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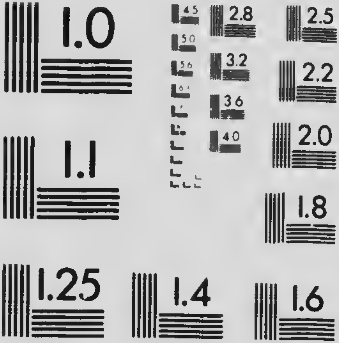

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The Measurement of Water

AN ADDRESS

By

SAMUEL FORTIER
Chief of Irrigation Division, Bureau of Public Roads,
U. S. Department of Agriculture

at the

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THE MEASUREMENT OF WATER

By Samuel Fortier, Chief of Irrigation Division, Bureau of Public Roads, U. S. Dept. of Agriculture.

Soil, water and climate are the three main elements in irrigation farming. Little difficulty is experienced in measuring soils for the reason that they overlie tracts of land which can be readily surveyed and the survey recorded. On the other hand, water and climate are very difficult to measure and record on account of their fluctuating character. As a rule water is in constant motion and the volume which passes a given point today may be quite different from that which flowed yesterday or will flow tomorrow. The same is true of climate. Rain and wind, heat and cold, not only vary with the seasons but with each day of the month and each hour of the day.

The people of Canada and the United States have reason to feel gratified that they possess so admirable a system of land subdivision, land surveys and land records. These form the chief interest to farmers living in a humid climate, but where irrigation is a necessity, water usually assumes prime importance. The reason for this is due to the fact that over the more arid portions of this continent the water supply is limited, while arable land of a very fine quality when irrigated, is abundant. The State of Nevada for example, has millions of acres of the finest kind of sage brush land, and an agreeable and healthy climate, but owing to the scanty rainfall only a small percentage of such land can ever be irrigated.

The precipitation in Western Canada is greater than it is in Nevada and some other western states, while the loss of water by evaporation is less. This larger supply of cloud water, coupled with greater natural conservation, gives to the western provinces of the Dominion, a large amount of water which can be utilized. It also follows that the more abundant the water supply the less is its value and the less is the necessity for its proper measurement and control. Notwithstanding these more favorable conditions as regards water, we believe the subject of more accurate measurement of irrigation water is deserving of the most careful consideration at the present time. Many arguments might be advanced in support of this belief, but the following may suffice:

(1) As time passes, the practise of irrigation is certain to be greatly extended throughout the provinces of British Columbia, Alberta and Saskatchewan. To secure reliable information concerning the water resources of these provinces in order to determine the feasibility of proposed irrigation enterprises and to safeguard capital invested therein, long-continued and systematic measurement of streams is a necessity. In this regard, the painstaking and efficient work carried on in recent years by the Water Branch of the Department of Lands of British Columbia, and the Hydrometric Surveys of the Dominion and the Province of Alberta, are to be commended. I might add that the stream measurement work of the United States in the far western

states has done perhaps more than any other agency of equal cost to develop and stabilize, not only irrigation but hydraulic power, mining and domestic water supplies. Conditions are so similar on each side of the international boundary that the same beneficial results are reasonably certain to accrue to the western provinces of Canada as a result of stream gaugings.

(2) The greater part of the water which is used for irrigation, power and other purposes, falls in the form of snow and rain on the elevated ranges and table lands. It is accordingly difficult to convey, distribute and apportion the water which collects in these great cold storage plants to thousands of users in the valley below. This task is well-nigh impossible without water measurements, and as a rule the more general and accurate the measurement, the greater the efficiency and the less the chance for controversies and litigation.

(3) The flow of rivers and creeks should not be only equitably apportioned among irrigation enterprises, municipalities, power companies, and other legal takers, but the flow of each canal or other water system should be equitably subdivided among those entitled to its use. Water deliveries based on guess-work lead to disputes, and disputes to litigation. Reliable water measurements and records usually safeguard the water user from both and enhance the value of his rights.

These and other arguments which might be presented point to the conclusion that utilized waters and those that might be utilized in the future, should be measured and the flow recorded. This conclusion, however, confronts us with another difficulty, and that is one expense. The water user has a right to enquire as to the cost of such measurements and whether he can afford to have measuring devices installed and maintained. In reply to such enquiries, it may be stated that most of the measuring devices, particularly those used in connection with irrigation systems, are relatively cheap. The costlier water meters are installed by municipalities usually at the expense of the consumer, to keep tab on the domestic supply, and this type could not well be used economically by irrigators. In what follows, the customary methods of stream, canal and water pipe measurements are briefly reviewed and the cheaper devices described.

The Measurement of Streams.

This work, in both the Dominion and the United States, is for the most part conducted by Government agencies, although private corporations sometimes make systematic and long-continued measurements independently of the Government. This is particularly true of streams utilized by power companies. The records of these companies are generally accepted at their full face value by the government, and in many cases are published in the same papers with the results of government measurements upon streams in the neighborhood. These government publications give the details of the methods of measurement used and of the equipment employed, and no object would be attained in repeating that information here, except to say that the current meter is the standard instrument for the measurement of the larger streams, and the meter or the weir for the measurement of small discharges. In many cases a meter is used during the flood flow, and the low water flow is led through a weir and determined with more accuracy than is possible with a meter. Among the publications that may be considered of an educational nature along the lines of river measurement may be cited:

Hydrographic Manual of the United States Geological Survey, House of Representatives Document No. 693; Water Supply and Irrigation Paper No. 94, U. S. G. S. Washington, D.C., U.S.A.

Accuracy of Stream Measurements, House of Representatives Document No. 694, Water Supply and Irrigation Paper 95, by E. C. Murphy, U. S. G. S. Washington, D.C., U.S.A.

Weir Experiments, Co-efficients and Formulas, Water Supply and Irrigation Paper No. 200, by R. E. Horton, W. S. G. S. Washington, D.C., U.S.A.

Equipment for Current Meter Gaging Stations, Water Supply Paper No. 371, by G. E. Lyon, U. S. G. S. Washington, D.C., U.S.A.

River Discharge, by Hoyt and Grover, published by Wiley and Sons, New York City.

Essential information is also given in condensed form in the annual reports of the Hydrometric Surveys (Stream Measurements), published by the Dominion Government at Ottawa.

Besides the meter and the weir, there are two methods of river or canal measurement that are used to slight extent when the equipment for the more accurate method is not at hand. The first of these is the float method which will be described further along in connection with canal measurement methods. The second is used to estimate flood discharges under conditions that preclude the use of the current meter, and river discharges when a meter is not available. This method consists in solving the Kutter or Manning formulas for V, signifying the mean velocity of the water in feet per second, when the other hydraulic elements, except the value of the friction factor, n, are known. These other elements are: the slope or rate of fall of the water surface, and the average area of the water cross-section. These elements are determined from measurements made in time of low water and preserved for just such uses. The value of the friction factor, n, is a matter of judgment, and may so vary from the actual value that discharges determined by this method should only be considered as accurate, say within, 25 per cent. When the value of V has been determined by one of these formula, then the discharge, Q, is found by multiplying the value of V by the mean area of the water cross-section in square feet. This gives the discharge in cubic feet per second. The Kutter and Manning formulas will be again spoken of in connection with canal measurements.

The Measurement of Water in Artificial Channels.

It may be stated in passing that the Division of Irrigation of the Bureau of Public Roads, U.S. Department of Agriculture, has included the measurement of water as one of its more important lines of investigation for the past six years. Some of his work has verified and confirmed similar investigations made throughout the world by various agencies, while other results have refuted the opinions of eminent hydraulicians who have attempted to apply one set of conditions the principles developed under other conditions.

This work has included the following special subjects:

(1) The determination of the carrying capacity of artificial channels.

(2) The capacity of weirs and submerged orifices under irrigation and power conditions, and the development of special measuring devices, based upon known hydraulic phenomena.

(3) The determination of the carrying capacity of wood-stave and concrete pipes.

(4) A comparison of results obtained by various methods used in the operation of the current meter in irrigation and power canals.

(5) A comparison of results obtained by floats and the more accurate current meters and weirs.

(6) The determination of velocities, from which discharges may be ascertained, by means of colors in pipe gagings.

(7) The testing of many types of special measuring devices to determine their adaptibility to irrigation and power conditions.

In order to design irrigation or power channels correctly or to estimate the capacity of canals which at the time of inspection are carrying but a part of their maximum capacity, a long series of experiments was conducted upon canals in commercial service. The results of these tests are embodied in "The Flow of Water in Irrigation Channels," Bulletin No. 194, U.S. Department of Agriculture, by one of our Senior Irrigation Engineers, Fred C. Scobey. This work may be considered as following the experiments made along the same lines by the writer more than twenty years ago, and described in Water Supply Paper No. 43, U.S. Geological Survey, entitled "Conveyance of Irrigation Water in Channels, Flumes and Pipes." The value of "n" in Kutter's formula, as listed by Mr. Scobey, confirm those recommended by the writer in so far as the types of channels are the same, but the later work covers some materials that were not in general use in the late eighties. For detailed information as to these values of "n" you are referred to the above publications, but in general they are as follows:

No values of "N" less than 0.011 are suggested for commercial construction. In isolated cases smaller values have been found, but we are of the opinion that these values are, for the most part, just those points on the low side of a general curve such as are found in any experimental work or that the conditions for experimentation were more nearly comparable to those obtaining in a laboratory than to those found in commercial use.

N=0.011 for smooth steel flumes under best of conditions. Some exceptionally high grade concrete and wood-stave pipe also show this low value.

N=0.012 to 0.016 for concrete lined channels and concrete flumes, the value to vary according to the conditions making for smoothness; a good design value for the average work to be about 0.014.

N=0.013 to 0.016 for timber flumes: the lower values to hold for the best lumber, alignment and workmanship, and the upper values to be used for unsurfaced lumber, in crooked alignment subject to deposits of rock ravellings and gravel.

N=0.016 to 0.025 for earth canals in materials ranging from smooth clays, without vegetable growth, up to old ditches in a fair state of maintenance, the accepted value for designing moderately sized canals that will receive pretty fair treatment being 0.0225, while small farm ditches are usually designed with a value of 0.025.

N=0.027 to 0.032 for mountain canals with cobble stone bottoms.

N=0.035 to 0.050 for rock cut canals, depending on the way the material breaks.

Moss, tree roots, rock ravellings, sand, etc., all tend to make the value of "N" high and are difficult to anticipate in design, but where conditions are such that these retarding elements are to be expected, a correspondingly high value of "N" is to be used; or better still, use a value of "N" as close as may be judged, but design for a large overload as a factor of safety.

In connection with the measurements of irrigation and power canals, described in Bulletin No. 194 as mentioned above, it was necessary to make a great number of gaugings by current meter. As most careful measurements were desired, the meter was held in a great number of verticals and in many points in each vertical. From the velocities at these numerous points could be developed the vertical velocity curves for a great number of verticals across the water section. The vertical velocity curve method is conceded by all authorities to be the most accurate means of operating a current meter. In the various verticals the meter was held at .2—.4—.6—.8 etc. of the depth and in many verticals, was also held near the surface and near the bottom of the channel. Holding the meter at these particular points enabled a comparison to be made between the results as obtained by vertical velocity curves and the results had any one of the so-called point methods been used. The most commonly used of the point methods are the "6-tenth" method and the combination of two points one taken at 2-tenths and the other at 8-tenths of the depth of the water.

Simultaneously with, or immediately following the basic measurements for the vertical velocity curves, the canal was measured by the so-called "integration method," in which the meter is moved slowly from the surface of the water to the bottom of the channel and back, a definite number of round trips. There is probably no type of engineering measurements that has the opinions of so many qualified men on diametrically opposite sides regarding its accuracy. There appeared to be ample ground for discounting the accuracy of this method for the reason that it is well known that the meter most used in irrigation and power work will revolve if moved in a vertical direction in still water, and the results of such movement are mentioned in "The Behaviour of Cup Current Meters Under Conditions Not Covered in the Standard Ratings," by Fred C. Scobey, published in Journal of Agricultural Research No. 2 (1914), page 77. Our findings in regard to the use of the current meter in the measurement of artificial channels may be summed up as follows:

In 96 measurements of the 0.2 and 0.8 depth, or the two-point method, gave results averaging 0.73 of one per cent high, while the 0.6 method averaged 4.8 per cent high. In 53 measurements the vertical integration method averaged 0.76 of one per cent too high. In other words either the two-point or the integration method is quite accurate, while the 0.6 method gives a discharge about 5 per cent too great. This last result is confirmed by some of the engineers of the U.S. Geological Survey. The results of these current meter method comparisons are described in an article: "Experiments in the Use of Current Meters in Irrigation Canals," by S. T. Harding, found in the Journal of Agricultural Research for November 8, 1915.

Mr. E. J. Hoff, of this Bureau, has recently invented a cup meter, similar to the type of the Price Meter, which does not revolve when moved up or down in a body of still water. With such a meter the integration method may be still more strongly recommended. As has been stated, the integration method when used with the old type of cup meter gives results sufficiently accurate for all practical purposes, and the ease with which a canal can be measured by this method is a strong incentive to its use.

At the time of the current meter observations in the canals, float measurements were also taken in order that comparisons might be made between the quite accurate current meter method and the approximate method of time floats over a given reach of canal.

The floats were operated in the following manner. A great many small sections of green wood were prepared by chopping willow or similar brush into pieces about two inches long. Green wood is desirable as it sinks low in the water beyond air resistance. Fifty or sixty of these were dumped from a hat into the swiftest part of the channel at the upper end of a measured reach of canal; generally the same reach as was used in computing the value of "n" for the major part of the experiment. The float first reaching the lower end of the reach was assumed to have taken the maximum threads of velocity throughout the reach, perhaps 1,000 feet long. Many floats must be used as they string out over perhaps 20 per cent of the course. When the final study was made by Mr. Harding he found that it was necessary to multiply the velocity as found by the fastes t float by a factor ranging from .60 for ditches having the value of "n" of about 0.030 and a cross sectional area of two square feet up to a factor of .91 for canals having a value of "n" of 0.012 and a cross sectional area of more than 30 square feet. Thus we see the co-efficient to be used varies with the size of the channel and also with the condition of the channel as regards smoothness. This information is not particularly new, being analyzed in Hering & Trautwine's translation of the original date of Kutter and Ganguillet, but somehow the standard works on hydraulics have advocated a co-efficient or factor of .80 to 0.83, but it is seen from the above statement of variation that his method can be but an approximation at best, and should only be accepted as such. Where the factor of .80 is used it is evident that the results are as liable to be from 20 to 30 per cent in error as to be right.

The Measurement of Water in Pipes.

In order to determine the actual carrying capacity of wood-stave pipe in commercial service, an extended series of experiments was conducted upon this type of pipe ranging in diameter from 8 inches to 13½ feet. The records obtained from these experiments were then analysed together with all other tests upon wood pipes and as the combined results were at variance with formulas at that time accepted for the flow of water in that type of pipe, a new formula was developed that did, as near as might be, fit all the experimental data. The result of this study was then submitted to several hydraulicians whose work qualified them to criticise it, and their discussions added to the original manuscript and the whole published as Bulletin 376 of the U.S. Department of Agriculture, "The Flow of Water in Wood-Stave Pipe," by Fred C. Scobey. The formula offered in this paper has been accepted for designing purposes by the U.S. Reclamation Service, many of the pipe manufacturers in the United States, and by the engineers generally throughout the country.

A similar series of experiments was conducted for two years upon the various kinds of concrete pipes and a bulletin has been prepared for publication, but it is not yet available in pamphlet form. However, the elements of the results for any particular kind of pipe may be obtained upon application to Irrigation Division, Bureau of Public Roads, Federal Bldg., Berkeley, California U.S.A.

In connection with the experiments upon the carrying capacities of wood-stave and concrete pipes, it was found that some method must be found of measuring the discharge within the pipe without installing a Venturi or other set type of water meter. A "gun" was developed with which solutions of powerful colors could be injected into the pipe against the pressure existing within the pipe. The passage of the color was timed as from the moment of injection to both the first appearance and the last appearance of the color at some outlet. Due to the variation of the velocities in concentric rings within the pipe, the color does not hold together as one mass, but it is distributed through a length of the pipe equal to about 10 per cent of the length over which the color has passed. The elapsed time used in computing the mean velocity of the water within the pipe is taken from the moment of injection to the mean between the moment of first and the moment of last appearance of the color. From comparisons with weirs and current meter measurements, it is believed that this method is accurate within about 3 per cent. The injection of coloring matter determines the velocity. In order to determine the discharge of the pipe, it is of course, necessary to multiply the mean velocity in feet per second, as found, by the mean cross-sectional area of the pipe, in square feet. The result will give the discharge in cubic feet per second. Of the possible colors that may be used, the following are probably the best, named in descending order: Fluorescein, Congo Red and Permanganate of Potassium. Fluorescein is very difficult to obtain at the present time and is practically prohibitive in price when found, but the Congo Red is still obtainable at reasonable rates.

Details of the equipment used and the results obtained by this method are found in Bulletin 376 of the Department of Agriculture, by Fred C. Scobey. It is entitled "The Flow of Water in Wood-Stave Pipes."

Weir Measurements.

The weir is the most common device for the measurement of water applied by irrigators to fields and farms throughout the west. In its simplest form it consists of a bulkhead or wall built across the channel of the stream to be measured, with an opening or weir-notch cut in the top of the wall. The enlarged channel immediately upstream from the bulkhead is called the weir pond and the height of the surface of the water in the pond above the bottom or crest of the notch is called the "head." When the water flows over the crest into the air before it strikes the surface of the water in the channel below the weir it is said to have a "free fall" and when this overpouring volume of water touches only the sharp upstream edge of the crest, the weir is said to be "sharp-crested."

The basic experiments with weirs were first made by James B. Francis at Holyoke, Mass., from 1848 to 1852. Mr. Francis' purpose was to devise a simple meter which would measure relatively large flows of water used to generate hydraulic power for manufacturing plants. His device has become quite general and is frequently applied to conditions other than those prescribed by him to ensure accurate measurements.

In order to test the accuracy of the Francis formula as applied to the smaller weirs used in irrigation practice and for the more general purpose of devising better methods of measuring irrigation water, our bureau in co-operation with the State of Colorado, constructed in 1912 and 1913 a hydraulic laboratory in connection with the Agricultural College and Experiment Station at Fort Collins, Colorado.

This plant consisted in a circular storage reservoir, lined with concrete, a brick laboratory, a series of carefully calibrated receiving reservoirs, rectangular in form, a pumping plant and the necessary apparatus. The work from its inception was placed under one of our hydraulic engineers—V. M. Cone. Mr. Cone was provided with the best apparatus obtainable, the water used in the tests was measured volumetrically in the most painstaking and accurate manner, and the results obtained may be regarded as basic and beyond question. Mr. Cone also devised and installed near the site of the laboratory, an up-to-date station for the rating and testing of current meters. This has proved a valuable adjunct to the equipment of the institution at Fort Collins, in that current meters used within the State of Colorado can be periodically tested, and if in error, re-rated at this station.

Referring once more to the subject of weirs, Mr. Cone and his assistant, Mr. R. L. Parshall, found among other things that the weir tables in general use, derived mainly from Francis' formula, contained a fairly high percentage of error when applied to small weirs under high heads. The errors varied from one to four per cent for low heads and from five to twelve per cent for high heads. These errors were corrected in a new formula which, though complicated, gave average results within 0.28 per cent of the experimental data. Weir tables for the smaller weirs used in irrigation practice having from one foot to four foot crests have been prepared from the new formula, and may be secured by writing to the U. S. Department of Agriculture for Farmers Bulletin 813 on the "Construction and Use of Farmers' Weirs," by V. M. Cone.

About the year 1885 an Italian engineer devised a trapezodial weir in which the sides of the notch sloped at an angle of 4 vertical to one horizontal. This was based on Francis' weir and the purpose of sloping the sides was to eliminate automatically the correction for end contractions necessary with the rectangular form of weir. In other words, he attempted to design a weir the discharge through which would be proportional to the length of the crest. Our Bureau has been instrumental in popularizing this trapezodial or Cipolletti Weir, as it is called, in the belief that it accomplished the purpose for which it was designed.

This belief has been demonstrated to be erroneous by hundreds of carefully conducted tests at the Fort Collins laboratory. It has been found that Cipolletti notches do not give discharges proportional to the length of the crests. The tests showed that for the smaller weirs from 1 to 4 feet in length the rectangular notches give discharges more nearly proportional to their lengths than do Cipolletti notches. The errors increase with the head and length of crest. The discharge through a four-foot Cipolletti notch with a 1-foot head, for example, was 9.2 per cent less than four times the flow through a 1-foot notch with a 1-foot head. In the case of the rectangular notch it was four per cent greater.

These defects in the trapezodial or Cipolletti weir together with its more complex form has led this Bureau to recommend the use of the rectangular weir instead. Those who care to look into this matter further will find a technical discussion given in volume V, No. 23, of the Journal of Agricultural Research, Dept. of Agriculture, Washington, D.C.

90° Triangular-Notch Weirs.

This form of weir is one of the best to measure small discharges of water of one-half second-foot or less. It can also be used for the larger discharges up to several second-feet, but the fall required is greater than for rectangular notches of equal capacity. 98 tests were conducted at Fort Collins, Colorado, on this type of weir, and the results are reported in No. 23, Vol. V, Journal of Agricultural Research; also in Farmers' Bulletin 813.

Recording Devices.

As has been stated, the flow of streams, artificial channels and other conduits fluctuate often between wide limits. The methods of measurement previously referred to give the discharge at the time the measurement is taken. In order to determine the quantity of water passing a given point for a period of time, as a day or a week, it is necessary to supplement the usual measurement by some recording instrument whose record will enable the observer to compute the flow between the interval of his actual measurements. More than a quarter of a century ago there were no reliable water registers made in this country. The first used by the writer was imported from Richard Bros., of Paris, France. Now there is a large variety of automatic water registers made by American firms. These devices either make a continuous record upon a chart revolving by clock work, or they possess a numbering apparatus similar to the dial on the ordinary house water meter, and this apparatus is operated by the velocity of the water. As a rule the first mentioned give the fluctuation of the water surface from which the flow is computed, while the second type of device gives the total flow in acre feet or cubic feet since the meter was installed in a manner similar to that of the ordinary house meter. This Division is now using principally the Gurley and Leitz registers for canals, each of which costs in the neighborhood of $65.00, and the Stevens' register for streams.