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THE RATING AND USE OF CURRENT METERS

By Carl Rohwer, Associate Irrigation Engineer

Based on data gathered under cooperative agreement between the Bureau of Agricultural Engineering, United States Department of Agriculture, and the Colorado Experiment Station.

Prepared under the Direction of W. W. McLaughlin, Chief, Irrigation Division, Bureau of Agricultural Engineering

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THE RATING AND USE OF CURRENT METERS[1]

BY CARL ROHWER, ASSOCIATE IRRIGATION ENGINEER
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Since Woltman invented the revolving current meter for measuring velocities of flowing water at different depths in 1790, many changes have been made in current meters, but the fundamental principle remains the same. Meters of this kind have a rotating element whose speed depends on the velocity of the water. They are of two types and are known as cup meters and propeller meters. Many conflicting claims have been made as to the advantages and disadvantages of these meters, and from time to time the accuracy of current-meter measurements in general has been questioned. For these reasons a series of tests was carried on by the Colorado Agricultural Experiment Station, in cooperation with the Bureau of Agricultural Engineering, of the United States Department of Agriculture, to investigate the behavior of these two types of meters and to determine the accuracy of current-meter measurements.

This investigation was divided into two parts; the first was devoted to the study of the action of the different types of current meters when rated under various conditions, and the second to the comparison of the discharge determined by different kinds of current meters under various conditions, using different methods of measurement and that from a standard Francis weir. The results of the study are summarized in this report. In view of the great mass of information collected in making the study, and since it was not possible to present all of the data in the report, it was necessary to select only the more important information.

Woltman's current meter was an adaptation of the float wheel invented by Borda and Dubuat so that it would be possible to measure the velocities at different depths. It was of the propeller type and

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(1) This bulletin was prepared under the direction of Mr. W. W. McLaughlin, Chief of the Irrigation Division of the Bureau of Agricultural Engineering. The work was carried on under a cooperative agreement between the United States Department of Agriculture and the Colorado Experiment Station. This project was started by V. M. Cone, formerly in charge of the Irrigation Investigations in Colorado. The experimental data pertaining to meter ratings were obtained by R. L. Parshall, Senior Engineer, and the data pertaining to current-meter measurements were obtained by the author. Messrs. Thomas McCarthy, T. L. Doyle, M. L. Lightburn and Duane C. Kelso (deceased) also assisted in the work. Manufacturers and other interested parties gave valuable assistance by loaning meters for the tests, and the Jackson Ditch company by providing facilities for conducting the tests at the Bellvue laboratory.

the revolutions of the propeller were registered on dials. Several attempts were made to improve the meter, but it was not until D. F. Henry replaced the registering dials by an electrical recording device that the meter attained a form sufficiently sensitive for accurate work and convenient enough for everyday use.

The invention of the electric revolution indicator for current meters was followed by other improvements, and the meters in use at the present time are the result of these developments. Two distinct types of meters were evolved: The cup meter, which is primarily an American type, was developed by Henry, Ellis and Price; the propeller meter, which is used principally in European countries, was perfected by Amsler, Stoppani, Haskell, Ritchie, Fteley, Ott and Hoff. Many others contributed to the development of the current meter, but the names are given of only those who perfected meters which attained general use.

Of these instruments, the Price cup meters and the Ott propeller meters are at present most extensively used. Due to the adoption of the Price meter as standard equipment by the United States Geological Survey and by the state engineering departments engaged in stream gaging, the use of this meter has become almost universal in the United States. It is also used in England and Canada. In Europe and parts of South America, the Ott propeller meters are most generally used. Other meters, such as the Haskell and the Hoff in the United States, and the Amsler and the Stoppani in Europe (all of which are of the propeller type) have been used extensively in the solution of special problems or have attained local importance.

TYPES OF METERS STUDIED

The Price meter was originally designed by W. G. Price in 1885. A modified form of the meter was adopted soon thereafter as the standard meter for the United States Geological Survey, and the type in use at the present time, known as the Improved Price Meter, is the result of the experience gained by many engineers under a great variety of conditions. Plates 1 and 2 show the latest-type Price meter. The improved Price meter consists of six conical-shaped cups concentrically arranged about a vertical axis which is supported by a C-shaped yoke to which the tail of the meter and the handling rod or cable are attached. The lower end of the shaft rotates on a pivot bearing and the upper end in a cylindrical bearing. The upper end of the shaft also carries the electric revolution-indicating device. In the latest models of the Price meter, the indicating device is so arranged that it registers either each revolution or every five revolutions of the cup wheel. This change is accomplished by merely changing one of the leads of the electrical circuit from one terminal on the meter head or contact chamber to the other. In the older models, in-

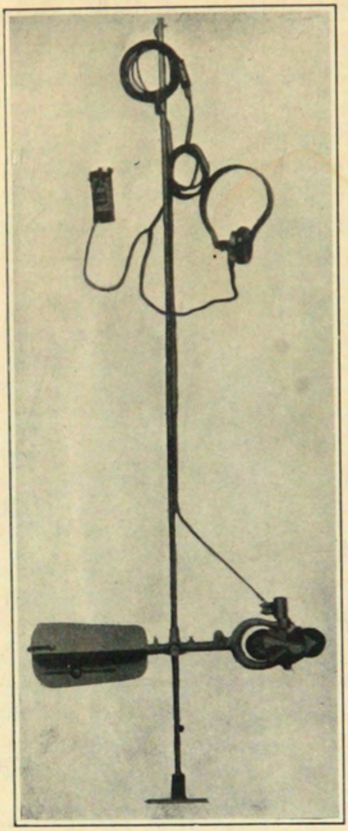

Plate 1.—Improved Price rod meter with combination head similar to number 29,502. (Photograph courtesy of W. & L. E. Gurley Company.)

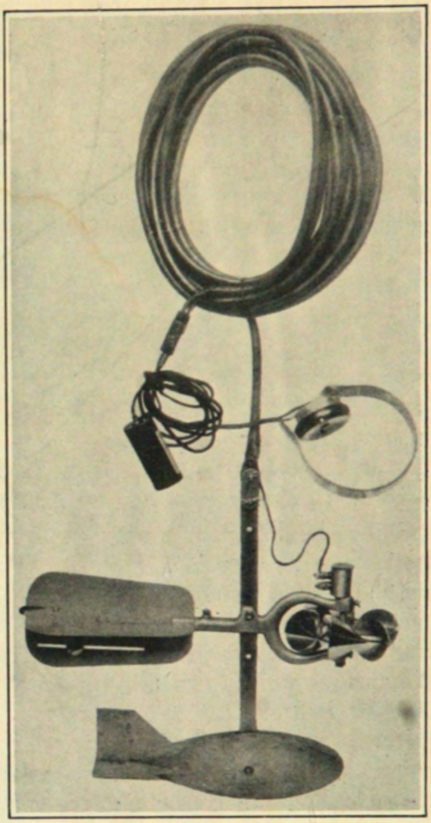

Plate 2.—Improved Price cable meter with combination head and latest type weight. (Photograph courtesy of W. & L. E. Gurley Company.)

terchangeable heads were used for registering the different numbers of revolutions. A telephone receiver or buzzer is placed in the electrical circuit so that the observer can count the revolutions of the meter. A small dry battery furnishes the current for the circuit. The lower bearing of the meter, which consists of a pivot and cone, is protected from injury while the meter is being transported by lowering the pivot so that the point cannot come in contact with the shaft. In the previous model of the meter, this was accomplished by lifting the shaft by a knurled nut which screwed on the shaft of the meter and bore down on the yoke when the meter was being transported. A tail, which is attached to the back of the yoke of the meter, is provided to balance the meter and hold it in the direction of the current. The tail may be removed when the meter is used with a rod.

The Price meter is designed so that it may be used either as a rod or as a cable meter. When used as a rod meter, the rod is connected by a special attachment either to the slot in the meter frame back of the yoke or is screwed into the top of the yoke. When it is desired to make it possible to move the meter up and down the rod, a sliding sleeve block thru which the rod passes is placed between the yoke and the tail. A knurled set screw in the sleeve serves to clamp the meter in place. A foot plate is attached to the rod to prevent the rod from sinking into the bed of the stream where soft materials are encountered.

When used with a cable, the meter is attached to a flat bar called the hanger which is passed thru the slot in the frame of the meter. The position of the meter is fixed by a pin thru the hanger and the sides of the slot. The width of the hanger is slightly less than the slot. This permits the meter to tilt up and down and be free to take a horizontal position when in operation. The meter is held in place against the current by a weight which is attached to the lower end of the hanger. Various sizes of weights are used, depending on the velocity of the stream. For ordinary velocities, the 15 and 30-pound weights are commonly used, but in deep channels where the velocities are high, 50, 75 or even 100-pound weights are used. These weights were originally made torpedo shaped, but recent experiments have shown that weights with blunt noses offer less resistance to the water. The latest weights are of this type. The cable which supports the meter is attached to the upper end of the hanger which carries the meter and the weights. The wires for the electric circuit are enclosed within the cable from which the meter is suspended.

Ott meters are made in several different forms (see Plates 3, 4, 5, 6 and 7) but all consist essentially of a propeller and horizontal shaft, a revolution-indicating device, a frame, a tail, and a rod or cable support. Several different types of propel-

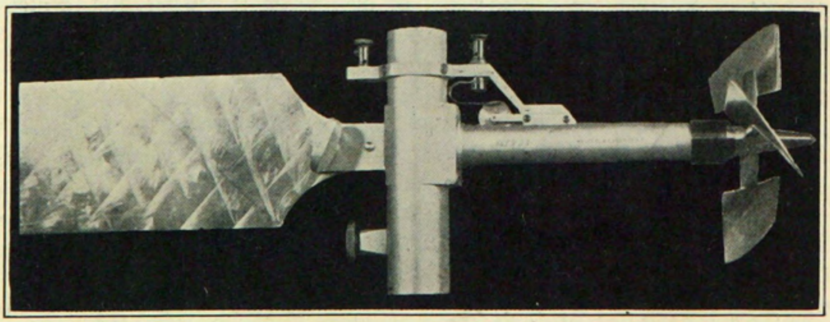

Plate 3.—Ott meter number 1933, with exposed contact mechanism.

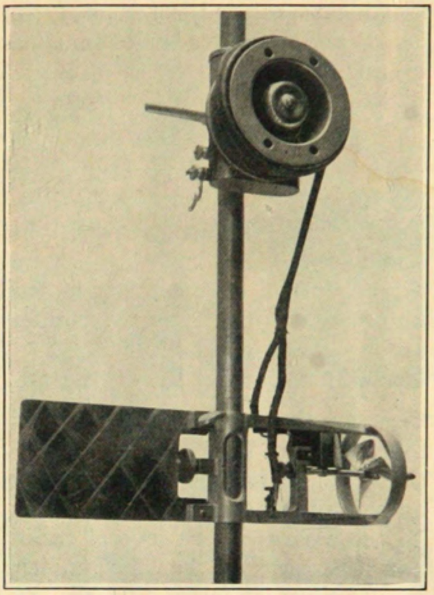

Plate 4.—Ott meter number 2956, with rod and with bell-ringing contact mechanism, same as meters numbers 1398 and 3718.

lers are used on the Ott meters. One consists of a series of vanes, either three or four, attached to spokes radiating from a hub; one consists of three light vanes attached directly to a hub and surrounded by a ring which protects the vanes from injury, and one consists of a two-bladed propeller of heavy aluminum cast integrally with the hub. The last-named type is made also with light vanes attached directly to the hub. The front edges of the propeller blades of the last two types are made sloping so that they will be self-cleaning. The cast aluminum propeller is made with either a high or a low pitch. The light vane meter with the guard ring is almost identical with the Stoppani meter.

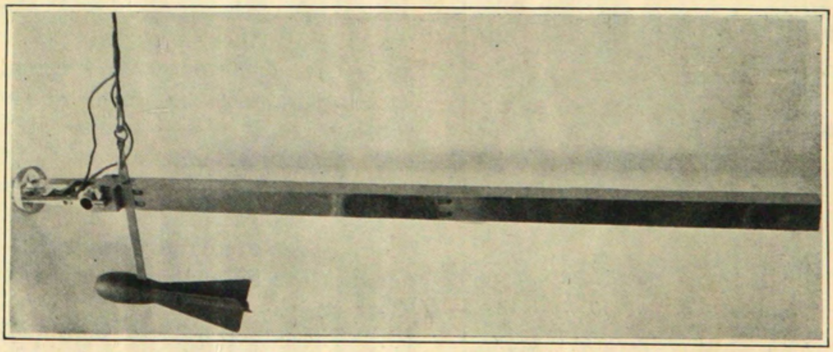

Plate 5.—Ott meter number 2956 with cable suspension and buoyant tail.

The propellers with the vanes attached to spokes, and the ones with the two vanes attached directly to the hub, both have axles with ball bearings at the propeller ends and agate bearings at the rear ends. The small meter with the guard ring has pivot journals running in agate bearings at both ends. The axle of the meter with the cast aluminum propeller is stationary and merely supports the ball bearings on which the propeller rotates. The bearing is kept

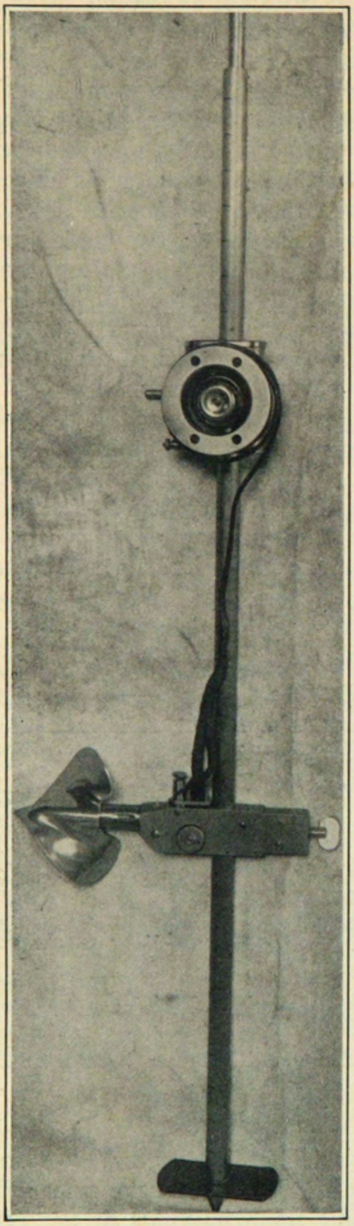

Plate 6.—Ott meter number 4184 with rod and bell-ringing contact mechanism, without tail.

filled with oil to protect it from corrosion by water and abrasion by grit.

The revolving axles of these meters are equipped with worms which mesh with the worm gears that operate the revolution-indicating devices. The meter with the stationary axle has the worm thread cut on an extension of the hub of the propeller which rotates around the fixed shaft.

The revolution-indicating devices for these meters are designed to contact at 10, 25 or 50 revolutions, depending on the meter and on the pitch of the propeller used. In those cases where several ratios are necessary in the same meter, the change is accomplished by changing the contact pins in the worm gear which is driven by the worm on the propeller axle or hub. All the meters except the small Ott meter with the guard and the meter with the vanes on radial arms have enclosed contact chambers to eliminate the danger of erroneous readings in saline or acid water, and these meters may be equipped with the enclosed contact chamber if desired. For conditions where reverse currents are anticipated, a special contact wheel with short and long contacts is provided. These meters are equipped with both telephone receivers and electric bells for indicating the revolutions.

The Ott meter is designed to be used either with a rod or a cable. When operated as a cable meter, a long hollow tail of rectangular section is used to balance the meter and hold it parallel to the current.

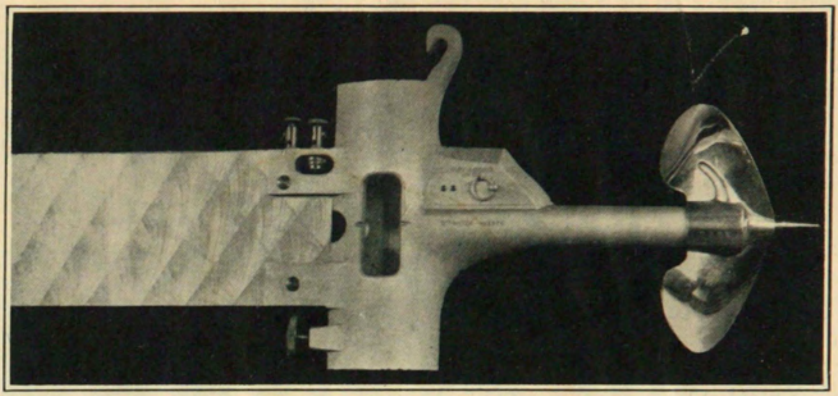

Plate 7.—Large Ott meter number 2575, with two-bladed propeller and enclosed contact mechanism.

The meter is attached to a flat hanger bar which passes thru a slot in the frame which is large enough so that the meter is free to assume a horizontal position. A blunt-nosed torpedo weight is attached to the lower end of the hanger bar to keep the meter from drifting downstream with the current. When operated as a rod meter, a tail is not

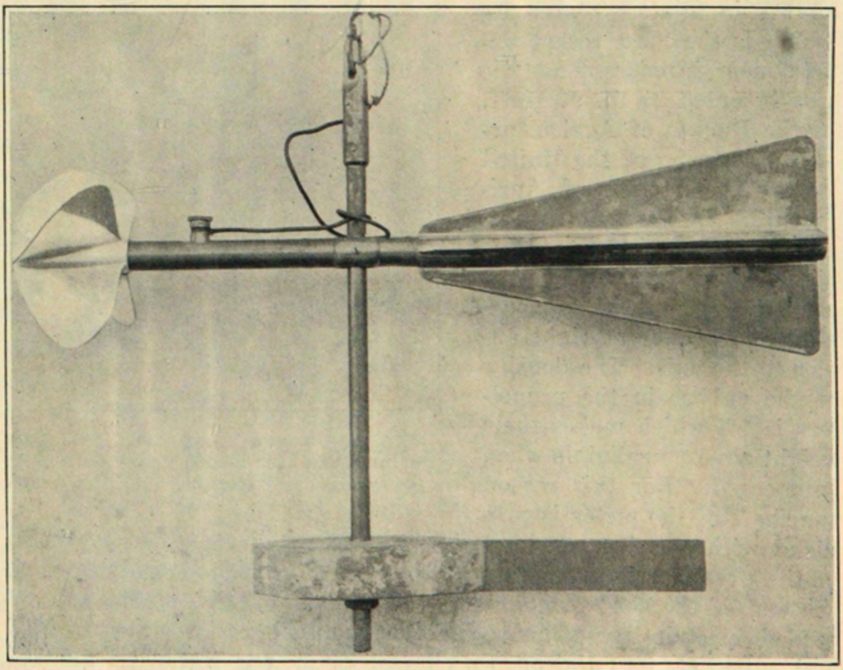

Plate 8.—Ritchie-Haskell cable meter number 162-B.

ordinarily used, but some of the meters are equipped with tails consisting of a rectangular plate which may be attached to the meter frame if desired. There is a hole in the frame of the meter thru which the rod passes. The meter is held in place by a set screw.

The Haskell meter was invented by E. E. Haskell, formerly Dean of the Civil Engineering Department at Cornell University, for use in river measurements. It is of the propeller type and is similar to the large Ott meters (see Plate 8.) The propellers have four screw-shaped blades which are attached directly to a hub and are made with either a high or a low pitch. The edges of the propeller blades slant backward so as to be self-cleaning. The meter was designed primarily for cable suspension, but may be used with a rod. A four-bladed tail is used to hold the meter parallel to the current. The revolutions of the propeller are registered electrically.

The Hoff propeller meter, shown in Plates 9 and 10, which is the most recent development in current meters, was invented by E. J. Hoff, of the Bureau of Agricultural Engineering of the United States Department of Agriculture. Two types are provided; one with a three-bladed weedless propeller, and the other with a four-bladed propeller at right angles to the axis. The density of the rubber in the propellers is 1.3 which makes their weight almost negligible when submerged. For this reason the shaft of the meter is provided with a guide bearing only at the propeller end. The thrust of the propeller is taken care of by a single steel ball against which the end of the shaft bears. The revolutions of the meter are recorded electrically. Three different contact ratios are provided and all that is required to change from one ratio to another is to move a small lever on the contact chamber. The meter is

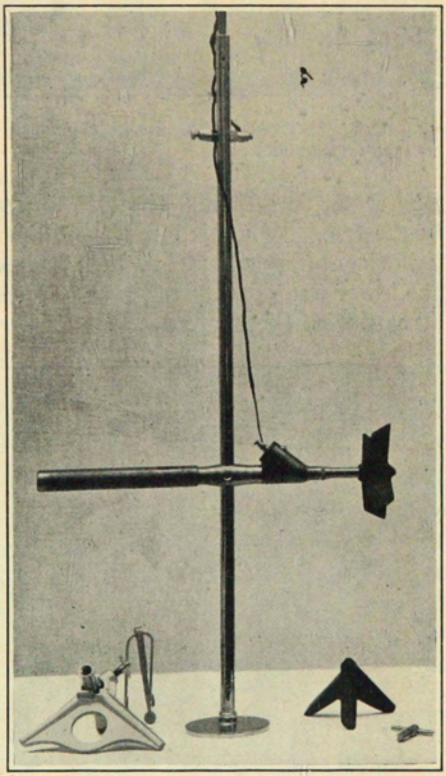

Plate 9.—Improved type Hoff rod meter with three and four-bladed propellers similar to meters used in tests.

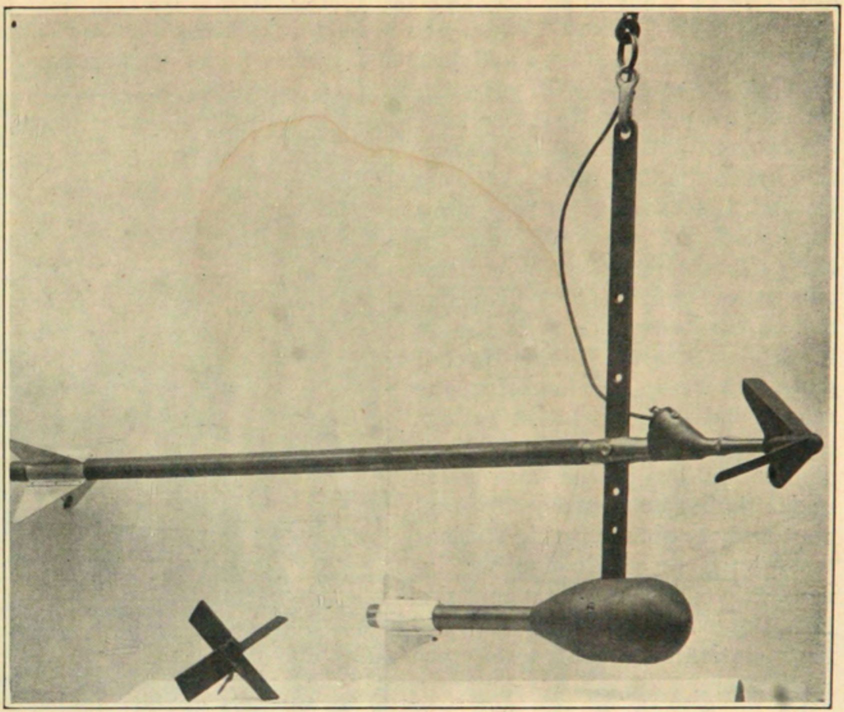

Plate 10.—Improved type Hoff cable meter with three and four-bladed propellers and new model weight.

equipped for either rod or cable suspension. When used as a rod meter, a short cylindrical tail is attached to the meter, and when used as a cable meter, a cylindrical buoyant tail with small guide vanes attached is added to the meter to hold it parallel to the current. The meter is held against the current by a blunt-nosed torpedo weight.

The Fteley-Stearns meter, see Plate 11, is of the propeller type and has six narrow helicoidal-shaped vanes which are attached at right angles to the axis of the meter and are surrounded by a metal rim the same width as the vanes. The propeller is surrounded by a D-shaped frame which carries the bearings at each end of the propeller shaft, and also a guide ring which protects the propeller. The meter is equipped with dials for recording the revolutions and also with an electric indicating device. The meter is made for use with the rod only.

CURRENT-METER RATINGS

TANGENT RATING STATION.—In order to check the operation and characteristics of the cup and propeller meters under various conditions, representative meters of the different types were rated at both the tangent and rotary stations at the hydraulic laboratory at Fort Collins, Colorado. The tests were conducted, for the most part, on the different models of the Price cup meters and the Ott propeller meters, but tests were made also on the Fteley-Stearns, Ritchie-Haskell and Hoff meters. In addition, the rotary and tangent-station ratings were compared by making ratings at both stations on the same meter under similar conditions. The tangent and the rotary rating stations were built especially for the investigations, but as the tangent station was completed before the rotary station, the first tests were made there.

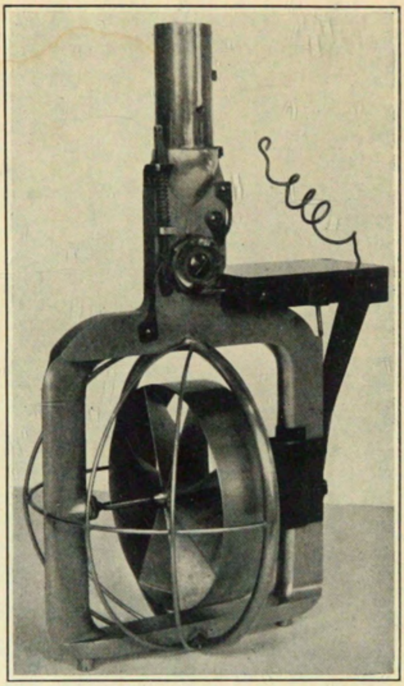

Plate 11.—Fteley-Stearns meter number 1, with counting gears and electrical contact mechanism.

The tangent rating station consisted of a concrete-lined channel 210 feet long, 5 feet wide and 3.5 feet deep, a variable speed electrically driven rating car, a clock having a second's pendulum, and an electric recorder for registering the time, the distance, and the meter revolutions. The rating channel is shown in Figure 1 and Plate 12. The channel was filled either from the storage reservoir at the laboratory or from the city water system. For rating, the channel was filled to a depth of about 3 feet 3 inches. The concrete walls of the channel carried the rails upon which the rating car ran. These rails were of the industrial railway type and weighed 20 pounds to the yard. They were held in place by cast-iron clips fastened to the wall by bolts cast in the concrete.

The rating car consisted of a channel-iron frame supported by four flanged cast-iron wheels which were keyed to two parallel axles running in roller bearings. See Figure 2 and Plate 12. The housings for the roller bearings were rigidly attached to the car frame. The rear wheels of the car were driven by a variable speed, direct

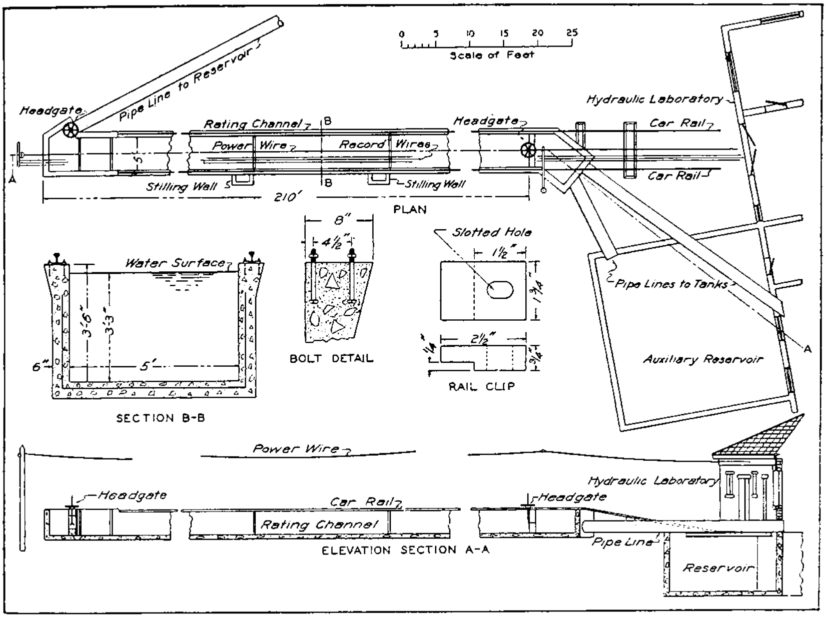

Figure 1.—Tangent rating station at the hydraulic laboratory at Fort Collins, Colorado.

current, 5 hp. motor thru a train of interchangeable gears. In addition to the variations in speed made possible by shifting gears, still further changes could be made by varying the rheostats on the motor and on the direct-current generator set. Changes in direction of the car were brought about by reversing the motor. The motor drew its current from an overhead wire thru a street-car-type trolley. The rails on the walls of the rating channel provided the return circuit. The brakes on the car consisted of cast-iron shoes which were forced into contact with the rails by a lever. This arrangement eliminated the possibility of wearing flat spots on the wheels due to applying the brakes. The current meter was held by a bracket, shown in Figure 2, which could be tilted horizontally and vertically.

The revolutions of the current meter and of the wheels of the car which showed the distance traversed, were transmitted to the recording apparatus by a separate trolley attached to the car which ran on three wires supported by the same poles and brackets which carried the power wire for the car motor. As originally designed, these conductors were affixed to a wooden rail at the side of the rating channel, and the contact was made thru three sets of rollers on a bracket attached to the side of the car. This system did not prove satisfactory, however, because the lateral movement of the car broke the contact at times.

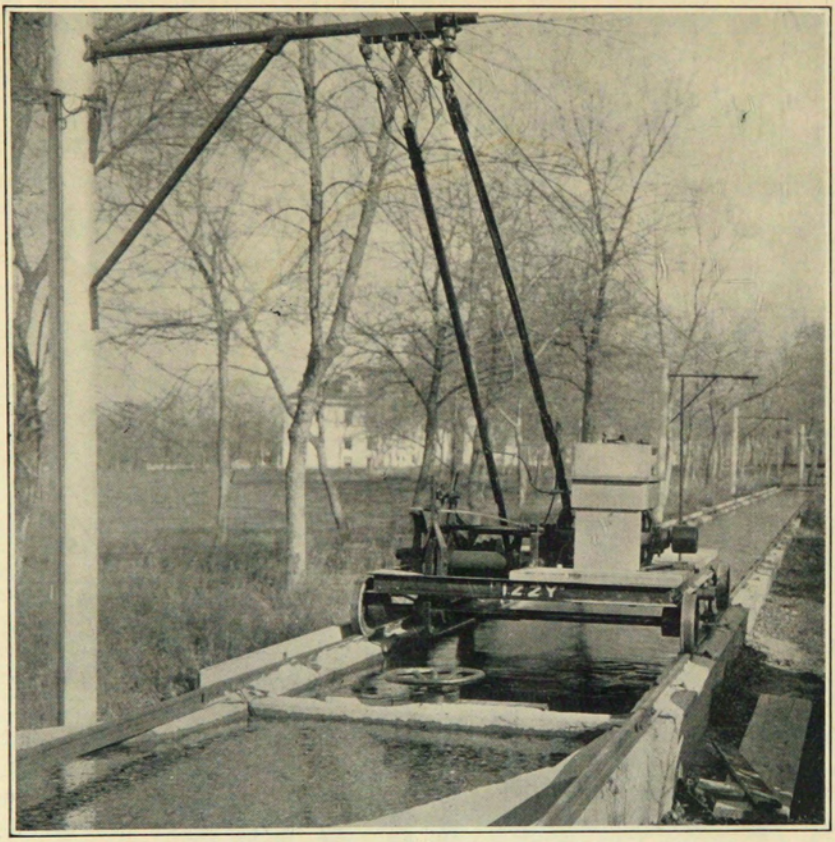

Plate 12.—Tangent-station rating car with overhead trolley for transmitting meter and distance records.

The distance traveled by the car was shown by the revolutions of the car wheels which were exactly 3 feet in circumference. An electrical contact was made once each revolution on a drum attached to the axle to which the wheels were keyed. The distance record was taken from the free wheels, as there was some danger of slippage of the driving wheels. The distance record was originally taken from contacts on lugs placed at regular intervals on the top of the wooden rail which carried the wires for transmitting the record of the meter revolutions and the car distance to the recording instrument. This method did not prove satisfactory, because the spring which made the contact on the lugs would start vibrating, and as a result would make poor contacts.

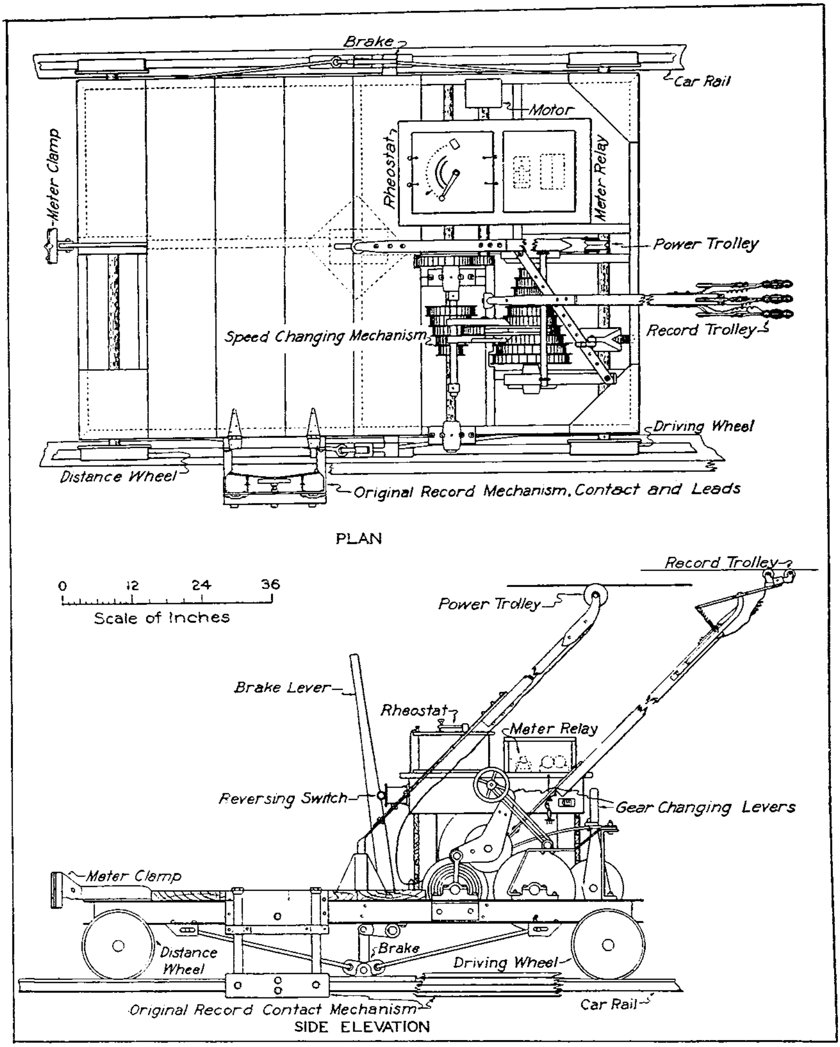

Figure 2.—Rating car used at the tangent station at Fort Collins, Colorado.

The time record was taken from the clock shown in Plate 13. This clock had a second's pendulum which was equipped to make an electrical contact each second by means of an electro-magnet attached to the end of the pendulum which pulled together two small iron weights, thereby bringing two platinum electrodes into contact which permitted the current to flow thru the circuit and operate the recording mechanism, see Plate 14. In order to protect the platinum contacts from sparking, a relay was placed in the circuit which was operated by a smaller voltage than the recording mechanism.

The device for recording the time, the distance and the revolutions of the current meter is shown in Figures 3 and 4 and Plate 15. It consisted of three electro-magnets which operated the pencils for making the record, a set of wet batteries to operate the electro-magnets, a paper ribbon for the record, and a pair of rolls driven by a spring motor to draw the paper ribbon under the pencils at a constant speed. The speed of the motor was regulated by a governor which could be adjusted by a lever so that the motor would run at any desired rate.

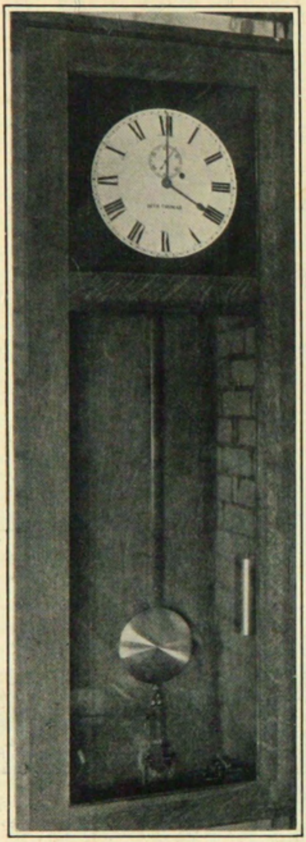

Plate 13.—Clock with seconds pendulum for current-meter rating time record.

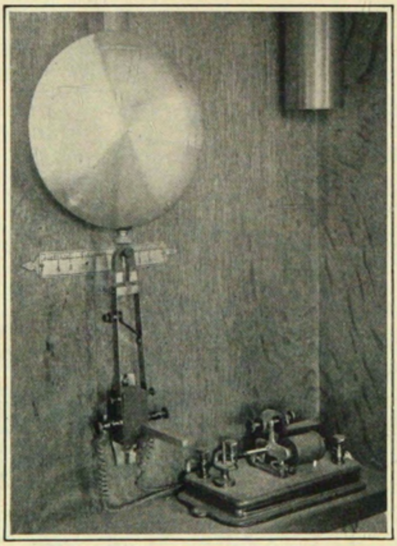

Plate 14.—Magnetic contact mechanism for current-meter rating time record.

The ratings made with the equipment were entirely free from any personal equation. As soon as the switches were closed and the motor started, the recording mechanism worked automatically.

With this equipment it was possible to rate the meter with the car moving in either direction and in both still and flowing water. The usual practice, however, was to make still-water ratings. When the ratings were made in flowing water, it was necessary to rate the meter in both directions in order to eliminate the velocity of the water from the results.

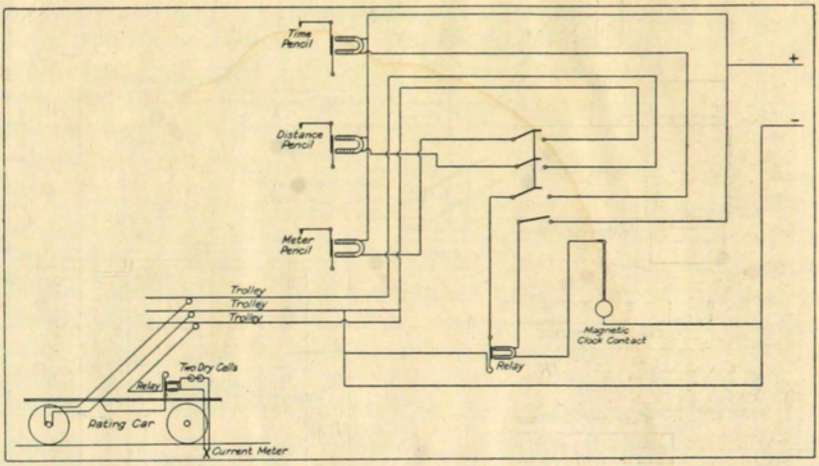

Figure 3.—Tangent-station rating-equipment wiring diagram.

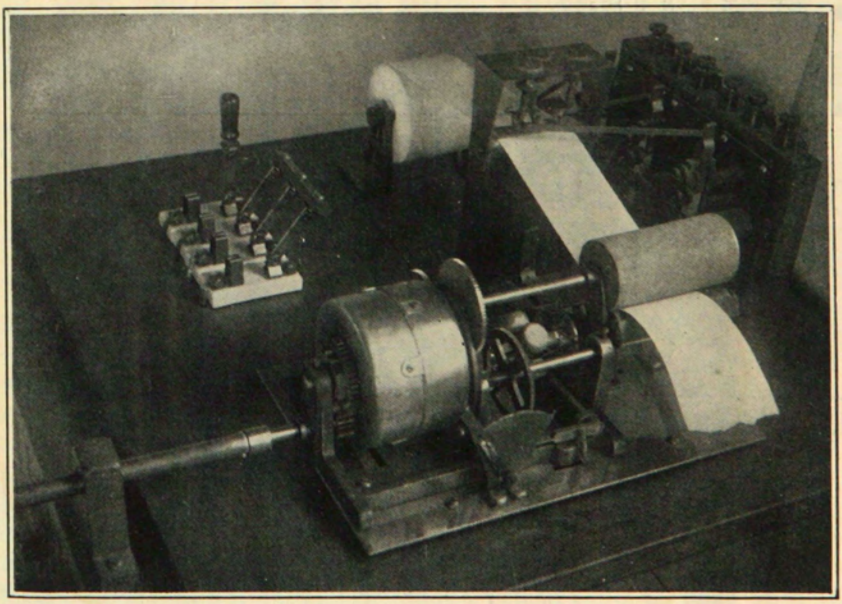

Plate 15.—Recording mechanism for current-meter rating, time, distance and meter record.

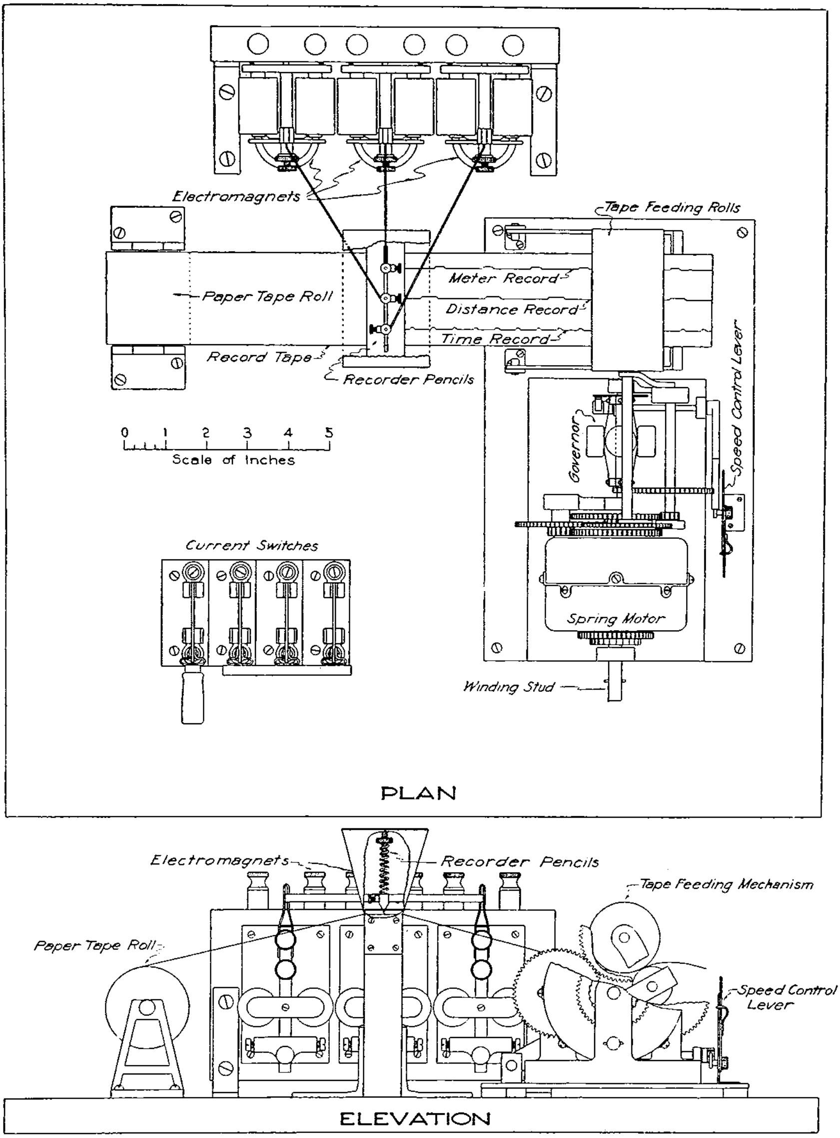

Figure 4.—Tangent-station recording mechanism which was used also for the rotary station. The type of record obtained is shown on the paper tape.

In making a standard rating, the meter was first adjusted and the contacts tested. The rod was then clamped in the meter bracket on the rating car in the desired position. For the ordinary rating with the rod vertical, the rod was plumbed by making the rod and its image in the water appear as a straight line. The meter was set parallel to the rating channel by bringing the axis of the meter parallel to the image of the trolley wire in the water. The special settings of the meter were made with a protractor and level. For cable ratings, the cable instead of the rod was clamped in the meter bracket. Under these conditions the meter could only be set in the position it naturally took in the water. As soon as the position of the meter was satisfactorily adjusted, a short preliminary run was made with the rating car to see if all the equipment was functioning properly. When everything was adjusted so the pencils made a good record of each contact on the record tape, the rating of the meter was started.

The ratings were always made beginning with the lowest velocity and increasing to the maximum thru the successive velocities, so the agitation of the water due to the passage of the meter would be as small as possible. For velocities higher than 5 feet per second, an interval of about 5 minutes was allowed between trips of the rating car in order to give the water ample time to come to rest. As the meter was not removed for the return trip of the rating car, the return speed of the car was kept low so as not to disturb the water unnecessarily. When possible, changes in the speed of the rating car were made by varying the setting of the rheostats, but changes which could not be made by the rheostats were made by changing gears on the car. After trying out the rating equipment, it was found that the rheostat control was so effective that only two gear ratios, the highest and lowest, were required to obtain all the desired speeds. The gears for making intermediate changes in the speed were unnecessary and were removed. With this equipment it was possible to run the car with the motor at speeds from 0.2 to 10.5 feet per second. Lower speeds were obtained by using a crank on the motor shaft and turning it by hand.

Ordinarily in making the ratings, the range of velocities covered was from 0.5 to 8 feet per second. In this range from 6 to 8 points were usually taken. On account of the greater curvature of the rating curves at the lower velocities, smaller intervals were used between velocities in this portion of the rating.

Altho the rating channel was 210 feet in length, the entire length was not covered by the rating car in determining each point on the rating curve. The length of the run was increased as the velocity increased, and for high velocities it was necessary to use the entire available length of the channel because the car had to travel some distance before it attained the desired speed at the start, and also before it could be stopped at the end of the run. Under these conditions, the maximum length of the channel available for the highest velocity determinations was 150 feet. For the low velocities, practically the entire length of the channel was available for velocity determinations because only a short distance was required to bring the car up to speed and to stop it. For this reason, two observations were made in a single trip of the car for all the low velocities.

In making a rating, the recording mechanism was set in motion just as soon as the rating car started, but the switches in the time, distance and revolution circuit were not closed until the operator of the car gave the signal that the desired speed had been reached. The switches were opened again before the signal to stop the car was given. As a result a graphical record was obtained of only that portion of each observation in which the velocity of the car was constant. Except for very low velocities, test of the uniformity of the velocity showed that the variation in the velocity was negligible. Even at low velocities, the lack of uniformity was so small that it has had but little effect on the results because the rating curves for most meters are nearly straight lines and, consequently, a small variation in the velocity would have a very small effect on the results. If the rating curve were a straight line, the variation in the velocity of the car would, of course, have no effect on the accuracy of the rating. Figure 4 shows a portion of the record of a typical rating of a Price meter.

The recorder tape gave a simultaneous graphical record of the time in seconds and revolutions of the meter and of the rating-car wheels. Before it was possible, however, to plat the rating curve, it was necessary to convert these data into feet per second and revolutions per second. This was accomplished by determining the distance traversed and the number of revolutions of the meter in a given time. The actual operation was performed by drawing a line at the beginning and the end of the record at right angles to the lines made by the recorder pencils. These lines were drawn so that the end portions of the records were excluded from the part of the record for which the velocity and revolutions of the meter were to be computed. After the desired portion of the record was segregated by the right-angled lines, the number of contacts in each record was counted and the fractional portions computed. The required information was then obtained by dividing the distance traveled and the number of revolutions of the meter by the elapsed time. For convenience in making this computation, the right-angled lines were usually drawn thru contact points on the time record. As a result, there were no fractional parts of a second. However, when rating meters having contact ratios greater than unity, the right-angled lines were drawn thru the meter contact points so chosen as to include a complete revolution of the contact wheel or some multiple thereof.

After computing the velocity and revolutions per second, these data were plotted to a large scale on cross-section paper, using the revolutions per second as ordinates and the velocities as abscissas. The curve which best fitted the plotted points was then drawn. If any points did not follow the curve, these values were recomputed.

Points that did not fall on the curve after recomputing were disregarded because previous experience had shown that the points would fall on a smooth curve unless something unusual had happened to the meter.

The equation of the rating curve was determined either by graphical methods or by the method of least squares, and for the purpose of comparison some were determined by both methods. The graphical method is best suited to the determination of the equations of the meters for which the portions of the curves under consideration are straight lines. It cannot be used in the determination of the equation of a curve. The method of least squares may be used to determine the equations of both straight lines and curves.

The equations of the meters with straight-line rating curves were expressed in the slope form,

$$V = M R + C \qquad (1)$$

in which V = velocity in feet per second
M = slope of the line
R = revolutions of the meter per second
C = intercept on the velocity axis, somtimes called the friction constant.

In this equation M and C are the unknowns. When using the graphical method, the value of C, the intercept on the velocity axis, was determined by reading the V coordinate of the point of intersection of the rating curve with the velocity axis, and the value of M was determined by taking the mean value obtained by subtracting C from the abscissas of a number of points along the line and dividing the results by the ordinates of the respective points. When the least-squares method was used, the observed data were substituted in equation 1 to form the observation equations, and from the observation equations the normal equations and the values of M and C were determined in the usual manner.

If the rating curve is not a straight line, the equation may be expressed in the form

$$V = A R^{n} + B R^{n-1} + C R^{n-2} \ldots\ldots\ldots\ldots + K \qquad (2)$$

and by increasing the number of terms any desired accuracy can be obtained. Usually, however, the form of the equation for a particular type is known, and in this case it is merely necessary to determine the parameters of the equation. This was done by the method of least squares in the manner described for the straight-line equation. Equations which did not fall into the two general classes mentioned before were determined by special methods.

Altho the equations of all the meters rated were determined, only those which illustrate a particular point are given in the report. All the data are shown graphically instead, because comparisons can be made more easily by studying the plotted results. As will be noted, the same scale was used when possible in plotting the results, but since the ordinates do not cover the same range, this fact should be given consideration when comparing results from different meters.

TANGENT-STATION RATINGS

Typical ratings of the principal kinds of current meters are shown in Figure 5. These ratings were all made under similar conditions at the tangent rating station, and the consistency with which the observed points fall on the curves indicates that it was possible to get accurate results with the rating equipment. All the lines drawn in the figure are straight except the one for the Ritchie-Haskell meter which is straight only for velocities greater than 1.2 feet per second. The lines for some of the other meters also are not exactly straight when plotted to a large scale, but the curvature is so slight that it does not show up in a small scale figure.

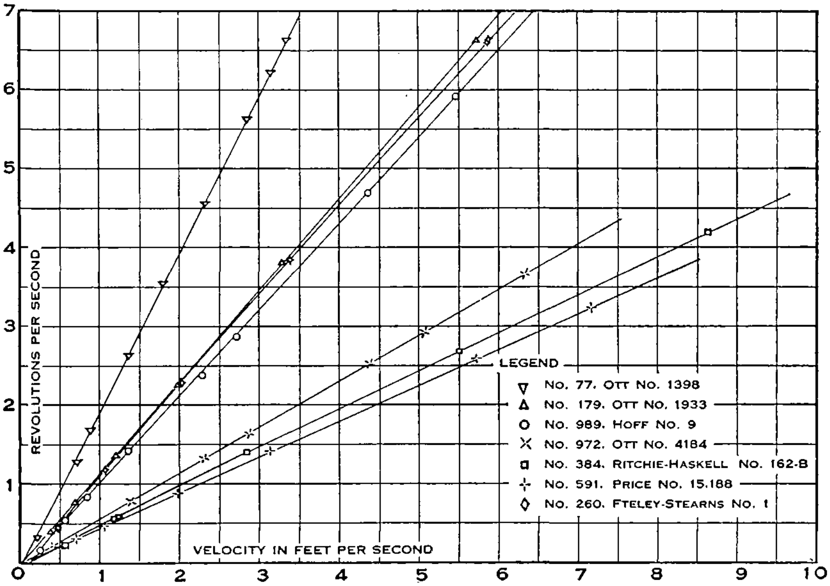

Figure 5.—Typical ratings of different types of meters.

A question which frequently arises concerning the rating of current meters is whether the same results are always obtained when rating the meter under the same conditions. This was tested by rating the meters several times under identical conditions, except that the meters were removed from the clamp on the car between the ratings. For Price meter number 15,188, which is a rod meter with tail similar to the meter shown in Plate 16, the equations resulting from the replicate ratings are as follows:

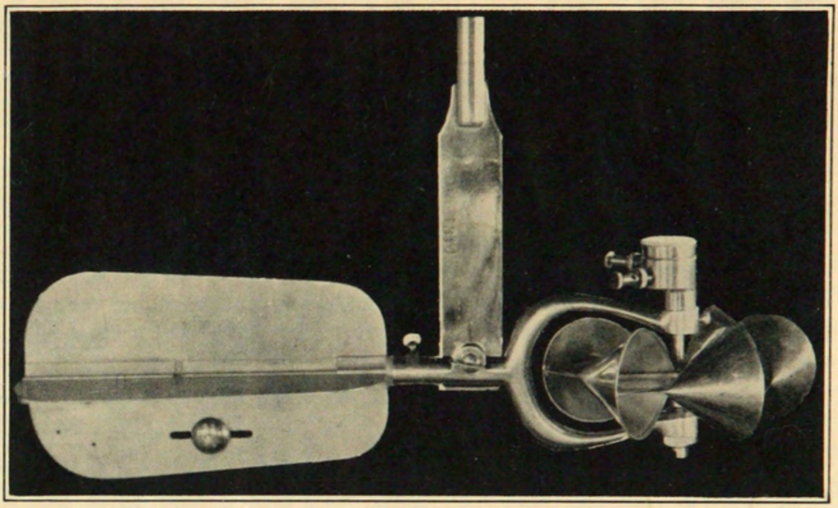

Plate 16.—Price meter number 1314, with bar for attaching rod and with Hoff combination head. (Similar to Price meters numbers 1728 and 15,188 except that these meters are equipped with standard heads and that meter number 15,188 has a movable rod clamp.)

No. 591................$V = 2.187\ R + 0.046$
592................$V = 2.196\ R + 0.036$
593................$V = 2.194\ R + 0.038$
594................$V = 2.205\ R + 0.027$
595................$V = 2.195\ R + 0.040$

These equations are not identical but the differences are slight. In order to show the differences graphically, the feet of travel of the meter per revolution were computed from the original data and were

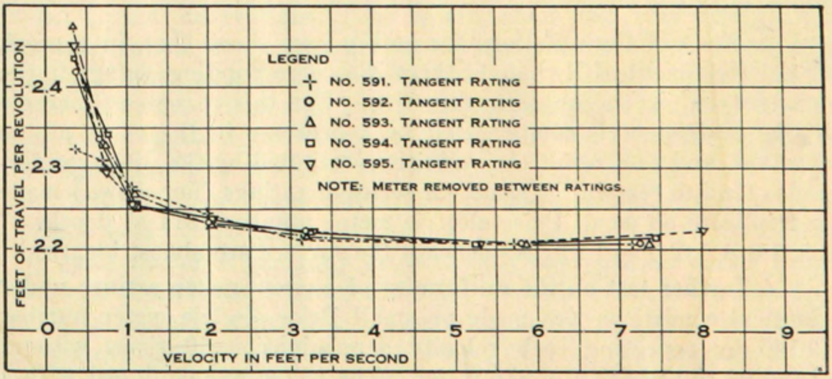

Figure 6.—Replicate ratings of Price meter number 15,188 made at the tangent station. The meter was rated with rod and tail at a depth of 2 feet in the center of the channel. Meter was removed between ratings.

plotted against the velocity of the meter. Since the feet of travel of the meter per revolution are nearly constant regardless of the velocity, the data may be plotted to a scale large enough to show small variations which would otherwise pass unnoticed. Figure 6 shows the results of the ratings plotted in this manner. It will be noted that all the points fall near the same line except those for velocities less than 1 foot per second, and these apparently become more scattered as the velocity decreases.

Duplicate ratings were also made on Price meter number 1728, which is likewise a rod meter with a tail, similar to the one shown in Plate 16. The meter was removed from the car and reset between ratings. The equations of the rating curves by both the least-squares and the graphical methods are as follows:

No. 537....................graphical $V = 2.199 R + 0.022$
least square $V = 2.200 R + 0.020$
538....................graphical $V = 2.192 R + 0.030$
least square $V = 2.193 R + 0.026$
539....................graphical $V = 2.201 R + 0.027$
least square $V = 2.201 R + 0.028$
540....................graphical $V = 2.194 R + 0.027$
least square $V = 2.192 R + 0.033$
541....................graphical $V = 2.192 R + 0.037$
least square $V = 2.196 R + 0.030$

These equations differ but slightly and it is interesting to note that the equations derived by the two methods are almost identical.

The feet of travel of the meter per revolution were also computed from the original data for these ratings and plotted against the velocity, (plot not shown). Here also a very close agreement was found between the plotted points for velocities greater than 1 foot per second, but considerable variation was found between the points for the lower velocities.

A study of the equations for both meters shows that, in general, as the coefficient of R changes there is a corresponding change in the constant but in the opposite direction. For this reason an increase in the coefficient is compensated by a decrease in the value of the constant, and as a result the velocities computed by the different formulas tend to remain the same. A series of ratings (not shown) made in triplicate on small Price electric meter number 1314 at depths of 0.5, 1.0, 1.5, 2.0 and 2.5 feet beneath the surface are almost identical.

A further test on the uniformity of current-meter ratings under identical conditions was made on small Price electric meter number 19,145 by repeating each velocity determination 10 times without changing the position of the meter. The meter was equipped with a rod and foot plate but without a tail, and was rated in the center of the channel with the meter submerged 1 foot.

A series of observations was made at each of four different velocities. When the four series were completed the meter was removed from the car and oiled, then replaced in as near its original position as possible, after which another series of tests was made. From the mean values of each group of 10 observations, the probable error of a single observation and of the mean was computed. The results are summarized in the following table:

TABLE 1.—Summary of results of replicated velocity determinations at different velocities on small Price electric meter number 19,145.

Rating number	Mean[1] velocity per second	Mean[1] distance per revolution	Probable error[2] in distance per revolution	
			Single observation	Mean of observations
	feet	feet	feet	feet
664	0.990	2.489	0.00736	0.00233
	1.697	2.446	.00554	.00175
	2.699	2.428	.00464	.00147
	3.140	2.399	.00269	.00085
665	0.996	2.464	0.00670	0.00212
	1.756	2.403	.00529	.00167
	2.777	2.384	.00286	.00091
	3.174	2.361	.00418	.00132
667	0.954	2.499	0.01301	0.00412
	1.730	2.460	.00658	.00208
	2.711	2.438	.00164	.00052
	3.085	2.423	.00447	.00141

[1] Mean of 10 observations under identical conditions.
[2] All probable errors plus or minus.

Table 1 shows, in general, that the probable error in feet traveled by the meter per revolution of the cups decreases as the velocity increases, and this is true both for a single observation and for the mean of the observations. The results show also that observations under identical conditions are uniformly consistent, the maximum probable error of a single observation being only 0.5 percent of the observed value. Removing and resetting the meter had a more definite effect on the results than that shown by the replicate ratings of Price meters numbers 15,188 and 1728.

When the current meter is used to measure water, the meter is usually held at predetermined points in the channel, and as the rating of the meter is generally made at only one position in the rating channel, there is some uncertainty as to whether the rating is applicable to the conditions under which the meter was used in making measurements. Since tests by Scobey (14) on cup current meters showed that there was a definite change in the rating curve due to the depth at which the meter was rated, particularly at points near the water surface, additional observations were made at the tangent rating station at the hydraulic laboratory on several different meters to study this phenomenon.

The meters on which the observations were made consisted of small Price electric meters numbers 1314 and 1728, improved Price meter number 29,502, small Ott meter number 1398 and Hoff rubber-propeller meter number 2. All the meters were equipped with tails except the Hoff meter, and were rated using the rod suspension. Meter number 1314, (see Plate 16), was equipped with a Hoff

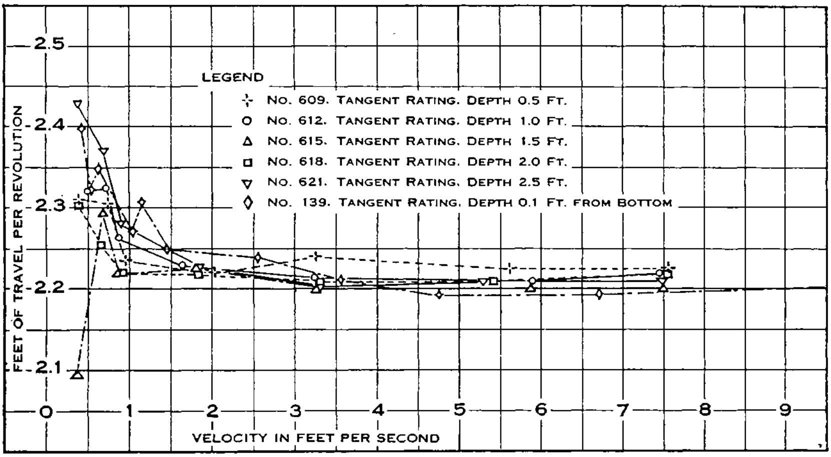

Figure 7.—Price meter number 1314, tangent-station ratings made at various depths in the center of the channel. The rod suspension was used and the meter was without a tail.

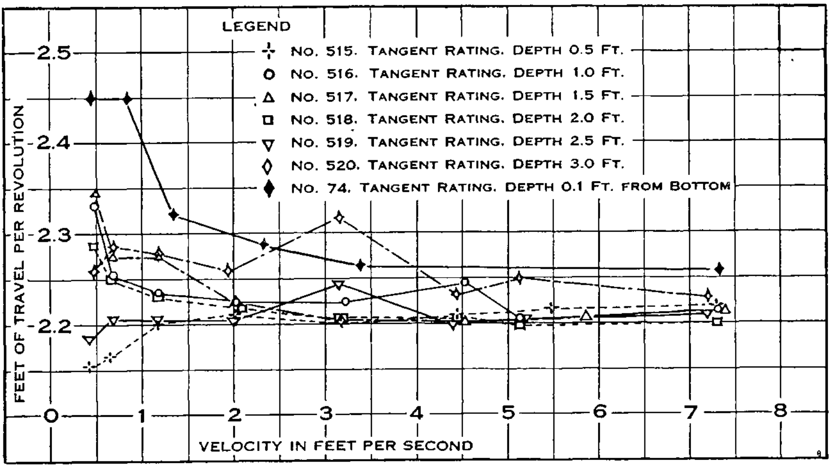

Figure 8.—Price meter number 1728, tangent-station ratings made at various depths in the center of the channel. The rod suspension was used and the meter was equipped with a tail.

combination head and special lower bearing. The Hoff head has both the single count and the penta count mechanism in the same contact chamber and eliminates the necessity of carrying two heads for the meter. The special bearing consisted of a cylindrical instead of a conical pivot, the end of which was in contact with a hardened steel ball in the meter shaft. Price meter number 1728 was a standard tail meter. The improved Price meter was of the latest type, having a combination head and a new type lower bearing, as shown in Plate 1. The Ott meter (see Plate 4), was of the propeller type equipped with a guard ring. The Hoff meter was similar to the one shown in Plate 9. All the meters were rated in the center of the channel and under as nearly identical conditions as possible.

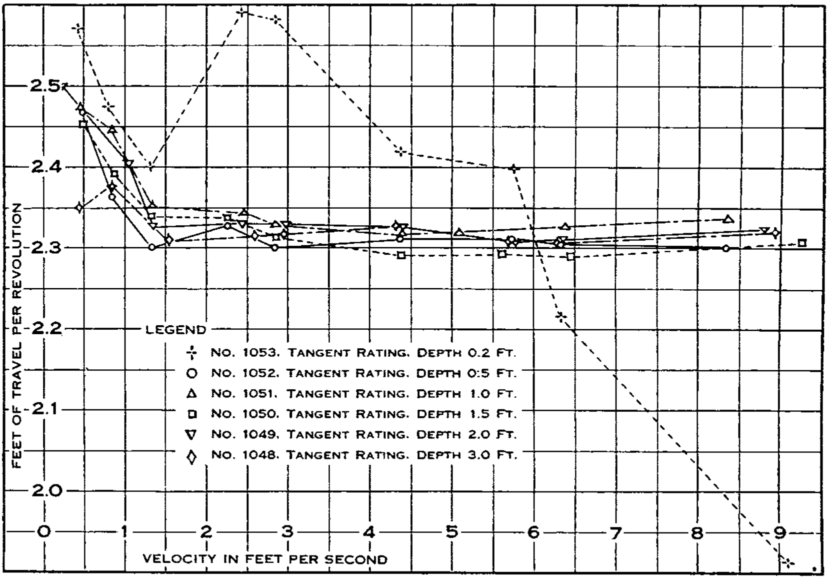

Figure 9.—Price meter 29,502, tangent-station ratings made at various depths in the center of the channel. The rod suspension was used and the meter was equipped with a tail.

The graphical representation of the data resulting from the plotting of the feet of travel of the meters against the velocity is shown in Figures 7 to 11. These plots show that the ratings are quite consistent except at low velocities, and when the meters are very near the water surface or at the bottom of the channel. When at the surface, see Figures 9 and 11, the improved Price meter runs slow at velocities less than 6 feet per second, and fast at higher velocities, whereas the Hoff meter is affected so little that it may be considered negligible. The plot indicates that when the improved Price meter is held near the surface, rating number 1053, the results

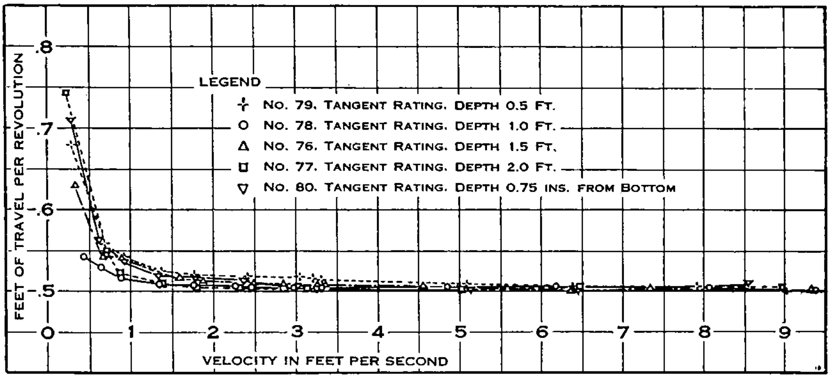

Figure 10.—Ott meter number 1398, tangent-station ratings at various depths in the center of the channel. The rod suspension was used and the meter was equipped with a tail.

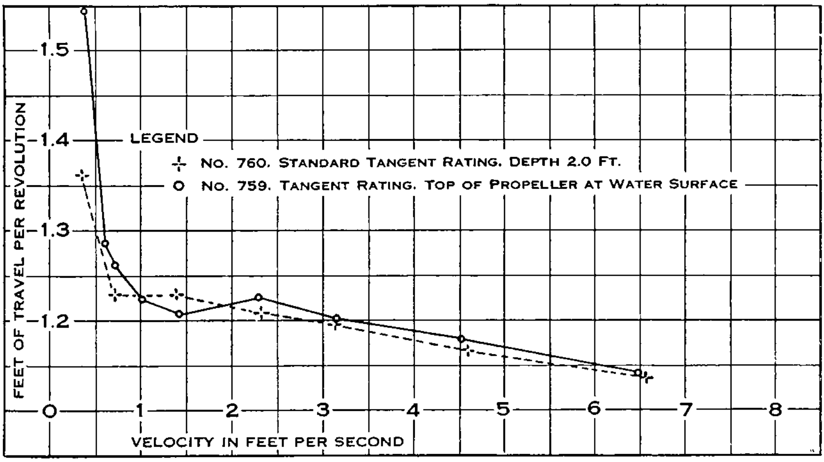

Figure 11.—Hoff meter number 2, tangent-station ratings at various depths in the center of the channel. The rod suspension was used and the meter was without a tail.

are very erratic. Figure 8, rating number 74, shows the effect of rating Price meter number 1728 near the bottom of the channel. The plot indicates that the meter runs slow under this condition. The other cup meters, however, do not show any effect due to rating near the bottom.

Altho there was considerable variation in the equations of the small Ott meter, the plot, Figure 10, shows that the ratings were very consistent. The indications are that the rating of this meter was not affected by its location.

Some observations were made on small Price electric meters numbers 1080, 1314 and 1728, and Ott propeller meter number 1933, to determine the effect of the distance of the meter from the channel wall on the rating. The small Price meters were the same as previously described except number 1080, which was of the tailless type with rod and foot plate. The Ott meter was of the propeller type with the vanes attached to radial spokes. The meter is shown in Plate 3.

The results of the observations on the different meters are shown graphically in Figures 12 to 15. These figures indicate that the nearness to the wall of the channel had little, if any, effect on the ratings except in the case of the Price meters when they were rated

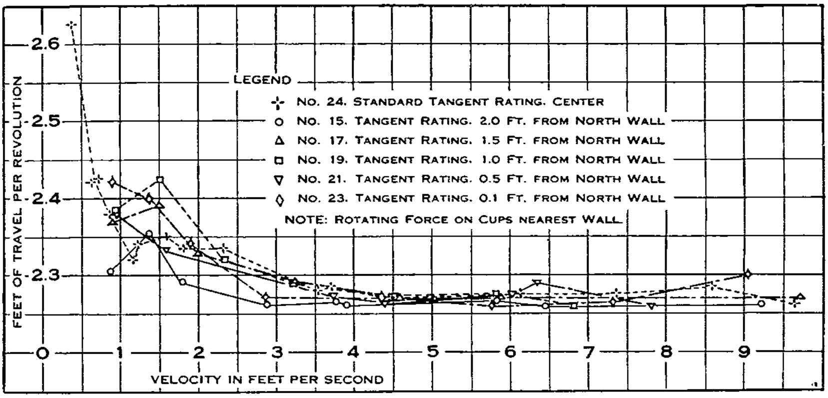

Figure 12.—Price meter number 1080, tangent-station ratings at a depth of 1.5 feet and at various distances from the walls of the channel. The rod suspension was used and the meter was without a tail.

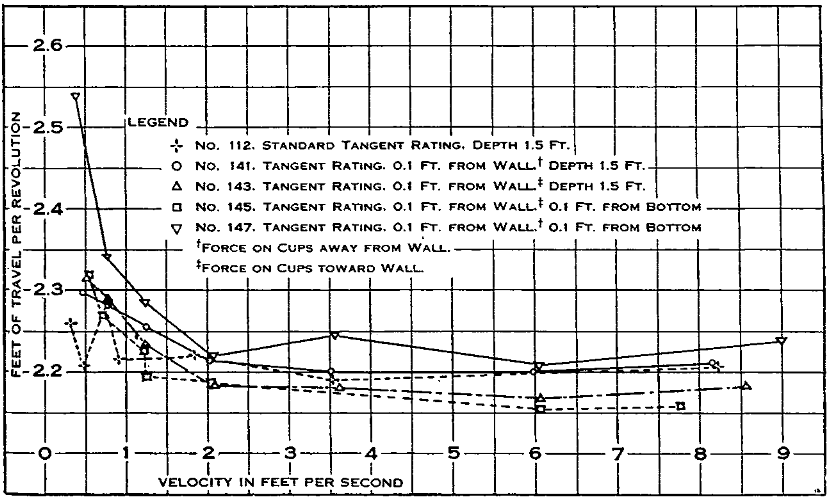

Figure 13.—Price meter number 1314, tangent-station ratings at different depths near walls of channel. The rod suspension was used and the meter was equipped with a tail.

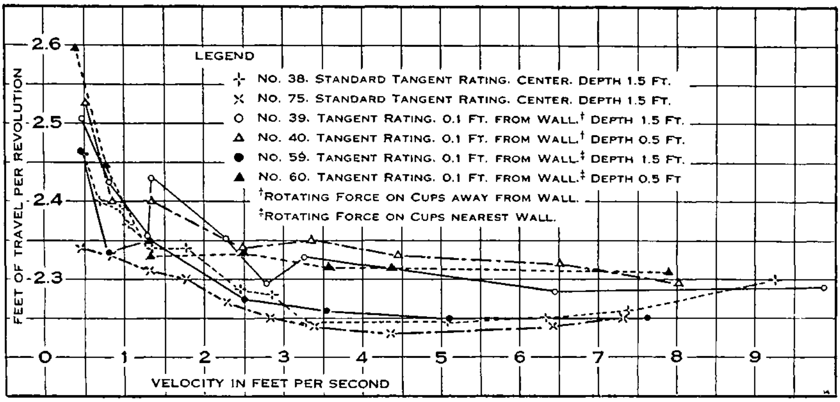

Figure 14.—Price meter number 1728, tangent-station ratings at various depths near the walls of the channel. The rod suspension was used and the meter was without a tail.

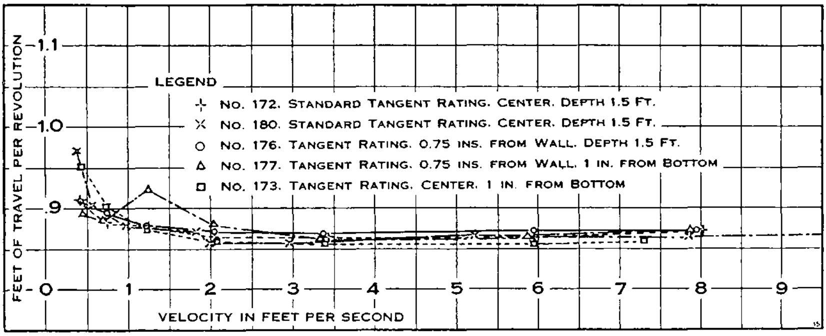

Figure 15.—Ott meter number 1933, tangent-station ratings at various depths near the walls of the channel. The rod suspension was used and the meter was without a tail.

so the rotating force was on the side of the meter cups away from the wall. Under this condition, in general, the meter ran more slowly than normally. A part of the variation in the results was probably due to errors in setting the meters. It should be noted in this connection, however, that the Ott propeller meter gave uniformly consistent results when rated in the different locations.

The tests on the ratings of the meters in different locations in the channel show that for the conditions tested, the only important effect was produced when the Price meters were rated at or near the water surface. This is probably true for all cup meters but not for propeller meters, as the tests on the Hoff meter show that it was not affected. Unfortunately the Ott meter was not rated nearer than 0.5 foot to the surface.

In the ratings of meters in different locations in the channel, the distances indicated in the diagrams when the meters are very near the bottom or sides show the clearances rather than the distances from the centers of the meters to the walls or bottom of the channel.

The vertical integration method is frequently employed in making measurements of small canals and streams. When this method is used, the meter is moved up and down vertically in each section of the channel so that the meter is exposed successively to all the velocities in the section. Since it is a well-known fact (14) that the Price meters will rotate in their normal direction when the meter is moved up and down, it has been assumed that this materially increases the measured velocity. In order to find out how great the effect of integrating is, meter tests were made at the tangent rating station at the hydraulic laboratory on both cup and propeller meters.

The equipment used to move the meter up and down consisted of a frame to which the meter rod was connected, and which was moved up and down on guide posts rigidly attached to the car by a crank mechanism operated by hand. The apparatus is shown in Plate 17. In operating the equipment, the meter was moved up and down by the crank at constant speed of about 0.25 foot per second, while the meter was being carried along the channel by the rating car.

Tests were made on Price meters numbers 1314 and 1728, and Ott propeller meters numbers 1933, 2575 and 1398. All of the meters

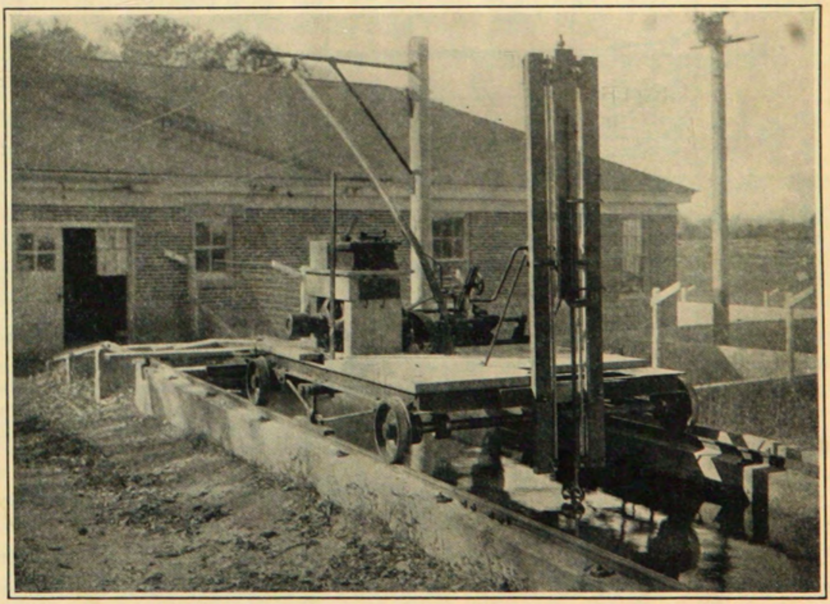

Plate 17.—Tangent-station rating car with special device for moving meter up and down while rating.

except number 2575 have been described previously. Number 2575, see Plate 7, was a propeller meter of the weedless type. The propeller of the meter consisted of two blades attached directly to the hub and reinforced by extensions cast integrally with the hub. Meters numbers 1933 and 2575 were practically the same size. The principal difference was in the propellers. Number 1933 had a propeller consisting of three blades attached to radial spokes in the hub, whereas number 2575 has a two-bladed propeller cast integrally with the hub. All the meters were equipped with tails and were rigidly fixed on rods while being rated.

The study of the effect of integration on the ratings of the meters was made by comparing the results obtained by rating the meter when it was being moved up and down with those from a standard rating. The comparisons were made on the basis of the graphical representation of the data given in Figure 16.

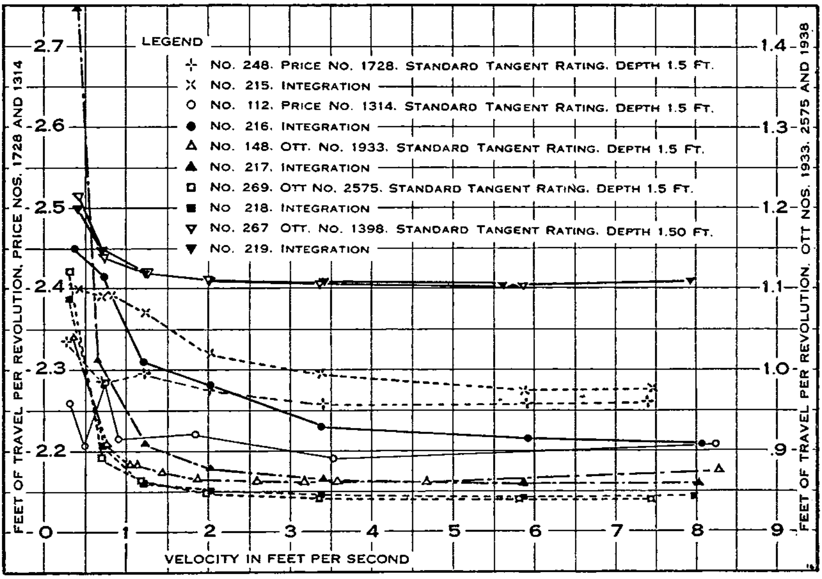

Figure 16.—Tangent-station ratings showing the effect of integrating Price meters numbers 1728 and 1314 and Ott meters numbers 1933, 2575 and 1398 while rating. The meters were moved up and down at a uniform rate of approximately 0.25 foot per second. They were all equipped with tails and the rod suspension was used.

A study of Figure 16 shows that there is a marked difference between the standard and the integration ratings of the Price meters but, strange as it may seem, the curves indicate that the meters run slower when moved up and down while rating rather than faster, as would be expected. The plots of the data show that integrating had practically no effect on the ratings of Ott meters numbers 2575 and

1398, but that there was a difference between the standard and the integration ratings, numbers 148 and 217 of Ott meter number 1933, particularly at velocities less than 2 feet per second. Just why this one Ott meter is affected by the movement of the meter is not clear. Since the propellers of the Ott meters present symmetrical surfaces to the current on both sides of their axes when moved vertically, there should be no tendency to either increase or retard the velocity due to the up-and-down movement.

As will be shown later, (see Figure 33), oblique currents do affect the ratings of cup meters and, to a slight extent, propeller meters. Altho in this case the meter moves thru the water obliquely, the results should be similar to the effect produced by oblique currents striking the meter. This may be the explanation of the results obtained when making the integration ratings.*

From the foregoing it may be said that moving the meter up and down while rating reduces the speed of rotation of Price meters and, in general, has no effect on the Ott meters except number 1933 which is retarded at velocities of less than 2 feet per second.

The filaments of flow in running water are seldom parallel to the axis of the stream. As a result when a meter is held in the water parallel to the stream axis while making a discharge measurement, the current will strike the rotating element of the meter at various angles in both the horizontal and the vertical planes, and, consequently, in order to measure the mean velocity accurately the meter should resolve all the velocities into their axial components.

The design of the rotating element of cup meters is such that oblique velocities in the horizontal plane exert practically the same rotating force regardless of the angle at which the current strikes the meter. As a result meters of this type should over-register when measuring the axial velocities under these conditions. Propeller meters are, on the other hand, not subjected to the maximum rotating force of the current unless the velocity of the water is in a direction parallel to the axis of the meter and the rotating force decreases as the obliquity of the current increases. This is true whether the obliquity of the current is in a horizontal, vertical or intermediate direction. For this reason the propeller meters seem better suited than the cup meters to the measurement of turbulent water in which the currents approach the meter at all angles. In respect to currents with vertical obliquity, the cup meters are similar to the propeller meters because the shape of the rotating element is such that the rotating force decreases as the obliquity increases.

Many tests (2, 12, 16 and 17) have been made to determine the accuracy with which different meters resolve the oblique velocities into their axial components. Most of these tests were made by holding the

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*Unpublished memorandum by E. J. Hoff.

meter at different angles to the current in water flowing at a known velocity, but some were made by rating the meter in still water when the meter was set at various angles to the direction of movement of the car. The conclusions drawn as a result of these investigations are substantially in accord, but in view of the importance of the subject a complete series of tests was made at the tangent rating station at the hydraulic laboratory on different types of cup and propeller meters when subjected to currents striking the meters at various horizontal and vertical angles with the axis of the meter in order to provide a series of tests, all of which were made under the same conditions. At each setting of the meter, a complete rating was made covering the range of velocities normally met with in using the meter.

During the investigation tests were made on the following meters: Price, numbers 1314 and 1728, Ott, numbers 1933, 2575 and 1398, Fteley-Stearns, number 1, Ritchie-Haskell, number 162, and Hoff, number 9. The last-named meter was equipped with both a three and four-bladed propeller, both of which were tested to determine the effect of oblique currents. These meters are shown in Plates 3, 4, 7, 8, 9, 11 and 16, and have all been described previously, except the Fteley-Stearns, Ritchie-Haskell and Hoff meters. The Fteley-Stearns meter was of the propeller type with windmill vanes, as shown in Plate 11, and was equipped with counting gears, but during these tests the revolutions were recorded electrically every hundredth revolution. The Ritchie-Haskell meter, shown in Plate 8, was designed primarily for cable suspension. For these tests, however, the meter was rated on a rod to which it was rigidly affixed. The meter was fitted with a high-speed and a low-speed propeller, but only the low-speed propeller was tested. Both propellers had four blades and were of the weedless type. The Hoff was also a propeller meter, and the two different propellers with which the meter was equipped are shown in Plates 9 and 10.

All the meters were rated from rods to which they were rigidly attached. The rods were held by the clamp on the rating car which was so arranged that the rod could be held in any horizontal position and tilted to any vertical angle up to 45 degrees. The adjustments to the various horizontal angles were made by turning the rod thru the proper angle which was determined by a protractor attached to the car, and a pointer rigidly affixed to the rod. The different vertical angles were set by the use of a spirit level and template. The templates were cut to the desired angles. Then by holding them against the rods in the plane of the channel axis, the desired position was obtained by tilting the rod until the edge of the template was plumb, as indicated by the level which was held against the vertical edge of the template.

In making the comparisons, the effect of rating the meter when held at various angles with the axis of the channel was investigated first. A standard rating of the meter under observation was made at the beginning of the test, and after that the meter was rated in the various positions for which information was desired. These data are shown graphically in Figures 17 to 25. They show the relation be-

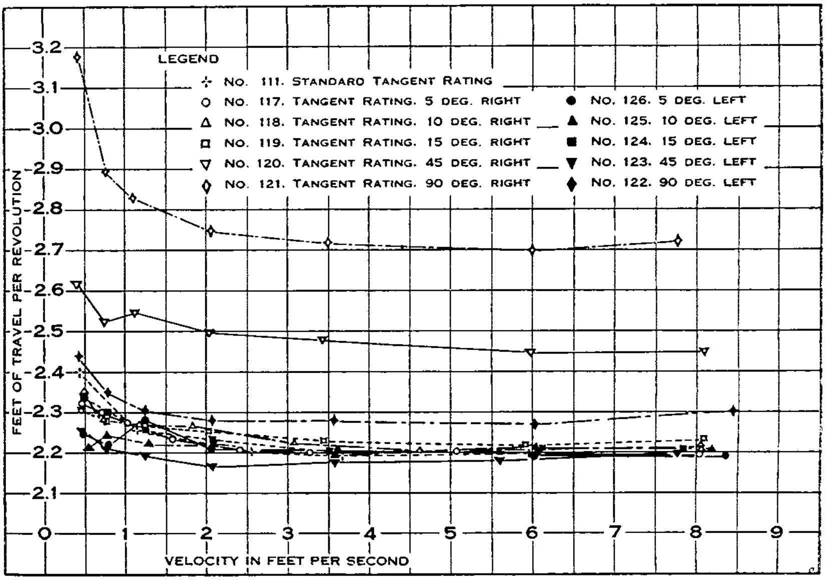

Figure 17.—Price meter number 1314, tangent-station ratings showing effect of turning meter to right and left. Ratings made in the center of the channel at a depth of 1.5 feet. The meter was without a tail.

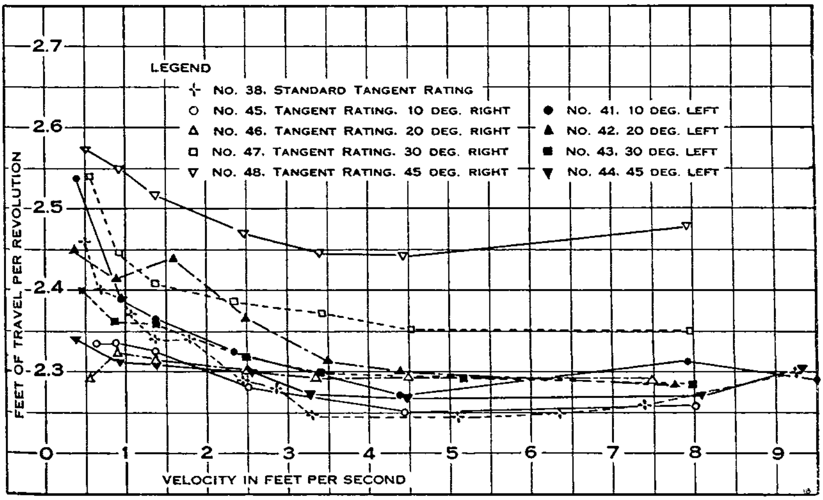

Figure 18.—Price meter number 1728, tangent-station ratings showing effect of turning meter to right and left. Ratings made in the center of the channel at a depth of 1.5 feet. The meter was without a tail and the rod suspension was used.

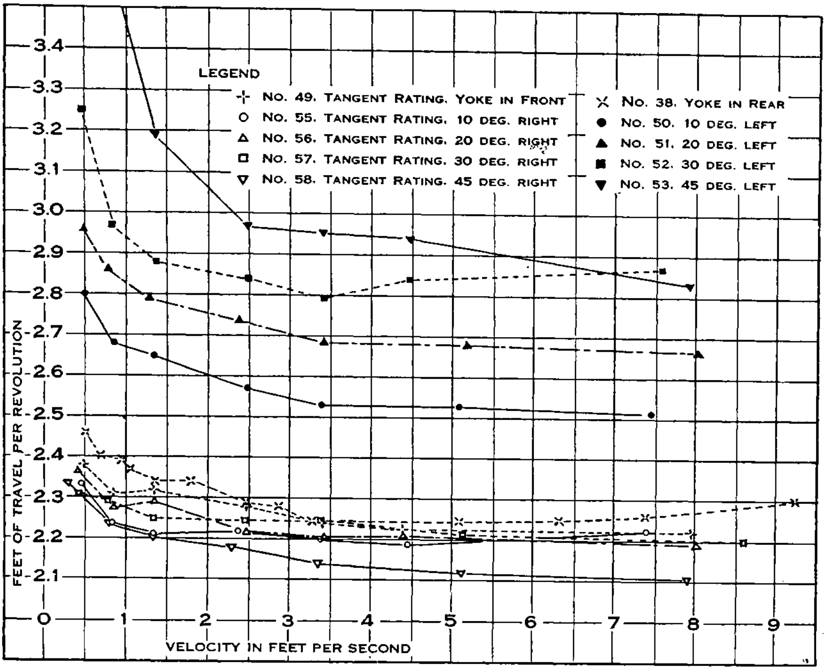

Figure 19.—Price meter number 1728, tangent-station ratings showing effect of turning meter to right and left when yoke was in front. Ratings made in center of channel at a depth of 1.5 feet. The meter was without a tail and the rod suspension was used.

tween the feet of travel per revolution of the meter and the velocity of the meter along the channel for each condition under which the meter was rated.

The ratings of the Price meters, as indicated by the plotted results, see Figures 17, 18 and 19, show that when the meter is turned to the right the cups rotate more slowly as the angle increases up to 90 degrees. Turning the meter to the left has, in general, a similar effect but the magnitude of the retardation is less. Tests made on Price meter number 1728 with the yoke to the front, show that the cups rotate more slowly when turned to the left, and faster when turned to the right. This is just the opposite of what happened when the meter was operated in the normal position, and was to be expected because the amount of the retardation depends on whether the rotating force is acting on the side to which the yoke was turned or away from it. The amount of the retardation differed because, in one case, the yoke was turned away from the side on which the rotating force was acting, and in the other case, toward the side on which the force was acting.

The tests on the Ott meters, see Figures 20 and 21, also showed that turning the meter to either side from the normal position retard-

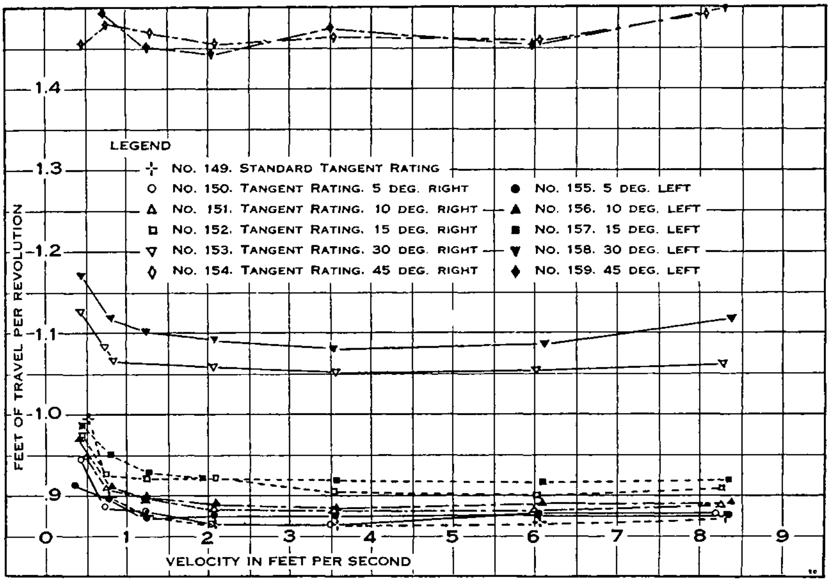

Figure 20.—Ott meter number 1933, tangent-station ratings showing effect of turning meter to right and left Ratings made in center of channel at a depth of 1.5 feet. The meter was without a tail and the rod suspension was used.

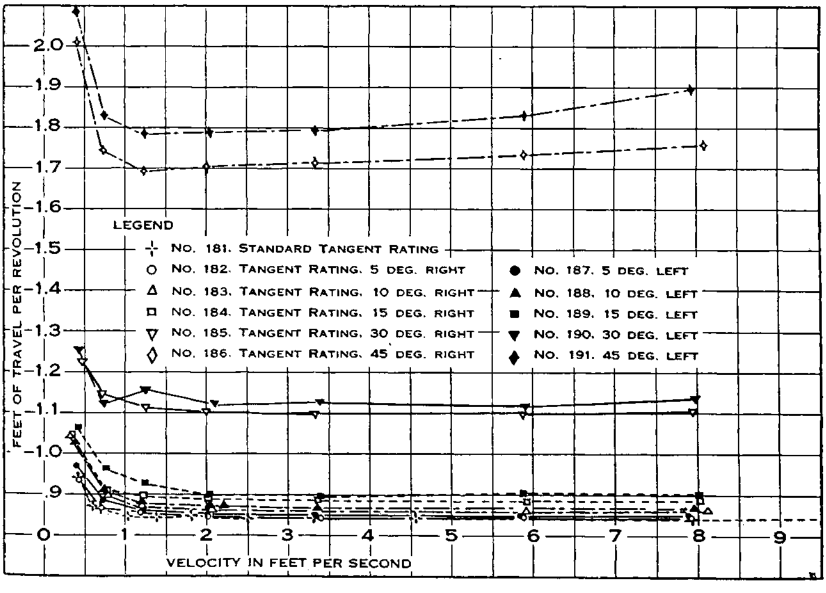

Figure 21.—Ott meter number 2575, tangent-station ratings showing effect of turning meter to right and left. Ratings made in center of channel at a depth of 1.5 feet. The meter was equipped with a tail and the rod suspension was used.

ed the revolutions of the propeller, but the extent of the retardation was much greater than in the case of the Price meters. There was also a difference in the retardation, depending on whether the meter was turned to the right or to the left, but in the case of the Ott meters the retardation was greatest when the meters were turned to the left. Altho the Ott propellers present a symmetrical face to the action of the current whether turned to the right or left, there is apparently some unexplained influence which causes the difference. This same effect has been noticed by other investigators, (16).

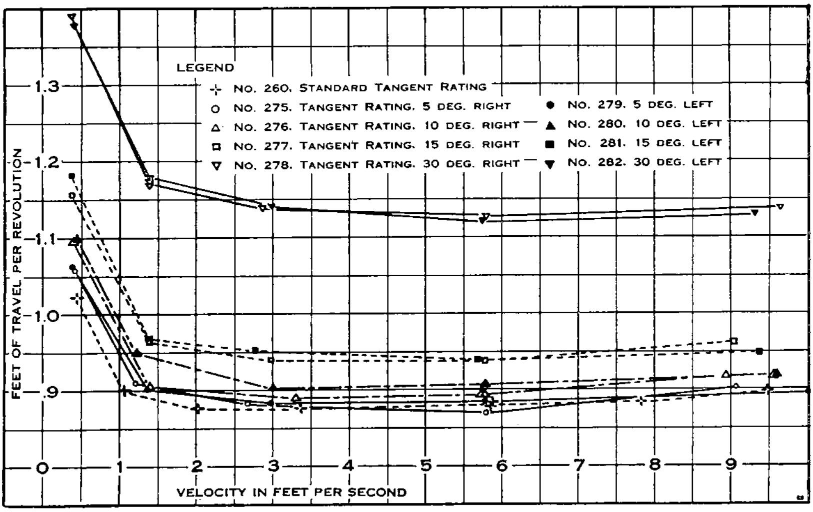

Figure 22.—Fteley-Stearns meter number 1, tangent-station ratings showing effect of turning meter to right and left. Ratings made in the center of channel at a depth of 1.5 feet. The meter was without a tail and the rod suspension was used.

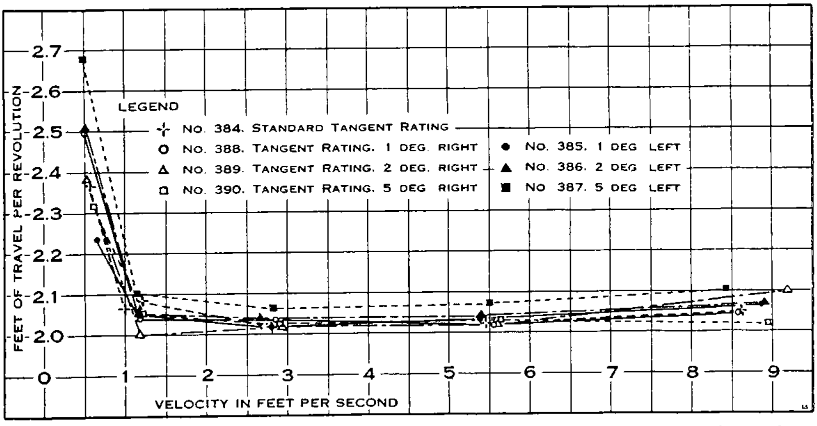

Figure 23.—Ritchie-Haskell meter number 162-B, tangent-station ratings showing effect of turning meter to right and left. Ratings made in the center of channel at a depth of 2.0 feet. Meter equipped with tail and the rod suspension was used.

As shown in Figure 22, the rotation of the propeller of the Fteley-Stearns meter is retarded by turning the meter at an angle to the current in the horizontal plane, but there is apparently no difference in

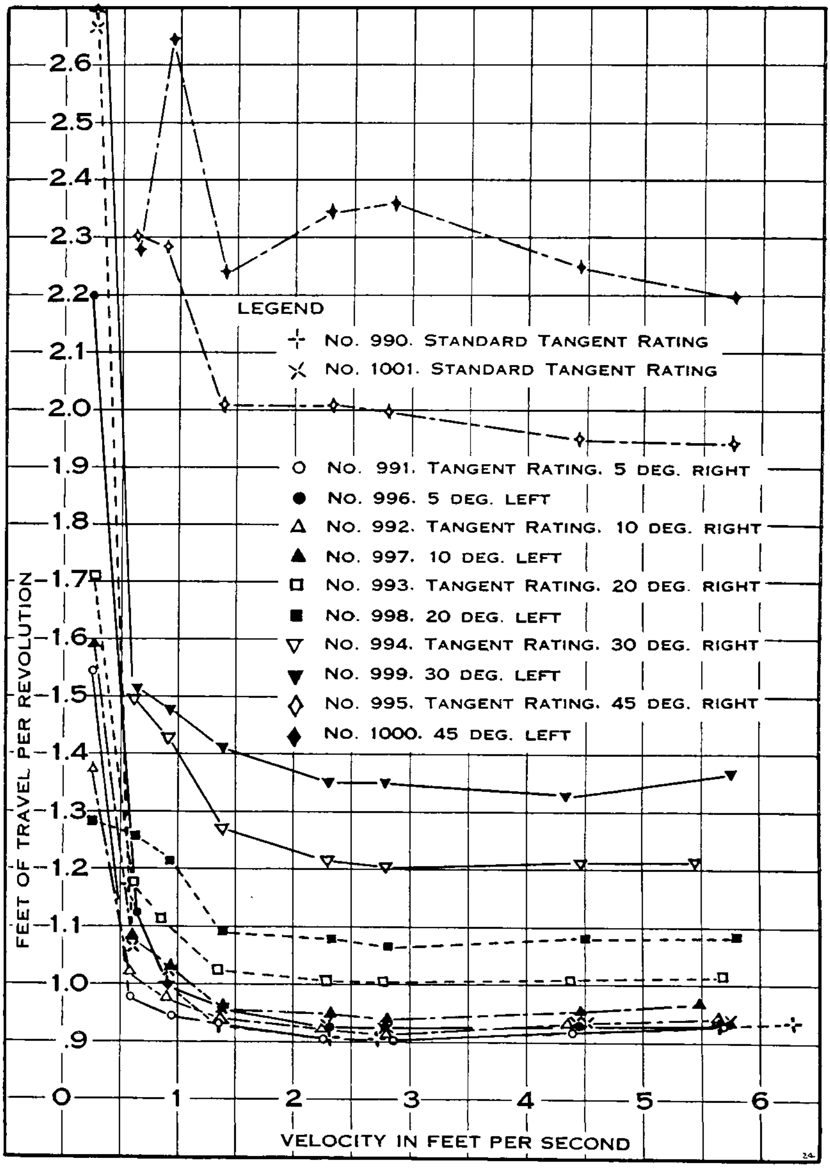

Figure 24.—Hoff meter number 9, tangent-station ratings showing effect of turning meter to right and left. Ratings made in center of channel at a depth of 2.0 feet. The three-bladed propeller was used. The meter was without a tail and the rod suspension was used.

the effect whether it is turned to the right or the left. The Ritchie-Haskell meter was tested only for small angles to the right and left. A very small retardation effect on the rotation of the propellers was

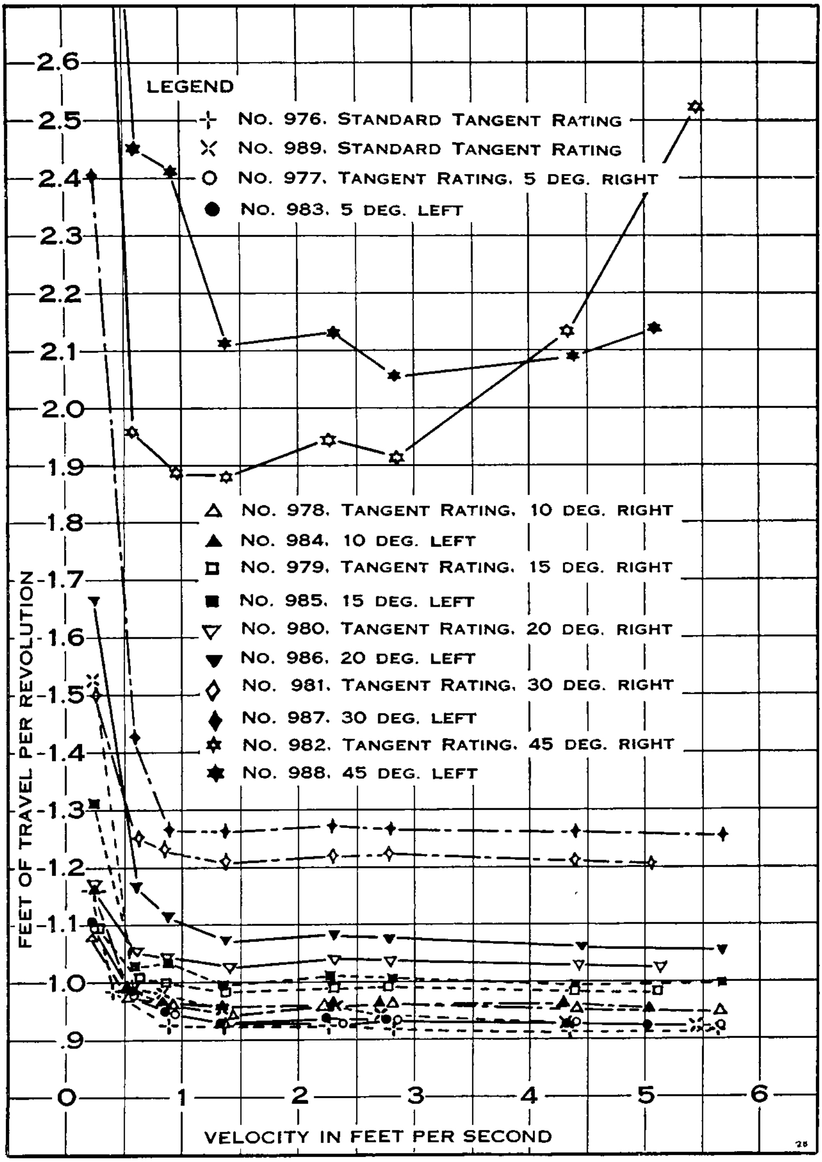

Figure 25.—Hoff meter number 9, tangent-station ratings showing effect of turning meter to right and left. Ratings made in center of channel at a depth of 2.0 feet. The four-bladed propeller was used. The meter was without tail and the rod suspension was used.

noticeable as the result of turning the meter thru these small angles (see Figure 23).

The tests on both the three and the four-bladed Hoff meters show that there is a definite retardation of the rotation of the propeller as the meter is turned thru horizontal angles to the right and left. See Figures 24 and 25. The amount of the retardation increases as the meter is turned at greater angles to the normal position, and turning the meter to the left retards the rotation of the propeller more than turning it to the right. This is true of both the three and the four-bladed propellers. These propellers are symmetrical about a horizontal axis and present a similar surface to the current, whether turned to the right or to the left; nevertheless there is a definite difference in the effect of the rotating force. It should be noted that both the Ott and the Hoff meters show a greater retardation when turned to the left, even tho the Ott meters rotate counterclockwise, whereas the Hoff meters rotate clockwise.

As previously stated, in order to make accurate discharge measurements in turbulent water, the meter should register only the component of the velocity of the current parallel to the axis of the stream. The component of the velocity is equal to the oblique velocity times the cosine of the angle which it makes with the axis of the meter. This is known as the cosine relation in current-meter measurements, and meters that register only the axial component of oblique velocities are said to satisfy the cosine relation.

The investigation of the effect of oblique currents on the registration of the different current meters previously made, showed merely that the meters tended to resolve the oblique currents into their axial components, but gave no indication as to the accuracy with which this was done.

The ratings made to determine the effect of oblique currents on the different current meters were not made at definite velocities thruout the range covered by the ratings, and as a result direct comparisons between axial velocities and corresponding resolved velocities were not possible. In order to make the comparison, the mean values of the feet of travel per revolution of the meter were computed for the standard rating, and the rating when the meter was turned at an angle to the current. In computing the mean, the feet per revolution for velocities of 1 foot or more only were used, because for lower velocities the values were very erratic. The velocity of the rating car times the cosine of the angle at which the meter is held is the velocity that the meter should indicate if it satisfies the cosine relation; or, in other words, the revolutions of the meter when parallel to the axis of the rating channel times the cosine of the angle between the axis of the meter and the channel when rated at an angle with the current at the same velocity, are the revolutions that the meter should make if it satisfies the cosine relation. Then, since the feet of travel of the meter per revolution of the propeller or cups is equal to the velocity divided by the revolutions per second, the feet of travel of the meter

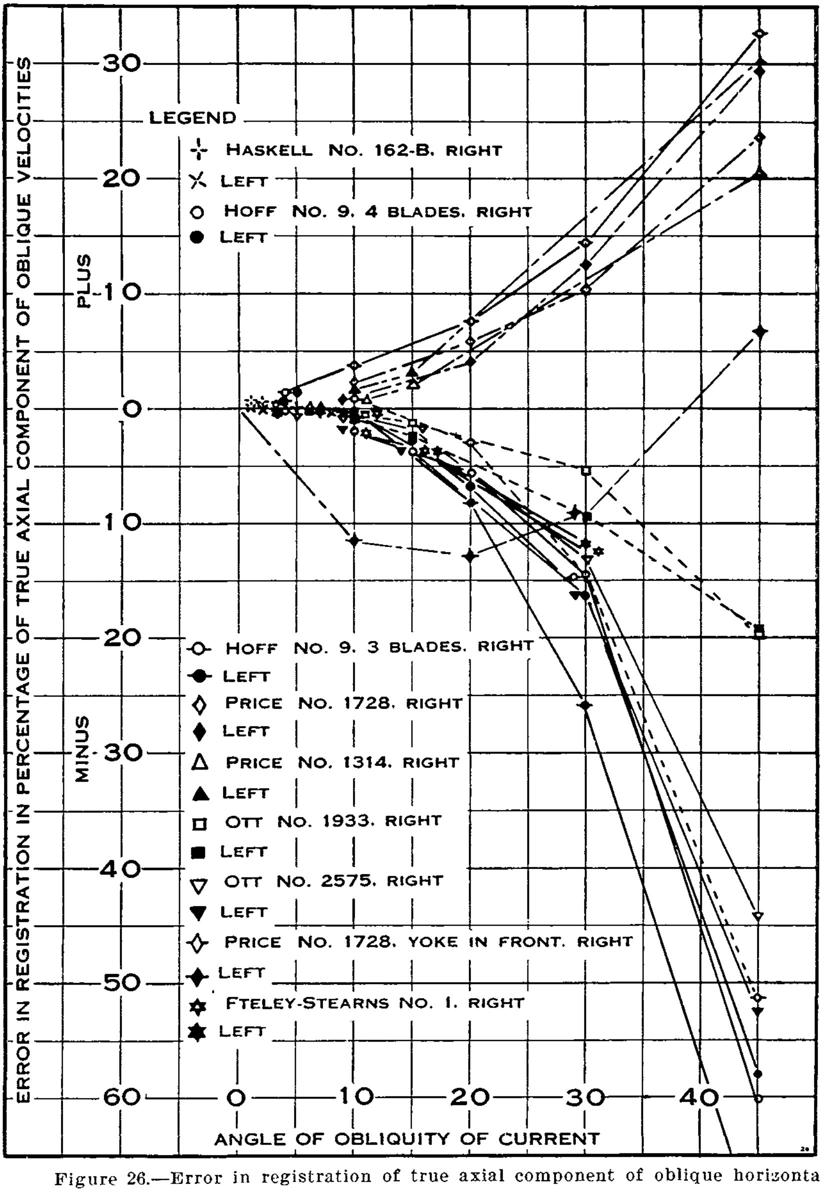

Figure 26.—Error in registration of true axial component of oblique horizontal velocities shown by tangent-station ratings of Price meters numbers 1314 and 1728, Ott meters numbers 1933 and 2575, Fteley-Stearns meter number 1, Ritchie-Haskell meter number 162-B and Hoff meter number 9, when turned at various angles to the right and left.

per revolution when parallel to the axis of the rating channel, divided by the cosine of the angle, is the feet of travel per revolution that the meter should register when set at an angle to the current if it satisfies the cosine relation. Therefore, in order to determine the accuracy with which the different meters satisfied the cosine relation, the mean values of the feet of travel per revolution of the propellers or cups when the meter was set at different angles to the current, were compared with similar values determined by dividing the feet of travel per revolution, when parallel to the axis of the rating channel, by the cosines of the respective angles at which the meter had been set. These later values were taken as the bases of comparison in determining the errors.

The errors in registration of the different meters at the various horizontal angles were plotted in Figure 26 using the errors as ordinates and the angles as abscissas. The plot shows that, in general, all the propeller meters under-register and that all the cup meters over-register. The Price meter, with the yoke to the front, is the exception to the general law. Under this condition the meter under-registers when turned to the left, except when turned at large angles to the axis of the channel. This is due to the fact that when the meter is turned to the left the yoke is in front of the side of the cups upon which the rotating force acts, and the retardation increases up to a certain point as the angle increases, and then decreases because the yoke no longer causes so much interference. When turned to the right, the performance of the meter was similar to that occurring when the yoke was in the normal position. Additional experiments (not shown) on another Price meter, number 1080, with the yoke in various positions, show that the principal effect due to the yoke occurs when it is on the side on which the rotating force acts.

These plots show that the propeller meters do not resolve oblique velocities in a horizontal plane into their axial components any better than the cup meters do. The propeller meters under-register as much as the cup meters over-register. For this reason it has been suggested (3) that cup and propeller meters be used simultaneously in measuring the velocity of turbulent water because the error of the meters would tend to balance each other.

As previously stated, tests were also made to determine the effect on the ratings when the meters were tilted at various angles in a vertical plane both above and below the horizontal. The tests were made on Price meters numbers 1314 and 1728, Ott meters numbers 1933 and 1398, Fteley-Stearns meter number 1. and Ritchie-Haskell meter number 162-B. The meters were rated at angles of 1, 2, 3, 5, 10 and 15 degrees from the horizontal, and from the observed data the feet of travel per revolution and the velocity for each of the meters were computed. All the meters were rated on rods in the center of the channel at a depth of 1.5 feet except the Ritchie-Haskell meter which was rated at a depth of 2 feet.

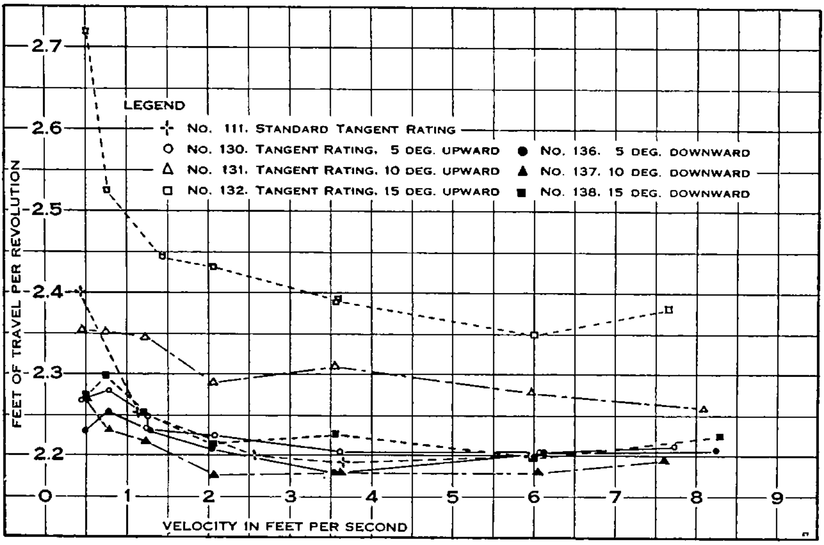

Figure 27.—Price meter number 1314, tangent-station ratings showing the effect of tilting the meter upward and downward. Ratings made in center of channel at a depth of 1.5 feet. Meter without tail, rod suspension used.

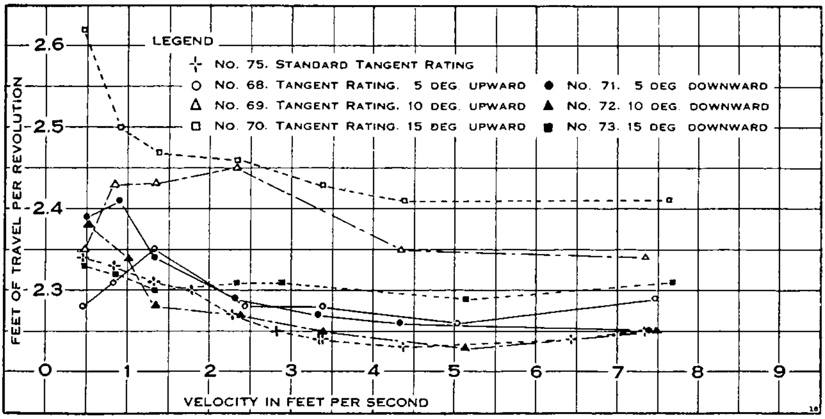

Figure 28.—Price meter number 1728, tangent-station ratings showing the effect of tilting the meter upward and downward. Ratings made in center of channel at a depth of 1.5 feet. Meter without tail, rod suspension used.

The results of the ratings are plotted in Figures 27 to 32 which show for each meter the feet of travel per revolution of the rotating element at the different velocities for each angle above and below the horizontal at which the meter was rated except those below 5 degrees, and for comparison, the same data for the standard rating of the meter. The data on the ratings made with the meters tilted less than 5 degrees from the horizontal were not shown because they differed so little from the results of the standard ratings.

The plotted data for the Price meters, (Figures 27 and 28), show that tilting the meter has very little effect on the rating when the angle is 5 degrees or less and that it does not make any difference whether the meter is tilted up or down. When, however, the angle is 10 degrees or greater, there is a definite effect due to the tilting of

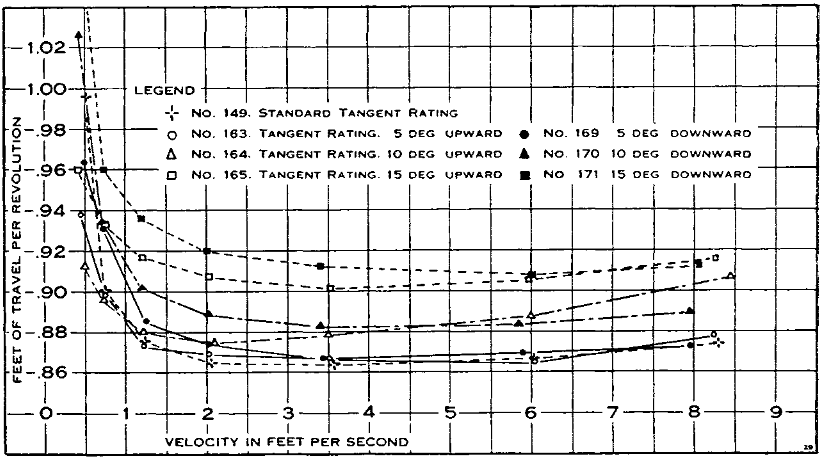

Figure 29.—Ott meter number 1933, tangent-station ratings showing the effect of tilting the meter upward and downward. Ratings made in center of channel at a depth of 1.5 feet. Meter without tail, rod suspension used.

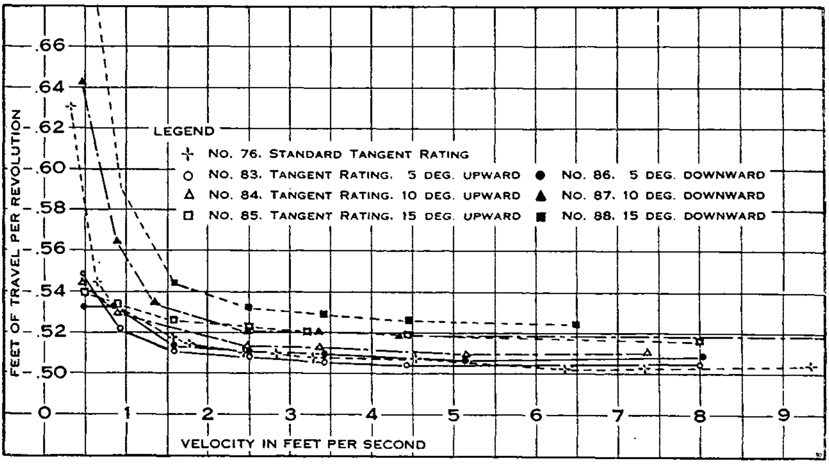

Figure 30.—Ott meter number 1398, tangent-station ratings showing the effect of tilting the meter upward and downward. Ratings made in center of channel at a depth of 1.5 feet. Meter with tail, rod suspension used.

the meter, and tilting the meter upward has a much greater effect than tilting it downward. This is probably due to the fact that when the meter is tilted upward, the cup shaft is lifted off the pivot bearing by the force of the water. This increases the friction because the thrust has to be taken up by the top bearing which offers more resistance than the pivot bearing. The effect produced is to retard the meter.

The ratings, (Figures 29 and 30) of the Ott meters when tilted at various angles do not show the effect of tilting the meter until the angle amounts to 10 degrees or more. The plots show that as the angle increases, the retardation of the meter increases and the retardation is greater when the meter is tilted downward than when it is tilted upward. This is just the opposite of what occurred in the case of the Price meters; the effect, however, is not so pronounced.

The action of the Fteley-Stearns meter when tilted at various angles above and below the horizontal was similar to that of the Ott meters (see Figure 31), except the retardation was less and there was little, if any difference whether the meter was tilted up or down.

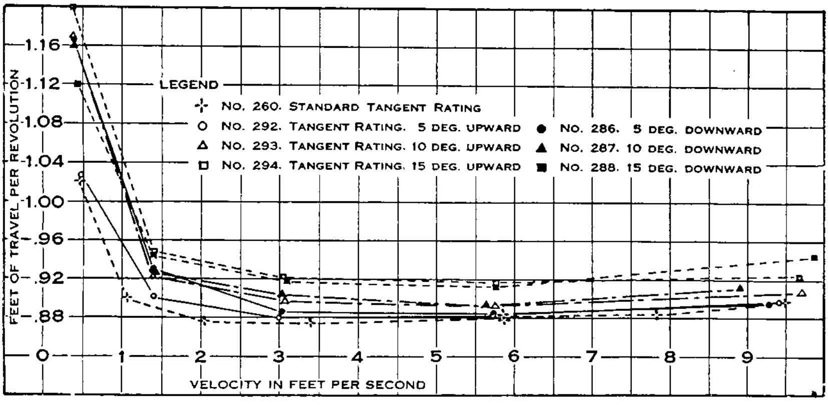

Figure 31.—Fteley-Stearns meter number 1, tangent-station ratings showing effect of tilting the meter upward and downward. Ratings made in center of channel at a depth of 1.5 feet. Meter without tail, rod suspension used.

Tests on the Ritchie-Haskell meter were made only at 5 degrees above and below the horizontal. The results (Figure 32) are similar to those obtained from the Ott meters.

The plots of the data obtained when the different meters were rated at various angles above and below the horizontal, show merely the effect of these changes. In order to determine how closely the different meters followed the cosine relation, the mean feet of travel per revolution of the meter for velocities of 1 foot or greater were computed from the original data for each of the meters at the various angles above and below the horizontal, and these values were compared with the feet of travel per revolution of the meter which should

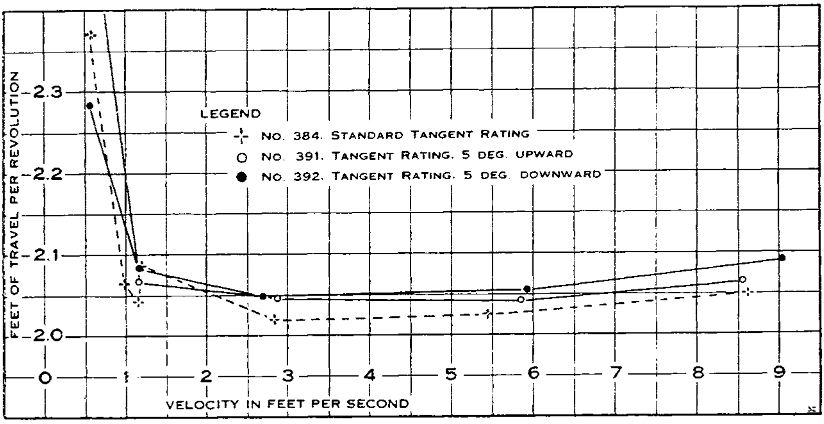

Figure 32.—Ritchie-Haskell meter number 162-B, tangent-station ratings showing effect of tilting the meter upward and downward. Ratings made in center of channel at a depth of 2.0 feet. Meter with tail, rod suspension used.

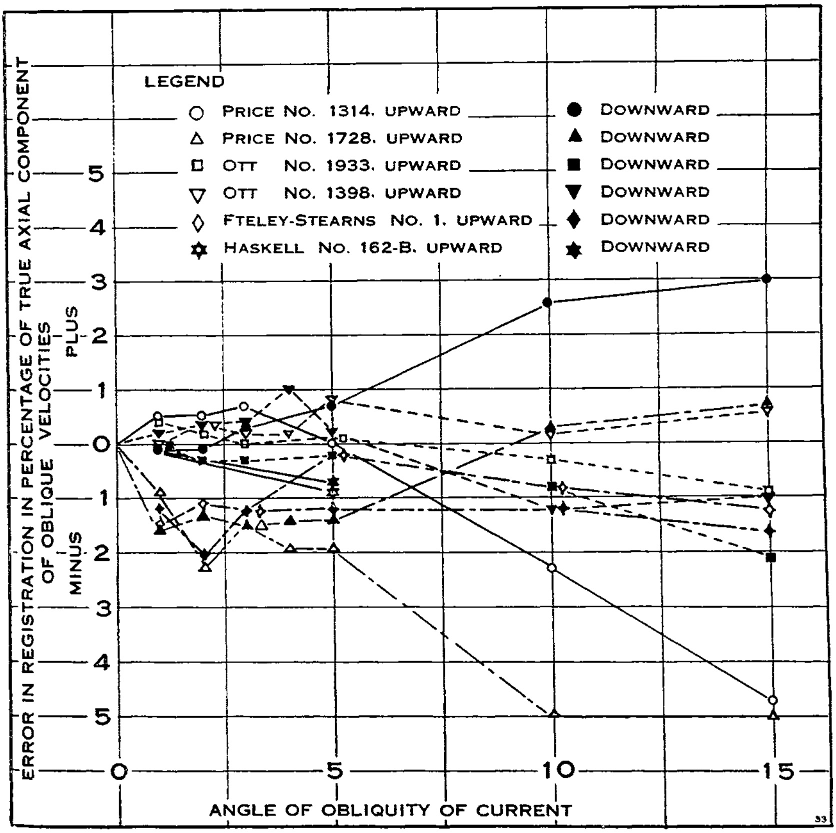

Figure 33.—Error in registration of true axial component of oblique vertical velocities shown by tangent-station ratings of Price meters numbers 1314 and 1728, Ott meters numbers 1933 and 1398, Fteley-Stearns meter number 1, and Ritchie-Haskell meter number 162-B, when tilted at various angles upward and downward.

have occurred if the meter followed the cosine relation as determined from the data on the standard rating in the manner previously explained. The results are shown in Figure 33, in which the errors in registration of each meter when tilted at various angles up and down are the ordinates and the angles are the abscissas.

The plot of the data shows that all the meters measure oblique velocities in the vertical plane fairly accurately when the angle is not more than 5 degrees, but when the angle is greater than 5 degrees the accuracy of the Price meter decreases considerably, whereas the accuracy of the Ott meters and the Fteley-Stearns meters remains about the same. Unfortunately the Ritchie-Haskell meter was tested only at 5 degrees above and below the horizontal, and, consequently, the effect of greater angles of obliquity is not known. The plot shows that in general the propeller meters resolve the oblique velocities into their axial components more accurately when tilted upward than when tilted downward, whereas the Price cup meters are more accurate when tilted downward, but the difference in the accuracy of the cup meters between the two positions is more pronounced. The re-

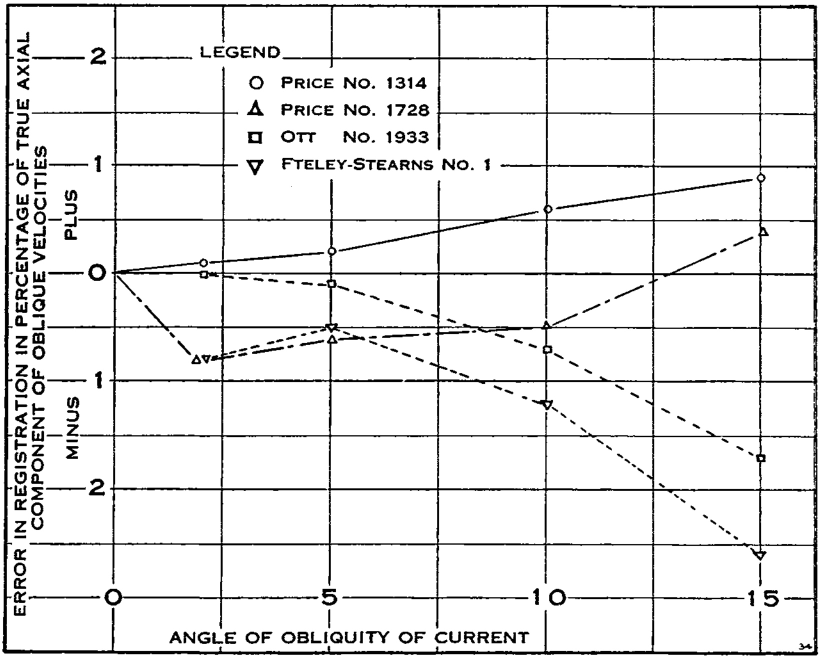

Figure 34.—Error in registration of true axial component of oblique velocities coming with equal frequency from all angles shown by tangent-station ratings of Price meters numbers 1314 and 1728, Ott meter number 1933 and Fteley-Stearns meter number 1.

sults of the observations show also that the propeller meters measure oblique velocities in the vertical plane more accurately than the cup meters.

In order to determine the accuracy of the meters when exposed to oblique velocities coming with equal frequency from all four directions, the mean value of the error in registration for each angle was determined by averaging the error in each of the four positions of the meter as read from the curves. The errors were determined for only Price meters numbers 1314 and 1728, Ott meter number 1933 and Fteley-Stearns number 1, because these were the only meters tested in all four positions. The results are plotted in Figure 34. Only the angles between zero and 15 degrees are included because the tests on the vertical angles were not carried beyond this point. These curves show that under these conditions the Ott and Fteley-Stearns meters under-register for all angles and that whereas Price meter number 1314 over-registers for all angles, Price meter number 1728 under-registers for small angles and over-registers at the maximum angles. This does not agree exactly with the results of Yarnell and Nagler (16) whose tests show that the Price meters over-registered at all angles and none but the propeller meters under-registered. These curves show that the errors, due to the effect of currents striking the meters at all angles with equal frequency, are usually small and, for the angles tested, are practically negligible. The curves indicate, however, that the cup meters are as accurate as the propeller meters when exposed to currents striking the meter with small angles of obliquity and probably more accurate at the higher angles.

Meter rods sometimes deflect to the right or left when making gagings. Under these conditions the rotating elements of cup meters no longer rotate in a horizontal plane. This changes the direction of the forces acting on the bearings, and in order to determine the effect of the changes Price meter number 1728 was rated when tilted at different angles to the right and left. No tests were made on propeller meters because their axes of rotation are parallel to the direction of the current and are subjected to the same force, regardless of how much the meter is tilted laterally.

The Price meter was rated in the standard position and when the rod was tilted at 5, 10 and 15 degrees to the right and left. The feet of travel per revolution for each condition were computed from the original data. The results are shown graphically in Figure 35.

No systematic difference due to tilting the meter rod to the right or left, is shown by the curves. They show, however, that the results are erratic at low velocities, that is less than 2.5 feet per second. At greater velocities the results are almost identical. This indicates that the difference in friction on the bearings, due to changing the position of the meter, has practically no effect at the higher velocities.

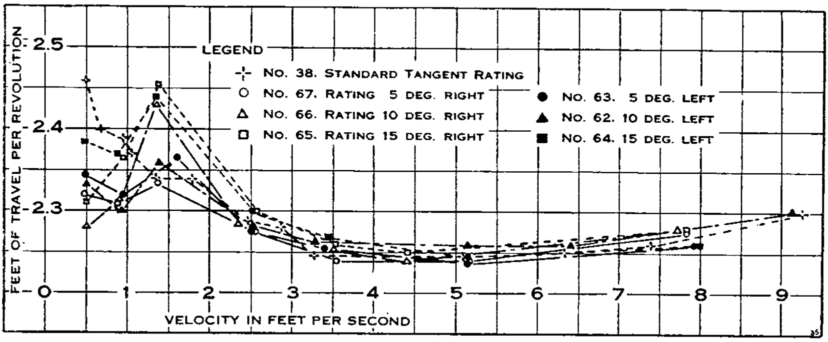

Figure 35.—Price meter number 172S, tangent-station ratings showing effect of tilting meter rod to right and left. Ratings made in center of channel at a depth of 1.5 feet. Meter without tail, rod suspension used.

The lower bearing of all small Price electric meters is adjustable and in order to determine the effect of changes in the adjustment on the rating of the meters, tests were made on two Price meters by rating them when the lower bearing was adjusted to different positions. The positions were obtained by first raising the pivot until all end play in the shaft was eliminated and then lowering the pivot by successive quarter-turns of the screw until each of the different adjustments was obtained at which a rating was desired. Both meters were rated in the center of the channel at a depth of 2 feet, using the rod

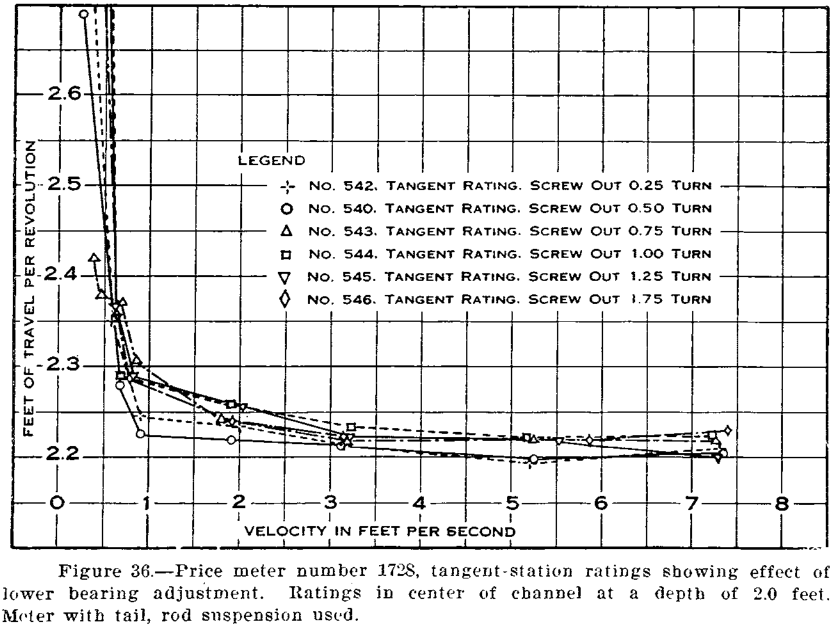

Figure 36.—Price meter number 172S, tangent-station ratings showing effect of lower bearing adjustment. Ratings in center of channel at a depth of 2.0 feet. Meter with tail, rod suspension used.

suspension. Meter number 1219 was of the tailless type and was equipped with a foot plate. Number 1728 was a standard tail meter.

From the original data, the feet of travel of the meter per revolution were computed and plotted against the velocity, as shown in Figures 36 and 37. The lines drawn thru the plotted points for the different settings do not seem to bear any definite relation to the bearing adjustment. The plots show, however, that in one case the loose adjustment causes the meter to run easier, and that in the other case the close adjustment seems to make the meter run more freely. There is, however, a definite indication that the effect of the bearing adjustment is greatest at the low velocities because the curves are farther apart under these conditions. One point to be considered in the explanation of the results is that it is necessary to remove the meter between adjustments of the bearing, and altho the effect of resetting the meter is usually small, it may have been sufficient to confuse the results due to the bearing adjustment.

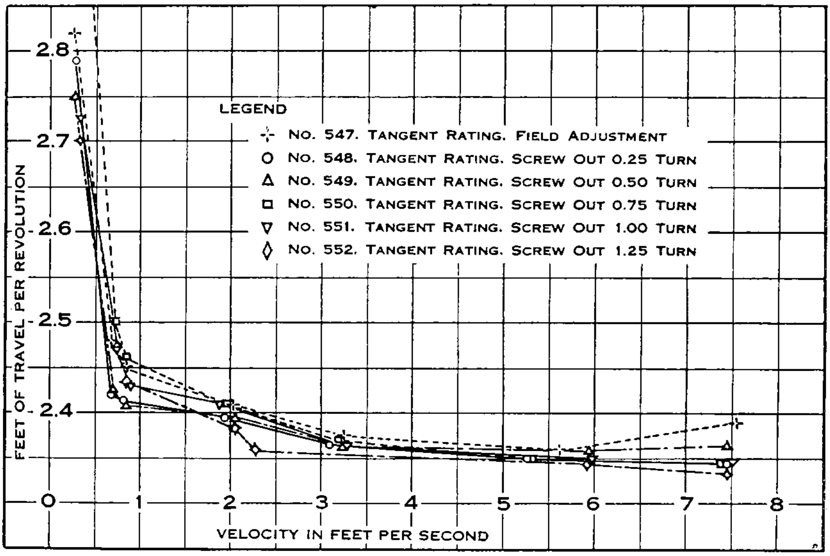

Figure 37.—Price meter number 1219, tangent-station ratings showing effect of lower bearing adjustment. Ratings in center of channel at a depth of 2.0 feet. Meter with foot-plate but without tail, rod suspension used.

In order to determine the effect of changes in the cups of the Price meters which occur thru accidents and from wear and tear, ratings were made on Price meter number 1314 under standard conditions and when the cups were bent, when one of the cups was loaded with lead, and when the cups were greased or given a sand finish. In making the tests to determine the effect of bending the cups, the bottoms of two of the cups which were not adjacent to each other, were crushed slightly, the maximum amount being 0.25 inch. The tests on the effect of the weighted cups were made with one of the meter cups loaded with a mixture of wax and lead shot. The added material weighed 5.73 grams. To test the effect of grease on the cups of the meter, they were liberally coated with machine oil and to test the effect of roughening the surface of the cups they were painted with shellac and then sprinkled with number 20 sand.

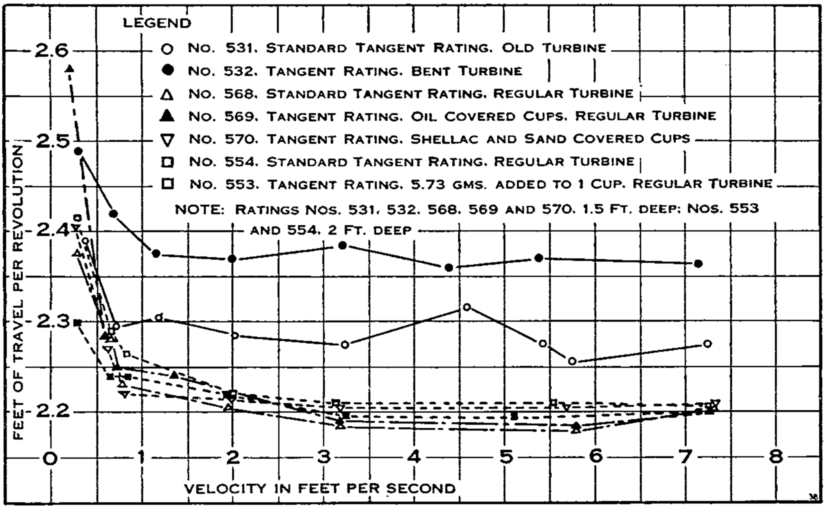

Figure 38.—Price meter number 1314, tangent-station ratings showing the effect of bending the cups, greasing the cups, covering the cups with shellac and sand, and adding a weight to one of the cups. Ratings made in the center of channel at a depth of 1.5 feet, except ratings numbers 553 and 554 which were at 2.0 feet. Meter with tail, rod suspension used.

The results are shown graphically in Figure 38 in which the feet of travel per revolution computed from the original data are plotted as ordinates and the velocities in feet per second as abscissas. The standard ratings do not agree because different sets of cups were used in the meter for the different tests.

The figure shows that bending the cups had a marked effect on the rating of the meter; that covering the cups with shellac and sand reduced the revolutions slightly, and that greasing the cups with oil or weighting one of the cups had little, if any, effect on the rating. It is obvious from the curves that bending the cups would cause serious errors in the results of current-meter measurements.

When measuring high velocities with a rod meter of the cup type, the meter rod bends, due to the force of the current. Guy wires are frequently used to support the rod, and in order to determine the effect of these wires on the rating of the meter, tests were made on Price meter number 1728 when supported by guy wires in different positions. In the first rating the guys consisted of two 16-gage black iron wires extending from the top of the yoke to points 36 inches apart, 32 inches in front and 28 inches above the meter. In the second test, the arrangement was the same except that the wires were attached to the meter rod 3 inches above the yoke. In the third test, the attachment was the same but the wire was replaced by sash cord. These data are shown graphically in Figure 39. The method of plotting is the same as previously described.

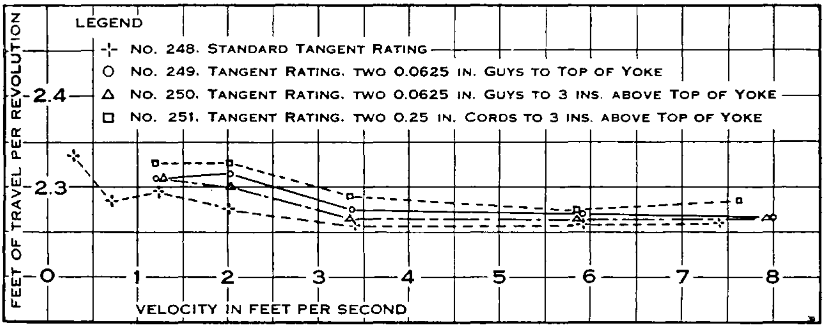

Figure 39.—Price meter number 1728, tangent-station ratings showing effect of use of guy wires in supporting meter. Ratings made in center of channel at a depth of 1.5 feet. Meter with tail, rod suspension used.

As shown by the plotted data, the guys cause the meter to rotate more slowly and the maximum reduction is caused by the sash cord guys. The wires attached near the top of the yoke have a greater effect than those attached 3 inches above it. The curves show, however, that if the wires are attached 3 inches above the top of the meter, the effect on the rating is very small.

When making the measurements with a current meter where a rod is used to hold the meter, the equipment furnished with the meter is ordinarily used, but when the water is deep and swift these rods are not strong enough, and under these conditions, it is sometimes desirable to use a heavier rod. In order to determine whether the size of rod affected the ratings, tests were made on Price meter number 15,188, when using the standard 0.5-inch rod furnished with the meter, and in addition when using a 1-inch and a 2-inch rod. The meter was equipped with a tail while making these tests. Pipes of the proper diameter were used for the large rods. These pipes were slipped over the standard rod and extended only to the top of the meter; when the 1-inch pipe was used, there was a noticeable deflection of the pipe at the maximum velocity tested. The results of the tests are shown graphically in Figure 40 which shows clearly that the meter runs more slowly as the size of the supporting rod is increased. Tests by Schmidt (13) at Munich, on both cup and propeller meters, show a similar effect.

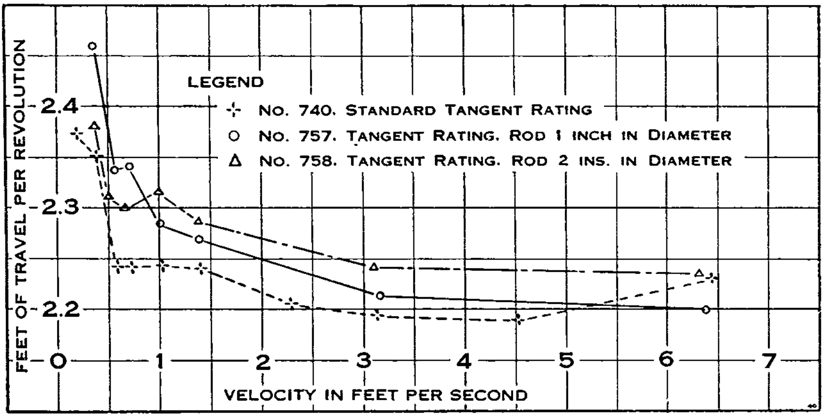

Figure 40.—Price meter number 15,188, tangent-station ratings showing effect of diameter of rods. Ratings made in center of channel at a depth of 2.0 feet. Meter with tail, rod suspension used.

While making the ratings when the meter was supported by a 2-inch rod, it was observed that at the high velocities a standing wave was caused by the rod. This wave sometimes formed as far as 4 inches in front of the rod. The pressure causing this wave probably occurred at the back face of the meter cups also, and would tend to retard the rotation of the meter. From the foregoing, it is evident that a special rating of the meter should be made, if a rod other than the standard is to be used.

In order to find out whether ratings made in flowing water agree with those made in still water, Price cup meter number 15,188 and Ott propeller meter number 2909 (see Plate 23) were rated in both still and flowing water at the tangent rating station at the hydraulic laboratory. Both meters were supported on rods and were rated at a depth of 2 feet. In making the tests in flowing water, a velocity of .5 foot per second was maintained in the rating channel by turning a constant quantity of water from the storage reservoir into the channel. The meters were rated in both directions at each velocity of the rating car at which observations were made. As a result, when the car was traveling with the current the meter under-registered, and when traveling against the current it over-registered, and if the amount of over-registration equalled the under-registration, then the mean of the observations in both directions would give the true value of the revolutions of the meter for the velocity at which the rating car was traveling, regardless of the velocity of the water so long as it remained constant. This was the method used in arriving at the correct number of revolutions of the meter when rated in the flowing water.

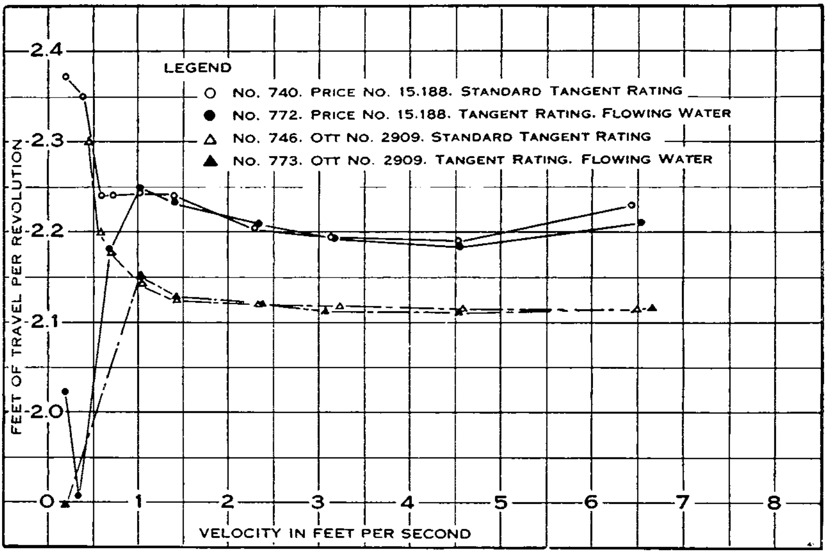

Figure 41.—Price meter number 15,188 and Ott meter number 2909, tangent-station ratings showing the effect of making ratings in flowing water. Ratings made in center of channel at a depth of 2.0 feet, velocity 0.5 foot per second. Meters with tails, rod suspension used.

Figure 41 is a plot of the data. Here, as previously, the feet of travel of the meter per revolution are plotted against the velocities. Figure 41 shows that for velocities of 1 foot or greater the results are identical for both conditions for both meters. It is evident when the rating car is going in the direction of the flowing water but at a lower velocity, that the rotation of the meter will be due to the water coming from the rear. This condition would cause the Price meter to rotate in the normal direction but would cause the Ott meter to run backwards. In either case the current approaching from the rear would make the meter register in a different manner than when striking the meter in the normal way. This explains the erratic results obtained at low velocities. It has been suggested that still water ratings should be used with caution (3), but the close agreement between the ratings at all but the low velocities makes it evident that for the velocities ordinarily encountered in current-meter measurements, it makes no difference whether the meter is rated in still or flowing water, at least for the conditions covered by the tests. Had it been possible to maintain higher velocities in the rating channel, the ratings under these conditions might have brought to light differences in the ratings which were not disclosed by the tests made.

Whenever large canals or streams are to be measured with a current meter, it is usually necessary to use a cable meter because ordinarily it is not possible to hold the meter with the rod under these conditions. In order to test the performance of the meters when supported by cables, observations were made on the different types of meters under these conditions. The observations included tests to determine the difference between rod and cable ratings, the effect of length of cable on the rating, the difference due to using one or two weights to hold the meter against the force of the current, and the influence of guy wires on the rating of the meter. Plate 18 shows the apparatus used.

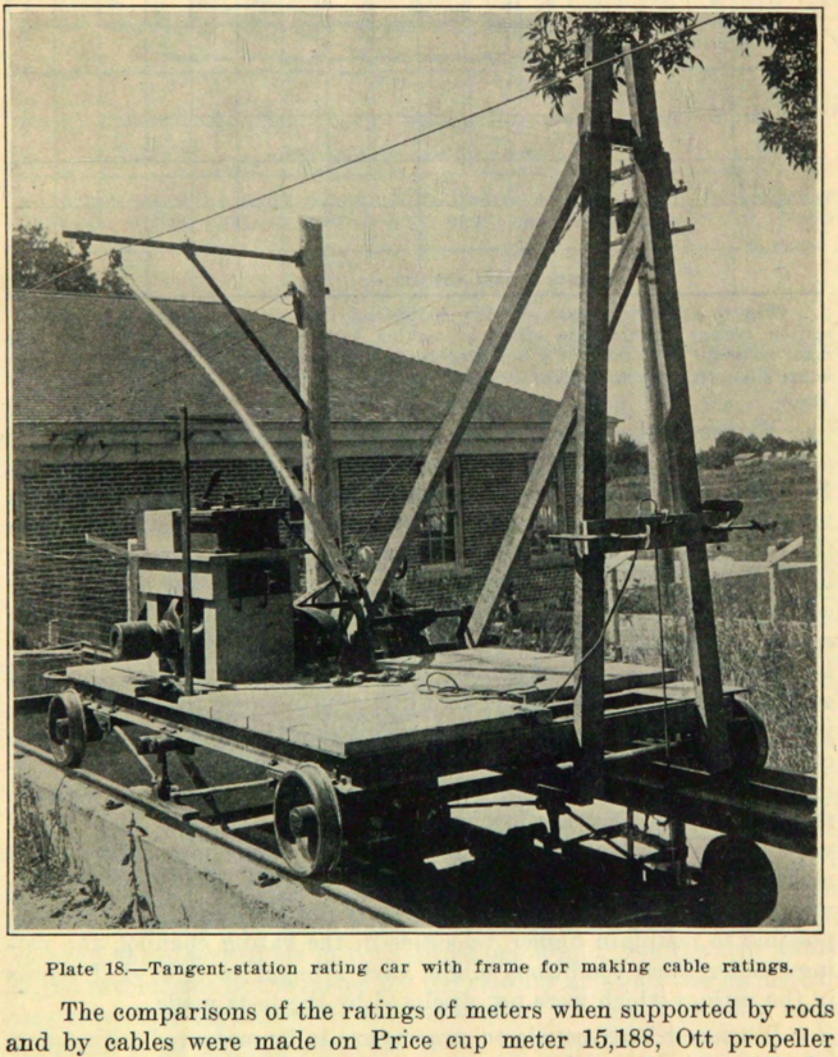

Plate 18.—Tangent-station rating car with frame for making cable ratings.

The comparisons of the ratings of meters when supported by rods and by cables were made on Price cup meter 15,188, Ott propeller meter number 2956 and Hoff propeller meter number 2. All the meters were equipped with tails and were rated at a depth of 2 feet.

In making the cable ratings, various lengths of cable and different sizes and positions of the weights were tried, but the standard hanger bars furnished with the meters for cable ratings were used in all the tests. While making the ratings of the meters with cable supports, it was noticed that the meters were carried back by the force of the current, sometimes as much as 6 feet when the rating car was traveling at its maximum speed and when the meters were supported by the greatest length of cable used in the tests. The Hoff meter also drifted laterally under these conditions. It is interesting to note here that altho the Price meter has a much greater bulk, it does not drift

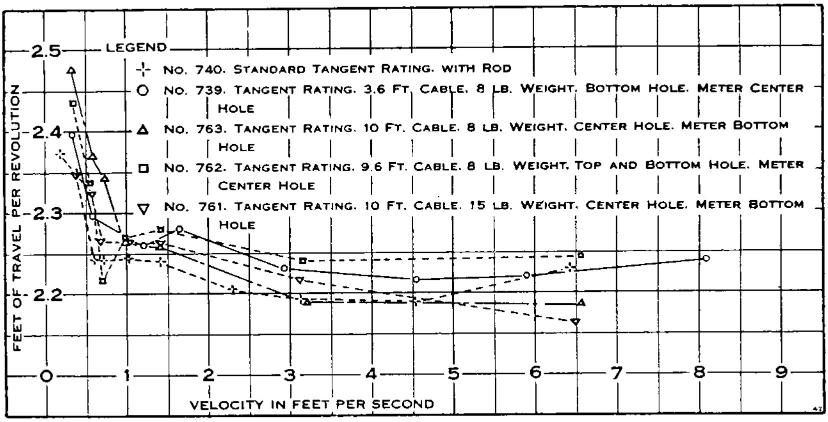

Figure 42.—Price meter number 15,188, tangent-station cable ratings showing effect of suspending weights at different points. Ratings made in center of channel at a depth of 2.0 feet. Meter with tail.

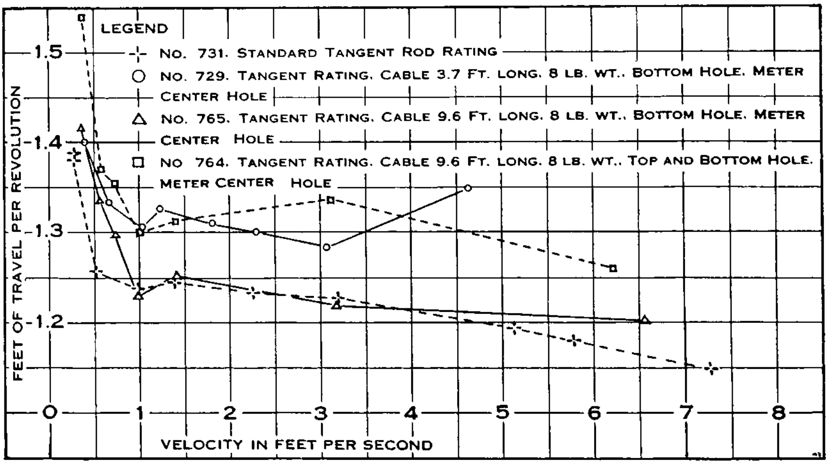

Figure 43.—Hoff meter number 2, tangent-station cable ratings showing effect of suspending weights at different points. Ratings made in center of channel at a depth of 2.0 feet. Meter with tail.

back any farther than the Hoff meter when rated with a cable support. The long buoyant tail with which the Ott meter was equipped for cable measurements was more effective in holding the meter steady in the water than were the old type tails. The new model Hoff meters are equipped with longer tails to correct this condition. The results of the comparisons of the rod and cable ratings are shown by the plots of the data in Figures 42 to 44. The data in the figures were obtained and plotted as previously explained.

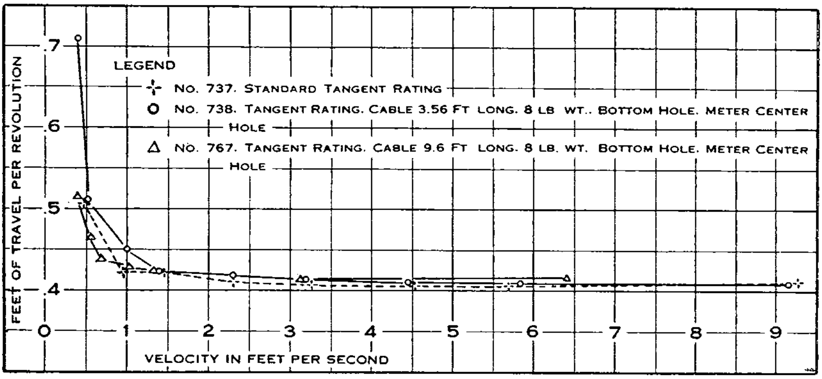

Figure 44.—Ott meter number 2956, tangent-station cable ratings showing effect of length of cable. Ratings made in center of channel at a depth of 2.0 feet. Meter with tail.

The plotted data show that, in general, all the meters run more slowly when rated with cable supports, and that weights above and below the meter retard it more than a single weight. If, however, as shown by tests on the Price meter (Figure 42) a single weight is placed above the meter, (ratings numbers 761 and 763) the meter will revolve more rapidly than when the weight is at the bottom, number 739, altho in this case the results may have been affected slightly by the length of cable. Tests by the Water Resources Branch of the United States Geological Survey on Price meters only, show similar results, (7 and 9). Tests by Rumpf (12) show that the Price meter runs more rapidly when rated as a cable meter. This seems unusual because the tests at the hydraulic laboratory at Fort Collins on both the cup and the propeller meters showed the reverse to be true.

The plotted data in Figure 44 show that the Ott meter operates much more consistently when rated as a cable meter than either the Hoff or the Price meters, and show also (Figures 42 to 44) that for accurate measurements the meter should be rated with the same type of support as is to be used in gaging.

The meters in the previous tests were supported by cables of different lengths, but in the case of the Price meter it was not possible to determine the effect of the difference in cable lengths because other conditions varied at the same time. Tests, however, had been made previously on Price meter number 1728 when different lengths of cable were used and when the other conditions remained the same. Both single and double standard weights were used. When one weight was used, it was attached at the bottom hole of the hanger and the meter was attached at the center hole. When two weights were used, they were both attached below the meter. The depth at which the ratings were made was not recorded, but it was probably about 2 feet. The results of these tests are given in Figures 45 and 46 which show the relation between the feet of travel of the meter per revolution and the velocity.

No conspicuous difference in the operation of the Price meter, due to the difference in the length of cable, is discernible in Figures

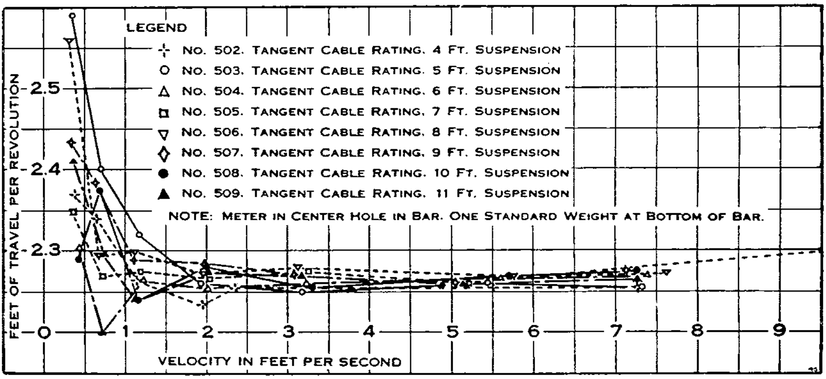

Figure 45.—Price meter number 1728, tangent-station cable ratings showing effect of length of cable. Ratings made in center of channel, depth not recorded. Meter with tail; one standard weight used.

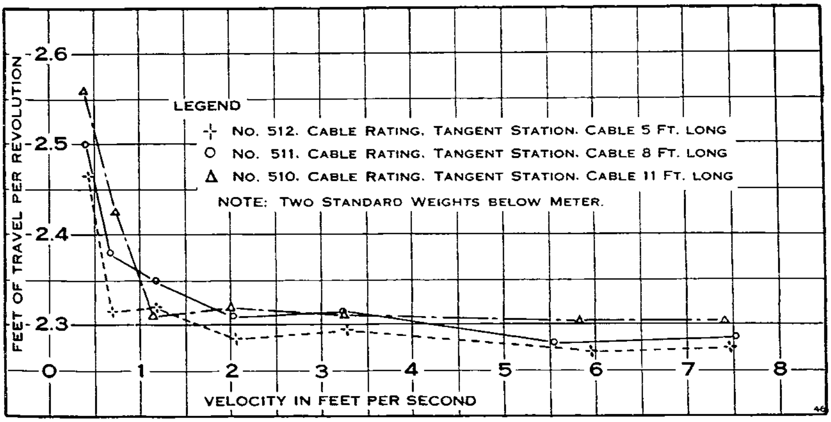

Figure 46.—Price meter number 1728, tangent-station cable ratings showing effect of length of cable. Ratings made in center of channel, depth not recorded. Meter with tail; two standard weights used.

45 and 46, but if any conclusion is to be drawn from the plotted results it is that the rotation of the meter is retarded as the length of the supporting cable is increased, but this conclusion is not true without exception. The observations on the Hoff meter (see Figure 43) show that the meter runs faster when the length of the cable is increased, whereas the observations on the Ott meter, (see Figure 44) show the opposite to be true, and in the case of the Hoff meter the difference is large enough to require consideration when making stream measurements.

Comparison of Figures 45 and 46, Price meter number 1728, for conditions when one and when two standard weights were used, in each case below the meter, shows that the two weights cause the meter to run slower. The tests on Price meters by the Water Resources Branch of the U. S. Geological Survey reported by Liddell (7) show that two 15-pound weights instead of one, attached below the meter, did not change the rating. It is obvious that greater variations will occur in cable ratings because the meter is not held rigidly, and, consequently, may assume a different position each time it is rated. This probably explains some of the inconsistencies in the results obtained when meters with cable supports are rated.

Additional tests were made on Price meter number 1728 when supported by a cable, in order to determine the effect of the guy wires which are frequently used to hold meters in place when making measurements where a cable support is required for the meter. In making the tests, the length of cable used was 3.2 feet and the depth of submergence of the meter was 2.2 feet. One standard torpedo weight

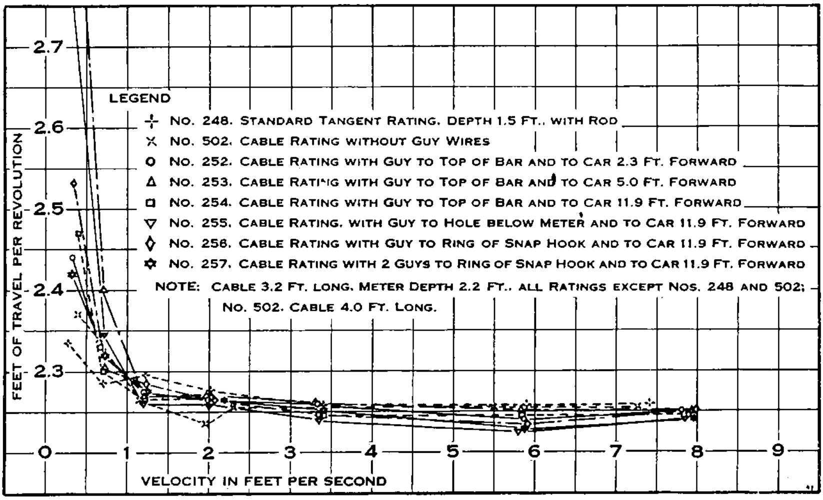

Figure 47.—Price meter number 1728, tangent-station cable ratings showing effect of guy wires. Ratings made in center of channel at a depth of 2.2 feet. Meter with tail; one standard weight used.

attached to the bottom hole in the hanger was used to keep the meter from drifting with the current. The meter was attached at the center hole in the hanger. The guy wire, which was one-sixteenth inch in diameter, was attached to the hanger and to the rating car at different points to determine the effect of changes in the points of attachment. The points of attachment to the car were all approximately 3.3 feet above the meter. The plotted results of the ratings are shown in Figure 47.

This group of tests shows that, altho the effect of guy wires is small, there is a slight tendency for the rate of rotation of the meter to increase as a result of the use of guy wires to hold the meter in place, and the greatest effect occurs when the guy wire is attached to the hanger below the meter. This is true only for velocities greater than 1 foot; for velocities less than 1 foot, the results are erratic. These tests show also that the meter when rated with a cable support without guys runs slightly faster at all but the lowest velocities than it does when held by a rod. This is contrary to the results previously obtained, but may be due to the fact that the cable rating was not made until a year after the rod rating.

No factors are given for correcting the results of ratings made under one condition into the results obtained under some other condition, because it is believed that the use of factors for converting results is likely to lead to serious errors because of the differences which occur in individual meters of the same type and make. Furthermore, the plotted data show that the differences between the ratings of the meters under various conditions change with the velocity and, consequently, no one factor would be satisfactory. When making current-meter measurements that require special methods or special equipment, it is believed that better results will be obtained if the meter is rated under the conditions in which it is operated.

ROTARY RATING STATION

A special channel must be provided when making tangent ratings except when the ratings are made from a boat in a stream, or in a body of still water. Since an artificial channel must be several hundred feet in length in order to have satisfactory conditions for making ratings, considerable expense is involved in construction. For this reason rotary stations are sometimes used because all that is necessary, in addition to the operating equipment, is a body of still water of sufficient size to permit moving the current meter in a circular path with a maximum diameter of about 50 feet.

There is some doubt, however, whether a rating made at a rotary station is the same as one made at a tangent station, because when the meter is moving in a circle, that portion of the rotating element of the meter toward the inner side of the circular path does not move with the same velocity as that portion toward the outside. In addition, the meters that rotate around a vertical axis either gain or lose one revolution each time the boom which supports them makes a complete revolution. By making comparisons between tangent and rotary-station ratings, it was thought that the effect of these factors could be determined, and for this reason a rotary station was built at the hydraulic laboratory.

The storage reservoir at the laboratory, which is 85 feet in diameter and 6.5 feet deep, was utilized for the still-water pool, and in it the apparatus for making the ratings was installed, as shown in Figure 48 and Plate 19. A 6-inch steel pipe was firmly embedded in concrete in the center of the reservoir to form the pivot about which the boom for supporting the meter rotated. The boom con-

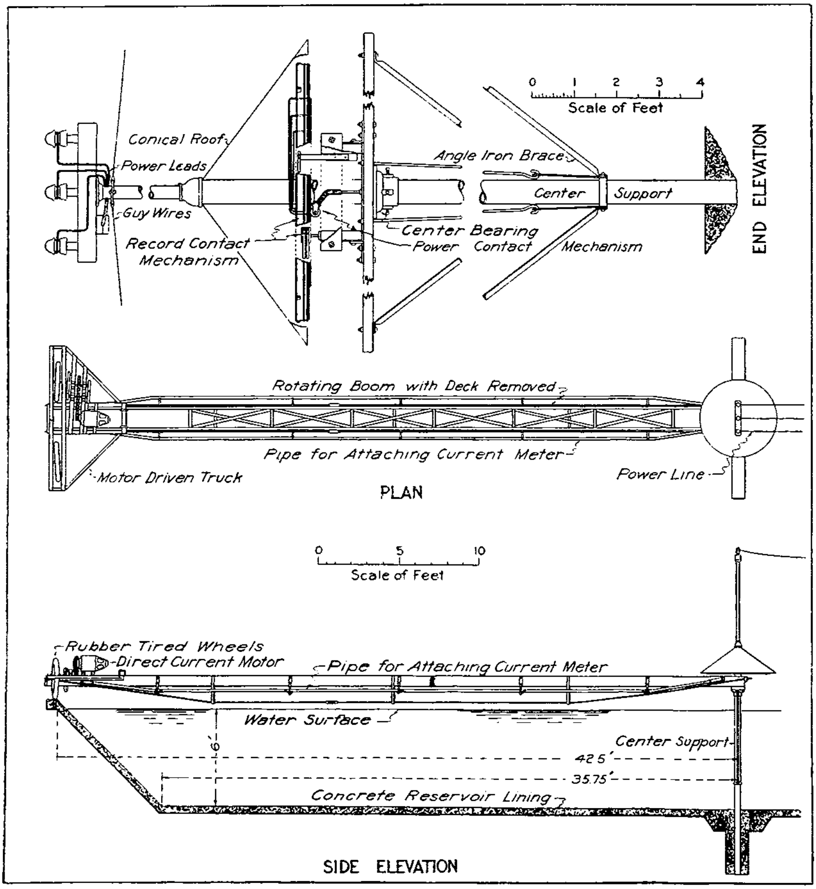

Figure 48.—Circular rating station at the hydraulic laboratory at Fort Collins, Colorado.

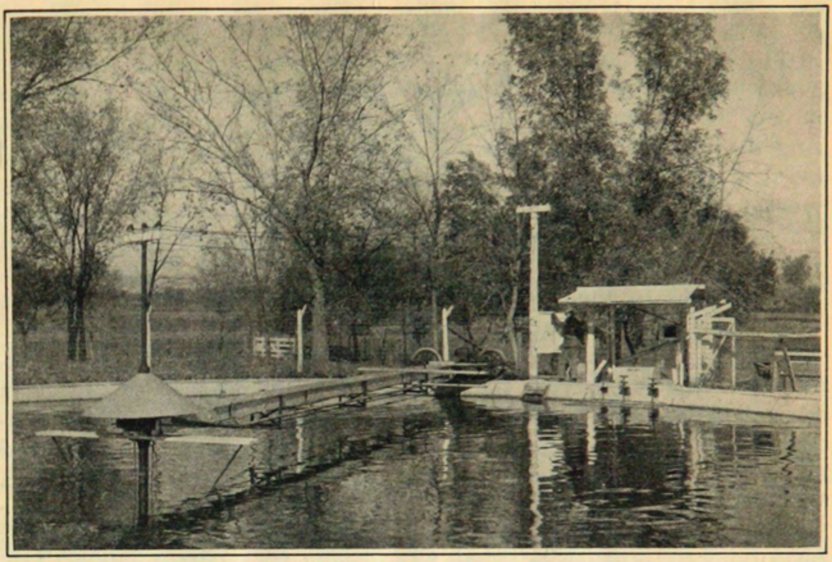

Plate 19.—Rotary rating station.

sisted of a frame bridge stiffened by steel tension rods. The boom was supported in the center of the reservoir by the steel pipe, and on the outer end by a two-wheeled rubber-tired truck which ran on the coping around the top of the reservoir. One of the wheels of

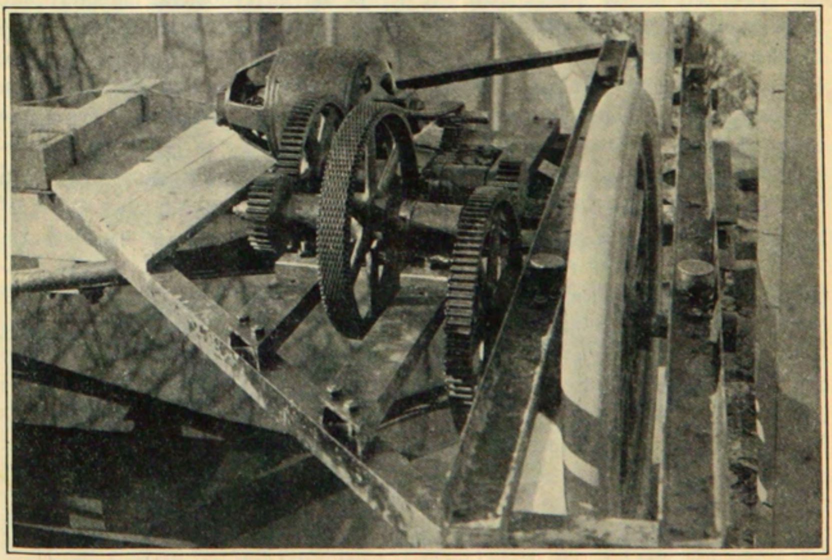

Plate 20.—Chain and interchangeable gear drive for rotary rating-station boom.

the truck was driven by a direct-current motor thru a silent chain and a train of interchangeable gears (see Plate 20). By using the proper combination of gears and by adjusting the rheostat on the motor and on the motor generator set, which furnished the current for the tangent station, it was possible to run the truck at any desired speed up to 20 feet per second, and by changing the direction of the current with the starting switch it was possible to change the direction of travel. The current to the motor was carried from the steel pole in the center of the reservoir to three circular copper conductors attached to the lower side of a wooden disc fastened to the center pole. Roller contacts attached to the boom were held against the circular conductors by spring supports. The rollers were connected to the leads from the motor and were attached to the boom in such a manner that they kept in contact with the copper conductors as the boom rotated. A 2-inch pipe was rigidly fastened along each side of the boom by iron brackets, as shown in Figure 48. The current meters were attached to these pipes by an adjustable clamp which made it possible to set the meter at any desired radius from the axis of rotation of the boom, and also to tilt the meter into any horizontal or vertical position.

The recording equipment of the tangent station was also used for the rotary station. However, in order to transmit the electric contacts showing the revolutions of the meter, it was necessary to provide a sliding contact at the axis of rotation of the boom between the leads from the meter and the leads to the recording mechanism. This mechanism consisted of two copper bands attached to the edge of the horizontal wooden disc which was fastened to the pole in the center of the reservoir. Two spring brushes attached to the boom pressed against these bands as the boom rotated. The leads from the current meter were attached to the springs and the leads to the recording mechanism were attached to the bands. The distance traveled by the meter was determined by the radius of the circular path of the meter and the angular distance thru which the boom had rotated. The angular distance was measured from contact points uniformly spaced on the periphery of the disc to which the bands were attached. The electrical circuit was made thru a spring brush attached to the boom, which pressed against a third copper band on the edge of the wooden disc, and a pointer on the boom which came in contact with the points on the periphery of the disc. The leads from the recording mechanism were connected to the copper band and the contact points, and the pointer and the spring brush attached to the boom were interconnected; consequently, each time the pointer on the boom touched a contact point there was an electrical impulse sent to the recording mechanism. The time record was obtained in the same manner as previously.

The radius of the path thru which the meter traveled was measured from the center of the axis of rotation of the boom to the center of the rotating element of the meter with a steel tape and plumb bob. In order to eliminate errors in the distance traveled by the meter, due to inaccuracy in the setting of the distance contact points, a complete revolution around the reservoir was used as the distance unit, and in order to have a uniform velocity thruout the entire revolution, the boom was brought up to speed before starting the record and then stopped after a complete revolution had been made.

The tape record of the revolutions of the meter, time in seconds and distance traveled was the same as that obtained when making ratings at the tangent station, but in computing the records one revolution of the boom was taken as the unit when segregating the portion of the tape from which the data were to be taken.

ROTARY-STATION RATINGS

The ratings at the rotary station were made to find, if possible, the conditions which gave results most nearly comparable to the ratings made at the tangent station. To do this, ratings were made with the meters set at different distances from the center of rotation to determine the effect of the radius of rotation. These ratings were made on the meters when equipped with tails and when without them, and the ratings on Price meters were made both with the rotating force acting on the cups toward the center of rotation and on the cups on the side away from the center of rotation. Guy wires were also used on some of the meters to see if holding them more rigidly made the rating any more nearly the same as the tangent rating. All the ratings were made with rod suspension.

The meters used in these tests were Price cup meters numbers 1314, 1728, 8374, and Ott propeller meters numbers 1933, 2575 and 1398. All these meters, except Price meter number 8374, have been described previously. This meter was similar to meter number 1314, but was made by a different company, and, like number 1314, differed from the standard Price meters in that it was equipped with

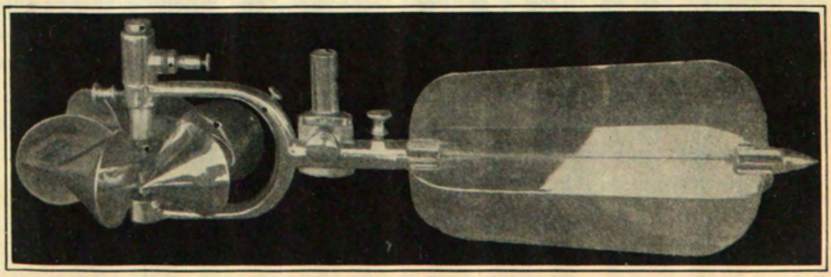

Plate 21.—Price meter number 8374; also designated as Lietz meter number 8374.

cylindrical bearings with a hardened steel ball in the lower bearing to carry the thrust from the weight of the cups (see Plate 21).

The results of the ratings of the different meters, except Price meter number 1314, at the rotary and the tangent station are shown graphically in Figures 49 to 53. The results from meter number 1314 were excluded because they were nearly identical with those for meter number 8374. The figures show the relation between the velocity of the meter and the feet of travel per revolution of the meter computed from the velocity and the revolutions per second.

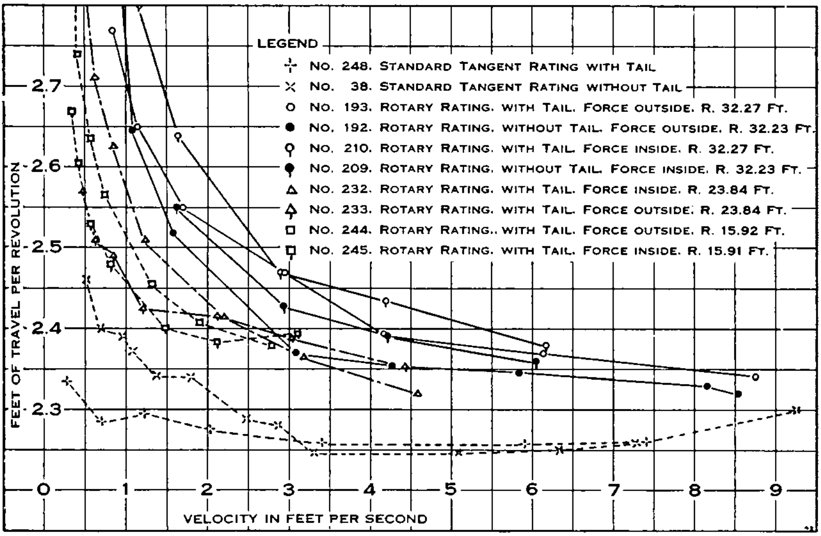

Figure 49.—Price meter number 1728, rotary-station ratings showing effect of radius of rotation, direction of rotation, and presence and absence of a tail. Ratings made at a depth of 1.5 feet, rod suspension used. Meter held in place by guy wires attached 0.2 foot above center of meter.

The comparison of the ratings of the cup meters made at the tangent and the rotary stations (see Figures 49 and 50) show clearly that the meters run more slowly when rated in a circular path than when rated on a tangent. This is true whether the radius of the circular path is small or large; it is true whether the meter is operated with or without a tail. Meters held rigidly by guy wires and meters supported by their rods only, all show the same result. Even when the direction of rotation around the reservoir is such that the rotating force acts on the cups toward the outside of the path, the meter still runs slower than it does when rated at the tangent station.

In computing the results of the ratings of the cup meters at the rotary station, no correction was made to take care of the fact that the meter either gained or lost one revolution each time it made a

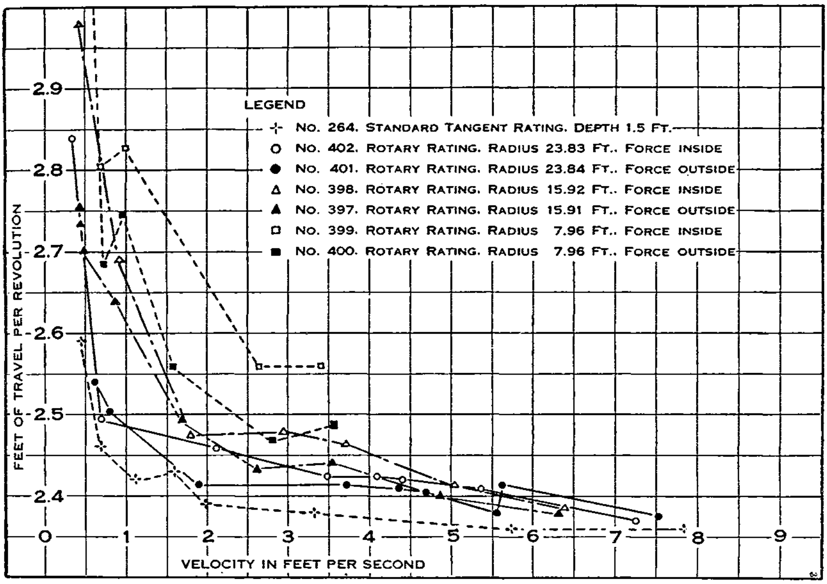

Figure 50.—Lietz meter number S374, rotary-station ratings showing effect of radius of rotation and direction of rotation. Ratings made at a depth of 2.0 feet. Meter with tail, rod suspension used. Meter held in place by guy wires attached 0.57 foot above center of meter.

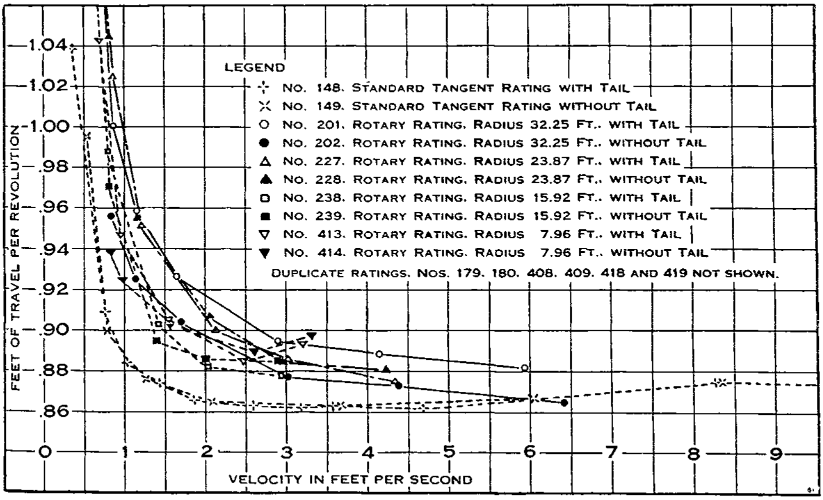

Figure 51.—Ott meter number 1933, rotary-station ratings showing the effect of the radius of rotation and the presence and absence of a tail. Ratings made at a depth of 1.5 feet, rod suspension used. No guy wires used to hold meter.

circuit of the reservoir, depending on the direction of rotation, because the ratings were made in both directions around the reservoir and the amount that the meter ran too fast in one direction would be equal to the amount that it ran too slow in the other direction. The mean of the ratings in both directions would be independent of this factor. Since, however, the meters rotated more slowly at the rotary station, regardless of the direction, than at the tangent station, the mean ratings were not determined because it was obvious that taking the mean ratings would not make the tangent and rotary-station ratings coincide.

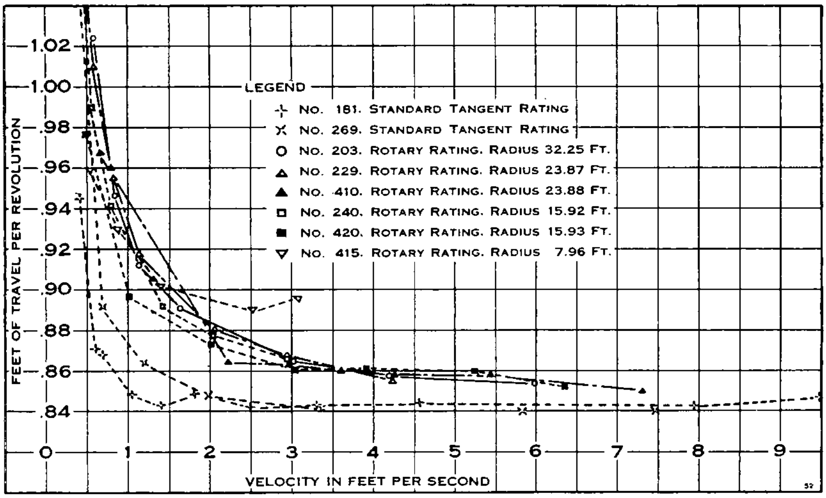

Figure 52.—Ott meter number 2575, rotary-station ratings showing effect of the radius of rotation. Ratings made at a depth of 1.5 feet, rod suspension used. No guy wires used to hold meter.

The ratings of the Ott meters (see Figures 51 to 53) in general show that the meters run more slowly when rated at the rotary station than when rated at the tangent station. The only exception is meter number 1398 which, under certain conditions, runs faster when rated at the rotary station than when rated at the tangent station, but the difference is small.

The figures show that as the radius of rotation decreases, Price meter number 8374 runs slower, whereas Price meter number 1728 and Ott meters numbers 1933 and 1398 run faster. Price meter number 1314 operates in the same manner as meter number 8374. Ott meter number 2575 is apparently not affected by the radius of rotation.

The ratings made with and without tails at the rotary station on Price meter 1728 and Ott meters numbers 1933 and 1398, show that the Price meter runs faster without than with the tail, regardless of

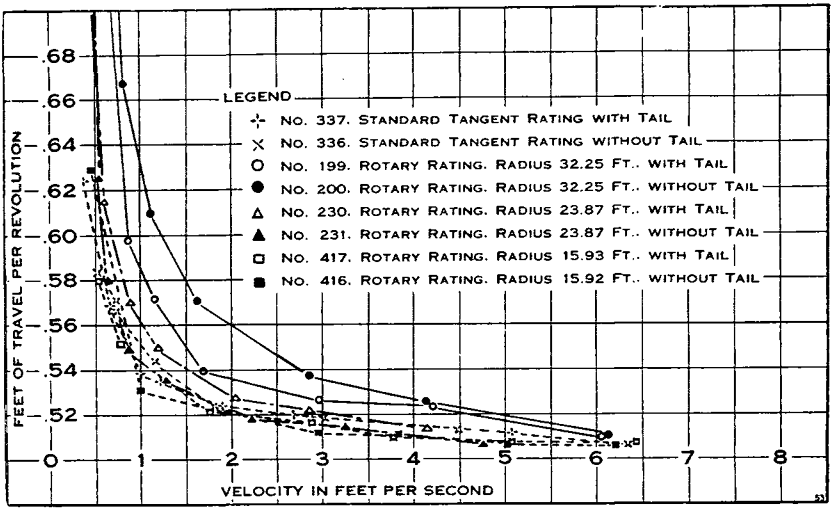

Figure 53.—Ott meter number 1398, rotary-station ratings showing effect of the radius of rotation and the presence and absence of a tail. Ratings made at a depth of 1.5 feet, rod suspension used. No guy wires used to hold meter.

the direction of rotation of the meter, and that the Ott meters under some conditions run faster and, under others, slower when operated without a tail. The ratings made on the same meters, with and without tails at the tangent rating station, show that the tail has little, if any, effect under these conditions. As the ratings at the rotary station were not made both with and without guy wires, no conclusions can be drawn as to their effect except that they did not make the rotary and tangent-station ratings agree.

Another series of tests was made to determine whether the depths at which the ratings were made at the rotary station were the cause of the differences between ratings at the tangent and the rotary stations. The tests were made on Price meters numbers 1314 and 8374 on depths from 0.5 foot to 3.5 feet beneath the surface. The standard ratings made at the tangent station for comparison were made at a depth of 1.5 feet beneath the surface. Both meters were supported by rods, and while making the ratings at the rotary station, the meters were held rigidly in place by guy wires.

The plotted results of the ratings (see Figure 54 which is similar to the plot for meter number 8374, not shown) revealed the fact that the meters do not run as fast when rated at the rotary station as they do when rated at the tangent station, except for one condition. At low speeds Price meter number 1314 runs faster when rated at a depth of 2 feet at the rotary station than when rated at the tangent station. The plotted data show also that the revolutions of the meters increase at the rotary station as the depth in-

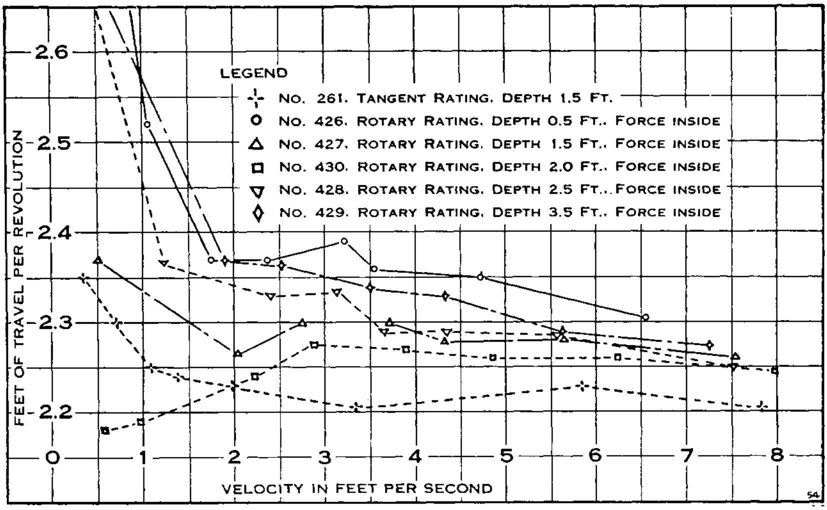

Figure 54.—Price meter number 1314, rotary-station ratings showing the effect of depth. Meter with tail, radius of rotation 23.87 feet. Rod suspension used. Meter held in place by guy wires attached 0.57 foot above center of meter.

creases up to a depth of 2 feet, and from then on the revolutions decrease for the most part. Ratings of these meters made previously at different depths at the tangent station showed that the depth had very little effect on the meter under the conditions tested at the rotary station.

Additional tests were made for the purpose of comparing the results of ratings made at the rotary station when the meter was rigidly held, and when free to rotate on the supporting rod. Price meters numbers 1728 and 15,188, both of which were equipped with tails, were used in the tests. In making the ratings, the meters were run in both directions around the reservoir so that the effect of having the rotating force act on the inside as well as the outside cups would be obtained. The radius of rotation was determined by running the meter at about the average speed and then measuring the distance from the center of the cups to the axis of rotation with a tape and plumb-bob. When using the fixed rod, the position in which the meter was set in going each way around the reservoir was determined from the position taken by the meter when free to turn on the rod. These places were marked by a pointer clamped to the rod, and when subsequently it was necessary to bring the meter to the same position when reversing the direction of travel, the meter was given the desired setting by means of the pointer which was set at the proper index point. The meters were free to take any position when on the swivel rod, but it was observed that they always returned to the same position when in motion. While rating meter number 1728, the

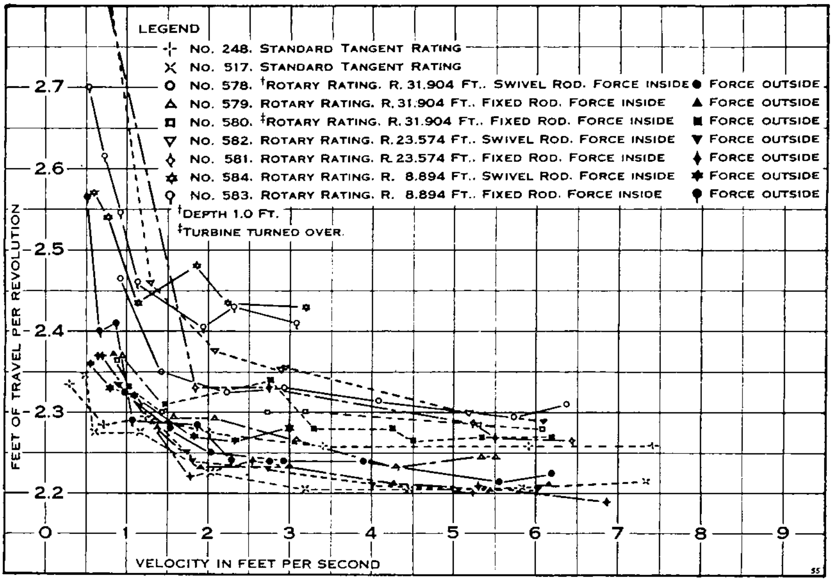

Figure 55.—Price meter number 1728, rotary-station ratings showing comparison between ratings made with fixed and with swivel rods, the effect of turning the turbine over in the yoke, and of changing the direction of rotation. Ratings made at a depth of 1.5 feet except as noted. Meter with tail. Three guy wires used to hold meter in place.

supporting rod was rigidly braced by three guy wires, but meter number 15,188 was held only by the rod without additional support.

The results of the ratings were plotted and they show that in general, the meters run faster when attached to the swivel rod than when rigidly held (see Figure 55). The plot for meter number 15,188 is not shown as it is similar to Figure 55. In some instances there is no difference between the results obtained under the two conditions, but in no case do the meters run faster when attached to the fixed rod than they do when attached to the swivel rod. From these tests it seems that the meter, when free to do so, will take the position that offers the least resistance to rotation of the cups.

The tests on the effect of turning the cups over in the yoke show that this change affected the rate of rotation, but not in a systematic manner. In the case of Price meter number 15,188 with swivel rod, when the rotating force was acting on the inside cups, the meter ran slower when the cups were turned over, but when the rotating force was acting on the outside, the meter ran slower when the cups were in the normal position. In the case of Price meter number 1728 with fixed rod, the meter ran slower when the cups were turned over, regardless of the direction of rotation.

An interesting fact to be noted in connection with these experiments is that when using the swivel rod and when the rotating force is acting on the outside cups, the meters run at about the same speed as they do when rated at the tangent station. It should be noted also that there is considerable difference in the check ratings on Price meter number 1728. This is probably due to the fact that the interval between the ratings was 2 years.

The results of the foregoing tests at the rotary rating station show, in general, that the meters run slower when rated at a rotary station than they do when rated at a tangent station. An explanation of this phenomenon is that the radius measured from the center of the meter to the axis of rotation is not the radius that determines the rate of rotation of the cups. To test this explanation, the meter, Price meter 8374, was rated at the radius of 23.87 feet, and then at larger radii, 0.4, 0.6, 0.8 and 1.0 percent greater than 23.87 feet. From these data the velocity was computed on the basis of the radius of 23.87 feet. The results are shown plotted in Figure 56. They show that, in general, they come nearer to the standard tangent rating equation as the radius used in computing the velocities is reduced more and more up to 1 percent. From the plotted data it appears that this meter requires for this setting a reduction of about 1 percent in the radius of rotation used to compute the results to make the rotary and the tangent-station ratings coincide.

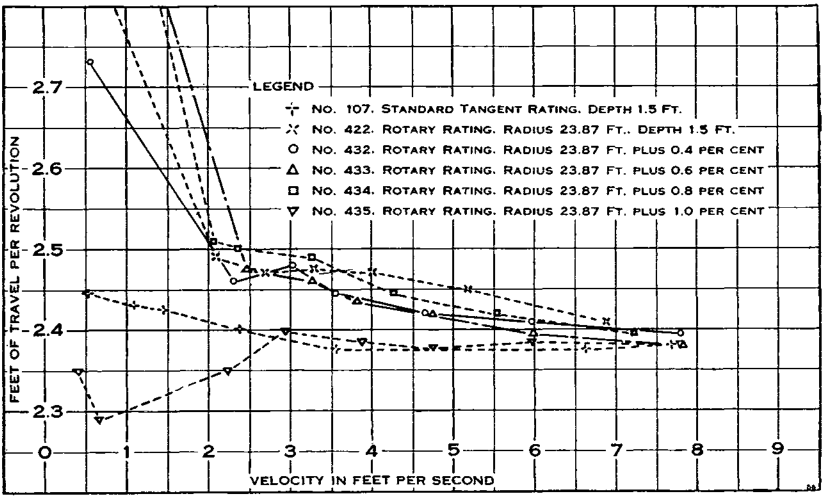

Figure 56.—Lietz meter number 8374, rotary-station ratings showing percentage increase in radius of rotation necessary to make rotary and tangent-station ratings agree. Ratings made at a depth of 2.0 feet except as noted. Meter with tail, rod suspension used. Meter held in place by three guy wires attached 0.57 foot above center of meter.

In order to find out if the difference between the tangent and rotary-station ratings was due to variations in the rotary-station ratings, a series of four ratings was made under nearly identical conditions at the Fort Collins laboratory. Price meter 8374 was used for the tests. It was equipped with a tail and supported by the standard half-inch meter rod which was held rigid by three guy wires attached to the rod 0.57 foot above the center of the meter. The results of these ratings are shown graphically in Figure 57.

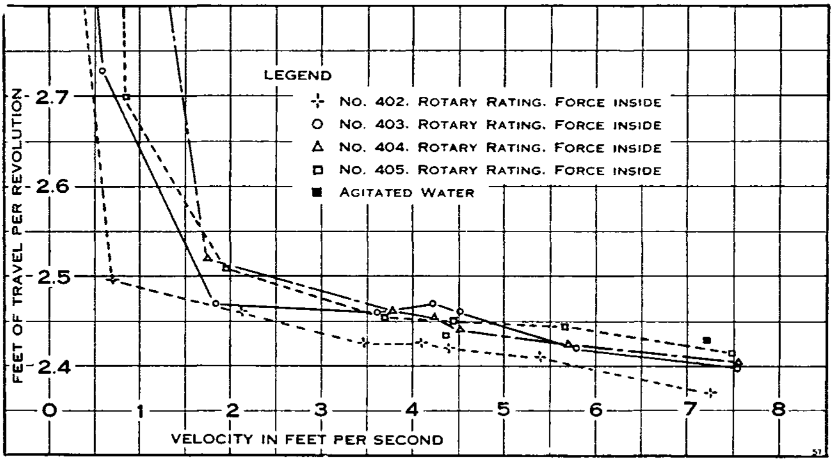

Figure 57.—Lietz meter number 8374, rotary-station ratings showing comparison between replicate ratings and also the effect of rating in agitated water due to the passage of the meter thru the water. Ratings made at a depth of 2.0 feet, radius of rotation 23.92 feet. Meter with tail, rod suspension used.

The plotted data show that the ratings are not identical. The greatest difference is shown by rating number 402, because, for some reason, the meter ran faster during this rating. There is apparently considerable difference in the results for velocities less than 2 feet per second, but this is due to the fact that no observations were taken at about 1 foot per second, the point where a large change in the revolutions of the meter per foot of travel occurred. As a result, chords connecting the observed points may deviate to a marked extent from the true curve in this region. On the whole these ratings show greater differences than those obtained when making replicate ratings at the tangent station. See Figure 6, replicate ratings numbers 591 to 595 on Price meter number 15,188.

Rating number 405 was made immediately after rating number 404, while the water was still in an agitated condition due to the passage of the meter thru the water during the previous rating, and the observation on the last point observed during the rating, marked with a solid square in Figure 57, was made after the meter had been run around the reservoir 10 times without stopping. As shown by the figure, the perturbed condition of the water had very little, if any effect on the rating.

From the foregoing experiments, it is evident that there is a real difference between the current-meter ratings made at rotary and at tangent stations at the Fort Collins laboratory. Experiments at the Worcester Polytechnic Institute rotary station however, are reported [*] to check those made at different tangent stations in the United States.

To check the accuracy of the ratings at the Fort Collins laboratory, a comparison was made between the ratings made at the tangent and rotary stations there and a rating made at the rotary station at the University of California, Berkeley. This station was located in a small storage reservoir and consisted of a horizontal boom rigidly attached to a vertical mast which acted as a pivot. The rotary station was manually operated. Price meter 15,186 was used in making the tests. The meter was equipped with a tail and the rod support was used. In making the ratings at the rotary stations the meter was attached to a rod with a swivel joint which permitted the meter to rotate in a horizontal plane and take a natural position with reference to the forces acting on it. The radius of rotation was determined at Fort Collins while the meter was in motion at each velocity.

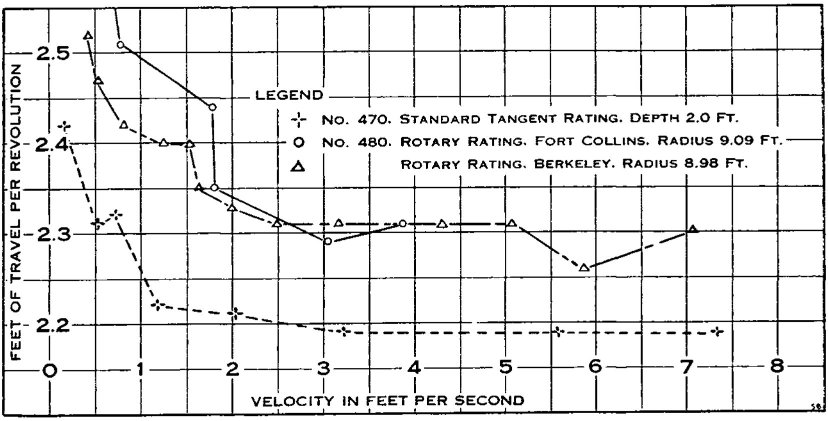

Figure 58.—Price meter number 15,186, rotary-station ratings showing comparison between ratings made at Fort Collins, Colorado, and at Berkeley, California. Ratings made at a depth of approximately 1.0 foot except as noted. Meter with tail, rod suspension used.

The results of the ratings are shown by graphs in Figure 58. They show that the meter was slower when rated at the rotary stations than when rated at the tangent station, and ratings at the rotary station differed less from each other than they did from the rating at the tangent station. The fact that the ratings, independently made, at the two rotary stations show the same tendency indicates that there is a difference between ratings at rotary and at tangent stations.

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[*] Letter from Professor Allen to Mr. Parshall.

Similar ratings (8) of Hoff current meter number 105, made at the tangent rating station at Fort Collins, Colorado, the rotary station at Berkeley, California, and the tangent station at Stockholm, Sweden, resulted in the following meter equations:

Rating No.	Condition	Meter equation	
....	Tangent rating, Fort Collins, Colorado	$V=0.945\ R$	$V>0.8<4.7$
....	Rotary station, Berkeley, California	$V=0.954\ R$	$V>1.2<10.5$
....	Tangent rating station, Stockholm, Sweden	$V=0.952\ R$	$V>1.3<10.5$

These tests show that this type of meter may be rated satisfactorily at either type of station. It should be mentioned, however, that to achieve these results at a rotary rating station, the face of the propeller should be placed so as to coincide with a radial line from the center of rotation to the propeller. The plot of the data was not shown because the necessary data were not available.

From the foregoing tests it might be assumed that the tangent-station ratings were in error, but ratings of Ott meter number 4184, made at the tangent station at Fort Collins, Colorado, and checked by Dr. Ott * at the tangent station a Kempten, Bavaria, show that the ratings of the two stations are practically identical for all velocities greater than 1 foot per second (see Figure 59).

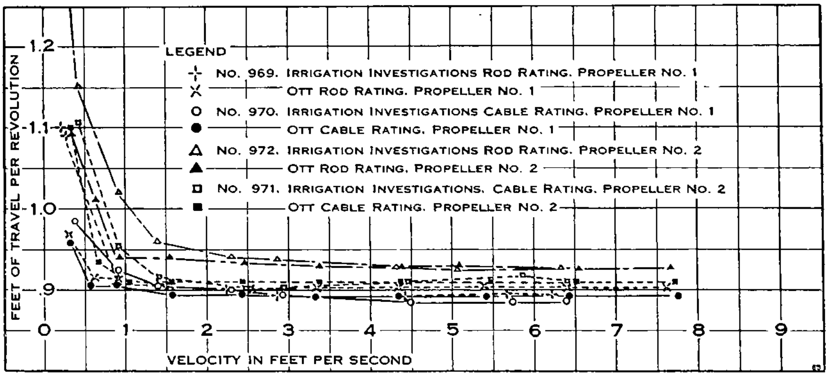

Figure 59.—Ott meter number 4184, tangent-station ratings showing comparison of ratings made at Fort Collins, Colorado, and at Kempten, Bavaria. Both rod and cable suspension used. Tests made on high and on low-speed propellers.

A similar comparison was made with Price meter number 15,188 which was rated at the tangent station at Fort Collins, and at the U. S. Bureau of Standards tangent rating station at Washington, D. C. The results of these ratings are given in Figure 60, which shows

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*Data furnished by courtesy of Dr. A. Ott.

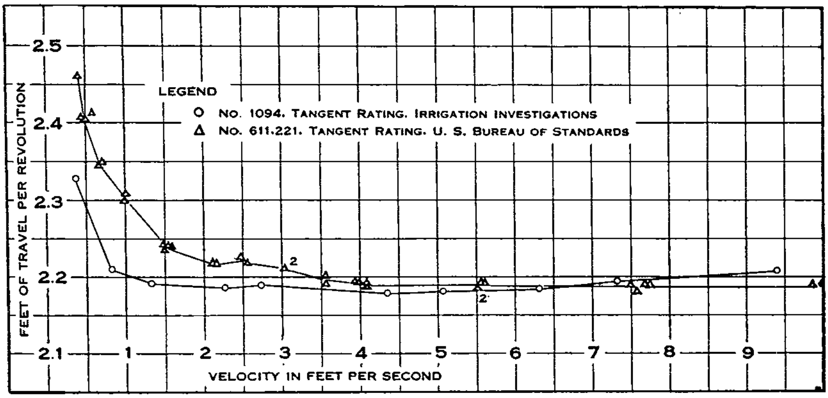

Figure 60.—Price meter number 15,188, tangent-station ratings showing comparison between ratings made by the Irrigation Investigations at Fort Collins, Colorado, and the U. S. Bureau of Standards at Washington, D. C. Ratings made at a depth of 2.0 feet. Meter rod in sliding-sleeve extension block instead of slot. Meter with tail.

that, altho the ratings are not identical, the difference between them is small except at velocities less than 1.5 feet per second.

Altho it is possible to get identical results from tangent and rotary stations under special conditions, the observations carried on at Fort Collins, Colorado, indicate that a correction is necessary before the ratings of meters made at a rotary station will agree with those made at a tangent station.

CURRENT-METER MEASUREMENTS

EQUIPMENT.—The ratings of the different types of current meters made at the tangent and rotary stations show the relations, under the conditions of the test, between the revolutions of the rotating element of the meters and the velocity with which they are traveling.

The sensitiveness of the meter, the consistency with which it operates under similar conditions, and the manner in which it performs when subjected to various special tests, are all indications as to the merits of the meter, but since its purpose is to measure the velocity of flowing water, the ultimate test of the meter is to find out how accurately it does this under the conditions met with in practice. This was the purpose of the second part of the study of current meters, which consisted of an investigation of the accuracy with which the several types of meters measured different quantities of water under different conditions when using the various standard methods of making gagings.

In order to make a comparison of the accuracy of the different meters and methods, an accurate standard of comparison was necessary. As facilities for making volumetric determinations of the quantity of water measured by the current meters were inadequate at the hydraulic laboratory at Fort Collins, it was decided to conduct these experiments at the field laboratory at Bellvue, Colorado, where quantities up to 100 cubic feet per second were available which could be measured over a standard 10-foot Francis weir with full contractions. The general arrangement of the laboratory is shown in Figure 61.

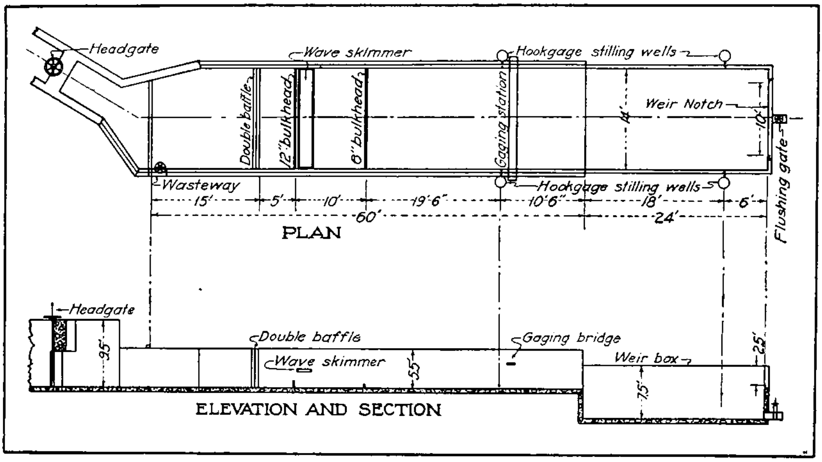

Figure 61.—Hydraulic laboratory at Bellvue, Colorado, with 10-foot Francis weir.

The laboratory consists of a flume 60 feet long, 14 feet wide and 5.5 feet deep, with wooden sides and concrete floor, a concrete weir box 24 feet long, 14 feet wide and 7.5 feet deep, and a standard 10-foot Francis weir (see Plate 22) with the crest 5 feet above the floor of the weir box.

The weir crest was made of 3 by 3 by $3/8$-inch angle irons with one edge planed straight and at right angles to the side. The head on the weir crest was measured by hook gages reading to thousandths of a foot, located in stilling wells on each side of the weir box at a point 6 feet upstream from the crest. These stilling wells were connected with the water in the weir box by short pieces of $3/4$-inch pipe placed normal to the side of the weir box and with the outer end flush with the side of the weir box.

The gaging station was placed 10.5 feet above the lower end of the flume, as at this point the flow was apparently most uniform. The depth of the water in the flume at this point was at first measured by one hook gage, but later the measurements were taken by two hook gages located at opposite sides of the flume. These gages, however, never showed any important difference.

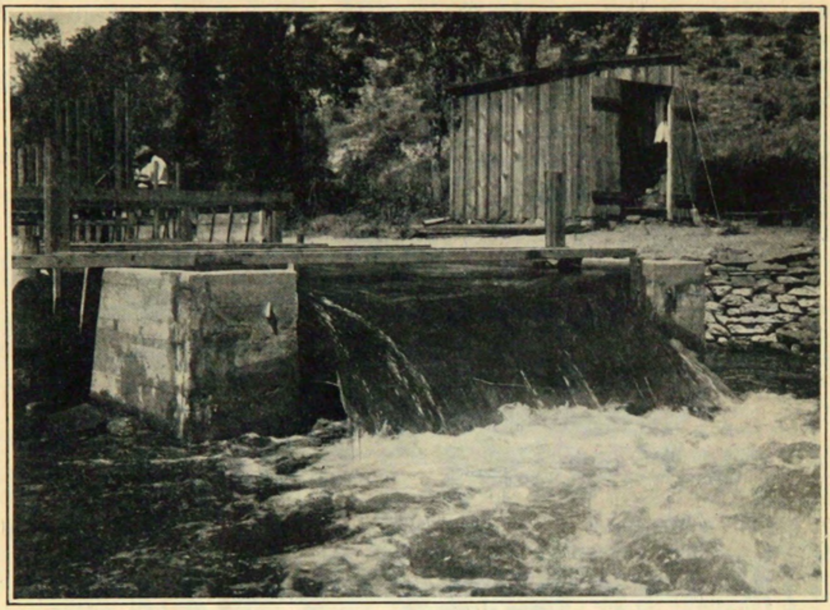

Plate 22.—Francis weir with 10-foot crest at Bellvue laboratory, discharging approximately 100 cubic feet per second.

The water used in the tests was taken from the Poudre River and, after going thru the flume, was discharged into the river again.

On account of the angle and the high velocity at which the water entered the flume thru the headgate, considerable difficulty was at first experienced in quieting the pulsations and straightening the lines of flow of the water sufficiently to obtain conditions suitable for current-meter measurements. A double baffle, as shown in Figure 61, was first installed, consisting of four rows of vertical 1 by 6-inch boards placed at 6-inch intervals, both transversely and longitudinally, in such a way that the boards in one row covered the spaces in the next row. This baffle was inadequate for quieting the pulsations and for straightening the lines of flow of the water. This condition was corrected by placing a 12 and a 6-inch bulkhead on the floor for straightening the lines of flow, and by placing a float made of 2 by 6-inch boards on edge in the flume just below the double baffle for reducing the waves. The locations of the bulkheads and float or wave skimmer are shown in Figure 61.

MEASUREMENT OF WEIR DISCHARGE.—The discharge over the weir was based on Francis' original data. His experiments, however, on this sized weir, were limited to discharges of less than 70 cubic feet per second. As quantities up to 100 cubic feet per second had to be measured over the Bellvue weir, and as a discharge of this amount requires a head of approximately 2.2 feet, which is less than one-third of the crest length, it would have been possible to use Francis' formula (1)

$$Q=3.333\ (L-0.2H)\ H^{3/2} \qquad 3$$

for computing the discharge. Since, however, this formula requires a correction for the velocity of approach, it was thought that it would be more satisfactory to derive a new formula from Francis' original data which would take into account the velocity of approach which exists in a weir box of the form and size used by Francis in his experiments, and in the duplicate box at the Bellvue laboratory. This formula was derived by plotting the head observed by Francis against the discharge on logarithmic paper. This gives a straight-line discharge curve from which the equation was easily obtained by computing the slope and reading the intercept. The resulting equation is

$$Q=32.701\ H^{1.486} \qquad 4$$

This formula was used in computing the discharge for a head of 2.1 feet and it was found that the quantity obtained agreed within 0.3 percent of the discharge computed by Francis' formula with correction for velocity of approach. This value and Francis' experimental data were used in plotting a large-scale, straight-line logarithmic discharge curve for the weir. Values taken from this curve were replotted on standard cross-section paper in order to simplify the taking of the discharge values from the curve.

METHOD OF MAKING TESTS.—All the meters used in the investigation were tested according to the same general plan. Four different methods—the vertical integration, the multiple point, the 2-and-8-tenths, and the 6-tenths methods—were used in making the discharge measurements with each meter. The multiple-point data were computed by both the vertical velocity-curve method and the weighted mean-velocity method. The measurements by the 2-and-8-tenths method and the 6-tenths method were at first made separately, but later it was decided to compute the 2-and-8-tenths and the 6-tenths-method discharges from the multiple-point data because the velocities at these points were always taken in the multiple-point gagings.

The meter measurements were made on discharges up to 100 cubic feet per second; but all the meters were not tested under such a wide range of conditions. After completing the tests in the 14-foot flume, the width of the flume was reduced to 8 feet by building auxiliary walls 3 feet from the sides of the flume. The velocities were proportionately increased. The meters were also subjected to a number of special tests in order to determine the effect of changes in the meter and variations in the method of measurement. In addition, some tests were made in a small flume 2.5 feet wide at the Fort Collins laboratory. For these tests the discharge measurements were checked volumetrically in the calibration tanks at the laboratory.

In making the tests at the Bellvue laboratory, the approximate quantity desired was turned in at the headgate at the upper end of the flume, and by means of the wasteway gate the head was adjusted to the required amount, as shown by the weir gages. Only the final adjustment was made by the wasteway gate because this gate had to be kept open as completely as possible so that the sand coming thru the headgate would flush out thru the wasteway. Very little difficulty was experienced in keeping the head constant because of the long spillway on the dam above the headgate; in fact, a difference in head from one gaging to the next was seldom more than a few thousandths of a foot.

Both the 14 and the 8-foot flumes were divided into 1-foot sections and unless otherwise stated the velocity was determined in the middle of each section in making a discharge measurement. When the vertical-integration method was used, the meter was started just beneath the surface of the water and at least two complete down-and-up trips were made at each station. The meter was moved with a uniform speed of approximately 0.2 foot per second and the revolutions were taken for an interval of not less than 50 seconds. All time intervals were taken with a stop watch to the nearest fifth of a second. When the multiple-point method was used, the meter was held from 30 to 40 seconds at each point in the vertical. Six points, the 2, 4, 6 and 8-tenths depths, and points as near the top and the bottom as it was possible to hold the meter without noticeably interfering with its action, were taken in each vertical. For small discharges, the top and bottom points did not differ materially from the 2-and-8-tenths depths.

The hook-gage readings, both for the weir and the gaging section, were taken once while the meter was at each section, and the mean weir gage and depth at the gaging section were computed from these readings. In case sand accumulated on the floor of the gaging section, it was necessary to reduce the depth of water in the flume by the amount of the sand. The hook gages were frequently checked with an engineer's level, usually every day, in order to eliminate chances of errors due to changes in the gages, but no serious error was ever detected.

The meters tested during these experiments consisted of Price meter number 15,188, Ott meters numbers 2909 and 2956, Lallie meter number 310 and Hoff meter number 2, and in addition observations were made on Irrigation Investigations meter number 1—an experimental model—and on Price meter number 1314 when equipped with special 4, 5, 6, 7 and 7-cup rotating elements. These meters, except the experimental models and the Lallie meter, are shown in Plates 4, 9, 16 and 23, which show clearly the details of their construction.

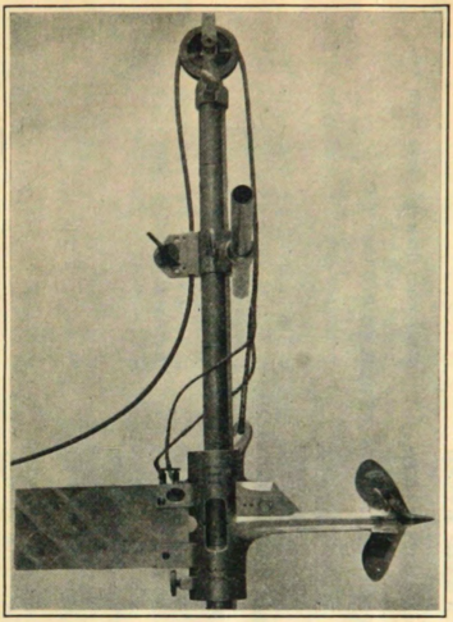

Plate 23.—Ott rod meter number 2909 with rod and lifting equipment.

The Lallie meter was similar to the Price meters except that it had five cups instead of six. All the measurements were made using the rod support to hold the meter unless otherwise specified, and all the meters were rigidly attached to their rods except the Irrigation Investigations number 1, which was free to rotate in a horizontal plane.

The meters were rated at the tangent station at Fort Collins about once a month during the period of the investigation. The ratings were made under the conditions under which the meters were to be used during the tests. The results of the ratings are given in Table 2, and it will be noted that there is frequently considerable difference in the equations of the meters rated at different times under similar conditions, but it will also be noted that for these conditions the ranges of velocities for which the equations apply are also different. Altho the equations vary, the velocities computed from the equations for comparable conditions within the limiting values usually agree within less than 1 percent. Velocities less than the limiting values were taken from the rating curves. These values, on account of the small velocities, show a greater variation. Two of the meters were rated in both still and flowing water, but the results computed from the equations of the meters for the two conditions were almost identical. Rating tables showing the revolutions per second and the velocity in feet per second were prepared for the various meters for the different ratings in order to facilitate the computation of the discharges measured by the meters.

In making the discharge computations, the depth of water was determined from the mean hook-gage readings and the floor elevation at the gaging station corrected for the accumulation of sand on the floor, if any occurred during the measurement. The width of all the sections except the last was taken as 1 foot, and the width of the last section was either slightly greater or less than 1 foot, depending on the exact width of the flume. As previously stated, the velocity

TABLE 2.—Current-Meter Ratings

Rating No.	Condition	Meter Equation	Limits
	PRICE CUP METER NUMBER 15,188		
686	Depth 2 feet, rod and tail	$V=2.199\ R+0.052$	
719	Depth 1.5 feet, rod and tail	$V=2.185\ R+0.010$	R greater than 0.20 less than 2.8
721	Depth 2 feet, rod and tail	$V=2.185\ R+0.022$	R greater than 0.15 less than 3.0
725	Depth 2 feet, rod and tail, check No. 721	$V=2.185\ R+0.026$	R greater than 0.20 less than 3.0
739	Depth 2 feet, cable and tail, suspension 3.6 ft., 8-lb. weight in bottom hole	$V=2.215\ R+0.023$	
740	Depth 2 feet, rod and tail	$V=2.176\ R+0.027$	R greater than 0.07 less than 2.25
747	Depth 2 feet, rod and tail, experimental turbine	$V=2.261\ R+0.023$	
757	Depth 2 feet, rod 1 inch in diameter, tail	$V=2.189\ R+0.040$	
758	Depth 2 feet, rod 2 inches in diameter, tail	$V=2.221\ R+0.027$	
761	Depth 2.5 feet, cable, tail, one 15-lb. weight above meter, suspension 10.0 ft.	$V=2.192\ R+0.038$	R greater than 0.1 less than 4.0
762	Depth 2.5 feet, cable, tail, 8-lb. weights above and below meter, suspension 9.6 ft.	$V=2.232\ R+0.025$	R greater than 0.1
763	Depth 2.5 feet, cable, tail, one 8-lb. weight above meter, suspension 10.0 ft.	$V=2.171\ R+0.048$	
772	Depth 2 feet, rod and tail, running water, check No. 740	$V=2.176\ R+0.023$	
	PRICE CUP METER NUMBER 1314, WITH SPECIAL CUPS		
735	Depth 2 feet, rod and tail, 4-cup type	$V=1.512\ R+0.122$	
752	Depth 2 feet, rod and tail 4-cup type	$V=1.575\ R+0.052$	R less than 2.2
733	Depth 2 feet, rod and tail, 5-cup type	$V=1.562\ R+0.060$	
751	Depth 2 feet, rod and tail, 5-cup type	$V=1.589\ R+0.049$	R less than 2.2
750	Depth 2 feet, rod and tail, 6-cup type	$V=1.505\ R+0.040$	
734	Depth 2 feet, rod and tail, 7-cup type	$V=1.430\ R+0.077$	
749	Depth 2 feet, rod and tail, 7-cup type	$V=1.440\ R+0.040$	
748	Depth 2 feet, rod and tail, 8-cup type	$V=1.142\ R+0.056$	
770	Depth 2.5 feet, cable and rod, 8-cup type, one 8-lb. weight above meter, suspension 10 ft.	$V=1.128\ R+0.050$	

	LALLIE CUP METER NUMBER 310		
700	Depth 2 feet, rod and tail	$V=2.219\ R+0.032$	
741	Depth 2 feet, rod and tail	$V=2.225\ R+0.038$	
768	Depth 2.5 feet, cable and tail, one 8-lb. weight below meter, suspension 9.6 feet	$V=2.361\ R+0.027$	
	OTT PROPELLER METER NUMBER 2909		
732	Depth 2 feet, rod and tail	$V=0.813\ R$	R greater than 2.80
746	Depth 2 feet, rod and tail	$V=0.811\ R+0.025$	R greater than 1.3 less than 8.0
773	Depth 2 feet, rod and tail, running water, check No. 746	$V=0.803\ R+0.050$	R greater than 1.0 less than 5.6
	OTT PROPELLER METER NUMBER 2956		
737	Depth 2 feet, rod and tail, propeller number 1	$V=0.407\ R$	R greater than 6.0
738	Depth 2 feet, cable, buoyant tail, propeller number 1	$V=0.410\ R$	R greater than 9.5
745	Depth 2 feet, rod and tail, propeller number 1	$V=0.401\ R+0.042$	R greater than 0.8 less than 16.0
767	Depth 2.5 feet, cable, buoyant tail, propeller number 1, meter 0.15 foot above weight	$V=0.408\ R+0.050$	R greater than 1.1 less than 12.0
	IRRIGATION INVESTIGATIONS, PROPELLER METER NUMBER 1		
716	Depth 2 feet, rod and tail	$V=0.943\ R+0.150$ $V=1.039\ R$	R less than 3.5 R greater than 3.5
722	Depth 2 feet, rod and tail, sleeve added to propeller	$V=0.939\ R+0.085$	
728	Depth 2 feet, rod and tail, propeller balanced	$V=0.955\ R+0.050$	
744	Depth 2 feet, rod and tail	$V=0.950\ R+0.062$	
769	Depth 2.5 feet, cable and tail, one 8-lb. weight, 0.30 ft. below meter, suspension 9.6 ft.	$V=0.926\ R+0.122$	
	HOFF METER, PROPELLER NUMBER 2		
723	Depth 2 feet, rod and hollow tail	$V=1.232\ R+0.079$	
729	Depth 2 feet, cable and hollow tail, one 8-lb. weight, 0.4 ft. below meter	$V=1.272\ R+0.037$	
731	Depth 2 feet, rod and hollow tail	$V=1.219\ R+0.020$	R less than 4.0
743	Depth 2 feet, rod and hollow tail	$V=1.190\ R+0.045$	R greater than 0.4 less than 4.0
764	Depth 2.5 feet, cable and hollow tail, 8-lb. weight, 0.2 ft. above and below meter, suspension 9.6 ft.	$V=1.251\ R+0.052$	
765	Depth 2.5 feet, cable and hollow tail, one 8-lb. weight, 0.2 ft. below meter, suspension 9.6 ft.	$V=1.190\ R+0.065$	
766	Depth 2.5 feet, cable and hollow tail, one 8-lb. weight, 0.2 ft. below meter, suspension 9.6 ft.	$V=1.377\ R+0.025$ $V=2.218\ R$	R less than 1.9 R greater than 1.9

determinations were made in the center of each section unless noted otherwise. The discharge thru each section was obtained by multiplying the area of the section by the mean velocity in the section. In the case of the vertical integration and the 6-tenths-method tests, the mean velocity was determined directly from the current-meter measurement, and in the case of the 2-and-8-tenths method, the mean was obtained by averaging the velocity determinations at the 2-tenths and at the 8-tenths depths. The mean velocities from the multiple-point measurements were determined in two ways. When the vertical-velocity-curve method was used, the velocities were plotted as abscissas and the depths at the points where the velocities were determined, as ordinates. Curves were drawn thru the plotted points as shown in Figure 62, and then the areas under the curves were planimetered. These areas, divided by the depths at the respective stations, gave the mean velocities. The other method of obtaining the mean velocities from the multiple-point observations consisted of taking the weighted means of the observations in each section by giving the top and bottom observations half the weight given to the observations at the 2, 4, 6 and 8-tenths depths. No corrections were applied to the velocities at the different depths for the purpose of cor-

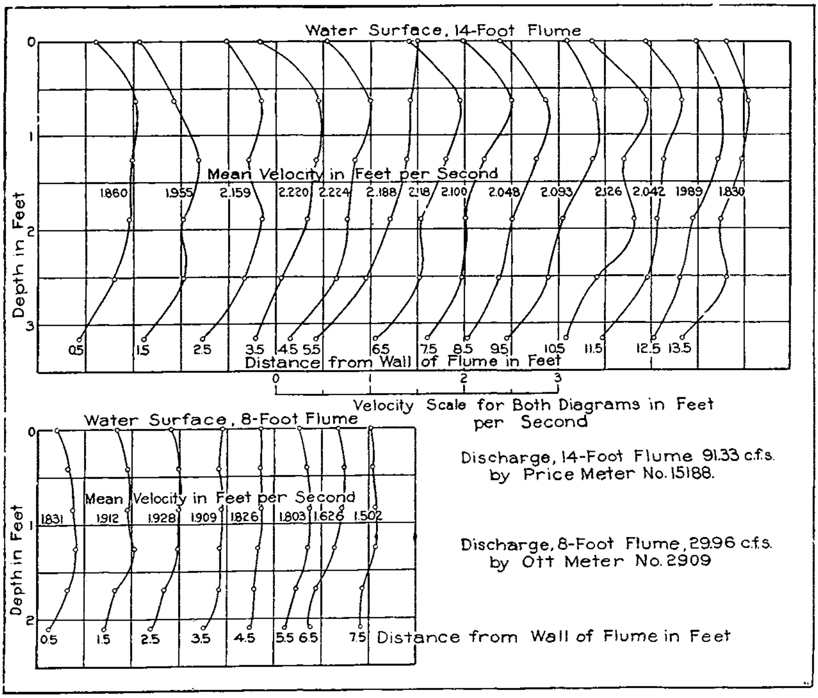

Figure 62.—Typical vertical-velocity curves for 8 and 14-foot flumes.

recting the errors, due to the fact that the meters do not function in the same way at all depths, because this is not the method practiced in the field.

COMPARISON OF CURRENT-METER MEASUREMENTS WITH FRANCIS-WEIR MEASUREMENTS.—The results of the current-meter measurements and the comparison with weir discharges are shown in Table 3. So far as possible, the discharge measurements for each width of flume are arranged in the order of their magnitude; but, as the measurements of a series had to be arranged to show the desired comparisons, some minor deviations from this order occur in the table. The name of the observer given in the table refers to the man who operated the meter, and it will be observed that comparable measurements were usually made by the same observer. In the column under method are given the names of the methods used. The weir discharge was determined from the mean gage height as measured by the hook gages, and the special discharge curves derived from Francis' original data. The average water depth is the depth indicated by the gaging station hook gages uncorrected for the sand on the floor, which was measured at the end of each test. The average width of flume is the average of the measurements with a steel tape and scale at intervals of 0.5 foot vertically at the gaging section. The meter-section area is the product of the width and the depth corrected for the accumulated sand. This area, divided into the weir discharge, is the mean velocity of the water in feet per second. The remaining columns in the table show the deviation of the current-meter discharge measurements from the Francis-weir measurements in percentage. In determining the percentages, the weir discharge was the basis of comparison. Negative values mean that the current-meter discharge measurements were too small, as shown by the weir measurement, and positive values mean that they were too large. The mean errors for each meter were computed for each width of flume and for each method of measurement. They are given at the end of the series of tests on each width of flume, and, in addition, the range of errors is also given.

The tests on small Price electric cup meter number 15,188, made in the different sizes of flumes, show that there is considerable variation in the accuracy of the individual measurements, but the mean errors regarding signs, as given at the end of each series of tests, show that the vertical-integration and the 2-and-8-tenths methods give the most accurate results, and that, altho the measurements by the multiple-point method are more consistent, the mean errors are larger because the meter measurements are all too small. This is true whether the vertical-velocity-curve or the weighted mean-velocity method was used in computing the results. The 6-tenths method gives results that are, in general, too large. Contrary to the general belief (4) the verti-

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions.

SMALL PRICE ELECTRIC CUP METER NO. 15,188

			Flume elements						Deviation from weir flow (1)				
									Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Per-centage	Per-centage	Per-centage	Per-centage	Per-centage
4906	Rohwer	V. I. (2)	8.17	1.533	0.000	13.973	21.405	0.381	–4.17				
4905	Lightburn	V. I.	11.05	1.616	.120	13.974	20.890	.528	5.80				
4921	Lightburn	V. I.	12.42	1.668	.000	13.975	23.295	.533	–0.72				
4922	Lightburn	.2 and .8	12.36	1.667	.000	13.975	23.280	.531				–2.58	
4923	Lightburn	6 tenths	12.31	1.666	.000	13.979	23.273	.528					0.57
4933	Lightburn	M. P. (3)	15.46	1.747	.000	13.980	24.407	.633		–4.26	–4.14	–3.17	–3.56
4934	Rohwer	V. I.	15.46	1.747	.010	13.980	24.267	.637	–3.17				
4901	Lightburn	V. I.	25.01	1.974	.050	13.977	26.862	.932	–0.08				
4924	Rohwer	V. I.	25.82	2.003	.000	13.982	27.975	.923	–1.55				
4925	Rohwer	.2 and .8	25.78	2.002	.000	13.982	27.960	.922				–0.58	
4926	Rohwer	6 tenths	25.74	2.002	.000	13.982	27.960	.920					3.81
4902	Lightburn	V. I.	38.27	2.253	.050	13.980	30.767	1.244	4.77				
4927	Lightburn	V. I.	44.86	2.389	.000	13.983	33.373	1.344	–0.58				
4928	Lightburn	.2 and .8	44.60	2.385	.020	13.983	33.057	1.349				1.72	
4929	Lightburn	6 tenths	43.70	2.382	.030	13.983	32.854	1.330					7.85
4930	Rohwer	V. I.	60.52	2.657	.200	13.985	35.447	1.707	–1.81				
4931	Rohwer	.2 and .8	60.45	2.659	.100	13.985	35.761	1.690				5.13	
4932	Rohwer	6 tenths	60.40	2.656	.130	13.985	35.294	1.711					4.86
4945	Lightburn	V. I.	77.20	2.929	.120	14.018	39.329	1.963	–1.90				
4946	Lightburn	M. P.	77.17	2.927	.070	14.018	40.001	1.929		–2.16	–2.46	1.35	0.40
4957	Lightburn	V. I.	91.92	3.157	.000	13.988	44.122	2.084	–0.25				
4958	Lightburn	M. P.	91.86	3.158	.000	13.988	44.126	2.082		–0.58	–0.70	2.56	0.58
			Mean error disregarding sign						2.254	2.333	2.433	2.441	3.090
			Mean error regarding sign						–1.333	–2.333	–2.433	0.633	2.073
			Range of errors						–4.17 to 5.80	–0.58 to –4.26	–0.70 to –4.14	–3.17 to 5.13	–3.56 to 7.85

5029	Rohwer	M. P.	7.19	1.496	0.000	7.986	11.947	0.602		-1.39	-2.22	-1.69	-1.11
5030	Rohwer	V. I.	7.26	1.498	.000	7.986	11.963	.607	-4.97				
5014	Rohwer	V. I.	24.08	2.010	.000	7.987	16.054	1.500	-2.12				
5015	Rohwer	M. P.	24.05	2.012	.000	7.987	16.070	1.497		-3.12	-2.83	-0.74	1.45
5016	Lightburn	V. I.	24.03	2.011	.000	7.987	16.062	1.496	-1.87				
5017	Rohwer	V. I.	45.65	2.520	.000	7.989	20.132	2.267	-2.04				
5018	Rohwer	M. P.	44.51	2.519	.000	7.989	20.124	2.212		-0.47	-0.58	1.08	4.24
5019	Lightburn	V. I.	67.18	2.959	.000	7.990	23.642	2.841	-1.13				
5020	Lightburn	M. P.	66.90	2.955	.000	7.990	23.610	2.833		-2.82	-3.00	0.82	2.39
5037	Lightburn	V. I.	93.55	3.174	.000	7.984	25.341	3.692	-1.64				
5038	Lightburn	M. P.	94.20	3.184	.000	7.984	25.421	3.705		-2.01	-2.42	1.20	1.16
			Mean error disregarding sign						2.295	1.962	2.210	1.106	2.070
			Mean error regarding sign						-2.295	-1.962	-2.210	0.134	1.626
			Range of errors						-4.97 to -1.13	-3.12 to -0.47	-3.00 to -0.58	-1.69 to 1.20	-1.11 to 4.24
Volumetric 3	Rohwer	V. I.	8.63	1.500	......	2.497	3.745	2.304	-2.90				
Volumetric 4	Rohwer	M. P.	8.63	1.500	......	2.497	3.745	2.304		-2.89	-3.25	-1.28	1.97
5110 (a)	Lightburn	V. I.	41.70	2.364	0.000	7.980	18.865	2.210	-0.29				
5111 (a)	Lightburn	M. P.	41.75	2.364	.000	7.980	18.865	2.213		-2.13	-2.42	1.12	3.30
5112 (b)	Rohwer	V. I.	41.88	2.370	.000	7.980	18.913	2.214	-0.76				
5113 (b)	Rohwer	M. P.	41.37	2.360	.000	7.980	18.833	2.197		-0.92	-1.28	2.39	4.32
5114 (c)	Lightburn	V. I.	40.63	2.344	.000	7.980	18.705	2.172	1.33				
5115 (c)	Lightburn	M. P.	40.26	2.335	.000	7.980	18.633	2.160		-1.61	-2.33	1.39	3.20
5128 (d)	Rohwer	V. I.	35.70	2.230	.000	7.980	17.795	2.006	-2.46				
5129 (d)	Rohwer	M. P.	35.80	2.231	.000	7.980	17.803	2.010		-2.37	-3.27	0.06	2.24
5130 (e)	Lightburn	V. I.	35.60	2.226	.000	7.980	17.763	2.004	-2.25				
5131 (e)	Lightburn	M. P.	35.37	2.224	.000	7.980	17.747	1.993		-2.23	-3.11	0.42	4.10
5132 (f)	Rohwer	V. I.	34.77	2.212	.000	7.980	17.652	1.970	-3.46				
5133 (f)	Rohwer	M. P.	34.48	2.205	.000	7.980	17.595	1.960		-4.29	-4.58	-1.42	1.30
5134 (g)	Rohwer	V. I.	25.35	2.002	.000	7.981	15.978	1.586	-1.46				
5135 (g)	Rohwer	M. P.	25.26	2.002	.000	7.981	15.978	1.581		-1.90	-2.26	0.36	2.02
5136 (h)	Lightburn	V. I.	25.20	2.000	.000	7.981	15.962	1.579	-0.95				
5137 (h)	Lightburn	M. P.	25.20	2.000	.000	7.981	15.962	1.579		0.40	-1.39	0.44	3.81
5138 (i)	Rohwer	V. I.	25.22	2.000	.000	7.981	15.962	1.580	-2.66				
5139 (j)	Rohwer	M. P.	24.70	1.988	.000	7.981	15.876	1.556		-2.51	-3.24	-1.70	1.70
5140 (k)	Rohwer	V. I.	16.78	1.788	.000	7.980	14.268	1.176	-1.37				

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

SMALL PRICE ELECTRIC CUP METER NO. 15,188

			Flume elements						Deviation from weir flow (1)				
									Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Per-centage	Per-centage	Per-centage	Per-centage	Per-centage
5141 (k)	Rohwer	M. P.	16.30	1.776	0.000	7.980	14.172	1.150		–0.37	–1.53	–0.18	3.44
5142 (l)	Rohwer	V. I.	14.96	1.742	.000	7.980	13.901	1.076	–0.33				
5143 (l)	Rohwer	M. P.	15.00	1.742	.000	7.980	13.901	1.079		–0.47	–0.13	0.07	4.07
5160 (p)	Rohwer	V. I.	23.79	1.965	.000	7.981	15.683	1.517	–0.08				
5164 (q)	Lightburn	V. I.	41.77	2.360	.000	7.983	18.841	2.217	–1.89				
5165 (q)	Lightburn	M. P.	41.75	2.359	.000	7.983	18.833	2.217		–2.99	–3.45	0.12	2.66
5166 (r)	Rohwer	V. I.	41.88	2.360	.000	7.983	18.841	2.223	–3.00				
5167 (r)	Rohwer	M. P.	41.77	2.362	.000	7.983	18.857	2.215		–2.80	–3.66	–0.72	2.01
Mean error disregarding sign									1.59	1.92	2.51	0.80	2.94
Mean error regarding sign									–1.40	–1.86	–2.51	0.18	2.94
Range of errors									–3.46 to 1.33	–4.29 to 0.40	–4.58 to –0.13	–1.70 to 2.39	1.30 to 4.32
5144 (m)	Lightburn	V. I.	14.80				7.65	1.934	2.97				
5145 (m)	Rohwer	6 tenths	14.82				7.68	1.930					3.17
5146 (n)	Rohwer	V. I.	14.90				7.78	1.915	0.13				
5147 (o)	Rohwer	6 tenths	14.58				7.65	1.905					–1.92
River 7 (s)	Lightburn	V. I.	56.04				44.72	1.250	3.54				
River 8 (s)	Lightburn	.2- .6- .8	55.74				42.27	1.320				–2.26	–2.08
River 26 (s)	Lightburn	V. I.	62.26				45.01	1.380	–3.14				
River 27 (s)	Lightburn	.2- .6- .8	63.46				46.18	1.370				–0.57	2.52
River 34 (t)	Lightburn	V. I.	70.56				52.82	1.340	1.86				
River 35 (t)	Lightburn	.2- .6- .8	58.39				52.59	1.110				1.39	5.27

								Mean error disregarding sign	2.33			1.41	2.99
								Mean error regarding sign	1.07			-0.48	1.39
								Range of errors	-3.14 to 3.54			-2.26 to 1.39	-2.08 to 5.27

(a) Cable, 15-lb. weight
(b) Cable, 8-lb. weight
(c) Cable, 2, 8-lb. weights
(d) Experimental turbine
(e) Experimental turbine, 1 cup loaded
(f) Experimental turbine, 2 bent cups
(g) Experimental turbine, nail point pivot
(h) Experimental turbine, standard pivot
(i) Experimental turbine, V. I. at stations
(j) Experimental turbine, M. P. at stations
(k) Standard turbine
(l) Standard turbine, 10 deg. to right
(m) River channel below weir
(n) River channel V. I. at mid-points
(o) River channel .6 at mid-points
(p) Continuous integration
(q) 1-inch diameter rod
(r) 2-inch diameter rod
(s) River 200 ft. above dam
(t) River 20 ft. above headgate

LALLIE CUP METER NO. 310

5094	Lightburn	V. I.	11.15	1.633	0.000	7.977	13.026	0.855	-0.36				
5095	Lightburn	M. P.	11.13	1.632	.000	7.977	13.018	.855		1.35	1.26	1.08	2.87
5067	Rohwer	V. I.	32.10	2.124	.000	7.980	16.950	1.894	-4.15				
5068	Rohwer	M. P.	31.98	2.124	.000	7.980	16.950	1.886		-2.19	-2.56	-0.50	2.00
5065	Lightburn	V. I.	69.85	2.802	.000	7.982	22.366	3.123	-2.28				
5066	Lightburn	M. P.	69.88	2.803	.000	7.982	22.374	3.123		-0.84	-0.94	0.94	2.89
5079	Lightburn	V. I.	89.46	3.196	.000	7.984	25.517	3.505	-0.42				
5080	Lightburn	M. P.	89.42	3.196	.000	7.984	25.517	3.504		-0.30	-0.37	1.04	4.08
5124	Parshall	V. I.	26.55	2.033	.000	7.979	16.221	1.636	2.30				
5125	Parshall	M. P.	26.46	2.031	.000	7.979	16.205	1.632		2.15	1.44	2.87	4.87
								Mean error disregarding sign	1.902	1.366	1.314	1.286	3.342
								Mean error regarding sign	-0.982	0.034	-0.234	1.086	3.342
								Range of errors	-4.15 to 2.30	-2.19 to 2.15	-2.56 to 1.44	-0.50 to 2.87	2.00 to 4.87
River 11 (a)	Rohwer	V. I.	56.85				40.12	1.42	2.50				
River 19 (b)	Rohwer	.2- .6- .8	69.24				38.83	1.78				-10.41	-7.81
River 22 (c)	Rohwer	V. I.	70.56				52.82	1.34	-1.91				
River 26 (d)	Rohwer	.2- .6- .8	58.39				52.59	1.11				4.22	6.05
								Mean error disregarding sign	2.205			7.315	6.930
								Mean error regarding sign	0.295			- 3.095	-0.880
								Range of errors	-1.91 to 2.50			-10.41 to 4.22	-7.81 to 6.05

(a) River section 200 ft. above dam
(b) River section 200 ft. above dam
(c) River section 20 ft. above headgate
(d) River section 20 ft. above headgate

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

OTT PROPELLER METER NO. 2909

Flume elements									Deviation from weir flow (1) Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Per-centage	Per-centage	Per-centage	Per-centage	Per-centage
4999	Rohwer	V. I.	14.06	1.704	0.000	13.979	23.804	0.590	−2.63				
5000	Rohwer	M. P.	14.03	1.704	.000	13.979	23.804	.589		2.85	3.28	3.14	3.14
5001	Lightburn	V. I.	29.11	2.061	.000	13.982	28.785	1.011	−0.65				
5002	Lightburn	M. P.	29.17	2.062	.000	13.982	28.799	1.011		−2.06	−2.06	−0.86	−2.92
5003	Rohwer	V. I.	51.13	2.478	.000	13.984	34.620	1.476	−2.50				
5004	Rohwer	M. P.	51.17	2.478	.000	13.984	34.620	1.478		−1.02	−0.88	−0.50	−1.51
4981	Rohwer	V. I.	83.25	3.022	.056	13.987	41.437	2.009	5.78				
4982	Rohwer	M. P.	82.38	3.013	.090	13.987	40.836	2.017		6.23	6.00	5.50	3.17
			Mean error disregarding sign						2.890	3.040	3.055	2.500	2.685
			Mean error regarding sign						0.000	1.500	1.585	1.820	0.470
			Range of errors						−2.63 to 5.78	−2.06 to 6.23	−2.06 to 6.00	−0.86 to 5.50	−2.92 to 3.17
5106	Lightburn	V. I.	11.17	1.638	0.000	7.977	13.066	0.855	2.06				
5107	Lightburn	M. P.	11.08	1.637	.000	7.977	13.058	0.848		3.97	4.15	3.61	6.85
5081	Rohwer	V. I.	25.46	2.004	.000	7.979	15.990	1.592	1.84				
5082	Rohwer	M. P.	29.16	2.094	.000	7.979	16.708	1.745		2.74	2.54	1.92	5.66
5063	Rohwer	V. I.	70.07	2.806	.000	7.982	22.397	3.128	0.49				
5064	Rohwer	M. P.	70.00	2.803	.000	7.982	22.374	3.129		1.57	1.54	2.18	4.15
5041	Lightburn	V. I.	97.10	3.224	.000	7.984	25.740	3.772	0.91				
5042	Lightburn	M. P.	97.53	3.230	.000	7.984	25.790	3.782		1.73	1.56	1.94	4.24
			Mean error disregarding sign						1.325	2.502	2.448	2.412	4.225
			Mean error regarding sign						1.325	2.502	2.448	2.412	4.225
			Range of errors						0.49 to 2.06	1.57 to 3.97	1.54 to 4.15	1.92 to 3.61	4.15 to 6.85

River 18 (a)	Rohwer	V. I.	67.06				41.99	1.60	7.69				
River 20 (b)	Rohwer	V. I.	70.43				52.26	1.35	0.47				
River 21 (b)	Rohwer	.2- .6- .8	70.67				52.92	1.31				2.01	6.92
			Mean error disregarding sign						4.080			2.010	6.92
			Mean error regarding sign						4.080			2.010	6.92
			Range of errors						0.47 to 7.69				
(a) River section 200 ft. above dam.							(b) River section 20 ft. above headgate.						
OTT PROPELLER METER NO. 2956													
5011	Rohwer	V. I.	14.58	1.717	0.005	13.979	23.916	0.609	-0.69				
5012	Rohwer	M. P.	14.55	1.717	.005	13.979	23.916	.608		-1.92	-1.93	-2.20	2.13
5009	Lightburn	V. I.	29.17	2.060	.005	13.982	28.707	1.016	0.69				
5010	Lightburn	M. P.	29.14	2.060	.005	13.982	28.709	1.015		0.75	0.69	1.30	1.85
5005	Lightburn	V. I.	51.95	2.492	.005	13.984	34.746	1.495	2.95				
5006	Lightburn	M. P.	54.81	2.542	.005	13.984	35.445	1.546		1.38	1.40	2.58	0.05
5007	Rohwer	V. I.	61.60	2.658	.005	13.985	37.070	1.661	4.54				
5008	Rohwer	M. P.	62.01	2.664	.005	13.985	37.154	1.669		1.80	1.80	2.53	1.85
4980	Rohwer	V. I.	87.20	3.092	.020	13.988	42.923	2.031	5.58				
			Mean error disregarding sign						2.890	1.462	1.455	2.152	1.470
			Mean error regarding sign						2.614	0.502	0.490	1.052	1.470
			Range of errors						-0.69 to 5.58	-1.92 to 1.80	-1.93 to 1.80	-2.20 to 2.58	0.05 to 2.13
5104	Rohwer	V. I.	11.25	1.636	0.000	7.977	13.050	0.861	1.15				
5105	Rohwer	M. P.	11.17	1.635	.000	7.977	13.042	.857		3.49	3.31	3.94	4.39
5077	Rohwer	V. I.	29.80	2.104	.000	7.980	16.790	1.775	2.42				
5078	Rohwer	M. P.	29.85	2.104	.000	7.980	16.790	1.777		2.18	1.94	2.58	4.72
5061	Rohwer	V. I.	70.17	2.810	.000	7.982	22.429	3.128	2.64				
5062	Rohwer	M. P.	70.26	2.810	.000	7.982	22.429	3.132		2.47	2.19	3.47	5.22
5039	Rohwer	V. I.	90.45	3.125	.000	7.984	24.950	3.625	-3.26				
5040	Rohwer	M. P.	91.28	3.140	.000	7.984	25.070	3.641		1.25	1.01	1.56	2.10
			Mean error disregarding sign						2.368	2.348	2.112	2.888	4.108
			Mean error regarding sign						0.738	2.348	2.112	2.888	4.108
			Range of errors						-3.26 to 2.64	1.25 to 3.49	1.01 to 3.31	1.56 to 3.94	2.10 to 4.72

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

OTT PROPELLER METER NO. 2956

			Flume elements						Deviation from weir flow (1) Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Percentage	Percentage	Percentage	Percentage	Percentage
5120 (a)	Rohwer	V. I.	37.73	2.278	0.000	7.980	18.178	2.075	2.12				
5121 (a)	Rohwer	M. P.	37.06	2.263	.000	7.980	18.059	2.051		2.77	2.51	2.46	3.24
5154 (b)	Lightburn	V. I.	29.74	2.102	.000	7.982	16.778	1.772	1.65				
5155 (b)	Lightburn	M. P.	29.22	2.091	.000	7.982	16.690	1.751		0.03	-0.24	0.14	3.56
5161 (c)	Lightburn	V. I.	23.73	1.963	.000	7.981	15.667	1.514	-0.76				
			Mean error disregarding sign						1.51	1.40	1.38	1.30	3.40
			Mean error regarding sign						1.00	1.40	1.14	1.30	3.40
			Range of errors						-0.76 to 2.12	0.03 to 2.77	-0.24 to 2.51	0.14 to 2.46	3.24 to 3.56
River 30 (d)	Lightburn	V. I.	67.06				41.99	1.60	3.04				
River 31 (d)	Lightburn	.2- .6- .8	69.24				38.83	1.78				-3.26	-3.64
River 32 (e)	Lightburn	V. I.	70.43				52.26	1.35	1.81				
River 33 (e)	Lightburn	.2- .6- .8	70.67				52.92	1.34				3.12	7.35
			Mean error disregarding sign						2.42			3.19	5.50
			Mean error regarding sign						2.42			-0.07	1.86
			Range of errors						1.81 to 3.04			-3.26 to 3.12	-3.64 to 7.34
Volumetric 1 (f)	Rohwer	V. I.	8.63	1.500		2.497	3.745	2.304	2.43				
Volumetric 2 (f)	Rohwer	M. P.	8.63	1.500		2.497	3.745	2.304		3.13	3.01	2.67	6.02

(a) Cable, buoyant tail
(b) 10 degrees to right

(c) Continuous integration
(d) River section 200 ft. above dam

(e) River section 20 ft. above headgate
(f) Fort Collins laboratory

HOFF RUBBER PROPELLER METER NO. 2

4947	Rohwer	V. I.	9.50	1.577	0.000	13.979	22.030	0.431	-6.84				
4948	Rohwer	M. P.	9.48	1.576	.000	13.979	22.016	.430		-7.07	-7.06	-7.06	-5.27
4949	Lightburn	V. I.	24.80	1.980	.000	13.981	27.650	.896	-0.72				
4950	Lightburn	M. P.	24.97	1.983	.005	13.981	27.622	.904		-0.36	-0.36	0.27	-0.48
4951	Rohwer	V. I.	48.00	2.448	.015	13.984	33.991	1.412	2.30				
4952	Rohwer	M. P.	48.07	2.450	.014	13.984	34.033	1.412		0.67	0.35	0.16	1.12
4953	Lightburn	V. I.	69.35	2.810	.050	13.986	38.569	1.798	0.25				
4954	Lightburn	M. P.	69.40	2.812	.080	13.986	38.178	1.818		1.24	0.94	0.68	2.41
4955	Rohwer	V. I.	92.35	3.167	.000	13.988	44.252	2.086	3.85				
4956	Rohwer	M. P.	92.63	3.172	.000	13.988	44.322	2.090		-0.85	-0.83	-0.99	-3.80
			Mean error disregarding sign						2.792	2.038	1.908	1.832	2.616
			Mean error regarding sign						-0.232	-1.274	-1.392	-1.388	-1.204
			Range of errors						-6.84 to 3.85	-7.07 to 1.24	-7.06 to 0.94	-7.06 to 0.68	-5.27 to 2.41
5027	Rohwer	V. I.	7.80	1.516	0.000	7.986	12.107	0.644	0.90				
5028	Rohwer	M. P.	7.77	1.516	.000	7.986	12.107	.642		2.32	2.44	2.06	3.73
5025	Lightburn	V. I.	26.98	2.012	.000	7.987	16.070	1.679	2.04				
5026	Lightburn	M. P.	26.96	2.012	.000	7.987	16.070	1.678		1.37	1.37	2.41	3.64
5023	Rohwer	V. I.	45.68	2.384	.000	7.989	19.046	2.398	1.07				
5024	Rohwer	M. P.	46.15	2.391	.000	7.989	19.102	2.415		0.06	-0.22	0.63	3.06
5021	Rohwer	V. I.	66.48	2.946	.000	7.990	23.538	2.824	0.54				
5022	Rohwer	M. P.	66.30	2.944	.000	7.990	23.522	2.819		-0.26	-0.45	0.69	2.53
5045	Rohwer	V. I.	91.65	3.152	.000	7.984	25.165	3.642	2.54				
5046	Rohwer	M. P.	91.58	3.148	.000	7.984	25.134	3.644		2.31	1.62	3.79	2.88
			Mean error disregarding sign						1.418	1.264	1.220	1.916	3.168
			Mean error regarding sign						1.418	1.160	0.952	1.916	3.168
			Range of errors						0.54 to 2.54	-0.26 to 2.32	-0.22 to 2.44	0.63 to 3.79	2.53 to 3.73

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

HOFF RUBBER PROPELLER METER NO. 2

Test No.	Observer	Method of measurement	Flume elements						Deviation from weir flow (1)				
									Method of meter measurement				
										Multiple point			
			Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Per-centage	Per-centage	Per-centage	Per-centage	Per-centage
5116 (a)	Rohwer	V. I.	39.04	2.310	0.000	7.980	18.434	2.118	2.74				
5117 (a)	Rohwer	M. P.	39.26	2.308	.000	7.980	18.418	2.131		2.67	2.57	1.86	5.63
5118 (b)	Lightburn	V. I.	38.88	2.300	.000	7.980	18.354	2.118	6.63				
5119 (b)	Lightburn	M. P.	38.88	2.301	.000	7.980	18.362	2.117		5.79	5.55	5.70	7.97
5156 (c)	Rohwer	V. I.	23.75	1.963	.000	7.981	15.667	1.516	-4.72				
5157 (c)	Rohwer	M. P.	23.75	1.963	.000	7.981	15.667	1.516		-2.65	-2.86	-2.24	-3.79
5158 (d)	Lightburn	V. I.	23.73	1.963	.000	7.981	15.667	1.514	2.74				
5159 (e)	Lightburn	M. P.	23.69	1.962	.000	7.981	15.659	1.513		2.32	2.20	2.40	4.55
			Mean error disregarding sign						4.208	3.358	3.295	3.050	5.485
			Mean error regarding sign						1.848	2.032	1.865	1.930	3.590
			Range of errors						-4.72 to	-2.65 to	-2.86 to	-2.24 to	-3.79 to
									6.63	5.79	5.55	5.70	7.97
River 14 (f)	Rohwer	V. I.	62.26				45.01	1.47	-0.42				
River 15 (f)	Rohwer	.2- .6- .8	63.46				46.18	1.37				-5.66	-10.38
River 24 (g)	Rohwer	V. I.	61.04				53.69	1.14	3.04				
River 25 (g)	Rohwer	.2- .6- .8	66.55				53.59	1.24				3.74	6.35
			Mean error disregarding sign						1.73			4.70	8.365
			Mean error regarding sign						1.31			-0.96	- 2.015
			Range of errors						-0.42 to			-5.66 to	-10.38 to
									3.04			3.74	6.35

(a) Cable, 8-lb. weight

(b) Cable, two 8-lb. weights

(c) 10 degrees to right

(d) Continuous integration

(e) M. P. at stations

(f) River 200 ft. above dam.

(g) River 20 ft. above headgate

IRRIGATION INVESTIGATIONS PROPELLER METER NO. 1

4935	Rohwer	V. I.	18.82	1.826	0.000	13.980	25.509	0.737	–9.45				
4936	Rohwer	M. P.	18.77	1.826	.010	13.980	25.381	.740		2.77	2.24	3.15	0.16
4915	Lightburn	V. I.	19.87	1.857	.000	13.976	25.933	.766	9.61				
4916	Lightburn	.2 and .8	19.87	1.858	.000	13.976	25.946	.765				7.30	
4917	Lightburn	6 tenths	19.87	1.858	.000	13.976	25.952	.765					7.85
4937	Lightburn	V. I.	30.90	2.107	.010	13.982	29.290	1.054	0.61				
4938	Lightburn	M. P.	30.82	2.105	.020	13.982	29.118	1.059		–0.29	–0.10	–0.52	1.98
4918	Rohwer	V. I.	43.06	2.353	.020	13.981	32.585	1.321	0.35				
4919	Rohwer	.2 and .8	43.25	2.356	.080	13.981	31.790	1.360				4.97	
4920	Rohwer	6 tenths	43.34	2.360	.080	13.981	31.848	1.360					5.58
4939	Rohwer	V. I.	45.12	2.395	.030	13.984	33.035	1.365	1.00				
4940	Rohwer	M. P.	44.28	2.381	.050	13.983	32.561	1.360		3.73	3.57	4.25	4.69
4941	Lightburn	V. I.	62.25	2.692	.080	13.985	36.498	1.706	0.10				
4942	Lightburn	M. P.	62.30	2.696	.100	13.985	36.273	1.717		1.22	1.09	1.36	3.71
4943	Rohwer	V. I.	77.55	2.932	.050	14.018	40.352	1.921	–0.97				
4944	Rohwer	M. P.	77.50	2.932	.070	14.018	40.068	1.934		0.97	0.70	1.72	–1.26
			Mean error disregarding sign						3.169	1.796	1.540	3.324	3.604
			Mean error regarding sign						0.191	1.680	1.500	3.176	3.244
			Range of errors						–9.45 to	–0.29 to	–0.10 to	–0.52 to	–1.26 to
									9.61	3.73	3.57	7.30	7.85
5031	Lightburn	V. I.	7.19	1.496	0.000	7.986	11.947	0.601	–1.39				
5032	Lightburn	M. P.	7.21	1.497	.000	7.986	11.955	.603		0.83	0.83	0.00	2.91
5033	Lightburn	V. I.	74.18	2.868	.000	7.990	22.915	3.237	2.01				
5034	Lightburn	M. P.	74.66	2.876	.000	7.990	22.979	3.249		1.90	1.79	2.29	6.42
5035	Rohwer	V. I.	93.24	3.168	.000	7.984	25.293	3.686	1.22				
5036	Rohwer	M. P.	93.15	3.168	.000	7.984	25.293	3.683		1.41	1.31	2.25	2.67
			Mean error disregarding sign						1.540	1.380	1.310	1.513	4.000
			Mean error regarding sign						0.613	1.380	1.310	1.513	4.000
			Range of errors						–1.39 to	0.83 to	0.83 to	0.00 to	2.67 to
									2.01	1.90	1.79	2.29	6.42
5122 (a)	Rohwer	V. I.	26.46	2.030	0.000	7.979	16.197	1.634	1.51				
5123 (a)	Rohwer	M. P.	26.63	2.036	.000	7.979	16.245	1.639		1.54	1.43	1.54	1.77

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

IRRIGATION INVESTIGATIONS PROPELLER METER NO. 1

			Flume elements						Deviation from weir flow (1)				
									Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Per-centage	Per-centage	Per-centage	Per-centage	Per-centage
River 16 (b)	Rohwer	V. I.	66.18				42.90	1.54	-2.42				
River 17 (b)	Rohwer	.2- .6- .8	67.76				42.57	1.59				-6.27	-6.15
River 12 (c)	Lightburn	V. I.	66.31				53.45	1.24	2.66				
River 13 (c)	Lightburn	.2- .6- .8	66.19				52.94	1.25				-1.95	0.98
Mean error disregarding sign									2.540			4.11	3.565
Mean error regarding sign									0.120			-4.11	-2.585
Range of errors									-2.42 to 2.66			-6.27 to 1.95	-6.15 to 0.98

(a) Cable (b) River 200 ft. above dam (c) River 20 ft. above headgate

SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 4-CUP PROPELLER

Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
4997	Lightburn	V. I.	17.58	1.793	0.000	13.980	25.050	0.701	-1.48				
4998	Lightburn	M. P.	17.56	1.793	.000	13.980	25.050	.701		0.68	0.74	0.06	-0.63
4995	Rohwer	V. I.	30.03	2.076	.000	13.982	28.994	1.036	6.13				
4996	Rohwer	M. P.	30.08	2.078	.000	13.982	29.022	1.035		2.13	1.90	1.50	2.79
4993	Lightburn	V. I.	60.68	2.640	.065	13.985	35.979	1.687	8.46				
4994	Lightburn	M. P.	60.80	2.639	.096	13.985	35.532	1.711		7.32	6.96	8.95	8.98
4991	Rohwer	V. I.	89.26	3.076	.017	13.987	42.738	2.088	7.01				
4992	Rohwer	M. P.	89.02	3.074	.003	13.987	42.942	2.073		8.50	7.82	12.40	8.54
Mean error disregarding sign									5.770	4.658	4.355	5.728	5.235
Mean error regarding sign									5.030	4.658	4.355	5.728	4.920
Range of errors									-1.48 to 8.46	0.68 to 8.50	0.74 to 7.82	0.06 to 12.40	-0.63 to 8.98

5102	Lightburn	V. I.	11.28	1.636	0.000	7.977	13.050	0.864	3.28				
5103	Lightburn	M. P.	11.19	1.636	.000	7.977	13.050	.856		5.36	5.27	5.45	6.88
5069	Parshall	V. I.	31.75	2.148	.000	7.980	17.141	1.852	3.40				
5070	Parshall	M. P.	31.80	2.148	.000	7.980	17.141	1.855		1.32	1.35	2.96	3.08
5059	Lightburn	V. I.	70.20	2.809	.000	7.982	22.421	3.131	4.96				
5060	Lightburn	M. P.	70.32	2.811	.000	7.982	22.437	3.134		2.90	2.70	4.67	5.77
5043	Rohwer	V. I.	97.35	3.228	.000	7.984	25.772	3.777	4.60				
5044	Rohwer	M. P.	96.08	3.209	.000	7.984	25.621	3.750		2.68	2.37	3.20	7.28
			Mean error disregarding sign						4.060	3.065	2.922	4.070	5.752
			Mean error regarding sign						4.060	3.065	2.922	4.070	5.752
			Range of errors						3.28 to	1.32 to	1.35 to	2.96 to	3.08 to
									4.96	5.36	5.27	5.45	7.28

SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 5-CUP PROPELLER

4989	Lightburn	V. I.	14.22	1.707	0.000	13.979	23.845	0.596	–4.36				
4990	Lightburn	M. P.	14.20	1.706	.000	13.979	23.831	.595		–4.22	–3.94	–4.30	–3.03
4987	Rohwer	V. I.	31.02	2.099	.000	13.982	29.317	1.058	–1.03				
4988	Rohwer	M. P.	31.08	2.098	.000	13.982	29.302	1.060		0.16	–0.13	1.90	–0.74
4985	Lightburn	M. P.	54.42	2.538	.012	13.984	35.293	1.541		0.97	0.70	1.76	–0.17
4986	Lightburn	V. I.	53.90	2.529	.000	13.984	35.334	1.525	0.93				
4983	Rohwer	V. I.	73.40	2.847	.015	13.986	39.560	1.855	2.40				
4984	Rohwer	M. P.	73.86	2.853	.011	13.986	39.698	1.860		0.57	0.43	2.58	–1.59
4978	Lightburn	V. I.	94.41	3.185	.030	13.988	44.088	2.141	5.56				
4979	Lightburn	M. P.	94.32	3.183	.005	13.988	44.405	2.124		7.20	7.09	8.52	8.41
			Mean error disregarding sign						2.856	2.624	2.458	3.812	2.784
			Mean error regarding sign						0.700	0.936	0.830	2.092	0.580
			Range of errors						–4.36 to	–4.22 to	3.94 to	–4.30 to	–3.03 to
									5.56	7.20	7.09	8.52	8.41
5100	Rohwer	V. I.	11.30	1.637	0.000	7.977	13.058	0.865	0.35				
5101	Rohwer	M. P.	11.28	1.638	.000	7.977	13.066	.863		2.57	2.39	4.25	3.28
5071	Parshall	V. I.	31.80	2.148	.000	7.980	17.141	1.855	0.97				
5072	Parshall	M. P.	31.70	2.148	.000	7.980	17.141	1.849		0.60	0.25	2.62	4.01
5057	Rohwer	V. I.	70.28	2.808	.000	7.982	22.413	3.136	2.12				
5058	Rohwer	M. P.	70.23	2.808	.000	7.982	22.413	3.133		1.91	1.58	3.62	4.74
5047	Lightburn	V. I.	91.67	3.156	.000	7.984	25.197	3.638	3.92				
5048	Lightburn	M. P.	91.65	3.156	.000	7.984	25.197	3.637		2.90	2.70	5.11	4.59

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 5-CUP PROPELLER

			Flume elements						Deviation from weir flow (1)				
									Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Percentage	Percentage	Percentage	Percentage	Percentage
			Mean error disregarding sign						1.840	1.995	1.730	3.900	4.155
			Mean error regarding sign						1.840	1.995	1.730	3.900	4.155
			Range of errors						0.35 to 3.92	0.60 to 2.90	0.25 to 2.70	2.62 to 5.11	3.28 to 4.74
SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 6-CUP PROPELLER													
5098	Lightburn	V. I.	11.26	1.636	0.000	7.977	13.050	0.862	0.80				
5099	Lightburn	M. P.	11.23	1.636	.000	7.977	13.050	.860		1.51	1.42	1.51	2.40
5073	Rohwer	V. I.	29.80	2.102	.000	7.980	16.774	1.776	1.04				
5074	Rohwer	M. P.	29.78	2.103	.000	7.980	16.782	1.775		0.51	0.27	1.48	4.20
5055	Lightburn	V. I.	69.91	2.803	.000	7.982	22.373	3.125	2.32				
5056	Lightburn	M. P.	70.10	2.806	.000	7.982	22.397	3.130		2.65	2.30	4.65	6.04
5049	Rohwer	V. I.	91.66	3.156	.000	7.984	25.197	3.638	3.33				
5050	Rohwer	M. P.	91.61	3.154	.000	7.984	25.182	3.638		2.78	2.50	4.67	2.71
			Mean error disregarding sign						1.872	1.862	1.622	3.078	3.838
			Mean error regarding sign						1.872	1.862	1.622	3.078	3.838
			Range of errors						0.80 to 3.33	0.51 to 2.78	0.27 to 2.50	1.48 to 4.67	2.40 to 6.04
SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 7-CUP PROPELLER													
4968	Rohwer	M. P.	15.30	1.740	0.005	13.980	24.239	0.631		–2.22	–2.88	–1.96	–2.35
4969	Rohwer	V. I.	15.18	1.738	.005	13.980	24.211	.627	–1.51				
4970	Lightburn	V. I.	31.70	2.125	.005	13.982	29.602	1.070	2.05				
4971	Lightburn	M. P.	31.61	2.123	.005	13.982	29.582	1.068		4.94	4.87	5.21	7.11
4972	Rohwer	M. P.	51.90	2.519	.000	13.984	35.194	1.475		3.39	3.32	5.98	4.66

4973	Rohwer	V. I.	51.73	2.517	0.000	13.984	35.164	1.471	5.47				
4974	Lightburn	V. I.	76.86	2.932	.000	13.986	40.958	1.877	3.62				
4975	Lightburn	M. P.	76.82	2.930	.005	13.986	40.861	1.880		4.34	4.03	6.88	3.45
4976	Rohwer	V. I.	94.50	3.186	.005	13.988	44.447	2.126	5.94				
4977	Rohwer	M. P.	94.92	3.192	.020	13.988	44.322	2.141		5.51	5.42	7.82	5.29
			Mean error disregarding sign						3.718	4.080	4.104	5.570	4.572
			Mean error regarding sign						3.114	3.192	2.952	4.786	3.632
			Range of errors						–1.51 to 5.94	–2.22 to 5.51	–2.88 to 5.42	–1.96 to 7.82	–2.35 to 7.11
5096	Rohwer	V. I.	11.30	1.637	0.000	7.977	13.058	0.865	3.01				
5097	Rohwer	M. P.	11.28	1.637	.000	7.977	13.058	.864		3.10	3.19	2.92	6.02
5075	Lightburn	V. I.	29.80	2.102	.000	7.980	16.774	1.777	2.48				
5076	Lightburn	M. P.	29.73	2.103	.000	7.980	16.782	1.771		2.22	2.02	2.69	6.15
5063	Rohwer	M. P.	69.78	2.802	.000	7.982	22.366	3.120		1.78	1.44	3.03	5.07
5054	Rohwer	V. I.	69.88	2.802	.000	7.982	22.366	3.124	2.39				
5051	Lightburn	V. I.	91.55	3.150	.000	7.984	25.150	3.640	3.51				
5052	Lightburn	M. P.	91.52	3.148	.000	7.984	25.134	3.641		2.58	2.24	4.01	3.52
			Mean error disregarding sign						2.848	2.420	2.222	3.162	5.190
			Mean error regarding sign						2.848	2.420	2.222	3.162	5.190
			Range of errors						2.39 to 3.51	1.78 to 3.10	1.44 to 3.19	2.69 to 4.01	3.52 to 6.15

SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 8-CUP PROPELLER

5092	Rohwer	V. I.	11.19	1.635	0.000	7.977	13.042	0.858	3.58				
5093	Rohwer	M. P.	11.21	1.634	.000	7.977	13.034	.860		4.37	4.02	3.84	5.35
5126 (a)	Parshall	V. I.	26.80	2.038	0.000	7.979	16.261	1.648	3.96				
5127 (a)	Parshall	M. P.	26.86	2.040	.000	7.979	16.277	1.650		1.93	1.56	3.57	6.62

(Continued)

TABLE 3.—Summary of current-meter measurements in a flume under various conditions by different methods compared with measurements by a Francis weir with full contractions. (Continued)

SMALL PRICE ELECTRIC METER NO. 1314 WITH SPECIAL 8-CUP PROPELLER

			Flume elements						Deviation from weir flow (1) Method of meter measurement				
										Multiple point			
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Correction for sand	Average width	Water section area	Mean velocity per second	Vertical integration	Vertical velocity curve	Weighted mean velocity	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Feet	Square-feet	Feet	Per-centage	Per-centage	Per-centage	Per-centage	Per-centage
River 28 (b)	Lightburn	V. I.	66.18				42.90	1.54	5.78				
River 29 (c)	Lightburn	.2- .6- .8	67.76				42.57	1.59				0.33	-1.51
River 36 (d)	Lightburn	V. I.	61.04				53.69	1.14	4.73				
River 37 (d)	Lightburn	.2- .6- .8	66.55				53.59	1.24				5.03	9.90
Mean error disregarding sign									5.255			2.680	5.705
Mean error regarding sign									5.255			2.680	4.195
Range of errors									4.73 to			0.33 to	-1.51 to
									5.78			5.03	9.90
Volumetric 5 (e)	Rohwer	V. I.	8.63	1.500		2.497	3.745	2.304	2.43				
Volumetric 6 (e)	Rohwer	M. P.	8.63	1.500		2.497	3.745	2.304		2.43	1.85	2.90	6.96

(a) Cable
(b) River 200 ft. above dam
(c) River 20 ft. above dam
(d) River 20 ft. above headgate
(e) Fort Collins laboratory

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(1) Deviation equals 100 times quotient obtained by dividing difference between current-meter discharge and weir discharge by weir discharge.
(2) Vertical integration.
(3) Multiple point.

cal-integration method, which is supposed to give results that are too large because integrating the meter makes it run faster, gave results that were too small, with few exceptions. The special tests with this meter show the same results, but the fact to be noted is that, regardless of the conditions, this meter measured the water with uniformly consistent results and that the best results were obtained when using the vertical-integration and the 2-and-8-tenths methods.

The tests on the Lallie meter, which is similar to the Price meter except that it has five cups instead of six and does not rotate when integrating in still water, were made only in the 8-foot flume and in the river. These tests show that the best results were obtained by the multiple-point method. They show also that the 6-tenths method gives results that are too large and the vertical-integration method gives results that are too small. These results check those obtained with the Price meter. The special measurements made in the river were not so accurate as those made with the Price meter.

The measurements made with Ott propeller meter number 2909 in the 8 and 14-foot flumes were uniformly quite accurate, but one of the measurements made in the river section was considerably in error. These tests show the vertical-integration method gave the best results, and that the 2-and-8-tenths method was more accurate than the multiple-point method. The 6-tenths method gave results that were, in general, too large.

The tests on Ott meter number 2956 show that the errors were uniformly small. The multiple-point method gave the best results on the 14-foot flume, whereas the vertical-integration method gave the best results on the 8-foot flume. The 6-tenths method gave results that were consistently too large. The volumetric tests at the Fort Collins laboratory on the small flume did not differ very materially from those made in the larger flumes at the Bellvue laboratory, where the discharges were measured over a Francis weir. The special tests, both in the flume and in the river, gave reasonably accurate results.

The measurements made with Hoff propeller meter number 2 in the 8 and 14-foot flumes check the Francis-weir discharges very closely, with the exception of those tests made when the velocities were less than 0.5 foot per second, and the agreement is excellent for all methods of measurement. F. Kuntschen (6) experimenting in Switzerland with propeller meters, concluded that measurements made with this type of meter were unreliable for velocities less than 1 foot per second. The special tests with the Hoff meter are more erratic, but as the errors are both positive and negative, the mean results are quite good. The tests made with the meter turned 10 degrees to the right show that the meter under-registers when it is not parallel to the direction of the current, whereas the Price meter is unaffected by this condition.

The special test meter of the propeller type was designed and built at the Fort Collins laboratory to see whether it was possible to improve on the present design of propeller meters. The meter was attached to the rod so that it was free to rotate in a horizontal plane, and adjust itself automatically to the direction of the current. The tests show that the meter gave good results except in a few instances. The special tests indicated that this meter would operate satisfactorily even under unusual conditions, but the results did not show that the meter was superior to those already in use.

A series of tests was also made on Price meter number 1314 when equipped with special cups, in order to find out whether it would be possible to reduce the size of the cups and also the diameter of the rotor. The cups used were hemispherical in shape, 1.25 inches in diameter, and varied in number from four to eight. The diameter of the rotor was 3 inches. The rotors were interchangeable in the meter, but the same shaft was used for all.

The tests on this meter, when equipped with the different rotors, show that the results are erratic. Altho some of the measurements were quite accurate, too many of the measurements differed materially from the weir discharge. Of the different rotors, the ones with the 5 and 6-inch cups gave the most consistent results. The standard Price yoke was disproportionately large for these small rotors, and it is believed that if all the parts of the meter were reduced in the same proportion as the rotor, a satisfactory meter would be obtained, but the results do not indicate that it would be superior to those already available.

The summary of the mean errors in the current-meter measurements under the various conditions by the different meters and the different methods, is given in Table 4. Excluding the experimental models, this table shows that, taken as a whole, regardless of the type of meter, the method of measurement, or the conditions under which the gagings were made, the mean errors are definitely less rather than greater than 2 percent. This is also true of the different methods of measurement, except the 6-tenths method, for all the meters except the experimental models. The errors were larger when the 6-tenths method was used, and in only a few instances were the measured discharges too small. The table shows also that, altho the mean errors were small, except for the experimental models, nevertheless occasional measurements were considerably in error as shown by the range of errors. Of all the tests, those made with the Price meter using the 2-and-8-tenths method were the most accurate. So far as the other meters and methods are concerned, no outstanding differences are evident. Another fact shown by this table is that the multi-

TABLE 4.—Summary of errors in vertical integration current-meter measurements under various conditions by different meters, as determined by measurements made volumetrically or by a Francis weir with full contractions.

Meter	Type	Number	Classification of tests	No. of tests	Vertical integration method Mean error Regarding sign	 Mean error Disregarding sign	Maximum range of errors
					Percentage	Percentage	Percentage
Price	Cup	15188	14-foot flume	11	−1.333	2.254	−4.17 to 5.80
Price	Cup	15188	8-foot flume	6	−2.295	2.295	−4.97 to −1.13
Price	Cup	15188	2.5-ft. flume (1)	1	−2.90	2.90	....
Price	Cup	15188	8-foot special	14	−1.40	1.59	−3.46 to 1.33
Price	Cup	15188	River	5	1.07	2.33	−3.14 to 3.54
Lallie	Cup	310	8-foot flume	5	−0.982	1.902	−4.15 to 2.30
Lallie	Cup	310	River	2	0.295	2.205	−1.91 to 2.50
Ott	Propeller	2909	14-foot flume	4	0.000	2.890	−2.63 to 5.78
Ott	Propeller	2909	8-foot flume	4	1.325	1.325	0.49 to 2.06
Ott	Propeller	2909	River	2	4.080	4.080	0.47 to 7.69
Ott	Propeller	2956	14-foot flume	5	2.614	2.890	−0.69 to 5.58
Ott	Propeller	2956	8-foot flume	4	0.738	2.368	−3.26 to 2.64
Ott	Propeller	2956	2.5-ft. flume (1)	1	2.43	2.43	....
Ott	Propeller	2956	8-foot special	3	1.00	1.51	−0.76 to 2.12
Ott	Propeller	2956	River	2	2.42	2.42	1.81 to 3.04
Hoff	Propeller	2	14-foot flume	5	−0.232	2.792	−6.84 to 3.85
Hoff	Propeller	2	8-foot flume	5	1.418	1.418	0.54 to 2.54
Hoff	Propeller	2	8-foot special	4	1.848	4.208	−4.72 to 6.63
Hoff	Propeller	2	River	2	1.31	1.73	−4.2 to 3.04
Irrig. Inv.	Propeller	1	14-foot flume	7	1.191	3.169	−9.45 to 9.61
Irrig. Inv.	Propeller	1	8-foot flume	3	0.613	1.540	−1.39 to 2.01
Irrig. Inv.	Propeller	1	8-foot special	1	1.51	1.51	....
Irrig. Inv.	Propeller	1	River	2	0.120	2.549	−2.42 to 2.66
Price	4-cup propeller	1314	14-foot flume	4	5.030	5.770	−1.48 to 8.64
Price	4-cup propeller	1314	8-foot flume	4	4.060	4.060	3.28 to 4.96
Price	5-cup propeller	1314	14-foot flume	5	0.700	2.856	−4.36 to 5.56
Price	5-cup propeller	1314	8-foot flume	4	1.840	1.840	0.35 to 3.92
Price	6-cup propeller	1314	8-foot flume	4	1.872	1.872	0.80 to 3.33
Price	7-cup propeller	1314	14-foot flume	5	3.114	3.718	−1.51 to 5.94
Price	7-cup propeller	1314	8-foot flume	4	2.848	2.848	2.39 to 3.51
Price	8-cup propeller	1314	8-foot flume	1	3.58	3.58	....
Price	8-cup propeller	1314	2.5-ft. flume (1)	1	2.43	2.43	....
Price	8-cup propeller	1314	8-foot special	1	3.96	3.96	....
Price	8-cup propeller	1314	River	2	5.255	5.255	4.73 to 5.78

(1) Comparative discharge determined volumetrically.

(Continued)

measurements made volumetrically or by a Francis weir with full contractions. (Continued)

Meter	Type	Number	Classification of tests	No. of tests	Multiple point method: Vertical velocity curve: Mean error Regarding sign	Mean error Disregarding sign	Maximum range of errors	Weighted Mean Velocity: Mean error Regarding sign	Mean error Disregarding sign	Maximum range of errors
					Percentage	Percentage	Percentage	Percentage	Percentage	Percentage
Price	Cup	15188	14-foot flume	3	-2.333	2.333	-0.58 to -4.26	-2.433	2.433	-0.70 to -4.14
Price	Cup	15188	8-foot flume	5	-1.962	1.962	-3.12 to -0.47	-2.210	2.210	-3.00 to -0.58
Price	Cup	15188	2.5-ft. flume (1)	1	-2.89	2.89	....	-3.25	3.25	....
Price	Cup	15188	8-foot special	13	-1.86	1.92	-4.29 to 0.40	-2.51	2.51	-4.58 to -0.13
Price	Cup	15188	River	....	....	....	....	....	....	....
Lallie	Cup	310	8-foot flume	5	0.034	1.366	-2.19 to 2.15	-0.234	1.314	-2.56 to 1.44
Ott	Propeller	2909	14-foot flume	4	1.500	3.040	-2.06 to 6.23	1.585	3.055	-2.06 to 6.00
Ott	Propeller	2909	8-foot flume	4	2.502	2.502	1.57 to 3.97	2.448	2.448	1.54 to 4.15
Ott	Propeller	2909	River	....	....	....	....	....	....	....
Ott	Propeller	2956	14-foot flume	4	0.502	1.462	-1.92 to 1.80	0.490	1.455	-1.93 to 1.80
Ott	Propeller	2956	8-foot flume	4	2.348	2.348	1.25 to 3.49	2.112	2.112	1.01 to 3.31
Ott	Propeller	2956	2.5-ft. flume (1)	1	3.13	3.13	....	3.01	3.01	....
Ott	Propeller	2956	8-foot special	2	1.40	1.40	0.03 to 2.77	1.14	1.38	-0.24 to 2.51
Ott	Propeller	2956	River	....	....	....	....	....	....	....
Hoff	Propeller	2	14-foot flume	5	-1.274	2.038	-7.07 to 1.24	-1.392	1.908	-7.06 to 0.94
Hoff	Propeller	2	8-foot flume	5	1.160	1.264	-0.26 to 2.32	0.952	1.220	-0.22 to 2.44
Hoff	Propeller	2	8-foot special	4	2.032	3.358	-2.65 to 5.79	1.865	3.295	-2.86 to 5.55
Hoff	Propeller	2	River	....	....	....	....	....	....	....
Irrig. Inv.	Propeller	1	14-foot flume	5	1.680	1.796	-0.29 to 3.73	1.500	1.540	-0.10 to 3.57
Irrig. Inv.	Propeller	1	8-foot flume	3	1.380	1.380	0.83 to 1.90	1.310	1.310	0.83 to 1.79
Irrig. Inv.	Propeller	1	8-foot special	1	1.5	1.54	....	1.43	1.43	....
Irrig. Inv.	Propeller	1	River	....	....	....	....	....	....	....
Price	4-cup propeller	1314	14-foot flume	4	4.658	4.658	0.68 to 8.50	4.355	4.355	0.74 to 7.82
Price	4-cup propeller	1314	8-foot flume	4	3.065	3.065	1.32 to 5.36	2.922	2.922	1.35 to 5.27
Price	5-cup propeller	1314	14-foot flume	5	0.936	2.624	-4.22 to 7.20	0.830	2.458	-3.94 to 7.09
Price	5-cup propeller	1314	8-foot flume	4	1.995	1.995	0.60 to 2.90	1.730	1.730	0.25 to 2.70
Price	6-cup propeller	1314	8-foot flume	4	1.862	1.862	0.51 to 2.78	1.622	1.622	0.27 to 2.50
Price	7-cup propeller	1314	14-foot flume	5	3.192	4.080	-2.22 to 5.51	2.952	4.104	-2.88 to 5.42
Price	7-cup propeller	1314	8-foot flume	4	2.420	2.420	1.78 to 3.10	2.222	2.222	1.44 to 3.19
Price	8-cup propeller	1314	8-foot flume	1	4.37	4.37	....	4.02	4.02	....
Price	8-cup propeller	1314	2.5-ft. flume (1)	1	2.43	2.43	....	1.85	1.85	....
Price	8-cup propeller	1314	8-foot special	1	1.93	1.93	....	1.56	1.56	....

TABLE 4.—Summary of errors in two-and-eight-tenths and six-tenths method current-meter measurements under various conditions by different meters, as determined by measurements made volumetrically or by a Francis weir with full contractions. (Continued)

Meter	Type	Number	Classification of tests	Two-and-eight-tenths method No. of tests	Mean error Regarding sign	Mean error Disregarding sign	Maximum range of errors	Six-tenths method No. of tests	Mean error Regarding sign	Mean error Disregarding sign	Maximum range of errors
					Percentage	Percentage	Percentage		Percentage	Percentage	Percentage
Price	Cup	15188	14-foot flume	7	0.633	2.441	-3.17 to 5.13	7	2.073	3.090	-3.56 to 7.85
Price	Cup	15188	8-foot flume	5	0.134	1.106	-1.69 to 1.20	5	1.626	2.070	-1.11 to 4.24
Price	Cup	15188	2.5-ft. flume (1)	1	-1.28	1.28	....	1	1.97	1.97	....
Price	Cup	15188	8-foot special	13	0.18	0.80	-1.70 to 2.39	13	2.94	2.94	1.30 to 4.32
Price	Cup	15188	River	3	-0.48	1.41	-2.26 to 1.39	5	1.39	2.90	2.08 to 5.27
Lallie	Cup	310	8-foot flume	5	1.086	1.286	-0.50 to 2.87	5	3.342	3.342	2.00 to 4.87
Lallie	Cup	310	River	2	-3.095	7.315	-10.41 to 4.22	2	-0.880	6.930	-7.81 to 6.05
Ott	Propeller	2909	14-foot flume	4	1.820	2.500	- 0.86 to 5.50	4	0.470	2.685	-2.92 to 3.17
Ott	Propeller	2909	8-foot flume	4	2.412	2.412	1.92 to 3.61	4	4.225	4.225	4.15 to 6.85
Ott	Propeller	2909	River	1	2.010	2.010	....	1	6.92	6.92	....
Ott	Propeller	2956	14-foot flume	4	1.052	2.152	-2.20 to 2.58	4	1.470	1.470	0.05 to 2.13
Ott	Propeller	2956	8-foot flume	4	2.888	2.888	1.56 to 3.94	4	4.108	4.108	2.10 to 4.72
Ott	Propeller	2956	2.5-ft. flume (1)	1	2.67	2.67	....	1	6.02	6.02	....
Ott	Propeller	2956	8-foot special	2	1.30	1.30	0.14 to 2.46	2	3.40	3.40	3.24 to 3.56
Ott	Propeller	2956	River	2	-0.07	3.19	-3.26 to 3.12	2	1.86	5.50	-3.64 to 7.35
Hoff	Propeller	2	14-foot flume	5	-1.388	1.832	-7.06 to 0.68	5	-1.204	2.616	-5.27 to 2.41
Hoff	Propeller	2	8-foot flume	5	1.916	1.916	0.63 to 3.79	5	3.168	3.168	2.53 to 3.73
Hoff	Propeller	2	8-foot special	4	1.930	3.050	-2.24 to 5.70	4	3.590	5.485	-3.79 to 7.97
Hoff	Propeller	2	River	2	-0.96	4.70	-5.66 to 3.74	2	-2.015	8.365	-10.38 to 6.35
Irrig. Inv.	Propeller	1	14-foot flume	7	3.176	3.324	-0.52 to 7.30	7	3.244	3.604	-1.26 to 7.85
Irrig. Inv.	Propeller	1	8-foot flume	3	1.513	1.513	0.00 to 2.29	3	4.000	4.000	2.67 to 6.42
Irrig. Inv.	Propeller	1	8-foot special	1	1.54	1.54	....	1	1.77	1.77	....
Irrig. Inv.	Propeller	1	River	2	-4.11	4.11	-6.27 to -1.95	2	-2.585	3.565	-6.15 to 0.98
Price	4-cup propeller	1314	14-foot flume	4	5.728	5.728	0.06 to 12.40	4	4.920	5.235	-0.63 to 8.98
Price	4-cup propeller	1314	8-foot flume	4	4.070	4.070	2.98 to 5.45	4	5.752	5.752	3.08 to 7.28
Price	5-cup propeller	1314	14-foot flume	5	2.092	3.812	-4.30 to 8.52	5	0.580	2.784	-3.03 to 8.41
Price	5-cup propeller	1314	8-foot flume	4	3.900	3.900	2.62 to 5.11	4	4.155	4.155	3.28 to 4.74
Price	6-cup propeller	1314	8-foot flume	4	3.078	3.078	1.48 to 4.67	4	3.838	3.838	2.40 to 6.04
Price	7-cup propeller	1314	14-foot flume	5	4.786	5.570	-1.96 to 7.82	5	3.632	4.572	-2.35 to 7.11
Price	7-cup propeller	1314	8-foot flume	4	3.162	3.162	2.69 to 4.01	4	5.190	5.190	3.52 to 6.15
Price	8-cup propeller	1314	8-foot flume	1	3.84	3.84	....	1	5.35	5.35	....
Price	8-cup propeller	1314	2.5-ft. flume (1)	1	2.90	2.90	....	1	6.96	6.96	....
Price	8-cup propeller	1314	8-foot special	1	3.57	3.57	....	1	6.62	6.62	....
Price	8-cup propeller	1314	River	2	2.680	2.680	0.33 to 5.03	2	4.195	5.705	-1.51 to 9.90

(1) Comparative discharge determined volumetrically.

ple-point method does not give as accurate results as some of the other methods which are much less time consuming. This is true whether the results were computed from the weighted mean velocities or from the vertical-velocity curves.

All the standard meters were tested under practically the same conditions, and the differences shown by the results are, in consequence, probably due to the characteristics of the meters. The different methods of measurement were all used when making observations on each meter, and as the meters were tested under approximately identical conditions, these different methods of measurement were also tested under comparable conditions and the differences noted should be due to the differences in the meters and the methods, rather than the variations in the conditions under which the tests were made. As shown by the vertical-velocity curves in Figure 62 which are representative of the entire series of tests, the flow conditions in the channels at the points where the gagings were made were not ideal, but neither was the water very perturbed nor the velocity distribution very irregular. Consequently, it cannot be said that the conclusions drawn were based on measurements made under specially favorable conditions.

The summary of the errors in the results obtained by the experimental propeller meter, Irrigation Investigations number 1, shows that the meter operates very satisfactorily when making vertical-integration measurements, but that it does not operate so satisfactorily when making measurements by the other methods. The Price meter with the different experimental rotors did not measure the discharges as accurately as the Price meter with a standard rotor, or as the different propeller meters. The mean errors are positive in every case, which means that the special rotors of this type tend to over-register. The results obtained from the experimental models, both from the propeller and the cup types, as explained previously, were not sufficiently promising in comparison with the results obtained from the standard meters to warrant attempting to improve the present types of current meters along these lines.

The conclusions drawn from these tests are limited to the conditions under which the tests were made, and are not assumed to be of general application. Under conditions of extreme turbulence or when measuring large streams, different results might be obtained. Murphy (9) at the Cornell Hydraulic Laboratory, with a small Price meter under conditions comparable to those at the Bellvue laboratory, showed that the multiple-point method ("ordinary method") agreed with the weir discharge within 1 percent under favorable conditions, that the 6-tenths method gave results that were too large, and that the integration method as a rule gave results in excess of those given by the weir. The last conclusion does not check the Bellvue experiments. Kirschmer and Esterer (5), making comparisons between volumetric measurements and multiple-point measurements with Ott current meters in a concrete channel, found that the Ott meters checked the discharges determined volumetrically very closely and gave more accurate results than the salt-velocity method but not such accurate results as the salt-concentration method. Similar tests by F. Kuntschen (6) on propeller meters, when using the multiple-point method, show that the results obtained with the current meters compare favorably with the salt-titration method and weir measurements when checked by volumetric measurements of discharge.

CURRENT-METER MEASUREMENTS IN SHALLOW FLUMES.—Current-meter measurements must frequently be made in shallow streams and flumes, and in view of the fact that the ratings of current meters are not the same near the water surface as they are when submerged 0.3 foot or more, particularly in the case of cup meters, it was decided to make a series of tests in which the measurement of flows of 1 foot or less in depth by different types of current meters and different methods of measurement, were compared with the same discharges measured over a 4-foot rectangular Francis weir with full contractions.

These tests were carried on at the Bellvue laboratory in the remodelled flume shown in Figure 63 and Plate 24. The rating flume built inside the concrete structure was 6 feet wide, 2 feet deep and 16 feet long, with the floor 2.5 feet above the floor of the concrete channel. The floor was extended upstream from the end of the flume and wing walls were connected with the sides of the channel by metal transitions, as shown in this figure. The discharge was measured over a 4-foot rectangular Francis weir with full contractions attached to a bulkhead in the 15-foot weir notch in the concrete weir box. The 4-foot weir had been calibrated previously at the Fort Collins laboratory by volumetric methods, and the tables prepared from the calibrations were used in determining the discharge thru the rating flume.

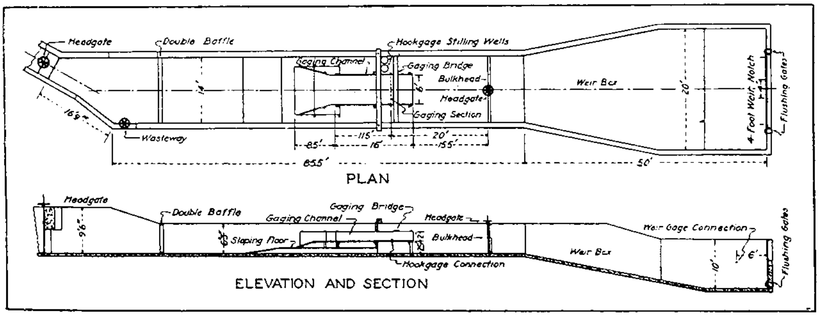

Figure 63.—Hydraulic laboratory at Bellvue, Colorado, with 4-foot Francis weir.

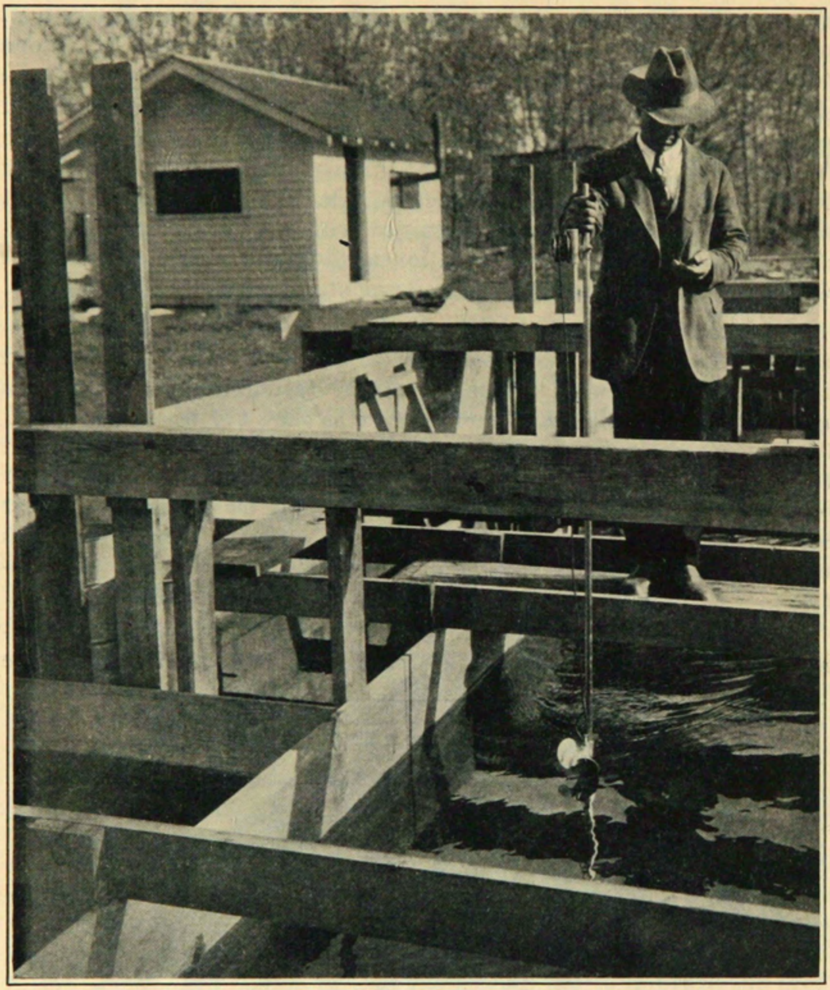

Plate 24.—Ott meter number 4184 being used in shallow flume tests at Bellvue laboratory.

The head on the weir and the depth of water in the rating flume were each measured by two hook gages reading to thousandths of a foot located on opposite sides of the channel. The hook-gage readings were taken once during the velocity determinations at each section of the rating flume. As the sections were 1 foot wide, six readings of each gage were taken during every test. The mean values were used in computing the gage heights.

The meters used in the tests consisted of Price cup meter number 15,188, Ott propeller meters numbers 3718 and 4184, and Hoff rubber propeller meter number 9. The meters themselves, or similar models, are shown in Plates 4, 6, 9 and 16. The depths of water in which the measurements were made were 0.4, 0.6, 0.8 and 1.0 foot, and the vertical-integration, 2-and-8-tenths and the 6-tenths methods were used in gaging the discharges, except at the shallower depths where the 2-and-8-tenths method could not be used on account of the fact that the meters would be exposed when at the upper point and would touch the bottom when at the lower point.

The quantities measured varied between 2 and 20 cubic feet per second, and at each depth in the flume the quantities were varied so as to obtain velocities ranging from 1 to 3 feet per second. In making the tests, the desired quantity in the flume was obtained by opening the headgate at the upper end of the flume and by adjusting the gate in the wasteway from the concrete flume. The depth in the rating section was regulated by the gate in the bulkhead in the concrete channel below the rating flume. No difficulty was experienced in maintaining a constant head, as the stage of the river was nearly constant and also because the long crest of the dam over which the excess water in the river poured, kept the pressure on the headgate supplying the flume from varying appreciably, even tho the quantity of water in the river changed slightly. The meter measurements with each meter were made by two different observers so as to eliminate the personal equation as much as possible from the gagings.

Each of the meters was rated at the tangent rating station at Fort Collins during the period that the discharge measurements were being made. The equations of the meters as determined from the ratings are as follows:

Meter No.	Condition	Meter equation	Limits
Price 15,188	With tail, depth 2 ft.	$V=2.173\ R+0.030$	
Ott 3,718	With tail, depth 2 ft.	$V=0.440\ R+0.030$	$R>1.868<14.13$
Ott 4,184	No tail, depth 2 ft.	$V=0.891\ R+0.025$	$R>0.94 < 7.0$
Hoff 9	With tail, depth 2 ft.	$V=0.370\ R+0.022$	$R>1.15 <16.95$

All the ratings were made with the meters rigidly attached to rods.

The results of the discharge measurements are summarized in Table 5 which is in the same form as Table 3, except that the classification is made according to the depth in the flume instead of the width of flume. In order to make a comparison between the accuracy of the meters in different depths of water, the errors for each meter and each depth and method of measurement were computed and are shown in the table.

The outstanding fact shown by these tests is that the errors in the results are consistently large, and that the errors increase in general as the depth decreases. In the case of the Price meter, the best results were obtained when using the vertical-integration method of measurement. Consistent results were obtained when the 6-tenths

TABLE 5.—Summary of current-meter measurements in a flume with water 1 foot or less in depth, under various conditions by different methods, compared with measurements by a Francis weir with full contractions.

SMALL PRICE ELECTRIC CUP METER NO. 15,188

			Flume elements					Deviation from weir flow		
								Method of meter measurement		
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Average width	Water section area	Mean velocity per second	Vertical integration	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Square-feet	Feet	Percentage	Percentage	Percentage
5271	Kelso	V. I.	2.359	0.4025	6.085	2.449	0.964	8.14		
5272	Kelso	.6	2.359	.4010	6.085	2.440	.967			7.21
5263	Kelso	V. I.	3.138	.4030	6.080	2.450	1.280	5.26		
5264	Kelso	.6	3.138	.4040	6.080	2.456	1.277			5.48
5255	Rohwer	V. I.	5.427	.4165	6.080	2.526	2.146	-13.25		
5256	Rohwer	.6	5.412	.4155	6.080	2.526	2.142			-6.76
5247	Rohwer	V. I.	7.271	.4330	6.080	2.633	2.761	-11.10		
5248	Rohwer	.6	7.315	.4320	6.080	2.627	2.799			-9.42
					Mean error disregarding sign			9.44		7.22
					Mean error regarding sign			- 2.74		-0.87
					Range of errors			-13.25 to 8.14		-9.42 to 7.21
5170	Rohwer	V. I.	4.050	0.6090	6.070	3.681	1.010	2.42		
5171	Rohwer	.2, .6, .8	3.910	.6355	6.070	3.955	.989		-4.20	0.620
5239	Rohwer	V. I.	4.278	.6105	6.080	3.712	1.152	6.71		
5240	Rohwer	.2, .6, .8	4.271	.6115	6.080	3.718	1.152		1.36	8.82
5231	Rohwer	V. I.	7.240	.6120	6.080	3.721	1.945	-2.58		
5232	Rohwer	.2, .6, .8	7.232	.6110	6.080	3.715	1.945		-13.16	5.60
5215	Kelso	V. I.	9.355	.5955	6.070	3.615	2.586	-4.12		
5216	Kelso	.2, .6, .8	9.322	.6065	6.070	3.675	2.536		-14.55	1.56
5168	Rohwer	V. I.	10.019	.6100	6.070	3.702	2.705	-7.94		
5169	Rohwer	.2, .6, .8	10.055	.6200	6.070	3.758	2.676		-13.00	1.30
5223	Rohwer	V. I.	12.061	.6135	6.080	3.724	3.238	-4.87		
5224	Rohwer	.2, .6, .8	12.052	.6145	6.080	3.744	3.240		- 8.74	3.38

5172	Rohwer	V. I.	12.484	.6245	6.070	3.791	3.293	-8.56		
5173	Rohwer	.2, .6, .8	12.466	.6395	6.070	3.872	3.220		- 9.70	1.85
					Mean error disregarding sign			5.31	9.24	4.10
					Mean error regarding sign			-2.70	- 9.05	4.10
					Range of errors			-8.56 to 6.71	-14.55 to 1.36	1.30 to 8.82
5207	Kelso	V. I.	6.654	0.8150	6.070	4.947	1.345	4.55		
5208	Kelso	.2, .6, .8	6.638	.8170	6.070	4.958	1.338		-0.99	8.54
5199	Kelso	V. I.	8.964	.8080	6.070	4.905	1.827	3.37		
5200	Kelso	.2, .6, .8	8.984	.8115	6.070	4.926	1.823		-7.24	9.76
5174	Rohwer	V. I.	11.601	.8120	6.070	4.929	2.354	-3.69		
5175	Rohwer	.2, .6, .8	11.583	.8155	6.070	4.949	2.424		-7.85	3.18
5191	Kelso	V. I.	14.070	.8105	6.070	4.910	2.868	-3.01		
5192	Kelso	.2, .6, .8	14.002	.8085	6.070	4.907	2.857		-7.33	4.86
5181	Rohwer	V. I.	17.206	.8140	6.070	4.950	3.477	1.10		
5182	Rohwer	.2, .6, .8	17.250	.8175	6.070	4.962	3.475		-1.10	6.31
5183	Rhower	V. I.	17.451	.8115	6.070	4.970	3.512	-3.17		
5184	Rohwer	.2, .6, .8	17.452	.8220	6.070	4.990	3.498		-4.87	1.67
					Mean error disregarding sign			3.15	4.90	5.72
					Mean error regarding sign			-0.64	-4.90	5.72
					Range of errors			-3.69 to 4.55	-7.85 to -0.99	1.67 to 9.76
5295	Kelso	V. I.	6.063	1.0020	6.080	6.092	0.996	3.64		
5296	Kelso	.2, .6, .8	6.049	1.0025	6.080	6.095	0.993		-0.07	5.90
5303	Kelso	V. I.	8.922	1.0050	6.080	6.110	1.462	5.34		
5304	Kelso	.2, .6, .8	8.956	1.0065	6.080	6.119	1.460		4.25	6.94
5279	Kelso	V. I.	15.096	1.0090	6.080	6.135	2.460	-1.86		
5280	Kelso	.2, .6, .8	15.115	1.0100	6.080	6.143	2.460		-3.82	5.51
5287	Kelso	V. I.	20.123	1.0165	6.080	6.179	3.256	-1.42		
5288	Kelso	.2, .6, .8	20.123	1.0160	6.080	6.177	3.256		-3.98	4.89
					Mean error disregarding sign			3.06	3.03	5.81
					Mean error regarding sign			1.42	-0.90	5.81
					Range of errors			-1.86 to 5.34	-3.98 to 4.25	4.89 to 6.94

(Continued)

TABLE 5.—Summary of current-meter measurements in a flume with water 1 foot or less in depth, under various conditions by different methods, compared with measurements by a Francis weir with full contractions. (Continued)

OTT PROPELLER METER NO. 3718

			Flume elements					Deviation from weir flow		
								Method of meter measurement		
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Average width	Water section area	Mean velocity per second	Vertical integration	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Square-feet	Feet	Percentage	Percentage	Percentage
5275	Kelso	V. I.	2.348	0.4205	6.085	2.559	0.918	10.10		
5276	Kelso	.6	2.337	.4220	6.085	2.568	.910			4.62
5267	Kelso	V. I.	3.132	.4100	6.085	2.495	1.256	9.80		
5268	Kelso	.6	3.132	.4085	6.085	2.486	1.260			4.44
5259	Rohwer	V. I.	5.412	.4190	6.080	2.548	2.122	7.39		
5260	Rohwer	.6	5.420	.4180	6.080	2.542	2.128			5.00
5251	Rohwer	V. I.	7.330	.4285	6.080	2.604	2.814	8.36		
5252	Rohwer	.6	7.315	.4290	6.080	2.608	2.908			3.20
					Mean error diregarding sign			8.91		4.31
					Mean error regarding sign			8.91		4.31
					Range of errors			7.39 to 10.10		3.20 to 5.00
5243	Rohwer	V. I.	4.264	0.6110	6.080	3.715	1.148	6.99		
5244	Rohwer	.2, .6, .8	4.264	.6085	6.080	3.700	1.152		3.31	4.90
5235	Rohwer	V. I.	7.146	.6235	6.080	3.791	1.885	5.16		
5236	Rohwer	.2, .6, .8	7.262	.6185	6.080	3.761	1.931		0.14	3.66
5219	Kelso	V. I.	9.322	.6100	6.070	3.702	2.518	7.86		
5220	Kelso	.2, .6, .8	9.313	.6115	6.070	3.712	2.506		1.77	5.86
5227	Rohwer	V. I.	12.034	.6110	6.080	3.715	3.240	7.77		
5228	Rohwer	.2, .6, .8	11.980	.6045	6.080	3.675	3.262		7.84	6.03

					Mean error disregarding sign			6.94	3.26	5.11
					Mean error regarding sign			6.94	3.26	5.11
					Range of errors			5.16 to 7.86	0.14 to 7.84	3.66 to 6.03
5211	Kelso	V. I.	6.462	0.7990	6.070	4.850	1.333	8.09		
5212	Kelso	.2, .6, .8	6.515	.8180	6.070	4.966	1.312		1.69	5.77
5203	Kelso	V. I.	8.922	.8200	6.070	4.877	1.830	7.38		
5204	Kelso	.2, .6, .8	8.916	.8245	6.070	5.006	1.780		3.02	5.71
5178	Rohwer	V. I.	11.520	.8025	6.070	4.871	2.363	4.20		
5180	Rohwer	.2, .6, .8	11.448	.7990	6.070	4.800	2.392		1.99	5.58
5195	Kelso	V. I.	13.820	.8065	6.070	4.886	2.828	3.88		
5196	Kelso	.2, .6, .8	13.812	.8045	6.070	4.883	2.828		1.85	4.93
5187	Rohwer	V. I.	17.500	.8245	6.070	5.003	3.497	2.49		
5188	Rohwer	.2, .6, .8	17.370	.8330	6.070	5.057	3.438		2.36	3.91
					Mean error disregarding sign			5.21	2.18	5.18
					Mean error regarding sign			5.21	2.18	5.18
					Range of errors			2.49 to 8.09	1.69 to 3.02	3.91 to 5.77
5299	Kelso	V. I.	6.070	1.0005	6.080	6.083	0.998	3.74		
5300	Kelso	.2, .6, .8	6.056	0.9995	6.080	6.077	.997		1.07	2.62
5307	Kelso	V. I.	8.914	1.0055	6.080	6.113	1.458	4.74		
5308	Kelso	.2, .6, .8	8.879	1.0055	6.080	6.113	1.452		2.54	4.72
5283	Kelso	V. I.	15.163	1.0120	6.080	6.153	2.463	3.92		
5284	Kelso	.2, .6, .8	15.153	1.0115	6.080	6.150	2.465		1.96	3.56
5291	Kelso	V. I.	20.277	1.0210	6.080	6.207	3.266	4.15		
5292	Kelso	.2, .6, .8	20.310	1.0225	6.080	6.217	3.269		1.82	4.00
					Mean error disregarding sign			4.14	1.85	3.72
					Mean error regarding sign			4.14	1.85	3.72
					Range of errors			3.74 to 4.74	1.07 to 2.54	2.62 to 4.72

(Continued)

TABLE 5.—Summary of current-meter measurements in a flume with water 1 foot or less in depth, under various conditions by different methods, compared with measurements by a Francis weir with full contractions. (Continued)

OTT PROPELLER METER NO. 4184

			Flume elements					Deviation from weir flow		
								Method of meter measurement		
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Average width	Water section area	Mean velocity per second	Vertical integration	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Square-feet	Feet	Percentage	Percentage	Percentage
5277	Rohwer	V. I.	2.337	0.4220	6.085	2.568	0.910	13.90		
5278	Rohwer	.6	2.337	.4220	6.085	2.568	.910			11.98
5269	Rohwer	V. I.	3.132	.4085	6.085	2.487	1.259	12.63		
5270	Rohwer	.6	3.132	.4095	6.085	2.472	1.267			11.20
5261	Kelso	V. I.	5.420	.4210	6.080	2.560	2.115	8.45		
5262	Kelso	.6	5.434	.4195	6.080	2.551	2.126			5.84
5253	Kelso	V I.	7.315	.4265	6.080	2.593	2.820	5.88		
5254	Kelso	.6	7.292	.4270	6.080	2.506	2.806			5.26
					Mean error disregarding sign			10.21		8.57
					Mean error regarding sign			10.21		8.57
					Range of errors			5.88 to 13.90		5.26 to 11.98
5245	Kelso	V. I.	4.252	0.6085	6.080	3.700	1.148	8.10		
5246	Kelso	.6	4.250	.6065	6.080	3.688	1.150			4.85
5237	Kelso	V. I.	7.090	.6170	6.080	3.751	1.890	8.06		
5238	Kelso	.6	7.080	.6155	6.080	3.742	1.892			6.60
5221	Rohwer	V. I.	9.322	.6110	6.070	3.709	2.512	8.09		
5222	Rohwer	.6	9.322	.6100	6.070	3.703	2.517			5.79
5229	Kelso	V. I.	12.007	.6035	6.080	3.666	3.291	10.66		
5230	Kelso	.6	11.998	.6020	6.080	3.660	3.276			6.92

					Mean error disregarding sign			8.73		6.04
					Mean error regarding sign			8.73		6.04
					Range of errors			8.06 to 10.66		4.85 to 6.92
5213	Rohwer	V. I.	6.477	0.8315	6.070	5.047	1.283	6.50		
5214	Rohwer	.2, .6, .8	6.455	.8315	6.070	5.047	1.278		6.20	6.46
5205	Rohwer	V. I.	9.049	.8045	6.070	4.882	1.854	7.58		
5206	Rohwer	.2, .6, .8	9.049	.8060	6.070	4.892	1.850		5.35	5.79
5197	Rohwer	V. I.	13.774	.8040	6.070	4.880	2.817	6.19		
5198	Rohwer	.2, .6, .8	13.764	.8055	6.070	4.889	2.814		4.00	6.13
5189	Rohwer	V. I.	17.590	.8370	6.070	5.081	3.460	4.67		
5190	Rohwer	.2, .6, .8	17.600	.8430	6.070	5.117	3.443		2.83	4.30
					Mean error disregarding sign			6.23	4.60	5.67
					Mean error regarding sign			6.23	4.60	5.67
					Range of errors			4.67 to 7.58	2.83 to 6.20	4.30 to 6.46
5301	Rohwer	V. I.	6.056	1.0000	6.080	6.080	0.996	4.64		
5302	Rohwer	.2, .6, .8	6.042	0.9995	6.080	6.077	.995		2.12	3.09
5309	Rohwer	V. I.	8.914	1.0050	6.080	6.110	1.458	7.04		
5310	Rohwer	.2, .6, .8	8.888	1.0055	6.080	6.113	1.455		4.34	6.44
5285	Rohwer	V. I.	15.125	1.0105	6.080	6.144	2.461	3.55		
5286	Rohwer	.2, .6, .8	15.144	1.0105	6.080	6.144	2.461		1.82	4.33
5293	Rohwer	V. I.	20.277	1.0210	6.080	6.207	3.265	4.54		
5294	Rohwer	.2, .6, .8	20.299	1.0210	6.080	6.207	3.269		1.29	4.50
					Mean error disregarding sign			4.94	2.39	4.59
					Mean error regarding sign			4.94	2.39	4.59
					Range of errors			3.55 to 7.04	1.29 to 4.34	3.09 to 6.44

(Continued)

TABLE 5.—Summary of current-meter measurements in a flume with water 1 foot or less in depth, under various conditions by different methods, compared with measurements by a Francis weir with full contractions. (Continued)

HOFF PROPELLER METER NO. 9

			Flume elements					Deviation from weir flow Method of meter measurement		
Test No.	Observer	Method of measurement	Weir flow per second	Average water depth	Average width	Water section area	Mean velocity per second	Vertical integration	Two and eight-tenths	Six-tenths
			Cubic-feet	Feet	Feet	Square-feet	Feet	Percentage	Percentage	Percentage
5273	Rohwer	V. I.	2.359	0.4025	6.085	2.449	0.954	9.88		
5274	Rohwer	.6	2.348	.4030	6.085	2.452	.958			7.03
5265	Rohwer	V. I.	3.132	.4070	6.080	2.475	1.266	10.95		
5266	Rohwer	.6	3.132	.4070	6.080	2.475	1.266			7.95
5257	Kelso	V. I.	5.427	.4160	6.080	2.529	2.142	8.64		
5258	Kelso	.6	5.427	.4170	6.080	2.535	2.140			5.55
5249	Kelso	V. I.	7.308	.4270	6.080	2.591	2.818	7.83		
5250	Kelso	.6	7.300	.4270	6.080	2.591	2.817			6.00
					Mean error disregarding sign...........			9.32		6.62
					Mean error regarding sign..................			9.32		6.62
					Range of errors..			7.83 to 10.95		5.55 to 7.95
5241	Kelso	V. I.	4.278	0.6120	6.080	3.721	1.148	7.62		
5242	Kelso	.6	4.269	.6135	6.080	3.730	1.143			8.18
5233	Kelso	V. I.	7.162	.6215	6.080	3.779	1.897	7.98		
5234	Kelso	.6	7.116	.6210	6.080	3.776	1.883			11.51
5217	Rohwer	V. I.	9.322	.6130	6.070	3.721	2.502	7.18		
5218	Rohwer	.6	9.322	.6110	6.070	3.709	2.512			7.38
5225	Kelso	V. I.	12.043	.6245	6.080	3.697	3.256	4.46		
5226	Kelso	.6	12.052	.6325	6.080	3.846	3.134			5.34

					Mean error disregarding sign			6.81		8.10
					Mean error regarding sign			6.81		8.10
					Range of errors			4.46 to 7.98		5.34 to 11.51
5209	Rohwer	V. I.	6.505	0.8240	6.070	5.002	1.300	4.93		
5210	Rohwer	.2, .6, .8	6.500	.8250	6.070	5.008	1.297		4.65	8.42
5201	Rohwer	V. I.	8.947	.8155	6.070	4.950	1.808	8.12		
5202	Rohwer	.2, 6, .8	8.939	.8180	6.070	4.965	1.800		4.53	9.52
5176	Rohwer	V. I.	11.722	.8060	6.070	4.893	2.393	5.37		
5177	Rohwer	.2, .6, .8	11.529	.8050	6.070	4.887	2.360		3.74	7.91
5193	Rohwer	V. I.	13.983	.8110	6.070	4.953	2.822	7.06		
5194	Rohwer	.2, .6, .8	13.954	.8120	6.070	4.929	2.834		5.34	8.21
5185	Rohwer	V. I.	17.430	.8185	6.070	4.958	3.518	5.09		
5186	Rohwer	.2, .6, .8	17.360	.8200	6.070	4.978	3.488		2.66	5.48
					Mean error disregarding sign			6.11	4.23	7.91
					Mean error regarding sign			6.11	4.23	7.91
					Range of errors			4.93 to 8.12	2.66 to 5.34	5.48 to 9.52
5297	Rohwer	V. I.	6.063	1.0010	6.080	6.086	0.996	5.38		
5298	Rohwer	.2, .6, .8	6.077	1.0005	6.080	6.083	.999		2.11	5.91
5305	Rohwer	V. I.	8.939	1.0070	6.080	6.122	1.460	7.46		
5306	Rohwer	.2, .6, .8	8.930	1.0065	6.080	6.119	1.460		5.10	8.75
5261	Rohwer	V. I.	15.144	1.0115	6.080	6.150	2.462	6.36		
5282	Rohwer	.2, .6, .8	15.163	1.0130	6.080	6.159	2.462		4.37	7.12
5289	Rohwer	V. I.	20.299	1.0205	6.080	6.204	3.268	4.98		
5290	Rohwer	.2, .6, .8	20.288	1.0220	6.080	6.214	3.267		2.84	6.61
					Mean error disregarding sign			6.04	3.60	7.10
					Mean error regarding sign			6.04	3.60	7.10
					Range of errors			4.98 to 7.46	2.11 to 5.10	5.91 to 8.75

method was used, but with two exceptions the results were all too large. The same was true of the 2-and-8-tenths method except that, with two exceptions, all the discharges measured by the current meter were too small.

The measurements made with the Ott and the Hoff meters were more consistent, but were without exception too large. There was, however, a definite decrease in the errors as the depth increased. All the propeller meters gave the best results when using the 2-and-8-tenths method of measurement. With the two Ott meters, better results were obtained from the 6-tenths method than from the vertical-integration method, but the latter method gave more accurate results in most cases when the Hoff meter was used.

Altho the errors shown by these tests are large, in view of the fact that the errors are quite consistently in one direction, and furthermore since the tests covered a considerable range of velocities, it seems reasonable to suppose that measurements made under similar conditions could have their accuracy materially increased by applying the correction derived from these observations. In order to supply this information in compact form, the results given in Table 5 have been summarized and are shown in Table 6. The table gives the mean errors with and without consideration of the sign of the error and also the range of errors. When it is desired, however, to apply a correction to current-meter measurements made under these conditions, the correction applied should be based on the mean error regarding the signs of the errors.

RATING FLUMES. — Current-meter measurements in irrigation practice are usually made in rating flumes. Most of these flumes are rectangular in shape and are built so that they contract the water channel to some extent. The purpose of these flumes is to define the water channel at the point of measurement and to improve the flow conditions. So far as defining the section where the measurement is to be made is concerned, the rating flume is very satisfactory, but in improving the flow the flume is frequently unsuccessful. The fact that the rating flume is usually narrower than the canal causes eddies to form in the flume and, due to the sudden increase in velocity caused by the contracted section, large waves sometimes form on the water surface. Both these conditions seriously interfere with making accurate current-meter measurements.

There are indications that the condition may be considerably improved by building the rating flume with converging walls which start at the sides of the canal, thereby eliminating the end contractions and at the same time causing the velocity to increase gradually. This is shown by a series of current-meter measurements made for the purpose of checking the calibration of the Parshall measuring flume, formerly known as the Improved Venturi Flume (10), which

TABLE 6.—Summary of errors in current-meter measurements in a flume with water 1 foot or less in depth under various conditions by different meters and different methods as determined by measurement by a Francis weir with full contractions.

				Vertical integration				Two-and-eight-tenths method				Six-tenths method			
					Mean error				Mean error				Mean error		
Meter	Type	Number	Depth of water	No. of tests	Re-garding sign	Disre-garding sign	Maximum range of errors	No. of tests	Re-garding sign	Disre-garding sign	Maximum range of errors	No. of tests	Re-garding sign	Disre-garding sign	Maximum range of errors
			Feet		Percentage		Percentage		Percentage		Percentage		Percentage		Percentage
Price	Cup	15188	0.4	4	-2.74	9.44	-13.25 to 8.14	..	.. ....	.. ....	.. ..	4	-0.87	7.22	-9.42 to 7.21
Price	Cup	15188	.6	7	-2.70	5.31	- 8.56 to 6.71	7	-9.05	9.24	-14.55 to 1.36	7	4.10	4.10	1.30 to 8.82
Price	Cup	15188	.8	6	-0.64	3.15	- 3.69 to 4.55	6	-4.90	4.90	- 7.85 to -0.99	6	5.72	5.72	1.67 to 9.76
Price	Cup	15188	1.0	4	1.42	3.06	- 1.86 to 5.34	4	-0.90	3.03	- 3.98 to 4.25	4	5.81	5.81	4.89 to 6.94
Ott	Propeller	3718	.4	4	8.91	8.91	7.39 to 10.10	..	.. ....	.. ....	.. ..	4	4.31	4.31	3.20 to 5.00
Ott	Propeller	3718	.6	4	6.94	6.94	5.16 to 7.86	4	3.26	3.26	0.14 to 7.84	4	5.11	5.11	3.66 to 6.03
Ott	Propeller	3718	.8	5	5.21	5.21	2.49 to 8.09	5	2.18	2.18	1.69 to 3.02	5	5.18	5.18	3.91 to 5.77
Ott	Propeller	3718	1.0	4	4.14	4.14	3.74 to 4.74	4	1.85	1.85	1.07 to 2.54	4	3.72	3.72	2.62 to 4.72
Ott	Propeller	4184	.4	4	10.21	10.21	5.88 to 13.90	..	.. ....	.. ....	.. ..	4	8.57	8.57	5.26 to 11.98
Ott	Propeller	4184	.6	4	8.73	8.73	8.06 to 10.66	..	.. ....	.. ....	.. ..	4	6.04	6.04	4.85 to 6.92
Ott	Propeller	4184	.8	4	6.23	6.23	4.67 to 7.58	4	4.60	4.60	2.83 to 6.20	4	5.67	5.67	4.30 to 6.46
Ott	Propeller	4184	1.0	4	4.94	4.94	3.55 to 7.04	4	2.39	2.39	1.29 to 4.34	4	4.59	4.59	3.09 to 6.44
Hoff	Propeller	9	.4	4	9.32	9.32	7.83 to 10.95	..	.. ....	.. ....	.. ..	4	6.62	6.62	5.55 to 7.95
Hoff	Propeller	9	.6	4	6.81	6.81	4.46 to 7.98	..	.. ....	.. ....	.. ..	4	8.10	8.10	5.34 to 11.51
Hoff	Propeller	9	.8	5	6.11	6.11	4.93 to 8.12	5	4.23	4.23	2.66 to 5.34	5	7.91	7.91	5.48 to 9.52
Hoff	Propeller	9	1.0	4	6.04	6.04	4.98 to 7.46	4	3.60	3.60	2.11 to 5.10	4	7.10	7.10	5.91 to 8.75

consists of a converging and a diverging section with a short throat between. The current-meter measurements were all made in the upper end of the converging section, and in making these measurements it was observed that the surface of the water was smooth (see Plate 25) and that the distribution of velocities was very uniform.

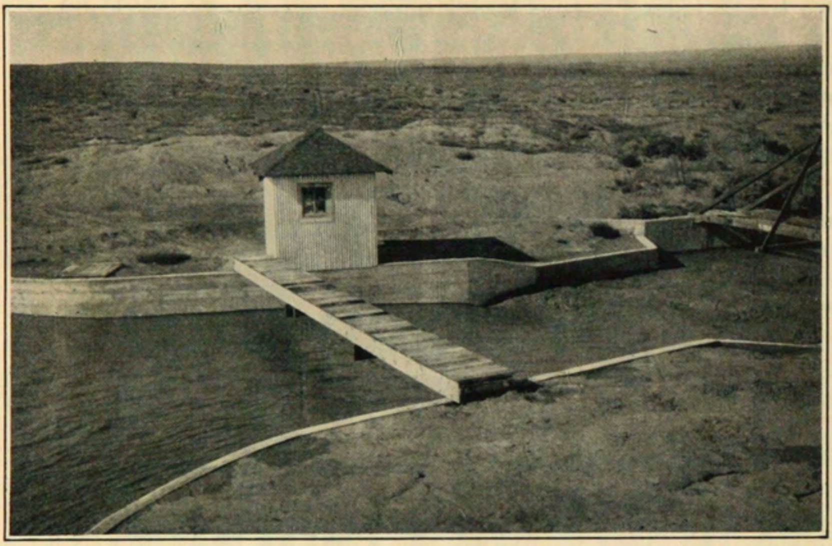

Plate 25.—Parshall Measuring Flume with rating bridge. Note smooth water surface at rating section.

Furthermore, the discharges measured by the current meter in this section agreed quite closely with the discharges computed from the formula for the Parshall flumes. These measurements were made by several different hydrographers using different meters and different methods, in flumes varying in width from 10 to 40 feet. The discharges varied between 13 and 1,500 cubic feet per second. In all, 118 measurements were made, and 30 percent of these measurements agreed with the computed discharges within 1 percent or less, and the mean error of the series was –0.45 percent (11). This does not mean that the current-meter measurements were accurate within these limits because the flume-discharge formula may have been in error to a certain extent, but it does show that very consistent measurements may be made in converging sections of this type.

These measurements were all made in the converging section of standard Parshall measuring flumes, but it is believed that satisfactory results could also be obtained if the measurements were made in simpler structures of this type where the total contraction is not so great. If this were possible, the loss of head in the structure could be reduced and it would not be so difficult to get the velocity of the water back to normal after passing thru the contracted section.

SUGGESTIONS REGARDING THE USE OF CURRENT METERS

As a result of the tests of the behavior of current meters under various conditions, the following suggestions are made regarding their use. These suggestions are for conditions met with in irrigation practice, and altho many of the recommendations are of general application, they should not be used indiscriminately without regard to conditions.

Some meter manufacturers furnish a rating table based on the average performance of their meters. These tables may be used when making approximate measurements, but when more accurate results are desired, individual ratings must be used. Ratings may be made at either tangent or rotary stations. There are, however, greater uncertainties in connection with rotary stations, due to the necessity at most stations of making corrections before the results will agree with those obtained by tangent stations. Ratings may be made in either still or flowing water, but the velocity of the water must not exceed the rate at which the meter is being moved. Meters should be rated under the conditions under which they are to be used in the field. A standard rating is satisfactory for most conditions; if, however, any changes must be made in the method of operating the meter or in the arrangement of the equipment, these facts must be taken into consideration when making the rating. Except in special cases, the meter should be rated at velocities ranging from 1 to 8 feet per second. For velocities less than 1 foot per second, the registration of most meters is unreliable, and velocities of more than 8 feet per second are seldom encountered in irrigation practice. In making rod ratings, care should be taken to see that the rod is vertical and that the axis of the meter is parallel to the direction of movement.

When making cable ratings, the tail of the meter should be balanced so as to hold it in a horizontal plane and sufficient weight should be added to hold the meter in position at the highest velocities to be measured.

Meters in constant use should be rated often because of the wear of the parts and the injuries sustained. Under ordinary conditions of use, meters need be rated but once a year unless injured, but in that event they should be rerated immediately. Injuries to the cups or blades are of particular importance because slight changes in their shape have a material effect on the rating. Precise bearing adjustment is, for cup meters, of minor importance except at low velocities; consequently the wear from ordinary use does not affect the rating materially.

Ratings disclose certain facts concerning the behavior of meters which should be taken into consideration when making current-meter measurements. They show that the registration of cup meters is affected when the meters are held close to walls or when the cups are at the water surface. In the latter event, the behavior of cup meters is very unreliable. Propeller meters are apparently unaffected under these conditions.

Integrating the meter, that is, moving it up and down at a uniform rate while making the rating, retards the rate of rotation of cup meters whereas it affects the behavior of propeller meters but slightly. Since cup meters rotate in a positive direction when moved up and down in still water, it has been assumed that measurements made by cup meters by the integration method would be too large. The ratings made when moving the meter up and down show that this is probably not true. This fact was confirmed by discharge measurements made by the integration method which were checked by Francis-weir measurements.

Meters should be held parallel to the axis of flow in making discharge measurements. Deviations of 10 degrees or more, either in the horizontal or vertical direction, have a material effect on the registration of most meters. Measurements in turbulent water should be made with both cup and propeller meters, as under this condition the tests show that cup meters over-register about as much as propeller meters under-register.

Guy wires to hold the meter in swift water should be attached to the rod above the meter so as not to affect the behavior of the meter. The size of the rod used in holding the meter affects the behavior of the meter and should not be changed unless the meter is rerated with the new type of rod. When making measurements with a cable meter, the weights should be attached in the same manner as when the meter was rated.

Any of the meters in common use will give accurate results under ordinary conditions, but when there are unusual features the type of meter recommended for the particular condition should be used.

Several methods are available for making current-meter measurements. Each of these methods has advantages under certain conditions, and the choice of the method will depend upon the conditions encountered.

In shallow streams and canals from 1 to 4 feet in depth with moderate velocities, where it is possible to work from a bridge or plank near the water surface, the vertical integration or the 2-and-8-tenths method should be used, if accurate results are desired. Under these conditions where no bridge is available and wading must be resorted to, the 2-and-8-tenths method should be used, as it is not possible to integrate satisfactorily when wading. Both the vertical-integration and the 2-and-8-tenths methods are rapid and accurate methods of making discharge measurements. When high velocities or flows of greater depths are encountered, the 2-and-8-tenths or the 6-tenths method should be used. For accurate results, the 2-and-8-tenths method is recommended, as the 6-tenths method is consistently too high. It has the advantage, however, of being a very fast method of gaging. When extremely high velocities are encountered, the propeller meters are to be recommended as they offer less resistance to the water.

In streams and canals where the stage remains constant for considerable periods of time, the multiple-point method may be used. It yields very consistent results under these conditions and in addition shows the velocity distribution in the channel. This method has the disadvantage of being much more time-consuming than the other methods, and if changes in stage occur while making the gaging, the advantage gained by the use of this method is lost.

When making measurements in streams 1 foot or less in depth, the method used will depend on the depth. If the water is around 1 foot in depth, either the vertical-integration, 6-tenths or the 2-and-8-tenths method may be used. For the shallower depths, however, the 6-tenths method should be used. None of these methods gives very accurate results, but the errors are quite consistently in one direction, and if a correction is applied, more satisfactory results would probably be obtained. In shallow water the propeller meters seem to operate more consistently than the cup meters.

At low velocities, around 1 foot or less per second, neither the cup nor the propeller meters give as reliable indications of the velocity as they do at higher velocities. Any of the standard methods of measurement may be used in low velocities, but when using the integration method the meter should be moved up and down slowly in comparison with the velocity of the water.

In deep channels and in streams at flood stage, meter rods are unsatisfactory for holding the meter. Under these conditions the cable suspension is used and either the 6-tenths or the 2-and-8-tenths method, depending on existing circumstances and the accuracy desired, should be chosen for making the measurements. If the stream is carrying considerable debris, only the surface velocities are sometimes taken in order to reduce the chances of losing the meter. To determine the average velocity, the surface velocities must be corrected by a factor based on the relation between the surface velocity and the average velocity. Either cup or propeller meters may be used in making cable measurements, but regardless of the type chosen they should be equipped with tails large enough to hold them parallel to the axis of flow, and with weights heavy enough to hold the meter at the point desired. For this the recently developed blunt-nosed weights have been found to be more effective than the old torpedo weights.

The number of velocity determinations made in each gaging will depend on the time available and the accuracy desired. For the conditions met with in irrigation practice, it is customary to take 1-foot stations in small canals and laterals but not less than five stations; 2-foot stations in canals of medium size and small streams; 4-foot stations in large canals and medium-sized streams; and up to 10-foot stations in the larger streams except at flood stage when a wider spacing of the station is frequently adopted. Where marked changes in the depth or velocity occur, additional velocity measurements should be made.

A fact which should not be forgotten in making current-meter measurements is that errors in depth or gage height have just as much effect in determining the accuracy of the measurements as errors in the velocity. For this reason the depths should be carefully measured.

SUMMARY

TANGENT-STATION RATINGS.—The consistency with which the plotted points fall on the curves of typical ratings of the principal kinds of current meters made under similar conditions at the tangent rating station, indicate that it is possible to get accurate results with the rating equipment.

Replicate ratings of Price meters numbers 15,188 and 1728, made under identical conditions except that the meters were removed from the car and reset between ratings, gave almost identical results for velocities greater than 1 foot per second but show considerable variation at lower velocities.

The probable errors in replicated velocity determinations at different velocities of Price meter number 19,145, increase as the velocity decreases but in no case did the error exceed 0.5 percent. Removing and resetting the meter between ratings, however, affected the results.

Ratings of Price cup meters numbers 1314, 1728 and 29,502, and Ott propeller meter number 1398 and Hoff propeller meter number 2 at different depths show that the depth at which the ratings were made had very little effect on the results except in the case of the cup meters. Under these conditions the cup meters showed some changes, and when at the water surface, the changes were so erratic as to make the ratings unreliable.

The Hoff meter only of the propeller meters was rated near the surface and it showed no effect when rated in this position.

Nearness to the walls of the channel had little effect on the ratings except in the case of the cup meters, as shown by ratings of Price meters numbers 1080, 1314 and 1728, and Ott meter number 1933. The Price meters ran more slowly than normally, in general, when the rotating force was acting on the cups away from the wall.

Integrating the meters while making ratings, as shown by the ratings of Price meters numbers 1314 and 1728, and Ott meters numbers 1933, 2575 and 1398, reduced the speed of rotation of the Price meters but had very little effect on the Ott meters.

Tests made on Price meters numbers 1314 and 1728, Ott meters numbers 1933, 2575 and 1398, Fteley-Stearns meter number 1, Ritchie-Haskell meter number 162-B, and Hoff meter number 9, to determine the effect of oblique currents in the horizontal plane on these meters, show that all the meters run more slowly when subjected to oblique currents, and the amount of retardation varies with the angle of obliquity and also with the side from which the current comes. The tests show also that the cup meters over-register and the propeller meters under-register in resolving horizontal oblique currents into their axial components. The cup meters over-register less than the propeller meters under-register.

Tests made on Price meters numbers 1314 and 1728, Ott meters numbers 1933 and 1398, Ritchie-Haskell meter number 162-B, and Fteley-Stearns meter number 1, to determine how closely these meters resolve oblique velocities in the vertical plane into their axial components, show that the propeller meters measure the axial components of vertically oblique currents more accurately than the cup meters, and that the cup meters are more accurate when the current comes from above, whereas the propeller meters are more accurate when the current comes from below.

When the oblique velocities come with equal frequency from all four directions, Ott meter number 1933 and Fteley-Stearns meter number 1 under-register, and whereas Price meter number 1314 over-registers for all angles, Price meter number 1728 under-registers at the small angles and over-registers at the maximum angles.

Tilting the cup meters to the right and left had little effect except at velocities less than 2.5 feet per second, as shown by the tests on Price meter number 1728.

No definite conclusions could be drawn as to the effect of bearing adjustment on the ratings of Price meters numbers 1219 and 1728 except that the effect was small and that the greatest changes occurred at the lowest velocities.

Tests on Price meter number 1314 to determine the effect of bending the cups, of coating the cups with oil, of covering the cups with a coating of sand and shellac, and of weighting one of the cups, show that bending the cups had a marked effect on the rating and that sanding the cups reduced the number of revolutions of the meter slightly, but that covering the cups with oil or weighting one of the cups had little, if any effect on the rating.

The effect of guys on Price meter number 1728 to hold it rigidly in place was to cause the meter to rotate more slowly, and the greatest effect was produced by guys of largest diameter. Guys attached near the top of the meter yoke had a greater effect than those attached 3 inches above it, and the effect of the latter was small.

Ratings of Price meter number 15,188, when held by rods of different diameters, show that the revolutions of the meter decrease as the diameter of the rod increases.

Observations on Price meter number 15,188 and Ott meter number 2909, to determine the effect of making ratings in flowing water, show that for velocities greater than 1 foot per second under the conditions of the test, there is no effect on the ratings.

Comparison of the ratings of Price cup meter number 15,188, Ott propeller meter number 2,956 and Hoff propeller meter number 2, when supported by rods and by cables, show that, in general, the meters run more slowly when rated as cable meters, and that having weights above and below the meters retards them more than single weights, but single weights above the meters make them revolve more rapidly than when the weights are at the bottom. These tests show also that the Ott meter operated more consistently when rated as a cable meter than either the Hoff or the Price meter.

Observations on the effect of the length of cable on the rating of Price meters number 1728, Hoff meter number 2, and Ott meter number 2956 show that, in general, the Price and Ott meters run slower as the length of the cable increases, whereas the Hoff meter runs faster. The difference in length of the cable causes an appreciable difference in the rating of the Hoff meter.

Comparison of the cable ratings of Price meter number 1728, when using one and two standard weights, both below the meter, shows that the two weights make the meter run more slowly than when the single weight is used.

The cable ratings of Price meter number 1728 to determine the effect of guy wires, show that for velocities greater than 1 foot per second there is a tendency for this meter to run faster when held by guy wires, and the effect was greatest when the guys were attached to the hanger bar below the meter. For velocities less than 1 foot per second, the results were erratic.

From the foregoing tests it was concluded that when making current-meter measurements requiring special methods or special equipment, better results would be obtained if the meter was rated under the conditions in which it was to be operated rather than by applying coefficients to the standard ratings.

ROTARY-STATION RATINGS.—Ratings of Price meters numbers 1314, 1728 and 8374, Ott meters numbers 1933, 2575 and 1398 made at the rotary station under various conditions, for comparison with those made at the tangent station, show that, regardless of the radius of rotation, the cup meters run more slowly at the rotary station than at the tangent station. This is also true of the propeller meters with the exception of Ott number 1398 which, under certain conditions, runs faster when rated at the rotary station than when rated at the tangent station, but the difference is small.

As the radius of rotation decreased, Price meters numbers 1314 and 8374 ran more slowly, whereas Price meter number 1728 and Ott meters numbers 1933 and 1398 ran faster. Ott meter number 2575 was apparently not affected by the radius of rotation. The cup meters ran more slowly at the rotary station than at the tangent station, regardless of whether the rotating force was acting on the inside or the outside cups.

The ratings made with and without tails at the rotary station on Price meter number 1728 and Ott meters numbers 1933 and 1398 show that the Price meter runs faster without than with the tail, regardless of the direction of rotation of the meter, and that the Ott meters under some conditions run faster and under others, slower when operated without the tail, whereas the ratings made at the tangent station show that the tails have little, if any, effect on the ratings.

The tests show also that the addition of guy wires to hold the meters more rigidly did not make the rotary and tangent-station ratings of the meters agree.

Ratings of Price meters numbers 1314 and 8374 at the rotary station at a constant radius but at different depths, show that the revolutions of the meters increase as the depth increases up to a depth of 2 feet, and that from there on the revolutions decrease for the most part, but with the exception of the rating of Price meter number 1314 at the 2-foot depth, the meters run slower at the rotary station than at the tangent station.

Observations at the rotary station on Price meters numbers 1728 and 15,188 when held rigidly by the supporting rod and when free to turn in a horizontal plane, show that, in general, the meters run faster when free to turn and that when the rotating force is acting on the outside cups and the meters are free to turn in a horizontal plane, the meters run at about the same speed at the rotary station as they do at the tangent station.

The tests made on Price meter number 8374, to find out how much the theoretical radius of rotation had to be increased to make the rotary and tangent ratings coincide, indicate that, if when the rotating force is acting on the inside cups, the meter is set on a radius about 1 percent greater than that used in computing the velocity, the ratings will agree.

Replicate ratings of Price meter number 8374 made at the rotary station do not agree so closely as those of similar meters at the tangent station.

Ratings of Price meter number 15,186 at the rotary stations at Fort Collins, Colorado, and Berkeley, California, when compared with a rating at the tangent station at Fort Collins, show that the meter runs slower at both rotary stations than at the tangent station. Similar ratings of Hoff meter number 105 made at the tangent-rating stations at Fort Collins, Colorado, and Stockholm, Sweden, and the rotary station at Berkeley, California, show that the ratings of the Hoff propeller meter at the rotary and tangent stations agree with each other. To make the ratings agree it was, however, necessary to set the meter so that the face of the propeller was perpendicular to the tangent to the path of the meter at the point.

Ratings of Ott meter number 4184, made at tangent stations by the Irrigation Investigations at Fort Collins, and by Dr. Ott at Kempten, Bavaria, check each other and indicate that the difference between the tangent and rotary-station ratings at Fort Collins are due to errors in the rotary station. Tangent ratings of Price meter number 15,188 made by the Irrigation Investigations and the Bureau of Standards show that these ratings agree with each other except at low velocities.

From the foregoing experiments it may be concluded that there is a difference between ratings made at the rotary and tangent stations at Fort Collins, Colorado, altho experiments elsewhere show that under certain conditions ratings made at rotary and at tangent stations are identical.

CURRENT-METER MEASUREMENTS.—The ratings of the current meters used in making the comparisons between the weir and the current-meter measurements show that, altho the equations of the ratings made at different times differ slightly, there are compensating factors in the equations which make the velocities computed from the equations of ratings agree quite closely with each other.

The individual measurements made with the small Price electric meter number 15,188 in the 14, 8 and 2.5-foot flumes, by different methods, show considerable variation, but the mean errors of the different methods show that the vertical-integration method and the 2-and-8-tenths-method measurements give the most accurate results, and that, altho the multiple-point measurements are more consistent, the mean errors are larger because the meter measurements are all too small. This is true whether the vertical-velocity curve or the weighted mean-velocity method was used in computing the results. The 6-tenths method gives results that are consistently too large, whereas, contrary to the general belief, the vertical-integration method gives results that are too small. In the special tests, this meter measured the flow regardless of conditions with uniformly consistent results, but the best results were obtained with the 2-and-8-tenths method.

The Lallie-cup-meter tests which were made only in the 8-foot flume, agree with the Price-meter tests except that the best results were obtained by the multiple-point method. The special measurements were not as accurate as those made with the Price meter.

The measurements made with Ott propeller meter number 2909 in the 8 and 14-foot flumes were uniformly accurate, but one of the measurements in the river was considerably in error. The best results were obtained by the vertical-integration method, and the 2-and-8-tenths method gave better results than the multiple-point method, but the 6-tenths-method results were, in general, too large. The meter measurements made by Ott meter number 2956 in the 14, 8 and 2.5-foot flumes, and the special tests in the flumes and in the river were reasonably accurate. The tests show that the multiple-point method gave the best results in the 14-foot flume, and that the vertical integration gave the best results for the 8-foot flume.

The Hoff-propeller-meter measurements, except those made when the velocities were less than 0.5 foot per second in the 8 and 14-foot flumes, were quite accurate for all methods of measurement. The special tests were more erratic and the tests with the meter turned 10 degrees to the right show that the meter under-registers under this condition, whereas the Price meter is unaffected.

The experimental test meter of the propeller type and the Price meter with the special rotors did not prove to be superior to the standard type of meters.

The summary of the mean errors in the current-meter measurements under the various conditions by the different methods, except the 6-tenths, and the different meters, excluding the experimental models, show that the mean errors are definitely less rather than greater than 2 percent. The 6-tenths method with few exceptions gave discharges that were too large.

The measurements by the Price meter using the 2-and-8-tenths method were the most accurate of any of the methods.

The discharges obtained by the multiple-point method were not, in general, as accurate as those obtained by some of the other methods.

The tests of the meters and methods were made under comparable conditions, representative of conditions in irrigation practice, and the differences noted are probably due to the characteristics of the meters and the methods, rather than the conditions under which the tests were made.

Experiments by other investigators on the accuracy of current meters as determined by comparison with weir or volumetric measurements, also show that reasonably accurate measurements can be made by the use of the current meter.

CURRENT-METER MEASUREMENTS IN SHALLOW FLUMES.—The tests to determine the accuracy of current-meter measurements in shallow flumes show that both cup and propeller meters are inaccurate under this condition, and that the errors increase, in general, as the depth decreases.

The Price cup meter gave the best results when the vertical-integration method was used, but the Ott and the Hoff propeller meters were most accurate when the measurements were made by the 2-and-8-tenths method.

In view of the fact that the errors in the measurements with each meter and by each method are quite consistently too large or too small, it seems obvious that the accuracy of the measurements in shallow water could be materially increased by applying the correction derived from these tests for the meter and the method.

RATING FLUMES.—The results of a series of current-meter measurements made in the converging section of Parshall measuring flumes indicate that more accurate current-meter measurements might be made if the gagings were made in structures with converging rather than parallel walls.

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