heads was later developed and was designated the 624-type or combination meter. The 624-type meter was modified by the introduction of the Covert yoke, which permitted a half-inch round rod to be screwed into the upper limb of the yoke. This change in method of suspension adapted the meter better for use without a tailpiece in measuring by wading or from ice cover. The meter with the Covert yoke and interchangeable heads was called the 623-type meter; the name combination meter was also applied to it, as it had the same feature of interchangeable heads that had been developed in the 624-type meter. A meter that was called the 618-type meter had previously been designed for use without a tailpiece. That meter had a circular base plate in a fixed position and was not much used by the Survey. In 1925 the design of the current meter was changed by putting both the single contact and the penta contact in the same chamber. At that time the design of the pivot and pivot bearing was changed to provide a shorter and stronger pivot; the bucket-raising nut, which was a part of the combination-type meter, was omitted; and the suspension hole in the yoke was raised 19/32 inch above the center line of the yoke and bucket wheel. This meter came to be known as the 622-type.

The 622-type meter differed from the later design known as the type-A meter (see pl. 20, *B*) principally in the design of the shaft assembly and pivot, which comprises the shaft, bucket wheel hub, pivot bearing, and pivot.

In the development of the type-A meter from the 622-type changes were made in the hardness of the pivot and pivot bearing, and the angles and radii at the apex; the pivot was lengthened and made of the same diameter throughout its length; the bearing was enlarged correspondingly; the bucket-raising nut previously used in the 623-type meter was replaced; and the position of the bearing seat was raised nearly to the center of gravity of the bucket wheel, thus creating a deeper air chamber at the lower bearing.

PRINCIPAL PARTS OF THE TYPE-A SMALL PRICE CURRENT METER

In order that a current meter may be properly used and cared for, it is essential that the user shall be familiar with all of its parts, as well as with the assembled meter. If any part fails completely because of excessive wear or injury, the condition is usually obvious, but small irregularities that may introduce large percentage errors in velocity determinations are not always readily detected. For this reason the parts of the type-A meter and their functional characteristics are described; the numbers assigned to the various parts in this description correspond to the numbers used in the assembly diagram of the type-A current meter shown in figure 12.



EXPLANATION

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

FIGURE 12.—Assembly diagram of type-A small Price current meter.

Yoke.—The yoke (8) is a one-piece, horseshoe-shaped casting made of chromium-plated bronze. A short horizontal rear extension contains a hole for connection of the tailpiece. This extension contains two bosses, one of which is slotted vertically and drilled horizontally for the hanger and hanger screw, the other is drilled vertically for the keeper screw of the tailpiece. The slot for the hanger is of such dimensions as to limit the tilting of the meter so that neither the yoke nor the tailpiece will strike the weight. The upper arm of the yoke is drilled to receive the stem of the P-shaped contact chamber; the lower arm is drilled to receive the pivot. These holes are coaxial so as to properly aline the rotor assembly and the pivot. The contact chamber and pivot are held in position by roundhead keeper screws; the tailpiece is held in position by a keeper screw having a knurled fillister head.

Tailpiece.—The tailpiece (10) is made of a hard-rolled, nickel-plated brass, and consists of two separate vanes which, when assembled, are locked together at right angles to each other by means of a lever arrangement. This two-piece construction permits the tailpiece to be taken apart readily for convenience in packing. The nosepiece of the tail fits into the rear extension of the yoke. A means to balance the meter assembly is provided in the lower part of the tailpiece by a long horizontal slot containing a short, heavy screw that may be adjusted to the proper position to obtain the desired balance.

Bucket wheel.—The bucket wheel (21) consists of six cone-shaped cups soldered to a frame to form a symmetrical and balanced assembly 5 inches in diameter and 2 inches high. The cups and frame are made of hard rolled brass, nickel-plated. The frame is centrally drilled for the shaft and notched for a dowel pin. The letter T is stamped on the frame to identify the top side of the bucket wheel.

Bucket-wheel hub.—The bucket-wheel hub (13) encases the pivot bearing and the lower end of the shaft and supports the bucket wheel. The hub is threaded in three places: (1) for the bucket wheel hub nut, (2) for the bucket-raising nut, and (3) for the shaft. A small dowel pin maintains the bucket wheel in a fixed position with reference to the bucket-wheel hub.

Shaft.—The shaft (12) is made of stainless steel and is of sufficient length to extend from the bucket-wheel hub to a point 0.008 inch below the cap of the contact chamber. The upper half inch of the shaft is turned to 0.125-inch diameter and is rounded at the top to provide a smooth bearing surface for the thrust of the shaft against the bottom of the contact-chamber cap. An eccentric is cut in the 0.125-inch diameter part of the shaft to provide a means for making an electrical contact for each revolution of the bucket-wheel hub. It also contains an acme thread that meshes with the penta gear within the contact chamber. A small hole is drilled at about the midpoint of the shaft to facilitate the use of a pin for tightening the shaft into the bucket-wheel hub.

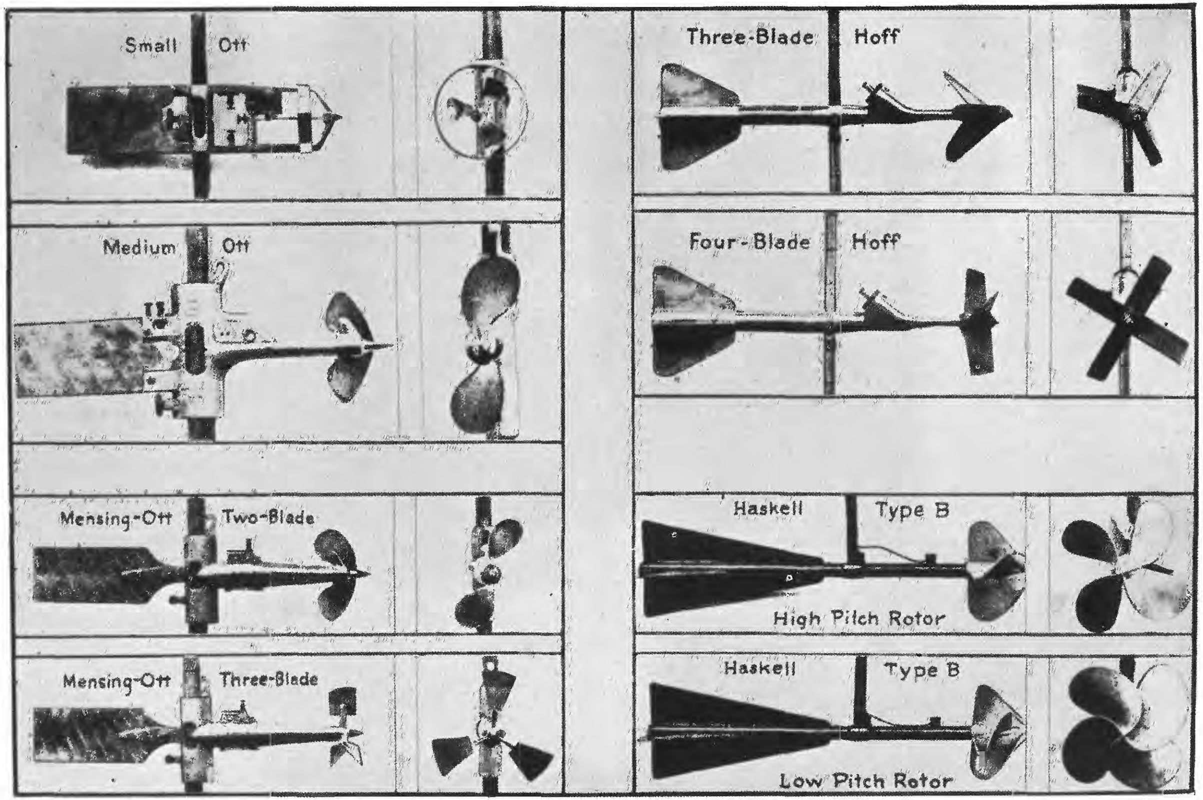
Pivot.—The pivot (17) is made of hardened and tempered close-grained tool steel. The upper end of the pivot is ground and polished to form an angle of 90° and the point rounded to a radius of 0.005 inch. It is heat treated to a Rockwell hardness of not less than C–57 or greater than C–59 within 0.125 inch of the point. The lower end of the pivot is threaded to provide for the hexagonal stainless-steel nut that is used to adjust the clearance between the pivot point and the pivot bearing. A slightly tapered flat surface on the pivot above the threads serves as a contact surface for the pivot-keeper screw.

Pivot bearing.—The pivot bearing (16) is made of the same metal as the pivot and has highly polished bearing surfaces. It is heat-treated to a Rockwell hardness of not less than C–61 and pressed into the cylindrical recess in the lower end of the bucket-wheel hub. Treating the bearing to a greater hardness than the pivot causes the major part of the wear to take place on the pivot which is easily replaceable.

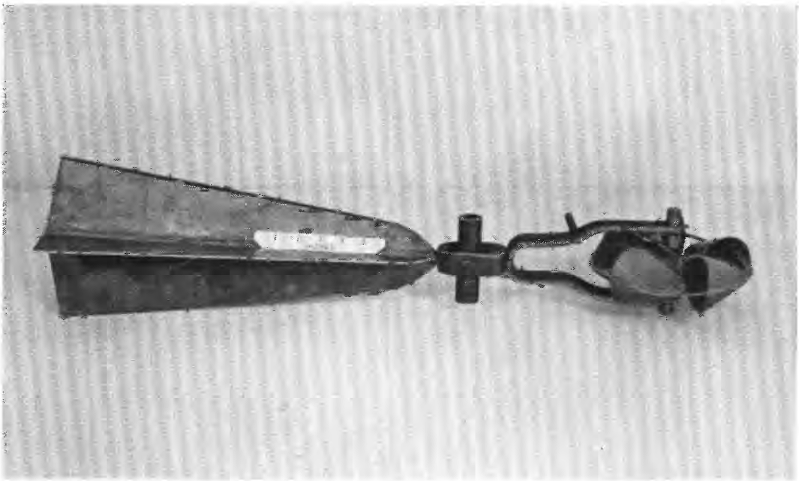
Penta gear.—The penta gear (6) is made of stainless steel and is fitted to mesh smoothly with the acme threads on the shaft. The gear makes one complete revolution for each ten revolutions of the bucket wheel. Two gear teeth, 180° apart, are extended beyond the others to provide a means for making two electrical contacts for each revolution of the gear, with the result that contacts are made at each fifth revolution of the bucket wheel. The gear is mounted in a bronze frame in a horizontal position and the assembly is housed in the contact chamber where it is held in place by means of a brass screw. The base of the frame through which this screw passes is slotted to permit the adjustment of the gear teeth with the worm on the shaft.

Contact chamber.—The contact chamber (2) is a P-shaped chromium-plated brass unit which houses the penta gear, the upper portion of the shaft, the shaft bearing, and the single and penta binding posts. The upper end of the chamber is drilled and threaded internally to carry a knurled cap. A small phosphor-bronze lug, brazed to the chamber wall, serves as the upper bearing for the shaft. The stem of the contact chamber extends through the upper arm of the yoke and is drilled axially so that the shaft can pass into the chamber with ample clearance. The cap is tightly fitted so that the chamber serves as an air trap to prevent silty water from entering the bearing.

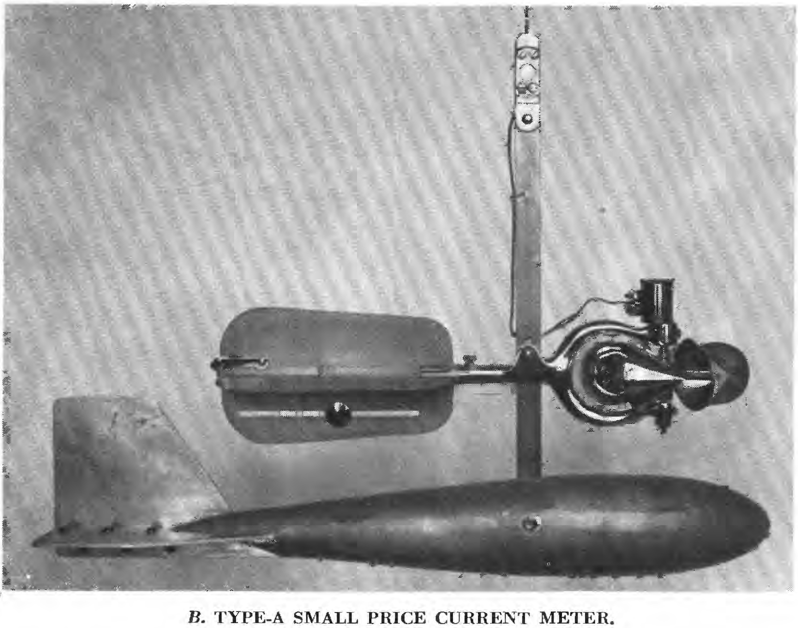
Binding posts.—Two stainless-steel binding posts (4) and (5) are placed at the rear of the contact chamber. One post is designed to contact the eccentric of the shaft and the other to contact the two extended teeth of the penta gear. They are identical in construction except for the lengths of the slender bronze cables that terminate in



HORIZONTAL-AXIS PROPELLER-TYPE CURRENT METERS.



A. ORIGINAL PRICE CURRENT METER.



B. TYPE-A SMALL PRICE CURRENT METER.

the beads of silver solder through which the contacts are made. Each binding post is insulated from the contact chamber by a bushing (3) made of laminated synthetic phenol-resin plastic.

Changes for special low-velocity work.—Two changes for special low-velocity work are sometimes made in the type-A meters before they are rated. First, the penta gear is removed from the contact chamber, thus leaving only the single revolution contact; and second, the radius of the pivot point is reduced from 0.010 to 0.005 inch, thereby lessening the frictional resistance between the point and the bearing. Shafts having an eccentric that makes two electrical contacts for each revolution of the bucket wheel are used in some of these current meters.

ASSEMBLY AND ADJUSTMENT OF THE TYPE-A CURRENT METER

The procedure in assembling the type-A current meters may best be followed by referring to figure 12 which shows a meter completely assembled. The meter is assembled as follows: First, assemble the two vanes of the tailpiece (10), insert the assembly in the yoke (8), and tighten the setscrew (7) that holds this assembly in place. Next, place the bucket wheel (21) on the bucket-wheel hub (13) with the side marked T up, and with the dowel pin on the hub fitting the notch in the bucket-wheel frame. These parts are clamped together by means of the bucket-wheel hub nut (14). This assembly is next placed in the yoke (8) and the shaft (12) is passed through the hole in the upper limb of the yoke and screwed into the bucket-wheel hub (13) by means of a pin inserted into the hole in the shaft. The penta gear (6) is next loosely fastened in the contact chamber (2) by means of a small screw passing through the adjusting slot of the gear pad. The contact chamber with the cap (1) removed is slipped over the upper end of the shaft and the lower end of the chamber inserted into the hole in the upper limb of the yoke. This should be done with care in order that neither the threaded shaft nor the penta gear become damaged. The contact chamber is then alined (by making the marks on the contact chamber and yoke coincide) and fastened in place by tightening the setscrew. The marks used for such alinement are placed on all Survey meters at the top front surface of the yoke and on the adjacent front surface of the contact chamber. The cap is then screwed into the contact chamber. Next the pivot (17) is inserted through the hole in the lower limb of the yoke, and after adjusting the pivot so as to give the proper vertical play to the shaft assembly, the setscrew for holding the pivot is tightened. The proper amount of play is obtained in the following manner: first, the keeper screw (19) in pivot-adjusting nut (18) is released, with the contact chamber cap tightly in place, the meter is turned over so that the top of the shaft rests against the cap. The pivot is then inserted into the pivot bearing until there is no vertical play. The screw for holding the pivot is then tightened and the pivot-adjusting nut (18) is advanced until it rests against the yoke. The setscrew is then released slightly and the pivot-adjusting nut (18) is further advanced a quarter of a turn. With the pivot-adjusting nut in this position, the keeper screw (19) is firmly tightened, thus locking the nut. Upon completion of this adjustment the set screw in the yoke is retightened. This adjustment provides a suitable end play of 0.008 inch. Because the meter is rated with this amount of play, it is essential that this adjustment be made when installing a new pivot or when the point becomes worn.

With the pivot adjusted as described above, the cap is again removed from the contact chamber, the penta gear adjusted to properly mesh with the threads on the shaft, and the screw for holding the penta gear assembly is firmly tightened. Contact wires are adjusted and the cap is replaced on the chamber. The assembled meter is then placed on a solid surface with the shaft in an exactly vertical position and subjected to a spin test. (See p. 180.)

OPERATION AND CARE OF CURRENT METERS

The successful operation of a current meter, like any other instrument of precision, will largely depend on the care with which it is used. Although the design, material, and construction of the meter are major factors contributing to its successful operation, they will not prevent inaccuracies caused by improper handling of the instrument. Therefore every person who operates a current meter should exert every possible effort to keep his meter in first-class condition, but in so doing he should not make replacements that are likely to affect the rating of the instrument. In order that he may satisfy himself as to the condition of the meter he should examine it both before and after each measurement with regard to the details described in the following paragraphs.

Balance with cable suspension.—In order to balance the assembled current meter, suspend it from a hanger, aline the tailpiece in such a manner that the balance weight (11) is vertically below the centerline of the meter, and then move the balance weight along the slot in the vane of the tailpiece to such a position that the meter will balance freely in a horizontal position. All Geological Survey meters, either new or when repaired by the Division of Field Equipment of the Geological Survey, are balanced in the manner described above before they are sent to the district offices. This balancing is done without a wire connection to the binding post on the contact chamber. The wire used in this part of the electrical circuit should be so flexible that it will not interfere with the free swinging and balancing of the meter.

The length of the wire should be such that it will not touch the bucket wheel when the meter is in a horizontal position and the top of the hanger pushed ahead as far as permitted by the slot in the yoke.

Mounting on wading rod.—The current meter, if used with a rod and sliding support, should be assembled with the axis of the bucket wheel parallel to the rod. Care should be taken to hold the rod in an exactly vertical position while making a velocity observation.

Care should also be taken with the rod suspension, as well as with the cable suspensions, to eliminate all possibility of interference in the rotation of the bucket wheel by the wire leading to the contact chamber.

Shaft alinement.—The shaft of any meter may become bent if (1) the meter receives a sharp blow, (2) if the bucket wheel is raised too forcibly, or (3) if an attempt is made to unscrew the cap of the contact chamber when the bucket wheel is in the raised position. When raising the bucket wheel from the pivot by means of the bucket-raising nut, the cups should always be held stationary and the bucket-raising nut turned. The bucket wheel should never be raised from the pivot by spinning the bucket wheel with the bucket-raising nut held stationary, as this method may cause several excess turns to be made which may result in the shaft becoming bent or the yoke becoming sprung. The shaft may also become bent by unscrewing the cap when the bucket wheel is in the raised position, as in that position the shaft is pressed tightly against the cap—and screwing the cap in either direction throws a severe torsional stress on the weakest part of the shaft. By spinning the bucket wheel slowly and watching the metal frame to which the cups are fastened, it can be observed whether the wheel runs true. If it does not run true, either the bucket wheel or the shaft is bent, and further investigation should be made. The cap should be removed and the movement of the shaft inside the contact chamber should be observed. If, when the bucket wheel is turning slowly, any eccentricity not caused by a worn bearing lug in the chamber is observed, the shaft should be removed from the assembly and further tested by rolling it on a flat surface. Any meter found to have a bent shaft should be repaired before it is again used.

Care of pivot and bearings.—After every discharge measurement the pivot and all bearing surfaces should be thoroughly cleaned and oiled. The pivot should be examined with a magnifying glass to see whether the point is fractured, worn flat, or rough at the apex. A pivot having a fractured or rough point should be discarded or reground. In order to examine and clean the pivot bearing conveniently, the contact chamber should be removed carefully and the shaft-and-bucket-wheel assembly tilted to one side so that the lower limb of the yoke will not obstruct the cleaning operation. The pivot bearing occasionally may become coated with an adhesive substance which cannot be removed with a cloth. In this circumstance a blunt soft wooden pin turned several times within the bearing will usually assist in the cleaning. If the bearing shows signs of rust a few drops of oil may be helpful if applied during the cleaning process as well as afterward. The pivot bearing, like the pivot point, should be examined for possible fracture, pits, or roughness. No current meter should ever be packed or transported, except to the extent required during the course of a discharge measurement, with the pivot bearing resting on the point of the pivot. The raising nut on the lower part of the bucket-wheel hub is provided as a convenient means for raising the bearing off the point of the pivot during shipment or other transportation of the meter.

In addition to the pivot bearing, type-A current meters have bearing surfaces above the bucket wheel. These consist of the cylindrical bearings of the shaft and of the penta gear, the thrust bearing between the shaft and the cap, and the bearing surfaces between the penta gear and the acme threads on the shaft. These bearings should be cleaned and oiled with a high grade instrument oil after each discharge measurement.

Insertion of new parts.—Bucket wheels, yokes, and contact chambers should not be replaced in the field except in an emergency; but if done, it should be with a full understanding that the rating used prior to the replacement of such parts may not be applicable afterward. When such replacements are made, an "as is" rating (one made of the meter in the exact condition as used in the field) should be obtained at the earliest opportunity thereafter. If the "as is" rating is not obtained before further changes are made in the meter, it is not possible to detect any errors that may be caused by use of the previous rating.

Although the field replacement of caps for contact chambers probably does not affect the ratings of current meters, special precautions should be observed when replacing them. All caps do not screw into the contact chambers to the same depth. In measurements of high velocities the caps become worn by the thrust of the shaft against the cap, and it occasionally becomes necessary to reface the cap when the meters are repaired; therefore the caps are not interchangeable without adjustment of other parts of the meter. Before a new cap is tightened into the contact chamber, the pivot should always be lowered and the bucket wheel released by means of the bucket-raising nut; otherwise the cap may be brought to bear against the head of the shaft with sufficient pressure to bend the shaft.

Spin test.—The spin test is a common method for determining the condition of the meter. In making a spin test, the meter should be so placed that the shaft is in a true vertical position and the bucket wheel protected from air currents. The bucket wheel is then given a quick turn to start it spinning. As the rotating bucket wheel nears the stopping point, it should be carefully observed to see whether the stop is abrupt or gradual. The bearings of any meter having a bucket wheel that will spin 1½ minutes and come to a gradual stop are in satisfactory condition for measuring all except very low velocities. If the spin is 1 minute and the meter is in satisfactory condition in all other respects, the meter may be used to measure velocities above 1 foot per second without appreciable error. If the spin test drops below 1 minute and it cannot be improved by the application of oil or the substitution of a new pivot, the meter should be reconditioned by competent instrument men and rerated. Four minutes is the approximate average spin test of a new type-A current meter and about the maximum that may be expected in the field when applying the spin test to meters of that type.

PYGMY CURRENT METER

The Geological Survey designed the first model of its "pygmy" current meter series in 1936. The pygmy current meter is of the Price type in that it contains a cup-type bucket wheel mounted on a vertical shaft having bearings that operate in air pockets. The bucket wheel is 2 inches in diameter (two-fifths the size of that contained in the small Price current meter). This meter is designed particularly for the measurement of those streams that are so shallow that the small Price current meter fails to perform with high accuracy, but which have too great a flow to be measured conveniently by either volumetric means or with small weirs. It is practicable, however, to use the meter for all wading measurements where the velocities do not exceed 3 or 4 feet per second.

The pygmy meter (see pl. 21, *A*) differs in other respects than its size from the type-A small Price current meter in that the contact chamber is an integral part of the yoke, it contains a single-revolution contact only, it has no tailpiece, and it has no provision for suspension from a cable.

The bucket wheel revolves about 2¼ times as fast as that of the small Price type current meter. This relatively high speed, combined with the fact that no multiple contact arrangement is provided, limits its use under field conditions where the revolutions are counted mentally to velocities up to 3 or 4 feet per second.

Various models have been made since 1936, and although the meter has been used in the work of the Survey with favorable results, its development in 1940 had not reached the stage where specifications had been standardized and where its manufacture had been undertaken by commercial agencies.

RATING OF CURRENT METERS

In order to determine the velocity of the water from the revolutions of the current-meter rotor, a relation must be established between the angular speed of the rotor and the velocity of the water which turns it. The establishment of this relation, known as "rating the current meter," is done for the Survey by the National Bureau of Standards. Although the ratings of different current meters of the same type are generally very similar, there may be enough differences in the ratings of individual meters so that the same rating cannot be used for all meters if a high degree of precision is expected. Ratings for the same meter also may differ for rod and cable suspensions and for different sizes or shapes of weights suspended below the meter; also if the meter is suspended at different distances above the same weight. In recognition of these differences each individual meter used by the Survey is rated for at least one suspension, generally the rod suspension, and coefficients based on the analysis of many comparative ratings are applied to the rod suspension rating to obtain ratings for other suspensions. However, when special conditions require exceptional accuracy, Survey current meters are rated with the exact suspensions that are to be used for the measurements.

Current-meter rating station at the National Bureau of Standards.—The meter rating station operated by the National Bureau of Standards in Washington, D. C., consists of a reinforced concrete basin 400 feet long, 6 feet wide, and 6 feet deep.[61] On the sides and extending the entire length of the basin are steel rails which carry an electric rating car. This car is operated to move the current meter at a constant rate of speed through the still water in the basin. Although the rate of speed can be accurately adjusted by means of a hydraulic regulating gear, the average velocity of the moving car is determined for each run by making an independent measurement of the distance it travels during the time that the revolutions of the bucket wheel are electrically counted. A scale graduated to feet and tenths along the side of the basin is used for this purpose. From 8 to 10 pairs of runs are usually made in the rating of each current meter. A pair of runs generally consists of two traverses of the basin, one run in each direction, at approximately the same speed. Practical considerations usually limit the ratings to velocities ranging from one-tenth of a foot per second to about 15 feet per second, although the rating car can be operated at both higher and lower speeds. For ordinary ratings, however, neither of these extremes is used; and unless a special request is made, the lowest velocity used in the

[61] Am. Soc. Mech. Eng., Trans., p. 582, October 1936.

rating is about 0.2 foot per second, and the highest is about 9.0 feet per second.

Current-meter ratings.—After Geological Survey current meters are rated by the National Bureau of Standards they are returned to the Survey's Division of Field Equipment where they are inspected and given performance spin tests. The rating curves are prepared by the National Bureau of Standards and show the plotting of each run made in the rating flume, with the revolutions per second of the rotor as the ordinate and the velocity in feet per second as the abscissa. The rotor of an ideal current meter in moving through still water would make the same number of revolutions for the same distance of travel, irrespective of the velocity. The rating curve for such a meter, when plotted with revolutions per second and velocity in feet per second as the coordinates, would be represented by a straight line passing through the origin. In practice, this relation is only approximately true, as the effects of friction and slight imperfections in construction cause variations from the ideal rating, and it is found that the ratings are generally represented graphically by two or three connected straight lines having slightly different slopes. Occasionally, however, ratings are obtained which can be represented by one straight line with only a small intercept on the velocity axis, although most ratings consist of two straight lines intersecting at approximately 1 revolution per second.

In studies of current-meter performance the ratings are sometimes plotted with revolutions per foot of travel as the ordinates and velocity in feet per second as the abscissas. This method of plotting emphasizes the effects of friction at low velocities and is helpful in making comparisons of different current meters.

For convenience in field use, the data from the rating curves are reproduced in tables, one of which is shown in plate 22. The velocities corresponding to a range of 3 to 350 revolutions of the bucket wheel within a period of 40 to 70 seconds are listed in these tables. This range of number of revolutions and periods of time have been found to cover general field requirements. A few exceptions may occur, and to provide information for extensions of the table if needed, the equations of the rating table are shown in the spaces provided on the table. An abbreviated form for presenting the equations has been adopted in order to adapt them to a very limited space. For example, in the equation $V=2.20\ R+0.020$ (2.22) $2.19\ R+0.030$, which is given in the table in plate 22, V represents velocity in feet per second and R represents the number of revolutions of the bucket wheel per second. That part of the equation to the left of the parenthesis, $V=2.20\ R+0.020$, is the equation used for computing velocities shown in the table below

2.22 feet per second. That part of the equation to the right of the parenthesis, 2.19 $R+0.030$, is a contraction of the equation $V=2.19R+0.030$, which is the equation used for computing the values for V above 2.22 feet per second. The term in parenthesis (2.22) represents the velocity common to both equations.

After "limits of actual rating" there is shown the velocities at which the slowest and fastest runs were made in the rating flume. Other information furnished consists of the type and number of the current meter, the method of current-meter suspension to which the table applies, the condition of the meter, the date of its rating, and the index number of the rating table.

It should be noted that the equations given are those of the table, and not necessarily those of the actual rating. The present practice of the Survey is to allow the following tolerances in preparing or selecting rating tables: For a velocity corresponding to 0.1 revolution per second of the bucket wheel, a tolerance of ±0.002 foot per second is allowed. This amounts to slightly less than 1 percent at the lower end of the rating. For greater velocities the tolerance percentage is decreased until it becomes ±0.5 percent at 1.0 revolution per second. This ±0.5 percent tolerance is allowed for all values above 1.0 revolution per second.

WATER-STAGE RECORDERS

A water-stage recorder is an instrument for producing a graphic or printed record of the rise and fall of a water surface with respect to time. It consists of a time element and a gage-height element which, when operating together, produce on a chart a record of the fluctuations of the water surface. The time element has a spring, weight, or electric clock mechanism, with accessories for transferring the record of time to a chart. The gage-height element may be actuated either by a pressure device or by a float, with accessories to correlate the height of the water with the record of time. In some types of recorders the time element moves the chart while the gage-height elements actuates a stylus; in other types the gage-height element moves the chart while the time element actuates the stylus. A water-stage recorder in operation at the gaging station on the Rahway River at Springfield, N. J., is shown in plate 2, *B*.

DEVELOPMENT OF WATER-STAGE RECORDERS

Probably the first float-type water-stage recorder used in the United States for obtaining records for river stages over a considerable period of time was installed on the Sudbury River at Framingham Center, Mass., in 1876. This instrument (see fig. 13), as described by Alphonse

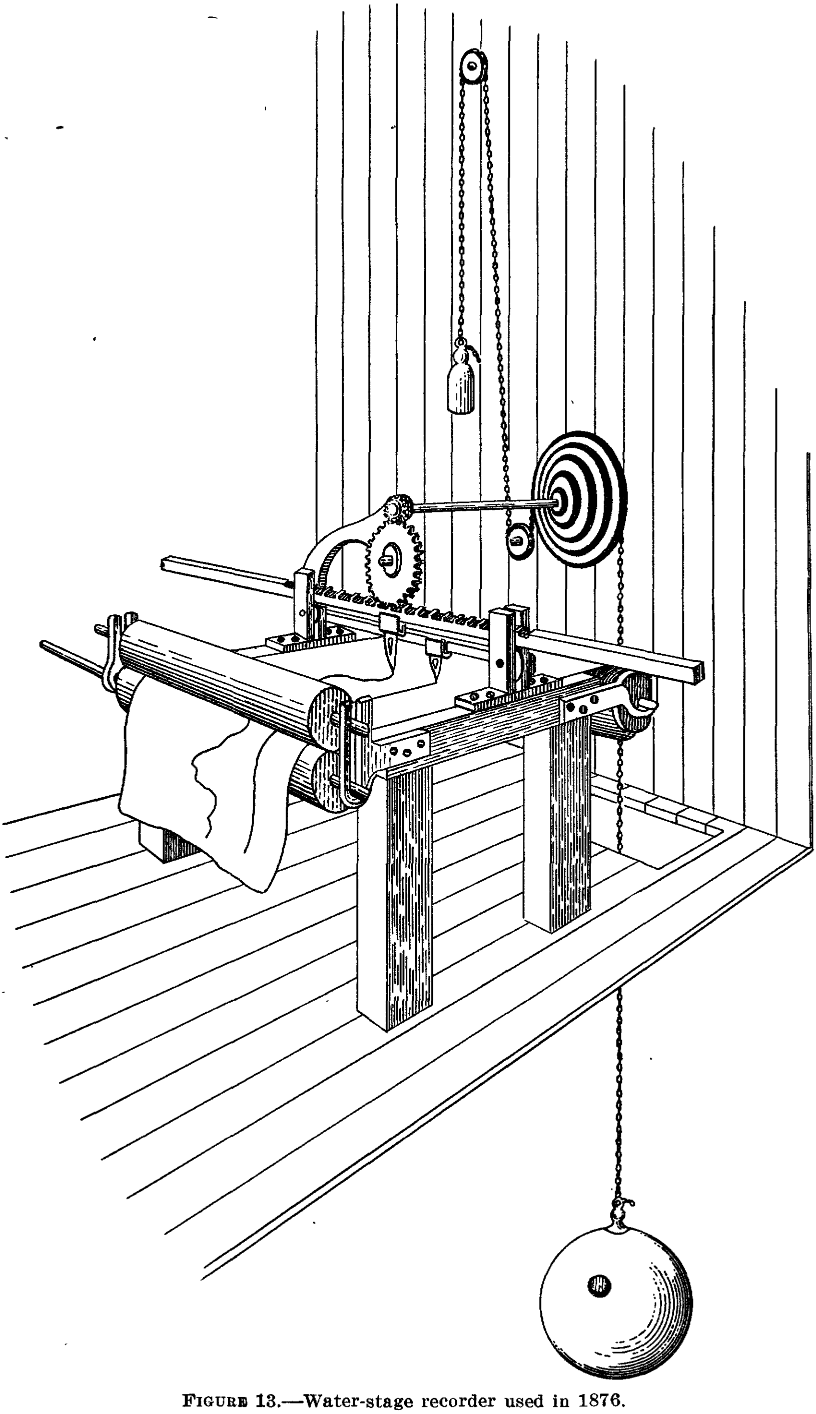


FIGURE 13.—Water-stage recorder used in 1876.

Fteley [62] appears to have been built in accordance with the same fundamental principles as those used in the design of water-stage recorders at the present time. A description of the instrument taken from Fteley's paper is as follows:

The levels, which in 1875 were taken three times a day, were afterwards ascertained by continuous diagrams recorded by a self-registering float. The float is contained in a box which can be connected, according to the way the water is made to flow, either with the still water above the dam or with the flume at its side.

An endless sheet of paper, moving between guides on a horizontal table, advances at the rate of 1 foot in 24 hours under the action of the brass roll *A*, which is moved by clock work.

The float *O*, is suspended by a slender metallic thread from the pulley *C;* the slack of the thread is taken by the weight *D*. The motion of the pulley, when acted upon by the float, is transmitted by the wheels *EF* to the horizontal bar *G*, which carries the pencil *H* and moves on two small rolls. The range of the variations of level at the dam being about 8 feet, it is often necessary, in order to remain within the limits of the paper, to reduce considerably the motion of the pencil; it is for this reason that the main pulley *C* has four grooves of different diameters. When the largest diameter is used, the motion of the pencil is one-eighth of that of the float; when the smallest is used, the pencil moves as the float; the largest has been used almost exclusively. The difference of temperature has no perceptible effect on the length of the wire, and the loss of motion in the transmission of the movements of the float does not cause any appreciable error. In the winter a kerosene lamp suspended in the float-box and a small kerosene stove kept burning in the room containing the apparatus, are sufficient to prevent freezing.

In order to render the diagram independent from the side motion of the endless paper, a stationary pencil *K* records a line which represents constantly a given height of the float ascertained by actual measurement of the level of the water, and the variations of level indicated by the diagram are measured by the distances between the two pencil lines.

The first water-stage recorder installed by the Geological Survey was on the Rio Grande at Embudo, N. Mex., in January 1889. The operation of this instrument, which was of the horizontal-drum type, was not satisfactory and its use was soon discontinued. In 1890 a recorder designed by Elwood Mead, then Territorial Engineer of Wyoming, was installed by the Survey on the Rio Grande near Del Norte, N. Mex. In August 1892 a recorder, the type of which is not known, was installed on Rock Creek in Washington, D. C., and operated until November 1894. On December 31, 1894, a chart recorder was installed on the Potomac River at Chain Bridge, in the District of Columbia. None of these instruments was entirely satisfactory and it was not until about 1903, when a 7-day recorder was introduced, that an instrument approaching reliability became available. In April of that year one of the 7-day recorders was installed on the Kings River near Sanger, Calif. Survey records also show that two 7-day

[62] Fteley, Alphonse, The flow of the Sudbury River, Massachusetts, for the years 1875–79: Am. Soc. Civil Engrs. Trans., pp. 225–250, 1881.

recorders were in operation in Arizona as early as 1905. In these early instruments only one time scale and one gage-height scale were available, and the length of the period of operation without rewinding was limited by the use of 8-day spring-driven clocks. Although the need for water-stage recorders had been recognized by the Survey at these early dates it was not until about 1910, when two or more gage-height scales were incorporated in the same instrument, that a water-stage recorder showed promise of satisfying general stream-gaging requirements. The first recorder to produce runs longer than a week was an instrument known as a hydrochronograph, several of which were used by the Survey in the White Mountain investigations in New Hampshire during 1911–12.

In 1911, J. C. Stevens, who was at that time an engineer of the Geological Survey, designed a recorder with a strip chart of sufficient length to provide a year's record. However, the length of run without a rewinding of the clock was limited by the distance the clock weight could fall, or the length of the weight chain furnished with the instrument, which was usually 15 feet. The advantages of this recorder were soon recognized.

In 1912 a printing gage became available and a few gages of that type were installed by the Survey. This instrument printed the gage height at 15-minute intervals on a narrow strip of chart. The development of the discharge integrator (see pl. 21, *B*), which can be used to obtain mechanically the mean daily discharge directly from a gage-height graph, made the printed strip undesirable and helped to promote the use of graphical records on standardized time and gage-height scales. During 1920–21 C. H. Au, then a hydraulic engineer of the Survey, developed a recorder which contained a "positive-drive" float wheel and provided a means by which the stylus could record directly on the supply roll.

Numerous other developments have since been made with the result that by 1938 ten different types of water-stage recorders were on annual contracts by the Federal Government. Each type contains special features that are required under certain conditions.

ADVANTAGES

A few of the advantages of water-stage recorders over staff gages read intermittently by local observers are: [63]

1. In streams having diurnal fluctuation due to power regulation or other causes, the possibility that the daily mean of the observed gage heights accurately represents the average gage height for 24 hours contains a large element of chance which is eliminated by the use of continuous recorders.

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[63] Pierce, C. H., Conditions requiring the use of automatic gages in obtaining records of stream flow : U. S. Geol. Survey, Water-Supply Paper 375, pp. 131–139, 1916.

2. A continuous record provides definite information regarding maximum and minimum stages. Such information generally cannot be obtained unless the stage is recorded continuously on a chart.

3. On streams subject to rapid fluctuation caused by artificial regulation, a continuous record of stage is necessary to avoid inaccuracies in the computed discharge. It is uneconomical and impracticable to obtain such a continuous record through the employment of local observers.

4. A graphical record, produced mechanically, is free from the element of personal bias, which may affect the record when local observers are financially affected by the data—a condition that may occur in some instances, such as where the water is used on irrigated lands.

5. For legal purposes a record produced by a water-stage recorder may be more readily authenticated than an observed record of stage.

6. Discharge records based on surface slope require simultaneous readings of two gages located at a considerable distance apart. This can be accomplished, (1) by the use of two observers, (2) by one observer and a properly installed water-stage recorder, or (3) by the use of two water-stage recorders, one at each end of the section of river involved. The greatest confidence is placed in the discharge records that are based on those computed from the two-recorder installation.

7. Water-stage recorders make practicable the obtaining of records at points on streams where local observers are not available.

8. Mechanical devices, such as the discharge integrator can be used in connection with a graphical record to produce highly accurate figures for the daily mean discharge.

GENERAL REQUIREMENTS

Any water-stage recorder, regardless of the type, should satisfy the requirements enumerated in the following paragraphs.

Height element.—The height element must be sufficiently sensitive to insure that the stylus and chart record accurately at a predetermined scale the elevation of the water surface. Instruments equipped with floats, float cables, and counterweights necessarily contain some friction and lost motion which result in a slight lag in the graphic representation of changes in water stages. The amount of this lag will depend on the resistance of certain parts of the instrument to motion, and on the original setting of the index or stylus relative to rising or falling stages. With every change of stage a portion of the float line passes from the rising to the falling side of the float pulley, thus introducing a shift in weight equivalent to twice to weight of the transposed line. This shift in weight will tend to cause a change in the depth of submergence of the float and therefore the recorded gage height will be correspondingly in error. If the stage rises until the counterweight and a portion of the line become submerged, the indicated height will be in error by an amount proportional to the water displaced by the line and weight. The error due to the submergence of the line and weight tends to compensate the error produced by the line shift. It follows, therefore, that by using a float of large diameter, reducing the instrumental friction, using light float lines and counterweights that are not too heavy errors due to the lag, line shift, and submergence of the weight and float line may be reduced to a negligible amount. If the accuracy requirements are greater than the limitations of available water-stage recorders, each source of error may be definitely measured and corrections applied to the graphical record.[64] A further source of error is due to the tendency of the recorder charts to expand and contract with changes in temperature and humidity, and to improper alinement of the paper on the instrument; or, if the chart paper is contained on a 25-yard roll, the graduations of the paper possibly may not be accurately spaced with respect to the margins.

Timing element.—The timing element consists essentially of a clock mechanism which must be both sturdy and reliable. In routine stream gaging, continuous operation may be more important than high precision as to time, but in obtaining records for special studies both continuous operation and high precision may be required. It is obvious that the best results will be obtained if the clock mechanism is of high quality and adequately protected from dirt, corrosion, and insects. A weight-driven mechanism is usually needed if the instrument is to operate for more than a week without attention. An electric clock mechanism, if a reliable electric current is available, offers two advantages: the length of run is not governed by the distance through which a clock weight might fall; and the congealing of lubricants in the mechanism during subfreezing temperatures, is largely prevented by the heat generated in the electrical unit. One disadvantage of such a mechanism is that an electrical unit may be subject to stoppages caused by current interruptions.

Recording mechanism.—The recording mechanism consists essentially of a pen or pencil. If a pencil is used, it must be of the proper hardness. A pencil that is too hard may fail to produce a legible graph, and in addition, it may tear the chart if the paper is softened by moisture. Too soft a pencil will wear rapidly and is unsafe to use in an instrument that does not have frequent attention. The recording mechanism should be designed so as to permit ready adjust-

[64] Stevens, J. C., The accuracy of water-level recorders and indicators of the float type; Am. Soc. Civil Eng. Trans., vol. 83, pp. 894–903, 1919–20.

ment of both the gage height and time scales. A slow-motion adjusting device is an essential feature if a highly accurate setting is required.

Gage-height ratio.—In general, the height element should be designed to permit a choice of at least two ratios between the vertical movement of the water surface and the resulting movement of the stylus. The selection of the most suitable ratio should be based upon (1) a consideration of certain stream-flow characteristics, which include the sensitiveness of the control (see p. 115), and the accuracy obtainable with a small gage-height scale on the recorder at a station with a "sensitive" control as compared with that obtained by using a larger scale on the recorder at a station with a less "sensitive" control, and (2), a comparison of the maximum rate of change of stage with the time scales available on the recorder. The relation of rate-of-change-of-stage to the time scale controls the angle between the trace produced by the stylus and the gage-height ordinates on the chart. It is desirable that this angle should not exceed 45°, although at many gaging stations the rate of change of stage is so rapid that the angle is necessarily greater than 45°. The two most commonly used gage-height ratios are those in which a 1-foot change in stage causes a 1-inch movement of the stylus (1:12 ratio) and a 1-foot change in stage causes a 2-inch movement of the stylus (1:6 ratio).

Time scale.—In order to meet a wide range of field conditions, it is generally desirable that water-stage recorders contain two or more time scales. A time scale of 2.4 inches per day in combination with a 1:6 or 1:12 gage-height ratio will meet the requirements on most unregulated streams. However, very flashy streams and streams that are regulated by the operation of dams generally require the use of more extended time scales than are needed on streams having small variations in stage. Consequently, in order to meet the different requirements, time scales of 1.2, 2.4, and 4.8 inches per day are commonly used.

Instrument case.—Owing to the fact that paper expands with an increase in humidity it is essential that the chart be protected as much as practicable from excessive humidity changes. The lateral expansion of a strip chart may be several times as much as the longitudinal expansion. For this reason, errors in gage height may result from the lateral variation, and errors in time from the longitudinal variation, the errors in gage heights generally being of greater magnitude and more serious than the errors in time. Therefore, if errors caused by changes in humidity are to be controlled, it is necessary (1) to ventilate the shelter which contains the water-stage recorder, (2) to prevent access of the moist air of the stilling well to the shelter, and (3) to enclose the instrument in a case that will exclude moisture. A noncorrosive dehydrant may be used in the instrument case to absorb excess moisture. The case also serves to protect the instrument from dust and insects.

PRECAUTIONS

Although a water-stage recorder may be simple in design and construction, may be easy to install and adjust, and may require but little attention, negligence on the part of the operator must constantly be guarded against. To this end, Federal specifications require that each new recorder be provided with complete instructions for its installation and operation. Engineers installing water-stage recorders are urged to follow carefully the instructions which accompany the instruments. A standard form, No. 9–176b, entitled "Inspection of recording gage" (see fig. 14), is used by the Geological Survey in connection with many of its recording gages. The operators should be required to use these forms in reporting their inspections of the recorders under their care.

SPECIFICATIONS

The specifications for water-stage recorders for use by Federal agencies are issued each year by the Procurement Division of the Treasury Department and are the bases for awards of contracts to manufactures of instruments of precision. Changes may be made in the specifications from year to year to meet the requirements of the work on which the instruments are to be used, and new specifications may be prepared if other types of instruments are required. Copies of the specifications for water-stage recorders and other instruments of precision that are available for purchase by Federal agencies from Class 18 of the General Schedule of Supplies for the period January 1 to December 31, 1942, are on the file in the Procurement Division of the Treasury Department and in the administrative offices of the various federal agencies using such instruments, including the district offices of the Geological Survey.

NONRECORDING GAGES

The earliest practical means of obtaining a record of stage was by systematic observations of a nonrecording gage. The first gage of this type used by the Geological Survey was the graduated vertical staff. It was soon followed by the chain gage and the inclined-staff gage. Later, in an attempt to eliminate errors in chain-gage readings caused by the wear and stretch of the chain and its susceptibility to errors due to effects of wind action when used from structures high above the water surface, the Canfield wire-weight gage and the type-A wire-weight gage were developed. Staff gages and the chain gages were used almost exclusively until 1903, when the first water-stage

9-176b

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

File No. ....
Washington ......
Field ....

Date ...., 19......

INSPECTION OF RECORDING GAGE

.... River, at ....

Was gage working properly when you reached it? ....
What is correct time by your watch? ....
What is the clock time? ....
What is the time by the pen or pencil? ....
What is the outside or river-gage reading? ....
What is the inside or well-gage reading? ....
What is the recording-gage reading? ....
Have you marked pen or pencil time on the chart by raising the float? ....
Did you remove old sheet and put on new one? .... At what time did you do this? ....
If you did not remove sheet, did you correct setting of pen or pencil and clock? ....
Did you wind clock? .... Regulate it? ....
Did you sharpen pencil or fill pen? ....
Did you mark pen or pencil time on new sheet by raising float? ....
Have you filled blanks on old sheet according to instructions? ....
Have you made sure that pen or pencil is down, sheet placed correctly, setscrew on drum fastened, and gage working correctly before leaving station? ....
Have you filled all blanks on this sheet according to instructions? ....

Remarks and questions: ....

....

....

....

....

....

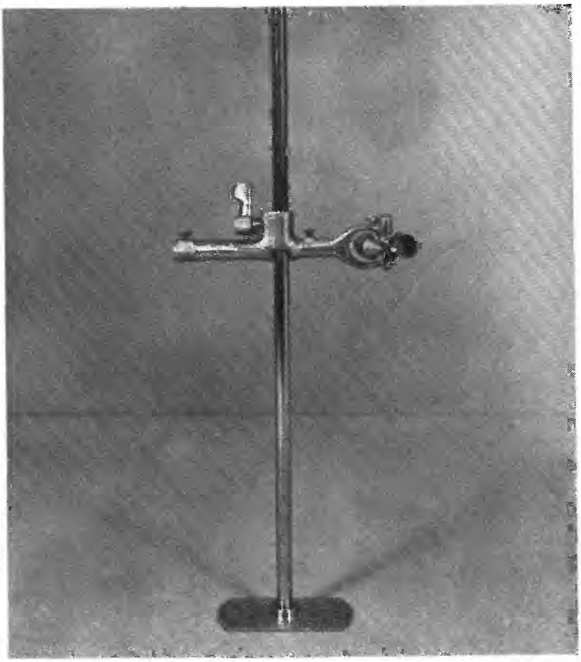
....

August 1935

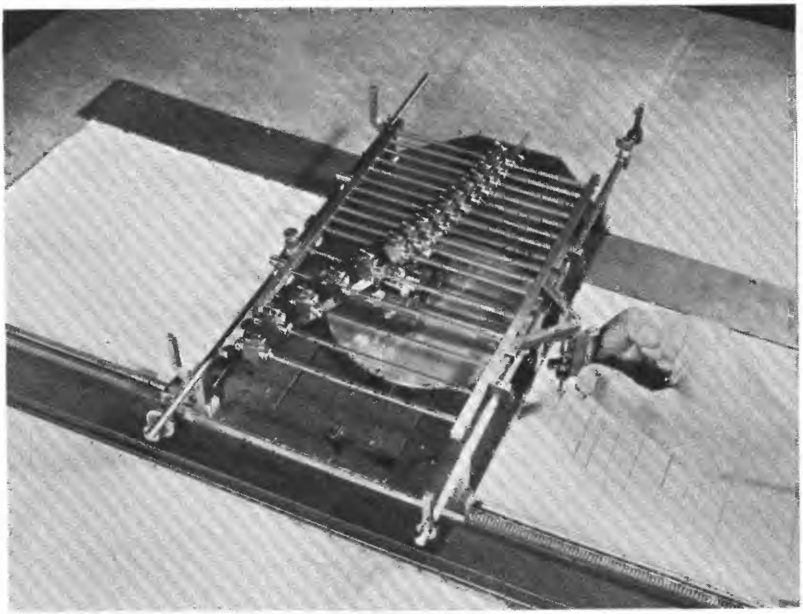
Signed by ....
Observer.

U. S. GOVERNMENT PRINTING OFFICE 6—8945

FIGURE 14.—Inspection of recording gage, form 9–176 b.



A. PYGMY CURRENT METER.



B. DISCHARGE INTEGRATOR.

DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
Water Resources Branch
RATING TABLE FOR TYPE..A...... CURRENT METER NO..1689....
SUSPENSION 15 C .5 RATED SEPT. 22, 1938

INDEX....258 - 257
EQUATIONS..V = 2.20 R + 0.020 (2.22) 2.19 R + 0.030
Limits of actual rating..0.2.. to..8.3.. feet per sec.
at Bureau of Standards, Wash., D.C. Condition of meter NEW

NO. 1689
15 C .5
SEPT. 22, 1938

Time, in seconds	VELOCITY, IN FEET PER SECOND									Time, in seconds
	Revolutions									
	3	5	7	10	15	20	25	30	40	
40	.185	.295	.405	.570	.845	1.12	1.40	1.67	2.22	40
41	.181	.288	.396	.557	.825	1.09	1.36	1.63	2.17	41
42	.177	.282	.387	.544	.806	1.07	1.33	1.59	2.12	42
43	.173	.276	.378	.532	.787	1.04	1.30	1.55	2.07	43
44	.170	.270	.370	.520	.770	1.02	1.27	1.52	2.02	44
45	.167	.264	.362	.509	.753	.998	1.24	1.49	1.98	45
46	.163	.259	.355	.498	.737	.977	1.22	1.45	1.93	46
47	.160	.254	.348	.488	.722	.956	1.19	1.42	1.89	47
48	.158	.249	.341	.478	.708	.937	1.17	1.40	1.85	48
49	.155	.244	.334	.469	.693	.918	1.14	1.37	1.82	49
50	.152	.240	.328	.460	.680	.900	1.12	1.34	1.78	50
51	.149	.236	.322	.451	.667	.883	1.10	1.31	1.75	51
52	.147	.232	.316	.443	.655	.866	1.08	1.29	1.71	52
53	.145	.228	.311	.435	.643	.850	1.06	1.27	1.68	53
54	.142	.224	.305	.427	.631	.835	1.04	1.24	1.65	54
55	.140	.220	.300	.420	.620	.820	1.02	1.22	1.62	55
56	.138	.216	.295	.413	.609	.806	1.00	1.20	1.59	56
57	.136	.213	.290	.406	.599	.792	.985	1.18	1.56	57
58	.134	.210	.286	.399	.589	.779	.968	1.16	1.54	58
59	.132	.206	.281	.393	.579	.766	.952	1.14	1.51	59
60	.130	.203	.277	.387	.570	.753	.937	1.12	1.49	60
61	.128	.200	.272	.381	.561	.741	.922	1.10	1.46	61
62	.126	.197	.268	.375	.552	.730	.907	1.08	1.44	62
63	.125	.195	.264	.369	.544	.718	.893	1.07	1.42	63
64	.123	.192	.261	.364	.536	.708	.879	1.05	1.40	64
65	.122	.189	.257	.358	.528	.697	.866	1.04	1.37	65
66	.120	.187	.253	.353	.520	.687	.853	1.02	1.35	66
67	.119	.184	.250	.348	.513	.677	.841	1.01	1.33	67
68	.117	.182	.246	.344	.505	.667	.829	.991	1.31	68
69	.116	.179	.243	.339	.498	.658	.817	.977	1.30	69
70	.114	.177	.240	.334	.491	.649	.806	.963	1.28	70
	3	5	7	10	15	20	25	30	40	

Time, in seconds	VELOCITY, IN FEET PER SECOND									Time, in seconds
	Revolutions									
	50	60	80	100	150	200	250	300	350	
40	2.77	3.31	4.41	5.51	8.24	10.98	13.72	16.45	19.19	40
41	2.70	3.23	4.30	5.37	8.04	10.71	13.38	16.05	18.72	41
42	2.64	3.16	4.20	5.24	7.85	10.46	13.07	15.67	18.28	42
43	2.58	3.09	4.10	5.12	7.67	10.22	12.76	15.31	17.86	43
44	2.52	3.02	4.01	5.01	7.50	9.98	12.47	14.96	17.45	44
45	2.46	2.95	3.92	4.90	7.33	9.76	12.20	14.63	17.06	45
46	2.41	2.89	3.84	4.79	7.17	9.55	11.93	14.31	16.69	46
47	2.36	2.83	3.76	4.69	7.02	9.35	11.68	14.01	16.34	47
48	2.31	2.77	3.68	4.59	6.87	9.15	11.44	13.72	16.00	48
49	2.26	2.71	3.61	4.50	6.73	8.97	11.20	13.44	15.67	49
50	2.22	2.66	3.53	4.41	6.60	8.79	10.98	13.17	15.36	50
51	2.18	2.61	3.47	4.32	6.47	8.62	10.77	12.91	15.06	51
52	2.14	2.56	3.40	4.24	6.35	8.45	10.56	12.66	14.77	52
53	2.10	2.51	3.34	4.16	6.23	8.29	10.36	12.43	14.49	53
54	2.06	2.46	3.27	4.09	6.11	8.14	10.17	12.20	14.22	54
55	2.02	2.42	3.22	4.01	6.00	7.99	9.98	11.98	13.97	55
56	1.98	2.38	3.16	3.94	5.90	7.85	9.81	11.76	13.72	56
57	1.95	2.34	3.10	3.87	5.79	7.71	9.64	11.56	13.48	57
58	1.92	2.30	3.05	3.81	5.69	7.58	9.47	11.36	13.25	58
59	1.88	2.26	3.00	3.74	5.60	7.45	9.31	11.17	13.02	59
60	1.85	2.22	2.95	3.68	5.51	7.33	9.15	10.98	12.81	60
61	1.82	2.18	2.90	3.62	5.42	7.21	9.01	10.80	12.60	61
62	1.79	2.15	2.86	3.56	5.33	7.09	8.86	10.63	12.39	62
63	1.77	2.12	2.81	3.51	5.24	6.98	8.72	10.46	12.20	63
64	1.74	2.08	2.77	3.45	5.16	6.87	8.58	10.30	12.01	64
65	1.71	2.05	2.73	3.40	5.08	6.77	8.45	10.14	11.82	65
66	1.69	2.02	2.68	3.35	5.01	6.67	8.33	9.98	11.64	66
67	1.66	1.99	2.64	3.30	4.93	6.57	8.20	9.84	11.47	67
68	1.64	1.96	2.61	3.25	4.86	6.47	8.08	9.69	11.30	68
69	1.61	1.93	2.57	3.20	4.79	6.38	7.96	9.55	11.14	69
70	1.59	1.91	2.53	3.16	4.72	6.29	7.85	9.42	10.98	70
	50	60	80	100	150	200	250	300	350	

TYPICAL RATING TABLE FOR CURRENT METER.

recorder was put into operation. Since their introduction water-stage recorders have been installed in increasing numbers until now they are used at most gaging stations. Nonrecording gages are still in general use, however, as auxiliary gages at water-stage recorder installations to serve as checks to indicate whether the pipes are clogged which lead from the river to the stilling wells over which the water-stage recorders are installed. In fact, two nonrecording gages are generally used at all such installations, one outside the stilling well to indicate the height of the river, the other to indicate the height of the water within the stilling well. Chain gages and inclined staff gages are not suitable for use within a stilling well. The types of gages most commonly used in such wells are graduated enameled scales attached to the inner walls of the wells, hook gages, float gages, and electric tape gages.

VERTICAL-STAFF GAGE

The staff gage most commonly used by the Survey is the vertical staff gage, which faced with a consecutive series of porcelain-enameled iron sections 4 inches wide and 3.39 feet long, graduated every 0.02 foot, each graduation being identified by figures representing the corresponding altitude. (See pl. 23, *A*.) A vertical-staff gage attached to a concrete gage well for use as an outside reference gage at the gaging station on the Congaree River at Columbia, S. C., is shown in plate 23, *B*.

CHAIN GAGE

The measuring scale of the chain gage generally consists of three enamel gage sections of the type described above, totalling 10 feet in length, extending horizontally from a specially designed box. (See pl. 24, *A*.) Attached to the inside of the box is a pulley over which runs a heavy sash chain carrying at one end a weight and near the other end a marker as indicated by the letter *M* in plate 24, *A*.

Below the pulley is a hole through which the weight may pass. As the weight is lowered to the surface of the water, the chain passes over the pulley with the free end extending along the gage sections. The gage box and scale are arranged in such a manner that when the weight contacts the surface of the water the gage height can be determined by reading the scale at the position of a marker consisting of a filed groove on a copper rivet located near the free end of the chain. If the range in stage is greater than 10 feet, additional markers are placed on the chain at 10-foot intervals, the arrangement being such that when the first marker (nearest the end of the chain) is used, direct readings may be made on the scale, and when the second and third markers are used, 10 and 20 feet, respectively, are added to the readings. The chain most commonly used is a sherardized-steel sash chain which should be thoroughly stretched or preworn before being installed. The gage weight is a 1½-inch steel bar slightly more than a foot long and painted or galvanized to prevent rusting. The lower end is squarely cut and the upper end is tapered and centrally drilled to a depth of about 2 inches. Five cotter-pin holes are drilled at the reduced end at right angles to the axis to permit connecting the chain to the weight. The cotter-pin holes are spaced ⅛ inch apart to allow for adjustments in the distance from the bottom of the weight to the first marker on the chain. Further details concerning construction of the chain-gage box and its installation are given in Water-Supply Paper 371.[65]

INCLINED STAFF GAGE

The design and construction of the inclined gage varies with the conditions attending each individual installation; therefore, it is impossible to standardize any part of this gage except the numerals used to designate the foot marks. Numerals for this purpose should be cast of a nonrusting material and should be drilled so as to permit the use of brass screws in fastening them to the gage backing. Heavy timber, securely attached to permanent foundations, should be used for the gage backing. Copper barrelhoop staples have been found satisfactory for identifying the intermediate markings at and between the numerals. Details concerning installation and construction of inclined-staff gages are contained in Water-Supply Paper 371.[66]

HOOK GAGE

The hook gage most commonly used by the Survey consists of a movable staff graduated in feet and placed so that the graduations read downward from the top to the bottom of the staff. (See pl. 24, *B*.) The staff has a steel hook at the bottom and is arranged to slide against a 1-foot level-rod scale which is screwed to a base. The scale is graduated to hundredths of a foot, from zero upward. The height of the water surface is determined by drawing the point of the hook to the surface of the water and, with the staff in that position, observing the foot mark on the movable staff and the fractional part of a foot on the fixed scale which is in juxtaposition therewith. The steel hook should be either plated or made of stainless steel to prevent rust and corrosion.

FLOAT GAGE

The float gage is used chiefly as an inside reference gage for a waterstage recorder and consists of a float attached to a counterweight

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[65] Lyon, G. J., Equipment for current-meter gaging stations: U. S. Geol. Survey Water Supply Paper 371, pp. 9–11, 1915.

[66] Idem, pp. 11–13.

by means of a stainless steel tape. (See pl. 25, *A*.) This tape is graduated to read in feet, tenths, and hundredths of a foot, and passes over a suitable float pulley. The float pulley assembly consists of a wheel, usually 6 inches in diameter, mounted in a standard. The front part of the base of the standard is flanged upward, and the top edge of the flange is used as a reference point. An arm extends forward from one of the trunnions to a point slightly beyond the tape to carry an adjustable index. Either the reference point or the adjustable index may be selected for indicating the gage height on the graduated tape. The tape is connected to the float by means of a clamp which also may be used for making adjustments too large to be accommodated by the adjustable index. Various assemblies are used, depending on the range in stage and the height of the float pulley above the water surface. For heights which may be accommodated with a 25-foot tape, a float 10 inches in diameter and a 2-pound counterweight will usually suffice. The same-size float and counterweight may also be used if a 50-foot tape is required, although for high precision a float 16 inches in diameter and a 3-pound counterweight are recommended. If the heights require a 75- or 100-foot tape, a float at least 16 inches in diameter should be used and if highly accurate results are to be obtained with those lenghts of tape, a 20-inch float and a 4-pound counterweight would be preferable if the space in the stilling well is adequate.

ELECTRIC TAPE GAGE

The electric tape gage, like the float gage, is used almost exclusively as an inside reference gage for water-stage recorders. It offers two advantages over float gages; it can be used in a stilling well which is too small to accommodate two floats, and the possibility of errors caused by leaky floats or by the passage of the float line from one side to the other of the float pulley is eliminated. This type of gage consists of a stainless steel tape, graduated in feet, tenths, and hundredths, to which is fastened a cylindrical weight, a reel for the tape, a source of electric current, and an electric indicating device. All of these parts are supported by an insulated bracket. The electric tape gage developed by the Geological Survey (see pl. 25, *B*) has capacity for tapes in lengths of 25, 50, and 100 feet. The electric indicating device consists of a light sensitive volt meter. The source of electric current commonly used is supplied by a 4½-volt dry-cell battery, one terminal of which is attached to a ground connection, the other to one terminal of the volt meter. The other terminal of the volt meter is connected through the frame, reel, and tape to the weight. The reel is provided with a ratchet arrangement to hold the weight at any desired height. The weight is drilled in the upper end to permit the insertion of two loose-fitting half-round bars used in connecting the tape to the weight. Adjustments for the over-all length are made by varying the amount of tape included between the half-round bars. With the gage properly set to correct datum, the weight is lowered until it contacts the water surface, which completes the electric circuit and produces a deflection in the needle of the voltmeter. With the weight held in the position of contact, the tape reading is observed at the index provided on the reel mounting. In order to prevent errors in the readings because of water collecting on the bottom of the weight, the contact surface of the weight is reduced to six conical points.

CANFIELD WIRE-WEIGHT GAGE

The Canfield wire-weight gage, designed by G. H. Canfield, district engineer, and later improved by other engineers of the Survey, consists of a cadmium-plated metal gage box containing the following assembly: a reel on which is wound a small stainless-steel cable attached to a flat-bottomed cylindrical weight made of noncorrodible material, a 1-foot graduated gage plate made of brass, and a compartment for holding the gage-height book. Brass lugs are attached to the cable at 1-foot intervals, each lug having the foot numerals stamped on two sides. The reel is equipped with a friction brake so that the weight can be held at any desired position. The gage plate, which is graduated in hundredths of a foot and reads from the bottom upward, is placed vertically behind the cable. The gage is set so that when the bottom of the weight contacts the water surface, the gage height in feet will be indicated by the numerals on the cable lug, which is opposite the graduated scale, and the fractional part of a foot of the gage height will be read on the scale at the position of the scale lug. The weight is drawn up into the box after the reading is obtained, and the hole provided for its passage is closed by a pivoted disk. For a description of the methods used in setting and adjusting a Canfield wire-weight gage see p. 218. A Canfield wire-weight gage installed at the gaging station on Locust Creek near Linneus, Mo., is shown in plate 26, *A*.

TYPE-A WIRE-WEIGHT GAGE

The type-A wire-weight gage consists of a drum wound with a single layer of cable, a weight attached to the end of the cable, a graduated disk, and a Veeder counter properly mounted in a cast-metal box. The disk is graduated in tenths and hundredths of a foot and is permanently connected to the Veeder counter and to the shaft of the drum. The cable is made of 0.045-inch stainless-steel wire, geometrically wound, and is guided to its position on the drum by means of a threading sheave. The reel is equipped with a pawl and ratchet for holding the weight at any desired elevation. The diameter of the drum of the reel is such that each complete turn represents a 1-foot movement of the weight. The drum is fastened to the shaft by a friction clamp which, when loosened, allows the turning of the shaft independently of the drum and permits adjustment of the gage to correct datum. For convenience, a horizontal checking bar is mounted at the lower edge of the instrument in such a manner that when it is moved to the forward position the bottom of the weight will rest on it. The gage is set so that when the bottom of the weight is at the water surface, the gage height will be indicated by the combined readings of the Veeder counter and the graduated disk. Plate 2, *A*, shows a type-A wire-weight gage installed on a bridge at the gaging station on Saluda River at Chappels, S. C. The method used in setting and adjusting the type-A wire-weight gage is described on page 217.

SOUNDING EQUIPMENT

The ordinary method of measuring the flow of a stream consists largely of (1) making a measurement of depth, commonly called a sounding, (2) placing the current meter at 0.8 of the depth and measuring the velocity, and (3) placing the current meter at 0.2 of the depth and making another measurement of velocity. This procedure is repeated at 20 or more points as the engineer advances from one bank of the stream to the other. Because the sounding and velocity observations are usually made alternately, and because stream-flow measurements can be made more quickly in that order, current meters are combined with sounding equipment in the apparatus used for such work. In measurements of shallow streams the current meter is mounted on a rod which is graduated in feet and tenths for the dual purpose of measuring the depth and conveniently placing the meter at the proper point for the measurement of velocity. Cable suspension is used in measurements of streams that are too deep for wading. The meter and sounding weight are suspended either by a hand line, which consists partly of a two-conductor rubber-covered cable and partly of a flexible steel cable about 0.1 inch in diameter, or by a crane and reel, on which a similar small flexible steel cable is used. A weight suspended below the meter is used for making the soundings. It also serves to hold the meter against the drag of the current while velocity measurements are made. The measurements of depth with this type of suspension may be made in several ways, such as by measuring with a metallic tape or a graduated stick the length of cable paid out as the meter is lowered from the surface of the water to the bed of the stream by the tag-line method, or by reading a depth indicator attached to the reel on which the suspension cable is wound. The design and construction of the equipment used in the various methods of current-meter suspension are described in the following paragraphs.

WADING RODS

The type of wading rod most commonly used by the Geological Survey is made of sections of round nickel-plated brass tubing, each section 1 foot long and one-half inch in outer diameter. (See pl. 26, *B*.) All sections contain a threaded stud screwed into the upper end and are internally threaded at the lower end with the exception that the base end of the bottom section is externally threaded so as to screw into a socket in a small rectangular base plate. The arrangement provides a flush-jointed coupling when the sections are screwed together. A device called a pole end may be screwed onto the upper end of the rod assembly for convenience in making electrical connections. Each rod has graduations which identify the foot, half-foot, and tenth-foot points. The tenth-foot graduations consist of single circumferential grooves, and the half-foot and foot graduations consist of double and quadruple grooves, respectively.

Some engineers prefer a flat rod instead of the round rods described above, and several different designs of flat rods have been made for use where the means of transportation does not require the compactness provided by the sectional round rods. Several designs of flat rods are shown in plate 26, *B*.

Sliding support.—The sliding support used with the type-A small-Price current meter on the flush-jointed round rod assembly consists of a one-piece nickel-plated bronze casting drilled vertically to accommodate the rod. The sliding support is inserted between the yoke and the tailpiece of the current meter and is held on the rod at the desired position by a brass screw which impinges against the rod. Most of the sliding supports now in use are constructed so that the distance from the top of the support to the center line of the meter is exactly 0.1 foot. This feature aids in the accurate setting of the current meter, as the body of the sliding support under some conditions obscures the graduations of the rod in the vicinity of the center-line of the meter. In placing the meter in the correct position on the wading rod the top of the sliding support is placed 0.1 foot above the position desired for the center line of the meter.

METER CABLES

Meter cables commonly used for the suspension of current meters and weights are generally two-conductor cables. The two-conductor cables may be of three types (1) those suitable for use as the upper portion of a hand line, (2) those suitable for use as the lower portion of a hand line, and (3) those suitable for use on reel-and-crane assemblies. The various types of meter cables in general use by the Geological Survey are described in the four paragraphs that follow.

Hand cable.—The hand cable, which is that portion of cable in a hand line normally used above the surface of the water, consists of ordinary No. 16 heavy-duty two-conductor electric cable. The breaking strength of this type of cable is between 300 and 400 pounds.

Direct-lay cable.—The direct-lay cable is constructed in two sizes having 0.09- or 0.11-inch diameters. The 0.09-inch-diameter cable is composed of six strands of seven steel wires each, which surround an insulated copper core consisting of twelve enameled No. 36 copper wires wrapped with several layers of cotton saturated with a moisture-resisting compound. The 0.11-inch-diameter cable is of the same construction except that the diameters of the individual wires are larger and the core has additional wrappings of saturated cotton. The breaking strength of the 0.09-inch direct-lay cable is from 400 to 600 pounds, and the breaking strength of the 0.11-inch direct-lay cable is from 600 to 1,000 pounds. The direct-lay cable is generally given preference over the reverse-lay cable for use on hand lines because its exterior is somewhat rougher. This roughness is an asset when the current meter and weight must be lifted by this bare wire hand over hand to the rail of a bridge or cable car.

Reverse-lay cable.—The reverse-lay cable is made in 0.10-inch and 0.125-inch diameters. The 0.10-inch-diameter cable is composed of 33 galvanized wires, of which the inner 15 are wrapped in one direction about an insulated core and the outer 18 are wrapped in the reverse direction. The insulated core consists of 6 No. 36 copper conductor wires and No. 36 stainless-steel wires, bunched together and wrapped in five or more layers of wax-saturated cotton. The 0.125-inch reverse-lay cable also consists of 33 similarly wrapped galvanized wires, but the wires are slightly larger than those in the 0.10-inch cable.

The insulated inner core is the same as for the 0.10-inch cable except that it contains sufficient additional wraps of saturated cotton to build up the diameter of the conductor core from 0.050 inch to 0.065 inch. The breaking strength of the 0.10-inch reverse-lay cable is from 800 to 1,000 pounds, and the breaking strength of the 0.125-inch cable is about 1,500 pounds.

Wrapping the two layers of wires in reverse directions reduces the amount of twisting which ordinarily occurs when current meters and weights are suspended from such cables. Owing to its smooth outer surface, the reverse-lay cable is better adapted for use with reels than with hand lines. Furthermore, its greater strength is sometimes demanded on crane-and-reel assemblies, whereas great strength in cables is not as essential for use on hand lines.

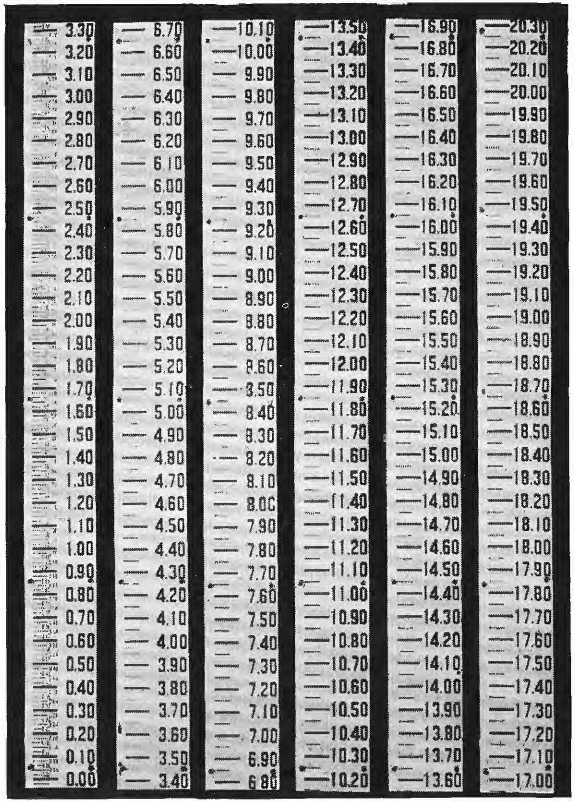
Single-conductor cable.—Galvanized airplane strand, which is commercially available, is commonly used where a single-conductor cable is desired. The most popular sizes are those having diameters of $\frac{1}{16}$ inch and $\frac{3}{32}$ inch.

HAND REELS

Two designs of hand reels, one known as the Lee-Au reel and the other as the Morgan reel, are extensively used to hold the steel cable of a hand-line assembly and to facilitate its electrical and physical connection to the rubber-covered cable used as the upper part of the hand-line. (See pl. 27, *A*.)

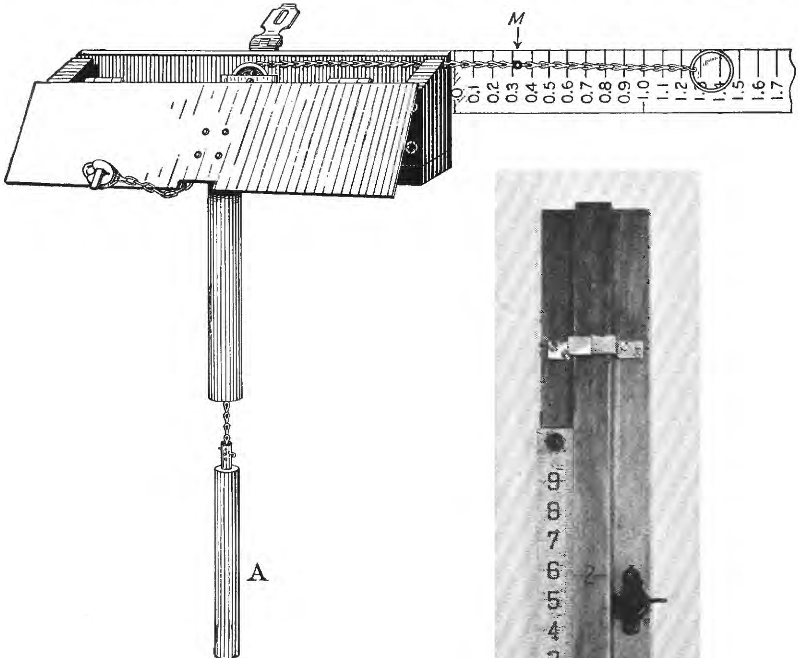
Lee-Au hand reel.—The Lee-Au hand reel is a one-piece oval-shaped aluminum casting constructed in such a manner as to provide sufficient capacity to carry about 50 feet of 0.09-inch direct-lay cable. Both ends of the casting arch over the drum and contain vertical holes for passage of the rubber-covered and steel cables. The lower end, through which the steel cable passes, is notched to permit the cable to be conveniently adjusted for length. In attaching the cables, the rubber cable is first passed through the hole in the upper arch and then laced through the three large holes provided for that purpose in the flat face of the casting. This cable terminates in the hollow center of the opposite side. The steel cable starts from the outer surface of the drum and is laced through the three small holes drilled in the drum, beginning with the hole nearest the upper end. This permits the end of the cable to be placed in the hollow center where it is passed through the loop formed by traversing through the first two holes. It is then electrically connected to the upper portion by means of small binding posts.

Morgan reel.—The Morgan reel consists essentially of two stainless-steel bars about 10 inches in overall length, $\frac{3}{4}$ inch in width, and $\frac{1}{8}$ inch in thickness, separated by spacers placed a short distance from each end through which bolts pass to hold the assembly together. This assembly serves as a reel which has a capacity of about 30 feet of 0.09-inch cable. Both ends of one bar are bent at right angles to form an elongated Z. The upper end of this bar is drilled to permit the rubber-covered cable to pass through it, and the lower end is slotted for the steel cable. The reel, when completely assembled, hangs in a vertical position. In attaching the cables, the rubber-covered hand cable is first passed through the upper hole, then laced through three large holes that are centrally located in the Z-shaped bar. The end of this cable terminates within the reel. The steel cable is looped around one of the spacers. The ends of the loop are held with a cable clip, and the loose end is electrically connected to the rubber-covered cable. The remaining part of the steel cable is wound on the two spacers described above. When in use, the steel cable

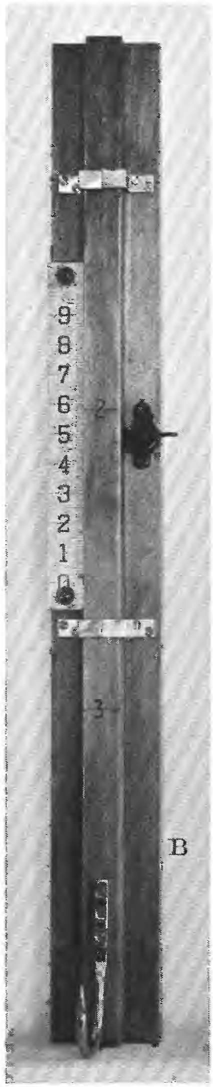


A. GRADUATED SECTIONS FOR VERTICAL-STAFF GAGES.

B. VERTICAL-STAFF GAGE ON CONCRETE GAGE WELL.

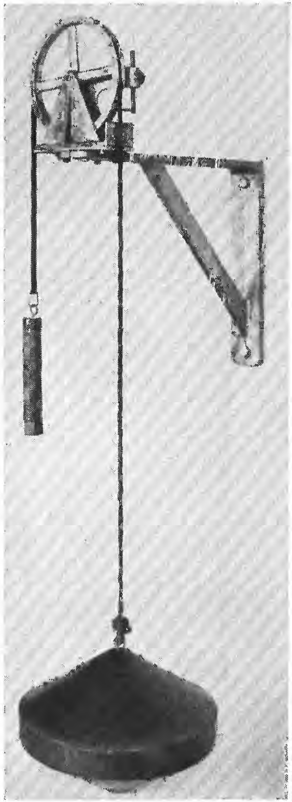


A



B

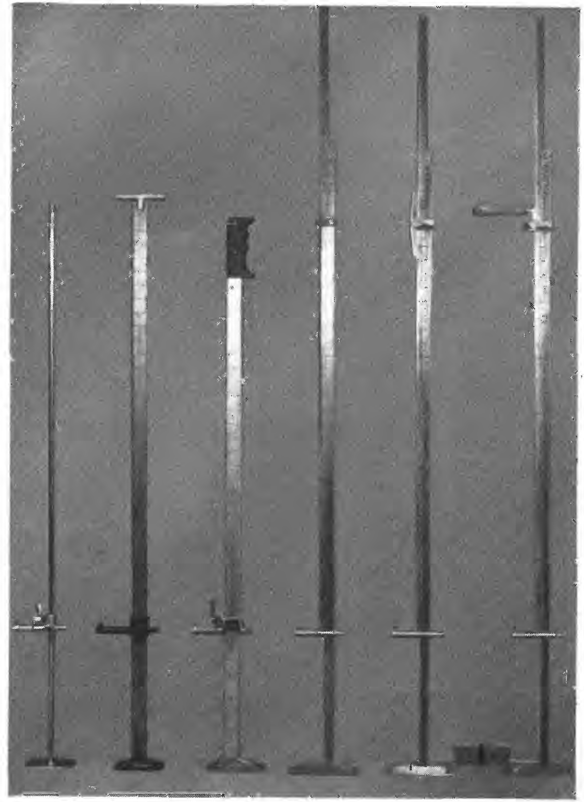
A, CHAIN GAGE; *B*, HOOK GAGE.



A. FLOAT GAGE.

B. ELECTRIC TAPE GAGE.

A. CANFIELD WIRE-WEIGHT GAGE.



B. FLAT WADING RODS.

may be unwound to any desired amount within the capacity of the reel and held from further unwinding by engaging the cable in the slot in the lower end of the Z-shaped bar.

CONNECTORS

A connector is used to join the lower end of the current-meter cable to the meter hanger. Various types of connectors used by the Geological Survey are illustrated in plate 27, *B*. Practically all the connectors illustrated therein have provisions for insulating the connector from the hangar. Such insulation is necessary if a single-conductor electrical circuit is used. One type of connector is attached to the cable by lacing the cable back and forth through a series of holes, with the end of the cable slipped underneath one of the loops thus formed. All the other types depend to a large extent on pressure and friction for keeping the cable from slipping through them. They differ, however, in the details of construction. Two of them have projecting knobs around which the cable is threaded before a pressure plate (having holes just large enough to accommodate the knobs) is forced tightly against the cable by means of screws. A third contains a spiral groove into which the cable is laid prior to the tightening of the pressure plate. The remaining two types are merely clevises containing a grooved wheel around which the cable is looped and clamped by means of cable clips.

WEIGHTS

The word "streamline" and the latest concepts related thereto were unknown at the time when current-meter measurements were first made. The earlier types of weights were shaped like a flatiron and were used with the pointed end upstream. Later experience indicated that the accuracy of a discharge measurement might be affected by the shape of the weight, its position with respect to the meter, the amount it permitted the meter to move downstream or to the side, and the rapidity with which it brought the meter to a steady position in the current. This experience led to the design of a torpedo-shaped weight which was cast of lead, pointed at the nose, and equipped with tail vanes as an aid in directing the meter into the current. Although the torpedo-shaped weight performed more satisfactorily than the flatiron-shaped weights, it did not maintain a stable position in swift water. Also, it had a tendency to affect the meter rating when placed in different positions with respect to the meter. This type of weight, ranging in size from 5 to 75 pounds, was used until 1926, when the so-called elliptical-type weight was introduced. The elliptical-type weight differed from the torpedo-type weight in that its overall length was less, it had a larger diameter, was ellipsoidal at the nose, and carried larger tail vanes. Further revision of the design of weights was made in 1934, when the designs for the Columbus-type weights, commonly called C-type, were completed. C-type weights in sizes of 15, 30, 50, 75, 100, and 150 pounds are shown in plate 28, *A*. Weights of this type were found to be superior to the other types, as they maintained a steadier position in water flowing at high velocities and adjusted themselves in position more quickly; they offered less resistance to flowing water, and had less effect upon the meter rating than any previous type of weight.

The C-type weights differ from the elliptical-type weight in that they are longer and of smaller diameter. They are made in sizes of 15, 30, 50, 75, 100, 150, 200, 300, and 500 pounds. The nose of each weight extends beyond the cups of the meter and hence affords protection against injury to the cups. The 15-pound weight is a one-piece casting of gun-metal bronze. All the other sizes are cast of antimonial lead and contain removable aluminum-alloy tail vanes attached to structural aluminum angles that are cast into the weight. This construction permits the removal of the vanes for straightening or replacement. The shape of the slot for the hanger permits the hanger to tip forward 15° and backward 5° from the vertical. This limitation in the angles prevents the weight and current meter from striking each other, thus avoiding possible damage to the meter. As the specific gravity of the tail vanes is different from that of other parts of the weight, a weight which balances horizontally in air will not balance horizontally in water. It is, therefore, necessary and desirable that the weight be balanced under water, the element in which it is used, regardless of the position it assumes when suspended in air.

HANGERS FOR SUSPENDING WEIGHT AND METER

With the introduction of the C-type weights, a new design of hanger was necessary. This design is known as the Columbus or C-type hanger and is used with C-type weights ranging from 15 to 150 pounds. It contains a hole threaded for a 3/8-inch weight pin at the weight end and a smooth 3/8-inch hole at the opposite end. Three holes, 7/32-inch in diameter, are at 4.9, 5.3, and 9.8 inches above the hole for the weight. The lower two of these three holes are used for supporting the meter so that its horizontal axis is 0.5 foot from the bottom of the 15-pound and 30-pound C-type weights; the lower of the two is for use with the 30-pound, and the upper, with the 15-pound weight. The third hole is located so that the distance from the horizontal axis of the meter to the bottom of the 50-pound weight is approximately 0.9 foot and to the bottom of the 75-, 100-, and 150-pound weights is 1.0 foot. The meter-suspension holes are spaced for use with the 622-type and type-A current meters. If the 623-type meter is used with the 15-pound C-type weight, it should be suspended from the hole marked "30." This is necessary because the suspension hole in the yoke of the 623-type current meter is approximately 0.4 inch lower than it is in the 622-type and type-A meters.

A combination-type hanger previously designed for use with all elliptical weights may also be used with the 50-, 75-, 100-, or 150-pound C-type weights if the upper suspension hole is used for the current meter. This hanger has two holes for weight pins, one for the 5/16-inch weight pins used for certain elliptical weights, the other for the 3/8-inch weight pin for C-type weights. The combination-type hanger also has three 7/32-inch holes for supporting the current meter. The lower two of these are for supporting the current meter 0.5 and 0.7 foot above the bottoms of 15- and 30-pound elliptical-type weights, respectively. The upper of the three holes is for suspending the current meter 0.9 foot above the bottom of 50-pound C-type and 50-pound elliptical-type weights. This hole is also used for suspending the current meter above 75-, 100-, or 150-pound weights and when so used, the meter is 1 foot above the bottom of the weights.

Meter hangers and weight pins, together with various other items of equipment, are shown in plate 28.

CRANES AND REELS

The use of heavy weights for holding current meters in position in the current of a stream and for making accurate soundings of deep swift rivers makes necessary the use of cranes and reels for their handling. It has been found that specially designed power-driven cranes are necessary at some stream-gaging stations. A notable example is in use at the gaging station on the Mississippi River at Vicksburg, Miss., where the crane is mounted on a 1½-ton automobile-truck chassis. This crane has a 13-foot boom which reaches from the vehicular thoroughfare of the bridge to a point beyond interfering bridge members. Power furnished by the truck's motor raises and lowers the current meter and weight. At times of high water a 300-pound weight is used at this station. Somewhat similar equipment shown in plate 5, *A*, is used at the gaging station on the Mississippi River at Memphis, Tenn. In general, however, the cranes used in the operation of current meters and weights are manually operated and are simpler in design.

Two sizes of cranes and four types of reels have been developed by the Geological Survey for use in making discharge measurements from bridges in addition to the power-driven cranes described above. The two sizes of cranes are designated type-A and type-D cranes, and the four types of reels which, with one exception, may be interchanged on either type of crane are designated types A, B, D, and E.

The exception is the type-D reel, which is too large to fit on the type-A crane.

The essentials for a satisfactory crane are that it shall be of adequate strength and of such design that it may be used conveniently on most bridges; also that it may be quickly assembled, conveniently dismantled and packed for transportation in passenger automobiles or light trucks, and handled manually without excessive labor on the part of the operator.

Reels are mounted on the cranes for use in lowering and raising the current meter and weight. Each reel is furnished with a depth indicator that indicates the length of cable paid out in making soundings and in placing the current meter at the proper positions for observations of velocity. The reels must be accurate, of adequate strength, compact, and light. They should have sufficient capacity to hold the length of meter cable which may be required at any gaging station in the region where the reel is to be used.

Reels are designed so as to be easily removed from the cranes and mounted on cable cars, boat booms, or devices which may be used in making measurements of the flow of streams under ice cover.

Owing to the interchangeability of the various types of reels on cranes and other types of equipment, the details regarding cranes and reels are discussed separately in the paragraphs that follow.

TYPE-A AND TYPE-D CRANES

The type-A and type-D cranes are similar in that they are mounted on wheels, have identical mounting plates for the reels, and have projectable booms which may be extended over or retrieved back of the railing of a bridge. At the outer end of the booms of both types of cranes is an angle-indicating device that shows the angle from the vertical assumed by the meter cable because of its being dragged downstream by the current. By the aid of this device corrections may be made to sounding observations and to the positioning of the current meter. Both types of cranes can be folded compactly for convenience in transportation.

The two types of cranes differ in that the type-D crane (see pl. 29, *A*) is slightly larger than the type-A; it is also heavier and of more rigid construction. It is intended for use with weights up to 200 pounds, whereas the type-A crane is intended for weights of 150 pounds and less. A further difference is that the type-D crane is always used with a four-wheel truck, whereas such a truck is used on the type-A crane only when 75-, 100-, and 150-pound weights are required. If weights of 50 pounds or less are used, the type-A crane with its usual three wheels is preferred. The position of the three wheels is such as to form an isosceles triangle with two wheels close to the bridge rail and parallel to it. When the boom of the crane is extended over the bridge rail the third wheel, which is on the opposite side of the crane from the bridge rail, is raised. The two wheels parallel to the rail then carry most of the load, but the rail itself provides the third point of support. A type-A crane and type-A reel in use at the gaging station on the Rillito Creek near Tucson, Ariz., are shown in plate 4, *A*. If a four-wheel truck is used with either a type-A or type-D crane, the bridge rail is not used as a point of support, as a toggle arrangement connecting the truck and the upright members eliminates any necessity for it.

Both the type-A and type-D cranes are designed to withstand any loads up to the full breaking strength (1,500 pounds) of the heaviest two-conductor cables commonly used on the reels.

TYPES A, B, D, AND E REELS

The types A, B, D, and E reels are similar in that each reel is fitted with a depth indicator, a threading sheave for laying the cable smoothly in a single layer on the drum, electrical connections for two-conductor cables, and a pawl and ratchet which can be used to hold the current meter and weight at any desired elevation. Furthermore, all the reels are made largely of aluminum parts for lightness and are designed to operate under any loads up to the full strength of the cables ordinarily used. All these reels have the same spacing of anchor studs so that they are, with one exception, completely interchangeable. That exception, which has been referred to previously, is caused by the lack of available space between the vertical members of the type-A crane to accommodate the large type-D reel. (See pls. 29, *B*; 30; and 31, *A*.)

The type-A reel, which is the smallest of the four, has a fixed crank and no brake, whereas the other three are fitted with brakes and quick-releasing cranks. When using any one of the three larger reels, the operator usually allows the weight to be lowered by the force of gravity and controls its movement by application of the brake, the crank being disengaged while the lowering progresses. Reverse-lay cable is recommended for use with all the reels.

Major differences in the design of the different reels are indicated in table 10.

The selection of the type of reel for use in a given region should be based largely upon the maximum length of cable that would be required. This length would be equivalent to the distance from the bridge railing of the highest bridge at which measurements are expected to be made to the lowest point in the stream bed, plus about 6 feet for threading over the sheaves of the crane and an allowance for the downstream drag of the cable. If weights as heavy as 200 pounds are to be used frequently, and two men are available for operating the equipment, the type-D reel with 0.125-inch cable, a jack shaft, and with cranks at both ends of the reel would best meet the requirements.

TABLE 10.—*Types of reels used in sounding*

Reel	Cable		Effective circumference of drum (feet)	Type of brake	Depth indicator	Remarks
	Length (feet)	Diameter (inch)				
Type-A	80	0.10	1.0	None	Similar to Veeder-type counter.	One 8-inch crank attached at right side of reel; keyed rigidly to shaft when in operation.
Type-B	125	.10	1.5	Prony type	Dial type	Two cranks 9 and 12 inches in length interchangeable, at right side of reel.
Type-D	175 200	.125 .10	2.5	do	do	Two 12-inch cranks, one for right and one for left side of reel, for 2-man operation. A special jack shaft with reducing gears is provided as an aid in raising heavy weights.
Type-E	175	.10	2.0	do	do	Two 12-inch cranks, one for right and one for left side of reel for 2-man operation if desired.

SOUNDING PROTRACTOR

A sounding protractor which has been extensively used for measuring vertical angles (see p. 45) consists of a protractor circle, a pendulum, a pointer, a protractor scale, an arm, and a bar. When these parts are assembled, they form two units that hang freely from the shaft of the sheave at the outer end of the boom. One of the units consists of the pendulum and the pointer. The position assumed by the pointer is determined by the action of gravity. The other, a U-shaped unit to which the protractor scale is attached, is suspended in such a manner that when the sounding cable hangs vertically, the pointer is opposite the 0-degree mark on the protractor scale, but when the sounding cable is inclined downstream by the action of the flowing water, the cable bears against the lower bar of the U-shaped unit, causing the unit to turn through an angle equivalent to that made by the sounding cable as it deviates from the vertical. This angle may be read opposite the pointer, on the protractor scale. A sounding protractor of this type, mounted on a type-A crane for use in bridge measurements, is shown in plate 4, *A*.

Another type of protractor, which is triangular, is used on the type-B gaging cars. This protractor in position on a type-B gaging car is shown in the illustration for the type-E reel (pl. 31, *A*). The upper corner of the triangle serves as the point of support. The lower side of the triangle contains the graduations. The angle from which the position of the meter cable deviates from the vertical is read at the point where the cable passes in front of the graduations on the triangle.

MISCELLANEOUS EQUIPMENT

HEADPHONES

Headphones convert into sound the electrical impulses resulting from contacts made in the contact chamber of a current meter at each revolution or at every fifth revolution of the bucket wheel. It is interesting to note that in general, as long as the current meter is immersed in water, a steady electrical current of small though measurable quantity flows through the circuit regardless of whether the contact is on "make" or "break." The impulse that occurs when the contact is made may either add to or detract from the steady current, and it is the sudden increase or decrease in current which produces sound in the headphone. One source of this steady electrical current is in the electrolytic action created by different metals that are submerged in the stream. Another source, when a battery is in the circuit, is the shunting of current around the insulation either on the binding posts of the current meter or on the cable connector. Occasionally, the current produced by the electrolytic action will exactly counteract the current of the battery, with the result that no audible sounds are produced.

It has been found that headphones having resistances of 5 to 80 ohms are more effective than headphones having high resistances if the sound-producing differential of the electrical current is very small. If the differential is large, adequate sound is produced by both low-resistant and high-resistant phones. Phones of the type shown in plate 28, *B* which have coil windings of either 5 or 80 ohms are generally used, as they meet the needs through the widest range of conditions.

GAGING CARS

Two types of gaging cars known as type-A and type-B are in general use. The type-A car permits the engineer to work from a sitting position. (See pl. 1.) It is provided with a seat at each end, has either one or two foot rests, and can be readily equipped for use with either a hand line or a reel assembly.

The type-B car is designed to permit the engineer to operate the meter equipment from a standing position. It is principally constructed of structural aluminum, although it contains a few steel parts. The floor is made of wood. It is more sturdily constructed than the type-A car and is better adapted for use with heavy sounding equipment.

A canvas shelter can be used with either type of car. A cast-aluminum gaging-car puller is a convenient means for moving the car and holding it at any desired position along the cableway. A type-B car in use at the gaging station on the Licking River at Toboso, Ohio, is shown in plate 3, *B*.

LEE-AU TAG-LINE REEL

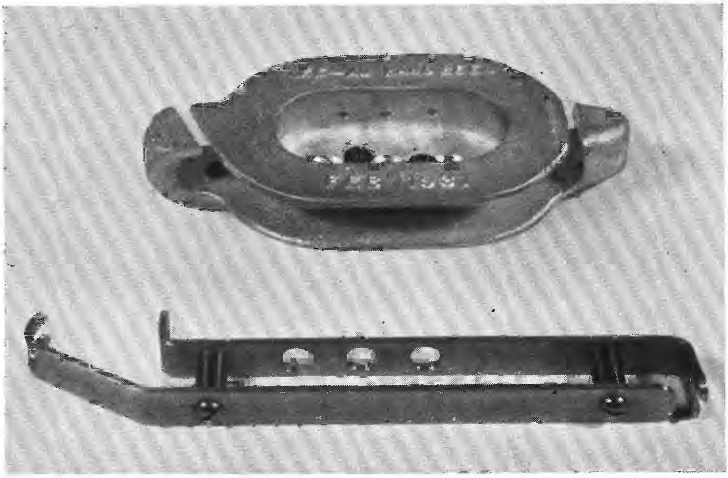
The Lee-Au tag-line reel used in measuring the distances and widths in discharge measurements is a one-piece hollow-center aluminum casting equipped with two aluminum-alloy sleeve handles, the bolts of which are screwed into a boss on the outer face of each rim diametrically opposite each other. Both rims are symmetrically perforated at regular intervals to assist in tightening and fastening the tag line. The tag lines most generally used consist of 1/32- to 3/32-inch steel airplane-strand cables marked with solder beads at 5-foot intervals. The 5-foot marking is usually designated by a single bead, the 25-foot, 50-foot, and 100-foot markings being indicated by two, three, and four beads, respectively. One end of the cable is laced through the holes drilled in the face of the drum, and knotted; the other end is equipped with a swivel snap or S link for fastening. Care must be exercised in keeping it taut, both when unwinding and rewinding, in order to avoid kinking. About 400 feet of 1/16-inch airplane-strand cable with the bead markings can be accommodated by this reel. Other reels, somewhat different in shape, are also used for the same purpose. (See pl. 31, *B*.)

VEATCH HORIZONTAL-ANGLE COEFFICIENT INDICATOR

The Veatch horizontal-angle coefficient indicator is a one-piece semicircular aluminum casting marked in coefficients directly applicable to the velocity or width observations in reducing either to their normal components. The base of the casting is drilled so that it may be bolted to the side of a cable car or to any structure from which a measurement is being made. An arm, pivoting about the center of the arc and reading unity when the current is normal, indicates the coefficient which is to be applied because of the angle of current.

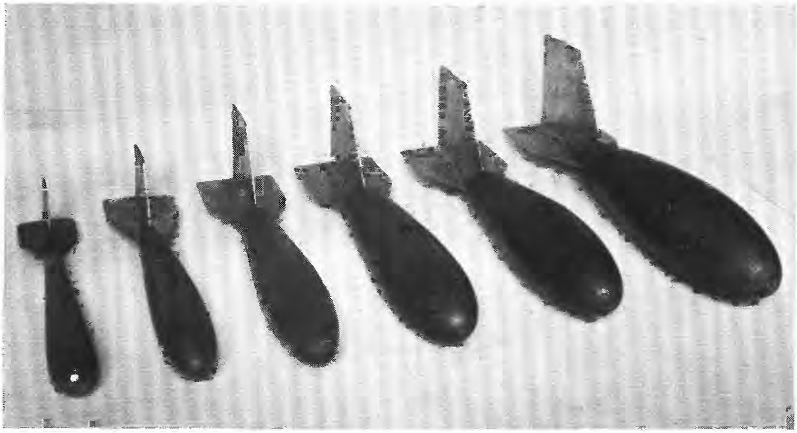
REFERENCE-MARK TABLET

The standard reference-mark tablet (pl. 32) used by the Water Resources Branch of the Geological Survey is a circular bronze casting with the center of the top slightly raised and circled. The stem of the tablet is spirally grooved to resist removal from the concrete setting. The top of the tablet contains depressed letters identifying the tablet as a gaging-station reference mark. In addition to their use in maintaining a constant datum at a gaging station (see page 211),

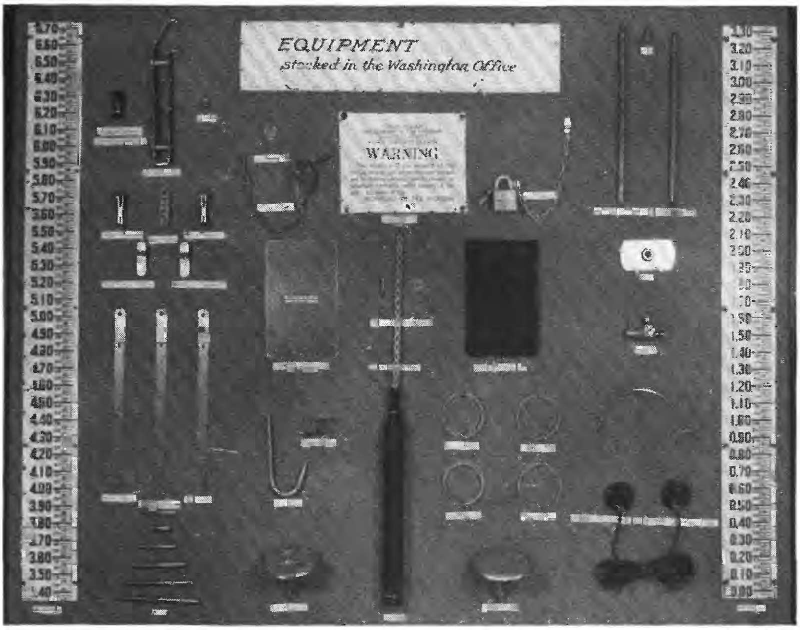


A. HAND REELS.

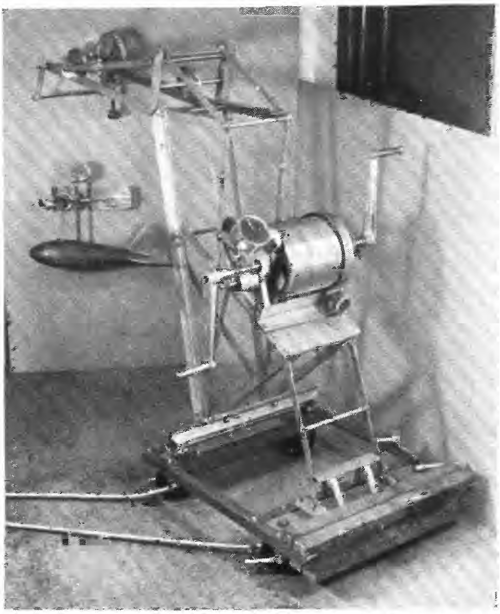
B. CONNECTORS.



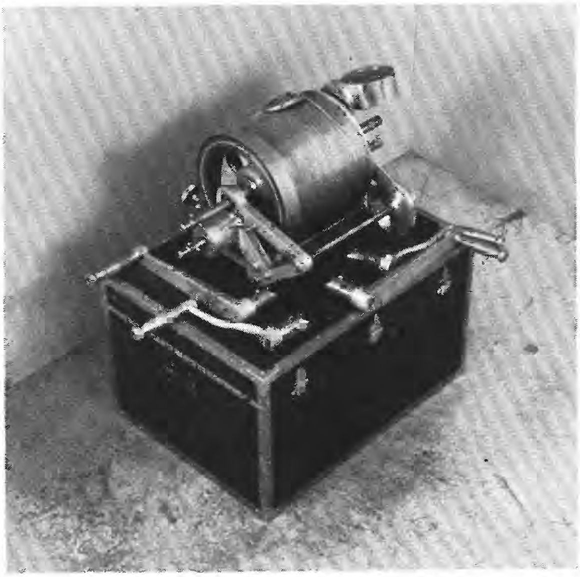
A. COLUMBUS-TYPE SOUNDING WEIGHTS.



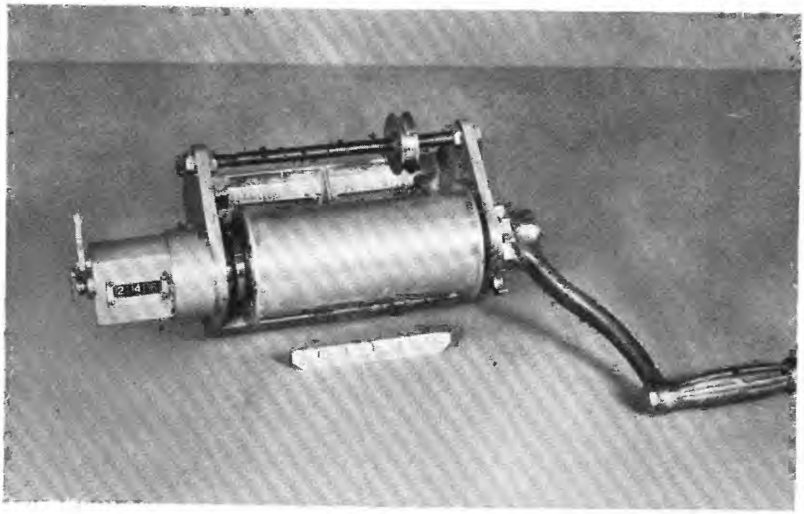
B. METER HANGERS, WEIGHT PINS, AND OTHER MISCELLANEOUS EQUIPMENT.



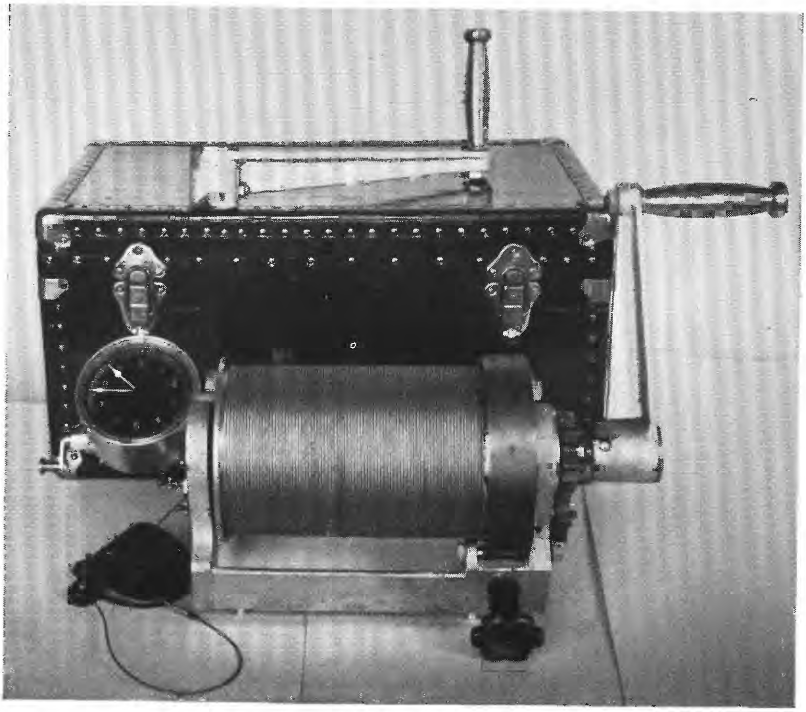
A. TYPE-D REEL MOUNTED ON TYPE-D CRANE.



B. TYPE-D REEL DISMOUNTED.



A. TYPE-A REEL.



B. TYPE-B REEL.

the sea-level elevation of these tablets is established at each gaging station wherever practicable.

LEVELING EQUIPMENT

The level generally used in stream-gaging work is the Geological Survey standard dumpy level. The telescope for this level is about 18 inches long and has a magnifying power of 26 to 30 diameters. The shortest focus obtainable from the center of the instruments is 9 feet. The tripod is of the extension-leg type, which collapses sufficiently for convenient transportation. The type of level rod most generally used is a 12-foot sectional rod, each section of which is 4 feet long. The sections are fastened together by means of a telescopic sleeve and rod extension arrangement, which automatically locks when the sections are properly joined.

TIMERS

The timer mostly used in stream-gaging work is a still-movement type stop watch in which the movement is set into motion each time the stem is depressed. It is usually a 7-jewel movement and registers accurately to a fifth of a second. It is equipped with two hands—one hand registers seconds and the other hand registers minutes up to as much as 30 minutes. The start, stop, and return mechanisms are all operated through the stem.

USE OF FIELD EQUIPMENT

The engineer should give the same care to the equipment used by him that he would give to his own personal property. All property requisitioned or purchased by the district engineer and charged to him on the Geological Survey property list is termed "nonexpendable property" and must be accounted for by the district engineer annually as of December 31. All property assigned to the field engineer for his use should be recorded in the district office, and its disposition should be reported to that office. Frequent inventories of all field equipment and supplies will not only stimulate the keeping of such a record but will also be of assistance when ordering additional supplies.

NONEXPENDABLE FIELD EQUIPMENT

Each article of nonexpendable property upon acquisition should be listed on a card, form 9–264, in the district office file. The record should show the name of the article, the date of purchase, the cost, and the allotment from which the purchase was made. A space is provided on the card for the name of the person to whom it was issued, the date of the issue, and the date on which it was returned

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to stock in the district office. The cards may be filed alphabetically by names of articles. When an article is issued for field use, the name of the engineer to whom issued may be inserted on the card and the card then placed in a file for issued articles. Upon return of the article by the engineer, the date of return is inserted on the card, and the card then returned to the alphabetical file. If nonexpendable field equipment is lost, a written report describing the article, the circumstances surrounding its loss, and the effort made for its recovery should be made to the district engineer, who will in turn make a report to the Washington office on the proper form in order that the article may be removed from the list of property charged to him. The success of this card system will depend largely upon the field engineer. His cooperation in keeping the records will aid in accounting for nonexpendable property for which complete returns must be made to the issuing officer.

EQUIPMENT IN STOCK

Additional equipment should be kept in stock in the district office. All equipment should be so arranged that it can be found easily when needed and can be checked readily when additional quantities are to be ordered. The equipment-supply room should be kept clean and the equipment systematically arranged.

MAINTENANCE OF GAGE DATUM

A permanent datum to which the records of stage at a gaging station are referred must be maintained if the records of stream flow are to be accurate. The datum selected for operating purposes should be such that the gage height of zero flow will be above zero on the gage so that minus signs will not be necessary in the records of stage. The procedure relating to a gage datum is as follows: First, the establishment of a definite datum plane at which the gage is to be originally set, independently of the structure supporting the gage; and second, the keeping of the gage at the proper position with respect to the established datum plane throughout the period of record. In maintaining a permanent gage datum, various terms such as "bench marks," "reference marks," and "reference points" are used in connection with the operation of gaging stations by the Geological Survey; and in order to avoid possible confusion and misinterpretation, these terms are defined.

Bench marks are nationally recognized points of known elevation above mean sea level established by the Coast and Geodetic Survey, by the Topographic Branch of the Geological Survey, or by other organizations.

A reference mark is a standard bronze tablet (see pl. 32) or other readily identifiable mark of known elevation above gage datum established in the vicinity of the gaging station. It should be placed in a permanent position, away from the structure supporting the gage and independent of it. It is used for reference purposes in maintaining the position of the gage at a definite elevation with respect to the station datum.

A reference point is a point of known height above the station datum and is ordinarily established for the purpose of making independent observations of stages or for simplifying the procedure of checking the gage. It is established on the structure supporting the gage and is of such a nature that when used independently of a reference mark it does not necessarily establish the correctness of the gage.

The above definitions of terms in common use in obtaining records of stream flow may be amplified as follows:

1. If the elevation of a permanent mark, regardless of its position, is established by the Topographic Branch of the Geological Survey, the Coast and Geodetic Survey, or any other organization whose business is to establish nationally recognized bench marks and it is designated as a bench mark by the organization that establishes it, it is likewise considered a bench mark when used in connection with the operation of river measurement stations. If such a bench mark is situated in the vicinity of a gaging station, the elevation of the station datum arbitrarily taken as the zero of the gage should be obtained and recorded by means of levels run to the bench mark.

2. If a permanent mark is referred to a known or arbitrarily selected datum by the Water Resources Branch or by agencies other than those mentioned above or by private organizations and is used in connection with the maintenance of the established datum of the gage, it should be referred to as a reference mark or a reference point depending on whether it is away from the structure supporting the gage or upon the structure itself.

3. A reference mark or reference point established by the Water Resources Branch will retain its classification in accordance with the above statement until it is included in surveys of the Topographic Branch, the Coast and Geodetic Survey, or other qualified agency and has been definitely established as a bench mark bearing the name of the organization responsible for the determination of its elevation.

NECESSITY FOR A SINGLE AND PERMANENT GAGE DATUM

The maintenance of a single and permanent datum for all gages at a stream-flow measurement station is of major importance in the establishment and maintenance of relations of stage to discharge.

Once this station datum is established, it should be maintained at the same elevation throughout the period of record. Changes in datum for the purpose of overcoming minor inconveniences should be avoided. If it is found necessary to change the datum at a station, a report should be prepared promptly, explaining the new datum and the reasons for the change. This report should be inserted in the history of the station for future reference. Changes in datum will generally be unnecessary if proper investigations are made before the establishment of the station.

Many gages established by other Government agencies and by private companies are used by the Geological Survey in obtaining records of river stages. Changes in the datum for those gages should not be made by Survey engineers unless first authorized by the party maintaining the gage, as the value of the data for which the gage was primarily established may depend to a large extent on maintaining the original datum.

CHECKING OF REFERENCE MARKS, REFERENCE POINTS, AND GAGES

The best assurance of maintaining all the gages at a gaging station at correct positions with respect to gage datum is obtained by periodic checkings of all reference marks, reference points, and gages associated with the station. The frequency of this procedure may depend in part on the degree of permanence of the gage and the reference mark installations. Regardless of their apparent permanency, it is good practice to check them by level at least once a year, preferably on a field trip organized and equipped for that purpose (see pp. 233).

PRECAUTIONS TO BE TAKEN IN CHECKING GAGES

Certain precautions should be taken in checking gages by level, and suitable preparation for this work should be made by the engineer before he leaves the office. He should see that the most recent descriptions of all bench marks, reference marks, reference points, and gages, together with their elevations, are recorded on the field copy of the station description (form 9–197) for each station he is to visit. He should examine the level and rod assigned to him and satisfy himself that they are in proper condition for use. If adjustments are necessary, their nature should be determined and the level and rod should be properly adjusted before they are taken into the field. If these adjustments are such that they can be made by the engineer, he will be assisted materially by referring to the instructions issued by the Geological Survey.[67] Frequent tests in the field

[67] Douglas, E. M., Leveling, in Topographic instructions of the United States Geological Survey: U. S. Geol. Survey Bull. 788, pp. 138–141, 1928.

for proper adjustment of the level will help to reduce the number of unsatisfactory closures in level circuits. As the level is a delicate and sensitive instrument, its protection and care when in use and when being transported are not only essential to the obtaining of accurate results but also prevent loss of time by the engineer while he is in the field.

In using a level that is slightly defective or out of adjustment errors may be avoided if equal distances are taken for backsights and foresights. Errors may be caused by the use of unstable turning points and by settling of the instrument if it is not in a firm position. The failure of the rodman to hold the rod vertically, the slipping of the target, and carelessness in the opening and closing of the rod are possible sources of error. Continual vigilance and care are the price the engineer must pay for accurate results in the running of levels and the recording of notes.

PROCEDURE IN CHECKING GAGES

The general procedure to be followed in the use of a level at a gaging station should be so planned that an independent check is obtained at every point where an elevation is to be determined. This requires a closed circuit of levels that will be complete in itself and will permit analysis of the results by any engineer even though he is unfamiliar with the procedure that was followed.

A circuit of levels is not complete without a closure. In general, any error of closure exceeding 0.01 foot for short runs and 0.02 foot for long runs should be reduced by rerunning the levels. At least two set-ups of the level at different elevations should be made in any circuit, even though all the bench marks—or reference marks—and gages can be seen from one set-up. This is to obviate the possibility of having the final reading on the starting point (usually a bench mark or reference mark) influenced by the initial reading on that point from the same set-up. If a reference mark, a reference point, a gage, or any section of gage, is found in error, no change should be made until the error is substantiated by further levels with a different instrument set-up. All new reference marks, reference points, gages, or gage sections established during the running of the original circuit should be checked by an additional circuit of levels with different instrument set-ups before their elevations are accepted. If a gage or any of its sections is corrected on the basis of levels, the new vertical position should be checked by at least two ties with the original circuit. No gage, regardless of its type, should be considered completely checked until the water surface elevation has been determined by level and compared with the gage reading. This comparison should show an agreement within the degree of precision to which the gage is read.

The refinement that is necessary in reading the level rod will depend largely upon the nature of the points of elevation which are being established or checked. If the gages are used for slope determinations it is highly desirable that a target rod be used and the readings made to 0.001 foot. For ordinary work the rod may be read directly to 0.002 foot if a closure of 0.01 foot is required, or to 0.005 foot if 0.02 foot is to be the limit of closure. However, when reading the rod directly, the sight must be sufficiently short to assure that all readings are within the required limits of accuracy. All readings should be recorded on form 9–276, which provides a space for each rod reading and the corresponding elevation. The notes should be kept neatly and in such detail that they may be clearly understandable by others who may not be familiar with the station. Consistency in the keeping of notes is desirable. This can be obtained by using a uniform system of recording level notes.[68]

The system for which a form of level notes is shown in plate 33 is preferable in some respects for use in keeping notes of levels in checking gages where several foresights are made from the same set-up of the level. At the top of the first sheet of level notes used for each gaging station, the elevation last determined for each bench mark, reference mark, and reference point is listed in consecutive order and designated "as given." For a wire, tape, or chain gage the length as last determined is also listed. A line should then be drawn separating these data from the notes that are to follow. In recording the notes, the backsight and the elevation of the point from which the backsight is taken are entered on the same line. A separate line is then used for entering the height of instrument. The foresight and the newly determined elevation, together with the description of the point on which the foresight is taken, are entered on the following line. If more than one foresight is taken from the same height of instrument they should be entered consecutively on separate lines. This procedure is repeated for each set-up of the instrument until a closure is completed. Upon completion of the levels a summary should be prepared showing the gages or sections of gages checked or changed, the nature of such changes, and the time of day the changes were made. For staff gages found to be incorrect, the statement should be made that the gage—or a certain section or sections—was "— foot low, reading high," or "— foot high, reading low." This will permit the ready preparation, in the office, of a list of corrections to be applied to gage heights previously obtained.

The specific procedure to be followed in checking the elevations of reference marks, gages, and reference points at a gaging station

[68] Douglas, E. M., op. cit., p. 135.

depends on the types of gages and their relative positions with respect to each other. The leveling usually can be simplified if the engineer visualizes at the start the relative positions of all points at which elevations are to be obtained.

Reference marks.—It is desirable to check the elevations of all reference marks independently of the gages, if that can be done without too much duplication of work. This practice will eliminate the possibility of using an incorrect datum in checking the gages. If it is impracticable to check the reference marks independently of the gages, the reference mark that appears to be the most nearly permanent should be selected as a starting point for the circuit of levels.

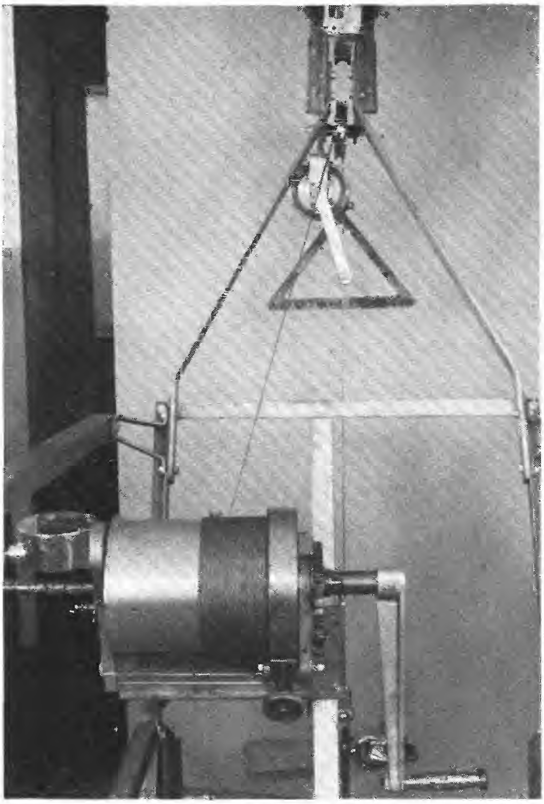
Reference points.—The procedure in checking reference points depends on the type of gage installation and the positions of the points with respect to established reference marks. Reference points on structures supporting the gage should be verified by a circuit of levels which includes one or more reference marks.

Vertical-staff gage.—A vertical-staff gage consisting of several sections should be so checked that the vertical position of each section is checked by the level or by measuring with a steel tape from a section to which a foresight has been taken with the level. The steel tape should be used only when the sections of the gage are in vertical alinement, and then only after the vertical position of one of the sections has been definitely checked by level. In order to have this section of the gage at correct datum, a gage reading determined by a foresight directly on the gage must correspond with the elevation of the height of instrument.. Any divergence in these readings represents the correction to be applied to gage heights or adjustment to be made in the gage section. If the line of sight of the level intersects a gage reading that is less than the elevation shown for the height of instrument, a plus correction to observed gage heights is necessary, and the gage section, if corrected, must be lowered a corresponding amount. If the line of sight intersects a gage reading that is greater than the elevation of the height of instrument, a minus correction to observed gage heights is indicated, and the gage section, if corrected, must be raised a corresponding amount. Sections other than the one on which a direct reading can be taken are checked by a series of foresights with the level rod held on the marks for which elevations are required.

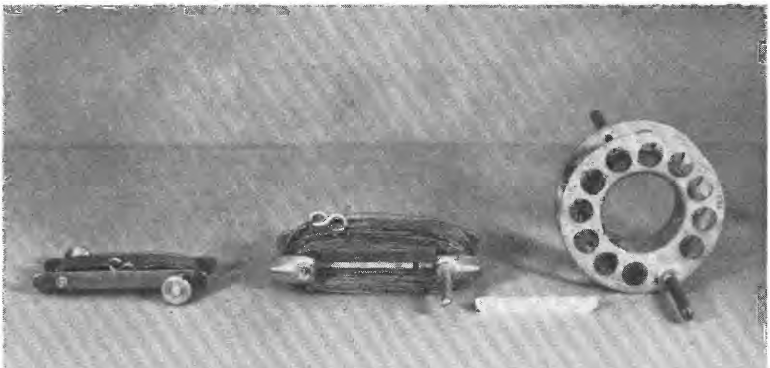
Inclined-staff gage.—An inclined staff gage is checked by level by taking a series of foresights with the level rod held on the graduations for each foot and at as many intermediate points as the condition of the gage requires. If the graduations are designated by raised markers, the rodman should be cautioned to hold the base of the level rod in line with the marker and not on top of it. In marking an inclined gage, the foot graduations should first be established by levels, after which the tenth and half-tenth graduations may be established either directly by levels or by dividing the slant distance between each foot marker into 10 or 20 equal parts by the use of a steel tape. All graduations thus made should again be verified by levels before the markers are finally set. In setting the markers it is good practice to place them as near as practicable to the upstream edge of the inclined gage so that there will be little question as to the correct gage reading if the line made by the water surface does not cross the face of the gage at right angles. If, on the basis of levels, it is found necessary to change the vertical position of any one of the graduations previously established, the new position is determined by shifting the base of the level rod on the gage board to a position giving the desired rod reading. When new graduations are placed on an inclined staff gage at new positions, all evidence pertaining to the old graduations should be removed in order to avoid confusion in future readings of the gage. The nature of corrections to observed gage heights, whether plus or minus, is the same as that discussed for the vertical staff gage.

Chain gage.—In checking a chain gage with a level it is customary to have an assistant read the gage when the bottom of the gage weight is at the height of instrument. (See pl. 24, *A*, and p. 193.) The height of instrument should be as near as practicable to the water surface so that about the same length of chain is used as when making a gage reading. Any difference between this gage reading and the elevation of the height of instrument represents the amount of correction to be applied to the observed gage height or the amount of the change to be made in the gage. If the reading on the gage is less than the elevation of the height of instrument, a plus correction should be applied in corrections to observed gage heights; and the chain, if the length is changed, should be lengthened. If the gage reading is greater than the elevation of the height of instrument, a minus correction should be applied to observed gage heights, and the chain should be shortened. The length of the chain should be measured with a steel tape in order to determine whether the error, if any, is caused by a change in the length of the chain or is caused by a change in the vertical position of the structure supporting the gage or in the scale on which the reading is made. If the chain length is found to be the same as when the gage was last checked with a level, it is evident that the error, if any, is due to a change in position of the structure supporting the gage or of the scale or indicator by which the gage is read.

A shift in the vertical position of a structure supporting a chain gage is determined by checking the elevation of a reference point established on the structure. This reference point should, if practicable, be placed on the bridge member to which the gage is attached.



A. TYPE-E REEL.



B. TAG-LINE REELS.

REFERENCE-MARK TABLET.

9-276
May, 1922

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

File No.
Washington
Field

LEVEL NOTES

Stream Waterbury River
Locality Waterbury, Vermont
Party Patch ⩚, Sweet ⏀ Date August 16, 1938

STATION	B. S.	HT. INST.	F. S.	ELEVATION	REMARKS
RM 1				7.142	As given
RM 2				20.142	As given
RP 1				19.870	As given
RM 2	1.510			20.142	Bronze tablet 40 ft. d.s. and 20 ft. from river
		21.652			
RP 1			1.784	19.868	Head of brass screw in sill of trap door
TP 1	0.224		10.910	10.742	
		10.966			
RM 1			3.834	7.132	Bronze tablet 20 ft. d.s.
			6.086	4.880	Water surface in river Float gage reads 4.90
			7.976	2.990	3.0 mark on inclined staff
			6.976	3.990	4.0 " " " "
			5.976	4.990	5.0 " " " "
			4.976	5.990	6.0 " " " "
			3.976	6.990	7.0 " " " "
			3.970	6.996	7.0 mark on vertical staff
			2.970	7.996	8.0 " " " "
			1.970	8.996	9.0 " " " "
			0.970	9.996	10.0 " " " "
			0.000	10.966	10.97 " " " "
TP 1	10.674		0.226	10.740	

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9-276
May, 1922

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

File No.
Washington
Field

LEVEL NOTES

Stream Waterbury River
Locality Waterbury, Vermont
Party Patch ⩚, Sweet ⏀ Date August 16, 1938

STATION	B. S.	HT. INST.	F. S.	ELEVATION	REMARKS
		21.414			
RP 1			1.546	19.868	Head of brass screw in sill of trap door
From RP1 to water in well				14.990	Measured with steel tape
				4.878	Water surface in well Float gage reads 4.90
	Changed float index			-0.02	
From RP1 to water in well				14.990	Measured with steel tape
				4.878	Water surface in well Float gage reads 4.88
RM 2			1.274	20.140	Bronze tablet 40 ft. d.s.

SUMMARY

Float gage found reading 0.02 high. Changed -0.02 at 3:40 p.m.

Inclined staff 3.0 to 7.0 found 0.010 low; reading high; not changed

Vertical staff 7.0 to 10.97 found 0.004 low; reading high; not changed

No. 2 of 2 sheets Comp. by M.A.P. Chk. by G.A.

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FORM FOR LEVEL NOTES.

Any changes in the total length of the chain and the length to any of the intermediate markers, together with the time of day such changes were made, should be recorded in the level note summary for the station.

Wire-weight gage.—Two types of wire-weight gages are used by the Geological Survey—the type-A (p. 196 and pl. 2, *A*) and the Canfield (p. 196 and pl. 26, *A*.)

The type-A wire-weight gage is checked by sighting on the bottom of the weight with the level at as low a gage height as possible. With the bottom of the weight in this position, the height of instrument is compared with the counter-and-graduated-disc reading. If they are not in agreement, the difference is noted and the two screws between the drum and the graduated disc are loosened, the drum is then held fast by hand, and the crank turned until the counter and the graduated disc indicate the height of instrument. After tightening the two set screws the new setting is given a final check with the level. The weight is then raised to a position a little higher than the checking bar, whose elevation has been previously determined, the checking bar is moved forward to a position under the weight, and the weight is lowered until it touches the bar. The counter-and-disc reading for that position of the weight should correspond to the regular checking length of the wire or the previously determined elevation of the checking bar.

In checking this type of gage there may be a slight difference in the results obtained by referring the gage height to the elevation of the checking bar and by referring the gage height to the height of instrument by a level sight on the bottom of the weight. If the results obtained by the two methods are not the same, those obtained by referring the gage height to the height of instrument should be used. If it is not possible to take an accurate level sight from the bank of the river to the weight because of the distance, the levels may be run to the checking bar and to a reference point on the guard rail near the gage. The reading of the gage may then be checked by measuring to the water surface from the reference point on the guard rail, using a steel tape fastened to a gage weight. If it is found by levels that the position of the checking bar has risen with respect to the zero elevation of the gage, the counter-and-graduated-disc reading will be too small, thus necessitating a plus correction to gage heights. If the position of the checking bar is found to be lower than the true position, the dial-and-graduated-disc reading will be too large and a minus correction must be made to the gage heights. This type of gage should be checked by the engineer each time he visits the station by observing the reading of the gage when the bottom of the weight is on the checking bar.

In checking the Canfield wire-weight gage a sight should be taken on the bottom of the weight with the level at as low a gage height as possible, and the reading of the foot marker on the graduated plate compared with the height of instrument. The next step in the procedure is the determination of the elevation of the zero mark on the 1-foot graduated vertical plate in the gage box. For this type of gage it is not always necessary to measure the length of the wire with the steel tape as errors due to stretching of the wire are usually negligible because of the nonelastic properties of the stainless-steel wire. However, the gage should be checked for possible slipping of the wire at the connection to the weight by measuring the distance from the bottom of the weight to one of the foot markers on the wire. If the vertical position of the graduated plate is found to be in error, the application of corrections to gage heights will be the same as stated above for the type-A gage.

Electric tape gage.—The electric tape gage which is sometimes used as a reference gage inside the float well is checked by levels by observing the reading of the tape opposite the index marker when the bottom of the weight is at the height of instrument, the level being set up so that the line of sight passes through the lower door in the gage well. (See pl. 25, *B*.) If the gage reading differs from the height of instrument, a shift in the vertical position of the index marker is apparent, and the deviation from the old position should be determined. If it is not possible to sight on the bottom of the weight, an accessible reference point may be established inside the well. The gage may then be checked by measuring from the reference point to the water surface with a steel tape attached to a gage weight or to an improvised hook. Application of corrections to observed gage heights for this type of gage will be the same as those given for the wire-weight gages.

Float gage.—In checking a float gage by levels it is necessary to determine the correct vertical position of a reference point inside the gage well. The distance from this point to the water surface is then measured with a steel tape. This measurement may be made by fastening an improvised hook or a weight to the end of the tape in such a manner that the correct distance can be read directly from the tape when it is held on the reference point. If an inconsistency is found, several independent readings from the reference point should be made before changing the position of the indicator on the float gage. (See p. 194 and pl. 25, *A*.)

Hook gage.—In a hook gage the vertical distance between the point of hook and the zero of the graduations on the staff must equal the elevation of the zero of the 1-foot graduated scale that is attached to the bed piece against which the rod slides. (See pl. 24, *B*, and p. 194.)

For this relation of length of staff and elevation of scale, the hook gage should give correct readings of water stages in the float well. If the length of staff—that is, the vertical distance from point of hook to zero of graduations on the staff—is more than the elevation of the zero of the 1-foot graduated scale, the gage readings are too large and minus corrections are necessary. If the length of staff is less than the elevation of the zero of the 1-foot scale, the gage readings are too small and plus corrections are necessary. Incorrect positions of any of the marks on the staff would cause similar errors in the readings taken at those stages.

The procedure used in checking a hook gage with a level requires two separate steps, namely, the determination of the elevation of the zero mark on the 1-foot graduated scale and the position of the point of the hook with respect to each foot mark on the hook-gage staff. After the position of the graduated scale has been determined the next step is to determine the position of the hook on the staff. This may be done either by sighting on the level rod held on the point of the hook and comparing the elevations thus determined with the reading on the graduated scale or by measuring with a steel tape the distance from a selected foot mark to the point of the hook. In the latter method a foot mark near the end opposite that on which the hook is fastened should always be used so as to reduce to a minimum the slight error caused by the angle between the selected mark on the hook-gage staff and the point on the hook. This source of error can be eliminated if a small try square is used to project the position of the point of the hook back to the hook-gage staff. If the gage is found to be in error, it can be corrected either by changing the position of the 1-foot graduated scale or by changing the position of the hook on the staff. As a matter of convenience, it is generally desirable to maintain the 1-foot scale at its original elevation and to adjust the position of the hook if corrections are necessary.

REFERENCE TO MEAN SEA LEVEL

If a gaging station is established near an existing bench mark, or if a bench mark is placed near a station after it has been established, the mean sea-level elevation of the zero of the gage should be ascertained. The elevation of the bench mark as determined from the latest level-net adjustment and the date of that adjustment should be obtained from the agency that established it.

Bench marks, other than those officially recognized as such (see p. 210), should be accepted only when their reliability and the basis of their establishment have been authenticated. Published references to a bench mark in connection with its use by the Geological Survey in referring river stages to mean sea level should always give the name of the agency responsible for the bench mark and the date of the level-net adjustment used in the determination of its elevation.

River surveys made by the Topographic Branch of the Geological Survey generally show the positions of gaging stations and the elevation of the zero of the gage at each station included in the survey. This is accomplished by cooperation between the district engineers of the Water Resources Branch who operate the gaging stations and the engineers of the Topographic Branch who make the surveys.

ROUTINE FIELD WORK

REGULATIONS AND INSTRUCTIONS GOVERNING TRAVEL

Upon entering the Survey each employee who is to travel in the performance of field work is furnished with an identification card, an authorization of field work, and a copy of the "Standardized government travel regulations."

PREPARATION FOR FIELD TRIP

Careful preparation affords the best assurance for a successful field trip. In order that he may be in readiness for any emergency that may arise, the engineer should overhaul his equipment and prepare for the next trip immediately after his return to the office. Lack of proper inspection of equipment and replacement of worn or damaged parts will result in trouble eventually and thereby cause delay and increased cost.

EQUIPMENT FOR CURRENT-METER MEASUREMENTS

The following lists of equipment needed for current-meter measurements are not intended as complete lists of the equipment that might be needed under all circumstances but may serve as a guide to the engineer in making his selection for a specific field trip. The articles to be taken on any one trip would depend upon the types of measurements that are expected to be made and the facilities at the gaging stations. Some of the articles of equipment might be indispensable, regardless of the type of measurement, whereas other articles could be used only at stations provided with certain facilities. Several of the items listed separately might be assembled into a complete unit ready for use. The most essential articles of equipment for the several types of measurements are listed below.

Wading measurements.—The engineer should carry the following articles of equipment in order to be prepared for making discharge measurements by wading:

1. Keys for padlocks.
2. Current meter, with one or more extra pivots.

3. Meter carrying case.
4. Notebook and pencil.
5. Stop watch.
6. Headphone receiver, 5 to 80 ohm, complete with cord and head band.
7. Battery (small dry cell, preferably not exceeding 4½ volts).
8. Connection plugs, screw driver, cutting pliers, wrench, can of oil, marking keel, metallic tape, stainless-steel tape, miscellaneous wire, and friction tape.
9. Wading rod, consisting of three or four intermediate sections of flush-joint wading rods, a lower section of flush-joint rod, a base plate, a pole end (not essential) and a sliding support.
10. Tag-line reel, complete with tag line.
11. Waders.

Measurements from cableways and bridges.—Articles of equipment for making discharge measurements from cableways and bridges with hand lines consist of items 1 to 8 listed above and the following additional articles:

12. Weights, C–type, in 15, 30, or 50-pound size.
13. Weight hanger, or hangers, corresponding to the sizes of weights to be used.
14. Weight pin, or pins, corresponding to sizes of weights.
15. Connector (complete with cable clips if needed).
16. Direct-lay cable, 0.09 or 0.11 inch in diameter and of adequate length.
17. Hand reel for meter cable.
18. Two-conductor No. 16 electrical cord of adequate length.
19. Cable-car puller.

If a crane is to be used in making bridge measurements, items 1 to 8 and 12 to 15 listed above, together with the following items, ordinarily would be required.

20. Type A or type D crane.
21. Type A, B, D, or E reel.
22. Reverse-lay cable, 0.10 or 0.125 inch in diameter and of adequate length.
23. Weights, C-type, in 75, 100, 150, or 200-pound size.

Boat measurements.—If measurements are to be made from boats, items 1 to 8, 10, 12 to 15, and 21 listed above and the following items ordinarily would be required.

24. Boat, complete with car and carlocks.
25. Boat boom, or special type of crane.

Measurements through ice cover.—In making discharge measurements through ice cover with the current meter supported by wading rods, items 1 to 10 ordinarily would be required and the following additional items:

26. Ice chisel.
27. Small shovel.
28. An adequate number of sections of flush-joint wading rods similar to those listed under item 9.
29. A device for measuring the thickness of the ice.

If the current meter is to be supported by a cable in making discharge measurements through ice cover, the equipment should consist of items 1 to 8, 10, 12 to 15, 21, 22, 26, 27, 29, and the following additional item:

30. Device for mounting type A, B, D, or E reel on short skiis or other means of support.

SUPPLEMENTARY ARTICLES

The supplementary articles that should be carried on a field trip if the occasion and purpose of the trip appear likely to require them are:

31. Extra parts and units for repairing any or all of the principal items of equipment listed above.
32. Water-stage recorder parts, including extra clocks, cable for float and counterweight, paper supply rolls, ink, pencils, mailing tubes, and other incidentals for servicing water-stage recorders.
33. Enameled gage sections and brass screws for the installation and repair of staff gages.
34. Tools, such as hammer, wood chisel, cold chisel, file, hand axe, wire cutters, knife, brace and bits, short handled shovel or spade, board saw, hack saw, pipe wrench, and wrecking bar.
35. Box of assorted nails, screws, bolts, and lag screws.
36. Paints and brushes.
37. Thermos jug.
38. Flashlight.
39. Bucket and rope for cleaning recorder wells.
40. Brush hook or pruning shears for clearing brush.
41. Reference-mark and flood-mark tablets.
42. Level and level rod.
43. Sling for recovering cable cars.
44. Supply of note forms, report forms, and stationery.

SUPPLIES

The selection of forms and supplies to be carried on a field trip should be given as much forethought as the selection and preparation of equipment. To be without the necessary supplies in the field is not only embarrassing but usually results in duplication of efforts.

The carrying of unnecessary supplies should be avoided, however, by carefully anticipating the needs.

In addition to forms and instructions described on pages 235–236, it is essential to have available a supply of notebook forms 9–275, 9–275a, 9–275c, 9–275d, 9–276, and 9–277 on which to tabulate observed data. Supplies such as rolls of recorder paper, slide rule, notebook containing current-meter rating table, angle chart, and other technical forms are of equal importance. If the engineer is to be in the field for several weeks, a supply of the following should be included: Expense vouchers, standard form No. 1012; charge sheets, form No. 9–272; service reports, form No. 9–245a; report of discharge measurements, form No. 9–221; stationery, franked envelopes and cards.

DATA CONCERNING RIVER-MEASUREMENT STATIONS

Copies of the rating curve and the station description for each station that is to be visited, and for many stations the station history, are very useful to the engineer in the field. The rating curve shows the stage-discharge relations and the gage heights at which additional measurements are needed. The station description provides essential information concerning the station which is of material assistance to an engineer unfamiliar with the station and the surrounding area. Excerpts copied from the station history regarding corrections to gage heights, changes in equipment, and difficulties pertaining to the station may result in obtaining important information which otherwise would have been overlooked. Other information which the field engineer should obtain before leaving the office relates to the nature and character of work each observer is doing. For instance, the observer may be reading the gage to half-tenths when readings to hundredths are desired, or he may have a habit of moving the float too much, thus distributing the setting of the pen or pencil. Faults of this nature may be discovered and corrected if the engineer examines the gage-height cards or charts before leaving the office.

A copy of the profile of the cross section at the measuring section may be very useful. It pictures the section where the measurement is to be made and gives the engineer an idea of the number of velocity observations that are necessary and the depths to be expected. For measurements made during floods when measurements of depths may be impracticable, the approximate depth of water may be determined from the profile and the depth at which the meter is to be placed may be computed. Accurate velocity observations usually may be obtained by the 0.2-depth method, which is described on page 39.

Velocities for plotting vertical velocity curves are often obtained during flood measurements to assist in the determination of coefficients for mean velocity. A knowledge of the vertical velocity curves previously plotted may prevent duplication and thereby give the engineer an opportunity to obtain observations at other places in the measuring section and at different gage heights.

Some district offices keep a "trouble book" in which are made notations regarding needed repairs, alterations, and changes to be made on subsequent trips to the various gaging stations. This book may also contain a record of the recorders in operation, the clocks in use, and the dates of the latest changings of recorder paper or the approximate dates on which new rolls will be needed. The engineer should consult this book just before he leaves on the field trip.

ITINERARY

If an extended trip is anticipated, an itinerary should be prepared and a copy left with the clerk in the district office. The itinerary should show the work that is expected to be done, the principal stopping places and points where the office may contact the engineer, with the anticipated date of arrival at each place. This schedule should not relieve the engineer from using his own judgment if unexpected conditions developed, as the work, and not the maintenance of the schedule, is of primary importance. Any changes in the itinerary and the reasons for them should be reported promptly to the district office, the type of communication depending on the urgency of the situation.

WORK TO BE DONE AT THE STATION

The field engineer is responsible for the collection of the basic data from which the determinations of discharge are made, and he should always remember that the accuracy of a discharge record can be no greater than the accuracy of the basic data from which it is computed. Experience in office computations and a knowledge of methods used in analyzing the data give the engineer in the field a better understanding of the necessity for thorough and careful field work.

INSPECTION OF GAGES AND WATER-STAGE RECORDER

The first work usually done by the field engineer at a station equipped with a water-stage recorder is to ascertain if the clock is running and to identify the point at which the pen or pencil is resting. He then reads all the gages and checks the position of the pen or pencil of the recorder, both for time and gage height. If the readings are inconsistent, the reasons for any inconsistencies must be determined.

One way to identify the position of the pen or pencil on the chart is to grasp the float cord or tape on the float side and raise the float a short distance, thus causing the pen or pencil to make a short vertical line. Usually it is not necessary to raise the float completely out of the water. The pull on the float cord or tape should always be upward to avoid slack and the possibility of kinking. Other methods of satisfactorily identifying the position of the pen or pencil may be used, but if the method used requires a vertical movement of the float, such movement should be limited to that necessary to produce a legible line distinguishable from the gage-height graph. If the clock has stopped or if there are rapidly rising or falling stages, it is undesirable to mark the chart by vertically moving the float, and a small cross or circle should be used to identify the position of the pen or pencil. In connection with the above procedure a statement should be written on the chart giving the following information: Name of station (when placing and removing chart); watch time, clock time, day, month, and year; outside and inside gage readings; and the gage height and time registered by the pen or pencil. In order to simplify the recording of the information the following symbols may be used: O. G., outside gage; I. G., inside gage; P., gage height and time as indicated by the pen or pencil; W., watch time; C., recorder clock time. If it is desirable to associate the type of the gage with the inside or outside gage readings the initial of the respective gage may be included; for example, I. F. G., inside flat gage; I. E. T. G., inside electric tape gage. After the notes are neatly recorded on the chart, a line is drawn from them to the point on the graph which identifies the position of the pen or pencil. It is the usual practice not to wind the clock or the clock weight until after the pen or pencil position has been inspected. A final inspection should be given the instrument to make sure that the procedure of winding did not cause the clock to stop or the paper to shift its position.

The procedure in removing the chart depends on the type of instrument in use. If it is of a weekly type, the chart is marked in the usual manner and left on the drum for removal by the observer. If the instrument is of a 60-day or continuous type, the engineer removes the record each time he visits the station, if the visits are spaced a month or more apart. To insure satisfactory results in removing the record and resetting the instrument the engineer should be acquainted with the mechanical operation of the various types of water-stage recorders in use at the stations visited by him.

If the chart is to be renewed, this should be done soon after the engineer reaches the station in order that he may again check the operation of the instrument after his other work has been completed and the new chart has been running for an hour or so. If trouble has developed it can then be remedied without loss of record. At

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those stations where the record is subject to reversals of the recording styles it is good practice to turn the chart forward a short distance and check the point of reversal before the chart is removed from the instrument. With this information as a matter of record, gage-height correction for previous reversals may be made more accurately.

Other duties in connection with the water-stage recorder consist of the determination of the amount of paper left on the supply roll and notations on the new chart in similar manner and form to those made on the record just removed. In an emergency, to avoid the loss of gage-height record, the paper for a 60-day or continuous-type recorder can be rerolled and used again, but in so doing care must be taken to set the pen or pencil so as to avoid confusion of graphs. A final inspection of the clock and the pen or pencil is always desirable before leaving the station.

It is essential that all recorder charts renewed from the instrument should receive proper care and protection. Lost charts are not replaceable and those damaged in transit to the office always necessitate additional work. To use patched and wrinkled charts is not only difficult but it is also time-consuming.

If the water-stage recorder does not operate properly the engineer should endeavor to find the trouble and to make the necessary adjustments and repairs. Improper operation of the instrument usually can be traced to lack of care and attention, to failure to make necessary repairs and adjustments, or to some oversight on the part of the engineer or observer. A loosened float wheel is a common source of lost record especially for water-stage recorders that require rotating the float-wheel shaft for gage-height adjustments.

The engineer should see that all shaft bearings and gears of water-stage recorders are oiled in accordance with instructions accompanying the instruments. Ball-bearing assemblies should be repacked or replaced if necessary. Noncongealing lubricants such as specified by the manufacturers of the instruments should be used. Recorder clocks that have been replaced by extra clocks carried by the engineer, should be taken to the district office for cleaning and adjustments in accordance with a schedule prepared by the district engineer, or at more frequent intervals if found necessary. In regions of extremely low temperatures special care must be taken to see that clocks are properly adjusted and that lubricants suitable for low temperatures are used.

INSPECTION OF FLOAT AND INTAKE PIPES

The inspection of the float and the intake pipes naturally follows the inspection of the water-stage recorder. If the intake pipe becomes clogged with mud and silt so that the flow of water to and from the float well is retarded, or if the float does not move freely with changes in stage, the graph made by the recorder is not a true record of river stages. This condition is usually detected by inconsistent inside and outside gage readings, although the readings may be in agreement at times even though the intake pipe is partly clogged. A knowledge of the characteristic fluctuations of the stream and information obtainable from the chart after it has been removed are generally sufficient to enable the engineer to decide if there is interference with free movement of the water to and from the float well.

Several things may occur which will interfere with the free operation of the float of the water-stage recorder. These troubles may be caused by mud or ice in the well, a punctured float, obstructions on which the float or counterweight may catch while responding to changes in stage, or a broken float cable. In northern regions the delayed removal of subfloors from the well after the freezing period has passed may result in the loss of valuable record. This is also true of failure to remove silt deposits from wells after floods.

CLEANING OF STILLING WELL AND INTAKE

If the station is equipped with a water-stage recorder it is essential that the water level in the stilling well should correspond to the stage of the river. Stream-flow measurement stations of recent construction are generally provided with flushing devices in the stilling well and valves in the intake pipes to facilitate cleaning of the pipes. Where the stations are not so equipped, clogged intakes may be cleaned by inserting sewer rods into the pipes or by building up a head of water inside the well sufficient to force the obstructions through the pipes. When a stopped or sluggish intake pipe is being cleaned the recorder stylus should be raised from the chart so that surge in the well while the pipe will not cause the ink to soften the paper and the pen to tear it. The gage should be read before and after the cleaning to ascertain what change, if any, has resulted. At stations having long intake pipes a silt trap near the outer end of the pipe will retard the entrance of silt into the well.

The necessity for cleaning the float well and intake pipe varies regionally and for individual stations. In some parts of the country special precautions must be taken to prevent accumulations of silt in the wells, and it is sometimes necessary to make use of a ground-water inflow to the well in order to prevent the deposition of silt. So far as possible, the engineer should have the stilling well, intake pipe, and silt trap clean and in the best of working conditions before he leaves the station.

REFERENCE OF FLOOD MARKS

If a high-water mark has been left in the gage well by a recent flood stage, the height of the mark should be referred to the gage for future reference and compared with the height of the flood crest as registered by the water-stage recorder. Once the gage height of this high-water mark is determined, the mark should be removed to avoid confusion with subsequent marks.

Flood marks at nonrecording-gage stations should be referenced to gage datums at the first opportunity, as those marks often furnish the basic information for maximum stages.

NECESSITY FOR DISCHARGE MEASUREMENTS

The necessity for making a discharge measurement when a station is visited largely depends upon the conditions and the needs of each individual station. The accuracy of a discharge-rating curve is generally greater than the accuracy of an individual discharge measurement, and several discharge measurements at approximately the same stage may be required to establish definitely the position of the curve at a station where the measuring conditions are poor at that stage. For this reason it may be desirable to make a discharge measurement even though a measurement has been obtained previously at the same stage. Measurements not only serve to define rating curves but also provide information in regard to changes that may have occurred in the stage-discharge relation since the last preceding discharge measurement. Changes in the conditions that control the stage-discharge relations are not always discovered from an examination of the river channel. The first information regarding such changes is generally obtained through the plotting of discharge measurements. Experience has shown that the time used in making a measurement generally has been a good investment even though the necessity for it was not evident.

If a shift in the stage-discharge relations is indicated by a measurement, a second measurement will confirm the results and will remove any question of the accuracy of the first measurement. It is generally good practice to make at least one discharge measurement at every visit to a station, a practice that is followed in most districts.

INSPECTION OF THE CONTROL

The control should be inspected at each visit to the station; this inspection is especially desirable if a discharge measurement does not check the rating curve. A record should be made of any changes observed in the stream bed at or near the control and the time of their occurrence. This information is helpful in the interpretation of the data and may save time in the office computations. Sloughing of banks, scour or fill of the channel, and lodgment of debris or ice on the control are some of the conditions causing changes in the stage-discharge relation which may be discovered by observation.

Backwater from tributary streams below the station or from the main stream during floods occasionally may occur at stations where the reconnaissance failed to indicate such possibilities. Any decrease in the mean velocity at a station as compared with the mean velocity at a lower stage should be given careful attention as a possible indication of backwater.

DETERMINATION OF STAGE OF ZERO FLOW

The stage of zero flow corresponds to the lowest point on the low-water control. A knowledge of the gage height of zero flow is helpful in determining the position of the rating curve for low stages, especially for that part of curve below the stage of the lowest discharge measurement. The elevation of this stage is easily determined for artificial controls, but for natural riffles or channel controls the determinations may be somewhat approximate.

Any opportunity to determine the position of zero flow at a time of low water when streams can be waded should not be overlooked. Several individual determinations by different engineers at various times may establish the elevation of the stage of zero flow within narrow limits, although a single observation may not be exact. This stage is determined by subtracting the depth of water at the lowest point on the control from the stage indicated by the gage reading. If the control is some distance from the gage, an adjustment should be made for the slope. The greatest difficulty in determining the stage of zero flow is in finding the lowest point on the control, as not all controls are easily identified. It is generally helpful to develop a cross section by measuring the depths across the stream at the first complete break in the slope below the gage, which is usually the upstream lip of the low-water control. The maximum depth directly opposite the gage will, in the absence of more definite information for a channel-controlled station, give a fair approximation of the depth to be subtracted from the gage-height to obtain the stage of zero flow.

MEASUREMENT OF CHAIN LENGTH

The length of the chain at a station equipped with a chain gage is measured for the purpose of determining the necessary corrections to the gage-height readings. The chain length is subject to variations regardless of the material from which it is made or the wear to which it has been subjected. The normal change is a lengthening, although corrosion and dirt between the links may result in a shortening. If the length is found to be less than that recorded for the preceding measurement, a careful recheck is desirable, as such a measurement may reflect on the accuracy of previous determinations. Large corrections to the length of a chain can be avoided if the chain is stretched and subjected to artificial prewear before it is installed.

The chain length should be measured when a discharge measurement is made, and if the chain has one or more markers, the length from the bottom of the weight to each marker should be measured and recorded. This information, together with notations concerning any corrections made to the chain length, should be entered in the field notes and later inserted in the station history. The chain, when measured, should be free from kinks, twists, and dirt. Any accumulation of dirt or corrosion between the links should be removed after measuring, and the chain remeasured. Chain lengths are measured only with a steel tape, with the chain under a 12-pound tension. Some districts follow the practice of correcting the length of the chain on each visit, regardless of how small the correction may be. In other districts the chain length is measured on each visit, but corrections to the length and positions of the markers are made only at times when levels are run. The latter practice has merit because the distribution of the change in length can be studied over a longer period of time and questionable measurements can be eliminated. The record made by the engineer should show the results of the measurements of chain length and should definitely state what changes, if any, were made in the length and the time when the changes were made.

The engineer often finds it necessary to measure the length of the chain without assistance. Several simple methods can be used in doing this, the methods varying somewhat in different districts. (See pp. 216–217.)

CHECKING AND CORRECTION OF WIRE-WEIGHT GAGES

The length of the wire of a wire-weight gage does not ordinarily require checking with the steel tape on each visit to the station, as the stretch of the wire is usually negligible.

If a type-A wire-weight gage is used, the engineer should determine and record the indicated elevation of the weight when it is resting on the check bar after the bar has been moved to its forward position. This reading is then compared with the true check-bar elevation that was determined at the time the gage was set or last checked with a level. (See pp. 217–218.)

CONTACTING THE OBSERVER

The engineer should contact the observer, if any, on each visit to a station. He should instruct him in his work, encourage his cooperation, and cultivate his friendship. The observer may be of either sex and of any class, race, or creed, ranging from the competent engineer to the most illiterate laborer. None is highly paid, and most observers are more necessary to the Survey than the Survey is to them. All observers are human, most of them have individuality and pride, and tact and diplomacy are required in dealing with them.

At stations equipped with nonrecording gages, it is not only essential to interview the observer on each trip but it is also necessary to examine his gage-height book and insert any additional readings that may have been taken by the engineer. If previous instructions have not been followed by the observer, or inconsistencies in readings are found, the engineer should ascertain the reasons for such and make the necessary notations on form 9–275d for the station report. It is usually found that frequent interviews with observers are helpful in promoting their interest in the work.

As soon as possible after reaching the station the engineer should see the observer, or should possibly call at his home before going to the station. Unexpected visits are sometimes helpful in discovering the extent to which the readings are kept up to date.

COLLECTION OF DATA FOR SUPPLYING MISSING RECORDS OF STAGE

If for any reason reliable records of stage were not obtained at a gaging station during some period of time it may be necessary to supplement the existing records by such data as may be obtained from other sources.

Information regarding the height of flood crests, the duration of floods, and the time of their occurrence, can often be obtained from the observer or from local residents. The elevation of the crest stage may be obtainable from flood marks left in the well, or at nonrecording-gage stations from flood marks on banks, trees, or structures in the overflow area. Information regarding pond gage readings, power output, and flow through wheels at power plants at and over dams may be obtained from power companies if power developments have been made near the station. These data are especially helpful in making estimates of low-water flow which may occur at times when the stage-discharge relation is affected by ice.

If the clock of the water-stage recorder is found to have stopped, special care should be taken in noting on the chart the exact position of the recorder pen or pencil. The extreme limits of the vertical line recorded during the time the clock was stopped gives the maximum and minimum stages for the period of missing record unless one or more reversals have occurred. Care should be taken not to destroy this record of maximum and minimum stages by moving the float before the chart is removed from the instrument. Different weights of this vertical line sometimes indicate quite clearly the range in stage that was most common during the period. If the loss of record is due to an exhausted paper supply, there is a possibility that the record may be found on the brass core, cylinder, or drum, depending upon the type of water-stage recorder. This record may, if found, be retraced with a fair degree of accuracy if the position of the pen or pencil is first identified with the corresponding gage height. Cross-section paper used for this purpose may be made temporarily transparent by wetting it with gasoline or kerosene. Where this record is on the cylinder or driving drum it should be erased before resetting the pen or pencil in order that confusion may be avoided if a similar situation should occur again.

FLOOD HEIGHTS

Accurate data concerning flood heights are valuable if referred to gage datum. Usually the available discharge or gage-height record covers but a short period of time and it is possible that the maximum known flood may have occurred before the station was established. Local residents often establish flood marks which, if verified from other sources, may be considered sufficiently reliable to warrant acceptance. Other records obtained from mill owners and from employees of power plants may assist in the collection and verification of such data. On navigable streams, records kept by lock masters and by towboat transportation companies may reveal not only the description and location of flood marks but also the time of their occurrence. In the event of a flood above the limits defined by current-meter measurements, the engineer should endeavor to obtain data for making a determination of discharge by one of the special methods discussed on pages 98 to 108.

The marking of the water-surface profile for a slope-area or a contracted-opening method of determination of discharge should be done as soon as possible after the flood. For stations where flood determinations are particularly needed and difficult to obtain, it may be worth while to establish suitable slope-area reaches and to take cross sections in advance so that the work of determining the discharge after a flood will be a minimum. (See pp. 100–102.)

REPAIRS AT STATION

The field engineer is responsible for the upkeep of the station equipment. He should make the necessary repairs and replacements in accordance with the instructions of the district engineer. If it is not practicable to make such repairs at the time the need for them is discovered, the engineer should make a complete report regarding the repairs that are needed. It is a further duty of the engineer to see that this report is properly recorded and made available for the benefit of the engineer who is selected to make the next trip to the station.

LEVELS

All nonrecording and auxiliary gages should be checked by levels at least once each year. This is usually done during the season of low flow when a greater range of gage sections is exposed.

PREPARATION FOR WINTER OPERATION

In regions where sub-freezing temperatures occur, provision should be made in the fall of each year to insure free actuation of the float and continued operation of the water-stage recorder throughout the winter.

Ice in the stilling well, moisture and frost in the upper parts of the stilling well and in the gage house, and the congealing of lubricants, particularly in the clock, are some of the most common sources of trouble in obtaining records of stage during the winter.

Installation of subfloors and oil cylinders for floats is the best assurance of free float movement during cold periods. A subfloor is a frost barrier installed to check the entrance of the cold air into the lower part of the stilling well and to prevent the entrance into the gage house of vapor rising from the water surface. To be most effective the subfloor should be placed at or below the frost line and should be kept as nearly air tight as possible. It must be high enough to allow normal winter fluctuations of the water and below any auxiliary intake pipe, door, or other opening that will permit the entrance of cold air. It should be made of material possessing the best insulating qualities obtainable within the limits of justifiable expenditure. Openings must be provided in the subfloor for the free vertical movement of the cables or tapes actuating the counterweight, clockweight, and floats. These openings may be shielded by strips of felt to prevent passage of moisture without interference with the counterweight or float. The subfloor will materially assist in checking the formation of ice in shallow wells.

If the conditions are such that a subfloor does not prevent the formation of ice in the well it may become necessary to install an oil cylinder for the float. This cylinder must be oiltight and preferably of a noncorrodible material. The oil cylinder must be of sufficient length to allow for the usual range in stage and of a diameter somewhat greater than that of the float. When installing the oil cylinder care must be taken to have it correctly centered in a vertical position. It may be supported by brackets extending either to the gage house floor or to the sides of the stilling well; or it may be suspended by wires from above. When suspended by wires the cylinder can be given a slight swing at the time of each visit to ascertain if the bottom is free. If silt accumulates in the well so as to seal the opening at the bottom, the cylinder may be raised slightly to permit the entrance of water. Formation of ice in the oil cylinder is prevented by placing in it a layer of kerosene or light fuel oil. It may be necessary to replenish the oil occasionally to offset losses from evaporation. The difference in the specific gravities of the oil and the water should be taken into consideration in setting the pen or pencil on the water-stage recorder, and the setting should be made to correspond to the height of water outside the cylinder.

Proper ventilation of the gage house will reduce trouble from the formation of ice on the moving parts of the recorder, but regardless of the care used in providing ventilation and in installing subfloors, instrument trouble often occurs during periods of subzero weather due to the freezing of condensed moisture. The use of felt at the openings through the instrument shelf will assist in reducing the moisture accumulation on the instrument. This felt, if saturated with a light oil, will also check the formation of ice on the cables or tapes. Certain noncorrosive chemicals possessing moisture-absorbing characteristics have been used to reduce the moisture within the instrument case. Activated alumina is one of the chemicals giving the most satisfactory results. This chemical may be obtained in the form of small balls which can be placed in an open container within the recorder case. The quantity of the chemical required will depend upon the severity of existing conditions. When it is found that the chemical is losing its absorptive power it may be replaced by a fresh supply or its original qualities may be restored by heating.

PREPARATION OF REPORT OF FIELD WORK AT STATION

The report of field work at a station is prepared for the purpose of assembling and preserving the information obtained in the field regarding conditions at the station which should be taken into consideration in making the computations of discharge. It may also serve as a means of bringing pertinent information to the immediate attention of the office engineer or the district engineer so that proper action can be taken by them. Form 9–275d is convenient for recording essential facts regarding some or all of the following subjects: Conditions affecting the accuracy of discharge measurements; condition of gage and reference marks; notes concerning the observer, the gage height record, and corrections that should be applied to observed gage heights; repairs that should be made to station equipment; descriptions of the channel, control, rating, backwater, diversions, regulation, cooperation, stage of zero flow, and suggestions regarding adjustments to measured discharge. These items are suggested by the headings that appear on form 9–275d and reference to them will lead to the collection of valuable data that might otherwise be overlooked. The preparation of this report on form 9–275d should be completed at the station and not left until some later date. Several stations may be visited during a day's trip and the engineer should not attempt to remember until evening all the specific information collected at each of the stations visited.

TRESPASSING

The fact that an individual is employed by the United States Government is no reason for him to assume the right to enter private lands without first obtaining permission. Although several States have laws whereby the right of entrance can be legally obtained, it is not good policy to take advantage of such laws. An agreement either verbal or written is usually made with the property owner at the time the station is established, and it becomes the duty of the engineer to see that the spirit as well as the letter or word of the agreement is not violated. The confidence and good will of the property owner is much easier to keep than it is to reestablish once it has been lost.

REPORTS TO THE DISTRICT OFFICE

Reports to the district office from an engineer on a field trip are more apt to suffer from indifference and carelessness than are any other phases of field work. All reports should be clear, concise, complete, legibly written, and made in accordance with instructions received from the district engineer.

Reports that require the daily attention of the engineer concern changes in his itinerary and a record of the discharge measurements made each day. The report of discharge measurement is usually made on form 9–221, a card prepared for the tabulation of results of discharge measurements. Even though the engineer has been unable to compute the measurements because of lack of time, this card showing the name of the stream, the date, and the gage height at which the measurement was taken should be promptly forwarded to the district office, especially if the stream is in flood stage. Another system used in some districts requires the field engineer to forward the station report on form 9–275d as soon as practicable after the measurement has been completed. These reports are examined by the district engineer and are retained and attached to the discharge measurement computations when they are received. Both methods have their merits; the cards if they contain full data concerning the discharge measurement are easily filed and serve as a duplicate record of the discharge measurement. It is essential that the station reports be mailed promptly.

If the engineer is to be in the field beyond the end of the month it is mandatory that his service report, salary charge sheet when requested, a list of temporary employees, a statement of expenditures for construction and repair for the Bureau of Labor Statistics report, and a summary showing the number of discharge measurements made during the month should reach the district office on or before the first day of the following month. His expense account with the necessary supporting data should be submitted on the first of each month. In order that effective cooperation may be maintained between the district offices and the Washington office it is essential that the field engineer recognize all of the above requirements and become familiar with any modifications of them which may be adopted by the respective districts to which he is assigned.

HAZARDS OF FIELD WORK

Measurements of river discharge are made under a wide range of conditions, including floods and ice cover. They are made from bridges, cableways, and boats, and by wading. Structures for use in measurements of discharge must be built and maintained, some at heights of 100 feet or more above the water. The work is highly specialized, and, like many other engineering activities, is not without hazards. A knowledge of these hazards and the means by which they may be minimized should be helpful in preventing accidents and in providing greater safety for those engaged in the work.

The Federal Government, recognizing the hazards related to its field activities, provides care for those who are injured. Its agency for such purposes is the United States Employees' Compensation Commission, with headquarters in Washington, D. C. As in all large organizations both public and private, "red tape" is necessary with respect to procedure, especially in reporting accidents and in the treatment of those who are injured. Federal field workers and especially chiefs of parties should therefore be familiar with prescribed procedure and should conform with it. All accidents should be reported as a step in the protection of the interests of the injured, as unexpected complications sometimes follow what appear to be minor injuries.

ACCIDENTS AND POISONING

All members of field parties should know how to give aid in cases of accident or poisoning, especially if they are working at a considerable distance from the customary routes of travel. The preventive or remedial measures suggested for the ailments mentioned in the following paragraphs are based upon recommendations of the United States Public Health Service.

Poison oak and poison ivy.—A 5-percent solution of ferric chloride in equal parts of glycerine and water applied to all exposed parts (forearms, ankles, and hands) and permitted to dry will neutralize the effects of poison oak and poison ivy. This is to be used before exposure. If one is working in water, apply a thin coat of vaseline to all exposed parts before exposure, removing this with soap and water after exposure.

Spotted fever.—As a preventive measure for spotted fever caused by tick bite, inoculation should be made with Rocky Mountain spotted fever serum. This inoculation can be obtained from most doctors in those parts of the country where spotted fever is prevalent, or it may be obtained free from the Public Health Service.

Snake bite.—For snake bite tie a belt, a piece of rope, or other material about the limb above the wound so as to shut off the circulation; then open the wound with a knife and allow it to bleed freely. Afterwards crush a tablet of potassium permanganate and rub it into the wound. Stimulate the patient with alcohol. Loosen the constriction about the limb gradually. Whiskey or alcohol is not a specific treatment for snake bite and should not be freely used.

Frostbite.—Treatment for frostbite is given for the purpose of gradually bringing the frozen part of the anatomy to its normal temperature. Never use heat. Rub the frozen part with snow, pieces of ice, or cold water. If the frostbite is old and the skin has turned black or has begun to scale off, do not attempt to restore its vitality by rubbing, but wrap it loosely in absorbent cotton or gauze.

FIRST-AID MANUAL AND EQUIPMENT

A standard first-aid manual should be provided for each field party. Two such manuals that are in general use are First-aid manual for field parties, prepared by Dr. H. W. Parker for the United States Forest Service and printed by the Government Printing Office in 1917; and Ship's medicine chest and First aid at sea, Miscellaneous Publication No. 9, prepared under direction of the Surgeon General and printed by the Government Printing Office. Questions and answers on first-aid training, published as Information Circular 6853, October 1935, by the United States Bureau of Mines, may also be referred to.

Each field party should be supplied with a standard first-aid kit, which can be purchased from the general schedule of supplies.

AUTOMOBILE OPERATION

The hazards resulting from the automobile lie generally not in the machine itself but in its operation and maintenance. Unreasonable speed and carelessness have no place in Survey practice and in no way are they justified, as courtesy and considerate treatment of the public by the employee is essential at all times. The fact that the employee provides himself with liability and property damage insurance before using any automobile on official work is no excuse for unnecessary risk. It may truly be stated that the engineer to whom the automobile becomes a hazard will in turn become a hazard to the Survey.

SWIMMING

Inability to swim and to work free from burdensome equipment and clothing if suddenly plunged into deep water is perhaps the most serious hazard in stream-flow measurement work. Even though proper care is taken, there is always the possibility that an engineer may lose his balance or overestimate his ability to wade, or that the structure from which he is working may fail. Any one of these occurrences may result in a fatal accident if he is unable to swim. A man should not overestimate his swimming ability, but in an emergency overconfidence is far better than no confidence at all. At the Conference of October 1931 the district engineers were recorded as being in favor of a requirement that all engineers of the Water Resources Branch be able to swim.

CABLEWAYS AND GAGE WELLS

The principal hazards of cableways are not the possibility of their failure through some unexpected loads or unforeseen weakness, although failures sometimes occur from such causes or as a result of deterioration or sabotage, but rather attend the operation of the cable car. Proper instruction regarding the use of the car and an explanation of the dangers may save an inexperienced engineer from losing a finger, a hand, or an arm. It is especially important that all cable cars be equipped with the necessary safety appliances, such as car pullers, brakes, and landing platforms, and that the towers or A-frames supporting the cable should be provided with suitable means of access to the cable. Recovery of loose cable cars which have come to rest in the lowest part of the cable over the middle of the stream should be attempted only in the most careful manner and with devices suitable for that purpose. Small steel flakes or splinters fly from the sheaves of the cable car when it is rolling on the cable; if sheave guards are not provided, proper precautions should be taken to prevent painful and often serious eye injuries.

Certain hazards attend the routine work both in and about the gage wells. Climbing through bridge trusses to inspect wells that are attached to bridge piers, or enclosed in them, is especially dangerous, as also is the cleaning of wells in which the instrument weights are left suspended. Gas from decaying vegetable matter may be dangerous in deep wells.

CONSTRUCTION

Construction of deep wells, much of which involves rock excavation, with the well and shelter extending above flood stages at streamflow measurement stations, and the erection of long-span cableways with high towers of timber or steel are attended by the dangers inherent in such construction work. Excavation requiring the use of high explosives should not be attempted by one who is unfamiliar with such work. The employment of an experienced foreman who understands the use of explosives is not only a necessary precaution against accidents but also promotes efficiency and reduces the cost of the work. The strength of shoring is often overestimated, and attempts to economize on timber for such work may prove dangerous. Caving from quicksand is almost instantaneous, and the safest protection is afforded by substantial shoring. Scaffolding is sometimes necessary and, if secure, is a protective measure, but injuries from insecure scaffolding are probably as numerous as those from all other construction hazards. The usual litter of material around a construction job provides opportunity for slight injuries which may become serious through infection. Such injuries, however slight, should be given prompt attention and should be reported promptly. (See p. 236.)

MEASUREMENTS THROUGH ICE

Discharge measurements through ice cover are sometimes made with considerable risk. The conditions of the ice on a stream are subject to change. The strength of the ice or its safety as a bridge cannot be estimated from the apparent thickness near the edges. In advancing across an ice-covered stream it is advisable to test the ice with a sharp blow of the ice chisel every few steps. Precautions of this nature are especially necessary when attempting a measurement of swift water. A few inches of new snow on top of the ice may conceal dangerous places that would be apparent if there was no snow. Work from ice cover during break-ups is particularly hazardous and requires that sound judgment be exercised before a discharge measurement is attempted. A measurement should never be made at the risk of the engineer's life. Floating ice is almost as destructive to meter equipment as other drift, and precautions should be taken both for personal safety and for safety of the equipment.

BRIDGE TRAFFIC

The use of reels and booms on bridges for handling meter equipment and heavy weights increases the hazards in working from such structures, especially in places where traffic is heavy. If it is necessary to partly obstruct traffic, suitable arrangements should be made in advance. Warning signals and signs of various kinds are a great help to the engineer when measuring from a bridge, and approval of their use is generally granted by the local traffic officials. When working on railroad bridges a knowledge of train schedules is necessary, and at no time should the engineer use any equipment which cannot be quickly removed from the proximity of a passing train.

A hazard in connection with the use of current-meter equipment from bridges or long-span cableways that may be especially serious if the structure is high and the channel is wide is caused by low-flying airplanes passing under the bridge or cableway. An auxiliary cable with red streamers attached and carrying a weight lowered nearly to the water would serve as a warning to an airplane pilot who might be flying at a low altitude. If the river is in a lane frequented by planes, an observer should be provided to watch for them whenever a current-meter measurement is being made. Signal warnings, or the dropping of flares, may prevent a serious accident to the plane and to the meter equipment.

FLOODS

Floods and high water are often accompanied by inclement weather, wash-outs, and inundation of highways. River-measurement structures are sometimes weakened by the action of high water; examinations of weakened structures should always be made before they are used. Meter equipment is occasionally damaged or lost by catching on drift. These elements of danger can usually be avoided by the alert and cautious engineer. In making measurements at high stages where the meter equipment may become entangled in surface or submerged drift, the engineer should never allow the meter line to become fastened or attached to any part of his body, and if working from a cable or boat he should be prepared to cut the meter line and sacrifice the meter if necessary for his safety.

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