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INVESTIGATION OF A 10-INCH VERTICAL FLOWMETER, FLOW CONTROLLER, AND INTEGRATOR

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16. ABSTRACT

A newly developed 10-in. (25.4-cm) rotameter-type flowmeter and flow controller was studied in the laboratory. The flow control meter totalizes flow, indicates flow rate, controls flow to present rates over a large range of line pressure, and provides shutoff. Laboratory head loss, accuracy, and other operational tests were performed. Data analyses indicated potential totalization accuracy of better than plus or minus 2%. No mechanical and operational difficulties were experienced for head differentials between 170 to 20 ft (52 to 6 m) of water. For head differentials of less than 20 ft, the meter shut off slowly and often leaked excessively. The design of the meter has potential economic advantages, and the difficulties encountered in the laboratory could probably be resolved by further research and development. The new flowmeter controllers are in use in a water district, and monthly operation and maintenance reports are made. Laboratory studies and field experience can be used to define more fully specifications for low-head operation in future contracts.

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Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION
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INTRODUCTION

Recently a rotameter-type farm delivery turnout meter has been developed. The meter incorporates a rate-of-flow indication, a controller to maintain preset supply rate at any pressure from free-flow head to maximum design head, an integrator to totalize the water delivered, and a shutoff of flow all in a single unit without an external source of electrical power. Presumably this combination of a flow-measuring device and high-limit flow control would require less supervision of the turnout by operating personnel.

Westlands Water District has been considering a limited-demand type of operation. This allows the farmer to turn the flow controller meter on and off but limits him to a locked preset maximum delivery rate. The district recognizes that the control flowmeter can be adopted for remote turning off or on and for varying the maximum delivery limit. Telemetry can be provided to transmit information to a computerized monitoring and operation center. The design concept of this control flowmeter offers possible economic advantages from an operating standpoint, provided the meter is accurate enough and is relatively free of maintenance problems.

The manufacturer supplied 70 meters to the Westlands Water District of the San Luis Unit. Messrs. J. C. Gilbert and H. E. Sheda, formerly of the Mechanical Branch made a field examination of five of these meters that were installed for varying periods in the Westlands Water District distribution system. They recommended comprehensive tests to finalize consideration of the meters for future specifications and installations.

One 10-inch (25.4-cm) vertical flowmeter, flow controller, and integrator was set to the Hydraulics Branch for testing. The specifications for this meter are included in the appendix. This meter has a rated flow range from 0.6 to 6 cfs (17 to 170 l/sec) and an operating head range up to 175 feet (53.3 meters) of water. The normal design flow for this meter is 3 cfs (85 l/sec).

Tests requested by the Hydraulic Structures Branch included accuracy of the rate-of-flow indication, totalization accuracy, head loss, opening and closing time, opening and closing reliability, closure leakage, and vibration during flow. This report covers results of laboratory tests made by the Hydraulics Branch from November 1967 to April 1968.

SUMMARY

Laboratory tests indicated that the minimum head loss required to pass the normal flow of 3 cfs is 30 inches of water (85 l/sec, 76 cm of water) as measured during laboratory tests of free or uncontrolled flow.

The flow controller regulates flow to a set discharge to within 2 percent as the head differential decreases from 170 to 20 feet (51.8 to 6.1 meters).

The flow control meter registered and indicated discharge about 6 percent greater than the laboratory discharge. This excess delivery was verified by tests of an independent third party. However, statistical analysis of the average dial indicator data indicates that with proper calibration and adjustment the flowmeter dial readings could indicate the discharge to an accuracy of ±5.5 percent true discharge. Statistical analysis of totalization data indicates a potential integration accuracy to within ±2.0 percent of true totalized flow.

Most operational difficulties were experienced at head differentials less than 20 feet (6 meters) of water. These difficulties included slow closing times and poor valve seating with greater leakage than specified.

Slow controller reaction to sudden large increases of pressure was experienced and flow of about 100 percent over a set discharge was delivered for about 5 minutes. Once the meter did not resume control after a sudden large increase of pressure.

Accelerometer measurements showed that no excessive vibration caused by flow around the meter float occurred during the laboratory investigations.

The flowmeter controller has certain recognized potential advantages. These laboratory studies can be used to help write specifications covering low-head capabilities when design requires such specifications. These low-head requirements would encourage the manufacturer to conduct further research and development to alleviate low-head operational problems noted during these laboratory tests.

DESCRIPTION AND CAPABILITIES OF FLOW CONTROL METER

Meter Capabilities

The vertical flowmeter, flow controller, and integrator combines capability of (1) flow measurement of instantaneous rate of flow and an integrator for totalized flow in acre-feet, (2) limiting of flow to a preset maximum rate or to maintain a nearly constant flow rate over a range of head by adjusting the set point, and (3) valve to shut off or turn on delivery to the customer all in a single unit. External electrical power is not required. However, internal power supplied by batteries is required for the integrator to totalize flow in acre-feet. An assembly drawing of the flowmeter is shown in Figure 1.

Flow Measurement

Basically the meter is a rotameter-type or variable-area flowmeter, Figure 1. Water enters the meter vertically from the bottom, flows upward and around the "metering float" in a "tapered throat," and leaves horizontally through the side outlet of the meter. The metering float moves upward from the seat in response to increasing flow rates through the meter. The position of the float in the tapered throat is determined by the balance of the upward thrust of the flowing water and the submerged weight of the metering float. The shape of the float and tapered throat causes the float to seek a unique elevation for a given discharge. Therefore, the meter can be calibrated in desired units of flow.

Conversion of Float Elevation to Readout

A round hollow "float shaft" extends through the center of the float and is guided for vertical movement by bearings, Figure 1. The "float shaft" extends up through the meter "top cover plate" into the "indicator-integrator unit." A "permanent magnet" is attached to the top end of the "float extension rod." As the flow increases from 0 to 6 cfs (170 l/sec) the permanent magnet is raised the same distance as the float. Not shown in Figure 1 is a vertical shaft, external to but coupled magnetically to the float extension rod, that converts change in float elevation into rotation.

The rate of flow is indicated by a pointer attached to the top of the shaft. The position of the pointer indicates the flow on a scale calibrated in cubic feet per second (cfs).

Delivery Totalization

For totalizing delivery flow, a horizontal cam is attached to the top of the vertical rotating shaft. A contact lever timed and operated by an electric clock and motor touches the cam once every minute. When there is no flow through the meter a reed switch responds to the magnet on the float extension rod and breaks the circuit to the motor of the contact lever drive. During flow the stroke of the contact lever from rest position to cam contact is accumulated by a digital dial counter. The cam is cut to proportion the length of stroke to the rate of flow. The dials read totalized flow in acre-feet accumulated at 1-minute intervals.

Setting Discharge Limit

Varying the maximum discharge limit of the meter is accomplished by raising or lowering the "pilot valve seat" by means of the "set point hand wheel," Figure 1. The top end of the float shaft is beveled to mate with or act as a needle for the pilot valve. When the needle is seated in the pilot valve, the float cannot rise. If the inlet pressure continued to increase the discharge would increase but seating of the pilot needle valve prevents bypass relief of the pressure on the "control piston" which is sealed with respect to the meter body by a "flexible diaphragm." As pressure increases on the control piston, it is forced downwards. A "sleeve valve" containing orifices is attached to the control piston. The orifices on the valve are shaped to restrict flow as the sleeve is forced downwards. Thus, inlet pressures in excess of that required to just seat the pilot valve is consumed as orifice loss rather than the meter delivering more water. When the inlet pressure drops below that required to seat the pilot valve, the float drops as the discharge reduces.

Closing and Opening

To shut off flow from the meter, all that is necessary is to close a small "external valve," Figure 1. The external valve controls the pressure bypass flow and thus the pressure in the "control chamber." When the external valve is shut, the pressure on the control piston builds up to the inlet pressure and the sleeve valve is forced downward until the "O-ring" at the top of the sleeve seats and shuts off the delivery flow. To open the flowmeter and controller, the small external valve is opened.

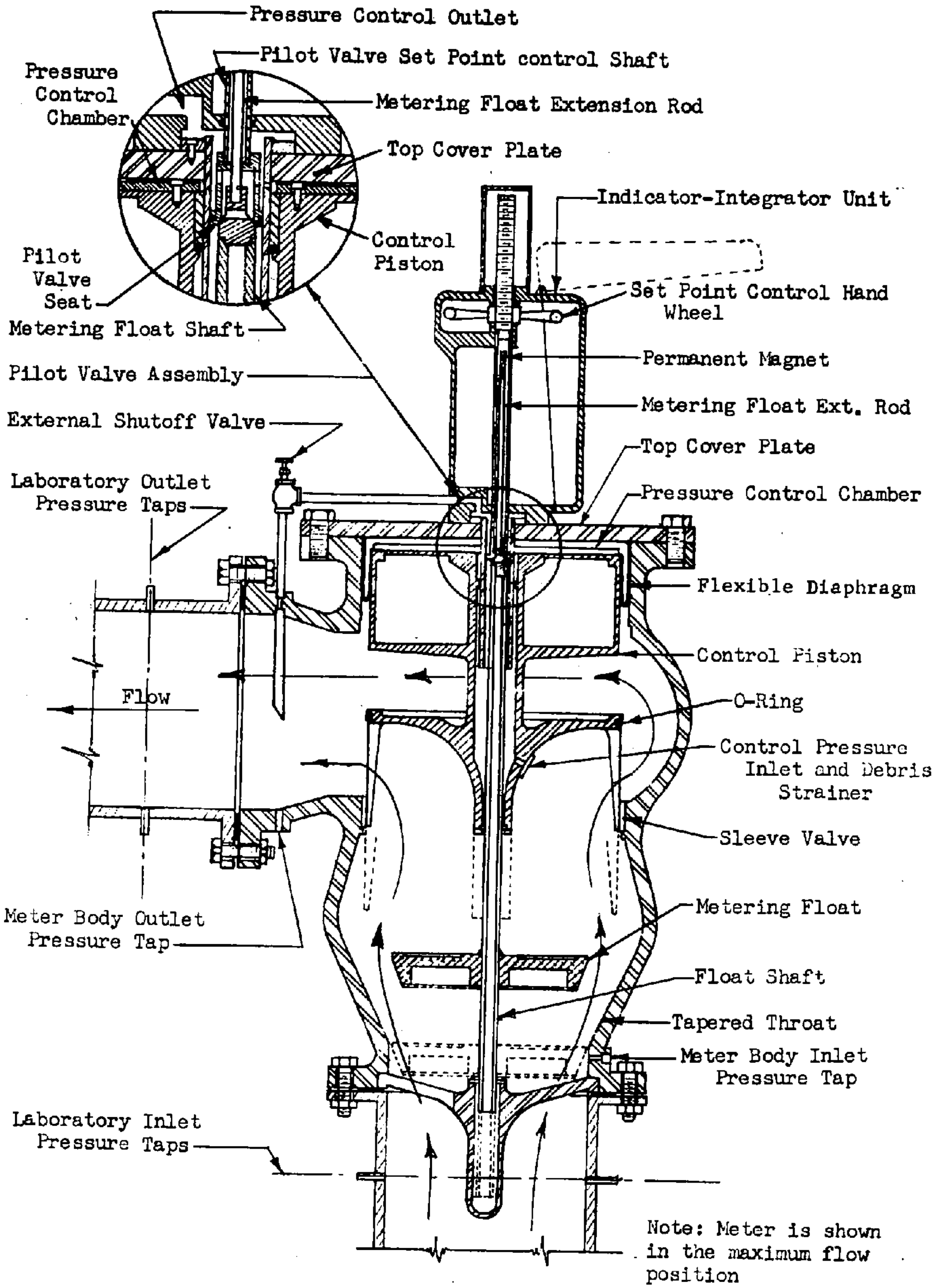

Figure 1. Assembly drawing.

LABORATORY INVESTIGATIONS

Installation

The flowmeter controller was uncrated, inspected, and initially installed with the assistance of manufacture representatives and according to their instructions.

Water was pumped from the laboratory supply through a 12-inch (30.5-cm) pipeline, through an upright tee, through a gate valve and then reduced to the diameter of the meter in 12 inches of flow length, Figure 2. On the outlet side of the meter was a short, horizontal section of 10-inch (25.4-cm) pipe, an upturned 12-inch-diameter elbow that maintained a positive outlet head and overflowed through a box back to the laboratory pump supply. Later 5 diameters of inlet pipe was added between the flowmeter inlet and the reducer to determine if an increase of approach pipe length would increase the meter accuracy, Figure 3.

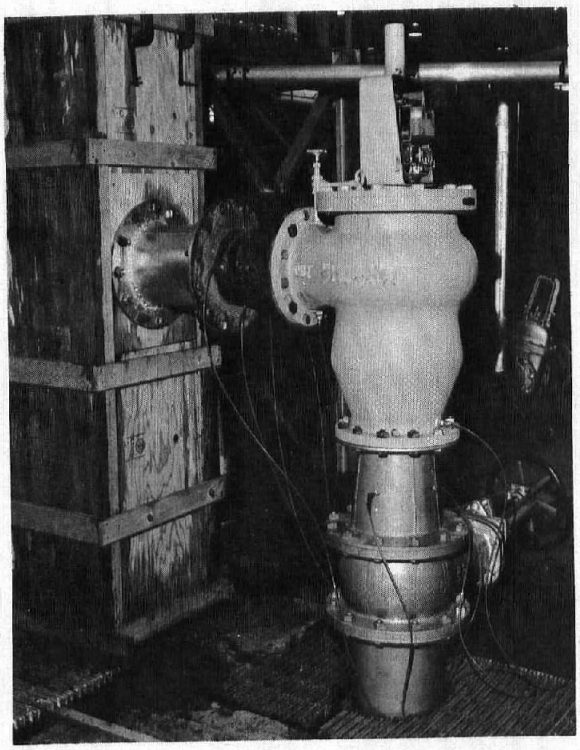

Figure 2. Initial installation of meter for laboratory tests. Photo PX-D-68156

Because the dial indicator would not return to the reference point and the totalization accuracy did not meet specifications, the meter was disassembled for inspection in the presence of company representatives.

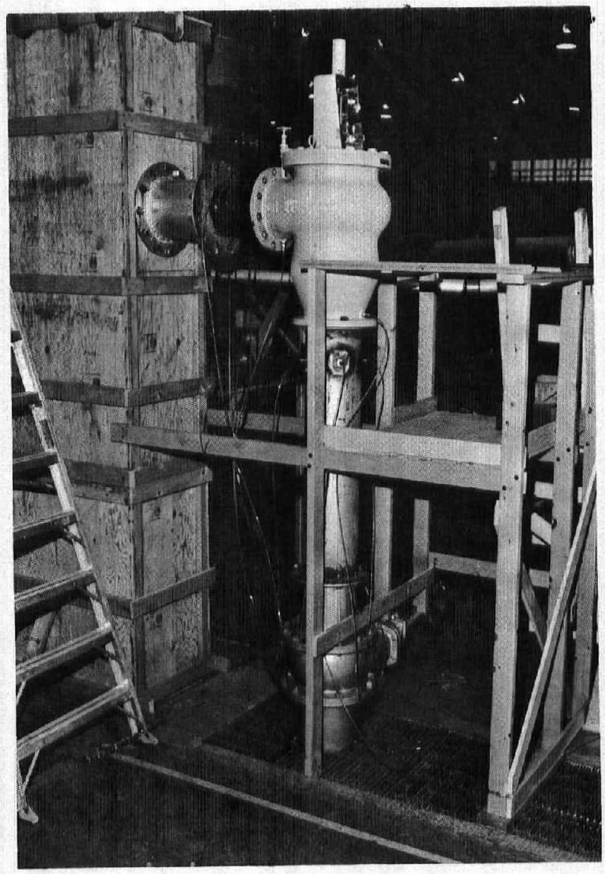

Figure 3. Meter with 5 diameters of vertical inlet approach pipe installed. Photo PX-D-68155

During this inspection, a weld bead that was interfering with referencing to zero was discovered on the metering float. The meter was returned to the factory for repair and then shipped back to Bureau of Reclamation laboratories for further testing where it was again installed with the longer vertical approach pipe.

Laboratory Measurements and Observations

Discharge measurements.—Calibrated venturi meters (Figure 4) that are permanent fixtures of the Hydraulics Laboratory were used to measure the true rate of flow through the vertical flowmeter. A mercury manometer was used to measure the head differential across the venturi meters. The manometer and a venturi were calibrated using the laboratory volumetric tank; thus, the measured flow rate to the vertical flowmeter should have an accuracy better than ±1 percent.

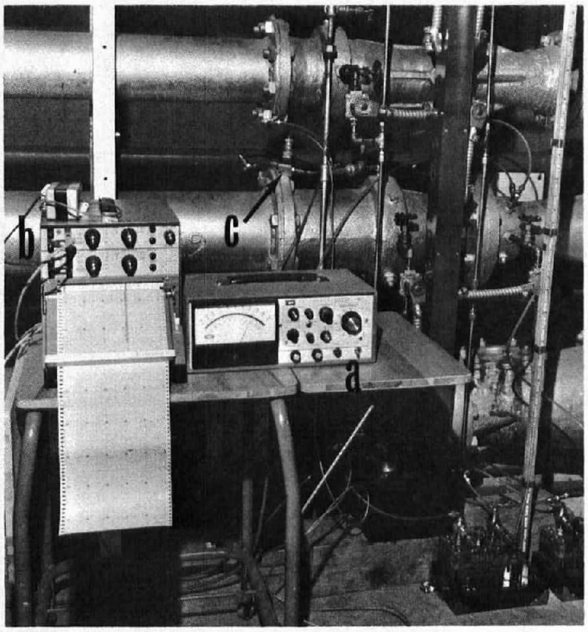

Figure 4. Head monitoring equipment, amplifier (a), recorder (b), pressure cell (c), venturis and manometer used during totalization tests. Photo PX-D-68157

Head loss measurements.—Piezometers were installed about 1/2 diameter upstream from the meter inlet and about 1 diameter downstream from the meter outlet. To obtain better average pressures at each of these measuring sections, four piezometers were placed 90° apart around the circumference of the piping and were connected to manifolds.

To obtain the differential head across the flowmeter, the manifolds were connected to manometers. For the high-head operating range and/or flow controlled by the vertical flowmeter, a mercury manometer was used. For the low-head range and/or flow controlled by a laboratory throttling valve, separate water columns were used to obtain better accuracy.

Differential head measurements were also obtained between the meter inlet and outlet from holes drilled and tapped by the manufacturer in the meter body. These holes were not ideally suited for true pressure readings but will provide convenient means for head differential comparisons if any subsequent tests of the same meter are made at a field site by operating personnel. However, all discussion of results will be in terms of data obtained with the manifolded laboratory taps.

Totalization measurements.—To check accuracy of the totalizer of the flow control meter, water was pumped through the meter for periods ranging from 1-1/2 to 6 hours. Sufficient manometer readings were taken during the test periods to determine a meaningful average discharge from the calibrated venturi meter. During totalization tests continuous charts of head differential across the venturi meter were recorded with respect to time, Figure 4. The charts were used to assure that the discharge remained essentially constant during the totalization measurements. The acre-foot dials were read at the beginning and ending of a time interval measured by a stopwatch.

Opening and closing times.—Opening and closing times were measured by stopwatch and the opening and closing of the sleeve valve was determined by observing the rate-of-flow needle and flow from the exit pipe.

Leakage.—The sleeve valve of the flow controller did not always fully close. The resulting leakage was not measured but was estimated.

Vibration measurements.—An accelerometer and recorder, Figure 5, were used to measure vibration of the flow control meter before the 5 diameters of

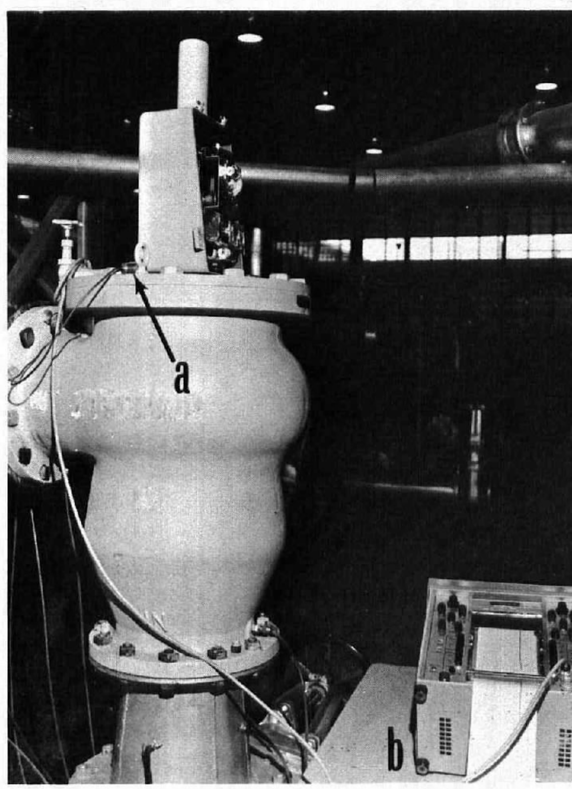

Figure 5. Accelerometer (a) and recorder (b) used to measure vibration of flowmeter. Photo PX-D-68154

approach pipe was added. The accelerometer was mounted on the meter cover plate to measure accelerations along the vertical axis of the meter, transverse to the delivery pipe, and along the axis of the delivery pipe.

Test Results

Minimum head losses.—The minimum head loss occurs for free or uncontrolled flow through the meter, Figure 6. Head loss for the initial installation is shown by the dashed line and for the additional 5 diameters of vertical pipe approaching the inlet by the solid line. These curves show that the meter meets the specifications of 30 inches of water loss at 3 cfs (76-cm water at 85 l/sec). The differences between the two curves are the result of unique flow conditions in the vicinity of the pressure taps for the additional 5 diameters of inlet approach pipe and for the short approach of the initial installation.

Controlling characteristics.—The flowmeter/controller is designed to limit the discharge by dissipating excess head through the orifices of the sleeve valve. The flow controlling characteristics of the meter are shown by the vertical curves in Figure 6. The control curves were obtained by adjusting the meter set point to give the dial reading of the discharge noted at the maximum head. Then leaving the meter set point unchanged, the motor speed of the laboratory supply pump was reduced in steps to produce data points successively approaching the minimum head for the free flow. These curves show that the discharge decreases about 2 percent as the head differential decreases from 170 to 20 feet (51.8 to 6.1 meters) of water.

Rate-of-flow indication and integration tests.—Initial tests showed that the meter did not meet the specifications stated in the Appendix that "The meter shall register any flow within ±2 percent between 25 and 100 percent of its maximum flow of 6.0 cfs (170 l/sec) and ±5 percent between 10 and 25 percent of maximum flow." Tables 1 and 2 show laboratory accuracy results for the initial installation of the meter. Compared to the laboratory venturi meter, the dial indicator averaged 6.8 percent high and integrator averaged about 9.0 percent high. The dial indicator reading during flow can be only estimated to ±0.02 cfs (0.57 l/sec) between scale divisions.

After dial and zero reference adjustments and the installation of 5 diameters of inlet approach pipe, additional dial accuracy tests (Table 3) and one integrator accuracy test were made. The dial accuracy averaged 7.8 percent high and the integrator was 9.1 percent high.

Table 1

INDICATOR ACCURACY
Initial laboratory installation
meter not controlling

Discharge		
Laboratory venturi cfs (lps)*	Vertical flowmeter cfs (lps)	Indication percent
1.044 (29.56)	1.15 (32.6)	110.0
2.009 (56.89)	**2.183 (61.81)	108.7
2.026 (57.37)	2.2 (62.3)	108.6
2.846 (80.59)	3.0 (84.9)	105.4
3.020 (85.51)	**3.18 (90.0)	105.3
3.035 (85.94)	3.15 (89.2)	103.8
4.002 (113.3)	4.3 (121.8)	107.4
4.028 (114.0)	**4.28 (121.2)	106.3
5.014 (142.0)	5.35 (151.5)	106.7
6.019 (170.4)	6.4 (181.2)	106.2

*Liters per second.
**Average dial reading during totalization tests.

Table 2

TOTALIZER ACCURACY
Initial laboratory installation
meter not controlling

Discharge		
Laboratory venturi cfs (lps)*	Computed from vertical flowmeter registration cfs (lps)	Registration percent
2.009 (56.89)	2.183 (61.81)	112.7
2.846 (80.59)	3.00 (84.95)	108.0
3.020 (85.51)	3.180 (90.04)	106.8
4.028 (114.0)	4.28 (121.2)	108.4

*Liters per second.

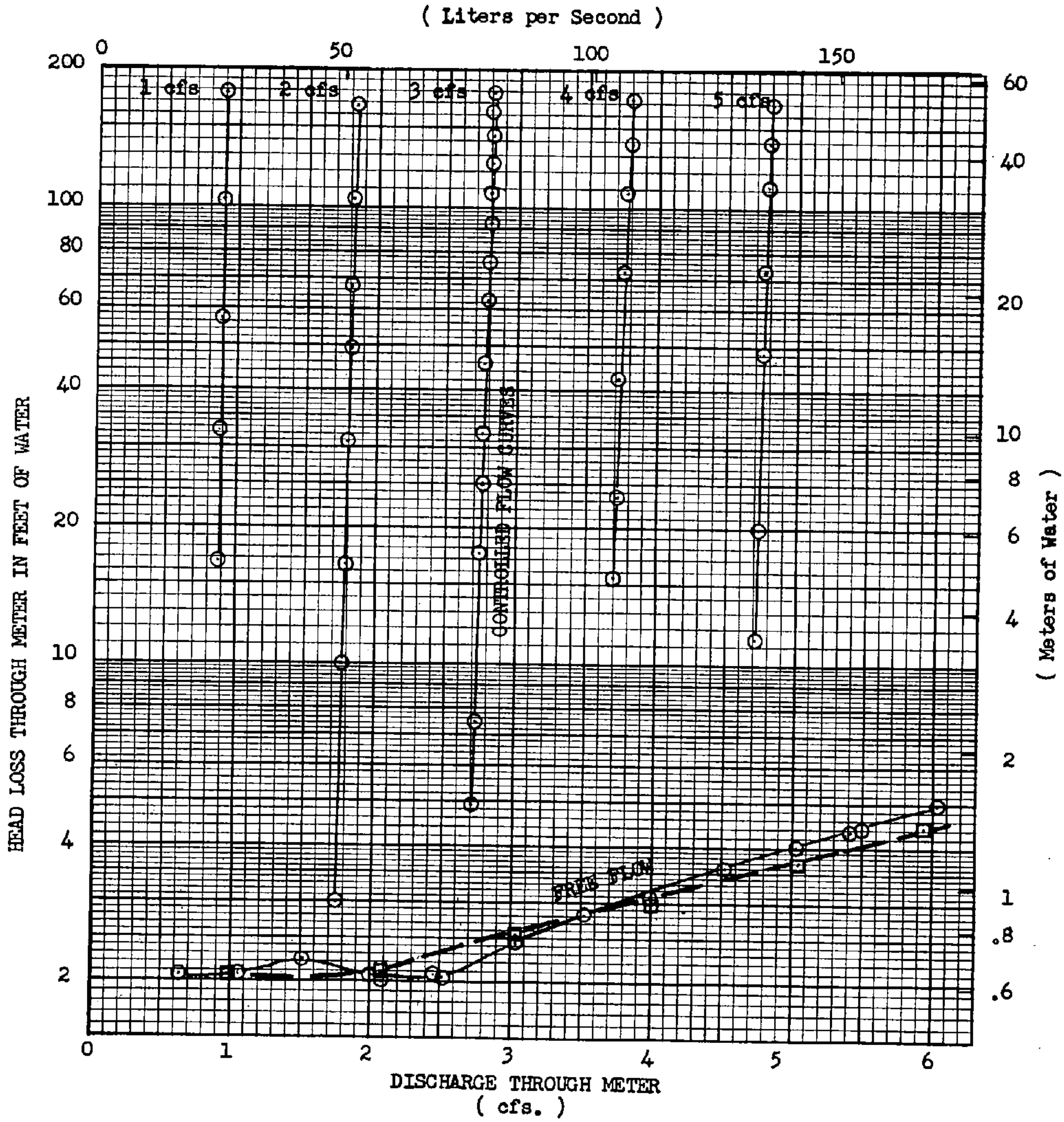

Figure 6. Head loss versus discharge.

Table 3

INDICATOR ACCURACY
5 diameters of inlet approach pipe added, meter not controlling

Discharge		
Laboratory venturi cfs (lps)*	Vertical flowmeter cfs (lps)	Indication percent
1.030 (29.16)	1.15 (32.6)	111.6
2.085 (59.04)	2.25 (63.7)	107.8
3.022 (85.57)	3.18 (90.21)	105.4
3.024 (85.63)	3.25 (63.7)	107.4
4.009 (113.5)	4.30 (121.8)	107.2
4.014 (117.2)	5.40 (152.9)	107.7
5.939 (168.2)	6.40 (181.2)	107.7

*Liters per second.

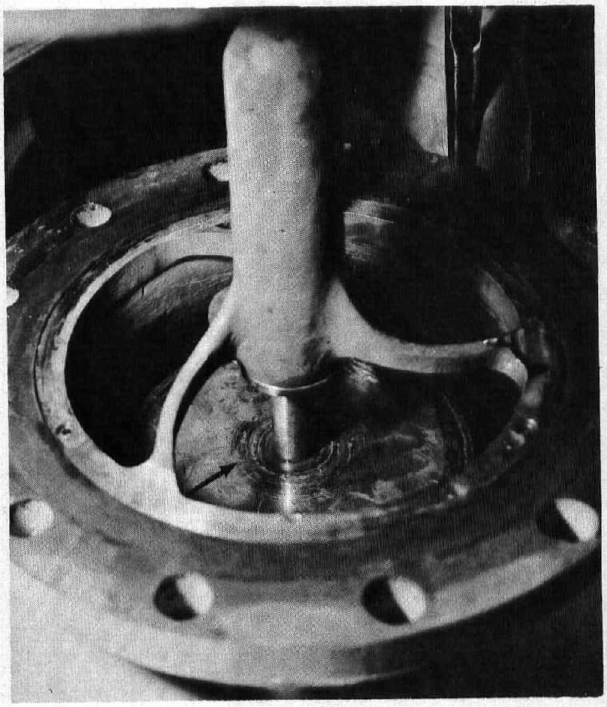

Figure 7. Weld bead on meter float. Photo PX-D-68153

Representatives of the manufacturer were concerned about the results of the accuracy measurements and came to the Hydraulics Laboratory to determine the cause of the high discharge readings. The meter was unbolted and lifted to examine the float assembly. A circular weld bead of variable height was found on the bottom of the float. The bead was in line with the heads of the three cap screws used as the zero reference level for the float, Figure 7. The calibration of the meter for the full range of discharge is referenced from this level. The variable thickness of the weld bead caused as much as 1/8-inch (about 3-mm) variation in the position of the indicator. The cam for the integrator could not be calibrated properly because of the lack of a fixed reference. The manufacturer's representatives indicated that this weld was used on only one float of an experimental meter. All production meters have a positive float seat for indicator reference. The representatives requested that the meter be sent back to the factory to modify the float and to recalibrate the meter.

Accuracy evaluation.—After being returned to the Hydraulics Laboratory, further accuracy tests were performed. These data (Tables 4 and 5) were analyzed in terms of statistical parameters to aid in determining the potential accuracy of the meter. For the rate-of-flow needle the average indication ($\bar{I}$) is 105.79 percent and the standard deviation (S_I) is 1.71 percent. For the integrator the average registration ($\bar{R}$) is 106.22 percent and the standard deviation (S_R) is 0.089 percent. These bar values and (S) values are only estimates for unknown true population means (μ) and population standard deviations (σ).

Table 4

INDICATOR ACCURACY
After weld bead was removed from float

Discharge			
Laboratory venturi cfs (lps)*	Vertical flowmeter cfs (lps)	Inlet pressure feet water (meters)	Indication percent
3.503 (86.45)	3.75 (106)	Meter not controlling	107.0
2.969 (84.07)	3.15 (89)		106.1
2.459 (69.63)	2.6 (74)		105.7

Table 4—Continued

Discharge		Inlet pressure feet water (meters)	Indication percent
Laboratory venturi cfs (lps)*	Vertical flowmeter cfs (lps)		
2.038 (57.71)	2.15 (61)	Meter not controlling	105.5
3.000 (84.95)	3.2 (91)		106.7
3.985 (112.8)	4.2 (119)		105.4
4.523 (128.1)	4.8 (136)		106.1
4.992 (141.4)	5.3 (150)		106.2
5.870 (161.2)	6.3 (178)		107.3
5.388 (152.6)	5.5 (156)		102.1
5.185 (146.8)	5.4 (153)		104.1
1.858 (52.61)	2.0 (57)	107 (32.6)	107.6
2.788 (78.95)	3.05 (86)	101 (30.8)	109.4
3.652 (103.4)	4.0 (113)	92 (28.0)	109.5
4.683 (132.6)	5.0 (142)	85 (25.9)	106.8
5.655 (160.1)	6.0 (170)	71 (21.6)	106.1
4.726 (133.8)	5.05 (143)	86 (26.2)	106.8
3.676 (104.1)	4.0 (113)	91 (27.7)	108.8
2.780 (78.72)	3.0 (85)	101 (30.8)	107.9
1.862 (52.72)	2.0 (57)	108 (32.9)	107.4
1.516 (49.93)	1.55 (44)	Meter not controlling	102.2
0.980 (27.7)	1.0 (28)		102.0
2.087 (59.10)	2.15 (61)		103.0
2.115 (59.89)	2.25 (64)		106.4
3.047 (86.28)	3.25 (64)		106.7
4.054 (114.8)	4.3 (122)		106.1

Table 4—Continued

Discharge		Inlet pressure feet water (meters)	Indication percent
Laboratory venturi cfs (lps)*	Vertical flowmeter cfs (lps)		
5.002 (141.6)	5.25 (149)	Meter not controlling	105.0
5.059 (143.2)	5.3 (150)		104.8
6.067 (171.8)	6.4 (181)		105.5
5.735 (162.4)	6.0 (170)	70 (21.3)	104.6
4.771 (135.1)	5.0 (142)	77 (23.5)	104.8
4.776 (135.2)	5.0 (142)	62 (18.9)	104.7
3.756 (106.4)	4.0 (113)	75 (22.9)	106.5
2.824 (79.96)	3.0 (85)	84 (25.6)	106.2
1.908 (54.03)	2.0 (57)	91 (27.7)	104.8
2.838 (80.36)	3.0 (85)	84 (25.6)	105.7
3.771 (106.8)	4.0 (113)	75 (22.9)	106.1
4.780 (135.4)	5.0 (142)	63 (19.2)	104.6
4.778 (135.3)	5.0 (142)	77 (23.5)	104.6
5.719 (161.9)	6.0 (170)	70 (21.3)	104.9

*Liters per second.

Table 5

TOTALIZER ACCURACY
After weld bead was removed from float

Elapsed time hr-min-sec	Discharge venturi cfs (lps)*	Totalized venturi flow acre-feet (cubic meters)	Inlet pressure feet water (meters)	Registration vertical flowmeter acre-feet (cubic meters)	Registration percent
1:42:00	3.01 (85.2)	0.423 (522)	48 (14.6)	0.450 (555)	106.38
6:00:00	3.00 (84.9)	1.489 (1,837)	48 (14.6)	1.575 (1,944)	105.78
1:21:00	3.03 (85.8)	0.338 (417)	99 (30.2)	0.360 (444)	106.50
2:00:14.4	3.02 (85.5)	0.500 (617)	80 (24.4)	0.530 (654)	106.00
2:00:02.8	3.01 (85.2)	0.498 (614)	82 (25.0)	0.530 (654)	106.42

*Liters per second.

However, upper and lower bounds for (μ) and (σ) can be determined for confidence intervals of 95 percent assuming normal distribution and taking into account of probability based on sample size. For the rate-of-flow needle the mean (μ_I) is bounded:

$$106.42 \text{ percent} > \mu_I > 105.16 \text{ percent}$$

and the population standard deviation (σ_I) is bounded by:

$$2.18 \text{ percent} > \sigma_I > 1.14 \text{ percent}$$

For the integrator (μ_R) is bounded by:

$$105.83 \text{ percent} > \mu_R > 106.60 \text{ percent}$$

and (σ_R) is bounded by:

$$2.70 \text{ percent} > \sigma_R > 0.56 \text{ percent}$$

Inspection of the bounds for the (μ) values indicates an accuracy of 5 to 6 percent for the meter as calibrated and adjusted by the company and as installed and tested in the Hydraulics Laboratory.

The population standard deviation values (σ) express the central tendency of the accuracy data to cluster around their mean. Therefore (σ) indicates the potential accuracy of a properly calibrated and adjusted meter.

If a ± error limit value is claimed as the accuracy of a meter or a laboratory technique, it is reasonable to infer that the value is equal to 3σ; i.e., 99.7 percent of individual values of accuracy fall within $\pm 3\sigma$ about the true population mean. Therefore 3σ was assigned to the ±1 percent discharge as determined by the laboratory venturi for the rate-of-flow indicator tests. During the integrator tests, readings were taken at each end of a time interval. Taking into account for this small interval and the precision of visual readings of the totalizer dial, a 3σ value of 0.4 percent was obtained. For the integrator tests the laboratory time measurement was considered an insignificant contributor to error. During the integrator tests, the discharge measurement was more precise because of continued reading and monitoring over longer time. Therefore, 0.5 percent was assigned as 3σ during the integrator tests for venturi discharge measurements.

Taking three times the upper σ bound and accounting for the contribution due to laboratory techniques, it is expected that meter has potential rate-of-flow accuracy of ±5.5 percent. Similarly, but also taking into account the error contribution due to small laboratory acre-foot intervals, the potential accuracy for the integrator is within ±2 percent.

Because the laboratory tests still indicated an excess measurement over the actual flow by about 5 to 6 percent, the manufacturer requested that the meter be tested by an independent disinterested third party. The Worcester Polytechnic Institute, Alden Laboratory, made flow accuracy tests on the meter. The Alden Laboratory verified that the meter was registering an excess over the actual flow by about 5 to 6 percent. The manufacturer expressed a feeling that the possible cause of the error in the factory calibration was in the use of a magnetic flowmeter at the low end of its flow-measuring range.

Controller closure time.—To prevent damage to distribution system piping from overpressure, the specifications in the appendix state that "The time of closing of the valve from normal flow to zero flow under all head conditions will be a minimum of 3 minutes and a maximum of 10 minutes." Closure times were measured over the range of the meter set point flow control. Closure time versus average inlet head during closure is plotted in Figure 8. For comparison the specified time band is shown by vertical dashed lines.

Often the valve would not seat for complete shutoff at head differentials below 20 feet (6 meters) of water. Generally under these conditions an estimated leakage of about 4 gallons per minute (15 l/min) would persist. For head differentials greater than 20 feet of water, no leakage was observed. The specifications in the Appendix state that "Flow through the meter in the shutoff position shall not exceed 1/4 gallon per hour (about 1 l/hour) at any line pressure up to 175 feet (53.3 meters) of head."

Controller opening time.—Laboratory measurements were also made of the time to open the flowmeter from zero flow up to various set point control flows. Opening time versus average inlet heads is plotted in Figure 8. No opening times less than 40 seconds were measured.

Vibration tests.—No vibrations capable of damaging the meter were noted during the laboratory tests. Vibrations were measured with an accelerometer when the valve was opening to the maximum meter discharge of 6 cfs (170 l/sec). For a head differential of about 105 feet (32 meters) of water, a maximum acceleration of 0.4g was observed in the direction transverse to the axis of the delivery pipe and also in the direction parallel to the axis of the delivery pipe. An acceleration of 0.3g was measured along the vertical axis of the meter. For the same final discharge and a differntial of about 15 feet (4.6 meters) of water, a maximum acceleration of 0.15g was observed in the direction transverse to delivery pipe axis and parallel to the delivery pipe axis and 0.06g along the vertical axis of the meter.

Reliability.—Besides not being properly calibrated, other mechanical and operational difficulties were observed during tests.

The magnetic reed switch was improperly positioned. This switch turns off the integrator motor when there is no flow. During early test runs the integrator motor would shut off between 10 and 13 percent of maximum discharge and would continue to run at zero discharge. The reed switch was adjusted by a manufacturer's representative and the integrator would shut off at zero flow. No further trouble was observed after the adjustment.

The clock assembly would not work when the meter was first put into operation. However, after disassembly and reassembly the clock began to work satisfactorily for some unknown reason after the second week. It was noted that the clock would at times lose approximately 1/2 second per 15 minutes. At other times the clock would be accurate. When the flow controller was returned to the laboratories after the factory modified the float assembly, the clock was observed to be accurate.

The totalizer cam and indicator needle stuck at a 25 percent maximum discharge reading several times when the actual discharge was being increased beyond this reading toward full discharge. A manufacturer's representative disassembled the vertical cam shaft assembly and cleaned the lower guide bearing. No further sticking of the needle was observed after the cleaning.

When the meter was controlling, it greatly exceeded its set limit for discharge for a period of about 5 minutes after the head on the system was suddenly increased from head differentials starting at 20 feet (6.1 meters) of water or less. By closing the external shutoff valve, the meter returned to the set point discharge more rapidly because this allowed the pressure on the opposing control piston to build faster. Once when the inlet pressure was increased from 20 to 120 feet (6.1 to 36.6 meters) of water, the meter did not regulate at a set point of 3 cfs (85 l/sec). The flow reached 6 cfs (170 l/sec) and the meter control would not return to the set discharge. However, by closing the external shutoff valve for a short period and then opening the valve again the meter control gradually returned to the set point discharge. These large excesses of delivery over set limits could cause damage to irrigated crops.

CONCLUSIONS

Based on the laboratory studies of the one flow control meter, the following is concluded:

1. Despite many adjustments in the laboratory and a factory modification and calibration of the meter float assembly, the flow controller still registered and indicated about 106 percent of the laboratory

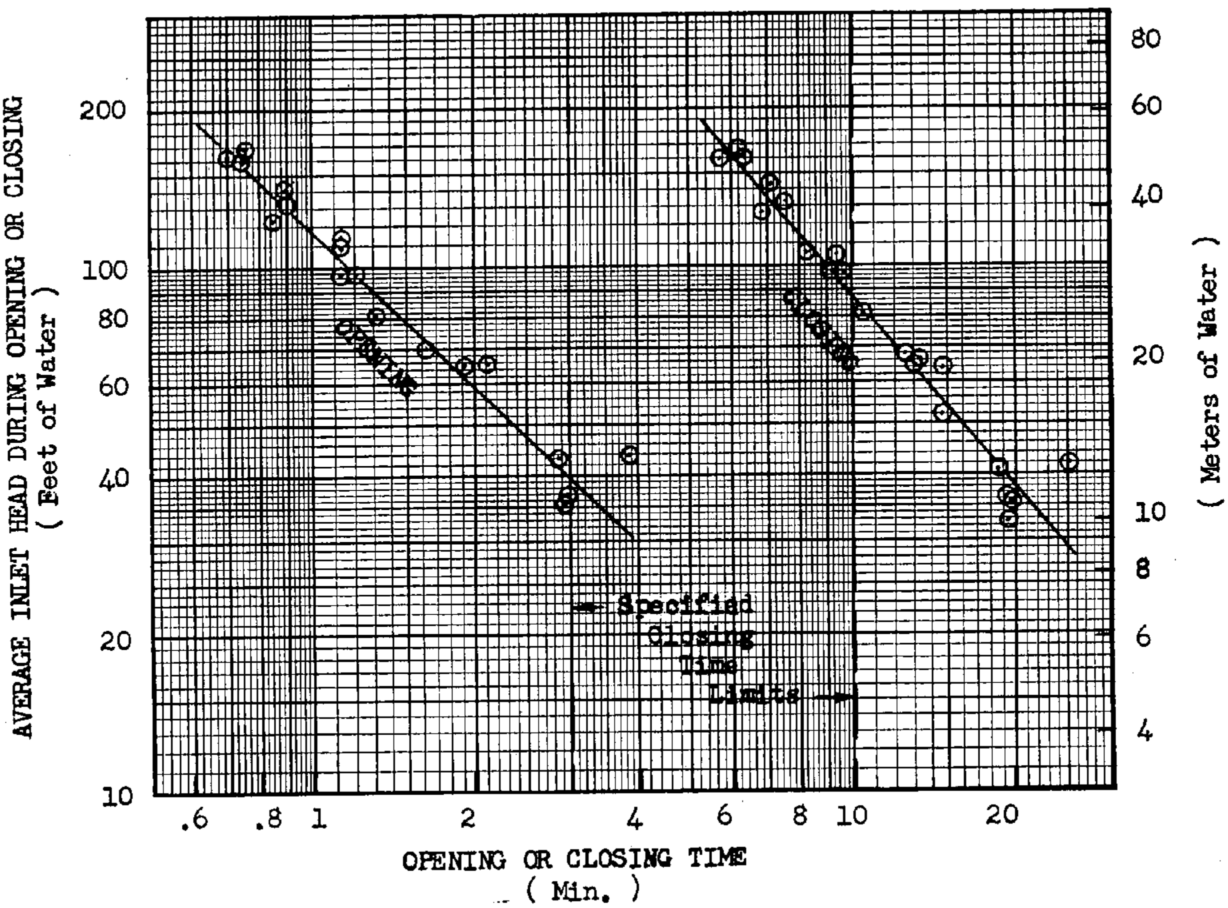

Figure 8. Average inlet head versus time to open or close.

discharge. This inaccuracy was verified by a disinterested independent third party. However, statistical analyses indicate that proper calibration adjustment and maintenance should result in totalization accuracy of ±2 percent or better and rate-of-flow needle reading accuracy of ±5.5 percent or better.

2. The meter met the specified head loss of 30 inches (76.2 cm) of water to deliver a normal uncontrolled flow of 3 cfs (85 l/sec).

3. The meter will control a set discharge to about ±2 percent. The curves in Figure 5 show that the set discharge drops about 2 percent as the differential drops from 170 to 20 feet (52 to 6 meters) of water. The specifications required ±2 percent control but no required head range for this control was stated.

4. The meter would close in 10 minutes at an average differential of 90 feet (27.4 meters) of water and in about 6 minutes at an average differential of 160 feet (48.8 meters) of water. The specifications require closure between 3 and 10 minutes for all head conditions.

5. At head differentials below 20 feet (6 meters) of water, the flow controller would not always completely shut off the flow and leaked at about 4 gallons per minute (15 l/min). The specifications require that leakage does not exceed 1/4 gallon per hour (about 1 liter per hour) for any head up to 175 feet (53.3 meters) of water.

6. A sudden large increase in head temporarily overdrives the controller delivering about 100 percent more flow than the set point indicates. The specifications do not state any required response times for the controller nor any permissible overdelivery flow limit.

7. The higher the inlet head the faster the flow control meter opens. No opening times less than about 40 seconds were noted. No opening time requirements were stated in the specifications.

8. No detrimental vibrations caused by flow passing around the float were observed or measured by the accelerometer during the laboratory tests.

APPLICATIONS

Westlands Water District and the flowmeter manufacturer have shown foresight by thinking in terms of limited demand irrigation systems using automatic and computerized devices. Representatives of the Westlands Water District, the Bureau of Reclamation, and the manufacturer recognize possible economic advantages of developing and using the flowmeter controller in pressure irrigation systems. Tentative specifications were agreed upon. However, as is usually the case for any newly developed mechanical device, unforeseen difficulties arise. Most of the mechanical problems encountered in the laboratory were caused by low-head operational difficulties in closing the meter and subsequent leakage at head differential less than 20 feet (6 meters) which may or may not occur in a specific irrigation system. The flow control meter also had slow control response time when there was a large sudden increase in line pressure of 100 feet (30.5 meters) of water which may or may not occur in a given irrigation system. These problems can presumably be eliminated by comprehensive specifications covering low-head capabilities when the design of a specific system requires such specifications. These low-head requirements would encourage the manufacturer to conduct further research and development to alleviate low-head operational problems noted during these laboratory tests.

Statistical analysis of laboratory tests indicate that meter totalizations can be accurate to within ±2 percent and rate-of-flow readings can be accurate to within ±5.5 percent if properly calibrated, adjusted, and maintained.

APPENDIX

SPECIFICATIONS FOR VERTICAL FLOWMETERS

1. OPERATING CONDITIONS

The vertical flowmeters will be used for the measurement and control of irrigation water delivered to the meter bases in the Westlands Water District Distribution System which will have an ultimate requirement for approximately 4,000 meters. The meters shall control and register any flow within plus or minus 2 percent between 25 and 100 percent of the maximum flow and plus or minus 5 percent between 10 and 25 percent of the maximum flow. Electrical power will not be available at the meter locations.

The 8-inch meters called for under Item 1 are preferred; however, the contractor may furnish 10-inch meters in lieu of the 8-inch meters: Provided, That payment for 10-inch meters substituted for 8-inch meters will be made at the unit price bid in the schedule for 8-inch meters.

During normal irrigation seasons, the meter installations will receive limited attention. The water to be measured and controlled will be taken from a lined canal, will be relatively free from silt and suspended solids, but may carry entrained weeds and moss.

The meters shall be suitable for outdoor operation under all weather conditions including severe wind-driven dust and sand conditions, and in direct sunlight and between ambient temperatures of 20° to 120° F.

2. VERTICAL FLOWMETER

a. General.—The vertical flowmeter shall have a flanged side outlet of the same size as the flanged inlet. Flanged inlet and outlet shall conform to AWWA Class D flanges. The flowmeter shall be capable of indicating and totalizing the flows and of controlling any set flow rate within the range specified regardless of the pressures in the pipeline and down to 1 foot of head in the discharge line. The flowmeter shall repeat flow rate after shutdown within the accuracy limits specified.

The flowmeter shall also have the capability of serving as a practically droptight shutoff valve for the irrigation turnout. Flow through the meter in the shutoff position shall not exceed one fourth gallon per hour at any line pressure up to 175 feet of head.

b. Flowmeter.—The flowmeter portion of the vertical flowmeter shall be of the variable-orifice type using a tapered waterway section and a weighted float which is positioned in proportion to the flow through the tapered section. The position of the float shall be transferred to an indicating and totalizing register by a magnetic drive or other approved device. The indicating scales shall be essentially linear over the ranges tabulated and shall read directly in cubic feet per second.

The totalizer shall integrate the flow and record the totalized flow in acre-feet and hundredths thereof on a straight reading six-digit dial or counter-type integrator operated by a battery having a minimum life of 3 months.

The flowmeter shall provide adaptability for future installation of remote control rate setting and remote reading of totalized flows.

c. Rate-of-flow controller and shutoff valve.—The rate-of-flow controller portion of the vertical flowmeter shall operate on upstream and

Meter size, inches	Flow range cubic feet per second Minimum	Normal	Head	Indicator range cubic feet per second	Head loss at normal flow*
8	0.40	2.0	175	0 to 4	30 inches
10	0.60	3.0	175	0 to 6	30 inches
12	0.80	4.0	175	0 to 8	30 inches
14	1.10	7.0	175	0 to 10	30 inches

*Head loss shall be considered as the total drop in pressure head between the inlet flange and outlet flange.

downstream water pressures acting on pistons of different areas through a pilot water control circuitry. The two pistons acting in unison shall control the set rate of flow through a throttling valve which also is the shutoff valve when water pressures are balanced on both pistons. Balancing of the water pressures shall be accomplished by some suitable means such as an accessible valve in the return line of the pilot water circuit. Rapid closure at the shutoff valve may be detrimental to the distribution system piping; therefore, the shutoff mechanism shall be such that the time of closing of the valve from normal flow to zero flow under all head conditions will be a minimum of 3 minutes and a maximum of 10 minutes.

3. CONSTRUCTION

The body of the vertical flowmeter shall be of fabricated steel or cast iron, or any combination of the two, at the contractor's option. The valve seat shall be field replaceable without special tools. All interior operating parts of the meter shall be fabricated from 300 series stainless steel. The meter register and rate-of-flow adjusting device shall be enclosed in durable, weatherproof housings, with hinged door and padlock hasp that can be opened to make adjustments in the rate of flow. The housing shall have a transparent window or windows to permit reading of the indicator and totalizing register without removing or opening the housing. The control device for closing or opening the shutoff valve shall be located outside of this housing.

After fabrication, each vertical flowmeter shall be shop assembled, tested for proper operation, and calibrated over its flow range.

Test reports of the accuracy of indicated flows and the total head loss through the meter, for all flows within the indicator range, are required for each meter.

Before shipment the vertical flowmeters shall be painted as noted below and in accordance with Paragraph 5. All internal ferrous surfaces in the water passage of each meter shall be painted with VR-3 system vinyl paint and mastic. Exterior surfaces of each meter shall be given one shop coat of red lead priming paint, Type IV, followed by one coat of light gray semigloss enamel.

4. WARRANTIES

The contractor shall warrant, for a period of 3 years from date of shipment that each meter meets the accuracy of these specifications as shown by the test reports, that the equipment is free from defects and that it will operate properly, trouble free under the conditions specified.

5. PAINTING

a. Preparing surfaces.—The contractor shall prepare interior and exterior surfaces of the vertical flowmeter before painting. All oil and grease shall be removed by the use of clean solvent and clean, lint-free wiping material. Following the solvent cleaning, the surfaces shall be blast cleaned to base metal using dry, hard, sharp sand or steel grit, to produce a gray-etched surface. The blasting material shall pass a No. 16 United States Standard screen and at least 85 percent shall be retained on a No. 50 United States Standard screen.

b. Application.—Materials shall be thoroughly mixed at the time of application. Surfaces shall be clean and free from moisture at the time of application. Items to be painted that are not thoroughly dry at the time of paint application shall be heated to a sufficient temperature (80° F) to drive off any moisture present before paint is applied. Effective means shall be provided for removing free oil and moisture from the air supply lines of all spraying equipment.

Each coat shall be applied in such a manner as to produce an even film of uniform thickness which will completely cover irregularities, fill crevices, and be tightly bonded to the metal or previous coat. Each coat shall be free from runs, pinholes, and sags.

Each coat shall be allowed to dry or to harden before the succeeding coat is applied. Thicknesses shall be measured by an approved dry-film thickness gage and shall be not less than the minimum specified thickness at any point on the coating. Acceptance will be based on the total dry-film thickness as measured by an Elcometer, Mikrotest, or other suitable dry-film thickness gage, after the complete paint system has thoroughly dried.

Red lead priming paint and enamels may be thinned if necessary to permit satisfactory application, in which event mineral spirits shall be used and the amount of thinner shall be kept to a minimum but in no event shall it exceed 1 pint per gallon of paint.

Paint shall not be applied when the temperature of the item to be painted or of the surrounding air is under 45° F, except that vinyl resin paints shall not be applied when metal or air temperatures are above 110° or below 40° F. Painting shall proceed only when the humidity and the temperatures of atmosphere and of surfaces to be painted are such that evaporation rather than condensation will result. Brush coats may be applied by the conventional brushing procedure, or the paint may be delivered to the surface in a fluid stream by means of spray equipment employing air pressure only on the material and the paint then spread immediately by brushing to an even, smooth coating.

Tinting, where required for color contrast, shall be accomplished by using not more than 3 ounces of tinting color per gallon of paint.

Application of specific materials shall be as follows:

(1) Red lead priming paint shall be applied at a maximum coverage of 450-square-feet-per-gallon per coat but the dry-film thickness shall not be less than 1.0 mil for the first coat. The shop coat shall be applied by brush or roller. Drying time between coats of Type IV red lead, or between Type IV red lead and any required topcoat, shall not exceed 48 hours over that required for the paint film to become dry through. (A paint film shall be considered dry through when it cannot be distorted or removed by exerting moderate pressure with the thumb and turning the thumb through 90° in the plane of the paint film.)

(2) Enamels shall be applied by brush, roller, or spray at a maximum coverage of 500-square-feet-per-gallon per coat.

(3) Vinyl resin paint VR-3 (see table below).

Shop application of only a portion of this paint system is not permitted.

The paint shall be applied in four or more coats to a minimum acceptable dry-film thickness of 6.0 mils in areas not covered by vinyl mastic and 20 mils in areas where coats of vinyl mastic are applied. In any instance where additional coats are necessary to obtain the required dry-film thickness, the color of the final coat shall be as specified above.

As a guide, 225-square-feet-per-gallon per coat usually gives a dry-film thickness of about 1.7 mils, but is not required to do so by the materials specifications. Variables such as solids content, surface roughness, application technique, amount of overspray, etc., affect the final coverage rates obtained.

Paint applied by brush shall be applied in generous brushfuls and quickly brushed out smooth before significant evaporation of solvents occurs and before brush drag develops.

Airless or conventional pressure pot spray equipment shall be used for spray application

Coat	Color	Application method	Minimum drying time
1	Gray	Brush or roller	12 hours
2	White	Spray	12 hours
Vinyl mastic*		Brush	*
3	Gray	Spray	12 hours if a fourth coat is to be applied or at least 10 days before placing in service if only three coats are used.
4	White	Spray	At least 10 days before placing in service.

*After the second coat, two or more coats of vinyl mastic shall be brush, trowel, or spray applied to a 14-mil minimum dry-film thickness over all rivets, welds, bolts, seams, sharp corners and edges, and in the absence of a weld, as a fillet between adjacent metal parts. The mastic shall be allowed to dry 4 hours minimum between coats and 12 hours minimum after the last mastic coat before application of the second coat. As a guide mastic coverage is about 50-square-feet-per-gallon per coat. Application greatly in excess of the required thickness may deteriorate adhesion of the preceding coats.

and the equipment shall be capable of operating at air atomization pressures up to 100 psi. Application shall be such as to avoid excessive loss of volatiles before the paint spray strikes the surface. Each stroke of the spray gun shall make a good lap over the previous stroke so that a continuous wet film is obtained on the surface. To prevent sagging and to insure the minimum dry-film thickness, it may be necessary to make repeated passes with the spray gun. Where this is necessary, each additional pass shall be by strokes at right angles to the previous pass.

Specific color matches will not be required except that all paint used for the last coat shall be uniform in color.

All vinyl paint material for any VR-3 coating shall be purchased from the same manufacturer and shall be ready mixed.

Thinning shall be as recommended by the manufacturer and tinting will not be permitted.

c. Materials.—All pigmented paints and primers shall be purchased in containers not larger than 5 gallons as packaged by the manufacturer. All colors shall be factory mixed and ground. Tinting with universal tinting colors will not be permitted and tinting with colors-in-oil is permitted only where specified for slight contrast between coats. Materials shall be in accordance with the following specifications, or may be in accordance with the subsequent revisions thereto: Provided, That the samples or certifications are identified with the proper specifications revision:

Group I

(1) Federal Specifications.—

(a) Red lead priming paint, TT-P-86c, Type IV.

(b) Enamel, semigloss, TT-E-529a, Class A.

(2) Bureau of Reclamation Specifications.—

(a) Vinyl resin paint, VR-3 and thinner.

(b) Vinyl mastic, VR-M (vinyl resin mastic coating).

6. REFERENCED SPECIFICATIONS

Copies of the specifications, standards, and codes referred to herein may be procured by the contractor, at his expense, from the following:

AWWA from the
American Water Works Association
2 Park Avenue
New York, New York 10016

Bureau of Reclamation Specifications from the
Bureau of Reclamation
Building 53, Denver Federal Center
Denver, Colorado 80225

Federal Specifications from the
Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

Copies of the Federal specifications may be examined at the office of the Bureau of Reclamation, Building 53, Denver Federal Center, Denver, Colorado.

Single copies of Federal Specifications required for bidding purposes may be secured without charge at Business Service Centers of Regional Offices of the General Services Administration.

Interior—Reclamation, Denver, Colorado

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 833-017

ABSTRACT

A newly developed 10-in. (25.4-cm) rotameter-type flowmeter and flow controller was studied in the laboratory. The flow control meter totalizes flow, indicates flow rate, controls flow to present rates over a large range of line pressure, and provides shutoff. Laboratory head loss, accuracy, and other operational tests were performed. Data analyses indicated potential totalization accuracy of better than plus or minus 2%. No mechanical and operational difficulties were experienced for head differentials between 170 to 20 ft (52 to 6 m) of water. For head differentials of less than 20 ft, the meter shut off slowly and often leaked excessively. The design of the meter has potential economic advantages, and the difficulties encountered in the laboratory could probably be resolved by further research and development. The new flowmeter controllers are in use in a water district, and monthly operation and maintenance reports are made. Laboratory studies and field experience can be used to define more fully specifications for low-head operation in future contracts.

ABSTRACT

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DESCRIPTORS--/ *hydraulics/ *discharge measurement/ water delivery/ flow control/ water measurement/ *head loss/ flowmeters/ calibrations/ flow rates/ laboratory tests/ reliability/ application methods
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