WATER MEASUREMENT PROCEDURES

by
Alvin J. Peterka, Hydraulic Engineer
Division of Engineering Laboratories
Bureau of Reclamation, Denver, Colorado

It is impossible at the moment to overstate the need for an improved water measuring program, not only in your district, project, or region, but nationwide, and even worldwide. In the western United States this need will be particularly acute within the next decade because of the increased demands for water for every conceivable use.

One way to increase the available water, of course, is to find new water sources. This is not always possible and is usually costly. The other way is to conserve and equitably distribute the water now developed and available. This latter course is usually possible and less expensive. We are interested in the latter course because this is our business and, as all of you know, more extensive use of the available water can be made if all measuring devices are accurate and dependable at all times. It is, therefore, important that every attempt be made to upgrade existing water measuring devices, not only in ditches, laterals, and canals, but in the supply systems as well. Every cubic foot of water saved as a result of improving the measuring devices is more valuable than a similar amount obtained from a new source because the saved water can be produced at considerably less cost.

Practically all measuring devices which are in error deliver more water than they indicate and it is important that each water user know exactly how much water he is receiving. If he thinks he is receiving 5 cfs and is actually getting 6 cfs he will be seriously hurt if at some future date he actually receives 5 cfs under a water rationing plan. It is often only necessary to understand the factors which influence measurement accuracy and make minor modifications to transform an inaccurate device into an accurate one.

The purpose of this article is to discuss the factors which influence accuracy and to show how each factor affects the commonly used measuring devices. In an attempt to simplify this presentation, only the important items are discussed and some of these have been interpreted by the author to provide practical answers to otherwise complex problems.

Standard and Nonstandard Devices

It has been said that a waterlogged boot in a ditch can be a measuring device--if it is properly calibrated. Certainly the boot would be a nonstandard device because no discharge tables or curves are available from which to determine the discharge. Many other devices including certain weirs, flumes, etc., are also nonstandard because they have not been installed correctly and, therefore, do not produce standard discharges. Although these commonly used devices may appear to be standard devices, closer inspection often reveals that they are not, and like the boot, must be calibrated to provide accurate measurements.

A truly standard device is one which has been installed correctly and maintained sufficiently to fulfill the original requirements. Standard discharge tables or curves may be relied upon, then, to provide accurate water measurements.

Any measuring device, therefore, is nonstandard if it has been installed improperly, is poorly maintained, is operated above or below the prescribed limits, or has poor approach (or getaway) flow conditions. Accurate discharges from nonstandard structures can be obtained only from specially prepared curves or tables based on calibration tests such as current meter ratings.

Calibration tests are costly when properly performed. Ratings must be made at fairly close discharge intervals over the complete operating range, and curves and/or tables prepared. It is therefore, less costly and usually not too difficult to install standard devices and use standard discharge tables.

In maintaining a standard structure it is only necessary to visually check a few items to be sure that the measuring device has not departed from the standard performance. In maintaining a nonstandard device it is difficult to determine whether accuracy is being maintained except by recalibration.

Principles of Water Measurement

To upgrade existing water measuring devices and improve the quality of installation of new devices it is necessary to understand some of the basic principles which influence the quantity of water passed by a measuring structure. Most devices measure discharge indirectly, i.e., velocity or head is measured directly and computations are used to obtain the discharge. Measuring devices may be classified, therefore, in two groups: (1) velocity-type and (2) head-type. Those using the velocity principle include:

A. Float and stopwatch
B. Current meters
C. Clausen-Pierce weir gage (or stick)
D. Propeller meters
E. Flow boxes
F. Vane deflection meters

When the velocity (V) principle is used, the area of the stream cross-section (A) must be measured and the discharge (Q) computed from Q = AV.

Devices using the head principle include:

A. Rectangular weirs
B. V-notch or multiple notched weirs
C. Cipoletti weir
D. Parshall flume
E. Meter gates
F. Orifice or venturi meters

When the head (H) principle is used, the discharge (Q) is computed from an equation such as the one used for a sharp-crested rectangular weir of length L,

$$Q = CLH^{3/2}$$

The area of the cross-section (A) does not appear in the equation but C, a coefficient, does. C can vary over a wide range in a non-standard installation but it is well defined for standard installations.

FLOW CHARACTERISTICS REDUCING ACCURACY OF MEASUREMENT

In inspecting a water measuring station, it should first be determined whether the device is a head or velocity measuring station. This is the key to the order and importance of other observations. In either case, the first observation should concern the visible flow conditions just upstream from the measuring device.

Approach Flow

Extremely large errors in discharge indication can occur because of poor flow conditions in the approach area. In general, the approach flow should be the same as tranquil flow in long straight canals (without obstructions) of the same size. Any deviation from a normal horizontal or vertical flow distribution, or the presence of water surface boils, eddies or local fast currents, is reason to suspect the accuracy of the measuring device. Errors of 20 percent are not uncommon and may be as large as 50 percent or more, if the approach flow conditions are very poor. Sand, gravel, or sediment bars submerged in the approach channel, weeds or riprap obstructions along the banks or in the flow area can cause unsymmetrical approach flow. Other causes may be too little clear length from a drop, check, turnout or other source of high velocity or concentrated flow, a bend or angle in the channel just upstream from the measuring device,

Figure 1, or excessive turbulence produced by a variety of causes. Standard weir installations for rectangular, Cipoletti, and 90° V-notch weirs are shown in Figure 2. The velocity of approach should be less than 0.5 foot per second. This value is obtained by dividing the maximum discharge by the product of channel width B and depth G measured at a point 4H to 6H upstream from the blade.

Turbulence

Turbulence is the result of relatively small volumes of water spinning in a random pattern within the flow mass as it moves downstream. It may be recognized as water surface boils or 3-dimensional eddies which appear and disappear in a haphazard way. Because of this local motion within the general motion of the flow mass, any particle of water may at any given instant be moving forward, sideways, vertically, or even backward. In effect, then, the water is passing a given point with a start and stop motion rather than with a uniform velocity which is ideal. It may be said that turbulent water does not flow as a train of railroad cars on a level track, but rather as a train of cars coupled with elastic bands, traveling over a series of rises, dips, and horizontal curves. Thus, fewer or more cars may pass a given point over identical short periods of time, depending on the observation point chosen. Turbulent water flows in the same manner, Figure 1.

Excessive turbulence will adversely affect the accuracy of any measuring device but is particularly objectionable when using current meters or propeller meters of any kind. Turbulence can be objectionable even without "white water" caused by air entrainment. Turbulence is usually caused by a stilling basin or other energy dissipator immediately upstream, by a sudden drop in water surface or by obstructions in the flow area such as operating or nonoperating turnouts having projections or indentations from the net area. Shallow flow passing over a rough bottom can also be the cause. Weeds or slumped riprap in the flow area or along the banks, or sediment deposits upstream from the measuring device also can cause excessive turbulence.

Measuring errors of up to 10 percent or more can be caused by excessive turbulence and it is absolutely necessary that all visible signs of turbulence be eliminated upstream from a measuring device.

Rough Water Surface

A rough water surface, other than wind generated waves, can usually be eliminated by reducing turbulence or improving the distribution of the approach flow. A rough water surface can cause errors in discharge measurements when it is necessary to (1) read a staff gage to determine head, or (2) determine the cross-sectional area of the flow. A stilling well will help to reduce errors in head measurement but every attempt should be made to reduce the water surface disturbances as much as possible before relying on the well.

Errors of 10 to 20 percent are not uncommon if a choppy water surface makes it impossible to determine the head accurately. It is sometimes necessary to resort to specially constructed wave damping devices to obtain a smooth water surface. Figure 3 shows a schematic of an underpass type of wave suppressor successfully used in both large and small channels. The channel may be either rectangular or trapezoidal in cross-section. Waves may be reduced as much as 93 percent by constructing the suppressor 4 times as long as the flow is deep. A slight backwater effect is produced by the suppressor for the most effective vertical placement. The suppressor may be supported on piers, can be constructed of wood or concrete, and need not be watertight. The design of several other types of suppressors, along with sample problems, is covered in Engineering Monograph No. 25, available through the Assistant Commissioner and Chief Engineer's Office, Denver, Colorado. Figures 4 and 5 (before and after) show the effectiveness of an underpass wave suppressor at a Parshall flume measuring station.

Velocity of Approach

It can be observed that as flow approaches a weir the water surface becomes lower on a gradually increasing curve, Figure 6. At the weir blade, the water surface is considerably lower than say, 5 or 10 feet upstream. The difference in elevation between two points on the surface of the approach flow is called the velocity head and represents the potential required to produce the increase in velocity between the points. The relation between head (h) and velocity (V) is expressed as

$$h = \frac{V^2}{2g}$$

g is the acceleration due to gravity, 32.2 (feet per second per second).

A drop in water surface of 0.1 foot is not uncommon just above a weir and (from the equation above) represents an increase in velocity of 0.8 foot per second. If the head on the weir is measured too close to the weir, the head measurement can be 0.1 foot too small. For a weir 6 feet long and discharging 7 cubic feet per second, the corresponding error in discharge would be about 35 percent, assuming that the indicated or reported discharge was 5.1 second-feet.

Standard weir tables are based on the measured head on the weir (velocity head negligible) and do not compensate for excessive velocity head. Any increase in velocity above standard conditions, therefore, will result in measuring less than the true head on the weir and more water will be delivered than is measured.

Causes of excessive velocity head include (1) too shallow a pool upstream from the weir, (2) deposits in the upstream pool, Figure 7, and (3) poor lateral velocity distribution upstream from the weir, Figure 1.

Poor Flow Patterns

It is often found that the poor flow distribution which exists upstream from a measuring device cannot be resolved on the basis of any one of the above-discussed causes. The best solution then is to assume that several or more basic causes have together caused the difficulty. Starting with the easy factors, work through the list, improving each probable cause of poor flow patterns until the desired flow conditions are obtained.

Operating or nonoperating turnouts located just upstream from a measuring device may cause poor approach conditions as may bridge piers, channel curves, or a skewed measuring section. Relocating the measuring device may be the only remedy in these cases.

Submerged weeds or debris can cause excessive turbulence or local high velocity currents. Sediment bars deposited from inflow or from sloughing banks can also produce undesirable flow conditions. More drastic remedial measures include deepening the approach area, widening the approach to make it symmetrical, or introducing baffles or other devices to spread the incoming flow over the entire width of the approach. Surface waves are usually very difficult to reduce or eliminate by ordinary procedures. These may require special treatment, as discussed under "Rough Water Surface."

Exit Flow Conditions

Exit flow conditions can cause as much flow measurement error as some of the approach flow problems. However, in practice, these conditions are seldom encountered. In general, it is sufficient to be sure that backwater does not occur sufficiently to submerge or tend to submerge a device designed for free flow. Occasionally, a Parshall flume is set too low and backwater submerges the throat excessively at high discharges. Extremely large errors in discharge measurement can be introduced in this manner. The only remedy is to raise the flume, unless some local obstruction downstream can be removed to reduce the backwater. Weirs should discharge freely rather than submerged, although a slight submergence (the backwater may rise above the crest up to 10 percent of the head) reduces the discharge a negligible amount (less than 1 percent). Gates calibrated for free discharge at partial openings should not be submerged nor should eddies interfere with the jet of water issuing from the gate. Gaging stations should be kept free of deposited sediment bars or other obstructions to prevent backflow or eddies from interfering with the uniform flow conditions which should exist in the cross-section being measured. The underside of weir nappes should be ventilated sufficiently to provide near atmospheric pressure beneath the nappe; between the under nappe surface and the downstream face of the weir, Figure 6.

If the nappe clings to the downstream side of the weir (does not spring clear) the weir may discharge 25 percent more water than the head reading indicates. An easy test for sufficient ventilation is to part the nappe for a moment with the hand or a shovel, to allow a full supply of air to enter beneath the nappe. After removing the obstruction, the nappe should not gradually become depressed (over a period of several or more minutes) toward the weir blade. If the upper nappe profile remains the same as it was immediately after being fully ventilated it may be assumed that the weir has sufficient ventilation.

EQUIPMENT CHARACTERISTICS REDUCING ACCURACY OF MEASUREMENT

Measuring devices themselves may be at fault in producing measurement errors rather than the flow conditions discussed in the previous section. The faults may be divided into two types--those caused by normal wear and tear, and those resulting from poor installation.

Weathered and Worn Equipment

An unwelcome but fairly common sight on older irrigation systems are weir blades, which were once smooth and sharp, in a sad state of disrepair. Edges are dull and have been dented; the blade is pitted or has rust tubercles--weir plates are discontinuous with the bulkheads and have water leaks. Weir blades have sagged and are no longer level. Staff gages are worn and difficult to read. Stilling well intakes are buried in sediment or partly blocked by weeds or debris. Parshall flumes are frost heaved and out of level. Meter gates are partly clogged with sand or debris and the gate leaves are cracked and worn.

These and other forms of deterioration are also the causes of serious errors in discharge measurements. This type of deficiency is difficult to detect because normal wear and tear may occur for years before it is apparent to a person who sees the equipment frequently. On the other hand, it is readily apparent to an observer viewing the installation for the first time.

It is imperative, therefore, that the person responsible for the measuring devices inspect them with a critical eye. His attitude should be--I am looking for trouble--not, I will excuse the little things because they are no worse today than they were yesterday.

Measuring devices which are rundown are no longer a standard measuring device, and indicated discharges may be considerably in error. To be certain of the true discharge, they should be rehabilitated and calibrated.

Repairing or refurbishing a rundown measuring device is sometimes a difficult or impossible task. Fixing the little things as they occur will prevent, in many cases, replacing the entire device at great cost at some later date. Regular and preventive maintenance will extend the useful life of measuring devices.

Poor Workmanship

Contrasting with the measurement devices which were once accurate and dependable and have deteriorated, are those which, because of poor workmanship, were never a standard device. These include devices which are installed out-of-level or out-of-plumb, those which are skewed or out of alinement, those which have leaking bulkheads with flow passing beneath or around them, and those which have been set too low or too high for the existing flow conditions. Inaccurate weir blade lengths, Parshall flume throat widths, or incorrect zero setting of the head or staff gage can also be the cause of measuring errors.

A transverse slope on a weir blade can result in errors, particularly if the gage zero is referenced to either end. The error can be minimized by determining the discharge based on the head at each end and using the average discharge. Errors in setting the gage zero are the same as misreading the head by the same amount. At low heads a zero setting error can result in errors up to 50 percent of the discharge or more. A head determination error of only 0.01 foot can cause a discharge error of from 5 percent on a 90° V-notch weir, to over 8 percent on a 48-inch Cipoletti weir (for a head of 0.20 foot). The same head error on 6- and 12-inch Parshall flumes can result in 12 and 6 percent errors, respectively, for low heads.

Weir blades which are not plumb or are skewed will show flow measurement inaccuracies of measurable magnitude if the weir is out of line by more than a few degrees. Rusted or pitted weir blades or those having projecting bolts or offsets on the upstream side can cause errors of 2 percent or more depending on the severity of the roughness. Any form of roughness will cause the weir to discharge more water than indicated. Rounding of the sharp edge of a weir or reversing the face of the blade also tends to increase the discharge. On older wood crests a well rounded edge can cause 15 to 25 percent or more increase in discharge, Figure 8.

The effect of a few deficiencies often found in measuring devices has been given to illustrate the degree of error to be expected in making ordinary measurements under ordinary conditions. Other effects have not or cannot be stated as percent error without an exact definition of the degree of fault or deterioration. The examples given should be sufficient, however, to emphasize the importance of careful and exact installation practices as well as regular and prompt repair or rehabilitation of the devices after they have been installed.

MEASURING TECHNIQUES REDUCING ACCURACY OF MEASUREMENT

It is possible to obtain inaccurate discharge measurements from regularly maintained equipment properly installed in an ideal location, if poor measuring techniques are used by the operator. Measurement of head is very important and some of the techniques now in use are not compatible with the relationships between head and discharge known to exist.

The frequency of head measurement is also important and may be the cause of inaccurate water measurement. These and other related miscellaneous techniques are discussed in the next paragraphs.

Faulty Head Measurement

Measurement of the head on a weir seems to be a simple matter but can be difficult under all but ideal conditions. The head is the height of water above the blade edge (or crotch of a V-notch) measured at a point where the velocity head (or velocity of approach) is a negligible value, Figure 2. In practice this means a point located 4 to 6 times the head upstream from the center of the weir blade. If the head is measured farther upstream, the head necessary to produce flow in the approach channel (water surface slope) may be inadvertently included to give a larger head measurement. If the head is measured closer to the weir blade, some drawdown (caused by increased velocity near the weir) may occur and less than the true head may be measured. If the head is measured at the side of the approach channel, more or less than the true head may be measured depending on the geometry of the approach pool, Figures 2 and 6.

The practice of placing staff gages on weir bulkheads or on bankside structures should be investigated in each case to be sure that a true head reading can be obtained. Placing a rule or a Claussen-Pierce gage on the weir blade also gives an erroneous reading. The taking of head measurements when debris or sediment has a visible effect on the flow pattern can also result in faulty head determination, Figure 9. Measuring head when the measuring device has obviously been damaged or altered, is also to be avoided. Figure 10 shows a weir performing properly for the discharge shown. At larger discharges the unsymmetrical approach pool may produce undesirable conditions. The principles described above also apply to head measurements on Parshall flumes, meter gates, or any other device dependent on a head measurement for discharge determination.

Improper gage location or error in head measurement in a Parshall flume can result in very large discharge errors. Throat width measurements (and weir lengths) can also produce errors although these are usually small because of the relative ease of making accurate length measurements. (Operators should measure lengths and not rely on values stated or shown on drawings.) Readings obtained from stilling wells, whether they are visual or recorded, should be questioned unless the operator is certain that the well intake is not partially or fully clogged. Data from an overactive stilling well can also be misleading, particularly if long period surges are occurring in the head pool. In fact, all head determinations should be checked to be sure that the instantaneous reading is not part of a long period surge. Sufficient readings, say 10, should be taken at regular time intervals, say 15 seconds, and averaged to obtain the average head. More readings may be required if it is apparent the pool is continuing to rise or fall. If this is too time consuming the cause of the instability should be removed.

Readings from gages or staffs which may have slipped or heaved should be avoided. Periodic rough checks can sometimes be made with a carpenters level from a reference point on another structure.

In short, it is desirable that each operator understand the measurement he is trying to make, and then to critically examine each operation to be sure that he is measuring what he intends to measure. He should try to find fault with every step in making a head measurement and try to improve his technique wherever possible.

Infrequent Head Measurement

When a head measurement is made to determine discharge, it can be concluded that the measured discharge occurred at the moment the head was measured. It cannot be concluded that the discharge was the same even 5 minutes later or 5 minutes earlier. Therefore, water deliveries can be accurate only if enough head measurements are made to establish the fact that the discharge did or did not vary over the period of time that water was being delivered.

In many systems, head measurements are made only once a day, or only when some mechanical change in supply or delivery has been made. Problems introduced by falling head, rising backwater, gate creep or hunting are often ignored when computing a water delivery. The problem is not a simple one, at times, and there are many factors to consider in determining the number of readings to be made per day or other unit of time. If the discharge or head in the supply system is increasing or decreasing, it will be necessary to take more than a single reading. If the rate of rise is uniform the average of two readings, morning and night, would be better than one. If the rate of change is erratic, frequent readings may be necessary. If a great many readings are known to be necessary, a recording device may be justifiable.

Sometimes when the discharge in the supply system remains constant, the water level changes because of a change in control, or because checks have been placed in operation. Temporary changes in discharge in the main supply system may occur because water, in effect, is being placed in storage as a result of the rising water level. Conversely, the discharge may temporarily increase in parts of the system, if the operating level is being lowered. The changing water level may make it necessary to take more frequent head readings.

Here again, the operator should try to visualize the effect of any change in discharge or level in the supply system, upstream or downstream from a measuring device, and attempt to get more than enough head readings to accurately compute the quantity of water delivered.

CURRENT METER GAGING STATIONS

In selecting a site for a gaging station or a location for a meter or any other propeller device, it is important that smooth uniform flow exist upstream (to some degree downstream) from the location at all times. The cross-section of the canal should be typical of the sections upstream and downstream and should be in stable material. Locations where banks or bottom can erode or where sediment is known to deposit, should not be used. A site where meters can be operated from the upstream side of a bridge is desirable because a cableway or other crossing need not be constructed. In general, the site should produce flow conditions that meet the requirements discussed under the section, "Flow Characteristics Reducing Accuracy of Measurement."

A staff gage and/or water stage recorder should be installed and carefully referenced to some meaningful datum. In operating the station, a standard procedure should be established and followed for each measurement. Procedures are given in detail in the Bureau's Manual for Measurement of Irrigation Water.

After the station is put into operation, it should be checked periodically and maintained in its original condition. Sediment bars should be removed from the bottom and corrections to the net section made, if erosion occurs on the banks or bottom. If the water surface is raised or lowered by checking, careful time records should be kept to determine when the staff gage or water stage records are an indication of the discharge.

USE OF WRONG MEASURING DEVICE

Every water measuring device has limitations of one kind or another and it is impossible to choose one device which can be used in all locations under all possible conditions. It is to be expected, therefore, that for a given set of conditions there may be several devices which would be suitable, but none could be considered entirely satisfactory. If flow conditions change or are changed by modified operations, an original device, which was marginal in suitability, may be found to be totally inadequate. It is possible, too, that the wrong device was selected in the first place. Whatever the reason, there are instances where accurate measurements are being attempted using a device which cannot, even with the greatest care, give the desired results. The operator should call attention to such a situation and attempt to have remedial measures taken.

For example, a weir cannot be expected to be accurate if the head is appreciably less than 0.2 foot, or greater than about one-third of the length. Large measurement errors can be expected (departure from standard), if these limits are exceeded appreciably. If a weir is submerged appreciably by backwater, large errors may be introduced depending on other factors. In view of uncertainties which cannot be explained satisfactorily, submerged weirs should be avoided wherever possible. Parshall flumes should not be operated at more than the critical degree of submergence (80 percent); in fact, they should not be submerged at all, unless provisions have been made in the flume for a downstream head measuring well, and the method of computing submerged discharges from the published "Free Flow" tables is thoroughly understood. This is explained in detail in Bulletin No. 426-A, March 1953, "Parshall Flumes of Large Size," by R. L. Parshall, U.S. Department of Agriculture, Fort Collins, Colorado.

Propeller meter devices should not be permanently installed where weeds, moving debris, or sediment are apt to foul the meter or grind the bearings. Submerged devices, such as meter gates, should not be used where a moving bedload can partly block the openings.

In short, it is necessary to analyze the flow conditions to be encountered at a particular site, and only then, select the measuring device which can best cope with the unusual condition to be encountered.

CONCLUSIONS

It is difficult, if not impossible, to establish definite rules which apply generally to water measurement procedures and equipment. Similarly, one measurement device cannot be recommended over any other device until all variables at the particular installation site are considered and properly weighted. It is therefore necessary for each operator to learn as much as possible about the device he is using and to evaluate the effect of each variable (at the particular site) on the measurement he is making.

Each operator must learn to look objectively at his equipment and procedures. He must be able to "see" that his equipment is rundown and in need of maintenance or that his measurement procedures are not compatible with what he is trying to measure. He should try to find fault with his equipment and every step he uses to make a discharge measurement, and try to improve wherever possible. This means that he must understand the basic measurement he is trying to make and then modify, if necessary, his methods of getting it. He should read available literature as much as possible to get background information on water measurement. He will thereby not only obtain more meaningful information, but will also have the satisfaction of knowing his job is well done.

NEW MEASURING DEVICES AND TECHNIQUES

Water has become sufficiently valuable in certain areas of the West that large sums of money are being expended to prevent seepage from canals and laterals. Conservation of water has become a keyword from the standpoint of both reducing conveyance losses and improving measuring techniques. Equipment manufacturers have become aware of this fact, and several new water measuring devices and techniques have been put on the market--on somewhat of a trial basis.

One manufacturer has developed a vane flowmeter which is claimed to be accurate within a few percent. The meter is portable and, in use, rests in permanent brackets mounted in a 6-foot long ditch-liner section, either trapezoidal or rectangular in cross-section. One meter will service any number of ditches of the same general size having the liner and brackets permanently installed. Larger or smaller ditches require another size meter with its corresponding ditch liner. About 30 sizes are available to handle discharges up to 30 cfs. Each meter will handle a range of flows in a given size ditch and automatically compensates for velocity and depth changes. There is negligible loss of head in making a measurement. No totalizing device is available.

A magnetic flowmeter has been placed on the market which is designed for use in measuring pipe flows. The meter contains no moving parts and therefore cannot clog or be affected by sediment, weeds, or debris. The water passing through the meter cuts the lines of force produced by a magnetic field which surrounds the flow and actuates an indicating and totalizing device. Calibration tests show the meter to be reasonably accurate. No device of this type is yet available for use in open channels.

The radioisotope method of measuring water is being rapidly developed and some of the first field measurements in large canals were performed this year. In this method, a radioactive tracer is introduced into the flowing water upstream from the point of measurement and, after thorough mixing of the tracer with the flow, the radioactivity in a sample of water is "counted" by means of specially devised instruments (similar to a Geiger counter). From the quantity of tracer introduced and the "total count" in the sample, it is possible to compute the discharge. It is not necessary to measure velocity, depth, cross-sectional area, or water surface level. Theoretically and mathematically, the method is sound; it remains to develop practical field procedures to fully adapt the method for open channel flow measurements. Procedures have been developed for measuring flow in pipes with a claimed accuracy of 0.1 percent. The use of radioisotopes in measuring open channel flows shows real promise and the Bureau is actively engaged in improving and evaluating the doubtful procedures now used in making a discharge measurement.

REFERENCES

The following publications are suggested as an aid in acquiring background in water measurement practices. The items have been selected to provide practical help or background information, or both, and should be of value to both new and experienced personnel. Copies may be obtained from a public library or from the sources listed.

Items 1, 2, and 8 are valuable as handbooks and would be of permanent value as reference books. The principles discussed will be found helpful in understanding and operating almost every type of measuring device.

1. Water Measurement Manual, United States Department of the Interior, Bureau of Reclamation, First Edition, Denver, Colorado, May 1953

2. Handbook of Hydraulics, H. W. King, Third Edition, McGraw-Hill Book Company, Incorporated, New York City, New York

3. The Discharge of Three Commercial Cipoletti Weirs, R. B. Van Horn, Engineering Experiment Station Series Bulletin No. 85, University of Washington, Seattle, Washington, November 1935

4. Precise Weir Measurements, E. W. Schoder and K. B. Turner

5. Accuracy of the V-Notch Weir Method of Measurement, Transactions ASME, Volume 48, 1926, page 939

6. Weir Experiments, Coefficients, and Formulas, R. E. Horton, Water Supply Paper 200, Geological Survey, U.S. Department of the Interior, Washington, D.C.

7. Stream-gaging Procedure, D. M. Corbett, United States Department of the Interior, Geological Survey Water Supply, Paper 888, 1945, U.S. Government Printing Office, Washington, D.C.

8. Parshall Flumes of Large Size, R. L. Parshall, Bulletin 426-A, March 1953, U.S. Department of Agriculture, Colorado State University, Fort Collins, Colorado

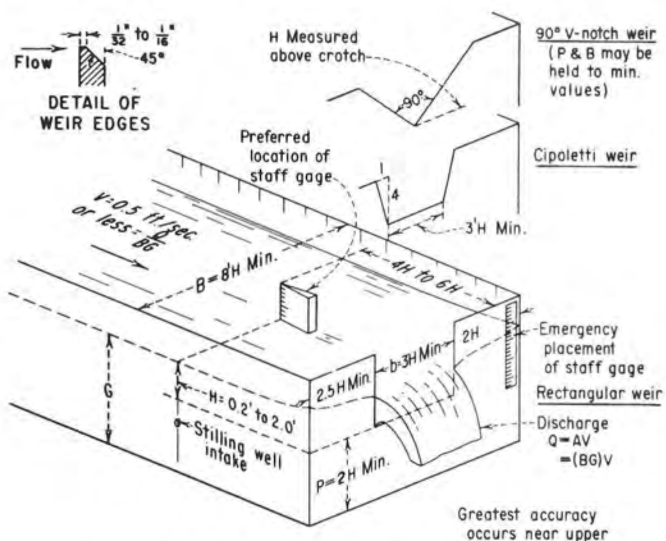
9. Improving the Distribution of Water to Farmers by Use of the Parshall Measuring Flume, R. L. Parshall, Bulletin 488, U.S. Department of Agriculture, Colorado State University, Fort Collins, Colorado

10. Measurement of Debris-laden Stream Flow with Critical-depth Flumes, H. G. Wilm, V. S. Cotton, and H. S. Storey, Transactions ASCE, Volume 103, 1938, page 1237

11. World Practices in Water Measurement at Turnouts, C. W. Thomas, Proceedings ASCE, Journal of the Irrigation and Drainage Division, Volume 86, June 1960, Part 1

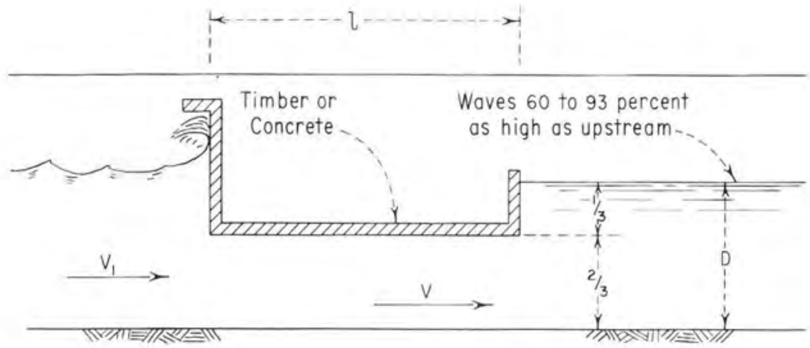
12. Common Errors in the Measurement of Irrigation Water, C. E. Thomas, Proceedings ASCE, Journal of the Irrigation and Drainage Division, Volume 83, September 1957

Poor approach flow conditions upstream from weir. The high-velocity, turbulent stream is approaching the weir at a considerable angle. Head measurement is difficult, and weir does not discharge a "standard" quantity. PX-D-30664 Figure 1



WEIR PROPORTIONS
RECTANGULAR, CIPOLETTI AND 90° V-NOTCH

Figure 2



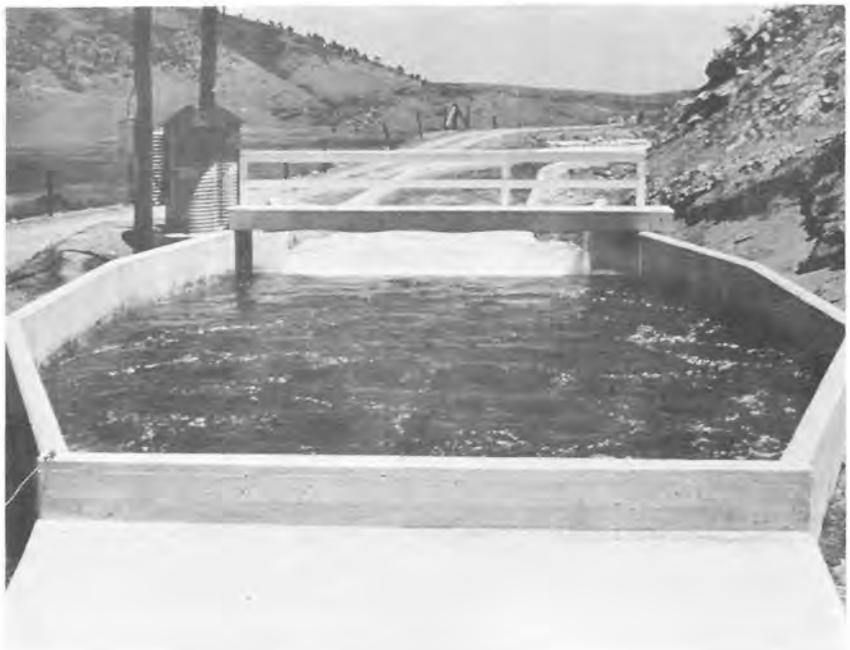
LENGTH l	PERCENT WAVE REDUCTION
1D TO 1.5D	60 TO 75
2D TO 2.5D	80 TO 88
3.5D TO 4.0D	90 TO 93

UNDERPASS WAVE SUPPRESSOR SECTION

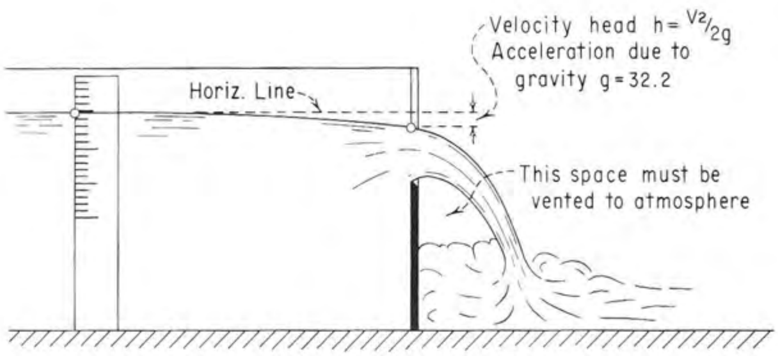
Figure 3

Turbulence and waves in a Parshall flume produced by an outlet works stilling basin made accurate discharge determination impossible. Log raft in foreground, used in futile attempt to quiet the flow, is inoperative. P245-D-30666

Figure 4



Underpass-type wave suppressor significantly reduces turbulence and waves in Parshall flume, making accurate discharge determination a routine matter. Compare with Figure 4. P245-D-30663
Figure 5



SECTION ON LONGITUDINAL CENTERLINE

Figure 6

Sediment deposits have reduced the depth of the weir pool sufficiently to increase the velocity of approach to well above the desirable level. Along with the head gage being located close to the weir blade, discharges over the weir would be larger than indicated in "standard" tables.

P-20-D-21558 Figure 7

The well rounded edge on this once sharp-crested weir will increase the discharge well above "standard." The weeds are also undesirable.

P-20-D-21557 Figure 8

Weeds protruding through the opening and sediment in the approach pool will result in inaccurate discharge determinations.
PX-D-30665 Figure 9

Cippoletti weir operating with good flow conditions in the approach pool. Flow is well distributed across wide pool and shows no evidence of excessive turbulence. Accurate or "standard" discharges can be expected under these conditions.
POAX-D-18350 Figure 10

GPO 851850