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Irrigation Flow Measurement - Instrumentation Development
Part II

by

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BACKGROUND

Early irrigation facilities built by Reclamation to store and convey water are still being used today. It is now our mission to manage these systems more efficiently and to consider multiple-uses for the water resources that were previously used for agriculture. Effective management of water systems is a high priority where many competitors vie for the use of a limited amount of water. Improved operation of water delivery systems is needed to accommodate irrigation enhancements, environmental concerns, and urban growth. In many river systems, more water needs to remain in the natural streams to preserve fish, wildlife, and the surrounding habitat.

Management of older irrigation systems requires the ability to accurately and cost effectively measure and record existing water use in systems not initially designed with water measurement in mind. Water must be measured and usage must be known before conservation and equitable distribution can be implemented.

The Water Resources Research Laboratory (WRRL) is continually working with Reclamation field offices, irrigation districts, and farmers to efficiently operate irrigation systems and to upgrade water measurement and recording capability. Sensors and recorders that are used on irrigation systems must endure heat, humidity, debris, vegetation, dust, lightning, and vandalism and still maintain reliability and accuracy. Instrumentation must also be easy to use and available for a reasonable cost. As part of this effort, the WRRL, has recently developed and are currently testing devices to assist farmers and irrigation districts with measuring and recording water. This work has been accomplished in cooperation Reclamation's Science and Technology Office, Policy Office, Montana Area Office, and Utah State University.

The September 1999 Operations and Maintenance Bulletin paper entitled "Irrigation Flow Measurement – Instrumentation Development Part 1" provides a description of several instruments and their initial testing under laboratory and various field irrigation applications. Those instruments included two newly developed devices for open channel applications and four commercially available flow meters for pressurized pipe system applications [1].

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The objective of this study has been to work with instrument manufacturers and Reclamation engineers to develop and test low cost devices that can be used by irrigation districts and farmers to manage diverted water. Generally, the more expensive devices are more accurate. But maintenance, ease of use, reliability in the operating environment, and cost often become more important features when selecting the proper device. Each measurement and recording device has strengths and weaknesses that must be evaluated for each application.

This article summarizes a study that is a continuation of that previous work. This article provides a brief description of the instruments, test facilities and installations and presents the results of laboratory and field tests. The results include comparison of reliability, accuracy, ease of use, effect of debris on operation, and cost.

INSTRUMENTATION

The instrumentation in this study has two types of applications; 1) open channel applications; and 2) pipe flow rate measurement applications. The open channel applications have been expanded since the previous work [1] and the investigation now includes:

- an open channel flow recorder with an ultrasonic sensor
- an open channel flow recorder with a bubbler sensor
- a low cost transducer in a pipe water level sensor
- an additional high frequency cable water level sensor

The pressurized pipe flow meters being investigated are:

- two paddle wheel flow meters manufactured by SeaMetrics and Data Industrial
- a propeller meter manufactured by GF+Signet
- a vortex shedding meter manufactured by Fluidyne

Open Channel Measurement Devices

Three devices were tested for application to open channel measurement in irrigation systems. Two of the three devices are simply water level sensors that must then be used with a data logging device and the third device is an open channel flow recorder with an ultrasonic or bubbler sensor.

Open Channel Flow Recorder with Ultrasonic or Bubbler Sensor

The open channel flow recorder (OCFR) consists of a small central processing unit chip (CPU), a water level sensor, and a solar power supply (figures 1 and 2). It is designed for installation on the upstream side of a measurement structure, such as a flume, where it measures the water depth. The open channel flow recorder can be used with any type of water level sensor and has been tested with an ultrasonic sensor and a bubbler system. We have applied for a patent which is currently pending approval under the name Flume or Weir Flow Rate Sensor and Recorder[3]. A

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[3]Patent pending case No. REC-3653

unique feature is the processing and display that has been adapted for irrigation use. The device can be easily adapted for weirs or other flow measurement structures provided a rating equation is available for the structure. A totalizing feature has also been incorporated into the program so that total volume of water diverted can be computed. The flow rate in cubic feet per second and total diverted water in acre-feet is displayed on an LCD screen. A reset feature allows the water user to push a button and reset the totalized flow for a new irrigation period. Data can either be recorded manually or downloaded to a laptop computer.

Over the past winter season, the flume or weir flow rate recording device was modified so that it could be used with either the original ultrasonic sensor or a bubbler sensor. The modifications required only a small wiring change to add the OCFR CPU to the existing electronics provided by the bubbler manufacturer and a larger enclosure (figure 3). The bubbler sensor increases the cost of the flow recorder but it allowed investigation into adaptability of the design.

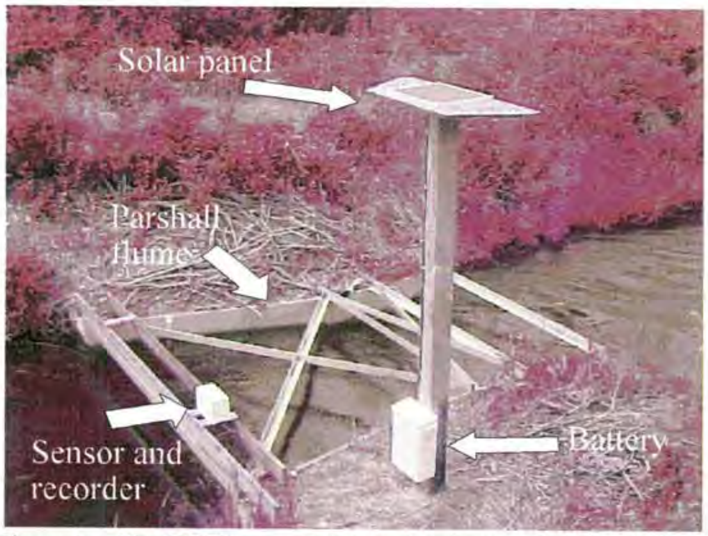

Figure 1. - The OCFR mounted upstream from an 8 ft Parshall flume in Montana.


Figure 2. - View looking into the OCFR. The cable is hooked to a laptop computer for easy programming of the CPU or downloading stored data. The display shows flow in ft^3/s and total flow in acre-ft. The ultrasonic sensor is underneath the box above the water level.

Water Level Sensors

The two water level sensors being investigated are:

- transducer in pipe
- high frequency cable

Both of these sensors can be used with the OCFR or other type of data logger.

Figure 3. - Close up of the bubbler electronics on top and the OCFR electronics on the bottom. This allows totalizing of the flow from the bubbler water level information.

Figure 4. - Pressure transducer threaded into a pipe cap prior to attaching the cap to the end of the PVC tubing. The voltage is then transmitted to a chosen recorder.

Transducer-in-Pipe Water Level Sensor

In many cases, a water level is required to compute flow through a flume or to maintain a canal at a desired level. At the time of the initial investigation, it was thought that commercially available submersible transducers were a little too expensive. Therefore, an inexpensive, nonsubmersible pressure transducer was mounted in a PVC pipe to keep the nonsubmersible portion of the sensor out of the water. To construct this device, a cap is drilled and threaded with pipe threads that fit the sensor threads. The transducer is screwed into the cap from the inside and the cap is fastened to the end of a 2 inch standard size PVC pipe (figure 4). To provide a water level reading, the pipe is fastened to a structure wall so that the transducer pressure port is submerged.

We have recently begun investigating another less expensive submersible transducer that could potentially replace this application.

High Frequency Cable Water Level Sensor

Under a cooperative agreement, Reclamation and Utah State University developed a cable-type water level sensor using high frequency signal reflecting techniques. This newly developed water level sensor consists of a non-coaxial cable similar to the twin-lead line used to bring signals in from a television antenna. One end of the cable is submerged in the water while a high frequency signal is generated down the cable from the electronics. The signal is reflected by the water surface back up the cable to provide information about the length of the cable from the electronics to the water surface, thus giving the water level in the channel. Figure 5 shows the sensor mounted in a clear vertical pipe in the WRRL. Further testing and development is needed because this instrument was just recently received from Utah State University.

Figure 5. - Laboratory test setup of the high frequency cable water level sensor. In the foreground, the 7-ft-long coaxial cable is mounted in a PVC pipe with a relief valve at the bottom to vary the water level. Data is being recorded by the people in the background where the electronics are located on a table.

Pipe Flow Meters

Four low cost flow meters are also being tested to determine their compatibility with irrigation water piping systems. There are a number of pipe flow meters available, but the majority of them are unacceptable for irrigation use due to high cost, incompatibility with untreated irrigation water, or high energy losses. Four pipe flow meters were tested:

- two paddle-wheel-type sensors manufactured by SeaMetrics and Data Industrial (figures 6 and 7)
- a unique propeller-type meter by GF+Signet (figure 8)
- a vortex shedding meter by Fluidyne (figure 9).

In all cases, the pipelines must be flowing full and must have sufficient length of straight pipe upstream of the meters for proper flow measurement. All these meters are mounted with pipe saddles and inserted into the pipes. The SeaMetrics, Data Industrial, and Fluidyne meters must be inserted into the pipe to the proper depth for correct measurements. These meters all have digital readouts that display flow rate and accumulated flow. The Data Industrial has several additional options for flow rate display. The GF+Signet also has a self-contained battery for operation.

Figure 6. - SeaMetrics paddle wheel flow meter with display installed on an 8 in pipe in Montana. These meters may be used on pipes between 2 and 48 inches in diameter. (The white can is placed over the sensor to provide shade.)

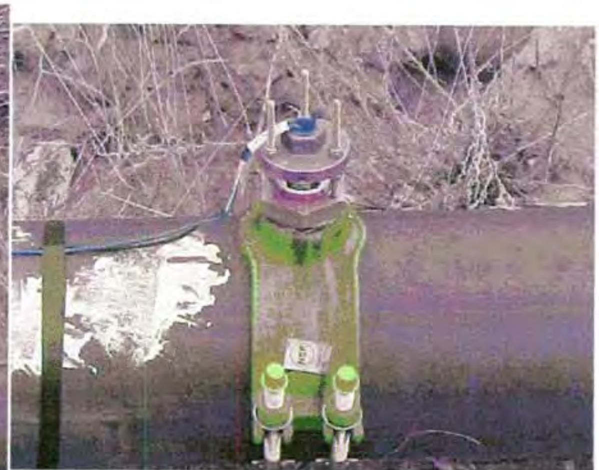

Figure 7. - Data Industrial paddle wheel flow rate sensor installed on an 8 in pipeline. These meters may be used on pipes between 3 and 26 inches in diameter.

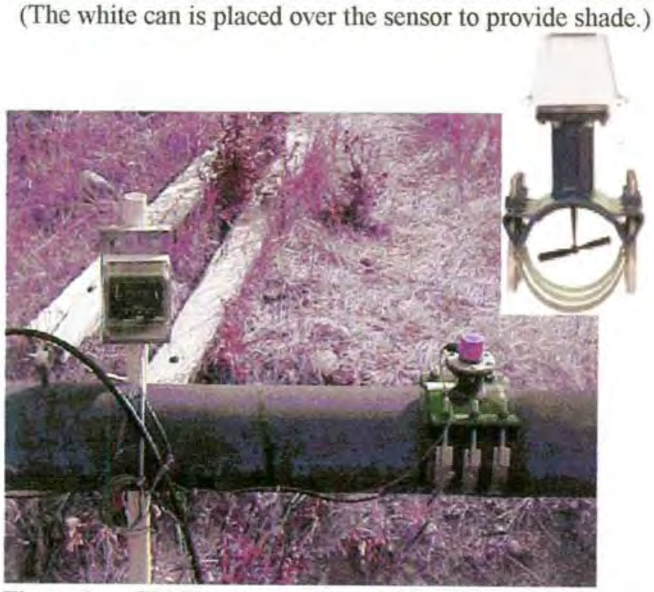

Figure 8. - GF+Signet propeller meter and display installed on a 10 in pipeline in Montana. These meters may be used on pipes from 6 to 30 inches.

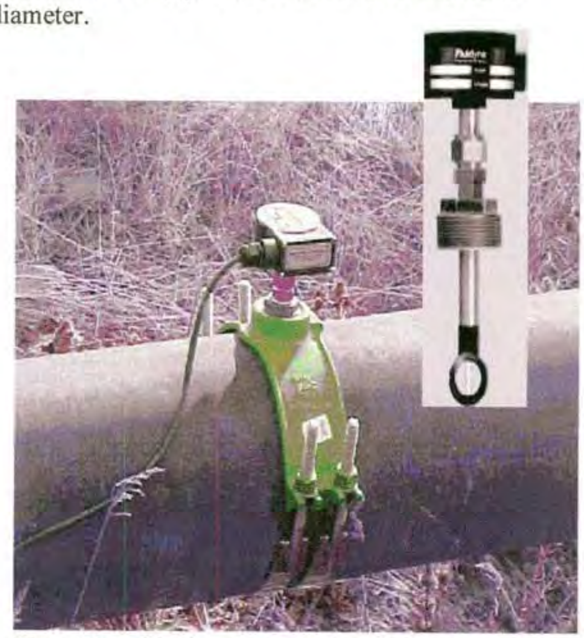

Figure 9. - Fluidyne vortex shedding meter and flow display which is also mounted on a 10 in pipe. These meters may be used on pipes between 3 and 20 inches in diameter.

LABORATORY INSTALLATION AND TESTING

Many of the instruments were installed and tested in the WRRL. The laboratory is the best location to develop and test new instruments, evaluate accuracy, and to test some aspects of use and reliability. This section discusses the WRRL facilities and instrument testing.

Open Channel Applications

The WRRL has a model canal facility that is used to test water measurement devices and instrumentation that are being considered for application by irrigation districts. The model canal has many of the control and flow measurement features currently being used on irrigation canals. Initial laboratory setup provided an efficient mechanism to ensure that all software and hardware was operational before installing the instrument at the field site in Montana.

Presently, two more OCFR devices are undergoing side-by-side long-term testing outdoors at the WRRL to ensure accuracy and reliability for future installations in an irrigation system (figure 10). Both devices are measuring and recording the water level in a bucket. These two devices have identical CPU's, with one using the ultrasonic level sensor (figure 2) and the other using a bubbler sensor (figure 3).

No laboratory testing was performed on the Transducer-in-Pipe water level sensor. The high-frequency cable water level sensor is currently installed in the laboratory for initial testing (figure 5).

Figure 10. - Long term side-by-side testing of the OCFR and the bubbler system. Both instruments are sensing and recording the water level in the bucket.

Pipe Flow Meters

The pipe flow meters were individually mounted into the WRRL pipe test stand. Figure 11 shows the pipe test stand with a pipe saddle showing the location where the meters were installed. Each meter was tested throughout a range of flow rates from 250 to 750 gal/m. Testing was accomplished by comparing measured flow into the pipe from the laboratory venturi system to the flow rate measured and displayed by the meter. The laboratory venturi meter has been extensively calibrated using a weigh tank to an accuracy of ±2 percent. Each instrument was rigorously tested with final comparisons given in the results.

FIELD INSTALLATION AND TESTING

Laboratory testing is necessary for development of new instrumentation and accuracy testing. However, field evaluation must be performed to ensure that the instruments will all operate as intended in a harsh environment.

The installation and use of these meters in the field is the main emphasis of this study. Field testing is the only way to evaluate the parameters that matter most to irrigators:

- ease of installation including mounting, initializing, programming
- ease of use during the irrigation season
- reliability
- sensitivity to debris, temperature, sediment, etc.

Figure 11. - WRRL pipe test stand showing the pipe saddle on the 8 in pipe where the flow meters were tested. The pipes in the stand are 4, 6, 8, and 12 inches in diameter.

Field testing of the sensors is ongoing at East Bench Irrigation District in Dillon, Montana with assistance from the Montana Area Office. The East Bench Irrigation District diverts water from the Beaverhead River into their canal system. The majority of the main canal has a buried membrane lining and water is diverted from the main canal into laterals or pumped directly into pipelines and sprinkler systems. The pipelines have screened entrances. Silt, vegetation, and trash are present in the water, as is typical of many canal systems in the west.

Open Channel Applications

Open Channel Flow Recorder

The original OCFR was installed during the 1999 irrigation season as shown in figures 1 and 2 and remains at that location today. The measurement system is contained in one enclosure. This allows for quick and easy installation using a simple support spanning the conveyance channel upstream of the flow measurement structure (i.e. flume or weir). The ultrasonic sensor must be pointed normal to the water surface. Programming is accomplished by entering a discharge coefficient and an offset for the head measurement into a universal flow equation programmed into the CPU. At this time, the programming is still being developed to be more user-friendly. Field personnel read the flow recorder and the staff gauge located at the flume at least once a week throughout the irrigation season. Installation, including the solar panel and battery, took about 2 hours to complete. Installation time may be reduced if conventional power is used.

The original OCFR remained in the field over the winter to test the robustness of the instrument to varying temperatures. At the test site, temperatures range from -30 degrees Fahrenheit in the winter to about 100 degrees in the summer.

The two OCFR devices currently located outside the WRRL are slated for field installation in September 2000 near Yuma, Arizona.

Water Level Sensors

Transducer-in-Pipe

Two Transducer-in-Pipe water level sensors were constructed in the WRRL and taken to the field site for installation in 1999. They were originally mounted to irrigation structures using thin metal straps. This initially appeared to be sufficient but the turbulent waters and the buoyancy force of the sealed pipe, eventually caused the instruments to break free from the mounting location. One transducer was destroyed and the other was salvaged and reinstalled. This installation was quite difficult to perform at the location chosen and took about 4 hours. Zeroing of the transducer could only be accomplished using a staff gauge located nearby. An available recorder was installed with the Transducer-in-Pipe sensors. Field personnel made observations of the sensor output and staff gauge readings throughout the irrigation season. The Transducer-in-Pipe water level sensors are still operating to date.

High Frequency Cable

The high frequency cable water level sensor has not yet been installed in a field application. This is planned for next fiscal year if funding is available.

Pipe Flow Meters

All of the pressurized pipe flow meters were installed on irrigation pipelines for the 1999 and 2000 irrigation seasons. Water is pumped into the screened pipelines from canals with algae, weeds, trash, and silt in the water, producing a realistic test situation at both pipeline test locations. The physical installation of the pipe flow meters was similar for all the meters. All the pipe flow meters required the use of a pipe saddle for mounting the sensor. The installation required drilling a 2-inch hole in the pipe before the saddle could be mounted and the meter installed. The SeaMetrics, Data Industrial, and Fluidyne flow meters required standard pipe saddles. The GF+Signet flow meter required a specialized saddle that was included with the meter. Assuming the installer had all the proper tools and parts, it would take approximately two hours to individually install any of these flow meters.

The four pipe flow meters were mounted on two irrigation pumping systems. At one pumping site, both paddle wheel flow meters, the SeaMetrics (figure 6) and the Data Industrial (figure 7), were mounted in line in an 8-inch pipe. At the other pumping location, the GF+Signet (figure 8) propeller and Fluidyne (figure 9) vortex flow meters were mounted in line in a 10-inch pipe.

The SeaMetrics and Data Industrial paddle wheel meters and the Fluidyne vortex shedding meter had to be inserted to the proper depth in the pipe to produce accurate flow rate results. The insertion depth of the GF+Signet propeller meter is set by a saddle which is designed for the meter.

Programming instructions for the SeaMetrics and the GF+Signet meters was easily accomplished using the manufacturer's instructions. The programing instructions that were provided for the Data Industrial flow meter were difficult to understand, but the meter did have more flow rate display options than the other meters. The programming for the Fluidyne meter was performed via a computer with the appropriate pipe dimensions input for it to display the correct flow rate. Therefore, the programming for the vortex meter should be performed before it is installed in the field.

Field personnel monitored the displayed flow rate from each pair of meters. The meter flow rates were compared with each other and with the stated design capacity of the irrigation system. The ability of the meters to stay free of debris and vegetation was compared for all the meters.

TEST RESULTS

Test results are reported as a combination of field and laboratory testing. Some instruments have limited laboratory data to report because they were mostly used in the field. Table 1 provides a summary of the findings. The overall rating includes general overall reliability aspects of the instruments from the perspective of the field personnel. There is no intent to compare pipe flow meters with open channel meters, even though all results are given in the same table.

Table 1. - Results from laboratory and field tests of each device with cost comparisons. The ratings were based upon a range from 1 to 10, with 10 being the best possible rating.

Instrument	Accuracy	Ease of installation	Ease of Programing	Ease of use	Debris Sensitivity	Approx. Cost* ($)	Overall Rating
OPEN CHANNEL APPLICATIONS							
OCFR w/ultrasonic	8	6	5	8	10	950	**7.4**
OCFR w/bubbler	8	5	4	8	9	1750	**6.8**
WATER LEVEL SENSOR							
Transducer-in-Pipe	8	4	N/A	8	6	300	**6.2**
PIPE FLOW METERS							
SeaMetrics	7	6	8	8	9	800	**7.8**
Data Industrial	7	6	4	8	9	900	**6.8**
GF+Signet	7	6	8	8	7	850	**7.2**
Fluidyne	8	6	6	8	3	900	**6.2**

*This cost includes the price of materials such as the pipe saddles. None of the costs include power supply.

Open Channel Applications

<u>Open Channel Flow Recorder</u>

Laboratory results for the OCFR devices are limited to one season of testing. In the side-by-side test between the device with the ultrasonic sensor and the device with the bubbler sensor, the totalized flow rates have been almost identical.

The OCFR has been used in the field for both the 1999 and 2000 irrigation seasons. The original CPU worked for the 1999 irrigation season, but failed during the winter. The replacement CPU has been more reliable and has operated through the 2000 irrigation season with no difficulties. Field comparison of the flow data gathered with the OCFR versus the computed flow from the staff gauge indicated less than a 5 percent variation. Unfortunately, no other flow rate comparisons were made at the field site. Because the ultrasonic sensor is above the water, most types of debris do not pose a problem with this sensor.

As table 1 shows, the OCFR is easy to install and use but programming the OCFR could be simpler. The code is still under development with simplicity the main goal. The OCFR with the ultrasonic sensor was cost effective at less than $1000. However, the water level sensor chosen for use with the OCFR can produce quite a difference in price. Fast Bench Irrigation District has been extremely pleased with the results.

Water Level Sensors

Transducer-in-Pipe

The Transducer-in-Pipe water level sensor was only installed in the field. As table 1 indicates, there may be some difficulty in installation. Problems are related to both ensuring the pipe is sealed, and to mounting. Because the transducer is nonsubmersible, water must be kept out of the pipe, including condensation. Buoyancy forces and flow conditions must be considered, keeping mounting depths shallow (below 6 to 8 ft) and site turbulence to a minimum.

Field measurements indicated that both of the Transducer-in-Pipe installations were accurate to within 0.02 feet of the staff gauge reading.

The nonsubmersible transducer is considerably less expensive than a comparable submersible transducer in rigorously sealed enclosures. More expensive submersible pressure transducers typically work reliably for 3 to 7 years. This is the baseline that will be used to determine if this alternative will continue to be successful.

High Frequency Cable

The original Utah State University laboratory tests of the prototype high frequency cable water level sensor indicated that it operated with a resolution of 1 mm. Initial testing in the WRRL has uncovered a problem with electrical noise that precludes proper functioning of the sensor. Also, the electronics of the prototype device must be properly enclosed before field testing can be considered. In addition, investigation into modifying the length of the sensor is needed. Further development is ongoing to resolve these issues. Potentially, the high frequency cable could be used as an alternate water level sensor for the OCFR or other recording device.

Pipe Flow Meters

The pipe flow meters were all tested for accuracy in the WRRL pipe test stand, figure 10. Table 2 shows the maximum error within ±5 percent for all the meters tested. Most errors were within the measurement accuracy of the laboratory venturi meter of ±2 percent. The readout on the SeaMetrics, GF+Signet, and the Data Industrial fluctuated quite a bit. Therefore a lower accuracy value was given to these meters, but the average of the readings was very good. The Fluidyne meter did not fluctuate significantly because of extended averaging times in the processing before the reading was displayed. GF+Signet is presently modifying their flow meter so that it averages over a longer time period and will likely fluctuate less.

Table 2. - Results for the WRRL tests of the pipe flow meters showing the maximum errors.

Flow Meter	**Meter Flow Rate (gal/m)**	**Venturi Flow Rate (gal/m)**	**Maximum Error (percent)**
SeaMetrics	221	211	4.7
Data Industrial	540	566	-4.5
GF+Signet	343	358	-4.3
Fluidyne	259	272	-4.7

These results are certainly adequate for most irrigation applications. Some adjustments could be made to the coefficients in the flow equations if it was thought necessary.

Field testing for pipe flow meters has just completed a second irrigation season. As shown in table 1, the meters were all easy to install. The Data Industrial meter was confusing to program and the Fluidyne meter should be programmed before going to the field to install. The SeaMetrics initially displayed values that did not agree with the irrigation system capacity but it was discovered that the meter did not have the proper insertion setting.

Throughout the two years of service, the meters have not exhibited significant problems in the field, other than varying sensitivity to debris handling. The SeaMetrics and the Data Industrial paddle wheel type flow meters have operated through the 1999 and 2000 irrigation seasons without experiencing difficulties with debris. Both the Fluidyne and GF+Signet flow meters stopped displaying a flow rate one month into the 1999 irrigation season. When the meters were removed, vegetation was clogging both the propeller of the GF+Signet and the sensing element of the Fluidyne meter. After cleaning and reinstalling the GF+Signet meter it performed with no further problems through the remainder of the 1999 and the entire 2000 seasons. The Fluidyne meter has continued to have problems handling debris.

The meters compared favorably to the design capacity of the irrigation system, which was the only field flow rate comparison made. Costs were almost the same for all the pipe flow meters.

CONCLUSIONS

Testing of the newly developed OCFR has proven its applicability and cost effectiveness for use with water measurement devices and any number of water level sensors. The device is easy to install and use, reliable, and cost effective compared to other combined data logging and sensor systems on the market today.

Each of the water level sensing devices has advantages and disadvantages. The important point is to select the instrument appropriate for each individual irrigation application.

All of the pressurized pipe flow meters performed adequately in the field. However, vegetation is still a concern for most of these types of applications.

FUTURE WORK

Several items of future work are being considered if funding is available. Many irrigation districts have expressed an interest in the OCFR. Additional field test sites would allow investigation of long term performance in the OCFR under varying environmental conditions. Some work is needed to refine the software that operates the OCFR. We would also like to investigate a low cost commercially available submersible transducer for measuring water level. Continued development of the high frequency water level sensor is needed before it would be applicable for field sites.

REFERENCES

"Irrigation Flow Measurement – Instrumentation Development Part I", Blair L. Stringam and Kathleen H. Frizell, U. S. Bureau of Reclamation, Water Operation and Maintenance Bulletin, September 1999.

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