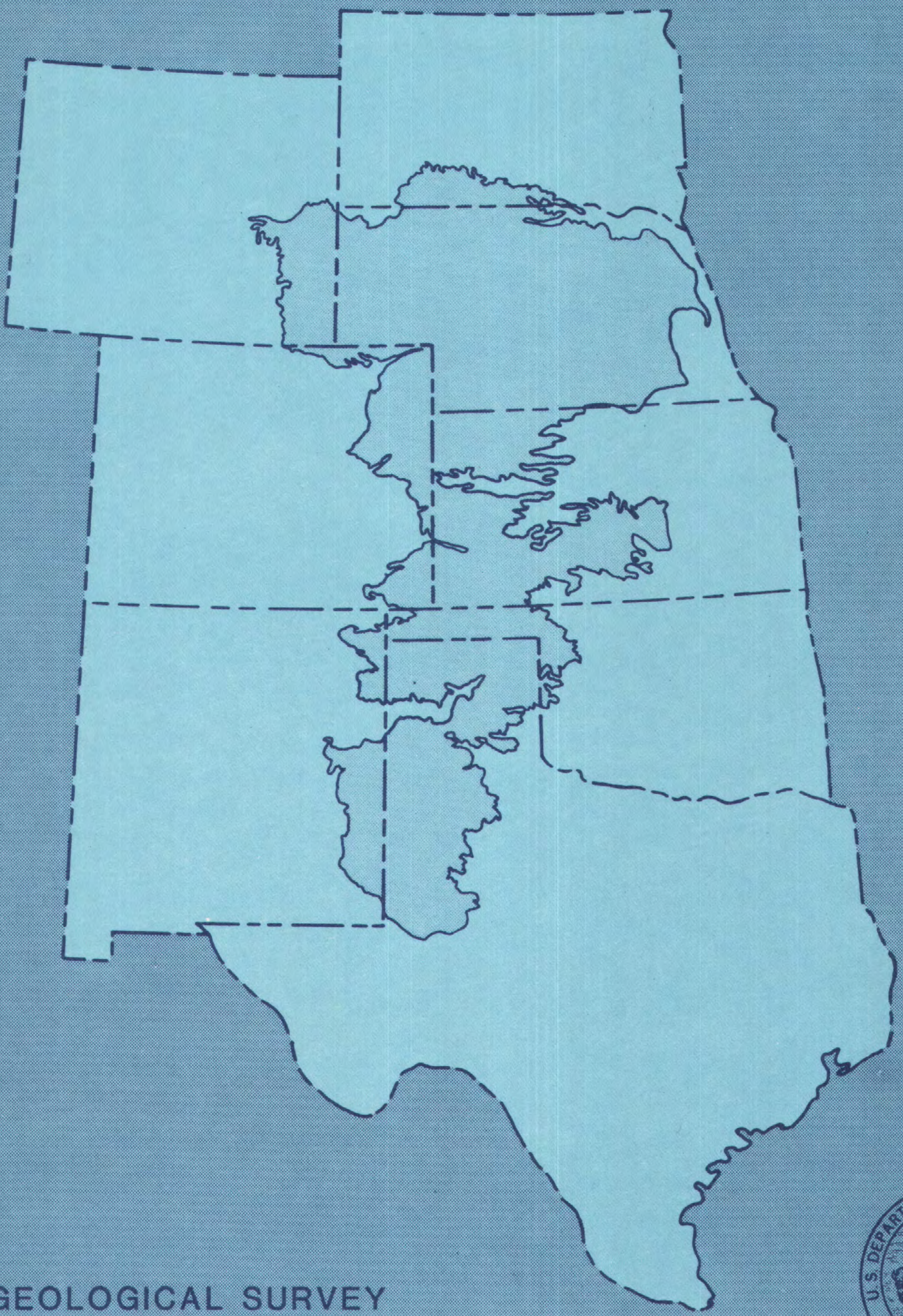
CALIBRATION AND TESTING OF SELECTED PORTABLE FLOWMETERS FOR USE ON LARGE IRRIGATION SYSTEMS



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CONVERSION FACTORS

For use of those readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply inch-pound units	By	To obtain SI units
foot per second (ft/s)	0.305	meter per second (m/s)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	3.785	liter per minute (L/min)
inch (in)	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
pound (lb)	2.205	kilogram (kg)
square mile (mi^2)	2.590	square kilometer (km^2)

CALIBRATION AND TESTING OF SELECTED PORTABLE FLOWMETERS FOR USE ON LARGE IRRIGATION SYSTEMS

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ABSTRACT

Existing methods for measuring discharge of irrigation systems in the High Plains region are not suitable to provide the pumpage data required by the High Plains Regional Aquifer System Analysis. Three portable flowmeters that might be suitable for obtaining fast and accurate discharge measurements on large irrigation systems were tested during 1979 under both laboratory and field conditions: propeller type gated-pipe meter, a Doppler meter, and a transient-time meter.

The gated-pipe meter was found to be difficult to use and sensitive to particulate matter in the fluid. The Doppler meter, while easy to use, would not function suitably on steel pipe 6 inches or larger in diameter, or on aluminum pipe larger than 8 inches in diameter. The transient-time meter was more difficult to use than the other two meters; however, this instrument provided a high degree of accuracy and reliability under a variety of conditions. Of the three meters tested, only the transient-time meter was found to be suitable for providing reliable discharge measurements on the variety of irrigation systems used in the High Plains region.

INTRODUCTION

The U.S. Geological Survey is currently conducting a study of the High Plains aquifer that encompasses an area of approximately 177,000 square miles in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (fig. 1). The objectives of the High Plains Regional Aquifer System Analysis are to (1) provide hydrologic information to evaluate the effects of continued ground-water development in the area, and (2) generate computer models and data bases necessary to predict aquifer response to future changes in ground-water development. The plan of study for the High Plains project is described by Weeks (1978).

Collection of water-use data is essential to achieving the objectives of the High Plains project because irrigated agriculture represents the major use of ground water in the High Plains region. During the 1979 irrigation season, selected areas in Colorado, Kansas, Nebraska, and Texas were used to develop methods and test equipment needed to sample agricultural water use.

This report deals with one aspect of determining agricultural water use: the calibration, testing, and application of discharge-measuring techniques and equipment. Specific emphasis was given to three instruments that potentially could reduce the time and effort required to make discharge measurements for the type of irrigation systems found in the High Plains: (1) A gated-pipe meter, (2) a Doppler meter, and (3) a transient-time meter.

There are several methods currently available to measure the discharge from a well. These methods include the trajectory and the Hoff-meter methods commonly used in open discharge pipes, a Pitot-tube method used in closed systems, and various types of volumetric methods. These traditional methods are not always suitable for the types of irrigation systems present in the High Plains.

The volumetric method for sampling discharge in gated-pipe systems, in which the discharge from a sample of gates is measured, is generally time consuming and physically difficult to apply in many field situations; therefore, a gated-pipe meter that can be inserted through the openings in gated pipe was tested.

Many high-pressure center-pivot systems are in use on the High Plains; the only previously mentioned method applicable to these systems is the Pitot tube. However, this time-consuming method requires shutting off the system, drilling a hole in the pipe, making the measurement, again shutting off the system, and plugging the hole. Two noninvasive meters (an access hole in the pipe is not required) were tested as an alternative to the Pitot-tube method. These two types, the Doppler and transient-time meters, are acoustic-electronic devices that do not require direct contact with the fluid stream.

The gated-pipe, Doppler, and transient-time meters were tested under laboratory and field conditions to determine their potential use and accuracy. Extensive laboratory testing was done at a flowmeter test facility in Aurora, Nebr. The authors wish to express their thanks to Milvern H. Noffke of McCrometer Corp., who was extremely helpful in obtaining permission to use

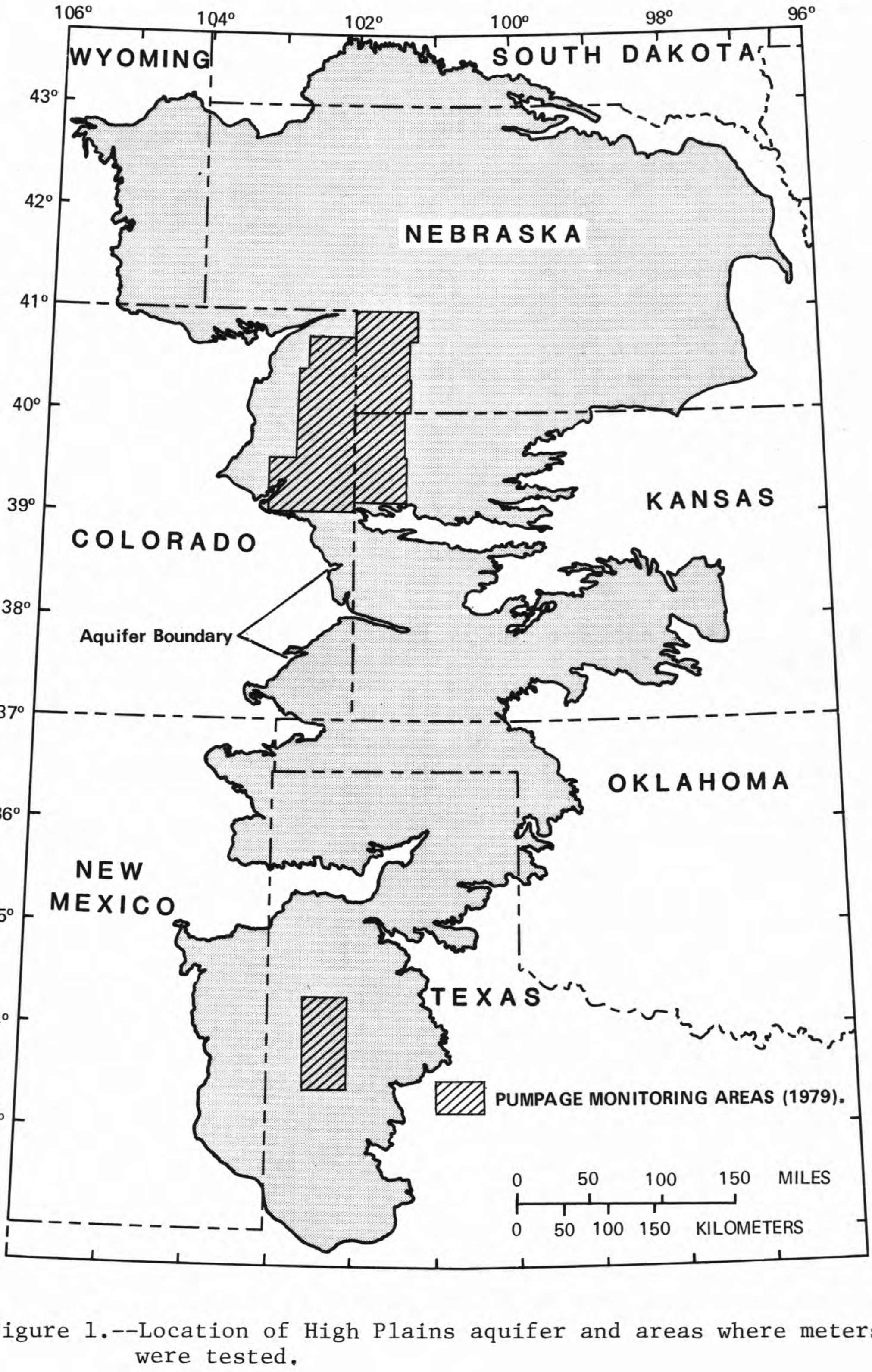

Figure 1.--Location of High Plains aquifer and areas where meters were tested.

the test facility and assisting in the laboratory tests. The McCrometer test facility uses a calibrated 6,000-gallon tank connected to a series of straight sections of pipe. These pipes range in size from a nominal 4 inches to a nominal 12 inches. Sections of pipe can easily be interchanged to test various materials and wall thicknesses. The storage tank contains electric float switches that activate at 5,000 gallons, 4,000 gallons, 3,000 gallons, and 2,500 gallons. These switches can be set to start or stop an electronic timer that reads to 0.0001 of 1 minute. Flow rates through the pipe systems are controlled by mechanical valves.

During a typical test, the storage tank is filled above the desired start level for the test. This allows the flow rate to be stabilized prior to activation of the clock by the beginning float-level switch. When the water in the tank reaches the selected level for the end of the test, this float switch simultaneously activates an air valve to stop the flow and stops the electronic timer. An average discharge is calculated by dividing the volume released by the elapsed time. The Division of Weights and Measures of the State of Nebraska has checked the calibration tank and evaluated it to be accurate within 0.2 percent. The system also contains calibrated inline flowmeters that were monitored for reference during tests, but were not used directly for calibration. During some tests, the flow was kept fairly constant during a release, by constantly adjusting a manual valve while watching an inline flowmeter.

All three instruments were tested under field conditions during the 1979 irrigation season. Pumpage was monitored at 250 randomly selected wells in the areas shown in figure 1. Discharge was to be measured at each of these wells. In most instances, two different methods were used to make discharge measurements at each well. The flowmeters were evaluated for accuracy and ease of operation.

The purpose of this report is to describe the results of calibrating and testing the gated-pipe, Doppler, and transient-time meters in the laboratory and in the field. The report also indicates the need for further testing on these three meters, including evaluation of their usefulness under conditions other than those generally found in large irrigation systems.

GATED-PIPE METER

The gated-pipe meter (fig. 2) tested was an invasive propeller meter designed for use with gated irrigation pipe. The meter consists of a velocity probe with a horizontal-axis turbine propeller and magnetic pickup, which is wired to a battery-operated velocity indicator. This instrument, Model No. FI-15 P, was manufactured by Mead Instruments Corp.[1] of Riverdale, N. J., and cost about $500 in 1979.

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[1]The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

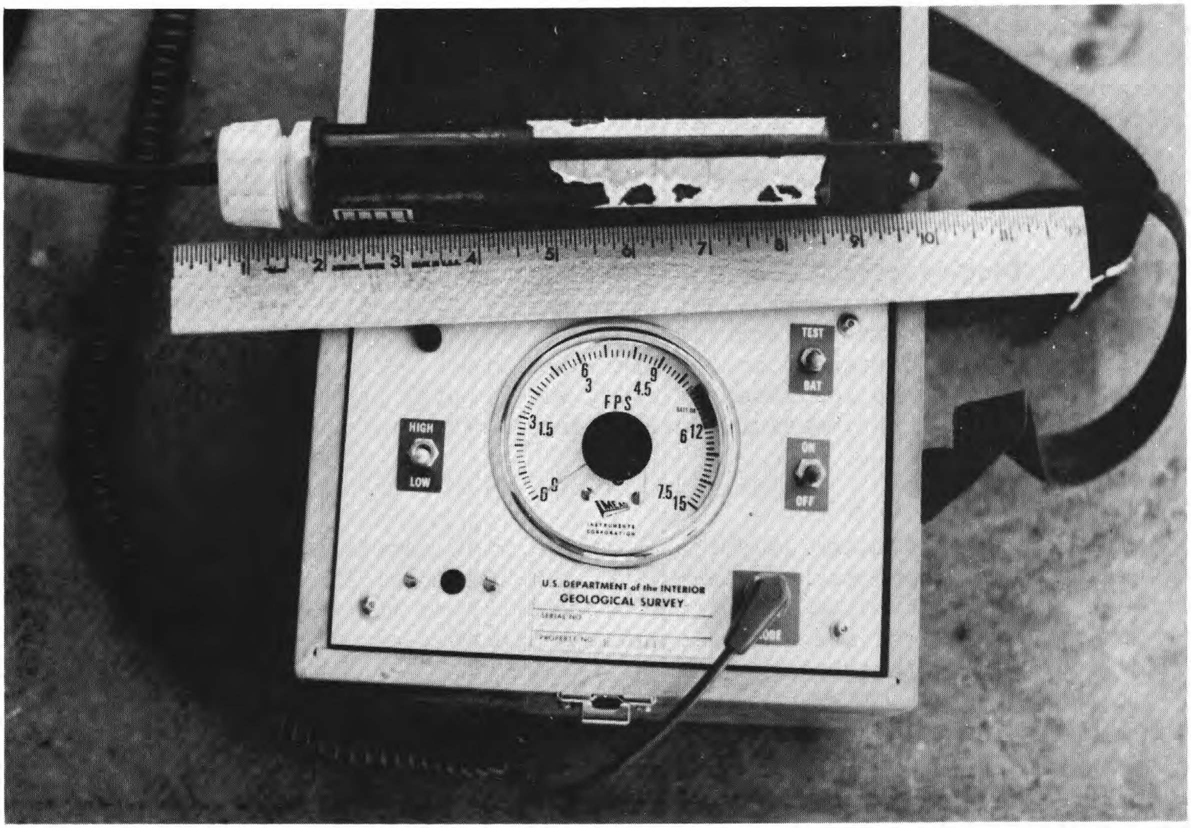

Figure 2.--Gated-pipe meter.

The velocity probe is about 1½ inches in diameter and about 8 inches long and can be inserted through the gate opening on most brands of gated irrigation pipe. The magnetic pickup unit senses the rotation of the propeller and transmits this signal to the portable velocity indicator by means of a flexible cable. The velocity indicator unit weighs about 5 pounds and is approximately 6 x 6 x 8 inches. The unit houses the electronics and the eight size C batteries that provide the power. The velocity is read on an indicator dial on one of two selectable ranges, 0-7.5 or 0-15 feet per second.

Laboratory Testing

Only limited testing of this instrument was done under laboratory conditions. The flow indicated by the meter versus the actual flow for an

8-inch aluminum gated pipe is shown in figure 3. The indicated flow was calculated by taking five velocity readings across the pipe at area-weighted distances from the middle. Average velocity for these five points multiplied by cross-sectional area gave the flow in the pipe. As shown in figure 3, indicated flow was consistently less than actual flow. This difference may be in part a function of the probe and turbine propeller design. The size of the probe is quite large relative to the size of the pipe, which could cause a distorted flow field in the vicinity of the turbine propeller.

The effect of cleaning and lubricating the propeller shaft was tested. Prior to cleaning, the meter was used to measure velocity in the gated pipe, with an actual velocity of about 4 feet per second. The probe was then disassembled and lubricated and the test was repeated at the same flow rate. This time, the indicated velocity was about 5 percent greater than it had been during the previous (prelubrication) test.

Field Testing

This propeller meter is portable and durable; however, there are several negative factors associated with its use under field conditions. It is sometimes difficult to insert the probe and then seal the gate sufficiently to get an accurate measurement, especially when the water in the pipe is under considerable pressure.

The velocity-indicator dial generally fluctuates considerably, so an average velocity for each point in the pipe must be estimated. The average indicated velocity can only be estimated within a few tenths of 1 foot per second with this meter.

The turbine seems to be sensitive to fine sand and other particulate matter in the water. Foreign material frequently gets between the shaft and the turbine and prevents the turbine from spinning smoothly. Based on field experience, it is probably important to clean and lubricate the shaft prior to each measurement.

The position of the turbine shaft relative to the flow lines in the pipe is critical. A slight rotation of the probe in the gate can make a considerable difference in the velocity reading. When using this meter, the probe needs to be rotated slightly to get the highest velocity reading. If it is not rotated, the velocity could be low by several tenths of 1 foot per second.

In summary, this instrument is portable and durable enough to be used routinely under field conditions; limited testing has indicated that it may be possible to develop calibration curves for various pipe sizes. If these curves can be developed, the instrument may give fairly reliable readings, providing it is cleaned regularly and properly alined for the measurements.

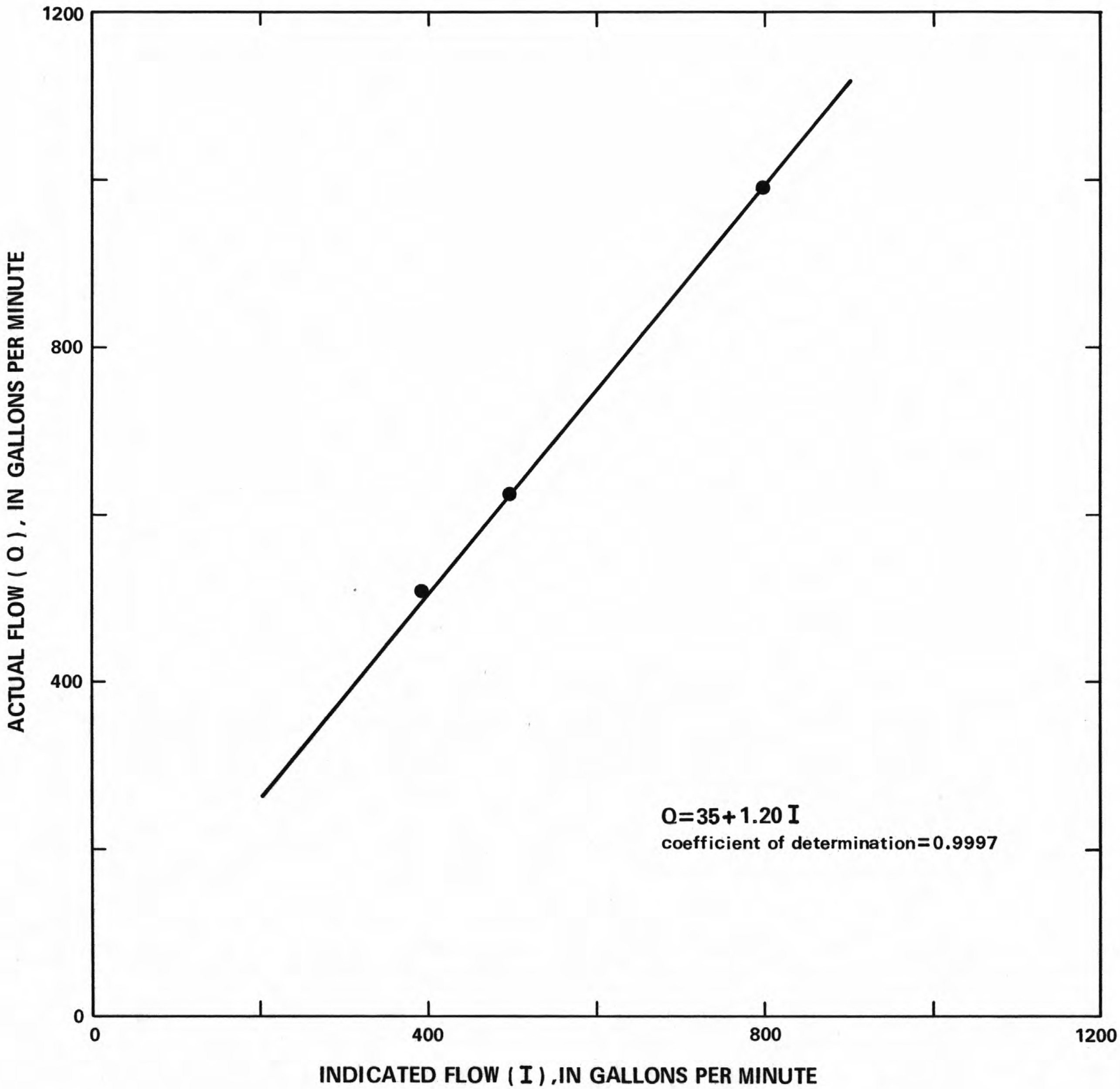

Figure 3.--Calibration curve for gated-pipe meter with 8-inch aluminum gated pipe.

DOPPLER METER

Doppler meters are electronic-acoustic devices that measure the velocity of water by measuring the Doppler shift in ultrasonic-sound waves bouncing off entrained particles, entrained air, or density interfaces due to turbulence eddies. The meter is noninvasive; that is, it is not necessary to insert a probe into the fluid stream. Ultrasonic waves from the meter probe are transmitted through the pipe wall, into the water, and are reflected back to the probe by entrained particles or eddies.

The meter tested was a Bestobell Doppler flow meter, Model No. P12, manufactured by Bestobell Meterflow Limited, Baldock, England (fig. 4), and sold in 1979 for about $1,200. All Doppler meters need some kind of a density interface to reflect the ultrasonic waves for proper operation; this model requires smaller particles or interfaces than most normally available meters.

The instrument is battery-powered and completely portable. It consists of a small hand-held readout unit that weighs about 2 pounds, and a single probe somewhat larger than a matchbox that is placed against the pipe wall. The probe contains two transducers: one for sending ultrasonic waves and one for receiving the reflected waves. The transducers are designed by the manufacturer for a specific depth of wave penetration. The readout unit consists of a velocity indicator, a sensitivity scale that indicates probable reliability of the reading, a calibration dial that is set to 5 for measuring the velocity of water, and a noise cancel adjustment. The noise-cancel adjustment cancels extraneous signals that might be received by the transducer. The effect of the noise-cancel adjustment on the sensitivity reading also gives an indication of the reliability of the velocity reading.

Laboratory Testing

Limited testing of this instrument was done under laboratory conditions. A calibration curve that was developed for 8-inch aluminum gated pipe is shown in figure 5. Distribution of the points about the line shows that, when using this calibration curve, an error of greater than 10 percent can occur in calculating actual flow in this size and kind of pipe. The manufacturer's operational guidelines indicate that an increase in accuracy might be expected as velocity increases; this phenomenon was not observed during testing. Indicated velocity on the meter would normally fluctuate several tenths of 1 foot per second for measurements at each flow rate.

The standard error of estimate of the regression line in figure 5 is slightly more than 100 gallons per minute. This indicates that this instrument could be used under laboratory conditions to predict flow within 100 gallons per minute of actual flow about two-thirds of the time. The manufacturer points out that, on pipes larger than 4 inches in diameter, the calibration may need to be adjusted, because only the velocity of the fluid near the pipe wall may be sensed by the instrument.

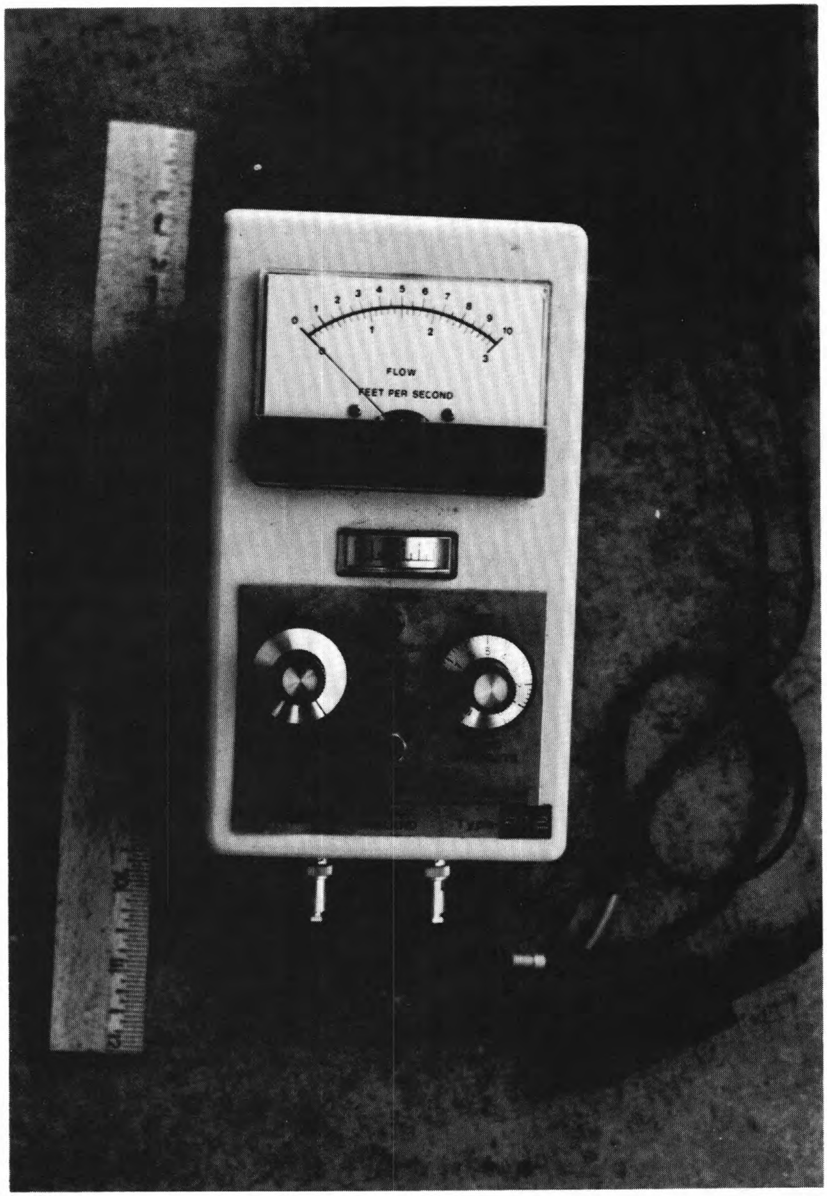

Figure 4.--Doppler meter.

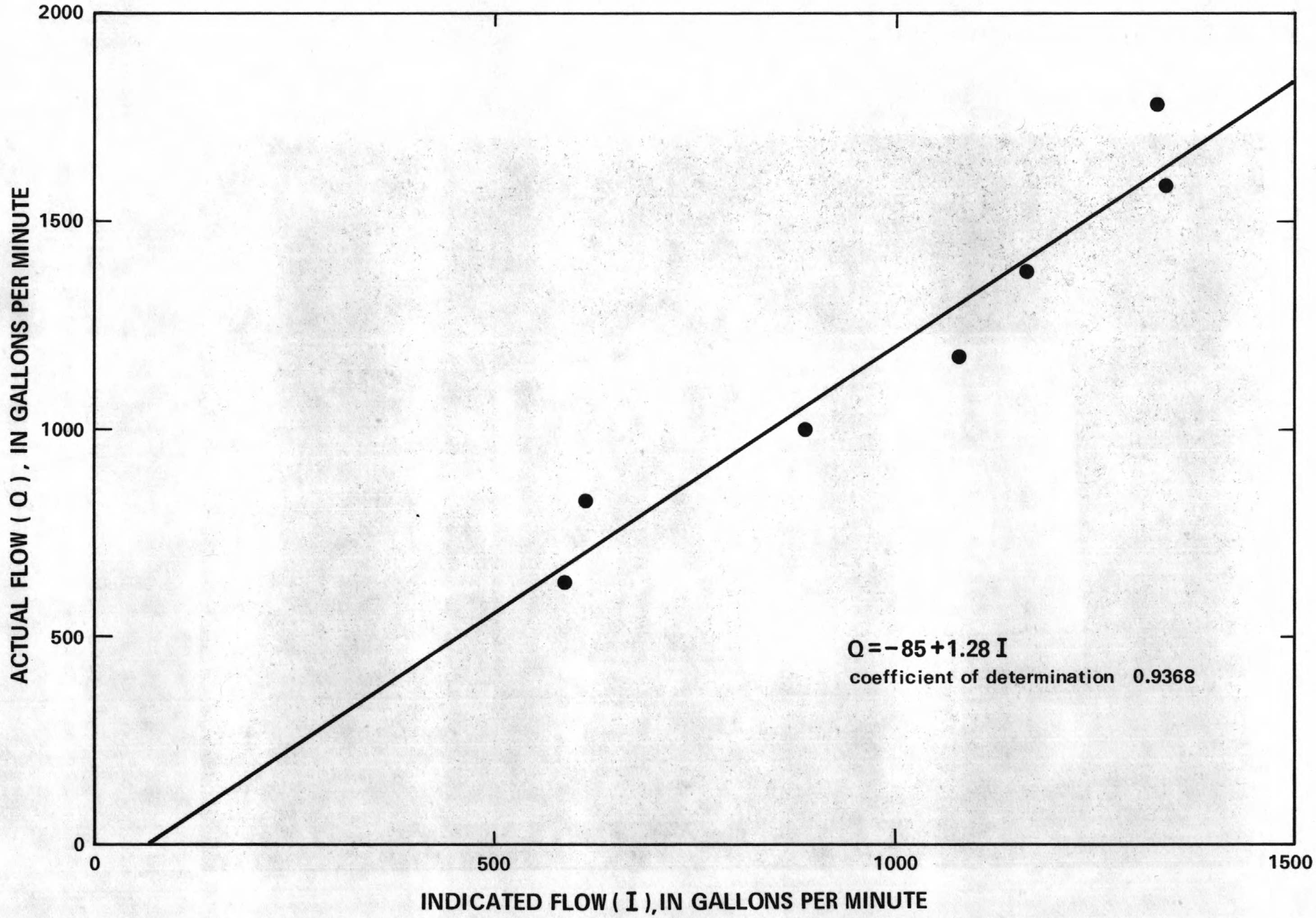

Figure 5.--Calibration curve for Doppler meter with 8-inch aluminum pipe.

Field Testing

The Doppler meter was field-tested during the 1979 irrigation season on a variety of pipe sizes and materials. The instrument is very easy to use under field conditions and seems to have the durability required for field use. The battery occasionally shorted out because of the way it was mounted in the instrument, but this was easily remedied. Under most field conditions, an acceptable reading could not be obtained with this instrument on 6-inch diameter or larger steel pipe. In most instances the indicated signal strength was less than the minimum specified by the manufacturer's instructions. When an acceptable signal was obtained, indicated velocity was frequently grossly in error. The ultrasonic waves may not have been penetrating far enough into the fluid stream. The Doppler meter operated somewhat better on aluminum pipe; acceptable readings could be obtained on aluminum pipe of up to 8 inches in diameter. However, a number of readings around the circumference of the pipe had to be averaged to get a meaningful velocity. Variation between individual readings was large; sometimes an average of several readings would provide reasonable accuracy.

Particles or entrained air were not visible in the water at most measurement sites; however, the sensitivity scale indicated that the signal was sufficient to allow the instrument to operate properly. Even with adequate sensitivity readings and proper adjustment of the noise-cancel control, the instrument sometimes would give totally extraneous readings. For example, at a well pumping less than 100 gallons per minute, the meter indicated a discharge of nearly 1,000 gallons per minute; the reason for this discrepancy could not be discovered. Near sources of noise and vibration, such as large internal-combustion engines, the problem was greatly aggravated; but occasionally these extraneous readings would occur far from any obvious external noise or vibration sources.

Because this instrument would not work on larger-diameter steel pipes, and extraneous readings were sometimes obtained on aluminum pipes found in larger irrigation systems, testing of the instrument was terminated. Although this instrument, as presently designed, was not suitable for use with the large irrigation systems on the High Plains, it may be suitable for other sizes and kinds of pipes under other conditions.

TRANSIENT-TIME METER

The transient-time meter, like the Doppler meter, is a noninvasive meter that uses ultrasonic waves to measure the flow of the fluid in the pipe. The transient-time meter tested was a Series 240 Clampitron flow meter manufactured by Controlotron Corp., Hauppage, N. Y. (fig. 6). The unit consists of a pair of transducers that are fastened to a pipe and connected to the analog computer display unit by coaxial cables. The cables come in various lengths; 50-foot cables were used on the instruments tested. The display unit is a large metal box that weighs about 28 pounds and is about 13 inches on each side. This display unit contains the electronic circuitry that generates ultrasonic pulses, analyzes incoming signals, determines that

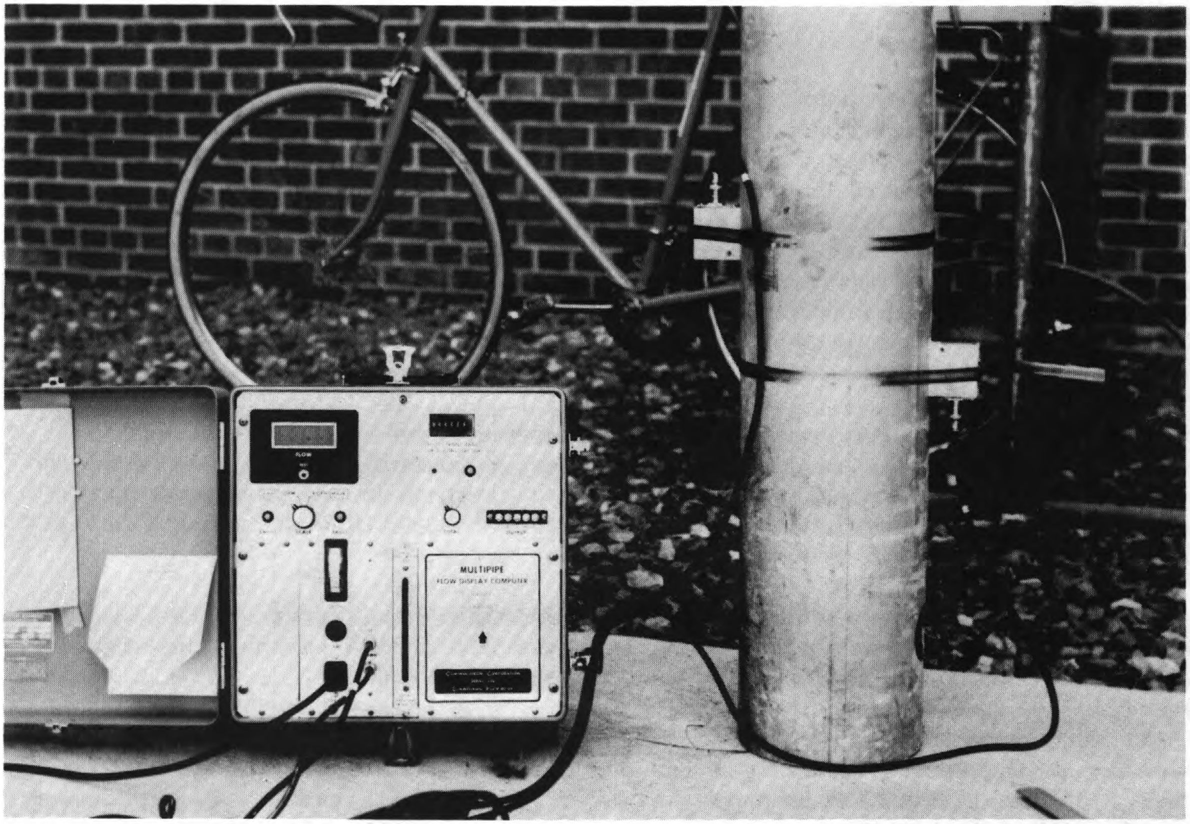

Figure 6.--Transient-time meter.

an adequate signal is being received, and displays flow rate in gallons per minute. This display unit also contains a scale that indicates when transducers are properly spaced on the pipe, and indicator lights that show if a faulty signal is being received or if the pipe is empty. The unit also contains a volumetric totalizer and may optionally contain an analog output signal for connection to another recorder. This unit is not specifically designed as a portable field unit. It requires 115-volt a-c power at 50 to 60 hertz. The power requirements are small (50 watts); but, if a portable generator is used, it must provide proper voltage and frequency.

This is the most expensive instrument that was tested; with the options that were selected, the delivery price in 1979 was more than $5,000. The purchase price varies with the options selected. The instrument is designed and manufactured with a plug-in module and transducers for use with one specific type and size of pipe; additional modules and transducers can be purchased for use with other pipe sizes and materials. Separate modules and transducers must be used with each additional pipe size or material to be measured, if the unit is to provide a correct readout of the discharge; the cost of each additional set ranged from about $930 to $2,140 in 1979, depending on the pipe size and material specified.

During operation of this meter, the two transducers are placed on diametrically opposite sides of the pipe, laterally offset from each other. The transducer heads are about 2 x 2 x 3 inches and fasten to the pipe with large hose clamps. Ultrasonic pulses are transmitted through the pipe and water between the transducers, and travel time is calculated in both upstream and downstream directions. The analog computer calculates flow rate from received pulses. A digital display indicates the rate of flow of fluid through the pipe. When the instrument is used on the specific pipe size and material for which it was manufactured, the digital display should provide a direct readout of discharge in gallons per minute. Laboratory tests were conducted to determine if calibration curves could be developed that would allow this instrument to be used on pipe materials and sizes other than that for which it was designed.

Laboratory Testing

Extensive testing of this instrument under laboratory conditions was performed, because separate calibration curves were needed for each size and kind of pipe that could be used in various well installations. The instrument tested was manufactured with transducers and module for 8.625-inch outside diameter (OD) carbon-steel pipe with a wall thickness of 0.125 inch. Calibration curves that were developed in this laboratory test are applicable only to an instrument containing transducers and a module for those specifications; instruments with other specifications would require separate calibrations.

The calibration curve for a pipe almost identical to the pipe specifications for which the tested instrument was designed is shown in figure 7. This pipe is 8.625-inch OD carbon-steel pipe with a measured wall thickness of 0.122 inch. The curve shows that the indicated flow rate from the instrument readout and the actual flow rate are almost identical, for rates ranging from 200 to 1,800 gallons per minute. This test was repeated using two instruments with the same design specifications for pipe size and material that were manufactured at different times. Both instruments produced readings that were virtually identical for the entire flow range.

The calibration curve for 8-inch thin-wall steel tubing is shown in figure 8; this tubing has an 8.00-inch OD and a wall thickness of 0.100 inch. The figure shows that the digital readout must be corrected to obtain actual flow. However, there is a linear relationship between indicated flow from the instrument readout and actual flow; deviations of individual data points from the straight-line relationship are extremely small. Tubing used in this test is similar to that commonly used in riser pipes of center-pivot systems.

Errors in the predicted actual flows for figure 8 are shown in figure 9. Errors range from -3 gallons per minute to +12 gallons per minute, and appear to be randomly scattered about the zero line. The errors do not appear to be related to the flow. A plot of errors for all the calibration curves had this same random pattern.

The 17 calibration curves for various pipe sizes and materials developed for this instrument are summarized in table 1. Fourteen of the curves are for steel pipe; two are for aluminum pipe; and one is for PVC pipe. These calibration curves include many of the pipes that are likely to be found in large irrigation systems.

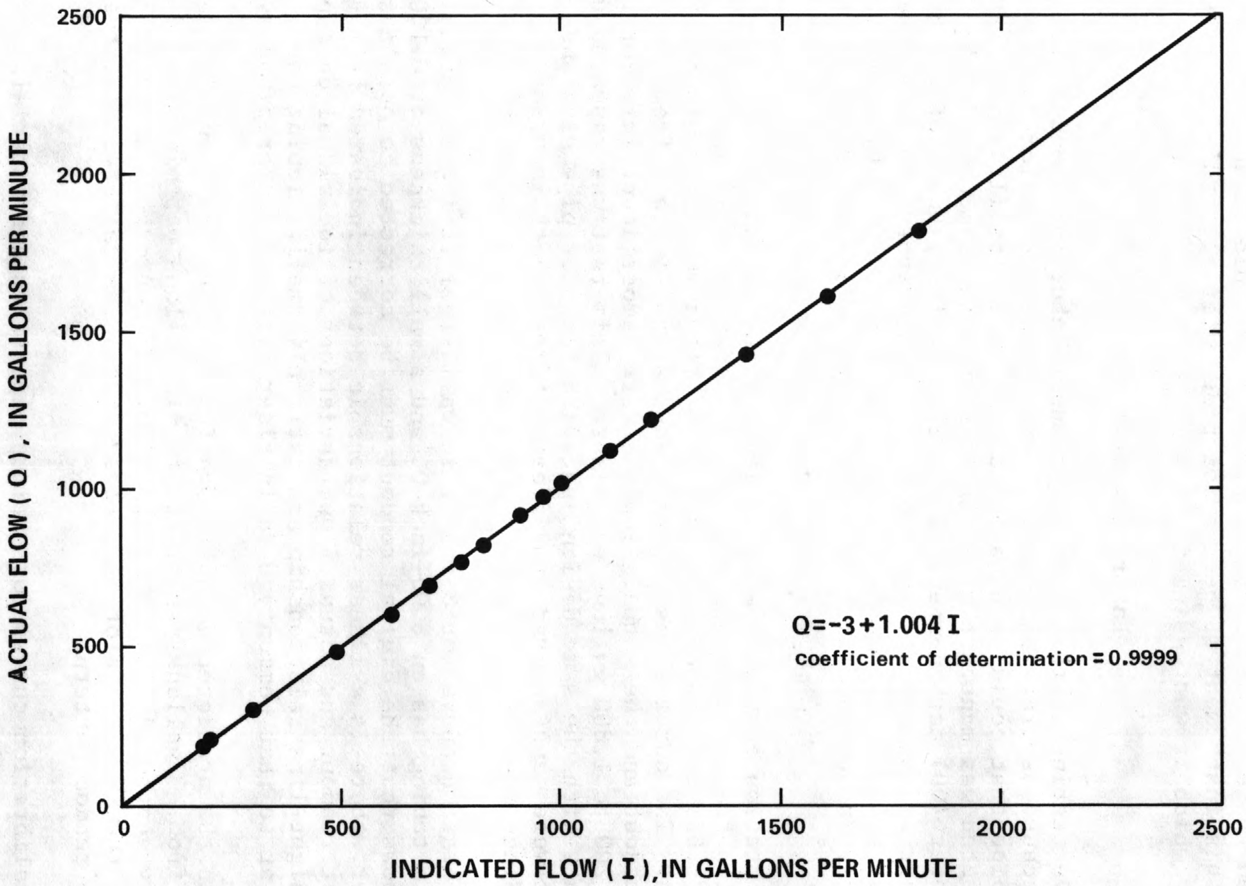

Figure 7.--Calibration curve for transient-time meter with 8-inch steel pipe.

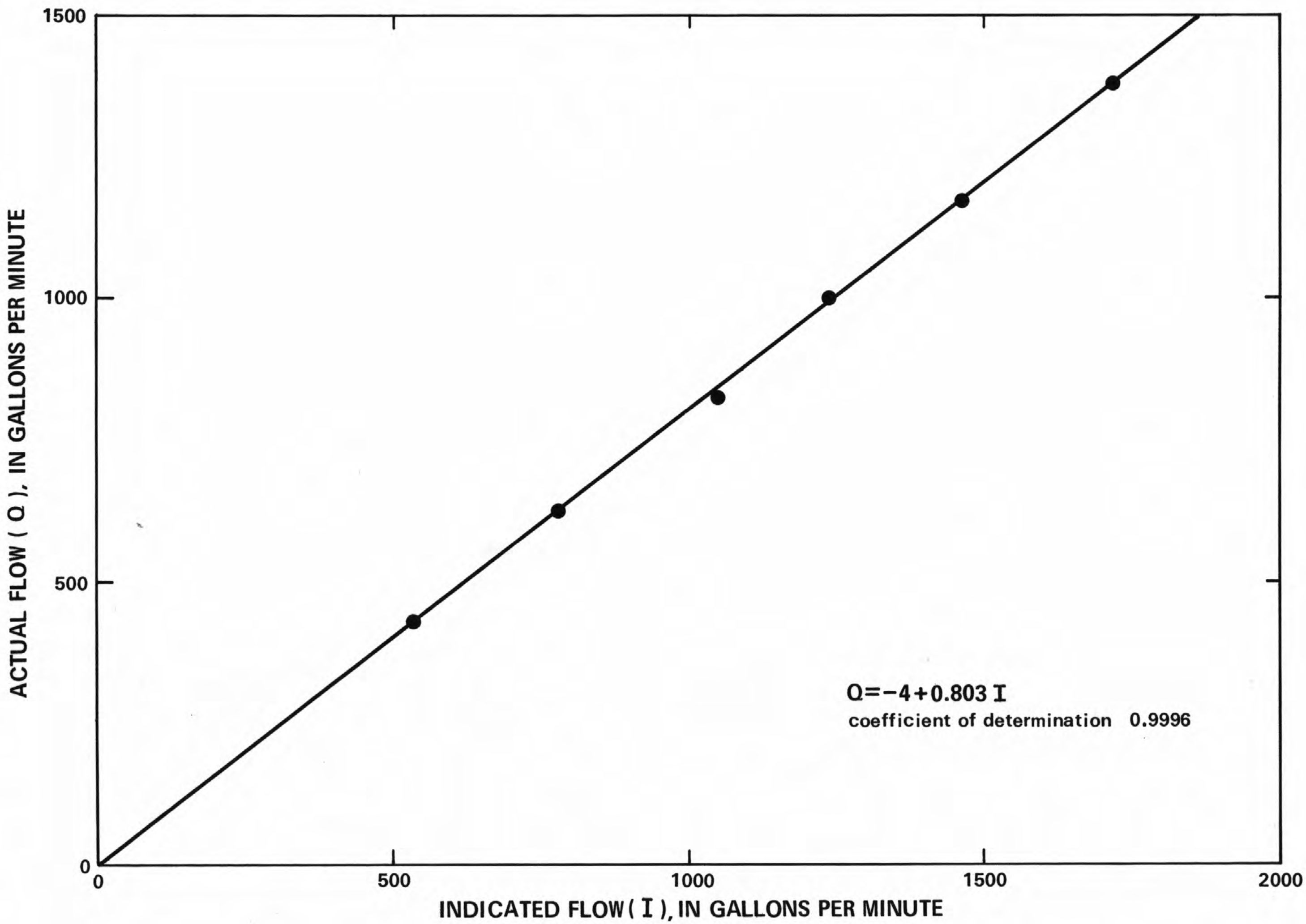

Figure 8.--Calibration curve for transient-time meter with 8-inch thin-wall steel tubing.

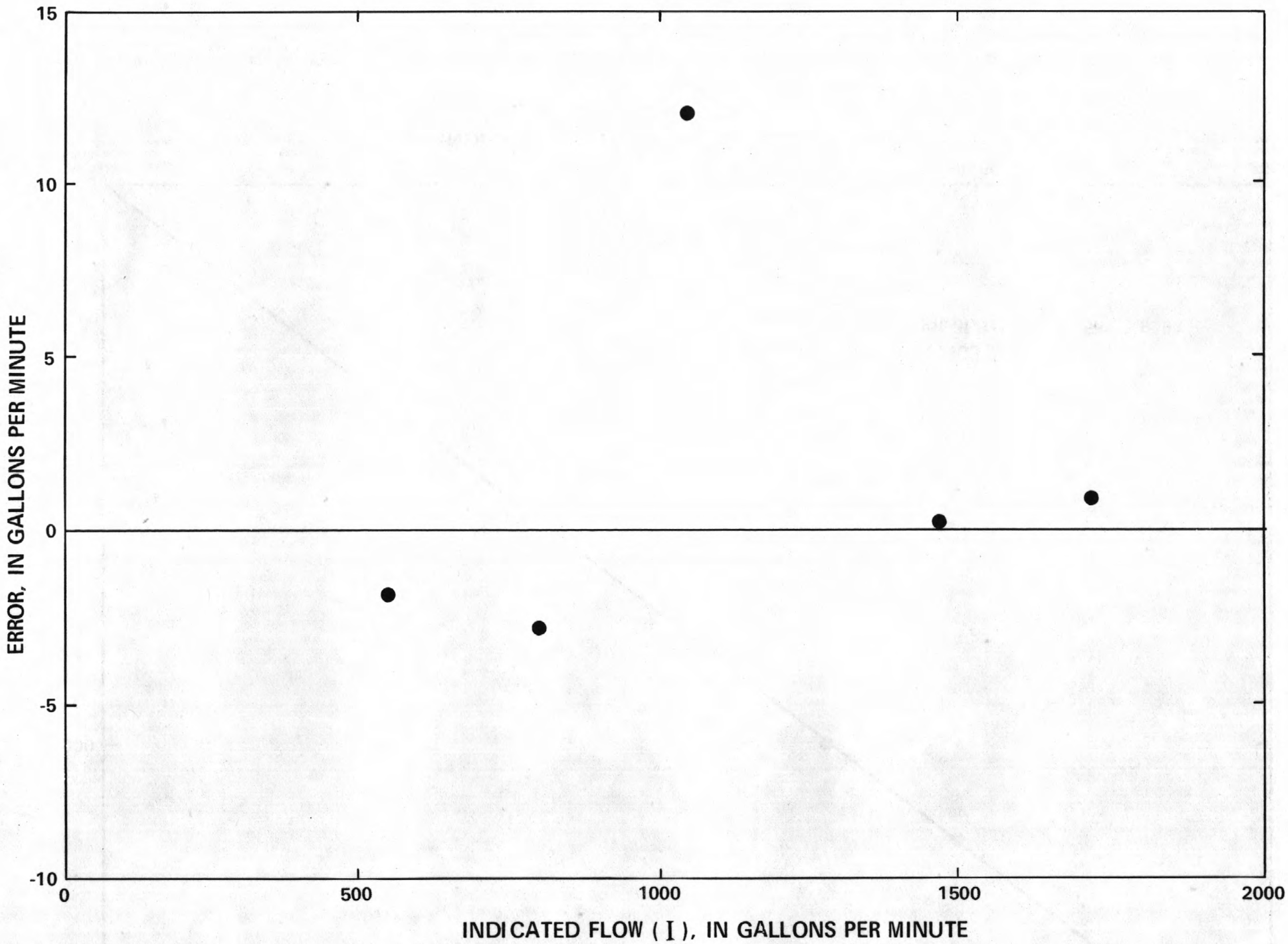

Figure 9.--Error points for transient-time meter with 8-inch thin-wall steel tubing.

Table 1.--*Calibration information for transient-time meter with typical pipes found in large irrigation systems*

[These calibrations can be used only for a 240 series Clampatron flowmeter manufactured by Controlotron Corp. for 8.625-inch outside diameter carbon-steel pipe with 0.125-inch wall thickness]

Pipe material	Outside diameter (inches)	Wall thickness (inches)	Spacing	Intercept	Slope	Coefficient of determination (r^2)
Steel	6.03	0.115	6.0	1.1	0.500	0.9999
Steel	6.03	.115	6.0	2.4	.499	.9960
Steel	6.03	.115	7.0	1.2	.568	1.0000
Steel	6.03	.115	7.4	1.6	.612	1.0000
Steel	6.65	.310	7.0	-1.5	.694	1.0000
Steel	8.00	.100	7.0	-3.9	.803	.9996
Steel	8.03	.125	7.0	4.5	.804	.9994
Steel	8.625	.122	7.0	-2.7	1.004	.9999
Steel	8.625	.191	7.0	18.3	.971	.9981
Steel	8.625	.284	7.0	-6.6	.962	.9968
Steel	8.65	.296	7.0	7.9	.946	.9961
Steel	8.65	.300	7.0	7.9	.946	.9961
Steel	10.05	.160	8.0	-26.2	1.445	.9993
Steel	12.00	.147	9.5	-11.6	2.201	.9999
Aluminum[1]	6.00	.04	5.0	5.4	.452	.9998
Aluminum[1]	8.00	.06	7.0	-12.2	.842	.9986
PVC	6.625	.121	6.0	6.8	.540	.9996

[1]Gated irrigation pipe; transducer heads placed 45° off plane of gates.

Slope and intercept values from table 1 should be used to compute the flow using the equation:

$$Q = \text{intercept} + (\text{slope} \times I) \quad (1)$$

where

Q = corrected flow, in gallons per minute; and

I = indicated flow from the instrument readout, in gallons per minute.

The coefficient of determination (r^2) in table 1 is a measure of the correlation between actual and indicated flow and represents the proportion of the total variation that is explained by the regression; the correlation was excellent for all 17 calibrations. The spacing value in the table comes from the display unit; the spacing is used to properly position the transducer heads on the pipe. The manufacturer indicates that the spacing is related to the density of the fluid in the pipe and should be set to 7.0 for water. This spacing was used when possible; however, some pipe sizes and materials require a different spacing value to obtain an acceptable signal. When these calibrations are used, the spacing must be set to the value indicated in the table.

Tests were conducted to determine how distorted flow fields, caused by elbows or obstructions in the pipe, could affect the response of the instrument. Distorted flow fields can be avoided by making measurements on straight sections of pipe, at least 5 to 10 pipe diameters from elbows or obstructions. When this was not possible, the most accurate and consistent measurements were obtained by placing the transducer heads at a 45-degree angle to the plane of distortion. Reasonably accurate measurements were obtained as close as three pipe diameters from right-angle elbows and gate valves by placing the heads at a 45-degree angle to the plane of distortion. If the plane of distortion cannot be determined, the best results can be obtained by averaging measurements made at several angles around the pipe.

The gated aluminum pipe used in the calibration tests had rubber gaskets around the gates that protruded inside the pipe. The two calibrations for aluminum pipe given in table 1 were developed with the transducer heads placed at a 45-degree angle from the plane of the gates, because of probable distortion in the flow field from protruding rubber gaskets.

Field Testing

The manufacturer did not design this meter as a field instrument; however, it did operate well under field conditions for the entire 1979 irrigation season. Calibration of one of the instruments was checked early and late in the season and it did not change. The instrument was handled in a reasonable manner, but with no special packing or handling.

Electrical power requirements of the instrument (115-volt a-c power at 50-60 hertz) was an inconvenience; a portable generator had to be taken to the well site. A small generator that weighs less than 40 pounds had the correct electrical characteristics, so the problem of providing electrical power was minimized. However, where it was necessary to walk to the well site, even this generator proved too heavy for comfort.

The size of the display unit made it cumbersome to handle. If only one person was at the site, it was necessary to carry the display unit and the generator to the measurement location so the spacing indicator could be observed while placing the transducer heads on the pipe. If two people were at the site, the display unit and generator were generally left at the vehicle, and one person observed the display unit while the other person adjusted the heads on the pipe. When it was necessary to climb a tower on a center-pivot system to make the discharge measurement and only one person was at the site, the person had to climb up and down the tower several times to get the transducers adjusted properly.

The fault indicator and the empty-pipe indicator lights were extremely useful; they would alert the operator immediately if a valid measurement could not be obtained. Near large internal combustion engines, the fault indicator would often light and the instrument would fail to give a reading; this problem could generally be solved by moving a short distance away from the engine.

The flowmeter had an optional totalizing meter that indicated the total volume of fluid flowing through the pipe in a given time period. A long-term average flow could be measured by using the totalizer and a stopwatch. In most instances, this would be better than using the short-term indicated flow from the digital readout, because the readout tends to fluctuate.

NEED FOR FURTHER TESTING

The testing done by the staff of the High Plains project during 1979 was limited to a few selected meters. Testing was not all inclusive and did not consider all possible meters suitable for measuring discharge in irrigation systems. Meters for measuring open-pipe discharge were not tested because this type of irrigation system is not common in the High Plains. In-line flow meters were not tested because the expense of installing these meters precluded their use in this study.

Further testing of the equipment discussed in this report remains to be done. The gated-pipe meter was laboratory tested on only one size of pipe, and at only three flow rates. This meter needs to be tested for a much greater range of flows for all common types of gated pipe. If possible, the meter needs to be calibrated for 4-inch, 6-inch, 8-inch, 10-inch, and 12-inch aluminum gated pipe, plus the common sizes of the PVC gated-pipe now available. Testing also needs to determine if this meter would be appropriate for measuring flow in flexible wall, collapsible gated pipe now being used in some areas.

Further testing also is needed for the Doppler meter. Only limited tests were conducted, because the reliability of the instrument could not be proven for use with large pipes. The meter may be appropriate for use on smaller diameter pipes and certain kinds of materials. Additionally, design changes may be possible which would make it suitable for use on larger pipe sizes. Calibration curves for the Doppler meter need to be generated for aluminum gated pipe less than 8 inches in diameter, and for steel pipe less than 6 inches in diameter. The current version of the meter probably could not be expected to give reliable results for pipes of larger diameters.

Although extensive testing was done on the transient-time meter, additional testing remains. Calibration curves were developed for most of the sizes and materials of pipe that are commonly used in the High Plains. However, testing was not sufficient to develop a general calibration formula that would include such factors as outside diameter, wall thickness, material, and spacing. Data acquired during this series of tests indicate that it may be possible to develop a calibration formula for general classes of pipe rather than each specific pipe. If this could be done, it would eliminate the necessity of developing a calibration curve each time a slightly different size of pipe is encountered. Additionally, the instrument needs to be tested to determine if it can measure the discharge in pipes of larger or smaller diameter than the range that was reported here.

SUMMARY AND CONCLUSIONS

Three instruments for measuring discharge in large irrigation systems were tested by the staff of the High Plains Regional Aquifer System Analysis project during 1979 under both laboratory and field conditions. The gated-pipe meter was found to be difficult to use and sensitive to particulate matter in the fluid. However, with proper training, experience, and calibration, this meter could have the potential to be used for measuring discharge in gated pipe.

The Doppler meter was easy to use, but acceptable measurements could not be obtained on steel pipe 6 inches or larger in diameter and on aluminum pipes larger than 8 inches in diameter. The meter seldom generated sufficient signal to obtain reliable measurements on steel pipe.

The transient-time meter is more difficult to use under field conditions than either the Doppler or gated-pipe meters. It takes a considerable amount of time and skill to set up the instrument properly. However, testing of the instrument indicates a high degree of accuracy and reliability in discharge measurements obtained under field conditions. The instrument clearly indicates when invalid signals are received.

Based on the results obtained in the testing of discharge-measuring instruments during the 1979 irrigation season, the transient-time meter will be the principal flowmeter used by the High Plains project for the 1980 irrigation season. Although costly, this instrument gave the most accurate and reliable results. The other meters tested might be appropriate for use in situations where different kinds of irrigation systems are in use.

REFERENCE CITED

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