WATER OPERATION AND MAINTENANCE BULLETIN

No. 196 **June 2001**

IN THIS ISSUE. . .

UNITED STATES DEPARTMENT OF THE INTERIOR **Bureau of Reclamation**

Available on the Internet at: **http://www.usbr.gov/infrastr/waterbull**

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***Cover photographs**: (Left) Delta Cross Channel downstream view of radial gates. (Right) A new equalizer bar completely installed.*

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COST-BENEFIT ANALYSIS OF ALTERNATIVE CANAL LININGS

by Jay Swihart, P.E.[1] and Jack Haynes[2]

Abstract

Over the past 9 years, the Bureau of Reclamation (Reclamation) has constructed 33 canal-lining test sections to assess durability and effectiveness (seepage reduction) over severe to moderate rocky subgrades. The lining materials include combinations of geosynthetics, shotcrete, roller compacted concrete, grout mattresses, soil cushions and covers, elastomeric coatings, and sprayed-in-place foam. Seven of the 33 test sections have failed, while the remaining 26 test sections are in very good to excellent condition. Unit construction costs range from $1 to $4 per square foot. Full-scale pre- and post-construction ponding tests have shown seepage reductions between 70 and 95 percent, with the geomembrane alternatives having the greatest water savings. Preliminary cost-benefit ratios have been calculated based on initial construction costs, maintenance costs, durability (service life) predictions, and seepage reduction. Alternatives utilizing a geomembrane with a concrete cover seem to offer the best long-term performance, as the geomembrane liner provides the water barrier, and the concrete cover provides protection from mechanical and environmental damage.

Introduction

Unlined canals can lose up to 50 percent of their water to seepage. Canals in the Pacific Northwest have the highest losses because they are constructed through fractured volcanic basalt (figure 1). Traditional canal-lining materials include compacted clay, reinforced or unreinforced concrete, and, more recently, buried geomembranes. However, these materials are not always viable because either (1) they are not locally available (such as compacted clay), (2) they are too expensive (such as reinforced concrete), (3) they require a large right-of-way for heavy construction equipment, or (4) they require extensive over-excavation and subgrade preparation (such as buried geomembranes). In areas with rock subgrades, over-excavation requires blasting, which is cost prohibitive. Reclamation's Technical Service Center (TSC) and Pacific Northwest offices have been looking at alternative canal-lining materials and techniques that are less expensive, easier to construct with limited access, do not require over-excavation, and are compatible with severe rocky subgrades.

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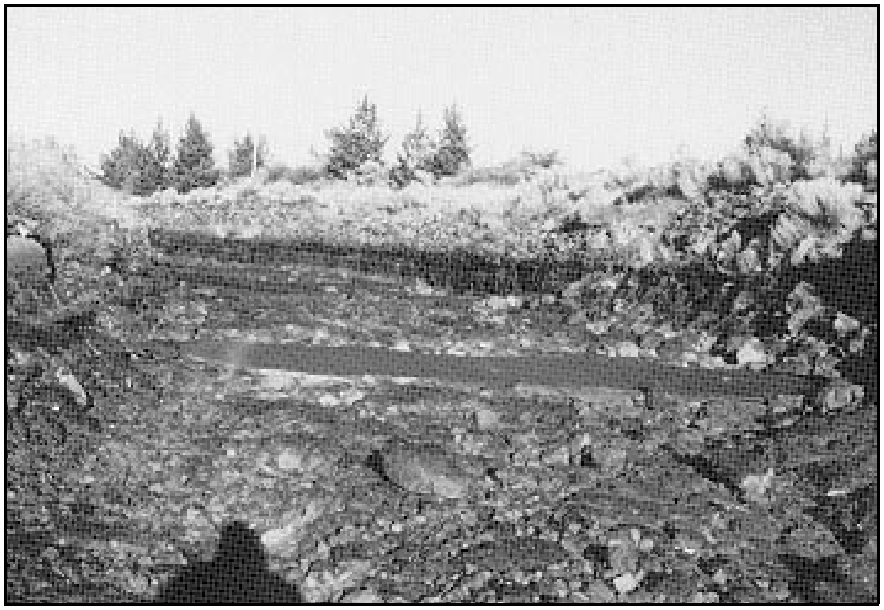

Figure 1.—Canals in the Pacific Northwest are constructed through fractured volcanic basalt.

Construction

Over the past 9 years, Reclamation has constructed 33 canal-lining test sections to assess durability and effectiveness (seepage reduction) over severe rocky subgrades (Swihart, Haynes, and Comer, 1994; Swihart, 1994). The lining materials include combinations of geosynthetics (geomembranes and geotextiles), shotcrete, roller compacted concrete, grout-filled mattresses, soil cushions and covers, elastomeric coatings, and sprayed-in-place foam. Typical construction is shown in figures 2 through 5. The test sections are predominantly located in central Oregon, and each test section covers 15,000 to 30,000 square feet. The test sections now range in age from 1 to 9 years. Of the 33 test sections, 7 failed during their first year of service, and another 8 are not evaluated because they have been in service for less than 3 years. The remaining 18 test sections are all performing well and are in very good to excellent condition. A preliminary cost-benefit analysis is presented for those 18 test sections.

Cost-Benefit Analysis

Preliminary cost-benefit ratios have been calculated for 18 of the canal-lining test sections (equation 1). Benefits are based on the market value of the conserved water. The costs are life-cycle costs, calculated from initial construction and maintenance costs and service life predictions (equation 2). Based on the type of materials, the test sections are divided into four categories, as shown in table 1.

$$\text{Cost-Benefit Ratio} = \frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Value of Conserved Water}}{\text{Life-Cycle Cost}} \qquad (1)$$

$$\text{Life-Cycle Cost} = \frac{\text{Construction Cost}}{\text{Service Life}} = \text{Annual Maintenance Cost} \qquad (2)$$

Figure 2.—Grout mattress is placed over polyvinyl chloride geomembrane and consists of cement grout pumped into place between two layers of geotextile.

Seepage Studies

Full-scale ponding tests (figure 6) were used to measure the amount of water conserved. Test sections were ponded both before and after lining of the canal. In addition, inflow-outflow measurements were taken over a 3-year period on a 24-mile reach of canal. These seepage studies show that pre-construction seepage rates were highly site specific and ranged from 0.6 up to 20 feet per day depending on soil type, geology, and topography. Seepage was reduced by 70 to 95 percent, depending on the type of lining (Haynes and Swihart, 1999). The seepage studies, including the value (benefit) of the conserved water based on a market value of $50 per acre-foot, a 180-day irrigation season, and an average pre-construction seepage rate of 1 foot per day, are summarized in table 2.

Figure 3.—Shotcrete is applied over geomembrane for mechanical protection. Geomembrane underliners include very low density polyethylene and a thin polyethylene geotextile composite.

Figure 4.—Exposed geomembrane is pulled into place over geotextile cushion. Exposed geomembranes included high density polyethylene and reinforced chlorosulfonated polyethylene.

Figure 5.—Asphalt emulsion is spray-applied to steel flume.

Figure 6.—Full-scale ponding test. Water is ponded 3 feet deep behind a 4-inch-thick concrete dike.

Table 1.—Life-cycle costs

Type of lining	Construction cost ($/ft^2)	Maintenance cost ($/ft^2-year)	Durability (years)	Life-cycle cost ($/ft^2-year)
Concrete				
RCC with shotcrete sideslope	2.00	0.005	60+ years	0.038
3-inch shotcrete with steel fibers	2.20			0.042
3-inch shotcrete with polyfibers A	2.14			0.041
3-inch shotcrete with polyfibers B	2.14			0.041
3-inch shotcrete – no fibers	2.07			0.039
3-inch grout-filled mattress	1.92			0.037
RCC - invert only	1.74	0.005	60+ years	0.034
Exposed geomembrane				
80-mil HDPE	1.38	0.010	20 - 40 years	0.056
30-mil PVC with geotextile cover	1.05		10 - 20 years	0.080
45-mil CSPE-R	1.11		20 - 40 years	0.047
36-mil CSPE-R	1.03		15 - 35 years	0.051
160-mil bituminous geomembrane A	1.53		20 - 40 years	0.061
160-mil bituminous geomembrane B	1.53		20 - 40 years	0.061
Geomembrane with concrete cover				
4-mil PE geocomposite with shotcrete	2.43	0.005	60+ years	0.045
30-mil VLDPE with shotcrete	2.52			0.047
40-mil PVC with 75-mm grout mattress	2.54			0.047
Fluid-applied membrane				
Spray foam with urethane coating A	4.33	0.010	5 - 15 years	0.443
Spray foam with urethane coating B	3.92		5 - 15 years	0.402
Geotextile A with urethane coating	2.64		1 - 5 years	0.890
Geotextile B with urethane coating	2.64		1 - 5 years	0.890
Asphalt emulsion over existing concrete	1.70		5 - 15 years	0.155
Asphalt emulsion over sandblasted steel	2.16		10 - 20 years	0.154
Asphalt emulsion over broomed steel	1.40		10 - 20 years	0.103

Maintenance

Through 8 years, maintenance costs have been relatively low for all the lining alternatives. As shown in table 1, exposed geomembranes need about twice the maintenance of concrete linings because of mechanical damage (animals, equipment, vandalism, etc). Maintenance activities include repairing thin spots in the concrete linings and patching small tears and punctures in the exposed membrane linings (figures 7 through 9). For all the lining alternatives, the cost-benefit analysis shows that every $1 spent on maintenance returns $10 to $20 in conserved water by maintaining water tightness (effectiveness) and extending service life (Swihart and Haynes, 1999). Therefore, more emphasis should be placed on maintenance. The irrigation districts are experienced with and quite capable of performing repairs to concrete linings. However, for the exposed linings, the irrigation districts need to be supplied with patching materials and equipment and periodically re-trained on proper repair methods.

Table 2.—Cost-benefit analysis

Type of lining	Effectiveness (percent)	Value of conserved water ($/ft^2-year)	Cost-benefit
Concrete	70	0.145	
RCC with shotcrete sideslope			3.8
3-inch shotcrete with steel fibers			3.5
3-inch shotcrete with polyfibers A			3.5
3-inch shotcrete with polyfibers B			3.5
3-inch shotcrete - no fibers			3.7
3-inch grout-filled mattress			3.9
RCC - invert only	40	0.083	2.4
Exposed geomembrane	90	0.186	
80-mil HDPE			3.3
30-mil PVC with geotextile cover			2.3
45-mil CSPE-R			4.0
36-mil CSPE-R			3.6
160-mil bituminous geomembrane A			3.0
160-mil bituminous geomembrane B			3.0
Geomembrane with concrete cover	95	0.196	
4-mil PE geocomposite with shotcrete			4.4
30-mil VLDPE with 3-inch shotcrete			4.2
40-mil PVC with 3-inch grout mattress			4.2
Fluid-applied membrane	90	0.186	
Spray foam with urethane coating A			0.4
Spray foam with urethane coating B			0.5
Geotextile A with urethane coating			0.2
Geotextile B with urethane coating			0.2
Asphalt emulsion over existing concrete			1.2
Asphalt emulsion over sandblasted steel			1.2
Asphalt emulsion over broomed steel			1.8

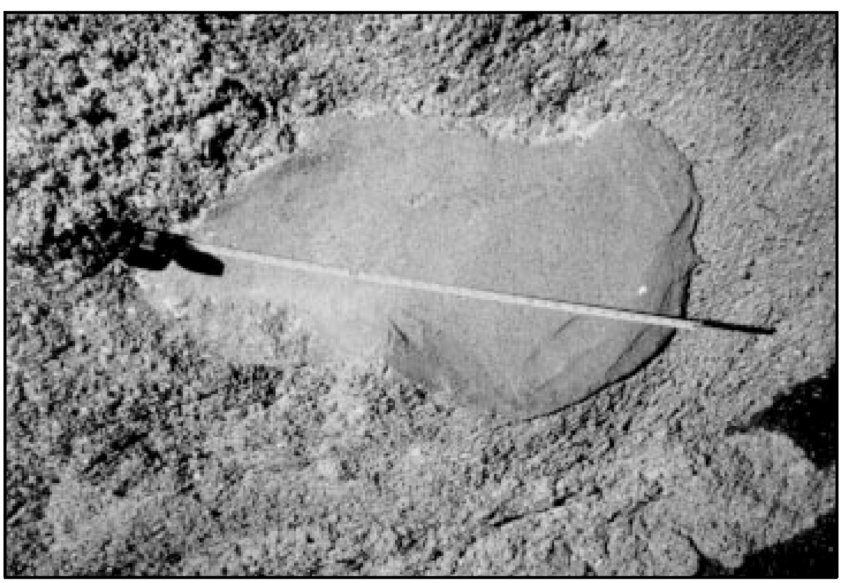

Figure 7.—Concrete patch in which shotcrete was less than 1-inch thick and broke loose after four to five irrigation seasons.

Figure 8.—Contractor uses extrusion welder to patch exposed geomembrane.

Figure 9.—Blisters in spray-applied asphalt emulsion are patched with hand-mix repair material.

Summary and Conclusions

Preliminary cost-benefit ratios have been calculated for the canal-lining test sections based on initial construction costs, maintenance costs, durability (service life), and effectiveness at reducing seepage. Based on the type of material, the lining test sections are divided into four categories, as shown in table 3.

Table 3.—Summary of cost-benefit analysis

Type of lining	Construction cost ($/ft^2)	Durability (years)	Maintenance cost ($/ft^2-year)	Effectiveness at seepage reduction (percent)	Cost-benefit ratio
Concrete alone	1.90 - 2.40	60+ years	0.005	70	3.5 - 3.9
Exposed geomembrane	1.00 - 1.60	20 - 40 years	0.010	90	3.0 - 3.9
Geomembrane with concrete cover	2.40 - 2.60	60+ years	0.005	95	4.2 - 4.4
Fluid-applied membrane	1.40 - 4.40	1 - 20 years	0.010	90	0.2 - 1.8

Each of the lining alternatives offers advantages and disadvantages. The geomembrane with concrete cover seems to offer the best long-term performance.

Concrete – Excellent durability but only 70 percent long-term effectiveness. Irrigation districts are familiar with concrete and can easily perform required maintenance.

Exposed Geomembrane – Excellent effectiveness (90 percent) but is susceptible to mechanical damage from animal traffic, construction equipment, and vandalism. Also, often poorly maintained because irrigation districts are unfamiliar with geomembrane materials and need special equipment to perform repairs.

Concrete with Geomembrane Underliner – The geomembrane underliner provides the water barrier, while the concrete cover protects the geomembrane from mechanical damage and weathering. System effectiveness is estimated at 95 percent. Districts can readily maintain the concrete cover but do not have to maintain the geomembrane underliner.

Fluid-Applied Membrane – Many of these test sections have failed and have been removed from the study. Most of the problems are related to poor quality control and poor bond because of adverse weather during construction. Unfortunately, inclement weather is quite common because most canal work is in the irrigation off-season (early spring and late fall). These types of linings may have the potential for special applications, such as lining of existing steel flumes.

Maintenance

For all the lining alternatives, the cost-benefit analysis shows that every $1 spent on maintenance returns $10 to $20 in conserved water; therefore, more emphasis should be placed on maintenance. For the exposed linings, the irrigation districts need to be supplied with repair materials and equipment as well as kept fully trained on proper repair methods.

New Test Sections

The newest test sections have been in service for less than 3 years. These test sections include Exposed Polypropylene over an existing steel flume, Exposed GCL (geosynthetic clay liner), Buried GCL, Exposed LLDPE (linear low density polyethylene), Exposed EPDM (ethylene-propylene diene monomer) Rubber, Exposed wet-applied Polyurethane Geocomposite, Exposed Reinforced Metallocized Polyethelene, and Exposed white HDPE. These exposed geomembrane test sections have some of the lowest construction costs; however, several irrigation seasons will be needed to evaluate them.

Future Studies

This cost-benefit analysis is considered preliminary because of the uncertainties in the estimated service lives of the linings; therefore, monitoring of these test sections will continue over the next several years to verify durability.

Acknowledgments

This study would not have been possible without the support and financial contributions of the irrigation districts and geosynthetic manufacturers. Many thanks to the Arnold, North Unit, Tumalo, Lugert-Altus, Juniper Flats, Ochoco, Frenchtown, Twin Falls, Lewiston Orchards, and Buffalo Rapids Irrigation Districts.

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PRECISION DRIVING TECHNIQUES—A PERSONAL EXPERIENCE OF RELEARNING HOW TO DRIVE

by Steven J. Melikean[3]

Remember your first time behind a steering wheel? Heart pounding and eyes straining, you were probably keenly aware of oncoming cars, darting pedestrians, and potential hazards of the road. However, driving, over time, can lead to a false sense of security. Chances are, you hardly think about those risks. Driving has become second nature, almost automatic. I can readily admit that I thought little about those risks.

Well, that all changed after I participated in Oklahoma State University's "Train-The-Trainer: Precision Driving Techniques" course, sponsored by the Department of the Interior (DOI), August 21-25, 2000. Before attending this hands-on course, I felt I was a seasoned motorist and that this course would probably be a waste of my time. WRONG! I was surprised to find that some of my driving habits were not as harmless as I thought. More important, I discovered that even a good driver can improve.

The purpose of this driving course was to train students in basic concepts, techniques, and skills involved in safely operating a motor vehicle. I (and 18 other DOI employees) learned about the physical science of vehicle dynamics, conditioning of reflexes, recognition of roadway hazards, and decisionmaking. To pass this course, each student had to achieve an acceptable hands-on level of competency in key vehicle driving skills, including shuffle steering maneuvers, forward serpentine, backing maneuver, controlled braking, turnaround, off-road recovery, evasive steering, and skid avoidance.

First Impressions

Still brimming with confidence, I began the first day of class with an introduction of the students and instructors, and then we had a few hours of classroom lecture. At this point, I was thinking that the majority of this class was going to be classroom instruction with very little "hands-on" training. However, I did find it peculiar that approximately 9-10 instructors were introduced at the beginning of the course. I asked myself, "Why the need for so many instructors?" So, I tried to keep my eyes open while one of the instructors discussed the Smith System of driving. This is a basic technique in which you "aim high in driving"—look as far ahead as possible or at least look one block ahead in city traffic and approximately one-half mile in rural areas, keeping the driver's view up rather than down at the area just in front of the car. The Smith System also involves keeping your eyes moving and taking in the big picture of the whole traffic scene.

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Department of the Interior students and Precision Driving Techniques course instructors pose for a class picture.

Reality Check

We began our hands-on training the afternoon of the first day. Each vehicle had two students and one instructor (I realized why we had nine instructors for this course). My heart pounded and eyes strained. I was very nervous during the shuffle steering maneuver where I demonstrated the use of the 9 - 3 hand position and turned the steering wheel in increments without crossing my hands. I distinctly recall knocking down a few traffic cones and my instructor telling me to relax. Fortunately, I did relax because other students knocked down many more cones than I did. In fact, one student wiped out 4-5 traffic cones during one maneuver, and the lead instructor had everyone laughing when he radioed, “bring out the cone ambulance.” This seemed to set everyone at ease, and the rest of the day was actually fun. Moreover, I learned quite a few things about my bad driving habits and how to correct them.

Driving Competition

The rest of the week was a combination of hands-on practicing of the various driving, braking, and avoidance maneuvers, as well as written classroom tests for each maneuver. Before taking our final written exam, we were to participate in a driving competition in which we had to demonstrate everything we had learned. The demonstration would be timed. I suspected that many of the students’ competitive juices were overflowing at the thought of being allowed to test their skills in this driving competition.

The next day, we were briefed on the competition. We were told what the safety and competition rules were, and each of us made a deliberately slow “dry run” of the course. A good time was important; however, knocking down cones deducted points from your overall time.

This vehicle has been modified with "skid avoidance" outrigger equipment. The modification helps drivers to develop the skill of coordinating steering and deceleration control as a means of controlling a front wheel skid, a rear wheel skid, and a four-wheel skid during rain, snow, and ice.

So, how did I do? Well, I did have the best time, but I "injured" two traffic cones and came in third overall.

Summary

During this course, I identified several areas where my driving could be improved, and the course allowed me to reinforce good driving habits I had been practicing all along. I learned that driving safely is more than a set of rules. It's an attitude and a commitment. Motor vehicle accidents are the single largest cause of accidental death and the leading cause of on-the-job fatalities in our country. A driver must resolve to be alert and to expect the unexpected. When you can do this, you'll be on the road to safety, wherever you drive.

FLUME OR WEIR CONTINUOUS WATER FLOW RATE RECORDER FOR IRRIGATION USE

by Blair L. Stringam[1] and Kathleen H. Frizell[2]

Abstract

The Bureau of Reclamation (Reclamation) 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 (CFM) and recorder. The CFM is designed to continuously measure flow rates passing through open channel measurement structures, such as flumes or weirs, by recording the water levels upstream. The water level measurements are then converted to a flow rate using a simple weir power equation. The CFM consists of a central processing unit (CPU), which is easily programmed, a liquid crystal display (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 $1,000 U.S. 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 CFM.

Introduction

There is an 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, and industrial, and for protecting environmental habitat and fisheries. Water measurement and recording are vital for effective management of an irrigation system, especially when there is pressure 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 of providing cost-effective methods to accurately measure and record

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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. Reclamation is continually working with irrigation districts regarding water measurement and recording issues, and we found that 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 ensure 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 or too much water is delivered.

In addition, continuous data logging devices in the common form of chart recorders, such as the Stevens Recorder (Reclamation, 1997), or other electronic devices are available. 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 very 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 setup 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 CPU that continuously records the water level, converts to flow rate and totalizes, and displays 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's CPU. Water level sensing devices include pressure transducers, bubblers, acoustic or ultrasonic devices, capacitance probes, and floats. A relatively low-cost, nonintrusive, 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 (figure 1). Because it is designed for agricultural use, it is much simpler to use, easier to install, and more compact than other generic data logging systems.

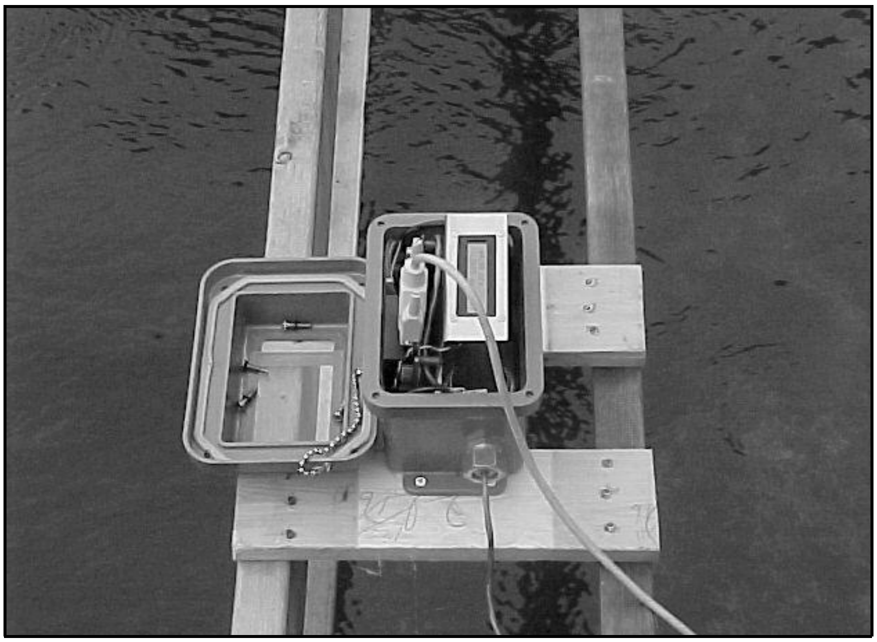

Figure 1.—The single-unit CFM installed just upstream from a measurement structure. The sensor part o the meter extends out of the bottom of the enclosure.

If required, the CFM may be constructed so that the CPU and display are separate from the sensing unit (figure 2). This allows for applications where the ultrasonic transducer must be mounted out toward the center of a canal but 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.

Several low-cost CPUs 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 CPUs that were considered required some fabrication. The first CPU that was selected would randomly lose 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 had digital input/output ports, one of which is

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, and the CPU and display are located in the enclosure to the right.

used to send the serial data to the LCD. The CPU also had an onboard analog to digital converter that was used to convert the analog signal from the sensor to a digital signal that was 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.

The CPU can be programmed in Basic or assembly language. The prototype is programmed in Basic. The program for the CPU is easily downloaded via software provided by the CPU manufacturer. The 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

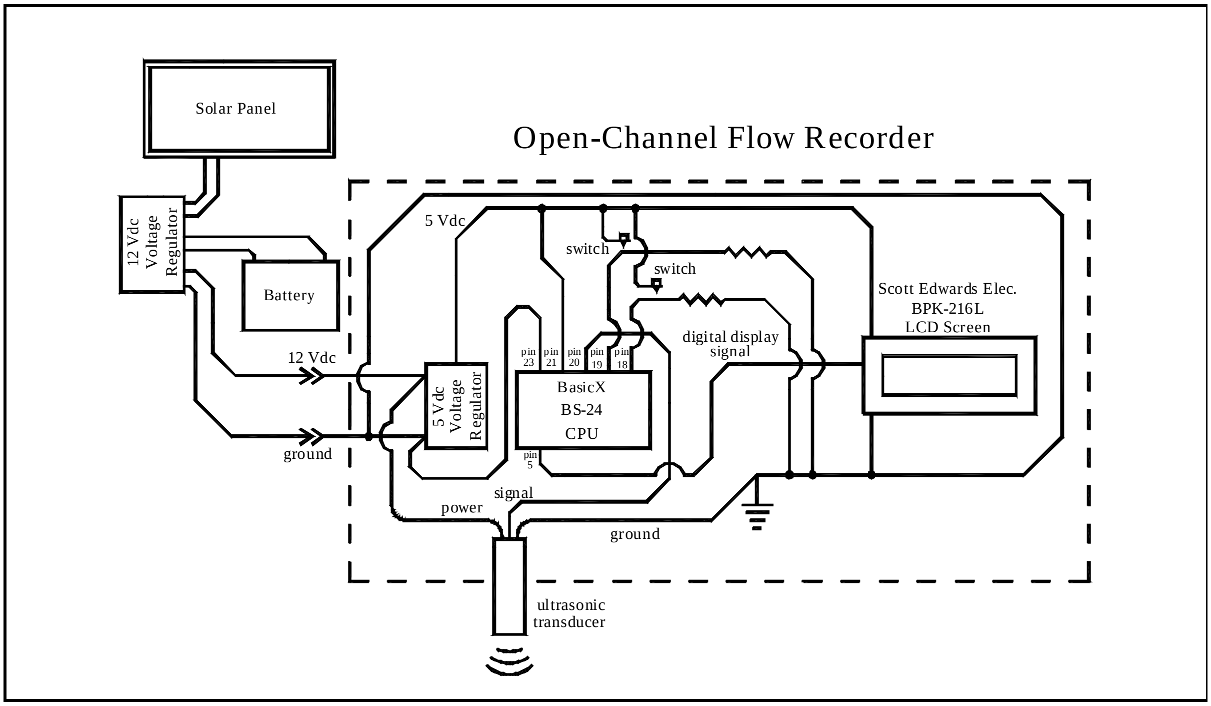

Figure 3.—Wiring diagram of the components required for the CFM.

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 meters. Once the water depth is determined, the flow rate is computed by the CPU using a generalized form of the weir equation:

$$Q = C_d H_d^K \tag{1}$$

where Q is flow rate in cubic meters per second, 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 meters, 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 to 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 feet per second (cfs) and acre-feet, but the data may be recorded or displayed in various formats such as gallons per minute, total gallons, 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.

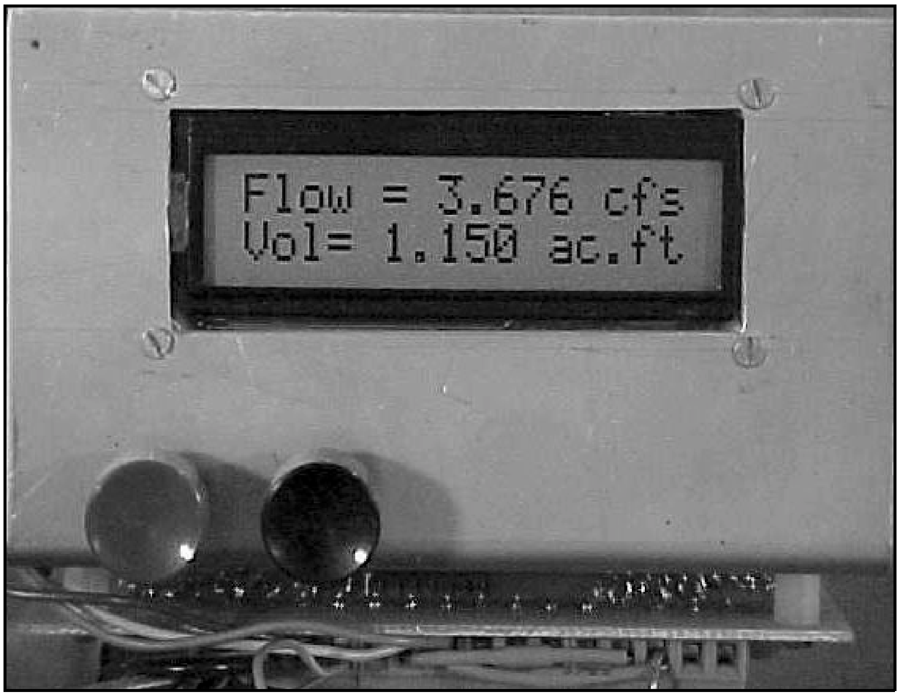

Figure 4.—Typical meter display of the current flow rate and totalized flow volume. (Note that the flow rate and volume are given in English units on the prototype.)

When the buttons are pressed, the operator may access previous irrigations for display and hand recording and can zero the totalized water from the previous irrigation. At this point in the menu, the operator is prompted to input a number code that prevents tampering with critical data and parameters. The number code comes with the unit and must be entered correctly before access is allowed to the rest of the setup menu. If the right number is entered, the water level will be displayed, and the operator will be prompted to change the water level offset. The discharge coefficient change prompt is then displayed, followed by the discharge power prompt. Finally, the operator is given the opportunity to zero the total water diverted. The totalized flow normally increases much like the odometer on an automobile. It is not recommended that this value be reset unless there is a valid reason. If no changes are needed, or the wrong number is entered (and no further buttons are pressed), the program will step through and return to the measurement and display routine.

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.

Laboratory Test Facility

The WRRL Group provides technical services and pursues applied research to provide application-based solutions and new water resource management tools to Reclamation engineers and managers. An important facility in the laboratory is a model canal facility. The model canal facility is 300 feet long and is made from clear acrylic Plexiglas and aluminum. It has motorized control gates, turnouts, a long-throated flow measurement flume, and an inverted siphon. The model canal has many of the control and flow measurement features currently being used on irrigation canals. The continuous flow meter was installed on this test canal just upstream from a long-throated flume. Extensive testing was conducted on the CFM to ensure that it would operate properly in an open channel application. The test facility has been invaluable in identifying and correcting potential problems. In addition, the CFM has been successfully tested with a bubbler sensor and several submersible pressure transducers.

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.

Figure 5.—CFM installed on a Parshall Flume at Dillon, Montana.

Temperatures range from 0 °F in the winter to about 100 °F in the summer.

Field personnel read the flow recorder and the staff gauge located at the flume at least once a 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 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 110 °F. 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 6.0 cfs to 50 cfs. One of the canals serves agricultural land on the Fort 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.

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

Cost

One of the main goals of CFM 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 costs is shown in table 1.

It should be noted that there are less expensive sensors that could be used, but they did not meet the nonintrusive 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.

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

[1] Costs are all based on parts purchased with U.S. dollars in the year 2000.

Conclusions

The 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.

References

Bureau of Reclamation, 1997. *Water Measurement Manual*, U.S. Government Printing Office, Washington, DC.

Stringam, B.L. and K.H. Frizell, 2000. "Irrigation Flow Measurement - Instrumentation Development Part II," *Operation and Maintenance Bulletin No. 193*, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

RADIAL GATE MODIFICATION
GATE LOCK
DELTA CROSS CHANNEL

by Connie Berte[1] and Don Read[2]

General

The Delta Cross Channel is a dug channel, less than a mile long, located approximately 28 miles south of the City of Sacramento, California, in Sacramento County. It is part of a complex navigable waterway system through six counties and is controlled by two 60-foot-wide by 30-foot-high radial gates, each operated by a wire rope hoist.

Delta Cross Channel aerial view (Bureau of Reclamation photo).

Delta Cross Channel downstream view of the radial gates (Bureau of Reclamation photo).

When the gates are open, the channel allows passage of low-overhead-clearance boats between the Sacramento River and the Mokelumne River System.

Delta Cross Channel upstream view of the radial gates.

Operating Conditions

Minimum water surface elevation: 4.50 feet.
Maximum water surface elevation: 17.50 feet.

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The Need

Although the wire rope hoists are designed for supporting and operating the large, heavy radial gates, they do not provide the required safety margin for overhead loads with public traffic underneath. In order to safely pass boat traffic, a mechanism is needed to hold the gates open that will provide a safety factor of at least five on the ultimate strength of critical mechanical components.

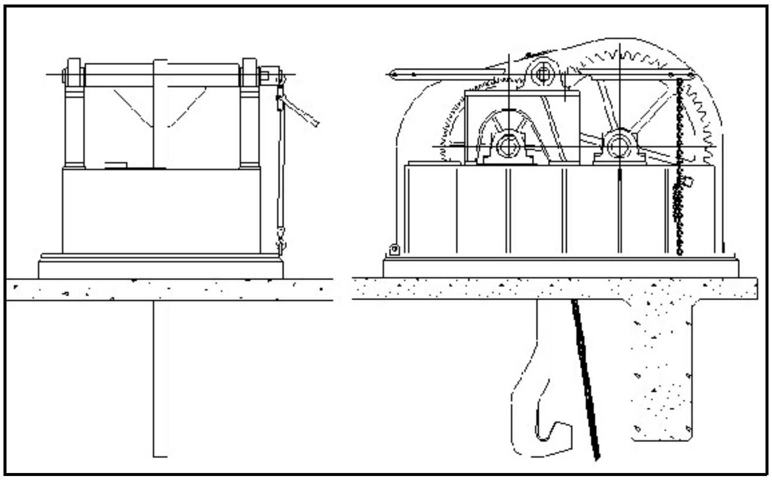


Figure 1.—Upstream and side view of drum unit with hook installed.

The Design

The initial mechanism design was composed of an arm supported by a pivot fixed on the downstream bridge deck edge next to the radial gate skin plate. The arm would swing over and against the raised gate and support the gate on a thrust pad mounted on the skin plate surface connected to the gate frame.

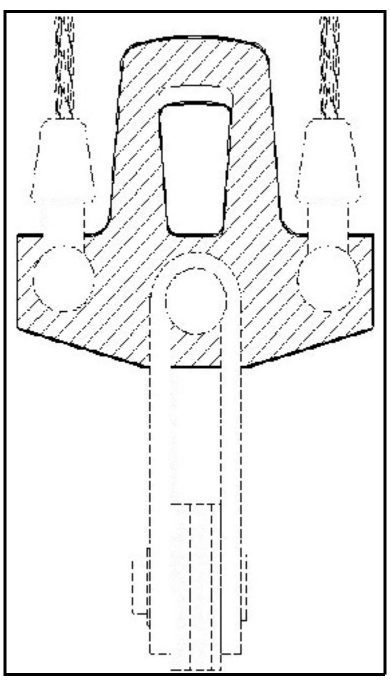


Figure 2.—Equalizer bar with integral eye.

This design had the advantages of simplicity and accessibility but imparted a significant side load to the bridge. This side load would have required modifications to the bridge supports, costing approximately $200,000.

A different design was in order.

Since the bridge was designed for the existing hoist load magnitude and direction of forces, the new mechanism design attempted to hang the gate while not changing the magnitude and direction of forces on the bridge. The hoist drum units are double-rope type, which allow a lock arrangement to be installed in between the ropes.

The drum units resemble a large clock, filled with gears and shafts. There is sufficient space within the unit to install a swinging hook.

This design had two advantages: (1) the forces on the bridge remained essentially unchanged and (2) the visual impact was minimized since most of the mechanism was contained within the drum unit case.

Each hook was a heavy pendulum that naturally hung in the disengaged position. This was important so that one man could quickly lower the gate by raising the gate off of the hooks, allowing the hooks to swing clear. Engaging the hooks to hang the gate would require one or two men on each hook lever and another operating the gate. In the event that only one man was available to lock the gate, cable winches were provided to pull the hooks into position.

It is crucial that both hooks be engaged before hanging the weight of the gate on them; therefore, the design included view ports (holes drilled in the bridge deck) to easily verify that both hooks were properly engaged in the gate.

The hook engages a specially designed equalizer bar with an integral eye.

The Installation

As with any modification to existing equipment, the success depends on competent installation as well as sound design. In the case of the Delta Cross Channel gate modification, this was evident. Mr. Dave Arter, Construction Representative, and the installation crew demonstrated the skill and flexibility needed to make the lock installation a success.

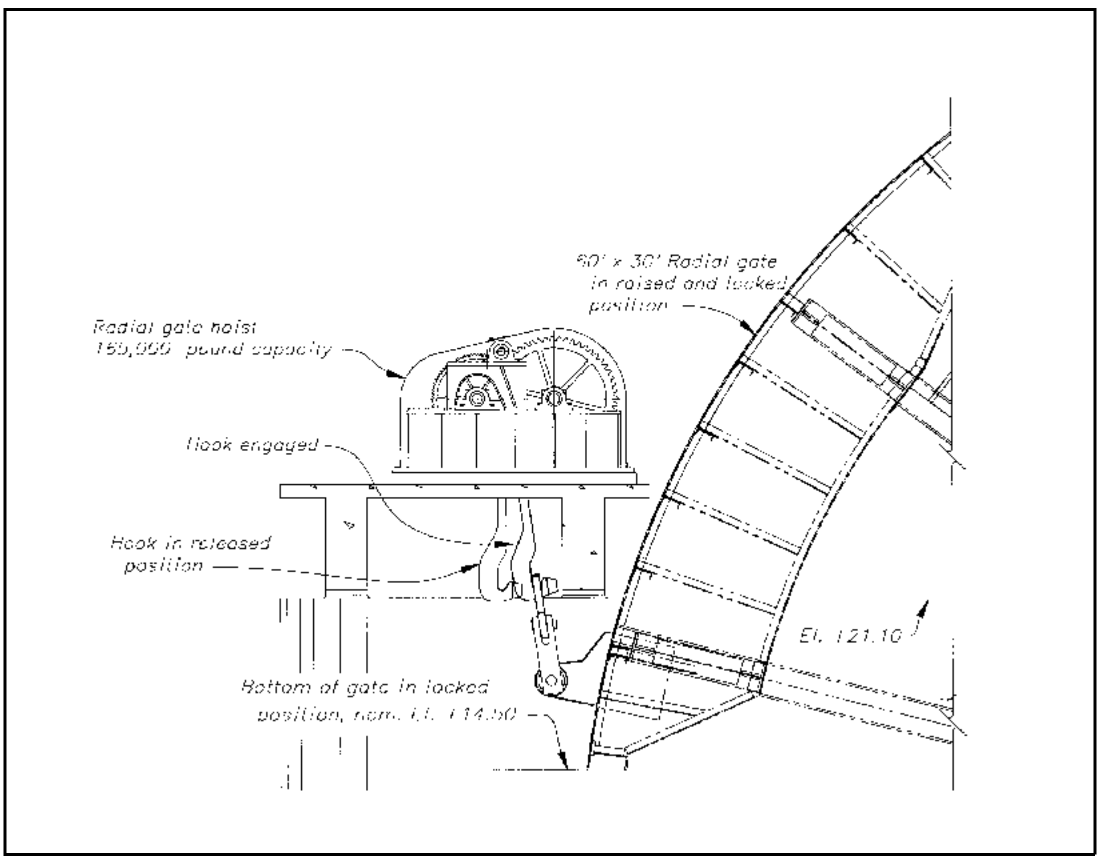


Figure 3.—Sectional elevation showing gate, hoist drum unit, and gate lock installation.

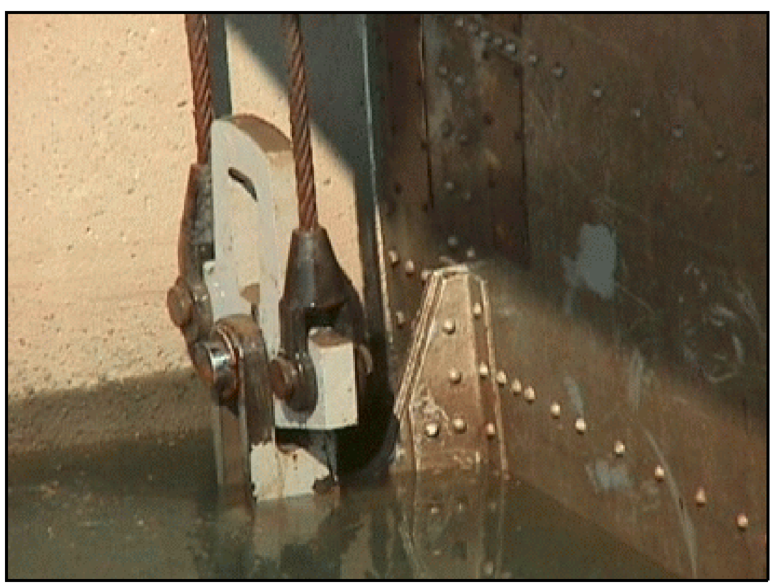
Old equalizer bar being removed.

Replacing the equalizer bar required divers to disconnect the existing equalizer bar from the gate. The gates had to be closed to perform the work. Once disconnected, the equalizer bar could be lifted out of the water and worked on from a boat.

As can be seen in the photo to the left, the old equalizer bar was large and heavy. With the added eye, the new equalizer bar was even heavier. Working so close to the gate connection provided an excellent opportunity to inspect the gate connection and wire ropes for possible corrosion damage—these areas are on a continuously submerged gate and are difficult to properly inspect.

During installation, it was discovered that the holes through the bridge deck through which the existing wire ropes passed were smaller than expected and had to be enlarged. A review of the original bridge drawings ensured that enlarging the holes would not affect the structural integrity of the bridge.

The view holes, planned to be drilled through the bridge deck to the side of the drum unit, were discovered to pass directly through a lateral bridge support. Field and Denver staff considered locating the view hole in the drum unit cover, but it was ultimately located on the upstream side of the unit through the deck. This provided a clear view of each hook as it engaged the equalizer arm eye.



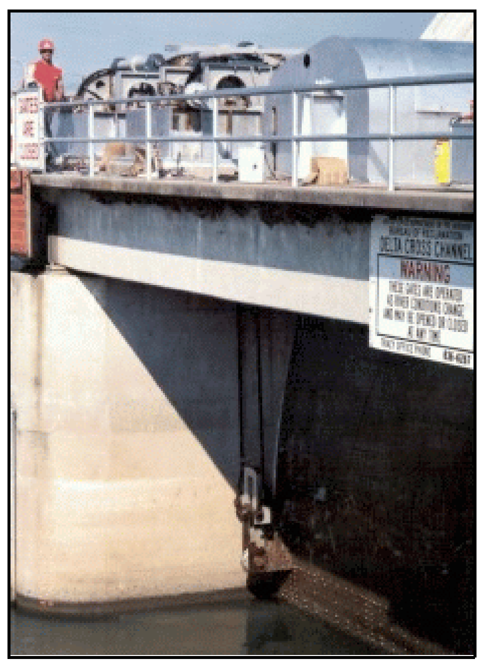
New equalizer bar completely installed.

Centering the hook in the equalizer bar eye required the addition of shims under the supporting pillow blocks. This caused the hook to interfere with the drum unit cover. Modifications were made in the field to add a spacer under the drum unit cover to raise it 1 inch. All details of the change were handled in the field.

Drum unit with cover removed showing the hook, pillow blocks, and bases. Shims are under the pillow blocks.

A combination of good communication and skilled installation resulted in a gate lock that is safe, neat, and relatively easy to operate.

Hook hanging vertically and centered between wire ropes. Lateral bridge supports are located to the left and right of the hook.



Upstream view of gate during installation.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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