Research Technical Completion Report

EVALUATION OF CLOSED-CONDUIT MEASURING DEVICES FOR IRRIGATION DIVERSIONS

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Submitted to:
Idaho Department of Water Resources
Boise, Idaho

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ABSTRACT

A field evaluation of closed conduit flow measuring systems was conducted to determine technically acceptable devices and develop guidelines for measuring irrigation water diversions from surface and ground water sources in the State of Idaho. Recommendations are made for standard installation of acceptable commercially available meters. Types of meters evaluated included propellor, impellor, turbine, differential head, and ultrasonic devices. The nature and quality of the water supply and the hydraulics of the diversion or distribution system greatly influence the acceptability of any flow measuring device and the average water user will not have sufficient technical knowledge for meter selection and placement in his system. Typically, most meters having advertised accuracies of two percent were shown to have field accuracies within 10 percent.

INTRODUCTION

Accurate and timely measurement of irrigation water diversions is necessary for efficient and equitable management of Idaho's water resources. Agreements reached by the State of Idaho and Idaho Power Company on the Swan Falls issue and adjudication of water rights in the Snake River Basin of Idaho will ultimately require timely measurement of all diversions, especially irrigation diversions, from surface and ground water sources. Pumped diversions which do not discharge to open channels are seldom measured, whereas surface water diversions are more closely monitored. It is important that accurate and reliable devices for closed conduit flow measurement be determined and guidelines for their installation and operation be developed for use by the Idaho Department of Water Resources and Idaho water users. Funding for this project was provided by the Idaho Legislature through the Snake River Advisory Committee and the Idaho Department of Water Resources.

OBJECTIVES

The overall project goal of the University of Idaho, Idaho Water Resources Research Institute was to evaluate and select available or modified closed conduit measuring devices for water diversion systems found in southern Idaho. The specific objectives of the project were to:

1) Select and evaluate measurement devices under actual field conditions found at diversion sites from the Snake River between the mouth of Salmon Falls Creek and Swan Falls Dam.
2) Evaluate meters currently installed by water users for accuracy and maintenance levels.
3) Develop guidelines for installation and maintenance of acceptable flow measurement devices and include equipment manufacturers and suppliers in the study to assure proper installation and operation of their devices.

PROJECT AREA

There are about 100 irrigation diversions from the Snake River in the study reach with installed pump horsepower from less than 100 hp to over 10,000 hp. Sites vary with respect to system design and operation. Most pumping systems are multiple pump systems with multiple users on the system. System flow rates vary from 1 to 200 cubic feet per second, operating under pressure heads from 10 to 700 feet. Diversion systems may have multiple discharge lines which may or may not have water hammer protection systems, check valves, and/or flow control valves. The nominal diameter of discharge lines ranges from 6 to 72 inches.

Diverted irrigation water is usually screened for large debris only. Sediment and fine moss are common in the diversion water and may affect the operation of flow measurement devices. The sediment concentration ranges between 10 to 200 parts per million and is typically comprised of silt and clay particles with some sand sized material. The moss found in the pumped water will have passed through a vertical turbine pump before it reaches the measurement device.

METHODS OF FLOW MEASUREMENT

Methods of flow measurement are classified as either direct or indirect methods. Direct methods involve actual measurement of volume displacement for a given time period. A prime example of this method is the use of a container and a stop watch. Other direct methods include positive displacement devices such as pistons and weighing tanks. These methods are usually limited to small flow rates for short periods of time. For irrigation water diversion sites the direct methods are not suited for long term measurements primarily due to the flow rate magnitudes.

Indirect methods involve measurement of some hydraulic parameter related to the flow rate. Devices utilizing indirect methods are usually termed rate meters and are classified by the physical property used to derive the flow rate. Differential head, variable area, force displacement, force velocity, thermal, and chemical dilution are a few of the classifications for devices using indirect methods. Indirect flow measurement systems typically consist of two components. The primary component is the physical sensor and the secondary component translates the sensor response to velocity or discharge. The suitability of indirect methods for measuring irrigation diversion is dependent upon the parameter used to estimate flow rate.

DIFFERENTIAL HEAD

Differential head methods of flow measurement utilize the relationship between velocity head (kinetic energy) and pressure head (potential energy) in a flow system. The primary component is typically a constriction in the pipe which reduces the cross sectional flow area and causes changes in velocity and pressure heads upstream and downstream of the constriction. The secondary component senses the change in pressure head across the device and relates the change to flow rate. These methods readily yield the flow rate; however, integration of the rate is necessary to determine flow volume. These methods also consume some of the available head. Orifice meters, flow nozzles, venturi tubes, and pitot tubes are examples of differential head meters.

Orifice meters consist of an orifice plate inserted in the pipeline with pressure taps one pipe diameter upstream and downstream of the plate where the vena contracta occurs. The flow rate through the orifice plate is related to the pressure differential across the orifice. Orifice plate devices require more head to operate than flow nozzles or venturi meters.

The nozzle meter is similar to the orifice meter except the entrance has been streamlined to produce a jet such that the vena contracta does not form. The basic equations relating the pressure differential to flow rate for the orifice meter are the same for the nozzle meters. Nozzle meters will consume less head than the orifice meters due to the streamlined entrance conditions; however, they will consume more head than venturi meters.

Venturi meters are similar to nozzle meters except that the entrance and exit are streamlined to reduce pressure loss and the vena contracta is eliminated. Shunt meters are basically a form of the venturi meter except that the differential pressure forces a measured portion of the total flow to be bypassed or shunted through a small water meter in a pipe connecting the upstream pipe to the venturi throat. The shunted flow is a function of the pressure differential and can be related to total discharge.

The relationships between flow and the change in pressure for the orifice, flow nozzle, and venturi are identical (Eq. 1) except for the discharge coefficient which is specific for each meter manufactured.

$$Q = CA_2 \sqrt{2g\ \Delta P} / \sqrt{1-r^4} \qquad \text{Eq. 1}$$

where:

Q = discharge

C = Meter coefficient

A_2= Flow area at constriction

P = Differential head

r = throat area/pipe area

The pitot tube is a point velocity measuring device which can be used to determine flow rates in a closed conduit. In this method, the pitot tube senses the velocity head by converting it into a static pressure head which is measured by either a manometer or differential pressure transducer. This measurement represents the fluid velocity at a single point in the cross sectional flow area. To determine the discharge in a pipe, multiple point velocity measurements must be taken at various locations in the cross section flow area to obtain the average fluid velocity in the pipe from which the discharge is readily obtained.

VARIABLE AREA

Variable area methods also operate by means of differential pressure. However, unlike differential head methods, the cross sectional flow area is allowed to vary as a function of flow rate producing a fixed differential head which is used to displace an object or float, indicating flow rate. The rotameter and the slotted cylinder and piston are examples of this type of meter. These meters do not perform satisfactorily with fluids containing variable amounts of solids because of the changing density of the fluid mixture which results in changes in the buoyant force imparted to the float. Because of this sensitivity to suspended solids, this type of meter is not applicable for most irrigation diversion measurements.

FORCE DISPLACEMENT

Force displacement methods are related to the variable area methods in that an object is displaced by the moving fluid. However, with these methods the cross section flow area is essentially held constant and the force, which varies with flow velocity, causes the object or target to deflect proportionately. The target flow meter and variable weight meter are examples of force displacement methods. Water quality effects these methods either by density changes of the fluid resulting from changing sediment concentrations and/or by debris which can be caught on the target changing the hydrodynamics of the target object. Because of these reasons, this method is usually not applicable for measurement of irrigation diversions from river water supplies.

VARIABLE HEAD AND AREA

Flow measurement utilizing head-area meters involve fluid flow producing a variation in cross section flow area and in pressure head or depth. These methods are used in open channel flow measurement and are commonly referred to as weirs and flumes. A vane meter is a example of this method for closed conduit pipes. In this meter the primary element is a hinged vane which is weighted and acts like a check valve in the pipe. As flow increases, the cross section flow area increases until the moment about the hinge caused by the flow impacting the vane equals the moment about the hinge caused by gravitation forces acting on the vane. Meters using this method must be mounted horizontally and are sensitive to changes in the fluid density resulting from sediment and moss. Because of this sensitivity, this method is not applicable for measurement of irrigation diversions from river water supplies.

FORCE VELOCITY

Force velocity methods primarily use a turbine, propellor, or impellor to sense velocity of the fluid. The average fluid velocity is sampled with large propellers or turbines; whereas, point velocities are usually sampled with impellers. The primary component consists of a spinning sensor for which the rotational speed and flow velocity are related. The secondary components are mechanical or electrical devices which sense the rotational speed of the sensor, contain the empirical relationships between rotational speed, pipe size, and fluid properties for flow rate calculation. These meters are affected by large debris; however, small debris typically should not interfere with operation. Sediment will decrease the life expectancy of these devices. Overall, these types of meters are applicable for closed conduit irrigation diversions.

THERMAL

Thermal meters utilize the principle that moving fluids absorb heat at rates in proportion to the fluid flow rates. Mass flow of the fluid is measured by injecting thermal energy, heat, into the fluid stream and measuring the increase in temperature at a fixed distance downstream of the injector. Other thermal meters measure the rate of thermal energy required to maintain a sensor at a fixed temperature above that of the fluid. These meters have high response and accuracy characteristics and are mainly used in laboratories for turbulence studies. They are expensive, require strict water quality standards, and the typical irrigation water user could not afford this type of meter.

TRACERS

Concentration methods involve injection of a solution containing a known concentration of dye or other tracer at a known injection rate. At some distance downstream of the injection point the fluid is sampled and the concentration is determined. The flow rate in the conduit can be calculated from the measured concentrations and the injection rate. This method assumes complete dispersion of the injected tracer in the conduit at the point of sampling and is therefore sensitive to the hydraulics of the system between the injection and sampling locations. Typical tracers used for concentration measurements are salts, color dyes, and radioisotopes. Care must be exercised in the selection of the tracer material to prevent damage to the environment and minimize absorption by the pipe material. Concentration dilution methods are best suited for instantaneous measurements. Long term continuous measurements with concentration methods require sophisticated automated sampling and interpretation equipment.

SPECIAL METHODS

Ultrasonic meters measure a change in frequency of sound waves traveling through flowing fluids. The shift in the frequency between sound waves transmitted and those received is directly related to the average fluid velocity in the sampling cross section. Some ultrasonic meters require that the fluid contain sediment or entrained air to reflect the sound waves to the receiver. Other types require a clean fluid, completely free of sediment or entrained air which could interrupt the sound waves between the transmitter and the receiver.

Magnetic meters or electromagnetic meters set up a magnetic field around the conduit containing a flowing electrically conductive fluid and relate the velocity to the voltage generated according to Faraday's Law. According to Faraday's Law, a voltage proportional to the velocity of the conductive fluid will be produced when it moves through a magnetic field. These meters, although expensive, are limited to fluids which are conductive by nature and are applicable to most water sources.

Vortex meters measure the velocity of fluids by measuring the frequency of vortices produced downstream of fixed bodies residing in the flow path. The vortex meter is generally limited to laboratory installations and to limited flow ranges.

The special metering methods: ultrasonic, magnetic, vortex, and others, require sophisticated tranducers and extensive signal processing electronics that are relatively expensive. Therefore, these metering methods are usually out of the economic reach of typical irrigators.

METER INSTALLATIONS

For accurate flow measurement, measuring devices require the velocity pattern in the pipe to be parallel and symmetrical with respect to the pipe center line. These restraints require sufficient lengths of straight uniform full-bore pipe upstream and downstream of the meter to diminish the effects of bends, valves, and other changes in cross sectional flow area on the velocity profile. The effect of a bend in a pipe leads to a distortion in the velocity distribution across the pipe cross section as shown in figure 1. The effect of a partially closed gate or valve on the downstream velocity profile is shown in figure 2.

These non-symmetrical velocity distributions lead to inaccurate measurement of flow with the indirect methods which rely on measuring the average fluid velocity or a point velocity in the pipe cross section. To reduce the potential problems caused by upstream pipe fittings, meter manufacturers have standard installation requirements in terms of lengths of pipe diameters and for flow straighteners or vanes.

DISTORTION OF VELOCITY DISTRIBUTION

The effect of a single bend in a pipe on the velocity distribution is dependent on the Reynolds number of the flow and the radius of the bend. The velocity distribution will be distorted immediately upstream of the bend and remain distorted downstream of the

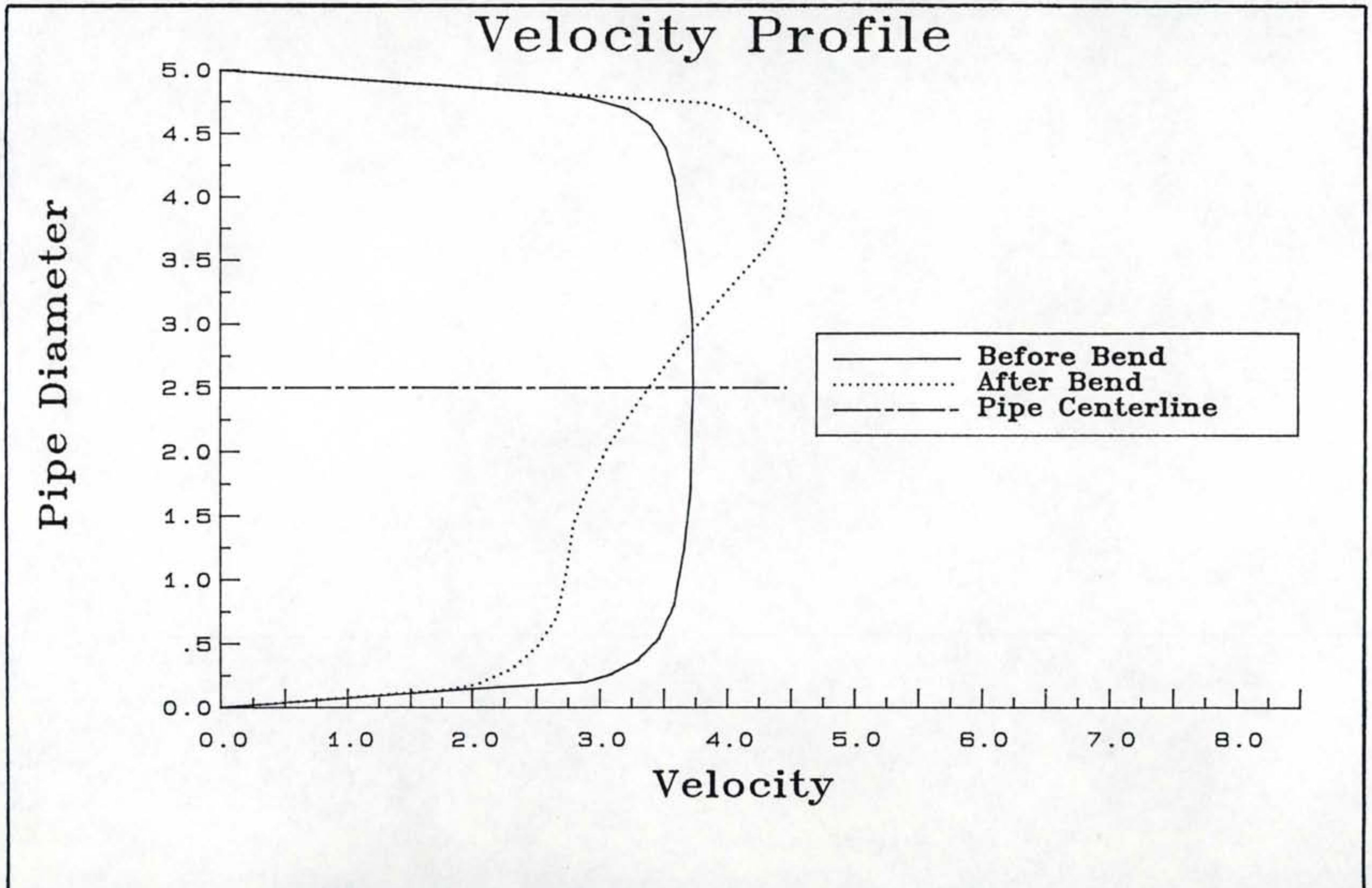

Figure 1. Effect of Pipe Bends on Velocity Profile

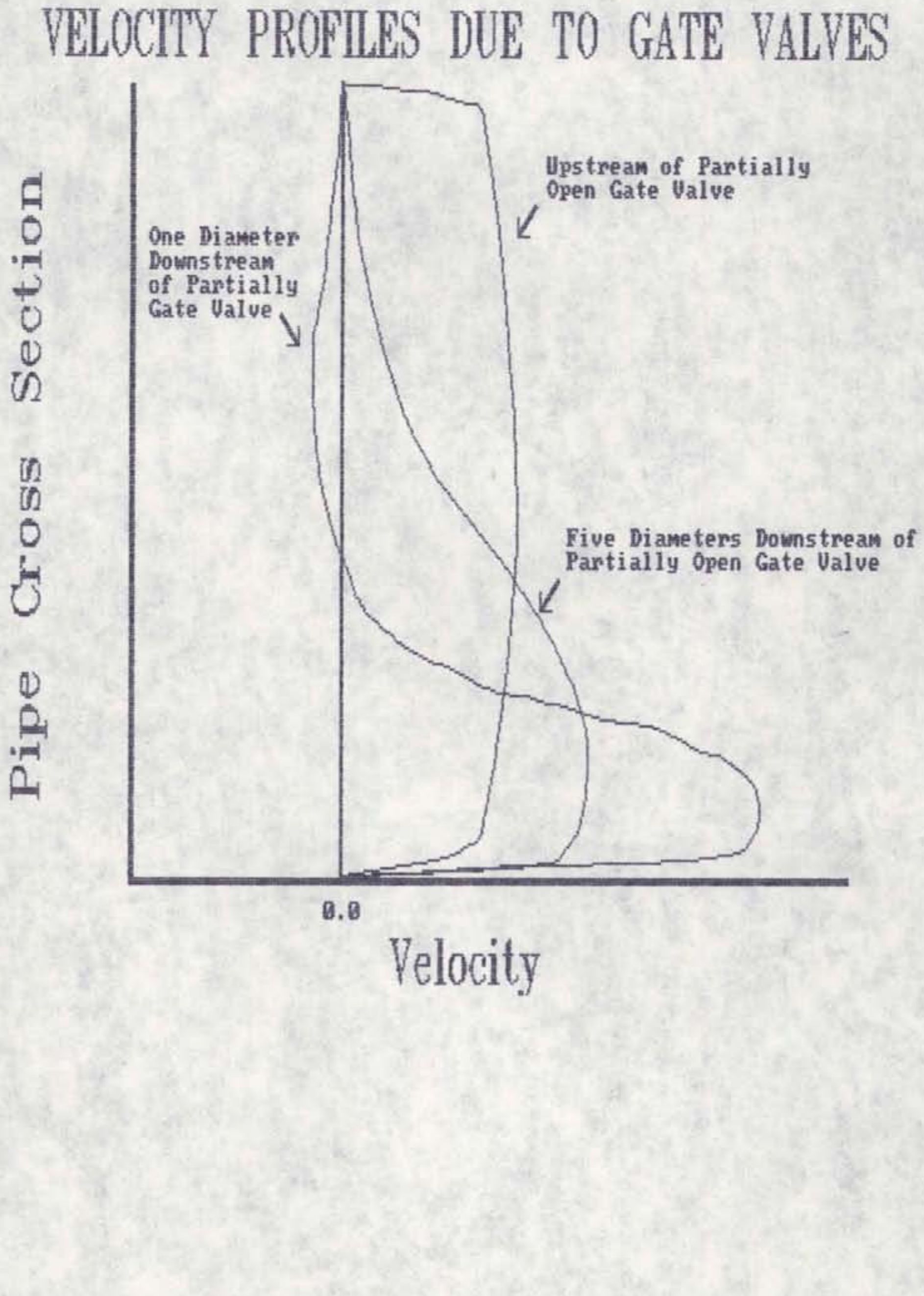

Figure 2. Effect of Valves on Velocity Distribution

bend as far as 40 pipe diameters. The literature attempts to qualify the velocity distribution symmetry with the use of two ratios: mean velocity to center-line velocity and the mean velocity to maximum velocity. For fully developed symmetrical velocity distributions the maximum velocity and the center-line velocity are coincident; therefore, the velocity distribution in the pipe is considered symmetrical when the two ratios are equal. Table 1 shows measured ratios for an eight inch diameter pipe downstream of a single long radius 90 degree bend as reported by West, 1961. The velocity profile in the pipe remains unsymmetrical for 63 pipe diameters downstream of the simple bend. Similar flow patterns occur downstream of throttled valves or other obstructions to flow. Sudden expansions or contractions in pipe size can also cause disruption of fully developed velocity profiles and cause errors in discharge determination by point velocity meters or partially inserted devices.

Table 1. Measured velocity ratios for an eight inch diameter pipe downstream of a simple bend (West, 1961).

Distance (Diameters)	Velocity Distribution Ratios Mean to Center-line	Mean to Maximum
5	1.015	0.904
20	0.937	0.864
40	0.876	0.838
63	0.818	0.818

SWIRL

Additional measurement problems will be experienced in pipe lines where the fluid swirls through the pipe. These swirls can be caused by spiral welded pipe, additive injection points, and any repetitive roughness pattern on the pipe wall. Swirl can be controlled through the use of straightening vanes placed upstream of the flow measuring device. Propellor and turbine devices are more sensitive to swirl than other devices.

STANDARD INSTALLATIONS

A standard measurement device installation requires a specified number of pipe diameters of straight, unobstructed, full-bore pipe upstream and downstream of the meter. Devices which base the discharge on a point velocity measurement in the cross section usually require more upstream diameters than devices which integrate velocity over the cross section. The larger the percent of flow area sampled by the sensor, the lower the upstream diameter requirement. Table 2 shows recommended unobstructed pipe distances for standard installation of general meter types as reported by various manufacturers. The standard installation diameter requirements usually can be reduced by conditioning the flow with straightening vanes, flow tubes, and concentric reducers. The point velocity methods, i.e. pitot tubes, require 40 diameters of straight unobstructed pipe upstream of the device when using a single point velocity for the discharge measurement. This straight piping requirement can be reduced if the mean velocity is measured by traversing the cross section and determining the velocity profile.

Table 2. Standard Installation Straight Piping Requirements

Device Type	Unconditioned Flow Upstream	Unconditioned Flow Downstream	Conditioned Flow Upstream	Conditioned Flow Downstream
	Length of straight unobstructed pipe in terms of diameters.			
Differential Pressure	10	10	3	2
Propellor	10	1	5	1
Turbine	20	10	10	5
Magnetic	4	1	2	1
Vortex	10	5	5	5
Ultrasonic	30	5	10	5
Pitot Tubes	40	5	(refer to text)	

FLOW METERS EVALUATED

This project evaluated differential head meters, force velocity meters, variable head and area methods, and special instruments. Where possible, these devices were obtained from the manufacturer on loan; however, some companies did not wish to participate in the evaluation project and those meters had to be purchased. At two of the evaluation sites, the flow meters had been previously installed and they were included in the study. Meters included in the study were manufactured by Data Industrial Corporation, Flow Research Corporation, Irrigation Industries, McCrometer, Signet Scientific, Sparling Instruments, Water Specialties, and Wilgood Corporation.

DATA INDUSTRIAL CORPORATION

Two Data Industrial flow measuring systems were included in the study. The measurement system consisted of a model 220 series impellor type brass sensor with a model 900T Digital Flow monitor. The brass sensor consisted of a two inch diameter brass probe with a star wheel impellor as show in figure 3a. The flow monitor, shown in figure 3b, converts the output from the flow sensor into meaningful units. The probe is installed in the pipe through a two inch diameter port and measures the fluid velocity at 1.50 inches from the inside pipewall. One sensor probe will work on all pipe sizes greater than 4 inches in diameter. The electronic flow monitor contains all necessary conversion factors and equations for field calibrations for all pipe sizes and display units. The accumulated flow volume is displayed on a non-volatile mechanical counter; whereas, the flow rate is displayed on a liquid crystal display with three significant digits. Standard installation of the Data Industrial sensor requires 10 pipe diameters upstream and 5 pipe diameters downstream of straight full bore unobstructed pipe. Data Industrial Corporation recommends that the sensor be installed on a pipe radius at 45 degrees from vertical.

FLOW RESEARCH CORPORATION

Three Flow Research flow measuring systems were included in the study. These systems consisted of a TR500 impellor type flow sensor shown in figure 4a and an FL2000 digital flow monitor shown in figure 4b. The flow sensor is similar to that marketed by Data Industrial Corporation. Installation of the probe is similar except that the

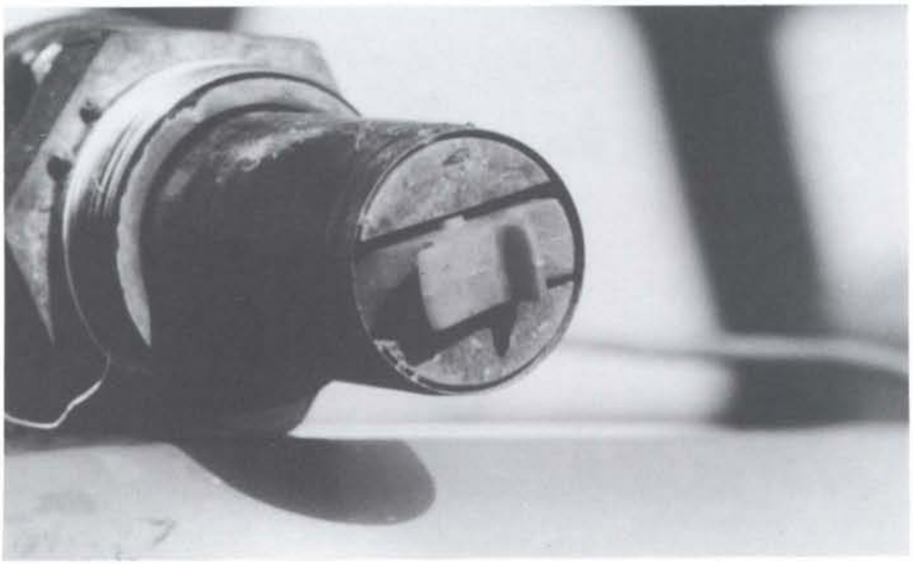

Figure 3a. Data Industrial Corporation Flow Meter Sensor

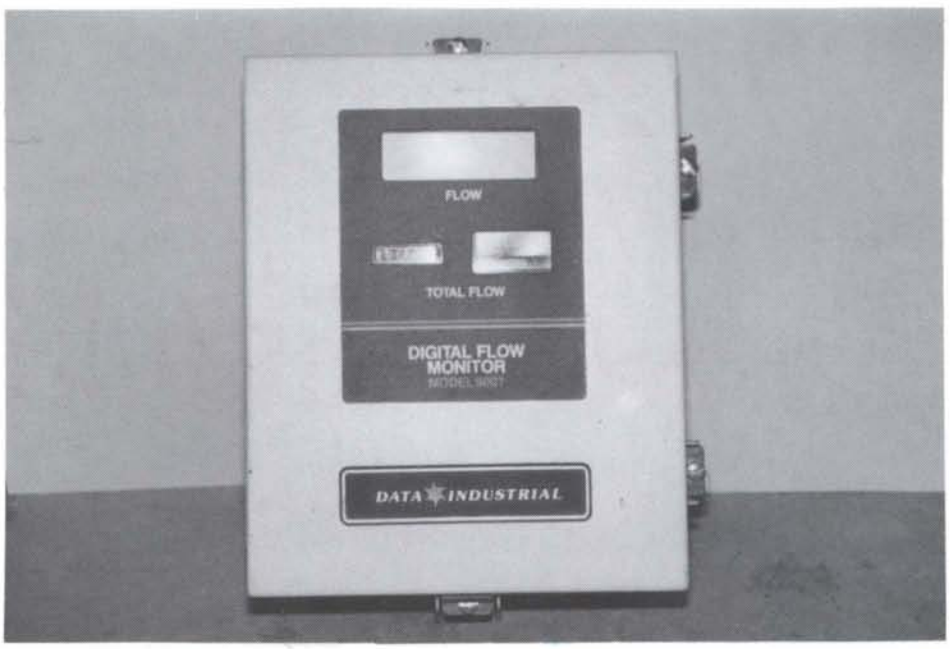

Figure 3b. Data Industrial Corporation Flow Meter Integrator

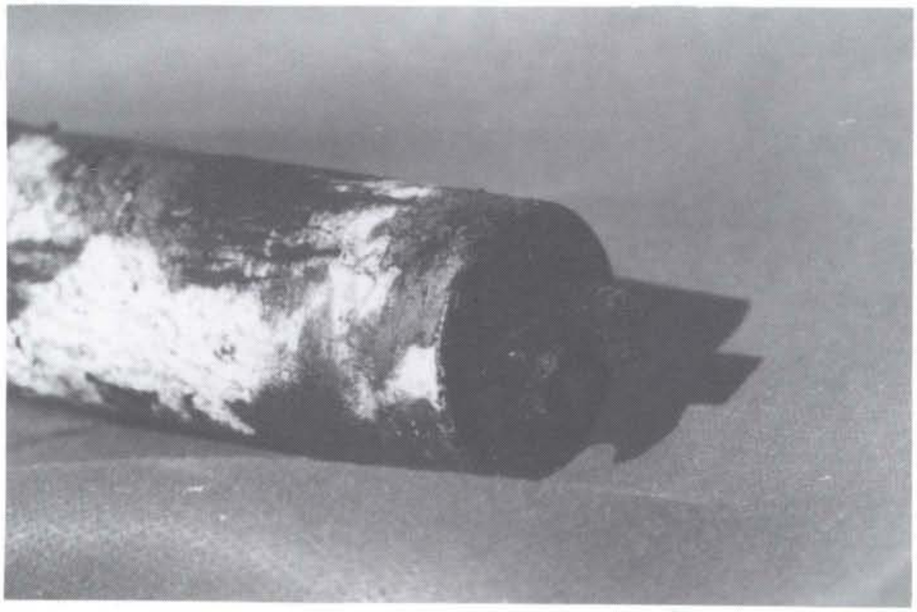

Figure 4a. Flow Research Corporation Flow Meter Sensor

Figure 4b. Flow Research Corporation Flow Meter Integrator

position of the impeller from the inside pipewall will vary with the pipe diameter and the flow range to be measured. The flow monitor system is factory calibrated specifically for the specified pipe size, flow range, and unit system required by the end user. The monitor is capable of displaying the instantaneous flow rate and the accumulated flow volume. On the units supplied for the demonstration project; the accumulated volume register reset to zero whenever the sensor was disconnected from the monitor. Standard installation of the Flow Research flow sensors requires 10 pipe diameters of straight full bore unobstructed pipe both above and below the meter.

IRRIGATION INDUSTRIES

Two Miller SLV shunt type flow meters from Irrigation Industries were included in the study. The flow measuring system consists of a tube venturi meter with a city water meter as the flow register as shown in figure 5. The small city water meter is placed in a bypass line which is connected upstream and downstream of the venturi contraction. The resulting differential head caused by water flowing through the venturi forces water to flow through the bypass line. The flow rate in the bypass line is proportional to the differential head across the venturi which is also proportional to the flow passing through the venturi tube. The Miller SLV meter is factory sized for the specific system on which it is to be installed. The standard installation for this meter requires 3 to 5 pipe diameters of straight unobstructed pipe upstream, and 2 to 3 pipe diameters downstream.

Figure 5. Miller SLV Shunt Type Flow Meter

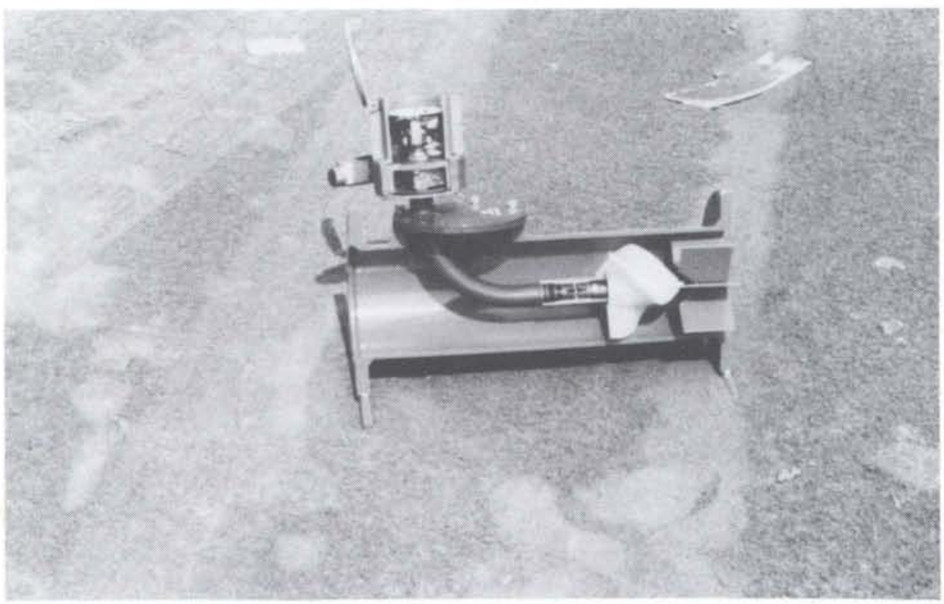

Figure 6. McCrometer Propellor Meter

MCCROMETER

Four McCrometer propellor meters were evaluated in the study. Two of the meters were purchased specifically for the study and two meters were previously installed by the cooperators. The McCrometer propellor meter shown in figure 6 consists typically of a three bladed propellor just smaller than the inside pipe diameter. The propellor is connected to an indicator-totalizer through a flexible drive cable. The propellor is trimmed or indicator mechanism changed to accomodate different pipe sizes. McCrometer requires five pipe diameters of straight full bore pipe upstream, and one pipe diameter downstream. The manufacturer encourages the use of flow straightening vanes installed immediately upstream of the propellor.

SIGNET SCIENTIFIC

One Signet Scientific rotor flow measuring system was evaluated. The system consisted of an MK 515 ROTOR-X Flow Sensor shown in figure 7 with an MK 575 ACCUM-U-FLO flow monitor. This paddle wheel type impellor meter is installed in a fashion similar to the Data Industrial and Flow Research probes. The electronic interface has to be calibrated at the factory for rate and volume. The flow volume can be recalibrated in the field if the measured or 'actual' flow is known. Again, 10 diameters upstream and 5 diameters downstream are required for standard installation.

Figure 7. Signet Scientific Flow Meter

SPARLING INSTRUMENTS

A Sparling Instruments flanged tube propellor meter shown in figure 8 was evaluated in this study. The meter head includes instantaneous flow readout in gallons per minute (gpm) and mechanized volume accumulator. Standard installation requirements for the meter are five pipe diameters upstream and one pipe diameter downstream of straight full bore, unobstructed pipe. More upstream diameters are required when there is a control valve upstream of the meter. Installation requires cutting out a section of pipe and welding of pipe flanges to accomodate the meter tube. The use of flow straightening vanes are strongly recommended by the manufacturer and are included with tube propellor meters. Saddle mounted propellor meters will require straightening vanes to be purchased.

WATER SPECIALTIES

Two Water Specialties propeller meters are evaluated. One type was a special 30" Hi Velocity clamp-on saddle mount propeller meter. The other propeller meter evaluated, shown in figure 9, is a 10" weld-on saddle meter designed to be installed at a 45 degree angle to the direction of flow. Standard installation of Water Specialties propeller meters requires five pipe diameters upstream and one pipe diameter downstream of straight, full bore, unobstructed pipe. It is recommended that flow straightening vanes be installed immediately upstream of the propeller to prevent errors due to swirling flow patterns. The flowing fluid causes the propeller to spin and the rotational speed is transmitted to the meter head. A set of change

Figure 8. Sparling Propellor Meter

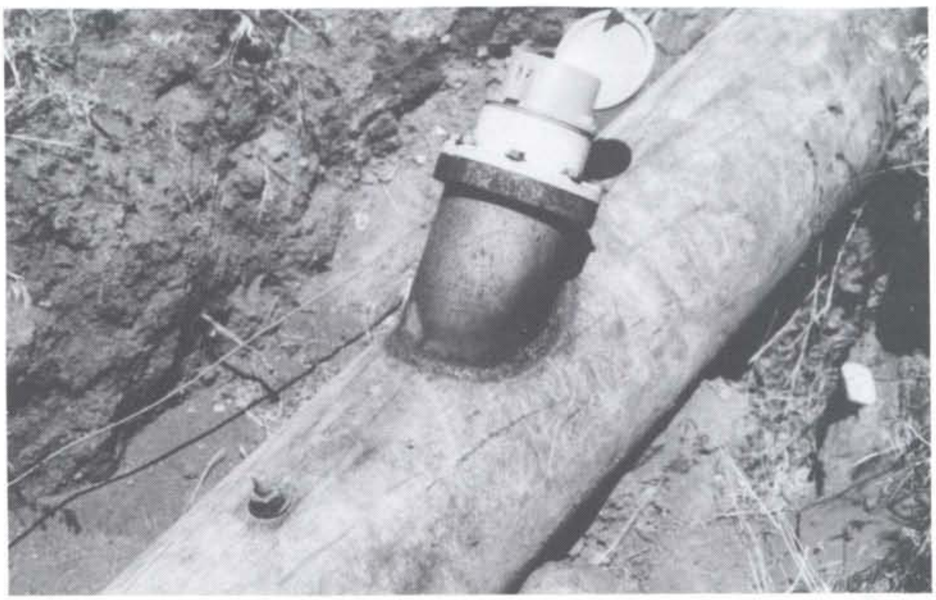

Figure 9. Water Specialties - Weld-on Inclined Propellor Meter

gears are used to convert it into the accumulated flow volumes based upon pipe size, propeller design, and the user's selected flow units.

WILGOOD CORPORATION

The Wilgood Corporation dual turbine meters evaluated are shown in figure 10a. The purpose of the dual turbine is to compensate for errors due to swirl in the pipe flow. The turbines have inverse pitches so that the upper turbine will spin in one direction while the other turbine spins in the opposite direction. If the flow in the pipe is swirling one of the turbines will spin faster than the other and the average of the two turbine speeds will represent the mean velocity in the pipe. The standard installation requirements of the dual turbine meter are only concerned with the relative location of valves and elbows upstream of the meter. The manufacturer does not have specific guidelines for standard installation except that the probe location should be one-third to one-half of the pipe diameter from the well. The meter head contains the necessary electronics to produce a pulse train for each meter in proportion to the velocity sensed by each turbine. The electronic integrator, figure 10b, averages velocity indicated by the two turbines and calculates flow based on factory installed coefficients for the probes and inside pipe diameter.

FIELD EVALUATION SITES

Seven field evaluation sites were selected from the many available pumped irrigation diversions located in the study area (see location map, figure 11). Criteria used for site selection embraced: ownership, access, sufficient pipe for multiple meter installation,

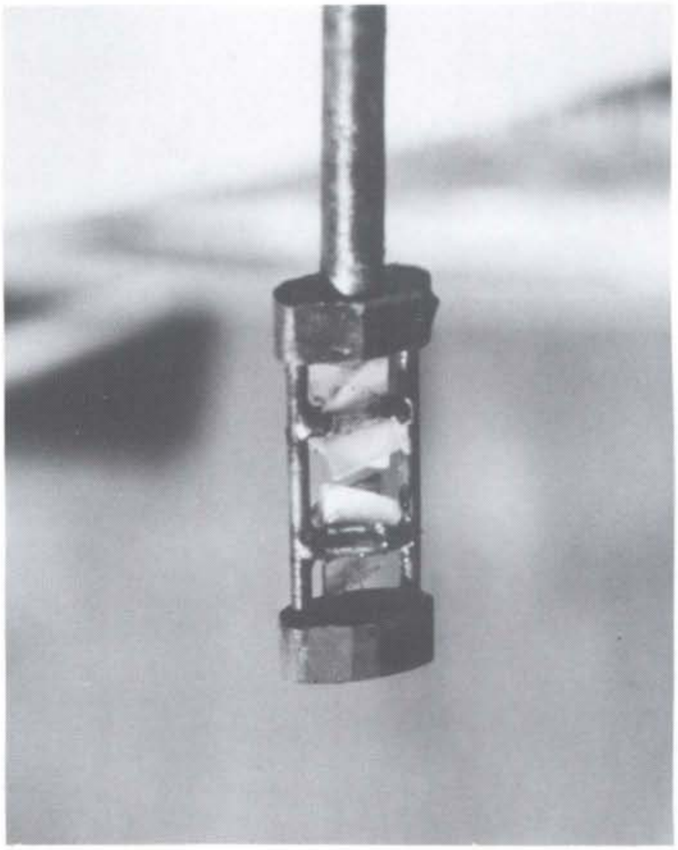

Figure 10a. Wilgood Corporation Dual Turbine Meter Sensor

Figure 10b. Wilgood Corporation Dual Turbine Meter Integrator

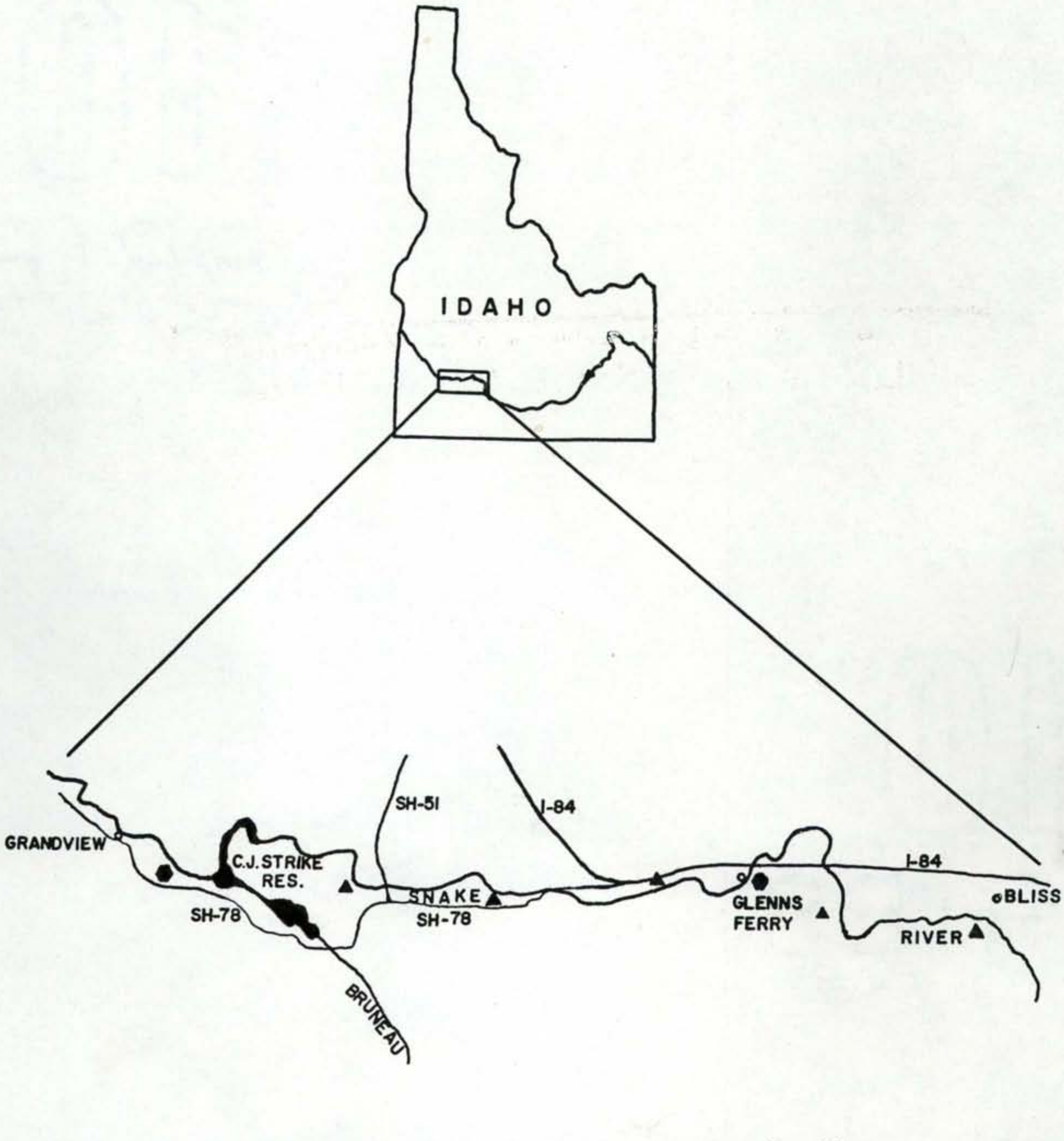

Figure 11. Location Map - Field Evaluation Sites

flow rate, pipe size, potential meter installation problems, and owner-operator cooperation. The seven evaluation sites encompass flow rates between 1 to 125 cfs with nominal pipe diameters ranging from 8 to 48 inches.

KING HILL IRRIGATION DISTRICT WILEY STATION

The King Hill Irrigation District (KHID) Wiley Pump Station is located approximately 5 miles southwest of Bliss, Idaho. At this location KHID lifts irrigation water from the Snake River 200 feet to the main canal location on a canyon bench. The station consists of six Layne vertical turbine pumps with a capacity of 40 cfs each, and an installed electrical horsepower of 1235 hp. The discharge line consists of a nominal 30 inch diameter steel pipe. The flow was measured using three different methods: a U.S. Geological Survey (USGS) gaging station, Water Specialties propellor meter and a Wilgood Corporation dual turbine meter. At the discharge structure, there are two pumps that supply the irrigated area adjacent to the site. These pumps take water from the system prior to the USGS gaging station.

The Water Specialties propellor meter was located 84.0 feet from the discharge structure in the penstock and 25.8 feet upstream from the Wilgood probe. The meter was a bolt-on saddle type and a 4 foot diameter cmp access pipe was installed to facilitate access and reading the meter in the buried penstock. Three flow straightening vanes were installed upstream of the meter according to the manufacturer's specifications.

The Wilgood Corporation dual turbine meter was located 58.2 feet upstream from the discharge structure in the penstock. At this point a one inch hole was cut into the pipe and appropriate fittings attached for probe installation. The integrator for the Wilgood system was mounted in a shelter 25' from the probe port and connected to the meter with electrical cable.

The USGS gaging station was located immediately downstream of the discharge structure. University project personnel recorded the stage from the USGS staff gauge when servicing the other meters. To account for the part of the irrigation diversion removed by the pumps discussed earlier, the pump operation was recorded and flow rates were obtained from KHID personnel.

KING HILL IRRIGATION DISTRICT BLACK MESA STATION

The King Hill Irrigation District Black Mesa pumping station is located southeast of King Hill, Idaho. At this location KHID lifts water from the Snake River approximately 270 feet to their main canal. The station consists of six Layne vertical turbine pumps that have a combined output capacity of 125 cfs and produce a total of 5100 horsepower. The pumps discharge into a manifold connected to a nominal 48 inch diameter discharge line which transports the water up the canyon wall to the canal (the flow was measured with two different methods at different locations). At the discharge structure, located between the measurement locations, KHID maintains a small pump to supply a single farm above the station.

The first method used was a Flow Research Corporation Impellor Meter installed on a 48 inch pipe about 100 feet down stream from the pump station pier. At this point, the pipe was uncovered and a 2" hole was cut in the pipe and a threadolet was welded on for installation of the probe. The electronic integrator was mounted in a shelter near the port site.

The second method used was a standard USGS gaging station located in the canal downstream of the discharge structure. This station was maintained by the USGS and University personnel recorded the stage from the USGS staff gage when servicing the other meter. In addition to reading the staff gauge the operation of the small pump was noted.

ED POTUCEK FARM

The Potucek site is located 2 miles east of Glenns Ferry, Idaho. Two Aurora vertical turbine pumps supply irrigation water from the Snake River to the sprinkler irrigation system. The 225 horsepower pumping station has a discharge capacity of 5.3 cfs at 320 feet of head. The pumps discharge into a nominal 10 inch diameter steel pressure line with a gate valve for flow regulation located approximately 30 feet downstream from the pumps. Six flow measuring devices were evaluated in a 126 foot section of the pressure line between the control valve and the distribution system. This section of pipe has a 15 percent grade. The devices evaluated were: a Miller SLV Inline Shunt Meter, a Sparling propellor meter, a Data Industrial Corporation impellor meter, a Water Specialties propellor meter, a Signet paddle meter, and a McCrometer propellor meter. In conjunction with another project, a pump station efficiency monitor was installed at this location and used the Signet meter for a flow signal.

The Miller SLV meter was located 4.5 feet downstream from a bend in the pipe where the line starts up the grade. A 30 inch section of pipe was cut from the line and flanges were welded on each end of the cutout for standard installation of the meter. Internally, the meter was equipped with flow straightening vanes.

The Sparling propellor meter was located nine feet downstream from the Miller meter. The meter style was also a flanged tube and was installed in the same manner as the Miller meter. Due to delivery problems, the meter was not installed until the middle of the irrigation season.

The Data Industrial Corp. impellor meter was located nine feet downstream from the Sparling meter. A 2" hole was cut into the pressure line and the sensor was installed according to manufacturer's recommendations.

The Water Specialties propellor meter was installed nine feet downstream from the Data Industrial meter. A hole was cut in the line that would accommodate the insertion of the meter and a mounting saddle was welded over the cutout. Before the saddle was welded in place however, straightening vanes were placed inside the line upstream from the center of the hole according to manufacturer's recommendations.

The Signet paddle wheel meter was installed nine feet downstream from the Water Specialties meter. At this location a 2 inch hole was cut into the pipe to facilitate insertion of the sensor according to Signet specifications. Due to delivery constraints the meter was not installed until the middle of the irrigation season.

The McCrometer propellor meter was installed in the pipe nine feet down stream from the Signet meter. A section of pipe was cutout and replaced with another section of a proper diameter pipe to accommodate the meter. Three straightening vanes were installed in this new section of pipe according to specifications.

KENNETH SEESEE FARM

The Seesee site was located on the Snake River about 5 miles east of Hammett, Idaho. This system lifts irrigation water approximately 43 feet into an open ditch using a single unregulated 7.5 hp Berkley centrifugal pump with a capacity of 1.0 cfs. There were two meters evaluated at this location: a Vibration Meter and a Cutthroat Flume with a Stevens stage recorder.

The Vibration Meter was firmly attached to the discharge line from the pump, about 3 inches from the fitting. The meter accumulates hours that the discharge pipe was vibrating, i.e., when the pump was running.

The cutthroat flume was installed in the field ditch according to specifications approximately 10 feet downstream of the pipe discharge. The level of water flowing through the flume was recorded with a battery operated Stevens stage recorder using monthly charts.

JOHN BRUBAKER FARM

The Brubaker pump station is located in the Indian Cove area, about 10 miles west of Hammett, Idaho. The pump station consists of a 10 hp Pomona vertical turbine pump with a capacity of approximately 2.0 cfs discharging into an open channel. The irrigation water is lifted approximately 32 feet depending on the Snake River water surface elevation. Mr. Brubaker has three different sizes of transmission pipe between the pump and the discharge box. The nominal diameters are: 10 inch, 12 inch and 14 inch. The flow measuring devices evaluated at this location were: a Miller SLV meter, a McCrometer propellor meter and a Data Industrial impellor meter.

The Miller SLV meter was installed in the 10 inch nominal diameter pipe. A 30 inch section of pipe was removed and flanges were installed to accommodate the meter tube. The Miller meter was then bolted into this section according to manufacturer's instructions. Mr. Brubaker felt the Miller meter was constraining his flow rate and requested that it be removed before the end of the irrigation season.

The McCrometer propellor meter was installed in the 12 inch section of pipe, eight feet downstream from the 10 to 12 inch transition. Flow straightening vanes were attached inside the pipe in front of the meter as recommended by the manufacturer.

The Data Industrial impellor meter was installed in the 14 inch section of pipe, 5.83 feet upstream from the discharge box at a 10 degree angle from vertical. A two inch hole was cut in the pipe and the probe, installed according to specifications. The electronic interface for this meter was mounted in a shelter next to the probe.

EDGINGTON IRRIGATION ASSOCIATION

The Edgington Irrigation Association pump station is located near Bruneau, Idaho, approximately 18 miles southeast of Mountain Home. At this location, the association pumps irrigation water from C. J. Strike Reservoir on the Snake River to farms located on the canyon mesa. The pump station consists of five 600 hp Layne vertical turbine pumps discharging into a nominal 34 inch diameter steel penstock. The station has 50 cfs capacity at 485 ft head. Two flow measuring devices were evaluated at this location: a McCrometer propellor meter and a Flow Research Corporation impellor meter.

The McCrometer was installed in the system when it was originally completed; however, it was not working prior to the 1986 irrigation season and was repaired at the start of the project. The repairs consisted of replacement of the propellor bearing assembly.

The Flow Research meter was installed 32 feet from the nearest joint in the line approximately 200 feet downstream of the McCrometer, at which point a 2 inch hole was cut in the pipe and necessary fittings attached to allow standard installation of the flow sensor. The flow signal integrator was installed in a weather shelter next to the port.

TRIANGLE DAIRY RE-LIFT STATION

The Triangle Dairy re-lift pump station is located on the Bybee Lateral about 5 miles southeast of Grandview, Idaho, near the Rimrock Junior-Senior High School. At this location, the pumps lift irrigation water from the Bybee Lateral to the Triangle Dairy canal system. The water originates from the Snake River where a group of farms jointly operate a pump station diverting water into the lateral. The 525 horsepower re-lift pump station consists of 4 vertical turbine pumps. The pump station discharges into a nominal 30 inch diameter spiral weld steel pipe which discharges to an open channel at an elevation 85 feet above the pump station. Four flow measurement devices evaluated at this location were: a McCrometer propellor, a Wilgood dual turbine, a Flow Research impellor and a USGS gaging station. Also, this location was equipped with a pump station efficiency monitor in conjunction with another project.

The McCrometer meter was installed in the system prior to the project probably when the station was established. Prior to the evaluation project the meter had been re-built by a third party for Triangle Dairy. However, the original installation did not include flow straightening vanes. Three straightening vanes were installed by Triangle Dairy upstream of the meter prior to the irrigation season.

The Wilgood probe was installed through a 1 inch existing port on the discharge pipe approximately 30 feet downstream from the McCrometer meter. The dual turbines on the probe were positioned near the centerline of the pipe.

The Flow Research meter was installed 30 feet downstream of the Wilgood meter through a 2 inch access hole with required fittings. The probe was installed according to manufacturer's specifications.

The USGS gaging station was located on the discharge canal immediately downstream of the discharge structure. The station was maintained and operated by the USGS, and University personnel recorded stage from the USGS staff gage when servicing the other meters.

DATA COLLECTION AND ANALYSIS

The majority of the flow measuring devices were evaluated by monitoring the installed meter in the cooperator's system for an extended period of time. An ultrasonic and a pitot tube device were evaluated by making measurements at specific points in time when the meters were available for demonstration.

The field evaluation sites were typically visited by project personnel on a weekly basis. During the visit to each site, the indicated instantaneous flow rates and accumulated flow volumes of the measuring devices were read and recorded. Additionally, instantaneous flow rate was determined by recording the time required for a fixed volume to be accumulated by the meter. If the flow rate was suspect, project personal would then clean the sensor by removing it from the pipe if possible and take another set of readings. For the USGS gaging stations the current stage was recorded and discharge was determined from a stage-discharge relation developed from Price current meter measurements by USGS personnel.

The flow data were statistically analyzed for mean, standard deviation, and range for each location and observation set. The mean standard deviation between the meters for each set was calculated. The flow data then were examined for rejection of a single meter's flow rate for each observation based on Chauvenets's Criterion for rejection of outlier observations set (Kennedy and Neville, 1976). Before rejecting the observation, physical reasons for rejection were established from the field notes regarding the status of the meter. Some of the physical reasons were trash or moss accumulating on the probe and meter calibration errors. Once the "unacceptable flow rates" were removed from the data sets; an adjusted mean flow, AMF, rate of all meters was calculated for each location and observation set. This adjusted mean flow rate, AMF, was assumed to be the best indication of the actual flow rate in the pipeline. The percentage error and deviation from the AMF was calculated for each observation including rejected observations. A similar analysis was performed on the accumulated flow volumes measured by the meters.

RESULTS

The U. S. Geological Survey has adopted criteria for classifying the degree of accuracy of daily discharge records (USGS, 1982). "Excellent" means about 95 percent of the daily discharges are within 5 percent; "good", within 10 percent; and, "fair", within 15 percent. "Poor" means that daily discharges have less than "fair" accuracy. This criteria is subjective and is entered by the hydrographer based on his or her knowledge of the gaging station characteristics. For purposes of this study, this USGS accuracy criteria has been applied to the data set of instantaneous readings for each meter type. Statistical analyses has been used utilizing the student's t test to develop 95 percent confidence intervals for each data set.

DISCHARGE ACCURACY EVALUATION

The ideal way to evaluate the accuracy of a flow meter is to compare the reported flow rate with the actual flow rate determined by some recognized standard; however, this was impractical since the actual flow rate was unknown and could not readily be determined. For the comparison of the different methods, the percent error between the indicated flow rate of an individual meter and the AMF rate for an observation set was used. Figures 12 through 20 show the error from the AMF for each device. These graphs indicate percentage variations of the indicated flow from the AMF without regard to installation location. Comparisons can therefore be made between meters independent of locations. For these graphs, the asterisks denote the observed errors from an AMF rate for each device. The dashed line represents the "best fit" equation relating the error to the AMF. Table 3 shows minimum, maximum, and average error terms for the devices with respect to AMF.

The USGS method reported flow rates which fluctuated from 14.6 to -13.8 percent in error from the AMF (Figure 12). The absolute mean error was 5.5 percent. This means that the USGS method reported a flow rate within ±5.5 percent of the AMF. At AMF rates greater than 30 cfs, the flow reported by the USGS method are less that AMF. These reported flows are from a single location indicating sensitivity to installation

Table 3. Device Error with respect to Adjusted Mean Flow.

Device	Number of Obs.	Mean Error[1]	Mean[1] Absolute Error	Error Min	Error Max	Standard Deviation of Error	95%[2] CI	Record[3] Accuracy Rating	Remarks
U.S.G.S.	37	-1.6	5.5	-13.8	14.6	6.4	±12	F	
Wilgood Turbine	34	-24.8*	24.8	-76.6	0.4	20.2	±40	P	Consistently under registers
Water Specialties	35	4.2*	5.8	-14.6	13.8	5.9	±11	P	
Flow Research	23	3.0*	4.0	-10.6	8.6	3.4	± 7	G	Consistently under registers
Data Industrial	29	2.2	3.9	-6.5	11.9	5.1	±10	F	
McCrometer	47	-4.9	5.1	-14.2	1.8	4.0	± 8	F	Consistently under registers
Miller Shunt	17	3.2	6.6	-11.1	13.8	7.4	±14	P	
Sparling	12	-3.2*	3.2	-6.3	-0.5	2.0	± 4	G	Consistently under registers
Signet	6	-1.1	2.2	-4.6	3.4	2.6	± 5	G	Failed near end of season due to excessive wear on impellor shaft
IMP	58	2.2	3.7	-10.6	11.9	4.4	± 9	F	
PRO	94	-1.3	5.7	-14.6	13.8	6.2	±12	F	

[1]Percent error of indicated flow to AMF (adjusted mean flow).

[2]Confidence Intervel

[3]E = Excellent, within 5% 95% of the time
G = Good, within 10% 95% of the time
F = Fair, within 15% 95% of the time
P = Poor, more than 15% 95% of the time

*Value is significantly different than zero at the 5% confidence level

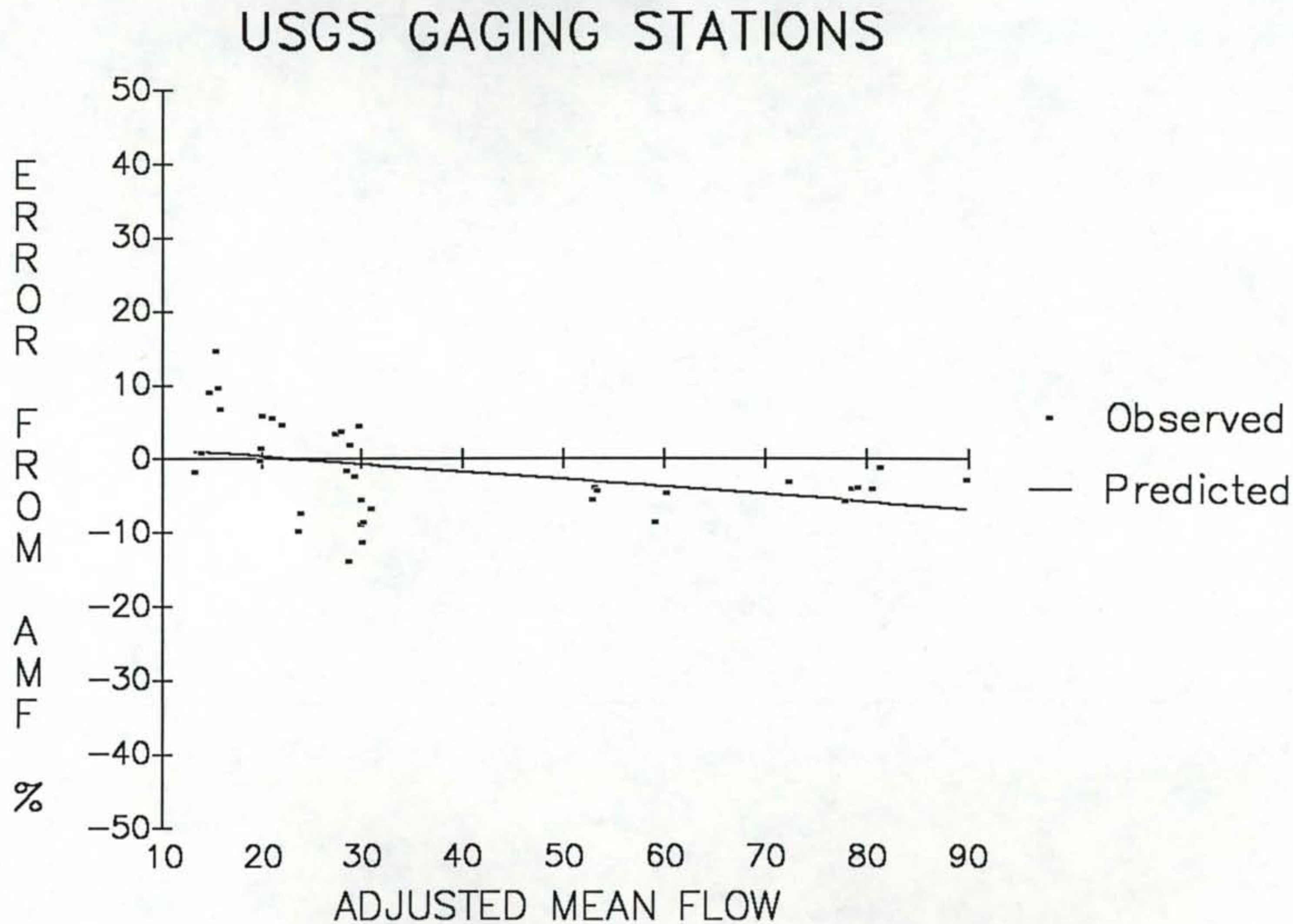

Figure 12. Deviations from Adjusted Mean Flow, USGS Sites

on a system. The reported flows below 30 cfs were measured at the other two locations and were distributed on both sides of the AMF.

Overall, for the three stations, the USGS method had a root mean square error of 6.5 percent and an average error of -1.6 percent. Statistically, the flow rates given by this method were not different than the AMF rate. Based on these 37 gage rated discharges, 95 percent of the time the error will be between -13.6 and +10.4 percent. These gage rated discharges meet the requirements for a 'fair' record accuracy of daily mean discharge according to USGS criteria (USGS, 1982).

Wilgood Dual Turbine:

The error in flow reported by the Wilgood meter ranged from .4 to -76.6 percent of the AMF rate (Figure 13). It should be noted that the three values of -66.6, -74.1, and -76.6 percent error from the mean flow rate were omitted from this graph for presentation purposes. The absolute mean error in flow was 24.8 percent from the AMF rate for the Wilgood meter including the omitted graph points. All of the points except one fall below the mean flow rate line. The primary reason for the underestimation of the flow is that the Wilgood meters almost without exception were plugged with debris, moss and leaves shortly after flow started. Even though the meter probes were cleaned before taking the flow measurement, the probes caught debris flowing in the water during the short time the observation was being made.

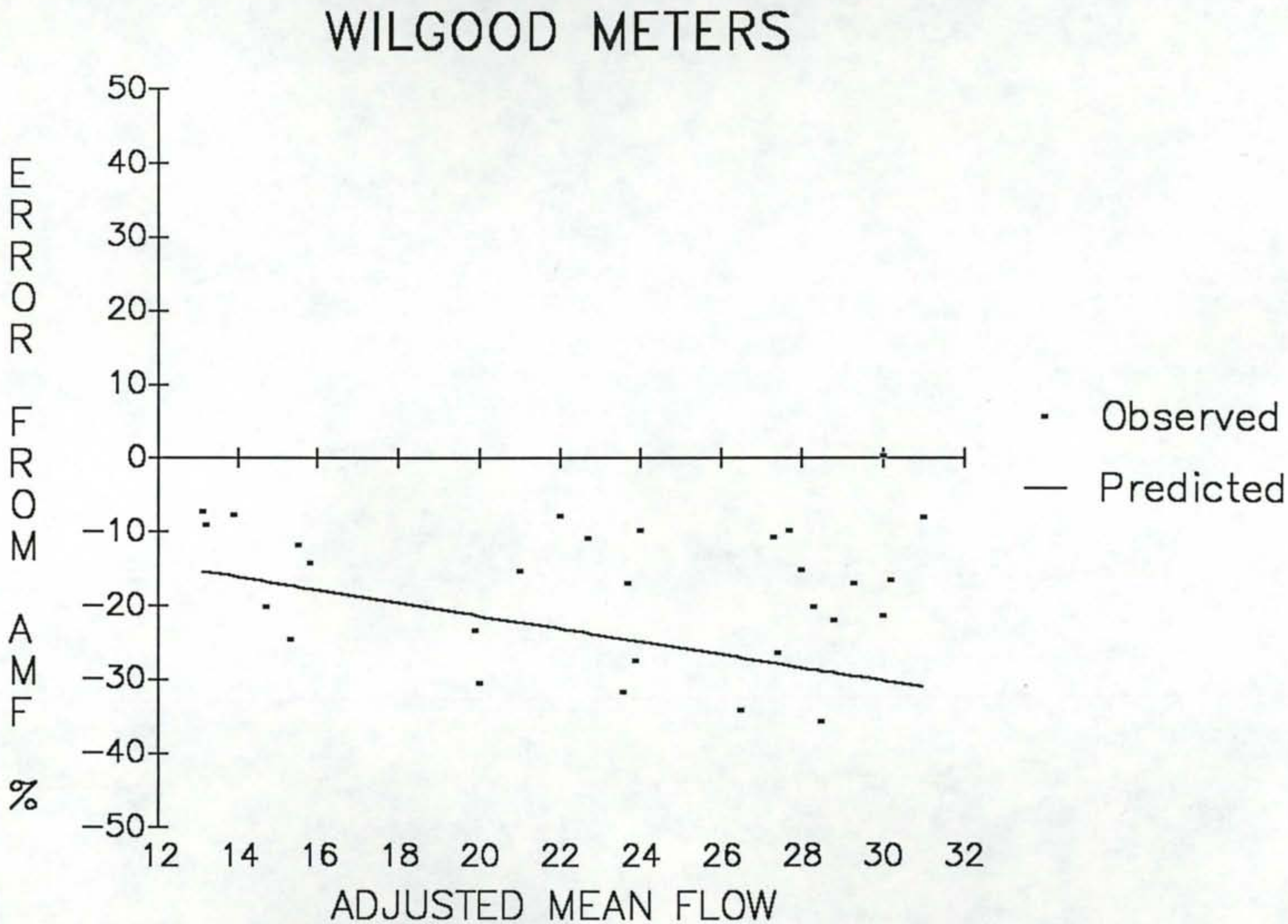

Figure 13. Deviations from Adjusted Mean Flow, Wilgood Meters

With an absolute value of the mean percent error of 24.8 percent, the Wilgood meter had the poorest performance of all the meters included in this study. The poor performance of the Wilgood meter appears to be directly caused by the debris load found in irrigation diversions.

Water Specialties:

The error in the flow rates reported by the Water Specialties propellor meters varied from 13.8 to -14.6 percent of the AMF rate (Figure 14). As indicated in the figure, this device tends to over estimate the flow. The increasing error with increasing AMF trend shown in the figure is not statistically supported; however, statistically there is an offset error associated with the tested meters. The mean error and intercept is significantly different than zero.

The two Water Specialties meters had a root mean square error of 7.23 percent and an average error of 4.23 percent which is significantly different than zero. Based on these 35 measurements, 95 percent of the time the error with respect to AMF will be between -6.8 and +15.2 percent. These measurements meet the requirements for a 'poor' record accuracy according to USGS criteria.

Flow Research Corporation:

The Flow Research devices registered errors fluctuating from 8.6 to -10.6 percent of the AMF rate. As shown by figure 15, the devices typically overestimated the flow and tended to have higher error at

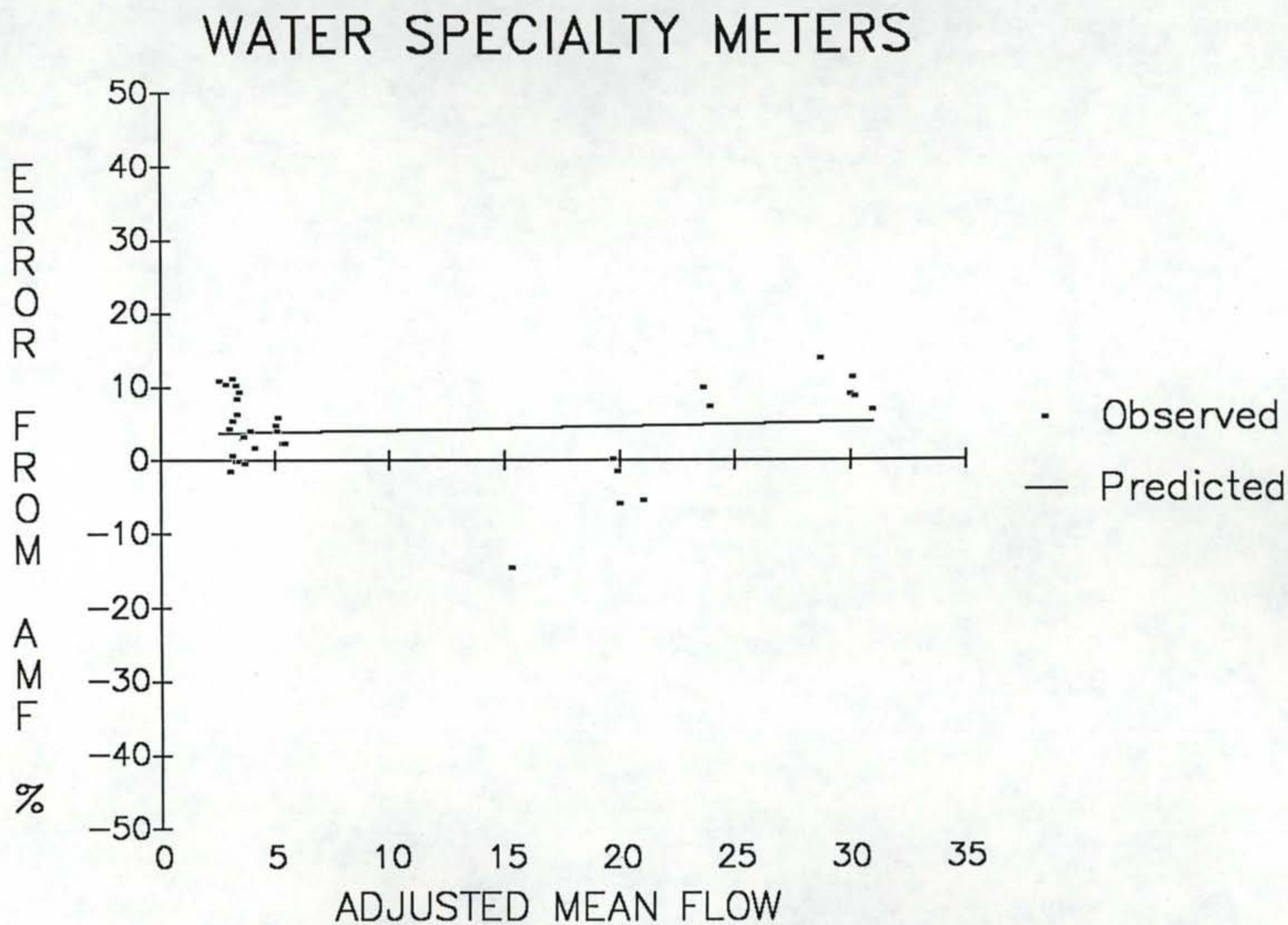

Figure 14. Deviations from Adjusted Mean Flow, Water Specialties

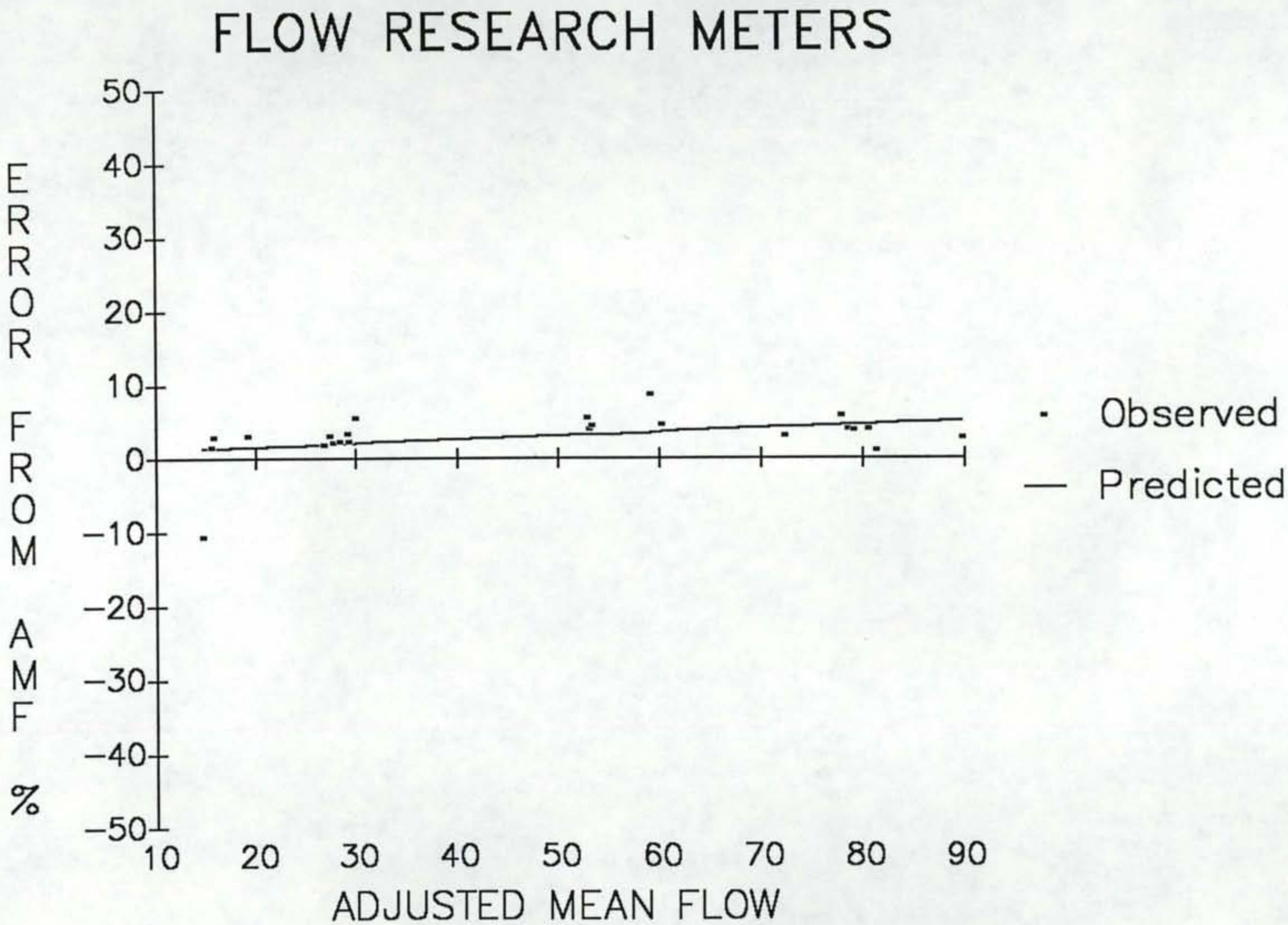

Figure 15. Deviations from Adjusted Mean Flow, Flow Research Corporation

higher flow rates. This trend is not supported by the regression of the error with respect to AMF. The overall performance was acceptable, although the three meters had a root mean square error of 4.5 percent and an average error of 3.04 percent which is significantly different from zero. Based upon these 23 observations, 95 percent of the time the error will be between -4 and +10 percent. These observations meet the requirements for a 'good' record according to USGS criteria.

The Flow Research probe experienced chemical plating of various elements on the probe at Triangle Dairy Site. The only difference between the Triangle Dairy site and the other sites was the presence of a chemical additive in the canal water to control the growth of moss. In this case, this plating out had a definite effect on the sensitivity of the probe. When exposed to this environment for a period of time, approximately three weeks, the meter ceased to function and needed to be removed and cleaned.

Data Industrial:

Indicated flow rate errors for the two Data Industrial devices were between 11.9 and -6.5 percent of the AMF rate. As shown in figure 16 the errors are distributed about the AMF. At AMF rates less than 2 cfs, the indicated flows are greater than AMF. These low flows are from a single location with one other meter installed. The other meter type consistently registered low at this site and other sites. For a more reasonable evaluation of the performance of the Data Industrial meters, flows below 2 cfs should be disregarded. For flows in excess

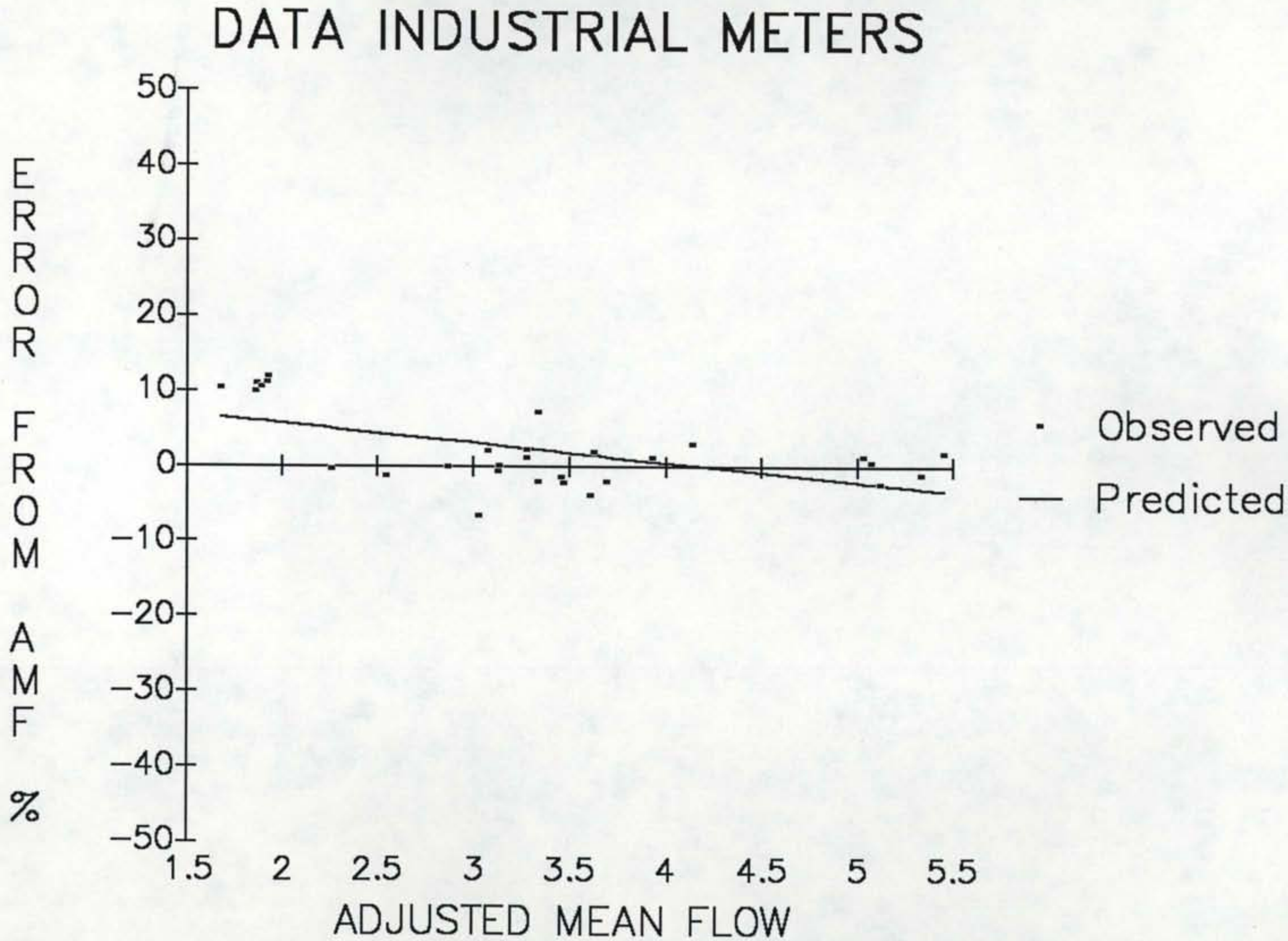

Figure 16. Deviations from Adjusted Mean Flow, Data Industrial Corporation

of 2 cfs, the AMF was computed in conjunction with at least four additional meters.

The average error for this device, including both sites, was 2.2 percent which is not statistically different from zero. Disregarding flow below 2 cfs results in an average error of -.05 percent and the error is not a function of discharge. Based on the 22 observations, 95 percent of the time the device error will be between -5.5 and +5.4 percent, which nearly meets USGS criteria for an 'excellent' record accuracy. No operational problems with trash or chemical plating were experienced by the Data Industrial probe at either location.

McCrometer:

The error in flow indicated by the McCrometer units varied from 1.8 to -14.2 percent from AMF rates. All but four measured flow rates were less than AMF rates as shown in figure 17 . The McCrometer flow meters registered values that were consistently less than the mean flow rates at both high and low flows. There is a significant error trend associated with flow rate as shown in figure 17. Most of the points seem to be scattered about a central offset error from the mean flow rate of approximately -4.9 percent which is significantly different from zero. The McCrometer flow devices had a root mean square error of 6.3 percent and an average error of -4.9 percent. Based upon the total record of 47 observations, 95 percent of the time this device error will be between -12.9 and +3.1 percent which meets USGS requirements for 'fair' record accuracy. If the seven measurements disregarded for the Data Industrial meter are disregarded for analysis of this device,

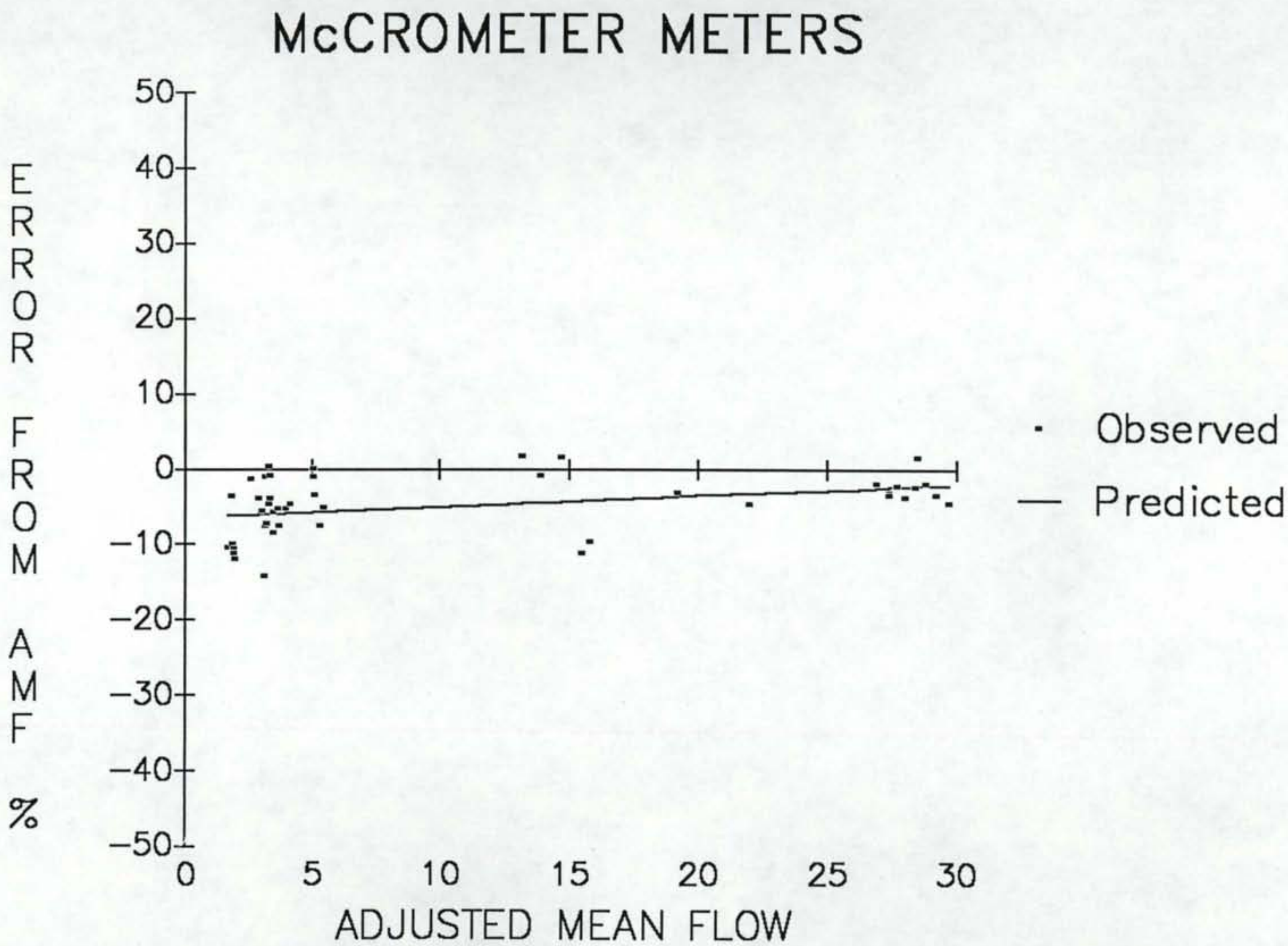

Figure 17. Deviations from Adjusted Mean Flow, McCrometer Meters

the error will be between -10.8 and +2.8 percent 95 percent of the time. This partial record of 40 measurements nearly meets the USGS requirements for a 'good' record accuracy.

<u>Miller SLV:</u>

The flow rate errors associated with the Miller Shunt Meter fluctuated from 13.7 to -11.1 percent of the AMF rate with all observations at one location except for two. The distribution of the error with respect to AMF is shown in figure 18 . The variability of measured errors is large as indicated by the second highest standard deviation, table 3. The root mean square error for this device was 7.8 percent and the average error was 3.2 percent, but the average error is not significantly different from zero. There is no significant error trend with flow. Based upon 17 measurements, the 95 percent confidence interval of the measurements is -10.8 to +17.2 percent which meets the requirements for 'poor' record accuracy according to USGS criteria.

The device was prone to plugging of the registering device by debris and required cleaning each visit. Generally, a large amount of scale and rust, which probably came from the inside of the pipeline, was flushed out at each visit. The difference in flow rates before and after flushing showed that the scale and rust had an adverse affect on the accuracy of this device since the reading before cleaning was always smaller than the reading after cleaning. The after cleaning flow rate was used for data analysis; but, it could still be in error due to small amounts of scale and rust remaining in the device after flushing.

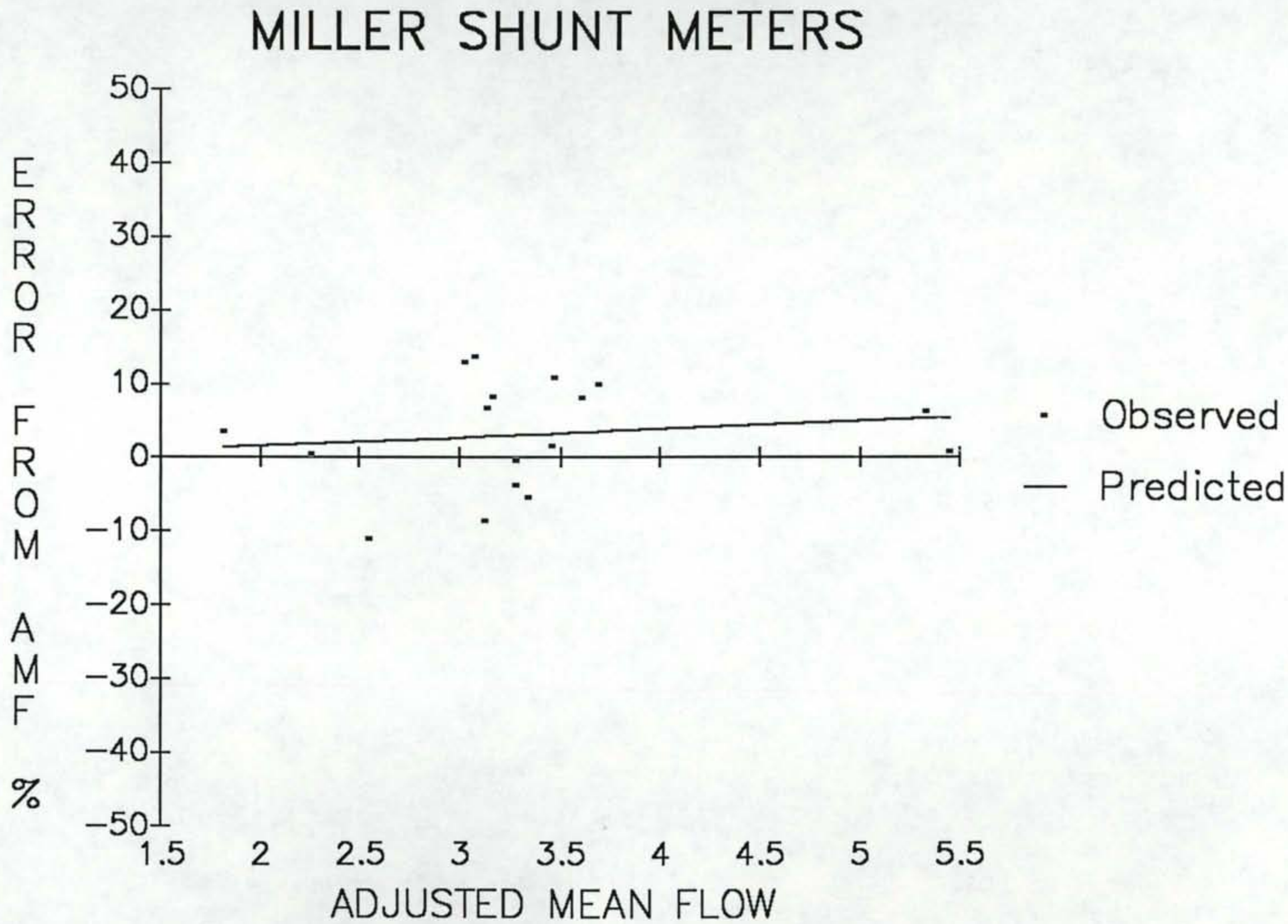

Figure 18. Deviations from Adjusted Mean Flow, Miller Shunt Meters

Sparling Propellor Meter:

The errors in flow measured by the Sparling Flow Meter at the one installation ranged from -.5 to -6.3 percent of the AMF rate as depicted in figure 19. All observed flow rates were below the AMF as computed using the six installed devices. There appears to be a relationship between the error and flow rate; however, it is not supported statistically. The root mean square error (RMS) for the meter was 3.7 percent and the average error was -3.2 percent, which was significantly different from zero, table 3. The 12 observations from the single location indicate that 95 percent of the time the device error will be between -7.2 and +0.8 percent which meets the USGS criteria for 'good' record accuracy.

Signet Flow Meter:

Initially, the Signet Flow Meter device continuously reported erroneous flow rates. The device tested was ordered with the proper inside diameter specified; however, it came calibrated for a different inside pipe diameter and initial errors in the observed flow were as much as 25 percent. The literature provided with the meter illustrated how to calibrate the meter given an actual flow rate. Using the AMF flow rate and the procedure outlined by the manufacturer, the Signet was calibrated in-place. After the in-place calibration, errors in the flow rates reported by the device ranged from 3.4 to -4.6 percent with a root mean error of 2.6 percent (Figure 20). It is very important to order this meter with a knowledge of the precise inside pipe diameter. Even though the meter can be field calibrated, it is necessary to know

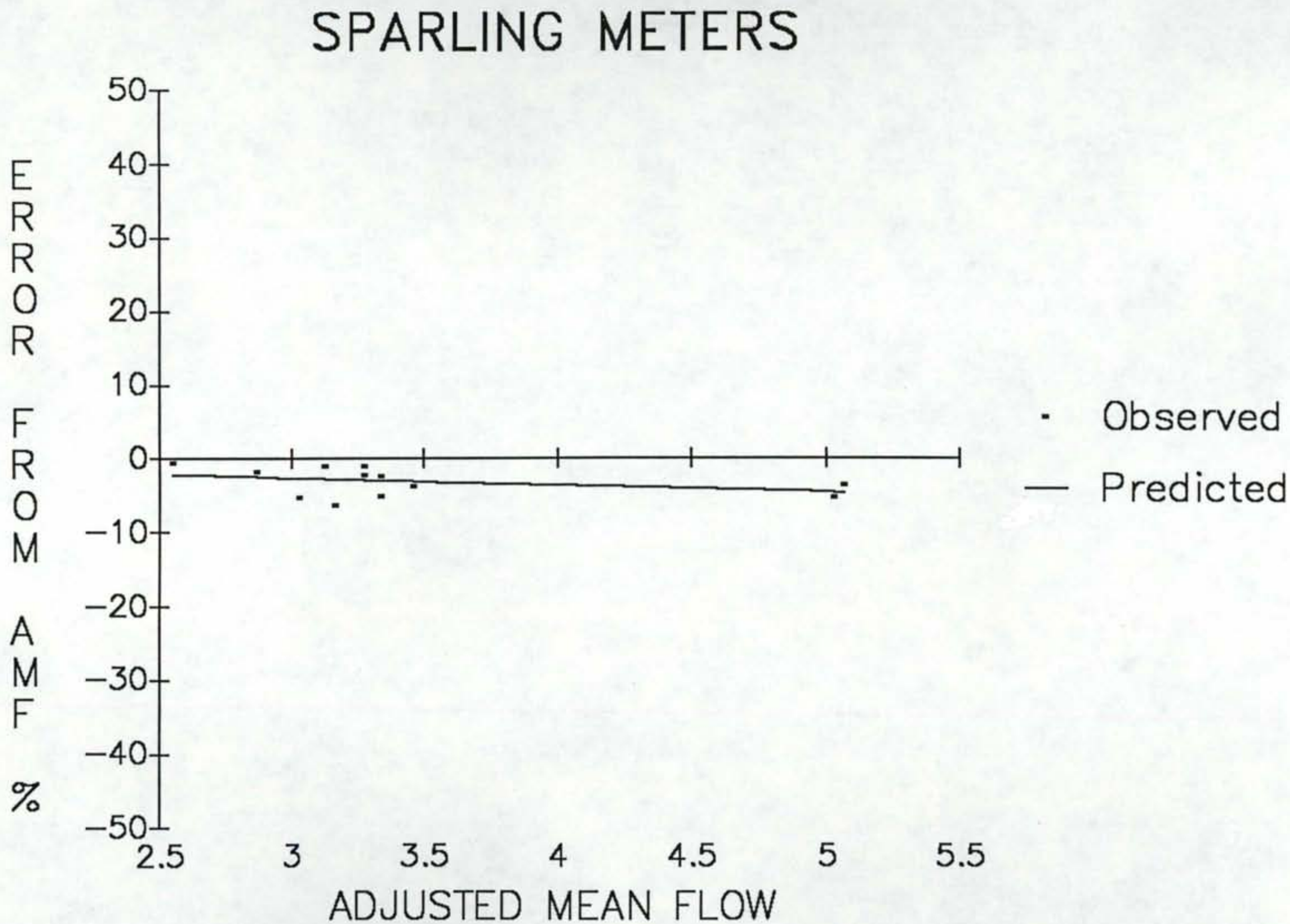

Figure 19. Deviation from Adjusted Mean Flow, Sparling Meters

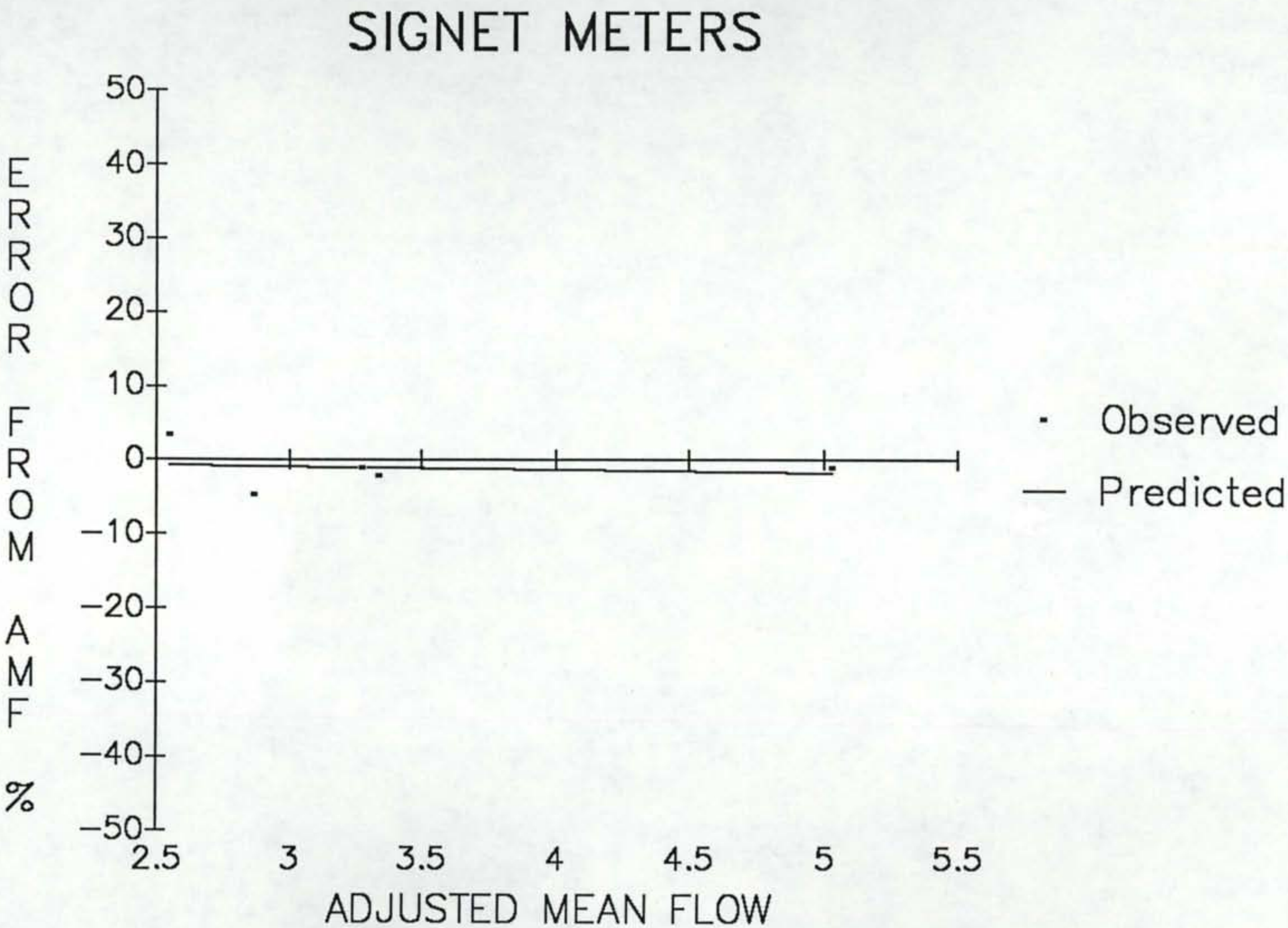

Figure 20. Deviations from Adjusted Mean Flow, Signet Flow Meter

the actual flow for calibration. The meter probe failed near the end of the irrigation season due to excessive wear on the impellor shaft. The Signet Flow Meter performed well when operating and calibrated to a specific installation. This is shown by the small value of the mean percent error, 1 percent, not significantly different from zero. There are obviously too few readings, six, to make a fair comparison between the Signet meter and the other meters.

<u>Generic Method Evaluation:</u>

To compare the methods, all propellor devices were lumped together. The average error in the flow rate from the AMF rate was -1.3 percent for all propellor devices with a root mean square error of 6.3 percent. The range in error was -14.6 to 13.8 percent. The propellor devices did not show a significant offset error as indicated by the mean error, nor did they show significant error trend with flow rate. The errors in the 94 measured flows for propellor devices show high variability, figure 21. This variability is also documented by the high standard deviation of 6.2 percent, table 3. Disregarding the one installation with the single propellor and single impellor devices, the standard deviation decreases to 5.9 percent. Generally, propellor devices can be expected to give 'fair' record accuracies.

The impellor devices had errors in flow with respect to AMF between -10.6 to 11.9 percent with a mean error of 2.2 percent and a root mean square error of 4.9 percent. This is a significant offset error but the error trend with flow rate is not significant. The errors in observed flow for impellor devices showed lower variability

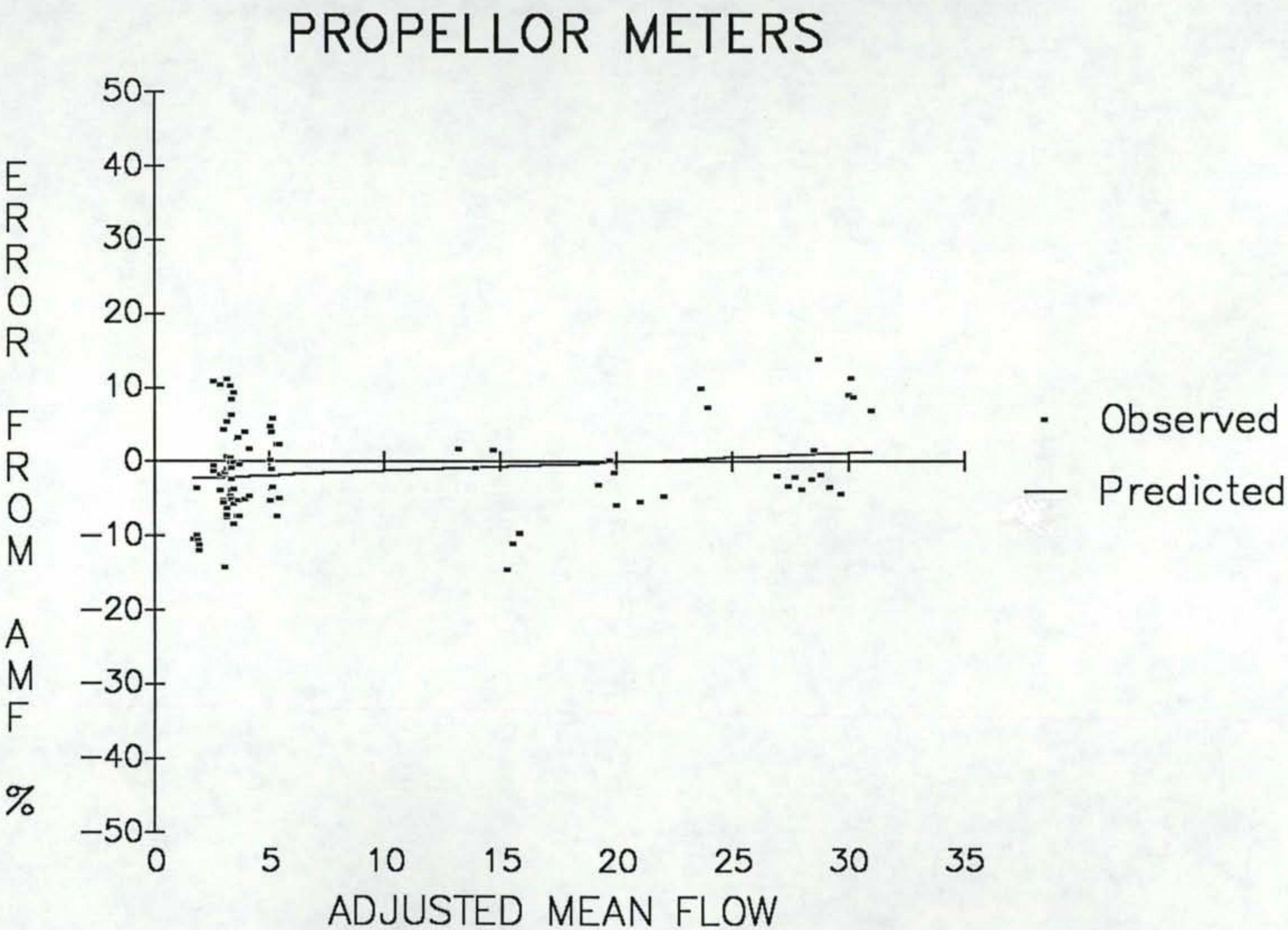

Figure 21. Deviations from Adjusted Mean Flow, Propellor Meters

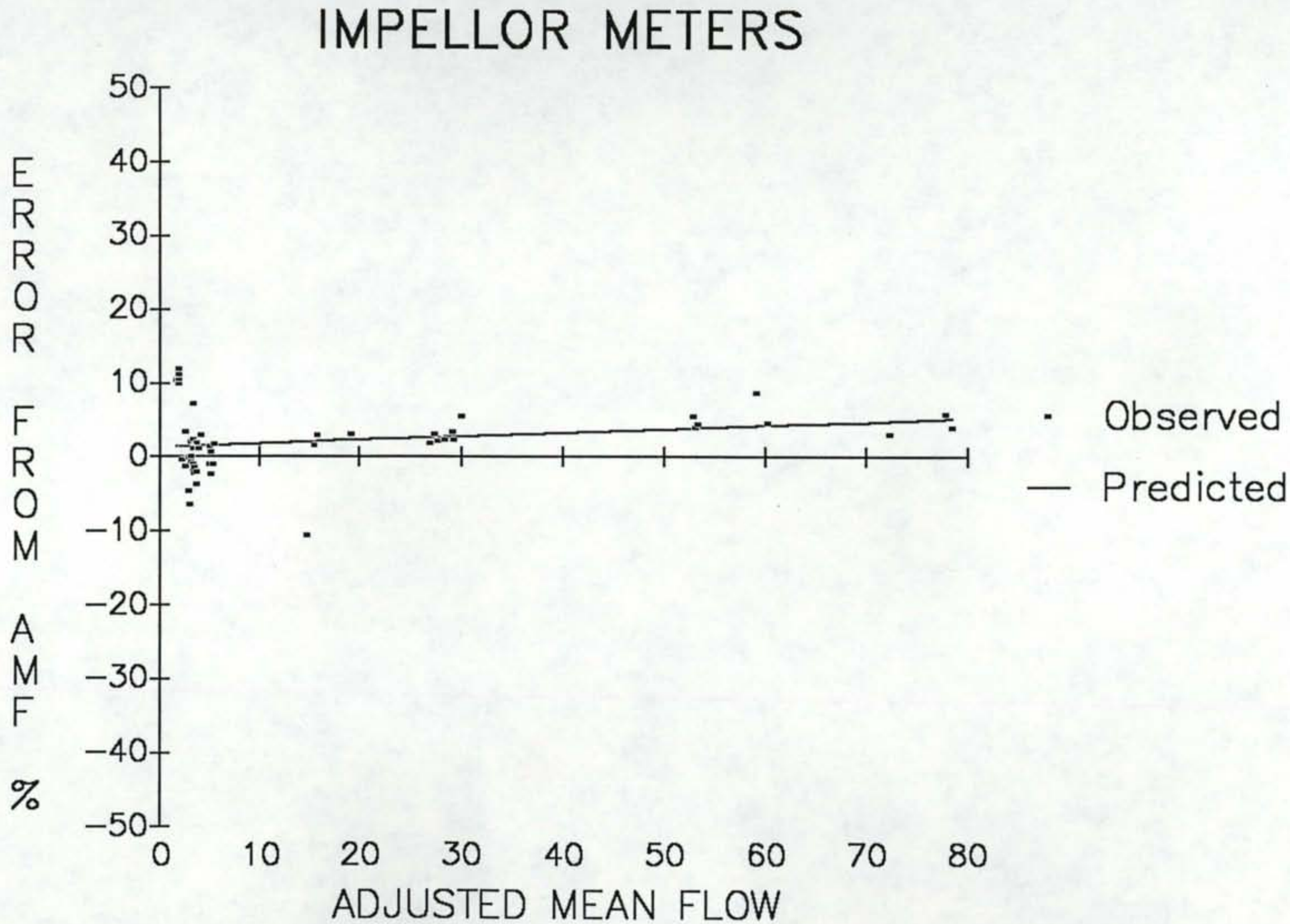

Figure 22. Deviations from Adjusted Mean Flow, Impellor Meters

than for propellor meters, figure 22. The standard deviation for the 58 measured flows was 4.4 percent. Disregarding the one installation with the single propellor and single impellor devices, the standard deviation was reduced from 4.4 to 3.4 percent. Generally, impellor devices can be expected to give 'good' record accuracies.

<u>Time of Operation Method:</u>

The vibration meter, DiVTT2, made by Triton Systems, installed on the Seesee Site was able to monitor the actual time of operation, pumping, with greater accuracy than the Stevens F-1 Recorder with an electric clock. However, the vibration meter was not able to track changes in the total dynamic head which affects the flow rate of the pump. At the Seesee Site the static head ranged from 49 to 53 feet. This range of static heads produced by changes in the river water-surface elevation caused a range in system flow rates of 0.86 to 0.99 cfs.

These numbers indicate a change in flow of 0.13 cfs (58 gpm) with a change in head of 4 feet which is supported by the head discharge curve for this pump. Using the integrated diversion volume from the flume for comparison, the error in calculated seasonal flow volumes with the vibration meter ranged from -6 to 5 percent. The range of errors depends on whether the minimum flow or maximum flow is used to represent the average flow coupled with the time of operation indicated by the meter.

The vibration meters are extremely sensitive to vibrations and cannot discern between pumps on a multiple pump station. Also, the internal power supply of the unit failed before the end of the irrigation season.

INSTALLATION AND OPERATION EVALUATION

All meters installed were observed or evaluated during one irrigation season. Ease of installation or installation problems were noted as were operating characteristics.

Table 4 lists the meter installation ease and operating characteristics of the commercial meters evaluated. Generally, propellor type meters are moderate to difficult to install, requiring welding and cutting equipment to cut pipe or access for saddle type meters or preparation of flanges for tube type meters. Impellor or turbine type meters which are inserted into a smaller hole still require welding apparatus, but less effort. Impellor or turbine type meters are also easier to remove for maintenance or repair. Turbine types, such as the Wilgood Meter, are very susceptible to plugging from debris. Propellor meters exhibited no operational problems for this one season evaluation, however, historic experience indicates that bearings and other moving parts are susceptible to excessive wear in water with high sediment concentration. Also, care must be taken in installation to prevent high velocity backflow through propellor meters since the propellor can be stripped from the shaft. The Miller Shunt Meter, which utilizes the small diameter bypass pipe and commercial water meter, was subject to deposition of sediment or scale in the meter head and had to be cleaned during each visit.

A significant factor in specifying meters is the ability to field calibrate the meter for internal pipe diameter at the time of installation. The Data Industrial impellor meter was the only meter evaluated for which the calibration could be changed at the time of installation. The calibration for the Water Specialties and Sparling propellor meters can be changed in the field by changing gear sets in the meter head. However, if the actual internal diameter is different from that specified in ordering, it may be necessary to reorder a different gear set thereby delaying installation. The Signet paddle wheel meter can be calibrated in the field only if the actual discharge is known, which may not be possible.

Actual installed costs of various types of meters depend on the pipe size and system hydraulics, location of the site, and data readout required. It is, therefore, not possible to present an accurate cost comparison for meter types. Table 4 shows whether or not the cost varies with pipe diameter for each meter calibrated.

A significant factor in selection of meters with electronic readout is whether or not the volume accumulator memory is volatile or protected. On the Flow Research impellor meter, the accumulated volume is lost whenever the meter probe is disconnected or power fails.

Table 4. Meter Installation and Operation Characteristics.

	Comments					
Meter	Readout	Installation	Power Requirements	Calibration	Costs	Remarks
Wilgood	Electromechanical volume only	Easy	External battery or AC	Factory	Fixed	Continuous plugging with debris
Water Specialties	Mechanical volume	Moderate to difficult	N/A	Factory or field (change gears)	Varies with pipe diameter	No operational problems
Flow Research	Electronic (volatile*) volume & rate	Easy to Moderate	Internal battery	Factory	Fixed	Buildup of scale on probe at one site
Data Industrial	Electromechanical volume, electronic rate	Easy to Moderate	External battery or AC	Field	Fixed	No operational problems
McCrometer	Mechanical volume & rate	Moderate to difficult	N/A	Factory (trim propellor)	Varies with pipe diameter	No operational problems
Miller Shunt	Mechanical volume	Difficult	N/A	Factory	Varies with pipe diameter	Prone to plugging from debris
Sparling	Mechanical volume and rate	Moderate to difficult	N/A	Factory or Field (change gears)	Varies with pipe diameter	No operational problems
Signet	Electromechanical volume, electronic rate	Easy	AC	Factory or field	Fixed	

*Volatile volume memory - lost on power disruption or probe disconnection.

CONCLUSIONS

An ideal experimental design would be to install one meter of every type at every location. However, this was not practical because of costs, time and site conditions. In cannot be stated that one meter type performed better than all others under all circumstances when all of the meters were not exposed to the same environments. This analysis does, however, give an indication of the relative meter performance over one irrigation season.

No single flow measuring method is best suited for all irrigation diversions in Idaho; however, there are some methods or meters which are better suited than others. To assure an accurate flow measurement, the most important factors are selection and installation of the meter given the meter capabilities and the hydraulics and water quality characteristics of the system. When selecting a flow measurement device, an evaluation of the inherent physical and hydraulic features of the system is required to determine a suitable measuring device. A flow measurement device cannot be purchased off the shelf, installed in any pipe and yield accurate measurements of flow. Professional assistance is recommended. The diversion system needs to be evaluated with respect to the following criterion:

1) The physical characteristics of the piping layout: size, especially inside diameter; type of pipe construction, spiral weld or longitudinal weld; available length of straight full bore, unobstructed pipe; and control valves in the vicinity.

2) The hydraulic characteristics of the diversion system: flow range, minimum and maximum expected flows to be measured; expected working pressures at the measurement location; surge pressures and method of surge control; and the possibility of backward flow in the pipe.

3) The quality of the diversion water flowing through the system: sediment particle sizes and amounts, moss, chemical additives, and trash. Sediment particles affect the life of the meter shafts, bearings, and other components. Moss will be caught on some meters thus lowering the indicated flow rate and accumulated volume. Chemical additives may create problems by causing material, sediment particles and dissolved compounds, to plate out on the measurement sensors.

Based on the extremely poor performance of the Wilgood dual turbine insertion meter; insertion meters which are not designed to shed debris and moss, are not recommended for installation on surface water diversions. Also, shunt meter types are subject to clogging by debris and sediment in surface water diversions.

Properly installed impellor and propellor methods can meet, or exceed, the accuracy of open channel flow measurements by the USGS. The overall performance of the impellor class of meters was better than that of the propellor class. However, some propellor meters performed with accuracies equal to impellor devices. Tube type propeller meters generally performed better than saddle type propeller meters that bolt or weld onto existing pipe. In the impellor class of meters, the "better" performing meter allowed for in-field calibration to the existing, measured, inside pipe diameter.

Since the actual inside pipe diameter greatly affects the measurement accuracy of the meter, any meter selected should be capable of field calibration to the inside pipe diameter or include a factory tube as part of the meter.

Another important selection criteria is the availability of a non-volatile display register for flow volume accumulation. One of the meters evaluated reset the accumulated volume display whenever the sensor was disconnected. This same problem would occur as a result of a power failure.

This study suggests that impellor meters, considering performance criteria, ease of installation and use, and reliability, have a greater potential for use over a wide range of metering environments than the other meter types tested. Generally, they are easy to install and remove for repair. The accuracy of the impellor meter was better than that of the other meter types. Of the impellor meters, the Data Industrial meter allows for in-field pipe diameter calibration, incorporates a debris shedding design, and has a non-volatile flow accumulation register.

REFERENCES

1. Henry, Zachary A., Editor, 1975. Instrumentation and measurement for environmental sciences. Special Publication SP-0375, American Society of Agricultural Engineers, St.Joseph, Michigan.
2. Harrison, Paul, 1980. Flow measurement - A state of the art review. Chemical Engineering 87:1, January 14, 1980, pp. 97-104.
3. Kennedy, John B. and Adam M. Neville, 1976. Basic Statistical Methods for Engineers and Scientists. IEP, A Dun-Donnelley Publisher, New York, New York.
4. Luckey, Richard R., Frederick J. Himes, and Neville G. Gaggiani, 1980. Calibration and testing of selected portable flow meters for use on large irrigation systems. United States Geological Survey, Water Resources Division Report Number WRI-80-72. USGS, Denver, Colorado.
5. U.S. Geological Survey, 1982. Measurement and Computation of Streamflow: Volume 2. Computation of Discharge. Water Supply Paper 2175, p.613.
6. U.S.D.I. Bureau of Reclamation, 1967. Water Measurement Manual, Second Edition. A water resources technical publication, United States Department of Interior, Bureau of Reclamation. United States Government Printing Office, Washington, DC.
7. Watson, G. A., 1978. Flowmeter types and their usage. Chartered Mechanical Engineer 25:2, February 1978, pp.27-30. Mechanical Engineering Publications Ltd., Suffolk, England.

8. West, R. G., 1961. The problems of non-standard installations and some general conclusions. Instrument Practice 15:8, August 1961, pp. 973-981.

APPENDIX A

1. Data Industrial Corporation
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   Pocasset, MA 02559

2. Flow Research Corporation
   P.O. Box 27871
   Houston, TX 77227

3. Irrigation Industries, Inc.
   P.O. Box 790
   Colorado Springs, CO 80901

4. McCrometer
   3255 W. Stetson Avenue
   Hemet, CA 92343

5. Signet Scientific Company
   P.O. Box 5770
   3401 Aerojet Avenue
   El Monte, CA 91734-1770

6. Sparling Instruments Company, Inc.
   4097 North Temple City Blvd.
   El Monte, CA 91731

7. Water Specialties Corporation
   191 W. Poplar Avenue
   Porterville, CA 93257

8. Wilgood Corporation
   P.O. Box 1247
   Dunnellon, Florida 32630