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THE USE OF CURRENT METERS
IN
MEASURING PIPE DISCHARGES

By Carl Rohwer

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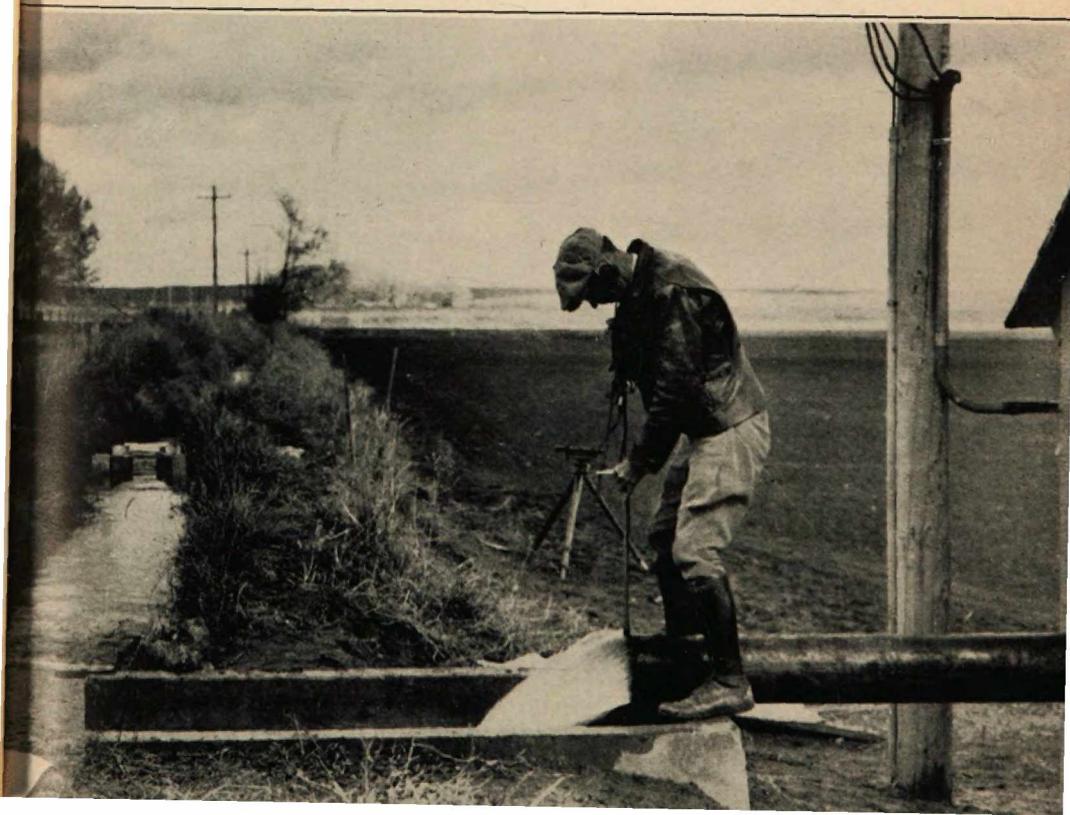
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THE USE OF CURRENT METERS IN MEASURING PIPE DISCHARGES[1]

BY CARL ROHWER[2]

Contents

Introduction

There are several methods by which the discharge from a pipe with free outlet may be measured, but all of them require the installation of special equipment, which is expensive and consumes much time. When it is necessary to make a large number of discharge measurements accurately and economically, these methods are not satisfactory; under such circumstances some other method must be adopted. For this reason the feasibility of measuring the discharge with a current meter in the pipe outlet was investigated.

The measurement of pipe discharges is of particular importance wherever it is necessary to determine the discharge of pumps delivering water for irrigation. The successful operation of a pumping plant requires that the pump deliver the largest amount of water possible for the power consumed and, in order to know definitely how efficiently the pump is operating, it is essential that the quantity of water being discharged be known. Since the efficiency of pumping plants may drop suddenly, frequent checks of the discharge are necessary.

The most commonly used means of measuring the pump discharge are the weir, the Parshall flume, and various types of meters, orifices, and flow gages. Most of these devices will give results of sufficient accuracy if properly installed and correctly operated.

When the quantities are large, current meters are sometimes used to determine the pump discharge by measuring the velocity in a ditch or flume. Very seldom is it possible to measure the discharge volumetrically. The use of the current meter in the pump outlet for measuring the discharge of a pumping plant was proposed as a possible means of simplifying the water measuring procedure because the only equipment required would be a propeller type current meter with the necessary accessories.

In the investigations reported in this bulletin the discharge of various sizes of pipes when flowing at different rates was measured with a current meter and simultaneously the same discharge was measured over a standard weir or other suitable measuring device which had previously been calibrated volumetrically. Two types of current meters were used. Discharge measurements were made on 4-, 5-, 6-, 8-, 10- and 12-inch standard pipe and 7-, 8-, and 9-inch O. D. pipe. The quantities measured ranged from as little as 50 gallons per minute for the 4-inch pipe to as much as 3,700 gallons per minute for the 12-inch pipe. During the first season all tests were made on pipes 8 or 10 feet long, but since it was believed that the length of the pipe might have some effect on the accuracy of the measurement, tests were made during the second season on pipes 2½, 6, and 14 feet long. The latter tests were made only on 6-, 8-, 10-, and 12-inch pipes. In addition special experiments were performed to determine the effect of various conditions which might be encountered in the field.

When the possibility of using the current meter to measure pipe discharges was first considered it was thought that the product of the area of the pipe and the velocity of the water as measured with the current meter would give the discharge. Preliminary tests, however, showed that this was not true and consequently the experimental procedure was arranged so that the correction coefficient necessary to reconcile the data would be determined under conditions likely to be met in the field.

Method of Conducting Experiments

In preliminary tests made at the Fort Collins laboratory the discharge measured with the current meter was checked with an 8-inch Venturi meter in the pump discharge line. The Venturi meter was equipped with a special single-column mercury manometer which had been calibrated at the factory for the 8-inch meter. Before these tests were started the calibration was checked volumetrically and found to be about three-fourths of 1 percent in error. All measurements were corrected by this amount. The general arrangement of the apparatus is shown in figure 1-A. The stilling box

was used in these preliminary tests to get comparable conditions for the pipes of different diameter.   Without the stilling box the regulation by means of the gate valve to reduce the discharge would markedly change the conditions for small pipes.   Later tests were made with the discharge pipe directly connected to the elbow as shown in figure 1-B.

Because of the limited capacity of the equipment at the Fort Collins laboratory most of the experiments were performed at the

ELEVATION AND SECTION

SECTION   PLAN
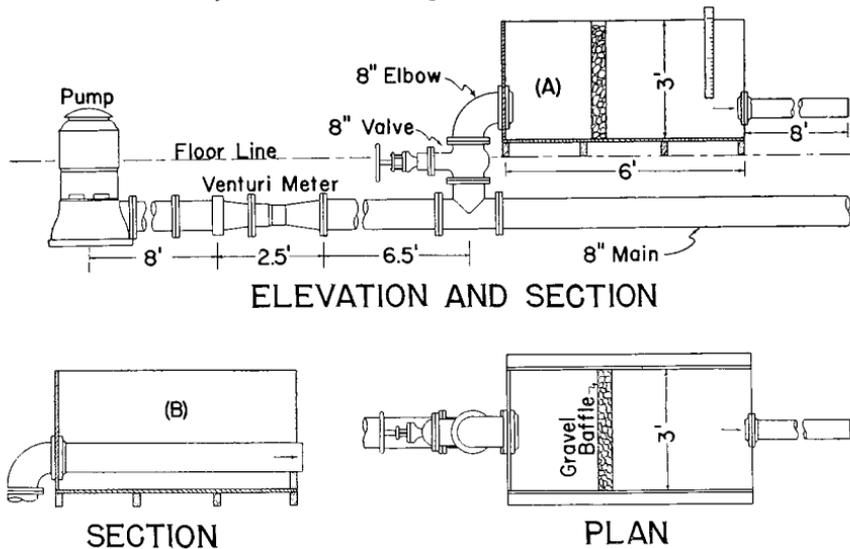
Figure 1—Arrangement of equipment for making current meter measurements of pipe discharges at Fort Collins laboratory. (A) Pipe connected to header box. (B) Pipe connected to elbow in discharge line.

Bellvue laboratory where quantities up to 100 cubic feet per second were available.   The discharges measured with the current meter were checked by means of a 4-foot rectangular weir that had previously been calibrated volumetrically at the Fort Collins laboratory.[3]

The general arrangement of the laboratory and the manner in which the equipment was installed are shown in figure 2.   Very small flows were measured over a 90° V-notch weir which was installed in a special weir box.   Water for the laboratory is supplied by the Cache la Poudre River through a wastegate in the headworks of the Jackson ditch (fig. 3).   A very constant flow was obtained from this source because the level of the pool above the headworks is held constant by the long spillway on the crest of the diversion dam (fig. 4).   The discharge pipe in which the current-meter

[3]Cone, V. M. "Flow Through Weir Notches with Thin Edges and Full Contractions." Jour. Agr. Res., Vol. 5, No. 23, pp. 1,051 to 1,113, illus. 1916.

measurements were made was bolted to the bulkhead in the channel by means of companion flanges as shown in figures 2 and 5.

When a test was being made, the approximate quantity desired was turned into the laboratory channel through the wasteway headgate.   Final adjustment of the quantity was obtained by means of flashboards in a wasteway 5 feet wide in the channel near its upper end.   As soon as the level in the channel became constant as indicated by the hook gages in the weir stilling wells, the test was started.   Each test consisted of five velocity determinations by the
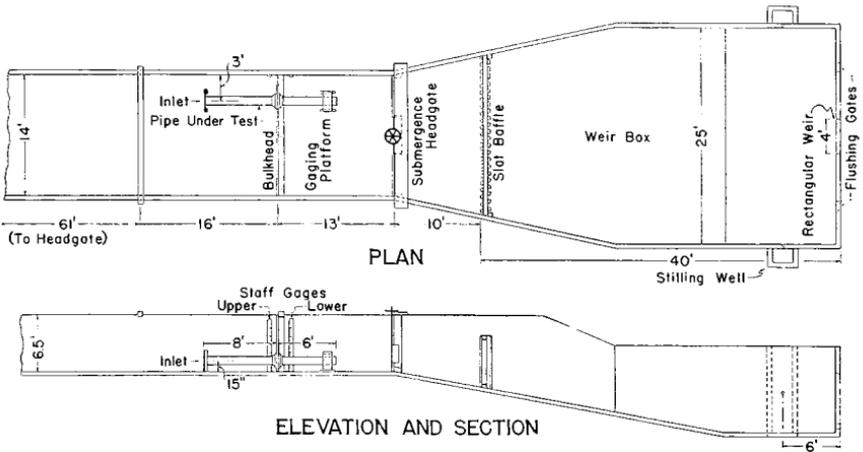
Figure 2—Arrangement of equipment for making current meter measurements of pipe discharges at Bellvue laboratory.

current meter in the outlet of the discharge pipe and five readings on each of the two weir hook gages.   Similar readings were taken on the staff gages located on the bulkhead to which the pipe was attached.   The upper staff gage was used to measure the depth of water above the pipe inlet and the lower gage to measure the depth of submergence on the pipe outlet.   The hook gages were read to 0.001 foot and the staff gages to 0.01 foot.

Hoff current meters with 4-bladed rubber propeller and special guard ring as shown in figures 6 and 7 were used in making the velocity measurements.   Three meters of this type, all identically equipped, were used. Figure 8 shows a Hoff meter being held preparatory to starting a test.   At the conclusion of the tests with the Hoff meters, a series of measurements was made with an Ott meter (fig. 9), which could be used in pipes as small as 4 inches in diameter.

All velocity measurements with the meters were made by the integration method.   The original method consisted of an equal number of integrations along the vertical and horizontal diameters

of the pipe. Because there was some doubt as to whether integration along the horizontal and vertical diameters would give an accurate integration of all the velocities throughout the cross-section of the pipe, another method, called the improved method, was adopted as the standard. This method consisted of horizontal and vertical integrations as before, together with circular integrations in both directions around the inner circumference of the pipe. Two circular integrations in each direction and two or more vertical and horizontal integrations were made, the number of the latter being adjusted to bring the total length of each velocity measurement to approximately 60 seconds. The meter was moved at a uniform rate of about one-fourth of a foot per second. The meter rod was held vertical with the axis of the meter parallel to the axis of the pipe (see fig. 10). The direction-indicating clamp with which the Hoff meter rod is equipped was used to keep the meter in the proper position and also to serve as a handle to hold it steady. The revolutions of the meter were timed with a stop watch reading to fifths of a second. The weir hook gages and the upper and lower pool staff gages were read at the beginning of each velocity measurement.

As soon as a complete set of velocity measurements was obtained, the headgate and wasteway were readjusted for a new discharge. Each pipe was tested for its complete range of normal discharges, consisting of a series of from 5 to 10 tests. All data for each test were recorded on a card at the time the observations were made. The revolutions of the meter per second were computed and then averaged to obtain the average speed of the meter for the test. The average velocity of the water in the pipe was then taken from the calibration curve of the meter which was checked several times during the progress of the work in the meter rating channel at the Fort Collins laboratory.[1] The calibrations of the meters remained practically constant; nevertheless, each time the meter was re-rated, the new calibration curve was used to determine the velocity from the meter revolutions. The mean value of the head on the weir was used in obtaining the weir discharge from the tables prepared for this particular weir.

Leakage from the concrete channel and weir box was checked from time to time by shutting off the water and noting the drop in the water surface during a definite time, as indicated by the weir hook gages. Usually the leakage was of small amount, not more than 1 or 2 gallons per minute. No correction was made for this loss since it was small in proportion to the quantities measured.

[1] Rohwer, Carl. Rating and Use of Current Meters. Colo. Agr. Exp. Sta. Tech. Bul. 3, 133 pp., illus. 1933.

During a period of cold weather in the fall the loss increased to 5 gallons per minute, probably because of contraction of the concrete and consequent opening of cracks. Discharges were corrected for this loss.

At the completion of each test the results were computed and plotted on a large scale chart with the velocity measured by the current meter as the ordinate and the discharge measured over the weir as the abscissa. If the point was found to be in error the test was rerun. The plot of the data for each pipe was also used to determine whether the complete range of capacity of the pipe had been covered and whether the points had been well distributed.

The diameter of each pipe tested was measured at the outlet end with an inside caliper and a steel scale graduated in feet and hundredths. By estimation the readings were taken in thousandths of a foot. The horizontal and vertical diameters were measured, and the mean was used in computing the area of the pipe. These dimensions were checked later by means of an inside micrometer caliper.

A total of 146 tests was made at the Fort Collins laboratory and 393 at the Bellvue laboratory. Of these tests 162 were on pipes in which the flow had a spiral motion. The latter tests are referred to only briefly in this report because the preliminary analysis of the results showed that they could not be used in the manner originally planned.

Analysis of Experimental Data

A preliminary study of the results of the measurements of the discharge from the $2\frac{1}{2}$-, 6-, 8-, and 14-foot lengths of the various sizes of pipes under standard conditions indicated that the flow through the 14-foot pipes was slightly less turbulent than that through the shorter pipes. For this reason the tests on the 6-, 8-, 10-, and 12-inch pipes 14 feet long were used as the basis for determining the mathematical relation between the velocity measured with the current meter and the discharge measured over the weir. Later, when it was found that the length of pipe did not materially affect the registration of the current meter under standard conditions, the tests on the 4- and 5-inch standard pipe and the 7-, 8-, and 9-inch O. D. pipes were included in the analysis although these pipes were all less than 14 feet long. All the tests were made with the Hoff meter except those on the 4-inch pipe; the latter were made with the small Ott meter because it would go inside a 4-inch pipe.

The data were plotted on large scale cross-section paper with the meter velocity as the ordinate and the corresponding discharge

measured by the standard weir or Venturi meter as the abscissa. The data for each pipe plotted on a straight line passing through the origin. Because of experimental errors and variations due to other causes, not all the points fell exactly on the line but they were so close that there was no doubt that the data followed a straight line law, that is, for each diameter of pipe, $Q=KV$. In this formula Q is the discharge in gallons per minute, K is a constant, and V is the velocity measured in feet per second by the meter.

After the data were plotted the straight lines best fitting the data for each pipe were drawn and the value of K in the formula
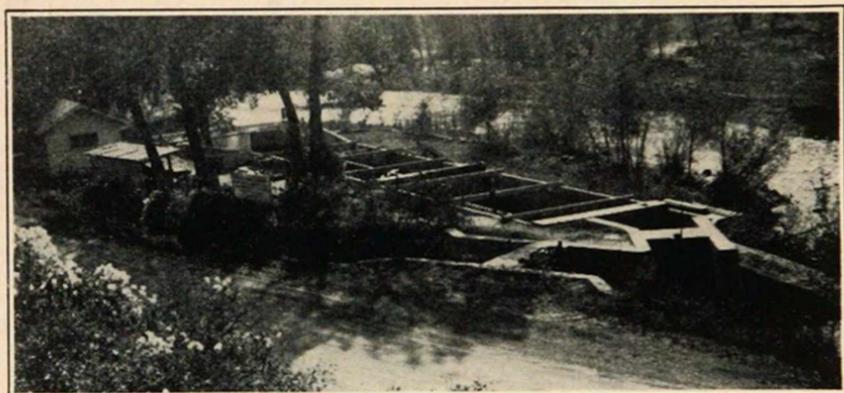
Figure 3—General view of Bellvue laboratory showing concrete channel and Jackson Ditch wasteway gate.

$Q=KV$ was determined. The results are set forth in table 1. From the values of K for the various sizes of pipes the general law showing the relation of the value of K to the area of the pipes was obtained by plotting the values of K as abscissas and the pipe areas as ordinates. These points also fell on a straight line, but since the line did not pass through the origin the equation of the line was of the form $K = mA + b$ where m is the slope of the line, b the intercept on the horizontal axis, and A the area of the pipe in square feet. From the line best fitting the data the equation $K=(419A—5)$ was determined; this when combined with the formula $Q = KV$ gives the general formula $Q=(419A—5)V$. The values of K computed by the formula $K=(419A—5)$ are given in table 1 together with the deviations from the observed values of K. The lines derived from values computed from the formula $Q=(419A—5)V$ are shown in figure 11 together with the plot of the experimental data. It will be observed that some of the lines fit the experimental data better than others, but this is to be expected because the general law cannot be adjusted to fit all the peculiarities of the experimental data, espec-

ially if one set of data contains a systematic error that is not involved in all the tests. Why these systematic errors or differences occurred could not be determined, but since the deviations are small as shown in the table they were disregarded.

The formula $Q = (419A-5)V$ is not well adapted for slide rule computation when the pipe diameter is different for every test because it is necessary to determine the area separately before K can be computed. For this reason a formula based on the pipe diameter was derived in terms of products so that the whole compu-
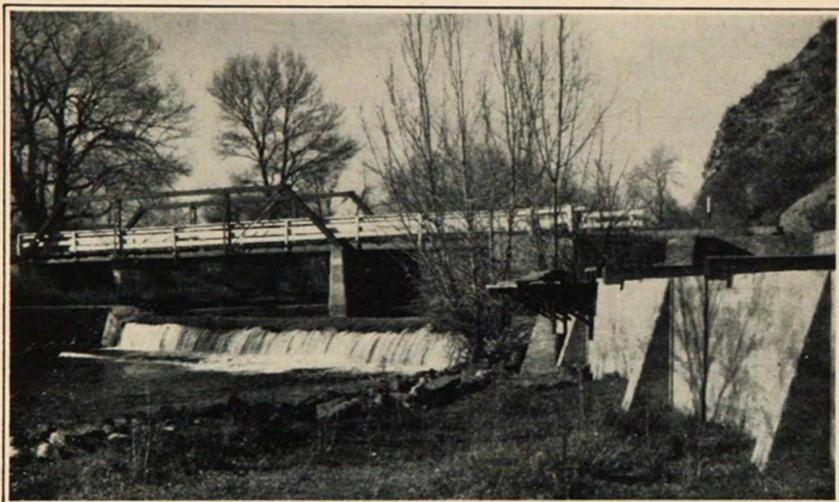
Figure 4—Jackson Ditch diversion dam which provides a regulated water supply for experiments.

tation can be made on the slide rule. This formula is $Q = 1.815D^{2.09}V$, in which Q as before is the discharge in gallons per minute, D is the pipe diameter in inches, and V is the velocity in feet per second measured by the meter. This formula is not a mathematical transformation of the equation $Q = (419A-5)V$ but is a new equation independently derived and therefore is not identical with it. The second formula gives values of K that are closer to the observed values than those computed by the formula $K = (419A-5)$ (see table 1). However, when the tests on all the pipes and all lengths were considered the formula did not fit the data as well as the formula $K = (419A-5)$. For this reason the formula $K = (419A-5)$ was used in determining the accuracy of the current meter measurements of pipe discharge.

TABLE 1—*Summary of observed and computed values of K in the formula Q = KV and pertinent data.*

Inside diameter	Length	Ratio length to diameter	Area	Observed K	Computed* K	Deviation	Percent deviation	Computed** K	Deviation	Percent deviation
Inches	Feet		Sq. Ft.							
4.09	3.5	10.3	0.0913	34.0	33.3	−0.7	−2.1	34.5	+0.5	+1.5
5.05	8	19.0	.1391	54.5	53.3	−1.2	−2.2	53.6	−0.9	−1.6
6.17	14	27.3	.2078	80.5	82.1	+1.6	+2.0	81.4	+0.9	+1.1
6.56	10	18.3	.2350	93.0	93.5	+0.5	+0.5	92.5	−0.5	−0.5
7.61	10	15.8	.3160	125.0	127.4	+2.4	+1.9	126.3	+1.3	+1.0
8.08	14	20.8	.356	143.5	144.2	+0.7	+0.5	143.0	−0.5	−0.3
8.60	10	14.0	.403	165.0	163.8	−1.2	−0.7	162.9	−2.1	−1.3
10.21	14	16.4	.568	230.0	233.0	+3.0	+1.3	233.3	+3.3	+1.4
12.11	14	13.9	.800	334.0	330.2	−3.8	−1.1	333.2	−0.8	−0.2

*Computed by the formula K = (419A-5) where A is the area of the pipe in square feet.

**Computed by the formula K = $1.815D^{2.09}$, where D is the diameter of the pipe in inches.

Accuracy of Discharge Formulas

The accuracy of the two formulas was compared by taking the discharge computed by each formula from the known size of pipe and the velocity of the water in the pipe measured by the current meter and checking it against the discharge measured by the weir or Venturi meter. The deviation of the discharge computed by each formula from the discharge measured by the weir or Venturi meter was then determined. The deviations were tabulated in groups according to the size of the error. All the positive errors from 0 to 1.00 percent were put in the first group, the errors from 1.01 to 2.00 in the second group, the errors from 2.01 to 3.00 in the third group, and so forth. The negative errors were similarly grouped. The errors for the tests on each pipe and for each condition were tabulated separately in order to be able to see how the formula fitted all conditions. Analysis of the deviations tabulated in this manner showed that the errors in the results computed by the two formulas were nearly the same. A summary of the results of all the tests made on all the pipes showed that 79 percent of the discharges computed by the formula $Q=(419A-5)V$ were in error by not more than 3 percent, and 92 percent were in error by not more than 5 percent. Of the discharges computed by the formula $Q = 1.815D^{2.09}V$, 77 percent were in error by not more than 3 percent, and 92 percent by not more than 5 percent. All the tests, except those made on spiral flows for which the formulas are not applicable, were included in the analysis of errors. Of the tests which were more than 5 percent in error, one-third were tests for which the velocities were higher than those recommended for a meter with rubber propeller; one-third were special tests on a short pipe with inlet designed to cause maximum disturbance to the flow; and the remaining one-third were tests for which there was no apparent reason for the large errors.

In computing the errors the observed values were used as the base; positive errors mean that the computed values are too large, and negative errors that the computed values are too small. When it is considered that the tests were made under a great variety of conditions in order to determine the reliability of the method under adverse circumstances, it is believed that measurements carefully made with accurately calibrated meters in pipes where the velocity is less than 10 feet per second and the flow is normal will not ordinarily be in error by more than 3 percent.

A summary of the errors in the discharges computed by the formula $Q=(419A-5)V$ is given in tabular form in table 2 and in graphical form in figure 12. It should be pointed out that the results computed by the formula are too large for more than 50 per-

cent of the tests, but this is due in part to the fact that all the tests on pipes $2\frac{1}{2}$ feet long are included and for this length of pipe the formula gives results that are quite consistently too high. Since such short discharge pipes are not recommended for pumping plants because of the danger in discharging the water so close to the well, the formula was not corrected to fit the flows from these short discharge pipes and in consequence there is a small excess of positive errors.

Computation of K by Means of Diagram

The formula for computing the discharge in gallons per minute after the diameter of the pipe has been measured and the ve-
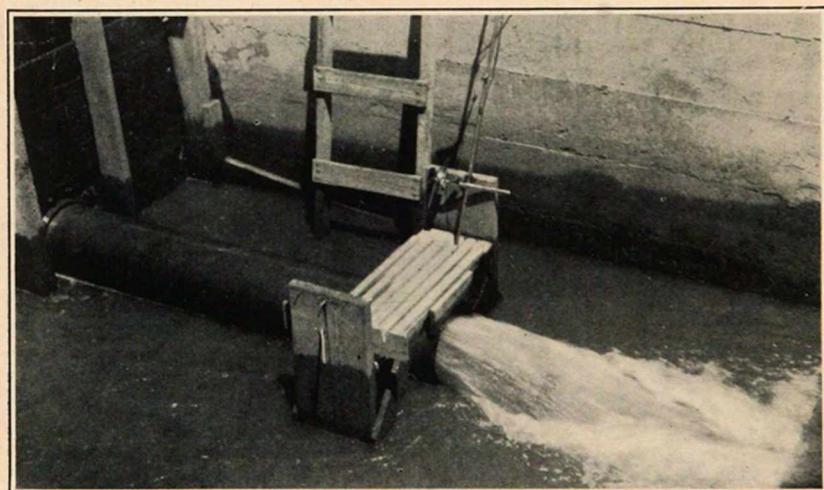
Figure 5—Pipe attached to bulkhead in concrete channel by means of companion flanges. Free flow discharge.

locity of the water determined with the current meter, is $Q = (419A-5)V$ which may also be written $Q = KV$ where K is the constant for the pipe in question. It is equal to $(419A-5)$ and is obtained by substituting the area of the pipe in this expression. In order to simplify the computation of K, figure 13 has been prepared from which it is possible to determine K for any pipe from 4 to 12 inches in diameter by entering the diagram on the line through the pipe diameter and then following it horizontally until it intersects the K curve. For convenience the pipe diameters in inches and eighths and inches and tenths are indicated on the diagram. Vertically below this intersection is the value of K for the pipe. The diagram permits reading the values of K to within 1 percent for small pipes; as the size increases, the accuracy increases. After the value of K has been determined, the discharge in gallons per

TABLE 2—*Summary of errors in discharges computed by the formula* $Q = (419A - 5)V$ *for various sizes of pipe.*

Pipe		Number of positive and negative errors between the limits indicated in percent

Diameter Inches	Type	0 to 1 +	−	1 to 2 +	−	2 to 3 +	−	3 to 4 +	−	4 to 5 +	−	5 to 6 +	−	6 to 7 +	−	7 to 8 +	−	8 to 9 +	−	Over 9 +	−
12	Standard	17	17	8	15	5	16	2	7	0	2	1	0	0	1	0	1	0	0	1	5
10	"	20	10	22	3	24	1	5	0	2	0	0	0	0	1	1	0	0	0	0	1
9	O D	2	3	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Standard	16	9	8	7	6	8	4	3	2	2	0	1	0	0	0	0	0	0	0	3
8	O D	1	1	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	" "	1	0	1	0	1	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0
6	Standard	7	12	9	16	7	6	4	6	3	1	6	1	1	0	0	0	0	0	3	0
5	"	1	2	1	1	0	1	0	2	0	1	0	1	0	0	0	0	0	1	0	0
4	"	1	2	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals		66	56	51	47	45	37	17	18	9	6	8	3	1	2	1	1	0	1	4	9
Total plus and minus		122		98		82		35		15		11		3		2		1		13	
Percentage of all tests		31.94		25.66		21.46		9.16		3.93		2.88		.79		.52		.26		3.40	
Cumulative percentages		31.94		57.60		79.06		88.22		92.15		95.03		95.82		96.34		96.60		100.00	

minute is then obtained by multiplying K by the velocity of the water as measured with the current meter.

This diagram (figure 13) may also be used to determine the area of the pipe when the diameter is known. In this case the intersection of the horizontal line through the diameter, with the area curve is used. The area is read on the top scale directly above the intersection. Multiplying the value by 419 and then subtracting 5 gives K as before.
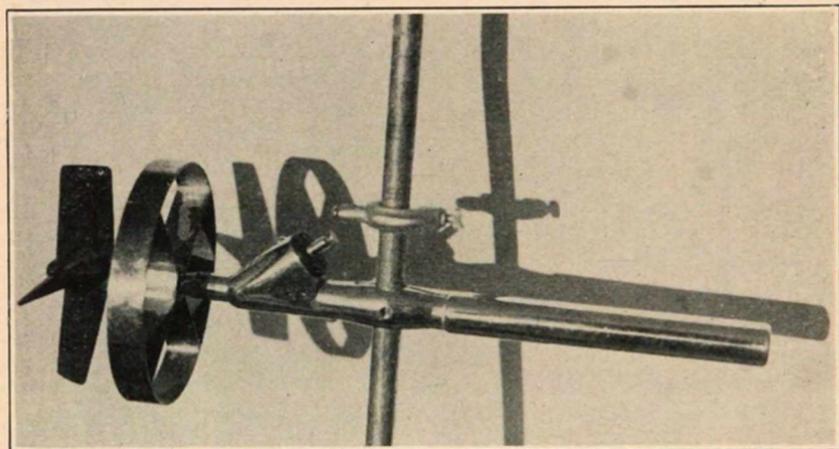
Figure 6—Hoff meter with 4-blade propeller equipped with guard ring for use in pipes.

Special Tests

Effect of Submergence on Discharge Measurements

In sections where the distribution of water for irrigation is by means of pipes, pumping plant outlets are frequently in boxes in which the water level is above the top of the outlet pipe. As a result the pump outlet pipe always flows full, and if the pump is operating at part capacity the velocity of flow through the outlet may be quite small. For this reason all the tests included observations on low velocities, usually 2 feet per second or less. These velocities were obtained by submerging the outlet of the pipe under test by means of flashboards and the regulating gate in the bulkhead shown in figure 2. The measurements were made in the same manner as previously described.

The submerged-flow data were plotted with the free-flow data, and apparently there was no difference between them. Of the points plotted on figure 11, the four lowest for the 4- and 8-inch standard pipes, the three lowest for the 6- and 10-inch standard pipes, and the five lowest for the 12-inch standard pipe are sub-

merged-flow measurements. These points fit the standard dis-
charge curves as well as the free-flow data. Since the discharges
under submerged conditions are relatively less, the percentage of
error may be slightly higher for the submerged flow tests, but it is
evident that submerging the pipe outlet does not affect the accuracy
of the discharge measurements. In the analysis of the data no dis-
tinction was therefore made between free-flow and submerged-flow
tests.

Effect of Meter in Pipe on Discharge

When a current meter is used to measure the discharge of a
pipe the presence of the meter causes some obstruction to the flow
of the water and consequently there will be an increase in the head
on the pipe and a decrease in the discharge. Since the head on the
pipe during these experiments was controlled by the elevation of
the spillway in the approach channel, the head remained practically
constant but the discharge decreased. This is shown in table 3
which is the summary of the results of a series of tests on 10- and
12-inch pipes 8 feet long. In these tests the head on the pipe and
the weir discharge were noted when there was no meter in the pipe,
when the meter was in the pipe only during the time the velocity
observations were being made, and when the meter was held in the
pipe continuously throughout the test. The weir discharges were
each based on five hook-gage readings and the head on the pipe on
two staff-gage readings.

The data in the table show that in every test holding the
meter in the pipe decreased the discharge and that the greatest de-
crease occurred when the meter was held in the pipe continuously
during the measurement of the discharge. In general the effect was
greater also for the higher velocities. However, the actual decrease
in discharge under both conditions was relatively small. The head
on the pipe increased but slightly as a result of holding the meter in
the pipe.

The effect on the discharge of a pump would be similar to
that shown by the tests. There would be a slight increase in head
on the pump and at the same time a decrease in the discharge. The
amount of these changes would depend on the characteristics of
the pump.[5] For this reason, when a high degree of accuracy is re-
quired in determining the discharge of a pump it would be neces-
sary to measure the increase in head with a manometer and to
correct the discharge by means of the head-discharge curve of the
pump. The maximum decrease in discharge shown by the tests is
3.6 percent. In smaller pipes the decrease in percentage is prob-

[5]Rohwer, Carl. Design and Operation of Small Irrigation Pumping Plants.
U.S.D.A. Circ. in press.

TABLE 3—*Summary of results of tests to determine effect of meter on discharge from pipe.*

Test no.	Pipe diameter	Meter velocity	No meter		Meter part time		Meter all time		
			Gage height	Weir discharge	Gage height	Weir discharge	Gage height	Weir discharge	Decrease*
	Inches	Ft. / Sec.	Feet	G.P.M.	Feet	G.P.M.	Feet	G.P.M.	Percent
211	12	7.48	2.39	2600	2.40	2552	—	2530	2.7
212	12	4.07	1.95	1384	1.94	1375	1.94	1371	0.9
213	12	3.35	2.16	1132	2.17	1129	2.18	1115	1.5
214	12	10.23	3.36	3556	3.37	3490	3.38	3430	3.5
221	10	8.12	2.60	1903	2.60	1875	2.62	1858	2.4
222	10	9.10	3.11	2230	3.12	2185	3.13	2150	3.6
223	10	10.30	3.63	2475	3.63	2435	3.64	2390	3.4
224	10	3.74	2.15	900	2.16	879	2.16	875	2.8
225	10	7.02	2.51	1668	2.51	1645	2.52	1627	2.5

*Decrease shown is for maximum deviation which occurs when the meter is held in the pipe continuously.

ably greater and for this reason the measured discharge should be corrected as just explained if the discharge, when pumping against a definite head, is required. The deviations given in table 3 are for a condition where the head does not increase materially because of the obstruction caused by the meter. In a pump, since the water is confined by the pipe, the obstruction due to the meter causes an increase in head which in part counteracts the effect of the obstruction on the discharge. For this reason the actual discharge from a pump would probably be less affected than were the pipes in these tests.

Comparison of Measurements Made by Different Methods of Integration

Two methods of integration as previously explained were used in measuring the velocity of the water in the pipe. The original method consisted of horizontal and vertical integrations along pipe diameters at right angles to each other. The improved method consisted of horizontal and vertical integrations together with circular integrations in both directions around the inner circumference of the pipe. This method was adopted because it resulted in a more complete integration of the entire cross-section of the pipe.

To find out whether there was any difference in the results obtained by the two methods, measurements of the same discharge were made by both methods on 6-, 8-, 10-, and 12-inch pipe 8 feet long. These tests were a part of the calibration of the discharge of these pipes; for that reason the tests by the improved method were made in the standard manner, that is, five observations of velocity were made for each discharge. The average values were used in making the comparisons. Only one measurement of velocity was made when the original method was used, and the measurement preceded the measurement by the improved method. The same observer made the measurements by both methods and the same meter was used. The results of these tests are set forth in table 4. The pipes were all installed in the manner shown in figure 2. It will be noted that there is no systematic difference between the measurements by the two methods; sometimes the measurement by one method is too high and sometimes the other, and the differences are generally less than 1 percent. It should be mentioned that the five observations made when the improved method was used differed from each other, but these differences also were small.

Tests of the two methods were made on the 12-inch pipe under standard conditions and also when the velocity was unequally distributed throughout the pipe section by an obstruction 2 feet from the pipe outlet. This obstruction consisted of the device used

to give spiral motion to the water (see page 24), but in these experiments the vanes were bent so as to throw the velocity to one side of the pipe. The tests show (table 4) that the obstruction did not increase the difference between the revolutions per second registered by the meter when using the different methods of integration. The tests on the 10-inch pipe were all made with the device for causing spiral motion and then straightening the lines of flow in the pipe (see page 27). The revolutions per second found by the two methods of integration in this case also are in close agreement.
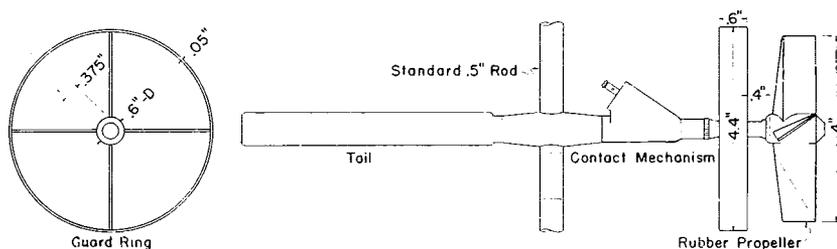
Figure 7—Details of Hoff meter and special guard ring.

The tests made on the different sizes of pipe by the two methods of integration are in such close agreement that it is difficult to say which is the better method, but since practically all the tests made in determining the formula for computing the discharge from the velocity measurements were made by the improved method of integration it is believed that this method should be used generally. The differences characteristic of this method are taken into account in the formula.

Effect of Length of Pipe on the Measurement of Discharge

The first tests to determine the accuracy of the current meter in measuring the discharge of pipes were made on pipes 8 feet long. Since it was believed that the length of the pipe might have some effect on the accuracy, a second series of tests was made on pipes 2½, 6, and 14 feet long under as near identical conditions as possible so that the only difference would be the length of the pipe. Tests were made on 6-, 8-, 10-, and 12-inch standard pipe. Where there was a slight difference in the pipe diameters for different lengths, the results were all reduced to a comparable basis by changing the discharges as measured by the weir in proportion to the differences in areas of the pipes, that is, if the area of a pipe was 2 percent too great the discharge was reduced by 2 percent. Since the differences in diameter were small it is believed that the use of this method did not affect the accuracy of the results. All measurements were made with the same meter and by the same observer.

TABLE 4—*Comparison of different methods of making velocity measurements as indicated by the revolutions per second of the meter propeller.*

12-inch pipe			10-inch pipe§			8-inch pipe			6-inch pipe		
Test no.	Revs. per sec. Original* method	Improved* method	Test no.	Revs. per sec. Original* method	Improved* method	Test no.	Revs. per sec. Original* method	Improved* method	Test no.	Revs. per sec. Original* method	Improved* method
173	9.15	9.11	157	8.40	8.40	238	7.41	7.35	250	8.96	9.01
174	10.03	10.00	158	8.81	8.84	239	10.08	9.89	251	7.58	7.63
175	11.36	11.16	159	9.50	9.66	240	8.90	8.65	252	6.04	5.92
176	7.74	7.69	160	7.42	7.41	241	8.54	8.51	253	5.25	5.19
177	6.69	6.68	161	6.21	6.15	242	7.58	7.44	254	4.24	4.21
178	4.88	4.91	162	5.06	5.00	243	6.46	6.40	255	3.11	3.13
179	3.85	3.85	163	4.54	4.51	244	5.45	5.45	256	2.57	2.59
216†	6.72	6.71	164	3.53	3.52	245	4.96	4.98	257	1.53	1.53
217†	5.98	5.90	165	5.22	5.19	246	4.30	4.34	258	10.08	10.09
218†	4.50	4.54	166	7.27	7.21	247	3.31	3.33			
219†	3.64	3.64	167	8.15	8.15	248	2.63	2.64			
220†	9.61	9.56	168	9.77	9.71						
			169	8.83	8.86						
			170	8.21	8.27						
			171	5.77	5.73						
			172	6.92	6.85						

*The original method consisted of an equal number of horizontal and vertical integrations. The improved method consisted of the horizontal and vertical integrations and in addition two circular integrations in each direction.

§The flow in the 10-inch pipe was given a spiral motion of about 15 degrees and then straightened by means of special straightener vanes 20 inches from pipe outlet.

†Current thrown to one side by vanes 2 feet from pipe outlet.

The results of the tests on the pipes of different length after reducing them to a comparable basis are shown graphically in figure 14. It is apparent that for velocities less than about $9\frac{1}{2}$ feet per second the length of pipe has very little effect on the discharge measurement, but there is a tendency for the points for the pipe $2\frac{1}{2}$ feet long to fall to the left of the others. Above $9\frac{1}{2}$ feet in velocity the meter under-registers considerably, and for that reason these points do not fall on the curve. In all interpretations of the data these points were disregarded.

Figure 8—Hoff meter being held preparatory to starting measurement of pipe discharge.

Because the effect of length of pipe on the measurement of discharge is too small to be clearly shown graphically, the data were studied statistically in order to see whether there was any significant difference in the results obtained from the long and the short pipes. Since the standard discharge formula as previously shown is $Q = (419A—5)V$, for a particular pipe the formula may be written $Q = KV$, from which, $K = Q$ over V. Since Q and V are both known, the value of K for each test of a series can quickly be determined. The difference between the average values of K for the tests on two different lengths of pipe is a measure of the effect of the difference in length on the discharge, and whether the difference is significant depends on how much the individual values of K vary. The greater the variation in the K values for each length of pipe the greater difference in the averages must be to be significant. These factors can be quantitatively evaluated by statistical methods.[6]

The results of the statistical analysis of the data are given in table 5. In preparing the table, six tests were excluded because the velocities were so high that, as previously explained, the operation of the meter was unreliable. The data in the table show that for each size of pipe the coefficient K is less for the $2\frac{1}{2}$-foot length than for the 14-foot length. However, the probable error of the

[6]Hayes, Herbert Kendall, and Ralph John Garber. Breeding Crop Plants. 2nd edition, (New York, McGraw-Hill, 1927) 438 pp., illus.

TABLE 5—*Summary of results of statistical analysis of effect of lengths of pipe on measurements of discharge.*

Pipe diameter, inches	6		8		10		12	
Length of pipe, feet	14	2 ½	14	2 ½	14	2 ½	14	2 ½
Number of tests	8	6	9	15	7	6	12	7
Mean value of K	79.0	77.8	142.0	141.1	230.3	229.7	331.0	328.7
Probable error of mean K	0.43	0.98	0.57	0.25	0.46	0.57	1.06	0.83
Difference in values of K	1.2		0.9		0.6		2.3	
Probable error of difference	1.07		0.62		0.73		1.34	
Difference divided by P. E.	1.1		1.4		0.8		1.7	

difference between the values of K is so nearly equal to the difference that this difference is not statistically significant. It is also apparent from the data that the values of K for the different lengths of pipe of each diameter are so nearly equal that disregarding the length of the pipe in field measurements would have very little effect on the results obtained. From a practical standpoint, however, it should be mentioned that the flow in the longer pipes is much more uniform, and consequently it is less difficult to hold the meter in position when making the measurements. Because of these conditions the measurements made in long pipes will probably be more accurate.

Effect of Using Different Types of Meters in Making Discharge Measurements

A 5-inch pipe is the smallest size for which the discharge can be measured with the Hoff meter because of the size of the propeller guard ring required. The Ott meter (fig. 9) has a much smaller propeller and guard ring and can be used to measure the discharge from pipes as small as 4 inches in diameter. Because it was necessary to use the Ott meter to measure the discharge of small pipes, tests were made also on larger pipes with this meter. Tests were first made on a 4-inch pipe, and later tests were run on 6- and 8-inch pipes.

Nine tests were made on the 4-inch pipe which was 3½ feet long and equipped with an elbow on the upper end. The flow through the 4-inch pipe was measured by means of a 90° V-notch weir which was installed in a special weir box 4 feet wide and 2 feet deep. The meter discharges computed by the standard formula all agreed quite closely with the weir discharge, the maximum deviation being 2.8 percent.

Two sets of tests were made on the 6-inch pipe with the Ott meter. In one of these the discharge was measured over the 90° V-notch weir and in the other over the standard 4-foot rectangular weir which was used for all the other tests made at the Bellvue laboratory. The pipe was 4 feet long and had an elbow screwed to the upper end. The discharges measured with the Ott meter when compared with the discharge over the 90° V-notch weir were with one exception too small; the maximum difference found in the 10 tests made was 4.1 percent. Although the actual error in this case
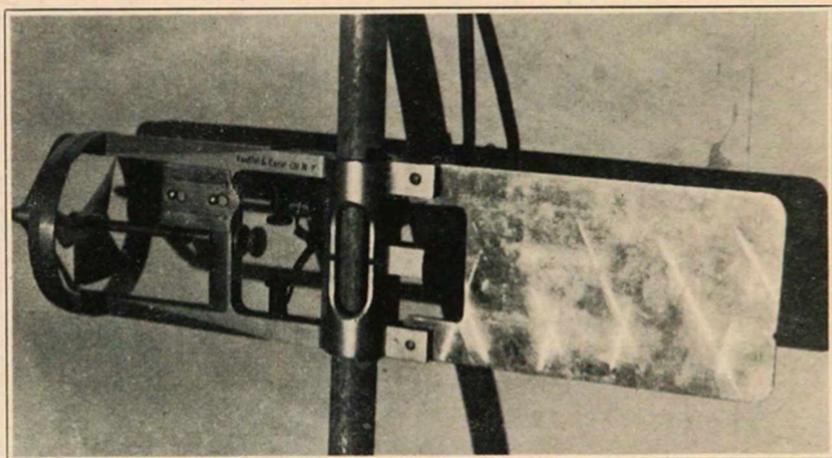
Figure 9—Ott propeller meter. Guard ring is integral part of meter

was only 10 gallons per minute (g.p.m.), the percentage of error was much larger than anticipated; for this reason a second set of measurements was made with the Ott meter for which the discharge was checked by measurement over the standard 4-foot rectangular weir. Six tests were made which covered the same range of discharges as those previously measured. These tests agreed quite closely with the discharge measured over the rectangular weir, the maximum deviation being only 2.1 percent. Although the two sets of tests were carefully examined, no reason was found why they did not check each other more closely.

Eight tests were made with the Ott meter on an 8-inch pipe 6 feet long with an elbow attached to the inlet end. The discharge was measured over the standard 4-foot rectangular weir. The discharges measured with the Ott meter, which ranged from 227 to 1,154 g.p.m., were all within 1 percent of the weir discharge. The tests on these pipes indicate that the Ott meter is as satisfactory as the Hoff meter in measuring pipe discharges for sizes up to and including 8-inch pipes and that since the Ott meter will measure the

discharge from these sizes accurately, there is no apparent reason why it would not be equally effective in measuring the discharge from pipes of larger sizes. This assumption was confirmed by 10 measurements with a Hoff meter made after this report was prepared. These tests were on a 12-inch pipe 9 feet long with an elbow at the inlet. The discharges measured ranged from 403 to 2,562 g.p.m. The errors in the discharges measured by the Ott meter ranged from +0.6 to —4.3 percent. In general the errors increased as the discharge increased.

Effect of Different Observers with Different Equipment on Measurements

A series of measurements was made on a 10-inch pipe 8 feet long to determine whether the observer or the meter had any effect on the results. In making tests each observer, using his own stop watch and meter, made five velocity determinations in the pipe. The same method of making measurements was used by each observer. The quantity flowing was held constant during the test, and weir gage readings were made at intervals while the velocities were being determined. One old and two new Hoff meters with four-bladed rubber propellers were used in making the velocity measurements. The results are set forth in table 6. Although the measurements by the different observers differ slightly from each other because of the personal equations of the observers and the characteristics of the meters they all agree fairly well with the discharge as measured over the weir. The maximum deviation is 2.4 percent, and it will be observed that most of the meter measurements are too large. This is probably due to the reason previously noted: that the formula gives results quite consistently too large for the 10-inch pipe (table 2).

Effect of Spiral Flow

Under certain conditions the jet issuing from the discharge pipe of a pump has a spiral motion. It is probably caused by the rotation of the pump impeller. Valves, elbows, and other obstructions seem to aggravate the condition. To investigate the effect of the spiral motion of the water on the registration of the current meter, a series of tests was made on 5-, 6-, 8-, 10- and 12-inch standard pipe 8 feet long in which the water had been given a spiral motion by installing vanes in the pipe. The amount of twist of the water was varied by changing the pitch of the vanes. The twist was measured by means of a protractor (see fig. 15) with a movable pointer attached at the center of the protractor. The protractor was held in a horizontal position at the end of the pipe just above the issuing jet with the center of the protractor over the center of the pipe. By moving the pointer until it was parallel to the filaments of the jet it was possible to get a fairly good idea as to the

TABLE 6—*Comparison of results obtained by different observers with different meters when measuring the same discharge in a 10-inch standard pipe 8 feet long.*

Observer	A	B	C
Meter	Hoff No. 182	Hoff No. 180	Hoff No. 9
Test No. 116			
Velocity in feet per second	9.63	9.30	9.57
Computed discharge in g.p.m.	2262	2185	2250
Weir discharge in g.p.m.	2230	2230	2230
Deviation in percent	+1.4	−2.0	+0.9
Test No. 117			
Velocity in feet per second	8.78	8.56	8.81
Computed discharge in g.p.m.	2062	2011	2070
Weir discharge in g.p.m.	2038	2038	2038
Deviation in percent	+1.2	−1.3	+1.6
Test No. 118			
Velocity in feet per second	7.57	7.46	7.61
Computed discharge in g.p.m.	1780	1754	1788
Weir discharge in g.p.m.	1746	1746	1746
Deviation in percent	+1.9	+0.5	+2.4
Test No. 119			
Velocity in feet per second	4.68	4.58	4.62
Computed discharge in g.p.m.	1100	1076	1086
Weir discharge in g.p.m.	1076	1076	1076
Deviation in percent	+2.2	0	+0.9

amount of the twist. The angle was designated either right or left, depending on whether the pointer was toward the right or left when looking along the pipe in the direction of flow.

The vanes used to give the spiral motion to the water had four blades as shown in figure 16. The vanes were from 10 to 15 inches long, depending on the size of the pipe, and were located from 1 to 4.7 feet from the outlet end of the pipe. The vanes were held in place by means of a wire threaded through the pipe and were kept from turning by trimming the vanes to a driving fit. Tests were made at various rates of flow at angles from 5 to 20 degrees to the right and left at approximately 5-degree intervals. The angle of the spiral was measured during each test. Some variation in the angle was noted in the individual tests of each series, but it was usually small. Some of the variation was probably due to the error in reading the angle and some also to the change in the velocity for the different discharges.

The results of the tests on the 6- and 10-inch pipes are shown graphically in figure 17. The results for the other sizes of pipes are

not included because they overlap and would cause confusion. However, they show the same general trend as the 6- and 10-inch pipes. For both the 6- and 10-inch pipes it will be observed from the plot that for a given velocity as indicated by the meter the discharge increases as the angle of the spiral to the left increases. This is also true for the other sizes of pipes. This increase does not occur, however, when angle of the spiral is to the right. In this case the discharge decreases in small pipes as the angle to the right increases and in large pipes decreases for small angles and increases for large angles. Furthermore, in all sizes of pipe the effect of the angle to the right is not so great as is the effect of the angle to the left. The reasons for these inconsistencies are not apparent. Ratings of Hoff meters made when the water strikes the blades at various angles show that the meter is retarded for all angles and that there is only a slight difference whether the angle is to the right or left.[7] The problem is complicated by the fact that in small pipes the propeller extends past the center of the pipe, whereas in large pipes the whole propeller is on one side of the center and consequently the water does not strike the blades of the propeller in the same manner in both cases. Furthermore, in small pipes the spiral flow will accelerate the meter when it is in the direction of rotation of the propeller and retard it when the rotation is in the opposite direction.

Figure 10—Measuring pipe discharge at Fort Collins laboratory with Hoff meter. Observer steadies meter with both hands and in addition holds stop watch for timing revolutions.

Before making these tests it was believed that it would be possible to determine the discharge in case of spiral flow by measuring the velocity in the usual manner and then making a correction for the spiral flow from a chart showing the effect of different angles of spiral. Since the effect of different angles of flow followed no known law, this plan had to be abandoned. To devise some means

[7]Rohwer, Carl. Rating and Use of Current Meters. Colo. Agr. Exp. Sta. Tech. Bul. 3, 1933. pp. 41-44.

of measuring these spiral flows, an attempt was made to straighten these flows so they could be measured by means of the current meter without making any corrections.

Straightener vanes were found to be effective in eliminating spiral flows. The straightener consisted of four vanes at right angles to each other and 22 inches long. To test the effectiveness of the straightener it was installed in a 10-inch pipe 20 inches from the lower end of the pipe and 12 inches from the spiraller. The vanes of the spiraller were bent so as to give a twist to the water of about 15 degrees. After the equipment was installed in the pipe, discharges from 800 to 2,200 gallons per minute were measured with the current meter in the usual manner. The results are shown in figure 17 by points having the square and horizontal bar symbol. The open squares show the results when the vanes were set to twist the water to the right and the solid squares for angles to the left. It will be observed that the straightener was very successful in correcting the effect of spiral flow to the left and apparently corrected too much for spiral flow to the right, as is shown by the position of these points with reference to the curves for flows 15° to the right and to the left without the straightener. A total of 16 tests was made to determine the effectiveness of the straightener; of these 14 had an error of less than 2 percent and the remaining 2 were less than 3 percent in error when compared to the discharge computed by the standard formula. These results indicate that it is possible to overcome the effect of spiral flow by means of a straightener of the type described.

Effect of Concentrating Current on One Side of Pipe

Various fittings frequently used in pump discharge lines, such as gates, elbows, and checks, may cause an unequal distribution of the velocity in the pipes. To determine how much unequal distribution of the velocity affected the discharge measurements, a series of tests was made on an 8-foot length of 12-inch pipe in which four vanes 15 inches long were installed 2 feet from the outlet end. The vanes were the same as those used to give the water a spiral flow (see page 24) but for these tests only two of the vanes were bent, both in the same direction. The bend in the vanes was equivalent to that given for the 15- to 20-degree spiral flow. The bent vanes were on the same diameter, and consequently the water was deflected to one side of the pipe.

Six tests were made with the water deflected in this manner. The velocities ranged from 3.44 to 9.02 feet per second and the discharges from 1,158 to 3,075 gallons per minute as shown by the weir. The discharges measured with the current meter were

from 1.5 to 4.9 percent in error, and the errors increased in a general way as the velocity increased. All measurements gave discharge readings that were too small.

In these tests the ends of the vanes deflecting the water were about 18 inches from the meter propeller. Subsequent tests on other disturbed-flow conditions showed that the length of pipe below the cause of disturbance in the flow has considerable effect on the accuracy of measurement (see tests on right angle inlets, page 30). For this reason it is believed that if the pipe had extended 4 feet farther beyond the end of the vanes probably little or no effect would have been noted.

Effect of Elbow on Pipe Discharge

Most pump discharge pipes contain an elbow near the outlet in order to make the water flow in a horizontal direction where it enters the distribution system. Because elbows produce unequal distribution of the velocities in the pipes, tests were made to determine whether this had any effect on the registration of the current meter when measuring the pipe discharge. Fourteen tests were made on a 6-inch pipe with the Hoff current meter; seven of the tests were on a pipe 38 inches long and seven on a pipe 81 inches long. Both pipes consisted of two sections connected by means of standard flanges. The elbow was screwed on at the upper end and turned so the outlet pointed straight down. No vertical pipe was attached because there was not sufficient clearance between the elbow and the floor of the channel. The general arrangement of the equipment, but without the elbow, is shown in figure 2.

The tests on the pipe 38 inches long covered discharges from 167 g.p.m. to 697 g.p.m. and those on the pipe 81 inches long from 134 g.p.m. to 751 g.p.m. The velocities ranged from about 1.5 feet per second to 8.5 feet per second in both sets of tests. The results of the tests on the pipe 81 inches long, and for comparison the standard tests on the pipe 6 feet long, are shown graphically in figure 18. All tests were corrected for differences in diameter as previously explained. To reduce the number of symbols required in the figure, the data for the 81-inch pipe are plotted with the symbols for the 6-foot pipe. Other tests (see page 19) indicate that small changes in length do not have significant effects on the discharge measurement. The curve shown is the line for the standard condition computed by the formula for 6-inch pipe. It will be observed that all the points fall very close to the standard line; the maximum deviations of the computed results from the observed data are —3.16 percent and +5.3 percent. The remaining errors are all less than 1.5 percent.

The results of the tests on the pipe 38 inches long are not in-cluded in the figure because the points overlap so that it would be difficult to distinguish one from the other. These points are, how-ever, in closer agreement with the computed values than those for the pipe 81 inches long, the range of errors being from -2.17 per-cent to +1.83 percent. On the 6-inch pipe the elbow apparently does not create enough disturbance to affect the accuracy of the cur-rent meter measurements.
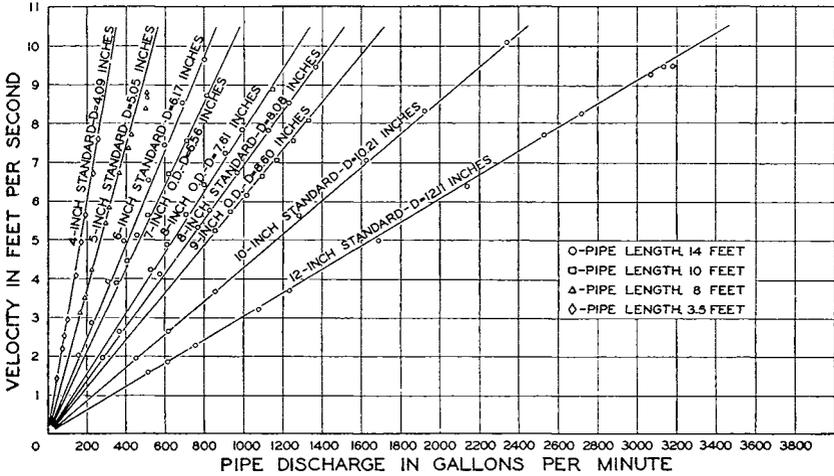
Figure 11—Discharge diagram showing plot of standard tests and discharge curves computed by the formula $Q = (419A-5)V$.

Another series of tests was made on an 8-inch pipe 6 feet long with the elbow attached in the same manner as in the previous ex-periments. Discharges from 227 g.p.m. to 1,154 g.p.m. were measured. In these tests the Ott current meter was used instead of the Hoff meter. The results are plotted in figure 18, together with the measurements made on the same pipe without the elbow with a Hoff meter. The straight line is the discharge under standard con-ditions computed by the formula. Eight measurements were made; the results all plot near the curve for standard conditions, the maximum deviation being 1.04 percent.

Three tests were made on a 5-inch pipe 8 feet long, with the elbow attached in the same manner as in the previous tests. The Hoff meter was used to measure the flow in the pipe and the flow was checked by means of a Venturi meter. The maximum devia-tion from the discharge under standard conditions computed by the formula was 4.1 percent; however, these tests agree more closely with the formula than do the tests made under standard conditions.

From the outcome of the foregoing tests it seems reasonable

to assume that equally good results will be obtained in making measurements of pipe discharges with a current meter whether or not the pipe has an elbow in the line if the unobstructed length of pipe beyond the elbow is more than 6 diameters. It is believed also that the conditions under which these tests were made are so nearly like those existing in most pump discharge lines that the laboratory tests may be used as a basis for estimating the accuracy of pump discharge measurements made with a current meter.
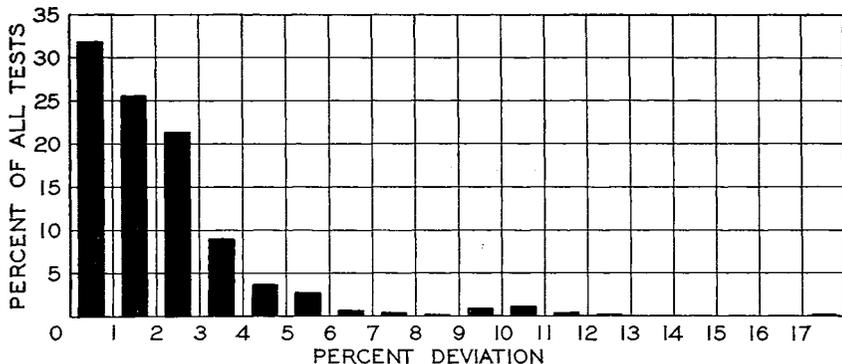
Figure 12—Deviations of current meter measurements in percent from weir and Venturi meter measurements.

After the completion of this report tests were made with a Hoff and an Ott meter on a 12-inch pipe 9 feet long with an elbow at the inlet. Ten measurements were made with each meter. The maximum error of the Ott meter measurements was —4.3 percent and of the Hoff meter measurements —6.1 percent. The latter error occurred in the smallest discharge measured where the velocity was only 1.16 feet per second.

Effect of Right-Angle Inlet on Measurements

Since attaching a standard elbow on the inlet end of the pipe had little if any effect on the discharge measurements, tests were made to find out whether a right-angle inlet in a horizontal plane would have any effect on the results. The tests were made on 12-inch pipes 2½ and 6 feet long. The right-angle inlet consisted of a square box 12 x 12 inches inside and 36 inches long with one end closed. A round hole 12 inches in diameter was cut in the side of this box near the closed end. A short galvanized iron nipple was fitted into the hole and then inserted into the pipe. A collar 4 inches wide was built around the inlet of the box. The water entering the box flowed 36 inches in a horizontal direction and then made a right-angle turn in a horizontal plane into the discharge pipe. This caused a very disturbed condition of flow which was still apparent at the pipe outlet. Because of the unequal distribu-

tion of velocities it was difficult to hold the meter in the pipe when making measurements; this was particularly noticeable in the 2½ foot pipe.

Tests were made on the 6-foot pipe for velocities from 1.48 feet per second to 7.90 feet per second for which the corresponding discharges as measured by the weir were 479 g.p.m. and 2,667 g.p.m. The tests on the 2½-foot pipe were on velocities from 1.34 feet per second to 7.44 feet per second. The corresponding discharges were 474 g.p.m. and 2,800 g.p.m. Seven tests were made on each length of pipe. The results are shown graphically in figure 18, together with the results of the tests on the same pipes under standard conditions. All data were put on a comparable basis by correcting differences in pipe diameters according to the area as previously explained. It will be observed that although the tests on the 6-foot pipe all plot on or near the standard curve for the 12-inch pipe, the tests on the 2½-foot pipe all fall to the right of the standard curve. This indicates that the unequal distribution of the velocities in the 2½-foot pipe caused the meter to under-register, whereas in the 6-foot pipe the additional length was sufficient to permit the velocity distribution to become more nearly normal. The differences between the current meter discharge measurements and the weir discharge measurements ranged from +2.1 to —3.3 percent for the 6-foot pipe and from —0.8 to —12.4 percent for the 2½-foot pipe. The weir discharge measurement is used as the base in computing the percentages. These tests show that the right-angle inlet has a marked effect on the current meter measurement of the discharge when the outlet pipe is not long enough to permit a redistribution of the velocities in the pipe before the water reaches the outlet. These tests also confirm the conclusion previously drawn (page 22) that although the length of the pipe has little effect on the discharge under ordinary conditions, much more accurate results will be obtained under disturbed conditions of flow if the pipe is at least 6 feet long.

Measurement of Laboratory Pump Discharge with Current Meter

Tests were made on the two-stage deepwell turbine in the laboratory at Fort Collins to determine the accuracy of the current meter in measuring the discharge. This pump has a carefully calibrated 8-inch Venturi meter in the discharge line which was used to check the current-meter measurements. The general arrangement of the pump and discharge line is shown in figure 1B. For these tests the discharge pipes, in which the current meter measurements were made, were connected to the elbow just above the gate valve by means of a standard flange. The pipes tested were 8 inches in

TABLE 7—*Summary of results of tests on laboratory pump.*

		Discharge		
Condition	Length of pipe	Venturi meter	Current* meter	Deviation
	Feet	G.P.M.	G.P.M.	Percent
Gate wide open	2½	1,375	1,335	—2.91
Gate ½ open	2½	1,384	1,318	—4.76
Gate ¼ open	2½	Water surging violently		
Gate wide open	6	1,380	1,355	—1.81
Gate ½ open	6	1,365	1,354	—0.81
Gate ¼ open	6	1,280	1,331	+3.98

*Computed by the formula $Q = (419A-5)V$.

diameter and were $2\frac{1}{2}$ and 6 feet long. The effect of partially closing the gate valve was also determined.

The results of the tests are given in table 7. For the condition with gate valve wide open the current meter measurements as computed by the formula $Q = (419A - 5)V$ are slightly less than the Venturi meter measurements, but the errors are of the same order of magnitude as those found when the tests were made in the straight pipe at the Bellvue laboratory. When the gate valve was one-half open and one-fourth open there was considerable surging of the water at the pipe outlet, particularly for the pipe $2\frac{1}{2}$ feet long. In fact the condition was so bad in this pipe when the valve was one-fourth open that it was impossible to measure the discharge with the current meter. The results show, as has been previously observed, that greater accuracy is obtained for the longer discharge pipes. A straightener was tried in an attempt to reduce the surging when the gate valve was partially closed, but although it apparently improved the flow condition it did not increase the accuracy of the measurements. These tests indicate that the current meter may be used to measure the discharge from pumps with reliable results unless the flow conditions at the outlet of the pipe are considerably disturbed by regulation with a gate valve.

Effect of Sloping Outlet Pipe on Discharge Measurement

Although most pump discharge pipes are generally horizontal it is possible that the pipe may have a slight slope as a result of defective fittings, poor workmanship, crooked well, or settlement of foundation. The effect of slope was investigated in a series of tests on a 6-inch pipe having a slope of approximately 5 percent upward or downward.

The pipe was made up of two sections 32 and 49 inches long, the 32-inch section at the outlet end being given the slope. The

AREA OF PIPE IN SQUARE FEET

DIAMETER OF PIPE IN INCHES

VALUE OF K IN FORMULA Q÷KV

AREA CURVE

K CURVE
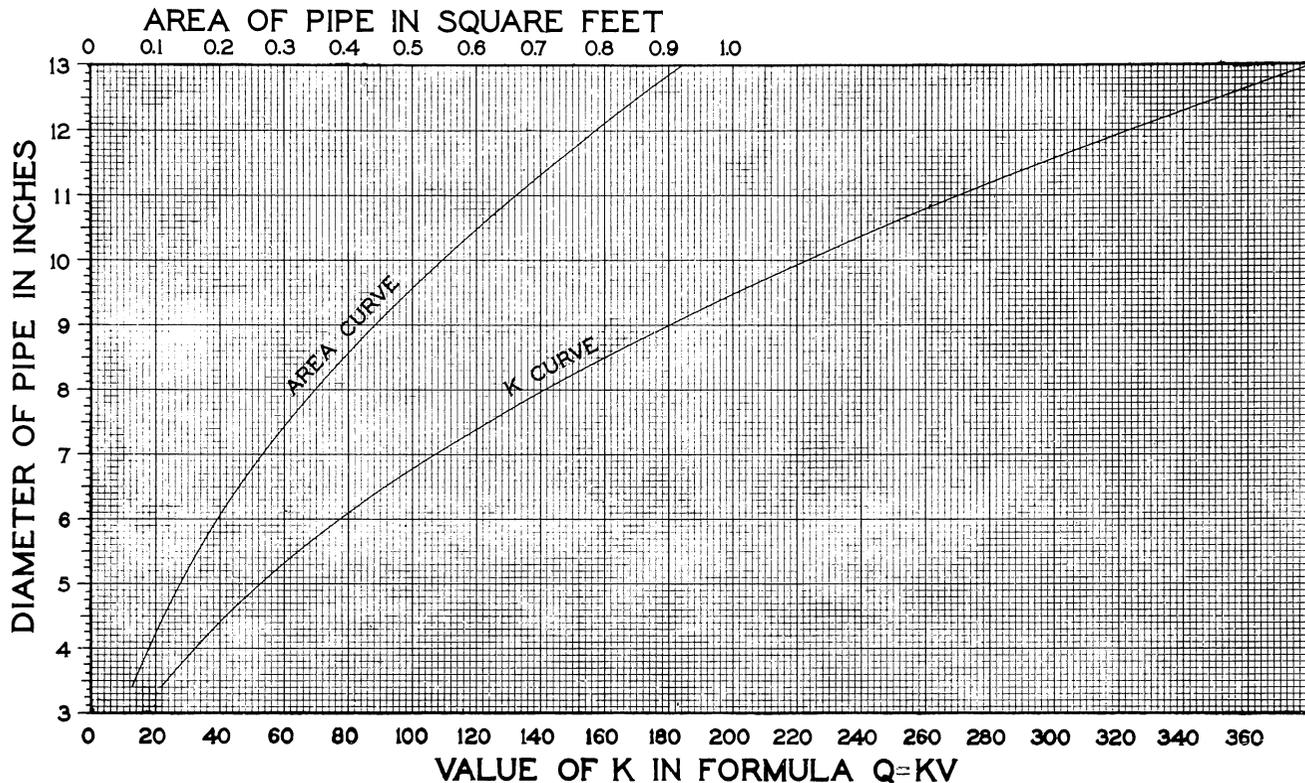
Figure 13—Diagram for determining K in formula $Q = KV$. Diagram may also be used for determining A in formula $Q = (419A-5)V$.

other section which was horizontal had an elbow at the inlet end. In the tests the axis of the meter was held parallel to the axis of the pipe. There were 12 tests in this series. The results are plotted in figure 18. The standard discharge curve and standard points are also shown. These tests covered a wide range of discharges and as shown by the figure the results check those made under standard conditions. The maximum deviation was 2.8 percent, but all except two of the tests were less than 2 percent in error. It is evident from these tests that a small slope does not affect the accuracy of the discharge measurement.
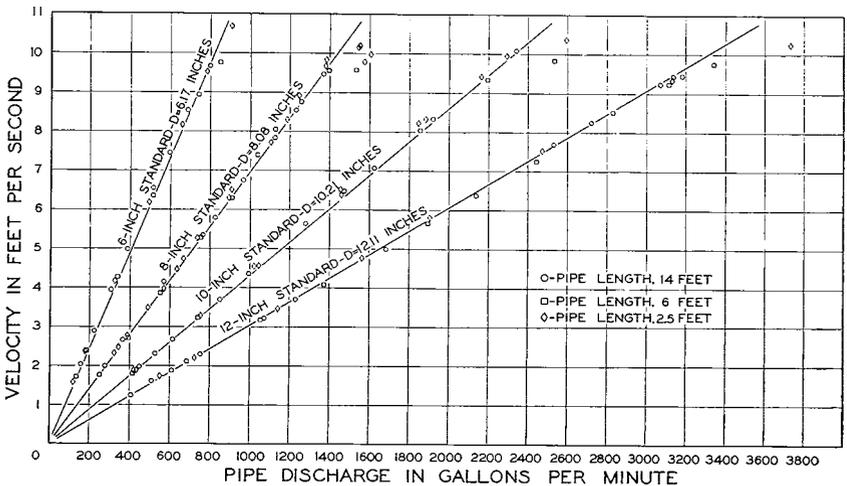
Figure 14—Diagram showing effect of length of pipe on discharge measurements. Standard discharge curves computed by formula $Q = (419A-5)V$ are also shown for comparison.

Effect of Roughness of Pipe on Discharge Measurement

The pipe used in the tests on the 10-inch pipe 8 feet long was rough inside because of rust; for this reason tests were made to determine whether the roughness affected the results. Tests were made on a section $2\frac{1}{2}$ feet long cut from the 8-foot pipe that was rough inside and then on the same section of pipe after it had been lined with a smooth galvanized iron sleeve. Eight tests were made on the rough pipe and six on the smooth pipe. The results were reduced to a comparable basis by correcting for the difference in diameter as previously explained. The data are shown plotted in figure 18 together with the standard curve for 10-inch pipes. The data for the rough pipe are plotted with open diamond symbols and for the smooth pipe with solid diamond symbols. Without exception the current meter measurements are all too large, but this fact regarding tests on the 10-inch pipe has been noted before (see table 2). The over-registration of the meter in the rough pipe is greater than

in the smooth pipe. For the rough pipe the range of error is from —6.52 to +4.87, and for the smooth pipe it is from —0.8 to +2.68. From these figures it might be contended that roughness has an appreciable effect on the discharge measurement. However, the previous tests on the 8-foot rough pipe and the 6-foot pipe that was 10 inches in diameter and was new and smooth may be used as the basis of a similar comparison. This is possible because it has already been shown that a small difference in the length of the pipe does not affect the results unless the pipe is short and there is some factor causing an unequal distribution of the velocities (see page 22). Thirty-two tests were made on the rough pipe and the errors on all but five were 3 percent or less. Six tests were made on the smooth pipe and the error in only one was more than 3 percent. Since the distribution of errors is almost exactly in the same ratio as the number of tests it is evident that the roughness did not have a significant effect in these tests.

From the foregoing analysis it may be assumed that roughness caused by pitting from rust probably has some effect on the discharge from a pipe $2\frac{1}{2}$ feet long but not on pipes 6 and 8 feet long.

Effect of Aeration on Discharge Measurements

In making tests on pipes partly full it was frequently observed that a slight temporary obstruction in the outlet would cause the pipe to flow full thereafter. It was believed that this was caused by cutting off the supply of air at the vena contracta, which led to the assumption that if there was an opening in the discharge pipe which allowed air to enter this might have some effect on the discharge measurement. To check this assumption a series of tests was made on a 12-inch pipe both with and without an air inlet. The sections of pipe tested were 6 and 14 feet long. The air inlet consisted of a $\frac{3}{4}$-inch pipe 30 inches long with an elbow and 2-inch nipple at the lower end. The pipe was fastened in a vertical position at the inlet end of the discharge pipe with the nipple inside just below the top of the discharge pipe and parallel to the axis. The top of the air inlet pipe was open to the air.

In making the tests it was found that it was impossible to cause the pipes to run full with the head available when the air inlet was in operation unless the outlet was submerged, and in one test on the 6-foot pipe under maximum head the pipe did not run full even though the outlet was submerged. A summary of the tests shows that the air inlet did not affect the discharge measurements except in the case when the pipe did not fill. Of 14 tests on the 14-foot pipe, only 2 of which were made with air intake in operation, the maximum deviation from the standard was 3.5 percent for the

standard tests and 2.5 percent for the aerated pipe. Of 18 tests on the 6-foot pipe equally divided between the two conditions all were less than 4 percent in error except the test on the pipe partly full. The maximum deviation from the standard discharge was 3.5 percent for the tests on the pipe with air excluded and 3.2 percent for the tests on the aerated pipe. The distribution of positive and negative errors was similar in both sets of tests.

Limitations of Method

The discharge of several hundred pumps was measured* during 1940 and 1941 by the method described in this report. These measurements were made to determine the amount of water pumped for irrigation in the South Platte Drainage Basin in Colorado. The men making this study had the opportunity to determine the limitations of this method of measurement in the field under a wide variety of conditions. Where they were able to check their measurements by other means they found that the agreement between the two methods was usually very close. Owing to the lowering of the water table resulting from the droughts of recent years there were a large number of pumps not operating at capacity. Under these conditions the pipes were frequently not flowing full and consequently it was impossible to measure the flows unless holding the meter in the pipes caused them to flow full. Other methods had to be devised to measure the discharge where this occurred.

Figure 15—Measuring angle of spiral flow with protractor.

In some instances when the outlet of the pipe was submerged and the discharge small the velocity was so low that it was not possible to make accurate measurements with the current meter. Also, it was not possible to measure the diameter of the pipe accurately when the outlet was submerged if the pipe was not exposed else-

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*The measurements were made by W. E. Code of the Colorado Agricultural Experiment Station and R. E. Kennedy and William Judd of the Water Conservation Board of Colorado.

where, and difficulty was experienced in measuring the diameter of badly distorted pipes. Some pumps had such short outlet pipes that the flow was too disturbed to be measured accurately.

No difficulty was encountered in learning to make the discharge measurements by the method described in this bulletin. The men making the field study of pumping plants found that the method was convenient and took very little time. Under favorable conditions they could easily make a complete measurement and compute the discharge in 15 minutes.
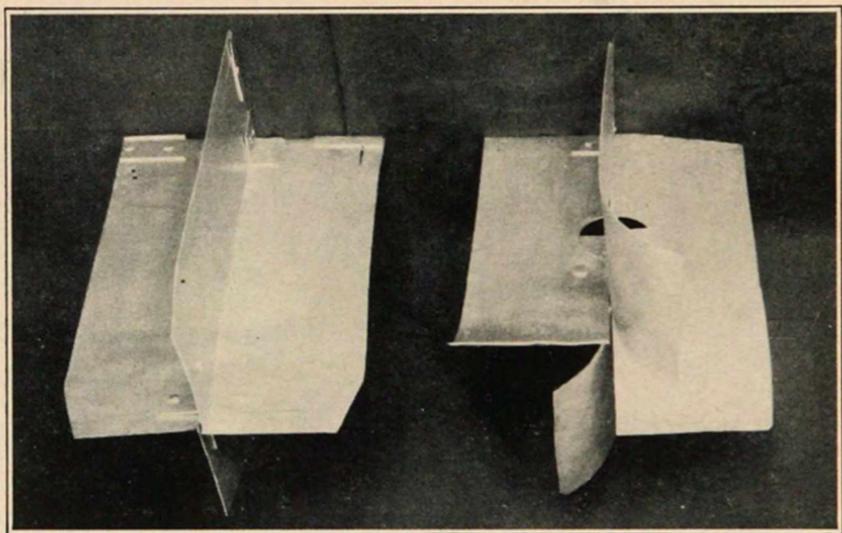
Figure 16—Vanes for straightening lines of flow and for producing spiral flow.

Summary

In measuring the discharge from a pipe with a current meter it was found that the product of the area and the velocity was not equal to the discharge. It was too large, probably, because the current meter did not measure the low velocities near the walls of the pipe, and consequently a correction factor had to be applied to the results to obtain the correct discharge. This correction factor was found to be constant under standard conditions for each size of pipe regardless of the discharge so long as the velocity was not sufficient to affect the registration of the current meter. The velocity became too great for accurate measurement at about 10 feet per second in 12-inch pipe and at about 9 feet per second in small pipes.

The general law showing the relation between velocity of the water as measured by the meter and discharge for all sizes of pipe

is given by the formula $Q = (419A-5)V$ in terms of area of the pipe and $Q = 1.815D^{2.09}V$ in terms of the diameter of the pipe. Both these formulas give satisfactory results, but the discharges computed by the formula $Q = (419A-5)V$ were in general slightly closer to the actual discharges. A comparison of the observed and computed discharges for all tests regardless of conditions except those with spiral flow showed that 79 percent of the computed results were not more than 3 percent in error and 92 percent were not more than 5 percent in error.
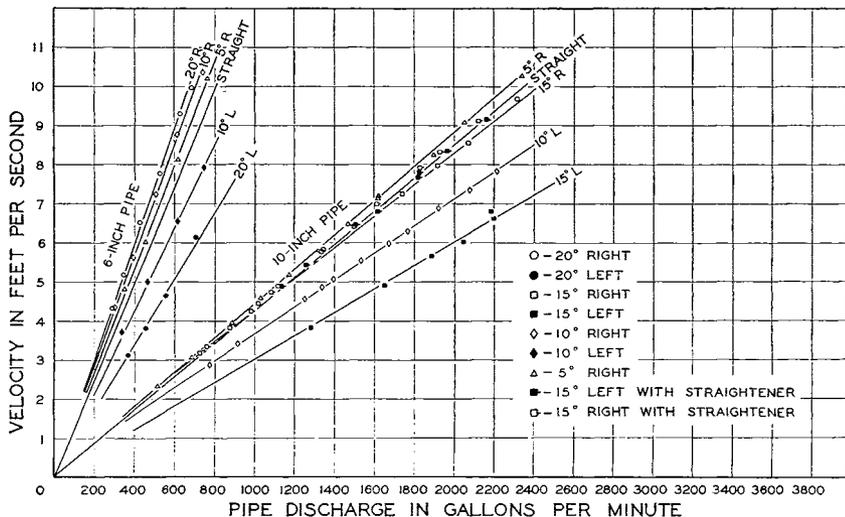
Figure 17—Plot of results of spiral flow tests.

Holding the meter in the pipe causes an obstruction to the flow which decreases the discharge and builds up the head. Although the effect is relatively small, a correction must be made when an accurate test of a pump is desired. The correction is readily made after measuring the increase in head by reference to the head-capacity curve of the pump.

Two methods of integrating the flow with the current meter were investigated and it was found that both were equally satisfactory. The combination of horizontal, vertical, and circular integration is recommended because the discharge formulas are based on measurements by this method.

A statistical analysis of the effect of length of pipe on the accuracy of the current meter measurements showed that the differences were not significant. **Outlet pipes at least 6 feet long are recommended because an obstruction in the pipe or other disturbing factor has less influence in long pipes.**

Both Ott meters and Hoff rubber-propeller meters of the type tested were equally satisfactory in measuring pipe discharges.

Measurements of the same quantity by different observers with different meters agreed quite closely to the true discharge.

Adding an elbow at the pipe inlet for the purpose of simulating the condition found in pump discharge pipes did not affect the accuracy of registration of the current meters for pipe lengths greater than six diameters.
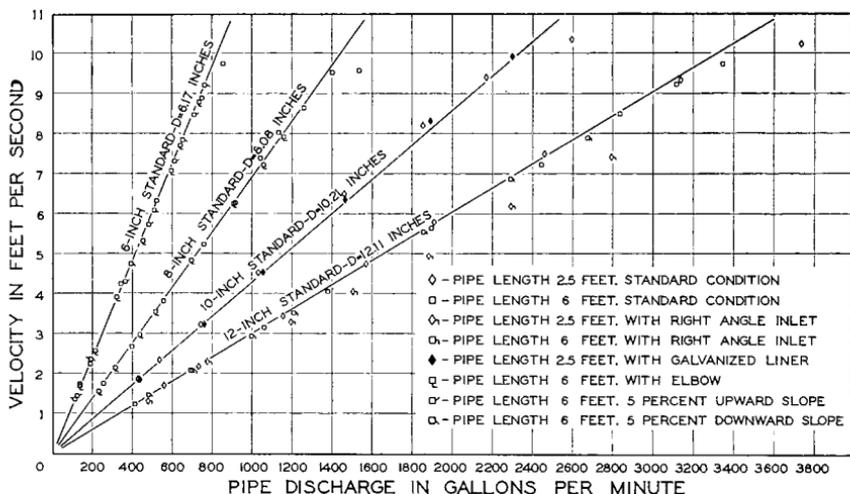
Figure 18—Diagram showing effect of special conditions on discharge measurements.

A right-angle inlet in a horizontal plane materially affected the registration of the meter if the outlet pipe was $2\frac{1}{2}$ feet long but had little effect if the outlet pipe was 6 feet long.

Measurements of the Fort Collins laboratory pump discharge with the Hoff current meter when the discharge pipe was 6 feet long checked the Venturi meter measurements if the gate valve was not more than half closed. There was a greater difference between the measurements when the discharge pipe was $2\frac{1}{2}$ feet long.

Measurements of spiral flow with a current meter were found to be unsatisfactory. Spiral flow to the left had greater effect than spiral flow to the right. Straightener vanes in the pipe were effective in straightening the lines of flow in the pipe and in reducing the error in the current meter measurements to less than 3 percent.

A slight slope in the discharge pipe did not affect the accuracy of the current meter measurements; neither did roughness such as would be caused by pitting due to rusting.

When an air inlet was provided at the upper end of the pipe there was difficulty in making the pipe run full unless the outlet was submerged, but if the pipe was full the registration of the meter was unaffected.   Submergence of the pipe outlet did not change the registration of the meter.

Several hundred field measurements of pumping plant discharges disclosed that difficulties in making measurements were sometimes encountered because the discharge pipe was not flowing full, the velocity was too low to measure with a current meter, or the area of the pipe could not be readily determined because the outlet was submerged or badly distorted. In general, however, the method was satsifactory and a great time saver, it being possible under favorable conditions to make a complete measurement and compute the result in 15 minutes.