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Flume or Weir Continuous Water Flow Rate Recorder for Irrigation Use

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U.S. Bureau of Reclamation

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Abstract

U.S. Bureau of Reclamation projects and irrigation districts need simple, low-cost, robust devices to measure and record water use for effective water management decisions. This need has resulted in the development of a continuous flow meter and recorder (CFM). The CFM is designed to continuously measure flow rates through open channel measurement structures, such as flumes or weirs, by recording the water levels upstream. The water level measurements are then converted to flow rate using a simple weir power equation. The CFM consists of a CPU, that is easily programmed, an LCD, for displaying the flow rate and total amount of water that has passed the measurement structure, and a water level sensor. The CFM, including a solar power supply may be purchased for under $1000 US dollars. The majority of that cost is for the water level sensor and may be reduced depending upon the needed accuracy. Presently, some of these devices have been installed on irrigation systems in the field where they have been exposed to harsh weather conditions. Despite the harsh environments, the CFMs have been functioning as designed. This paper discusses the design, installation, and testing of the continuous flow meter.

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Résumé

Les projets des districts d'irrigation du Bureau de Réclamation des E.U. ont besion d'un appareil simple, durable et de bas prix pour le métrage et l'enregistrement d'usage de l'eau, afin de faire de bonnes décisions dans son maniement. Le résultat de cet besoin était le dévelopement d'un instrument pour mesurer et enregistrer l'écoulement continu de l'eau par-dessus un déversoir ou un barrage. Cet appareil enregistreur se mettre à l'ouvrage par le métrage du niveau d'eau en avant du déversoir, et le transformant par une équation simple du pouvoir du déversoir au chiffre d'écoulement proportionnel. L'appareil enregistreur comprend un ordinateur de programmation facile, un appareil d'étalage en cristal-liquide pour montrer l'écoulement d'eau et le montant totale d'eau qui s'écoule par-dessus le déversoir, et un appareil pour mesurer le niveau d'eau. L'appareil enregistreur, qui comprend un panneau du pouvoir solaire, peut être acheté au moins de mille dollars E.U. La plupart des frais revient á l'appareil pour mesurer le niveau d'eau, qui peut être moins cher si la précision est moins important. Plusieurs des appareils enregistreurs ont été installés et fonctionnent exposés aux conditions de temps sévères. Malgré ça, les appareils enregistreurs ont bien fonctionnés aux intentions du dessein. Cette composition depeint les exigences du dessein et l'installation pour l'appareil.

Introduction

There is increasing demand on the world's water supply as various entities vie for water use. Traditional water control structures were built to store and convey needed water for agricultural or municipal use, with little attention given to measurement and conservation. Today, water managers must provide water for multiple uses including agricultural, municipal, industrial, protecting environmental habitat, and fisheries. Water measurement and recording are vital for effective management of an irrigation system, especially when pressure is being applied to conserve and divide water resources for other non-traditional uses.

New irrigation facilities are usually equipped with measurement and recording devices for conservation and equitable distribution. Managers of older irrigation systems are presented with the challenge to provide cost effective methods that accurately measure and record water use in systems not initially designed with water measurement in mind. This paper will describe the development and use of a low-cost continuous flow meter specifically designed for irrigation water management.

Background

Historically, most older irrigation districts have had no water management plan. Districts often have a mixture of old, sometimes inoperable, measurement structures and have varied measurement techniques. Water masters or "ditch riders" use "experience" to set diverted flows. The U.S. Bureau of Reclamation (Reclamation) is continually working with irrigation districts regarding water measurement and recording issues. Most districts need low-cost, relatively maintenance free devices that continually measure and record diverted water.

Educating operators and users about the importance of knowing the total volume of diverted water is paramount to addressing other issues. There are two components needed to assure that users receive the correct amount of water: 1) the measurement device; and 2) the recording or data logging device. The measurement device must provide a unique discharge for a given depth over the structure under free flow conditions. The measurement device for most open channel canal systems is usually a flume or weir. The measurement device itself does not provide a continuous record of the total flow over or through the device. An electronic recording device must accompany the measurement device to provide a continuous record of the flow quantity and duration.

For example, manual reading of a staff gage upstream of a weir or flume provides only an instantaneous record of the flow. The flow rate often changes throughout the time water is being delivered for each irrigation. Without continual readings, the flow volume delivered is often unknown and, in many cases, either too little of too much water is delivered.

In addition, continuous data logging devices are available in the common form of chart recorders such as the Stevens Recorder (US Bureau of Reclamation 1997) or other electronic devices. In the past, chart recorders have commonly been used for continuous recording of diverted water. The chart recorder plots a running record of the water level on a paper chart. These records are tedious to read and do not permit simple, quick flow evaluation. In addition, chart recorders are mechanical and require extensive effort to maintain. Available electronic data logging devices have been designed for general industrial or wastewater applications and are overly complex and costly.

Reclamation contracted for a single-unit water level sensor and recorder system. This device was specifically designed for typical open channel-type water measurement structures that are used on irrigation systems. This attempt resulted in a stripped down costly version of a company's existing product line which did not meet design needs. Therefore, Reclamation decided to design, build, and test an in-house device that would meet the requirements of most irrigation districts.

Objective

Several goals were defined for the development of the continuous flow meter for irrigation use. The water measurement and recording device for open channel irrigation systems should:

- be easily used with farm head gates,
- be inexpensive,
- be reliable,
- pass debris and work with sediment-laden flow,
- have a built-in programmable data logger using a generalized form of the weir equation with simple button or keypad input,
- have a continuous display of flow rate and totalized flow volume,
- have an easily resettable totalizer,
- be easy to install, including set up, and programming,
- be easy to use and maintain by local ditch riders and farmers.

The following instrument was developed to meet these goals.

Instrument Description and Development

The device developed is referred to as the continuous flow meter or CFM. It includes a water level sensor and a central processing unit (CPU) to continuously record water level, convert to flow rate and totalize, and display flow rate and total volume of water delivered - all for a reasonable cost.

Recent advances in technology have made inexpensive components available that can be combined in a compact single unit. These components are easily configured to suit the needs of various water measurement applications. The flow meter was constructed from readily available components to minimize the cost.

Any water level sensor that outputs a voltage or current signal is compatible with the device CPU. Water level sensing devices include pressure transducers, bubblers, acoustic or ultrasonic devices, capacitance probes, and floats. A relatively low-cost, non-intrusive, ultrasonic water level sensor was chosen for the prototype device. The ultrasonic water level sensor does not require a stilling well and is easily mounted above the canal water surface. Mounting the sensor above the water surface greatly reduces the installation cost and maintenance because the sensor is not subjected to sediment, algae, or debris in the irrigation channel. In addition, this sensor has temperature compensation to reduce error that may occur from fluctuating air temperatures.

The initially developed CFM combines an ultrasonic transducer, data logger, and readout into a single compact system (fig. 1). Because it is designed for agricultural usage, it is much simpler to use, easier to install, and more compact than other generic data logging systems.

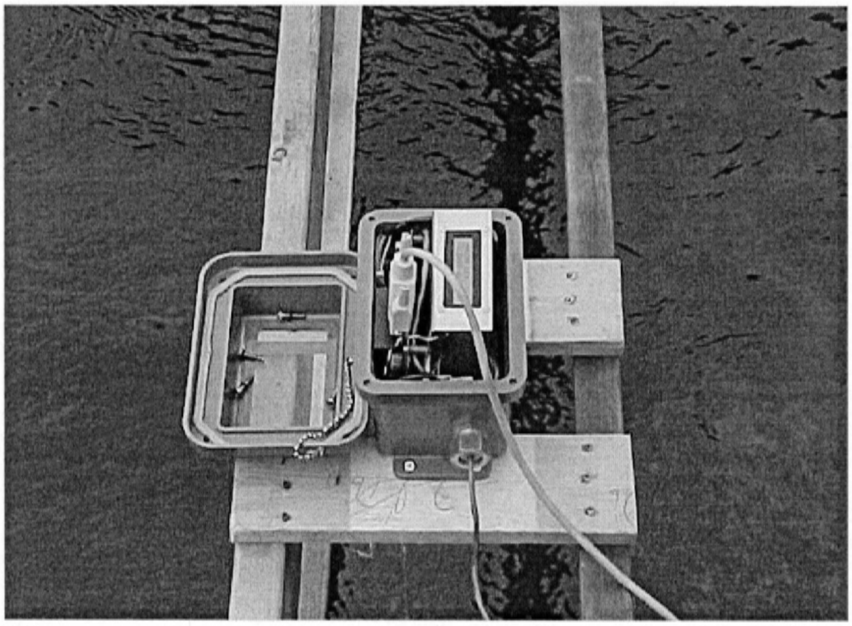

Figure 1. The single-unit continuous flow meter (CFM) installed just upstream from a measurement structure. The sensor part of the meter extends out of the bottom of the enclosure.

If required, the CFM may be constructed so that the CPU and display are separate from the sensing unit (fig 2). This allows for applications where the ultrasonic transducer must be mounted out toward the center of a canal but it is more convenient to have the CPU and display mounted on the side of the canal. Other types of water level sensors that require different installations may also be used.

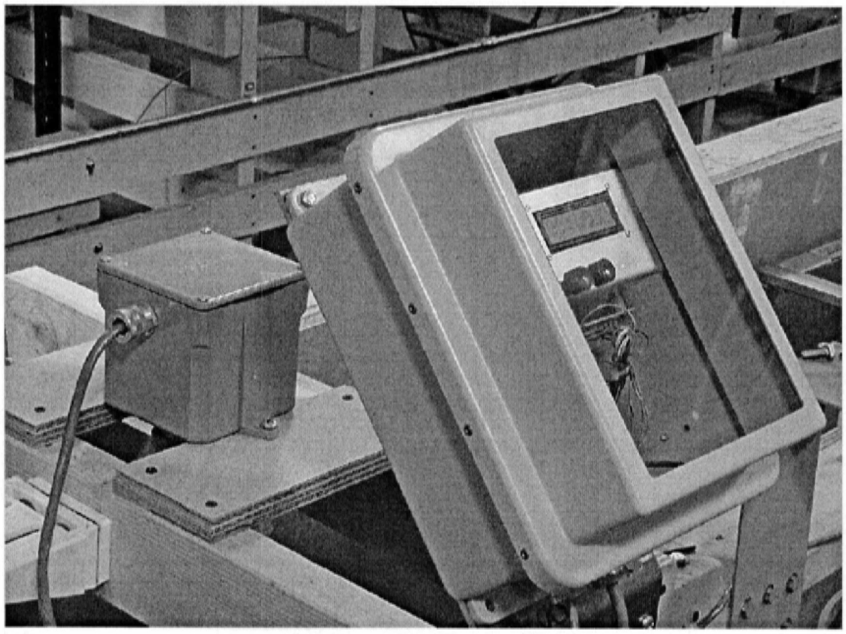

Figure 2. Continuous flow meter mounted in Reclamation's Water Resources Research Laboratory. The ultrasonic sensor is located in the smaller enclosure to the left while the CPU and display are located in the enclosure to the right.

Several low-cost CPU's were considered for this project. The criteria used for selecting the CPU were availability, low cost, ease of programming, little or no fabrication requirement, an adequate number of input/output ports, and reliability. All of the CPU's that were considered required some fabrication. The first CPU that was selected would randomly loose its program and have to be reprogrammed. It also had problems with operating the analog to digital converter accurately. Therefore, another CPU was selected that was also readily available and easily adaptable for the application. It has digital input/output ports, one of which is used to send the serial data to the liquid crystal display (LCD). The CPU also has an onboard analog to digital converter that is used to convert the analog signal from the sensor to a digital signal that is used by the CPU to determine the water depth and subsequent flow rate. A wiring diagram of the CFM circuit is shown in figure 3.

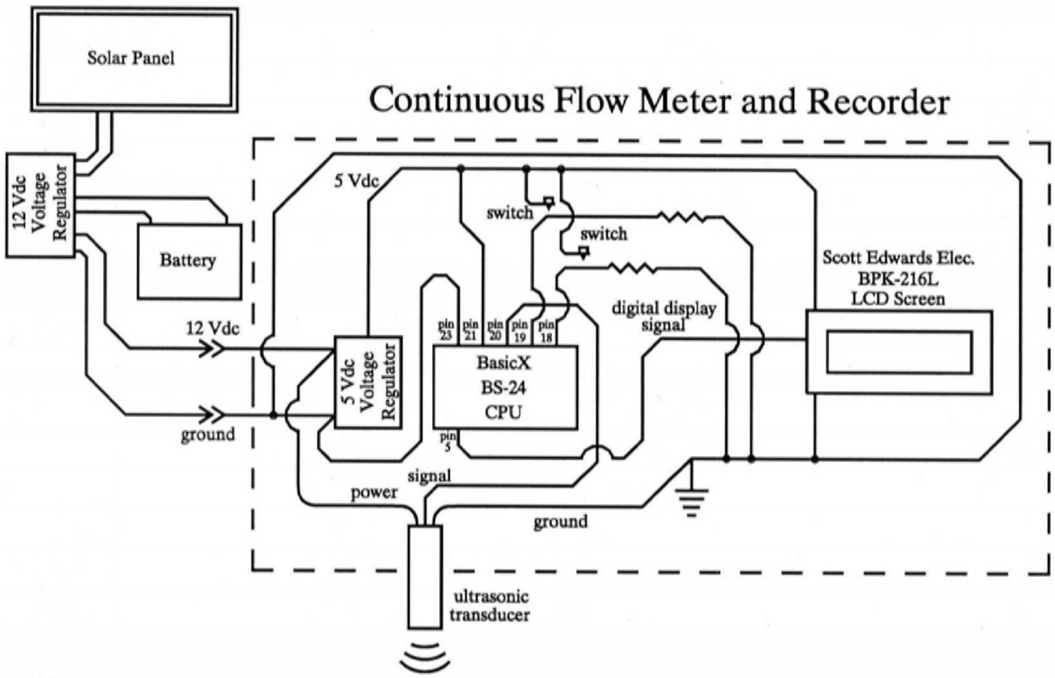

Figure 3. Wiring diagram of the components required for the CFM.

The CPU can be programmed in Basic or assembly language. The prototype is programed in Basic. The program for the CPU is easily downloaded via software provided by the CPU manufacturer. The flow meter program is downloaded with a laptop computer, a 9 pin serial cable, and the interface program. The program is menu driven and user friendly. The code programmed into the CPU performs five tasks:

- Gathers multiple voltage readings from the sensor.
- Converts the voltage readings to a water level.
- Computes the flow rate from the water level using a generalized weir equation.
- Computes the total amount of water that has been diverted and stores it.
- Checks to see if the operator has accessed the CPU to make calibration changes to the meter.

Multiple voltage readings are recorded by the CPU in a short period of time and averaged to reduce variability that may occur in the sensor readings. The water level is computed from these readings using a standard calibration equation. This equation relates voltage to water depth in metres. Once the water depth is determined, the flow rate is computed by the CPU using a generalized form of the weir equation:

$$Q=C_d H_d^K \qquad (1)$$

where Q is flow rate in m^3/s, C_d is a discharge coefficient that includes the width of the control section, H_d is the head on the flume or weir in metres, and K is the discharge power. The initial coefficients are downloaded using the computer. The initial coefficients are entered during the meter installation and are based upon water measurement structure design. A coefficient for correction in the head measurement could have been included, but it was omitted to simplify meter set up procedures and avoid possible confusion. The head correction coefficient has a minor effect on the flow calculation. The CPU then computes the total amount of water that has been diverted. The LCD is updated with the flow rate and total amount of diverted water.

The LCD is also a readily available, low-cost device that is easily connected to the CPU. It is designed to take an RS 232 signal and display the data that is contained in the signal. The display operates on 5 Vdc and draws a low amount of current. The meter displays the flow rate data in cubic metres per second (m^3/s) and cubic metres (m^3), but the data may be recorded or displayed in various formats such as litres per minute, total litres, etc.

After the CPU has computed, displayed, and stored the total volume of water it checks to see if the operator wants to make changes to the meter configuration. Changes can be made if the initial parameters are not correct.

To access the meter configuration parameters, the operator simultaneously presses the two buttons that are on the case of the enclosure, figure 4. A series of prompts are then displayed. The prompts indicate the button that must be pressed to change values within the program.

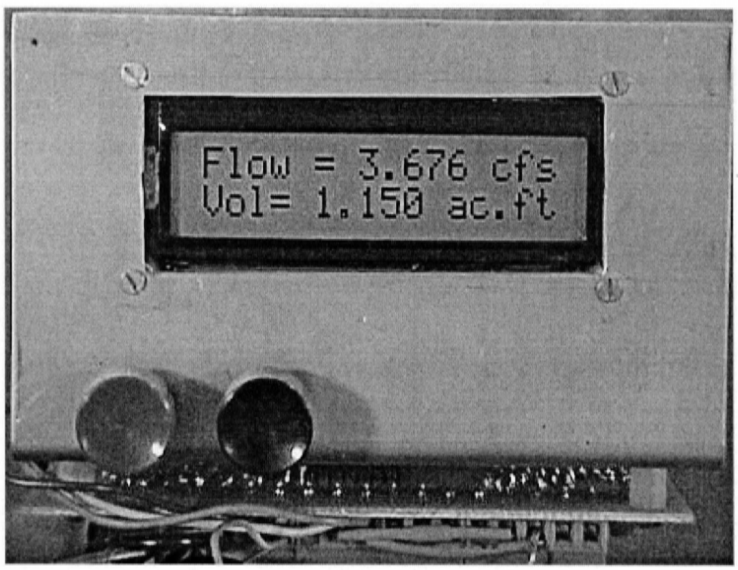

Figure 4. Typical meter display of the current flow rate and totalized flow volume. (Note that the flow rate and volume are given in English units on the prototype.)

The CFM with an ultrasonic water level sensor has slightly greater power requirements than a device that would use a pressure transducer or a float and pulley transducer. This is because ultrasonic transducers draw more current. A 15 watt solar panel, voltage regulator, and 20 amp hour battery were selected for the power requirements of this device. If AC power is available, an AC to DC converter can be substituted for a solar panel and voltage regulator.

The CFM (case No. REC-3653) is U.S. patent pending under patent application serial No. 09/640,710.

Testing

The CFM was developed and tested in Reclamation's Water Resources Research Laboratory (WRRL). Laboratory testing ensured that the CFM was working properly before installing it in the field.

Field Test Sites

Presently, field testing of the CFM with ultrasonic and bubble sensors is being conducted at the East Bench Irrigation District in Dillon, Montana and at two locations near Yuma, Arizona.

The East Bench Irrigation District diverts water from the Beaverhead River into their canal system. The majority of the canal has a buried membrane lining and water is diverted from the canal into lateral canals or pumped directly into sprinkler systems. Silt and aquatic vegetation are mixed in the water which is typical of many canal systems in the west. Installation, including the solar panel and battery, took about 2 hours to complete. The original CFM was installed during the 1999 irrigation season as shown in figure 5 and remains at that location today (Stringam and Frizell 2000). The irrigation season is only in the summer months, but the irrigators do not remove the instruments during the winter months. Temperatures range from -1 °C in the winter to about 38 °C in the summer. Field personnel read the flow recorder and the staff gauge located at the flume at least 3 times per week throughout the irrigation season. Comparison of the flow data gathered with the CFM to manual staff gauge readings indicated less than a 5 percent variation. Unfortunately, there have been no other flow rate comparisons made at this site, but the

Figure 5. Continuous flow meter (CFM) installed on a Parshall Flume at Dillon Montana.

CFM has been extremely reliable and the district has been pleased.

The installations on the Fort Mojave Indian Reservation north of Yuma, Arizona include an ultrasonic water level sensor and a bubbler, both with the same data logging capability. These sites have longer irrigation seasons and a desert environment with temperatures approaching 43 °C. The flow meters have been mounted upstream of long-throated flumes which are located in concrete lined irrigation canals, figure 6. Flow rates in both canals range from 0.17 m^3/s to 1.42 m^3/s. One of the canals serve agricultural land on the Fort

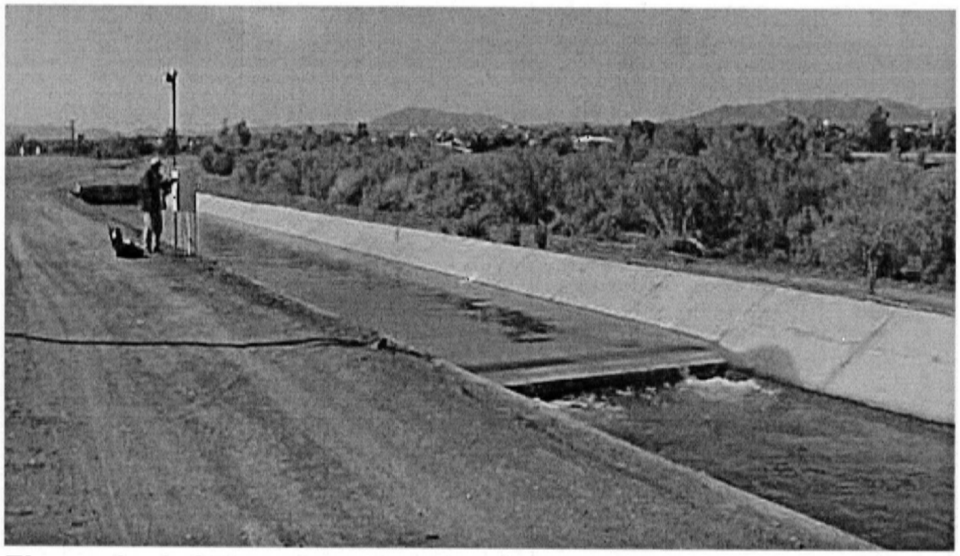

Figure 6. A CFM using a bubbler installed upstream from a long-throated flume at the Fort Mojave Indian Reservation Arizona.

Mojave Indian Reservation while the other canal serves the reservation and the Mojave Valley Irrigation District. These meters were just installed in May of 2001 and preliminary results are not yet available.

Cost

One of the main goals of the continuous flow meter development was to have a device available to irrigation districts and farmers that would be relatively inexpensive. The sensor is the main factor that governs the cost of this device. Great effort was taken to find an ultrasonic sensor with temperature compensation that was accurate but inexpensive. In addition to the sensor, a CPU, an LCD, a solar power supply, voltage regulator, battery, instrumentation enclosure, and miscellaneous parts are required. A summary of the parts and cost is shown in table 1.

Table 1. Parts summary and cost*.

Part	**Cost**
CPU	$50
Circuit board	$40
LCD Display	$52
Sensor	$450
Instrument enclosure (NEMA 4)	$40
Solar Panel	$150
Voltage Regulator	$50
Battery	$60
Miscellaneous Parts (wire, post for solar panel)	$100
Total	**$992**

*Costs are all based on parts purchased with US dollars in the year 2000.

It should be noted that there are less expensive sensors that could be used but they did not meet the non-intrusive criteria. A submersible pressure transducer is available on the market for about $260 while a float and pulley sensor can be constructed for about the same cost. If one of these devices were used the cost of the instrument would be reduced but there would be additional costs for the construction of a stilling well to house these types of sensors.

Conclusions

This device, called the continuous flow meter (CFM) was designed specifically for irrigation use and has broad application to thousands of water diversions that are currently made without accurate flow measurement. It can be easily used upstream of an open channel measurement device to continuously sense the water surface level and directly convert and display the volume of water diverted or used. This is a great advantage over staff gauges, existing generic data logging devices, and chart recorders. The CFM is also a cost effective device. Continuous measurement and totalized volumes of water delivered provides the best method of accounting for diverted water. The continuous measuring capability is really the only way for water resource managers, whether a governmental agency, irrigation district, private firm, or individual farmer to accurately measure and potentially conserve water.

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