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UNIQUE REPLOGLE FLUME INSTALLATIONS AT THE TRUCKEE-CARSON IRRIGATION DISTRICT

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ABSTRACT

The Water Measurement Program (WMP) for Truckee-Carson Irrigation District (TCID) began in 1997, when the Irrigation Training and Research Center (ITRC) of Cal Poly State University was asked to develop a volumetric measurement plan for TCID, funded by the U.S. Bureau of Reclamation, Mid-Pacific Region. This program was intended to develop and install reasonably accurate turnout delivery measurement techniques in the district. As part of the WMP, TCID was required to install a number of new open-channel measurement devices. TCID opted for the Replogle flume as its primary flow measurement device using the newly developed WinFlume computer program.

A few key problems prevented TCID from using the typical Replogle flume design that is used in most irrigation districts. For example, the majority of flow measurement sites were to be installed in earthen channels. In addition, the head loss available at each of the sites was relatively small for this type of structure. This required a new design where the cross section and the ramp portion of the flume had to be incorporated in the same construction package. The process used in the design and the unique aspects of construction used on these projects are documented in this paper.

INTRODUCTION

With demand on worldwide water supplies continually increasing, it is necessary to find ways to both improve the efficiency of its use as well as promote conservation. In order to achieve these simultaneous goals, good water management is required that relies on effective and practical flow measurement. Flow measurement in canals can be a complicated problem that is often solved with the use of critical-flow devices. These devices measure the flow in sections of the canal that have been structured to create “critical flow” (Clemmens et al. 2001). Critical flow is created by maintaining conditions that prevent any changes downstream of the critical flow point from affecting the upstream head. This allows the flow rate through the control section to be computed as a function of the upstream head (Clemmens et al. 2001). Many types of critical-flow devices have been utilized for decades, including sharp-crested weirs, broad-crested weirs, and different types of flumes. Some devices are better than others; one particularly effective device is the Replogle flume, technically known as a broad-crested weir but known in different regions as a “ramp flume”, “ramp weir”, “BCW”, “RBC flume” (short for the Replogle-Bos-Clemmens flume), “Burton flume”, or “long-throated flume”. The senior author worked with Dr. Replogle when the original design was developed and has

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used the term “Replogle” over the course of 30 years’ experience with these flumes and over 2,500 installations.

Some flow measurement devices are found to be relatively expensive to maintain, difficult to install, or costly to construct. Others have problems with accuracy. The hydraulic properties of the Parshall flume, for example, cause the accuracy of the measured flow rate to be greatly affected by the accuracy of installation and the constructed dimensions. Many of these devices are laboratory calibrated, so construction or installation errors cannot be easily evaluated, causing the accuracy of the measured flow rate to vary by installation.

Discussion of Advantages and Placement of Flumes

The development of the Replogle flume has greatly reduced the issues stated above (Clemmens et al. 1984). Clemmens et al. (1984) describes the recommended design and installation of Replogle flumes as follows:

(1) The discharge for any prismatic-shaped flume can be computed from existing hydraulic theory to within +/-2% of the true discharge; (2) the flume cross section can have a wide variety of shapes; (3) head loss over the flume for a unique (upstream) head-discharge relationship is the lowest of known devices and can be estimated with sufficient accuracy from existing hydraulic theory; and (4) this type of flume is presently the least expensive structure that can measure flow accurately under similar hydraulic conditions.

In general, flow measuring flumes consist primarily of a contraction of the side walls, with the flume bottom being slightly lower, on-grade, or slightly higher than the existing channel bottom. For monitoring flow in irrigation canals, the writers have found that a bottom contraction has many advantages over the side contraction. A flume with a bottom contraction resembles a broad-crested weir but is shaped in such a way that it acts hydraulically like a long-throated flume. The advantages of this “modified” broad-crested weir over other long-throated flumes are: (1) Construction of a bottom sill is much simpler and less expensive than the construction of side walls; (2) the bottom width of the flume is much wider and thus construction tolerances on width are much greater; (3) the wider bottom provides good sediment transporting capabilities; and (4) the absolute head loss over the structure required for modular flow is low. If the water level downstream from the structure does not affect the head-discharge relationship, the flow is said to be modular. (Clemmens et al. 1984)

Clemmens et al. (1990) performed an experiment “to determine the effects of entrance and exit conditions on the discharge and required energy loss.” Flumes were tested with different entrance and exit ramp slopes, and different H_1/L ratios, where H_1 is the sill referenced energy head and L is the length of the throat. It was concluded that entrance slopes of 2:1 and 3:1 resulted in errors of 1-2%. These errors can be improved if the approach ramp at the throat was rounded. The necessity of having an exit ramp depended on the H_1/L ratio. Ratios up to 0.4 resulted in errors less than 1% using no exit ramp

slopes of 0:1 and 6:1. The error in discharge measurement increased at ratios higher than 0.4 for both exit ramp slopes; however, the 6:1 exit ramp slope had a lower percent error than the 0:1 exit ramp slope. Based on these tests and experience, the ITRC recommends to irrigation districts a standard design of a 3:1 slope with rounded entrance conditions and a 6:1 exit ramp slopes.

The placement of a Replogle flume in a canal is crucial for accuracy. Clemmens et al. (1987) developed a Froude number approach to designing flow measurement devices. This approach concentrated on “providing an appropriate Froude number in the approach channel for the passage of sediment and for producing a stable readable water surface at the head measurement station.” Three basic design requirements for critical-depth measuring devices need to be met for this approach to work:

- (1) The flume should provide enough constriction to flow so that it is unaffected by downstream backwater effects, but not so much that the upstream water level is too high at maximum flow;
- (2) the upstream channel Froude number should be high enough so that upstream water levels can be accurately measured;
- and (3) the flume should have acceptable sensitivity to flow changes and provide sufficient accuracy. (Clemmens et al. 1987)

The target value for the entrance condition is to have the Froude number be less than 0.5.

WinFlume Software Program, Version 1.06.0004

The USBR developed software to design, analyze and run feasibility tests on proposed Replogle flumes. WinFlume is a Windows-based program that can be downloaded from the USBR’s website. Primary funding for the software was provided by the USBR’s Water Conservation Field Services Program. This software is essential to optimizing the Replogle flume installation and operation. With the development of the WinFlume program, users are able to create possible flume situations under various conditions. The ease of use and flexibility in design are some WinFlume’s advantages. Further design capabilities are discussed in the following methodologies (Wahl 2012).

TCID’s Use of Replogle Flumes

Since 1997, TCID has installed many flow measurement devices in its canal systems, following the recommendations of the United States Bureau of Reclamation’s (USBR) *Water Measurement Manual*. The 3rd edition of the manual, published in 2001, states:

Long-throated flumes are coming into general use because they can be easily fitted into complex channel shapes as well as simple shapes. Long throated flumes have many advantages compared to other measuring devices, including Parshall flumes. Long-throated flumes are more accurate, cost less, have better technical performance, and can be computer designed and calibrated. Thus, long-throated flumes are preferred over Parshall flumes for new installations. (USBR 2001)

In 2009, Dr. John Replogle, a consultant and retired USDA/ARS flow measurement expert, Tracy Vermeyen of the USBR Technical Service Center (TSC), and Dr. Charles

Burt of ITRC, went to Fallon, Nevada to evaluate the Water Measurement Program for TCID. Table 1 shows the number and types of flow measurement devices that have been installed in the TCID service area as of 2009. The Replogle flume has been the most frequently used flow measurement device since the WMP was started. The conclusion from an independent review of these flow measurement experts was that “the broad-crested weir designs of TCID are of excellent design and construction overall” (ITRC 2010). Currently, in 2013, over 100 Replogle flumes have been installed in TCID canals.

Table 1. Number of Flow Measurement Devices Installed in TCID (ITRC, 2010)

Type of Measurement Device	# of Devices in 2009	Datalogger?
Broad-crested weir (a.k.a. “ramp”, “Replogle Flume”)	53	Yes
Weir	20	Some
Trapezoidal flume	13	Yes
Other (Parshall flume, rated pipe or section, propeller meter in a pipe)	8	Some

ITRC METHODOLOGY

The Cal Poly ITRC developed a report on the basic design of Replogle flumes as a guideline for irrigation districts. According to this report, “one of the primary advantages of the Replogle flume is the capability to custom design and calibrate structures for unique operational and site requirements using the Windows-based computer program WinFlume” (ITRC 2002). The report provides a list of the steps for properly constructing a Replogle flume. These steps are summarized below.

Definition of the Existing Channel Conditions

The first design step is to select the proper site and determine the field conditions under which the flume must operate. The following characteristics of the installation should be established through site surveying and a thorough review of the conditions at high and low flows:

- Range of flows to be measured
- Freeboard requirement at maximum flow
- Access to the site for construction and subsequent measurement
- Influence of any downstream control structures, if any
- Uniform flow, Froude number
- Lining material and material used for flume construction (roughness coefficient)
- Cross-sectional dimensions and side slope

For design purposes, it is usually necessary to measure the cross section of the canal at about four locations: the site where the flume will be, one location upstream of the site about 50 ft, and two downstream locations (at about 50 ft intervals). The survey data required at each location includes top of left bank, top of left concrete, invert at left toe, invert at centerline, invert at right toe, top of right concrete, and top of right bank.

In addition, the water level elevation in the canal should be surveyed at 100 ft intervals, for approximately 200 ft upstream and 300 ft downstream of the proposed site. This needs to be done at the maximum and minimum flows, with estimates made of the approximate flow rates.

The upstream and downstream channels should be investigated for possible flow restrictions including culverts, check structures, turnouts, etc. that might affect flows. The size and locations of these structures should be obtained.

It is critical that the backwater effects of downstream control structures, if any, be evaluated at the proposed flume location. To determine the potential impacts from submergence, the water level at the nearest downstream control structure should be raised to its highest point, while at low flow conditions, and then survey data of the water level obtained at the flume site.

Recommended Site Conditions, Location and Specifications

Figure 1 shows a possible location for a Replogle flume. The following conditions should be met for accurate flow measurement:

- The Froude number of the approaching channel should not exceed 0.5. A Froude number closer to 0.2 is preferred.
- Note: H_{1max} is the sill-referenced energy head at maximum flow
- There should be no high turbulent flow upstream of the structure for a distance of $30H_{1max}$

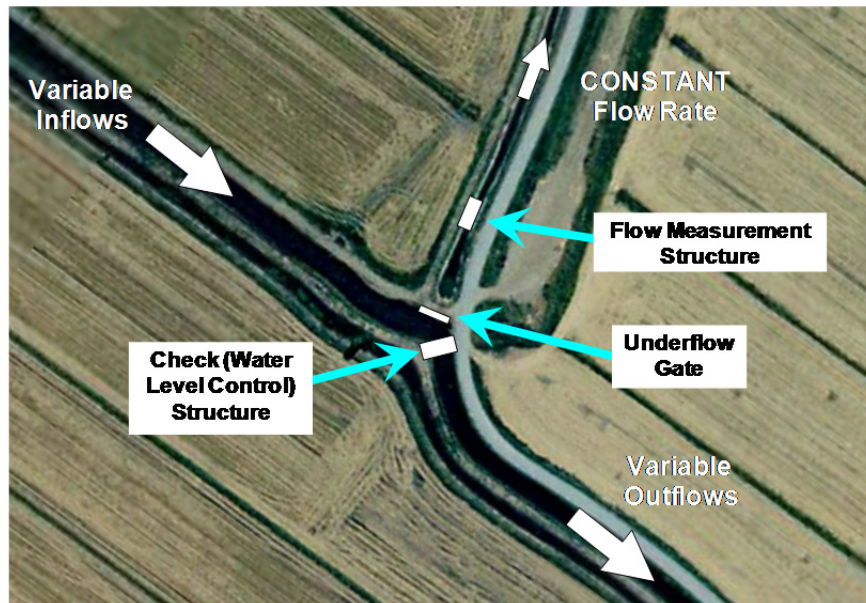


Figure 1. Customer (or lateral) turnout location for a Replogle flume

Method of contraction. Options of contractions include a bottom-only contraction or a side contraction using a change in slope of the vertical walls. The size and dimensions of these contractions can be determined using the WinFlume program. In rare cases, a side

and a bottom contraction can be used. These types of designs are discouraged due to the constructability issues with a more complex cross-section.

Suggested flume dimensions. In order to properly design the length of the approach channel, converging transition, throat, and diverging transition, the sill-referenced energy head (H_1) at maximum flow must be known. Once all of the parameters for the design are known, data can be entered into the WinFlume program for a design. When designing the flume in WinFlume, using a sill height of half the normal flow water depth is a good place to start. The height can be adjusted as long as a check for adequate submergence protection is done.

Head loss design criteria. Minimizing the head loss is a key issue for flow measurement in canals. Having a contraction helps avoid submergence but there cannot be so much contraction that the canal overtops. The amount of contraction needed depends on the height of the sill of the Replogle flume. It is important to verify that the design does not have any “design errors” flagged in the WinFlume software.

Head measurement method. Head measurement should be done with electronic water level sensors that are accurate within +/- 1/16 inch. This is easily achievable with the availability of numerous pressure transducers and other measurement devices.

Flush pipe: A flush pipe should be installed at the bottom of the Replogle flume to prevent pooling when the canal is drained. The pipe should be flush with the concrete and be at least 4” in diameter for flows above 5 cubic feet per second. Typically, a PVC pipe is cut in half and two drains are installed.

Staff gage. WinFlume is able to print out a full scale staff gage that can be transferred to metal or plastic so it can handle outdoor conditions. A custom gage can be used or a simple staff gage can be used. The key to improving the volumetric accuracy on an installation is to have the water level monitored with a logger.

Verification of as-built dimensions. After the flume has been constructed, the as-built dimensions must be precisely measured and entered back into WinFlume so it can generate the proper discharge tables with the as-built dimensions.

ITRC has been recognized by Dr. Replogle as one of the key organizations to help with the field implementation of the Replogle flume measurement device. ITRC continues to recommend this device to irrigation districts in the US and internationally if the site conditions are appropriate.

TCID METHODOLOGY

The Truckee-Carson Irrigation District (TCID) has developed its own detailed protocols in designing and constructing Replogle flumes in its canals. Their protocols are outlined in the following paragraphs.

Education of District Growers

The first step of the process was that the district had to convince growers that Replogle flumes are a viable flow measurement device. TCID began by explaining to the growers how they work. This education of the growers on the meters has been the key to the successful acceptance of this device as a standard, robust measurement device. TCID staff has to be able to explain the device as a flow rate measurement device and also how the loggers allow TCID to record the flow rate over the time of an irrigation event.

Meter to Measure Flow Rate

Replogle flumes work as a flow meter by creating critical flow conditions as water passes through the sill of the flume. Critical flow condition means that for a single depth, there is a single flow rate associated with that depth. The speed of the water accelerates through the throat of the flume until critical flow is achieved at the sill of the flume. WinFlume is used to design the size of the flume and after it is constructed, the as-built dimensions are entered in the program and a staff gage is generated with the zero reference being the top of the sill. This staff gage can either have the flow rate measurement or the water level above the sill on it. If it is the water level above the sill, WinFlume also generates rating tables that give the flow rate over the flume with a given height that is read from the staff gage.

Construction to Record Events

TCID has a specific construction method for the Replogle flume. WinFlume is used to determine the required dimensions of the flume for the given application before construction is started. The first part of construction is to lay the foundation of the contraction. When the foundation is poured, vertical steel rebar is left extruded out of it to be used when the walls are poured. After the contraction section is built, water is run through it and the data set is re-run to ensure that putting a flume in the contraction will work. The Replogle flume is then constructed using the dimensions from WinFlume. As-built dimensions are then verified and the final calibration of the flume is done in WinFlume.

The installation process is described in detail below:

1. A detailed site evaluation is performed where the flume will be installed. The site evaluation consists of site survey data, high and low flows in the canal throughout the season, and the high water mark in the canal. All of these values are used to design an appropriate Replogle flume using WinFlume (Figure 2).

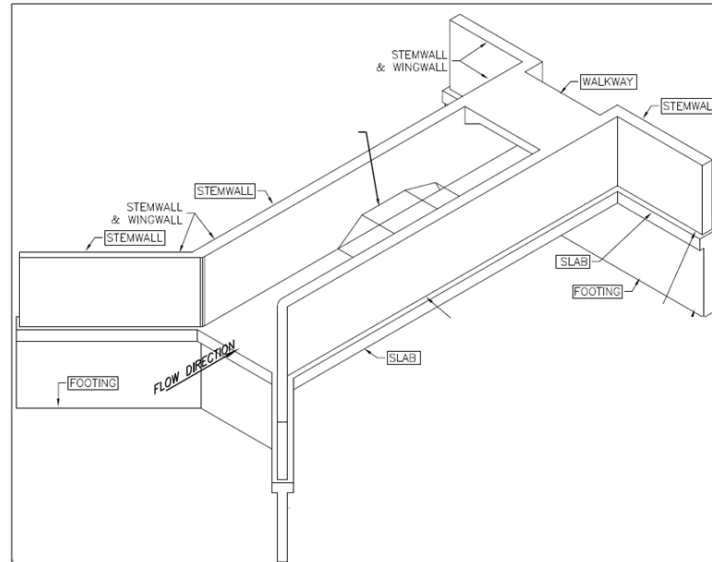


Figure 2. TCID's standard design for Replogle flumes

2. Cross section of the structure is built. TCID uses a set of standard-sized cross sections. Depending of the size and capacity of each canal, the widths and lengths of the cross sections range from 2ft to10ft and 12ft to 36ft, respectively.
3. After cross section construction, water is run through the canal and the tail water data is recorded. This step is to ensure that putting a Replogle flume there will actually work. This is a **KEY** step in the process.
4. The tail water data obtained in step 3 is used to adjust the original dimensions of the Replogle flume in WinFlume, to make sure the flume will not submerge and to ensure accuracy of the flume.
5. After the flume has been carefully and accurately designed in WinFlume, the flume itself is finally constructed inside the cross section. This process takes TCID about 3-5 days. The canal must be drained and the cross section prepared to lay the concrete forms for the flume, then the concrete is poured. Figures 3 and 4 show the construction of a cross section.



Figure 3. Framework and steel for the foundation



Figure 4. Vertical steel rebar to be used for the walls of the flume contraction

6. The as-built dimensions are measured and entered into WinFlume to obtain the proper staff gages to be used for the flume.
7. A final calibration is done and the accuracy of the flume is checked via current metering.



Figure 5. Standard TCID Replogle flume



Figure 6. Standard TCID Replogle flume with water flowing

DISCUSSION

WinFlume. The USBR program has been a tremendous aid to the successful implementation of the Replogle Flume. The program is regularly updated and improved to help even the novice designer.

Water Measurement Program Review. As mentioned previously, Dr. John Replogle, Tracy Vermeyen, and Dr. Charles Burt visited TCID in 2009 to evaluate the devices that had been installed due to the WMP. During this trip 30 measurement sites were randomly selected and these experts evaluated their accuracy. They determined that “the existing Water Measurement Program, with some modifications, appears to be functional, reasonably accurate, and reasonably cost-effective to administer” (ITRC 2010). Some of these proposed modifications included:

- Develop a standardized procedure for verifying flow rates.
- Re-check the zero elevations/settings for its data collection at flumes and weirs, where errors are greater than 2%.

CONCLUSIONS

In this decade-long project, ITRC and TCID have demonstrated that the Replogle flume is the preferable device for open channel flow measurement for this application. TCID has taken basic knowledge of the ITRC’s recommended flume design and modified it into its own device, fit for the district’s purposes. TCID’s conveyance of material to and education of farmers in the district is commendable. Enabling other entities to properly customize the Replogle flume design is a continuing goal of ITRC.

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