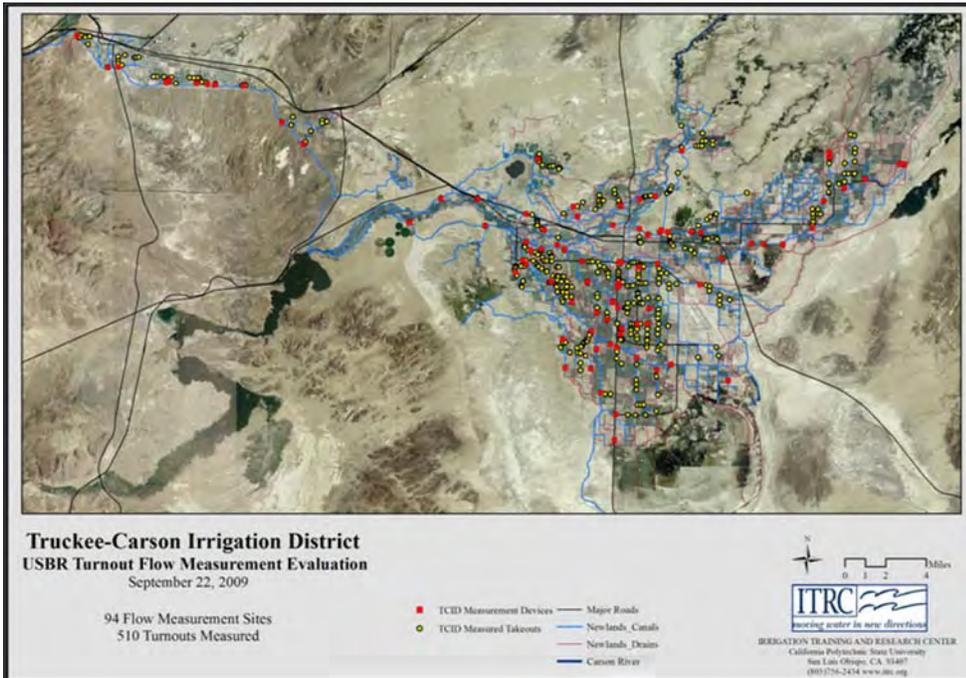


**APPENDIX E – ITRC TCID WATER DELIVERY MEASUREMENT PROGRAM
Update to the June 1997 Water Measurement Study Report**

Truckee-Carson Irrigation District Water Delivery Measurement Program

Update to the June 1997 Water Measurement Study Report



U.S. Bureau of Reclamation

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Irrigation Training and Research

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1. Background

1.1 The 1997 Study

The O&M contract between Truckee-Carson Irrigation District (TCID) and the US Bureau of Reclamation (USBR) requires that TCID make reasonably accurate measurements of delivered irrigation water volumes to individual water users.

The Mid-Pacific Region of the USBR funded a study in 1997 with the objective of developing recommendations regarding what changes, if any, were needed in the existing TCID water measurement program. TCID and the Mid-Pacific Region of the USBR agreed that the Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo (Cal Poly), would conduct the study, and both parties would accept the recommendations. TCID allocated 10% of the O&M assessment from its budget to make any changes that are necessary to meet the requirements of “reasonably accurate” water measurement and other provisions of the approved water conservation plan.

Improved water measurement was expected to provide better accountability of water deliveries. Anticipated benefits were that farmers will have greater confidence in the accuracy of their recorded usage of water, and that delivery operations will be improved if flow rates are more accurately known. There was, however, no guarantee that any project water savings would result from the implementation of the water measurement program.

Since 1997, TCID has made many changes to its field and office measurement and water accounting program. Over time, changes were made to the original program design. In 2009, USBR again asked ITRC to review the status of the TCID measurement program, and to make recommendations for modifications or improvements. A report was submitted to both USBR and TCID in early 2010, and accepted without substantial changes. This update incorporates the new procedures, and recommendations for future actions that were included in that report.

1.2 2009/2010 Update Team and Review Process

The review of the Truckee-Carson Irrigation District’s (TCID) Water Measurement Program (WMP) was conducted by ITRC under contract with USBR, Mid-Pacific Region.

Thirty measurement sites were randomly selected to visit. Three water measurement specialists (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) visited each site and then assigned an estimate of measurement accuracy.

With the exception of some devices that may have had sensor calibration problems, and several devices along the Truckee-Carson Canal that are maintained/operated in some joint manner between USBR and TCID, the measurement devices were found to be designed, operated, and maintained in good/excellent condition.

A review was also made of TCID’s evolving procedure to explain and document how individual turnout volumes are computed.

1.3 Flow Rate vs. Volumetric Measurement

The challenge at TCID is to measure the delivered *volumes* of water. *Flow rate* measurement is just one step in the process of measuring volumes. It is much more difficult to measure the delivered volume within 5-10% than it is to measure a flow rate within 5-10%.

Volumetric measurement can be accomplished by doing one of the following:

1. Measure an instantaneous flow rate and then assume that the flow rate remains constant over the time that water is delivered. The resulting volume is:

$$\text{Volume} = (\text{Flow Rate}) \times (\text{Time})$$

The potential errors with this procedure are:

- a. The measured instantaneous flow rate may not be the same as the actual instantaneous flow rate (i.e., measurement device error). This may be caused by poor construction, installation, or design of the measurement device. For example, a staff gauge may be installed at the wrong location (vertically or horizontally).
 - b. The estimate of the delivery time may be in error. An error of 15 minutes for a 24-hour delivery is not very significant (1%), but an error of 15 minutes for a 1-hour delivery is very significant (25%).
 - c. The flow rate may vary during the duration of the delivery. This may be caused by changes in the supply canal water level, changes in seepage between the flow rate measurement device and the final delivery point, or changes in the water level downstream of the flow measurement device.
 - d. Human error in measuring or recording otherwise correct data.
 - e. In the case of TCID, there can be losses between the point of measurement and the point of delivery.
2. Measure an instantaneous flow rate and accumulate (totalize) these instantaneous readings throughout the delivery time. This is done in one of two ways:
- a. Propeller meters are generally equipped with totalizers.
 - b. Flumes, weirs, or undershot gates can be equipped with water level sensors that are tied into a datalogger that takes readings frequently and stores the individual flow rates and totalizes the volume.

1.4 Reasonableness and Accuracy

In making the initial recommendations, and in evaluating progress as of 2009, ITRC addressed two aspects of water measurement:

- Reasonableness
- Accuracy

These two aspects are inseparable. No water measurement device is 100% accurate or without problems. If installed incorrectly or in unsuitable conditions, supposedly accurate measurement devices can be expensive to maintain and can be inaccurate and worthless. Accuracy relates to the precision or correctness with which a volume of water can be measured. Reasonableness is affected by other factors such as the affordability, durability, and practicality of the measurement device or technique.

Most of the common flow measurement devices (flumes, weirs, and propeller meters) are accurate to within 6% or so if installed and operated correctly. However, there are inherent problems with many flow measurement devices, either from a technical or economic standpoint.

The challenge, then, is to design a program that is relatively simple and affordable to implement and maintain. Furthermore, it must provide delivered water volumes with a verifiable accuracy. This report does not review the countless means that have been developed to measure turnout flow rates.

A new irrigation project has the luxury of standardizing dimensions and constructing canals, structures, drops, etc., so that one effective volumetric measurement device will work equally well at all sites. TCID has a very different situation, and therefore a program is provided that first evaluates the potential measurement sites, and then recommends technical solutions to different categories of delivery points. All of the recommendations given in the 1997 report had a *proven* verifiable accuracy, which is a requirement in Article 11(b)(1) of the O&M contract between TCID and USBR. The verification process does require additional work in TCID when a single flow measurement device is used for multiple turnouts. The selection (turnout categorization) process addressed which of the proven measurement methods are most appropriate for each location.

1.5 Costs, Timelines, and Verification

Three key points were missing from the 1997 report: (i) total cost estimates, (ii) a detailed timeline for the complete program, and (iii) a verification procedure. The lack of these three points can be understood by

examining the first three recommended steps for the program, and by understanding why those three steps were necessary. The first three program steps were:

- a. Categorize the turnouts
- b. Test water level sensors, dataloggers, and associated software/hardware
- c. Prioritize turnouts for inclusion in the program.

It was impossible to define the timeline and costs until TCID knew what it was facing; different conditions require different solutions. The solutions were defined, but it was unknown how many turnouts would require each type of solution. In 1997, TCID did not even have a map showing the locations of all the turnouts, much less a description of the dimensions and hydraulic characteristics of those turnouts. Such information is necessary before making final decisions. A few individuals in the district had good but non-quantifiable experiences from which they are able to speculate about the extent of various conditions, but that is insufficient for the development of specific solutions at specific turnouts.

Additionally, there were some new technical developments on the horizon. It was hypothesized that there may be some opportunities for TCID to work with various datalogger manufacturers to rapidly develop robust equipment for a fraction of current prices. Such advancements would have an impact on program costs.

It was understood in 1997 that an annual review should be included in the program. Annually, targets (cost and performance) for the next year could be developed after the previous year's work had been evaluated.

2. TCID Conditions As Of 1997

2.1 Study Area

The 1997 study covered the Factory, Island, N-System, Old River, Reservation, St. Clair, Scheckler, Smart, and Stillwater sub-districts of TCID.

2.2 Number of Turnouts

Water delivery records for 1996 were examined. The analysis showed that 1,429 turnouts had deliveries. During the month of July, 1091 turnouts received water from TCID. This analysis required a major effort, and the budget did not allow for a more detailed analysis that might include more years. ITRC believes that the one year of good data was sufficient to develop the program steps.

Seventy-five percent (75%) of the total annual acre-feet delivered occurred through 444 turnouts (31% of all active turnouts in the year 1996). The 1997 report referred to “444 turnouts” for convenience, but it was only an approximate number. As the flow measurement improvement program was implemented, it was envisioned that the number would probably decrease as some turnouts were consolidated for economics or improved accuracy of measurement. The number of turnouts that were to be modified or calibrated was not considered to be important; more important was the percentage of annual acre-feet delivered that is represented by those turnouts.

2.3 Turnout Flow Rates

An annual frequency distribution was determined for turnout delivery flow rates and durations. The analysis used the individual water orders listed in the TCID billing records. The time period of the analysis was from 25 March to 10 September 1996. During that period there were 10,016 water orders for the 9 sub-districts. The results of the flow rate analysis for TCID are summarized in **Table 1**.

Table 1. TCID – Delivery Flow Rates and Percent of Delivery Events (1996)

Flow Rate per Delivery	Percent of Total TCID Deliveries
0 < CFS <= 4.99	8.5 %
5 < CFS <= 9.99	12.7 %
10 < CFS <= 14.99	18.1 %
15 < CFS <= 19.99	33.7 %
20 < CFS <= 24.99	18.9 %
25 < CFS	8.1 %

The average turnout flow rates in TCID are much greater (about 20 CFS) than those in most water districts in the USBR Mid-Pacific Region. The large flow rates require large flow measurement devices, with a relatively large cost per turnout. Since a typical field size is only about 40 acres, this results in a relatively large cost per acre.

In contrast, the 500,000-acre Westlands Water District (WWD), a Mid-Pacific USBR water customer, supplies water to individual 160-acre fields at a typical flow rate of about 4 CFS/turnout (0.025 CFS/acre in WWD, compared to 0.50 CFS/acre in TCID).

2.4 Event Durations

Table 2 shows that half of all deliveries during 1996 had durations of less than 6 hours. This indicates that the canal operators have a large challenge in shifting water around in their districts to meet the changing demand amounts, durations, and locations. This also means that some deliveries are made in the middle of the night, when it is difficult for operators to visit individual turnouts.

Table 2. TCID – Delivery Event Durations and Cumulative Percentages of Delivery Events (1996)

Delivery Duration	Percent of Total TCID Deliveries
15 minutes or less	0.6 %
30 minutes or less	2.6 %
1 hour or less	8.7 %
2 hours or less	18.8 %
3 hours or less	27.9 %
4 hours or less	36.3 %
6 hours or less	51.2 %
8 hours or less	63.4 %
10 hours or less	71.4 %
12 hours or less	78.2 %
15 hours or less	83.9 %
18 hours or less	87.8 %
24 hours or less	92.3 %

2.5 Turnout Locations and Accessibility

One of the initial challenges in the 1997 project was to determine where the individual turnouts were located. There were no maps available showing turnout locations or access routes. This has not been a problem for operation, since the operators certainly knew the locations. However, for the purposes of a study and characterization of turnouts an accurate map is very useful if not essential.

Although some turnouts (called "direct turnouts" in this report) are connected directly to the main canals and are therefore relatively easy to access, many of the turnouts must be accessed through closed gates or via private farm roads. Accessibility is a key concern for this project, because any program that requires that individual turnout delivered volumes be directly measured will require easy access to the turnouts. It was stated that if easy access proved to be a major problem, TCID and its water users would need to improve or simplify the access to some sites.

As of March 8, 1997, TCID had completed AutoCAD maps of 6 of its sub-districts, showing canal names and check structures. Turnout locations had yet to be identified.

In 1997, the Fallon Office of the USBR was exploring methodologies to locate all of the turnouts and major structures on an excellent map (elevations and horizontal coordinates). The Lahontan Basin Area Office (LBAO) in Carson City had purchased Global Positioning System (GPS) equipment and was in the process of setting up a Geographic Information System (GIS) in its office. The work plan for developing the map was to be a subset of a larger effort to map all of the project facilities and lands and was to be incorporated into that effort.

2.6 Condition of Existing 1997 Turnouts

It was beyond the scope of the ITRC contract to inventory the condition of all the turnouts. However, several field visits indicated that the conditions vary from excellent to very marginal, in relation to the maintenance of the hardware and surrounding areas.

Some of the open channel turnout gates have very little drop across the gate, which at first glance may indicate a problem for installing flow measurement flumes. However, such a condition does not necessarily mean that sufficient head would be unavailable once a flume is installed.

Some direct turnouts (turnouts that deliver directly from canals that are almost always full of water) have good conditions for accurate submerged orifice usage and others have unsubmerged discharges.

The laterals are often dry, so when a delivery is made to a turnout along a lateral, the pond in the lateral must

first be built up (filled up with water) before a flow rate can be delivered.

In summary, it was clear that the conditions of the individual turnouts and the associated ease of installation of a good flow measurement device would need to be assessed as the program was implemented. Since only about 444 turnouts need to be improved/calibrated, it was not considered necessary to assess the condition of all turnouts.

2.7 Trash and Plugging Potential

There are many sections of canal that are unlined. In addition, the main canals are occasionally used for flood releases. Both conditions contribute to large amounts of water-borne trash and weeds at some times of the year. This is important when considering different types of flow meters or water level sensors.

Propeller meters are ineffective in water that is full of algae and trash, such as is often the case in TCID. It would be unreasonable, for example, to require the installation of the elaborate and expensive trash screening equipment that would be necessary at each turnout for the accurate use of propeller meters. Propeller meters only have a proven accuracy in clean water conditions.

From another technical standpoint, propeller meters require a full pipe to operate accurately, a condition that apparently would not be met in many TCID turnouts.

2.8 Economics

The water users' ability to pay is low, based on the fact that TCID has a very short growing season, thereby limiting the types of crops that can be grown. The average profit from short season alfalfa and small grains is typically low.

The main implication for the 1997 ITRC study was that the initial and on-going costs of any flow/volume measurement program must be kept as low as possible, while still yielding relatively accurate results. The proposed 1997 program was intended to meet those objectives. There are only a limited number of effective ways to measure delivered water volumes in TCID, and those have been selected. They happen to correspond to relatively inexpensive solutions (as opposed to very expensive solutions such as acoustic Doppler meters, propeller meters with moving trash screens at each turnout, Dethridge meters, or other such options).

3. 1997 TCID Measurement Procedures

3.1 Division of TCID and Operator Responsibilities

The area of interest in TCID has 9 sub-districts, often referred to as "districts" within TCID. Each district has its own characteristics in terms of the percentage of lined canals, canal capacities and lengths, slopes, and soil types.

Typically, one operator is responsible for arranging the deliveries within one sub-district, and for moving the flows throughout his sub-district to match the short duration, high flow rate deliveries that are characteristic of TCID.

Water orders are called into the central TCID office. Once sub-district operators learn of the orders, they communicate daily with individual water users to arrange on/off times.

3.2 Determining Delivered Water Volumes

Total water volumes for individual deliveries are often not measured at the individual water user turnouts. In most cases, operators make a measurement of the flow rate into a lateral and then one or more water user(s) downstream will take the water, usually in sequence but sometimes simultaneously. The operator must determine the discrepancy between the amount of water placed into the lateral and the amount delivered to individual user turnouts.

Each operator had developed his own procedure for allocating the amount of seepage and spillage water that occurs in a lateral. Some operators determine that the seepage will vary throughout the season and make adjustments according to their experience. Other operators use a constant amount of seepage per delivery for all dates. TCID and USBR have conducted some studies to verify values of canal seepage losses. That field work was useful for past operations, but it was not saved in a format that could be used by ITRC for this report.

In many cases, the durations of deliveries are reported to the ditchriders by the water users themselves; the individual turnouts are not always visited personally by the canal operators. Water users sometimes question the subsequent water delivery statement, but there is some question as to how the arguments are resolved, since most of the individual turnouts lack flow meters and the flow rates probably vary with time.

In short, many TCID procedures have evolved over time and had been satisfactory for operation purposes up to 1997.

4. 1997 PROGRAM Strategy

The recommended program addressed the different concerns that had been expressed by both TCID and USBR. On one hand, TCID believed that its existing procedures for billing delivered water volumes were reasonably accurate. USBR must have verification that whatever measurement procedure is adopted is reasonably accurate.

4.1 Verifying the Accuracy of Existing Procedures

If the existing procedures are sufficiently accurate, it would be unreasonable to require TCID to change just for the sake of change. In any case, it is important to document the accuracy that presently exists. This means that after the verification program is completed, a new measurement program will be implemented on none, some, or all of the TCID turnouts.

4.2 What Constitutes "Sufficient Accuracy"

Several conditions must be met in order to meet the condition of "sufficient accuracy".

1. The annual delivered volume to each turnout is the particularly important value in question, rather than the average volume per district acre (that could be measured by taking a district average).
2. A key component of the ITRC recommendation was the decision that it may be sufficient to construct an aggressive flow rate measurement program to individual turnouts that account for 75% of the annual volume delivered to users. This represents 444 turnouts with the current configuration of turnouts. In order to upgrade measurements on an extra **5%** of the annual volume (i.e., account for 80% of the annual volume), the number of turnouts studied and improved would need to increase from 444 to 522, an increase of **17%**, which would significantly increase costs. Furthermore, the accuracy measurement of the remaining 25% of the delivered volume (if 75% of the turnouts are upgraded) will improve because the recommended program includes:
 - a. The installation of better flow measurement at lateral entrances and better water level control in the main canals, both of which will improve the controllability of water throughout the district.
 - b. Integration of lessons learned (regarding seepage and conveyance loss values) into the procedures for measuring flows for the remaining 25% of the delivered volume.

Of course, the exact costs of installing improved measurement devices/conditions on the 444 turnouts were unknown in 1997. Once the program was in the implementation phase and a verification program was in place, the annual review process was intended to re-evaluate the initial target number. If costs were less than anticipated and the proposed volumetric measurement procedures were unsatisfactory, it was understood that it may be necessary to expand the program beyond the initial 444 turnout estimate.

3. Given the fact that an excellent flume design installed perfectly and with perfect measurement of water levels will only give about $1-3\% \pm$ accuracy over a range of flows, ITRC believed that a **$10\% \pm$ volumetric measurement accuracy on individual field turnouts** is reasonable for TCID conditions. This was based on ITRC experience with actual field problems of volumetric measurement including errors in water depth sensors and totalizers, fluctuating flow rates, calibration curves, etc. A $6\% \pm$ accuracy has been identified as a target in some water conservation programs outside of TCID. However, that accuracy is generally applied to flow rate measurement devices rather than to volumetric measurement.

The volumetric measurement program (see Section 5) would generally be considered to be more accurate than $10\% \pm$ because the 10% applies to individual turnouts and therefore the average error is less.

Measurement errors are of two types: random and biased. Random errors (due to construction parameters being plus or minus, water depths being measured plus or minus, etc.) probably contribute to at least half of the total errors. This type of error cancels out when computing a district-wide average. As a result, the actual deliveries to all measured fields will probably be known with better than $5\% \pm$ accuracy.

Several steps for verification of delivered volumes to individual field turnouts were suggested in 1997, as

follows:

1. An undefined number of turnouts were to be selected for verification.
2. Volumetric measurements must be made at each of the selected field turnouts. This was to be done for the complete season.
3. In order to accept the present (1997) accounting procedure at any location, the annual determination of deliveries to that location must be within $\pm 10\%$ of the actual annual value.
4. In order to maintain quality control in the verification procedure, it would be necessary for the operators to make their determination of delivered volumes without any knowledge of the measured volumes at the individual turnouts. This means that operators must turn in their water delivery notes before collecting the dataloggers (see Section 5), or the dataloggers might be collected by other persons. The exception will be sites that do not require dataloggers, because the flow rate is constant over time (see Section 6).

It was recognized in 1997 that there may be situations in which the totalized measurements from a single new flume can accurately estimate the volumes made to a “group of 2-5 turnouts” that are typically irrigated as a unit, at the end of a canal. This was initially verified by installing flumes at the individual turnouts, unless they are all within 500 feet of a common upstream point. In the 2-5 turnout cases, it would be sufficient to allocate an estimate of seepage to each turnout in proportion to its volume delivered. The verification procedure was intended to define the amount of seepage to allocate.

5. Volumetric Metering

5.1 Hardware Components

The 1997 program required some hardware changes in the field. These included:

1. Installation or calibration of flow rate measurement devices for approximately 444 individual turnouts. This is a first estimate, and the final number will depend upon program costs that are to be re-evaluated annually.
2. Some new flow rate measurement devices at the heads of lateral canals.
3. Some new or modified canal check structures to provide more pressure (head) to laterals or field turnouts.
4. Some new or modified canal check structures to stabilize canal water levels.

5.2 Flow Rate Metering at Turnouts

Three types of flow rate meters were recommended, depending upon the situation at the turnout. These are discussed in the following sections.

5.2.1 Replogle Flume

The Replogle Flume (a.k.a. "Broadcrested weir" or "ramp weir") was designed at the U.S. Water Conservation Laboratory in Phoenix in the early 1980's. As of 1997, ITRC personnel had apparently designed more of these than any other group in the world, in sizes ranging from about 2000 CFS down to 0.02 CFS. This flume has excellent characteristics such as:

- A high tolerance for construction errors.
- Calibration using a theoretical computer program. Most measurement devices, such as other flumes and various sharp-crested weirs, have empirical discharge equations and they can only be calibrated in the field by using some other field measurement of flow rate.
- Ability to operate with a minimum of water surface drop (2-4 inches).
- Ability to pass trash.
- The water level at only one location must be measured for all flow rates and conditions.
- Simple and relatively inexpensive construction. It is estimated that a single field turnout flume for TCID will average less than \$1000. This is considerably less than an equivalent propeller meter or other device.

There are two conditions under which the Replogle Flume will not be the flow measurement device of choice:

- If the turnout is a "direct turnout" and already has an excellent submerged orifice installation.
- If there is less than 2-3 inches of head loss available at the turnout.

It was intended that ITRC could work with TCID and the Fallon office of USBR to develop some standard Replogle Flume designs. These should be conservatively designed, in the sense that the ramps might be too low in some installations. If they are too low to eliminate submergence, it will be easy to raise the ramp heights by adding some concrete in the field.

Each flume should be equipped with an easy-to-read staff gauge that reads out directly in CFS (as opposed to tenths of feet of water depth). This would be important for the water users who will want to know instantaneous flow rates when they pass by the flumes.

These flumes were proscribed from being "field calibrated" with current meters, as current meters are less accurate than the Replogle Flumes if the dimensions have been properly measured.

5.2.2 Canal Submerged Orifices

Submerged orifices (a.k.a. "Metergates" or similar designs) have been used for decades. They are used to both adjust and measure flow rates. Flow rates are measured by determining the pressure drop across the gate and the gate opening, and then referring to a standard table for that gate size. If the submerged orifices are of a standard design and installation, they will measure within the necessary proven accuracy.

Submerged orifices were deemed to be acceptable for this program if they meet the following conditions:

- They are of a standard design.
- They are located on a canal that is always full before and after the delivery.
- The downstream head measurement can be taken accurately and at the correct location.
- The upstream and downstream water levels do not vary substantially (see Section 6) during a delivery.
- The submerged orifice will be at least 30% closed during a delivery. (The accuracy of these devices degrades rapidly if the gate is more than 70% open.)

It was noted that it might be necessary to develop calibration tables for some standard designs. A portable Replogle Flume with an adjustable ramp could be used for such field calibration. A current meter can also be used for calibration if the flow is not turbulent. Calibration must account not only for the proper discharge coefficient (Cd), but must also utilize the proper measurement technique and equation(s). ITRC could review the calibration procedures with USBR and TCID when the program was implemented.

There may be some additional types of orifices in TCID that do not qualify as “metergates”. Some of these may have free flow (unsubmerged) conditions, and others may have flow conditions that vary from submerged to unsubmerged, depending upon the flow rate delivered. Further classification of such orifice installations was required to determine if they could be included as “acceptable”.

5.2.3 Electromagnetic Meter (“Flo-Tote”) or Other Similar Device

In 1997, it was recognized that there may be some cases for which there is less than 2 inches of drop available. These locations would have a low priority (see Section 6.3) because of the inherent flow measurement problems. As of 1997, there was no excellent, reasonably priced technology available for measuring open channel flows with this condition with dirty water. However, if some of these sites must be measured because other sites cannot be added or canal banks cannot be raised, an option to explore (Flo-Tote) was described. *It was anticipated that this would only be a last resort condition, and hopefully by the time the priorities had advanced this far, new technology would be available.*

This option would require that a standard cross section be installed with sufficient length to create a uniform velocity profile across the cross section width. In these situations, the "Flo-Tote" device from Marsh-McBirney might be used successfully. This device has a probe that is set in the bottom of a standard section. It measures both a point velocity of the water and the depth, from which it computes the flow rate. It must be calibrated at each site, which requires additional expense. Furthermore, it is susceptible to trash pickup. This device has a datalogger to totalize flow rates into volumes. As with the totalizer and depth sensor for the Replogle Flume, it was expected that the Flo-Tote could be a portable unit that would be moved between locations, with a standard frame in which to set it at each site. Again, it should be emphasized that this type of device would not be needed until the 6th or 7th year of the program, and it was hoped that improved technology would be available by then. However, it was recommended that no additional work be done as of 1997 with the Flo-Tote for this particular flow measurement program.

5.3 Volumetric Measurements at Turnouts

The three flow rate measurement devices described in Section 5.2 were intended to be used for the program as of 1997. As mentioned earlier, the objective was to measure volumes rather than flow rates. Flow rates were to be converted to volumes using one of the following techniques, depending upon the turnout:

1. Volume = (Constant Flow Rate) × (Time)
This procedure will be acceptable only where all of the following conditions are met:
 - a. The operator has easy access to the turnouts.
 - b. The operator is present at the turnout when the flow begins and ends.
 - c. The flow rate is "relatively constant" throughout the duration of the delivery.
 - d. The measuring device is a Replogle Flume or submerged orifice.
2. Volume = Sum of [(Flow Rate Measurements) × (Time between Measurements)]
This will require the use of a datalogger and would only be used with the Replogle Flume or similar

flumes. Measurements must be taken at least as frequently as given in **Table 3** in order to accurately totalize the delivered volume.

Table 3. Required Frequency of Flow Rate Measurements for Totalizers

Delivery Duration	Minimum Frequency, minutes
15 minutes	0.5
30 minutes	0.5
45-90 minutes	1
2 hours	2
3-6 hours	3
7-10 hours	5
10-20 hours	10
More than 1 day	15

Determining the volumetric measurement with a totalizer on a Replogle Flume requires an accurate, calibrated water level sensor and a datalogger, as well as the software and hardware for retrieving (downloading) the data into a useful form. The most practical water level sensor was envisioned to be either:

- a. A float in a stilling well to the side of the flume, suspended to a transducer that will provide a 0-5 volt or 4-20 milli-amp signal to a datalogger. ITRC and others have had excellent long-term success with some of these units. They are very simple, easy to troubleshoot, and require a minimal power draw. The stilling well access tube (between the stilling well and the canal) must be designed so that it can be easily cleaned. The float must also be large enough to eliminate hysteresis. Installation and equipment details have been provided to TCID and the Fallon Office of USBR.
- b. A double bubbler system. The bubbler systems can utilize a relatively small bottle of compressed air or CO₂ that can last for several months without replacement. The double bubbler feature (instead of a less expensive single bubbler) provides self-calibration of the pressure transducer that sends the electrical signal to the datalogger.

The dataloggers for each type of sensor could be basically the same. A configuration could be designed so that the float/sensor assembly or double bubbler/gas cylinder assembly could be enclosed in a vandal-resistant enclosure and left on-site. Quick disconnect couplers could be used to connect a portable datalogger to the transducer wires. Both configurations have a low power requirement, and could use small and easily portable, rechargeable batteries for operation.

As of 1997, it was estimated that an analysis of the delivery trends of approximately 500 turnouts would indicate how many dataloggers will be needed. A rough estimate was that 200 units would eventually be needed if individual turnout flows were eventually metered throughout the district, representing 75% of the total annual volume.

6. 1997 Program Steps

The essential elements of the recommended 1997 volumetric measurement program are listed below in outline format.

6.1 Categorize the Turnouts

The first step was to categorize each of the 500 potential turnouts. This was greater than the 444 that utilize 75% of the district volume, so that other turnouts with equivalent volumes can be substituted for very difficult locations that may occur in the first 444. A "difficult location" is one that would be very expensive to modify, or that has very poor conditions for the installation of a flume. The term "difficult" does not imply that the current measurement of volumes at that location is any more or less difficult or accurate than at other locations.

6.1.1 Location

There are three classifications of turnouts:

1. Direct Turnouts
 - a. Those with water level fluctuations (upstream or downstream) during a delivery that would cause less than $5\% \pm$ flow rate change during a delivery. **Table 4** indicates the allowable rise or fall in water level *if the flow into the turnout is controlled by an undershot (orifice) gate located at the turnout*, which should be the case in almost all of the direct turnouts.

Table 4. Allowable Rise or Fall in Canal Water Level during a Turnout Delivery, to Maintain Steady Turnout Flow Rates (less than 5% change)

Drop across turnout undershot gate, feet	Allowable change in canal water level, feet
0.2	0.02
0.4	0.05
0.6	0.07
0.8	0.10
1	0.12
1.2	0.14
1.4	0.17
1.6	0.19
1.8	0.22
2	0.24
2.4	0.29
2.8	0.34
3.2	0.38

- b. Those with water level fluctuations (upstream or downstream) that would cause more than $5\% \pm$ flow rate change during a delivery. Those with upstream water level fluctuations would require improved water level control in the canals, through the use of modified check structures such as Begemann gates, long-crested weirs, AMIL gates, or PLC-controlled electrical gates.
2. Turnouts that are grouped (2-5 turnouts) close together (within 500 feet of each other and a common upstream point), which may be eventually served by a single flow rate measurement device.
3. Turnouts along long laterals.

6.1.2 Available Head

Each turnout will have one of the following conditions:

1. Sufficient head for a flume (2 inches minimum).

2. Insufficient head for a flume, but a new cross-regulator could provide sufficient head.
3. Insufficient head for a flume and a new cross-regulator would not provide sufficient head.

6.1.3 Estimated Delivery Life

Some fields may be sold for their water rights and those should have a low priority for inclusion in the program.

6.1.4 Probability of Error

Main turnouts with a maximum probability of error under the present measurement procedures should receive a high priority (see priority #3 in **Table 5**).

6.2 Develop Software and Procedures for Recording Volumes

(Note: Step 6.2 should begin at the same time as Step 6.1)

1. Select float/transducer water level sensors and double bubbler sensors.
2. Select datalogger manufacturers to work with and experiment with various dataloggers.
3. Identify software to download and record.
4. Develop procedures to blend with existing water records.

6.3 1997 Prioritization of Turnouts for Inclusion in the Program

Table 5. 1997 Turnout Priorities

Priority	Conditions	Recommended Action
1	Turnouts with existing totalizers.	Examine the sites for proper design and frequency of measurement.
2	> 200 AF delivered/year. Direct turnouts from full canal. Canal operator will be at turnout when delivery starts and stops. Sufficient head. CONSTANT canal water level. CONSTANT downstream conditions (if d/s conditions would affect the T.O. flow rate).	Install Replogle Flume or use existing good submerged orifice. Existing submerged orifice calibration must be verified. No totalizer needed.
3	> 200 AF delivered/year. Direct turnouts from full canal. Canal operator will be at turnout when delivery starts and stops. Sufficient head. VARYING canal water levels. CONSTANT water level <u>downstream</u> of the T.O., or changes downstream of T.O., does not affect the T.O. flow rate significantly.	Install improved canal water level control. Install Replogle Flume or use existing good submerged orifice. Existing submerged orifice calibration must be verified. No totalizer needed.
4	> 200 AF delivered/year. Direct turnouts from full canal. Canal operator will be at turnout when delivery starts and stops. Sufficient head. CONSTANT canal water level. VARYING water levels <u>downstream</u> of the turnout that would affect the T.O. flow rate.	Install Replogle Flume. Use portable totalizer.

5	Adjacent turnouts with a single owner that can be consolidated into a single large turnout.	Install Replogle Flume at new turnout. Install Replogle Flume at the head of the lateral. Use portable totalizer at individual turnouts.
6	> 200 AF delivered/year. Sufficient head. Turnouts at the ends of laterals and are close enough to each other and a common measurement point, that eventually they might be grouped together (2-5 turnouts) using one new flume w/ totalizer.	Install Replogle Flume at each turnout. Install Replogle Flume at potential new measurement site in the lateral. Use portable totalizers at individual turnouts.
7	>200 AF delivered/year. Sufficient head. Turnouts are located along long lateral, with flow (volume) presently only measured at the head of the lateral.	Install Replogle Flume at each turnout. Use portable totalizer at ind. turnouts. Install a new Replogle Flume at the head of the lateral.
8	Less than 200 AF delivered/year. First priority should go to those with greater than 130 AF delivered/year. Sufficient head. Turnouts are located along long lateral, with flow (volume) presently only measured at the head of the lateral.	Install Replogle Flume at each turnout. Use portable totalizer at ind. turnouts. Install a new Replogle Flume at the head of the lateral.
9	All others with insufficient head, which could have sufficient head if a new cross regulator would be installed. First priority should go to those with greater than 130 AF delivered/year.	Install a new cross regulator. Install Replogle Flume at ind. turnouts. Install Replogle Flume at head of lateral. Use portable totalizer at ind. turnouts.
10	All others from the top 500 with insufficient head, for which a new cross-regulator will not help.	Install a standard control section at individual turnouts. Use Flo-Tote or better device at individual turnouts, with totalizer.

6.4 Develop Timelines and Verification Procedures

Steps 6.1 - 6.3 have defined the problem, identified equipment and associated costs, and established priorities. At this point, it will be possible to establish good timelines and verification procedures for the remainder of the project.

6.5 Design New Structures

TCID may investigate the possibility of using several pre-cast flume designs in its yard. It is recommended that TCID designate specific personnel to work full-time on the entire design, installation, calibration, data collection, etc., effort.

6.6 Install New Structures

Installation of some new structures could begin in the winter of 1997.

6.7 Train Operators

Operators will need to understand the program, as well as proper procedures for collecting and recording data. Office personnel will need to know how to incorporate the data into existing water accounting procedures.

6.8 Compare Results

Results from the existing TCID procedures must be compared with individual turnout results, on a case-by-case basis.

6.9 Re-Assess the Program

This program will need an annual re-assessment for successful implementation. The procedures which have been used, the results obtained, the use of those results, and other factors should all be reviewed. As an example, at the time of the writing of this report it is not known how many turnouts fall under various categories. The categorization of the turnouts will definitely impact the eventual cost of the program.

7. Status as of Fall 2009

7.1 Mapping Information

As recommended in the 1997 report, since 2001, the USBR Carson City office has developed several GIS files showing GPS locations of structures throughout the Newlands project. The key files are:

- **Allpoints** – This file, provided in 2001, originated as GPS coordinates, elevations, and identification of over 18,000 individual points throughout the region. Nearly every structure was surveyed including canal centerlines and tops of banks at key locations. However, the identification of the sites was incomplete and the naming conventions of turnouts and checks were not always uniform. This file was used in this evaluation only to locate sites missing from the other files.
- **Structures.shp** – This file was provided in 2007. This file is more concise than the Allpoints file, and only shows turnouts, headgates, check structures, spills, and measurement devices. The naming conventions are much more uniform and for many sites there is a structure description. Some sites are missing in this file, but this file is nevertheless used as the basis of this evaluation. Missing sites were added based on approximated locations using the Allpoints shapefile.
- **Inventory.shp** – This file was provided in 2009. It has a uniform naming convention (although it differs from the first two), but has more missing locations than the Structures.shp file.

7.2 Flow Measurement Devices

As of the fall of 2009, there were 94 flow measurement devices utilized to quantify flows at 510 turnouts. **Figure 1** shows the locations of these devices. The broadcrested weir designs of TCID are of excellent design and construction overall.

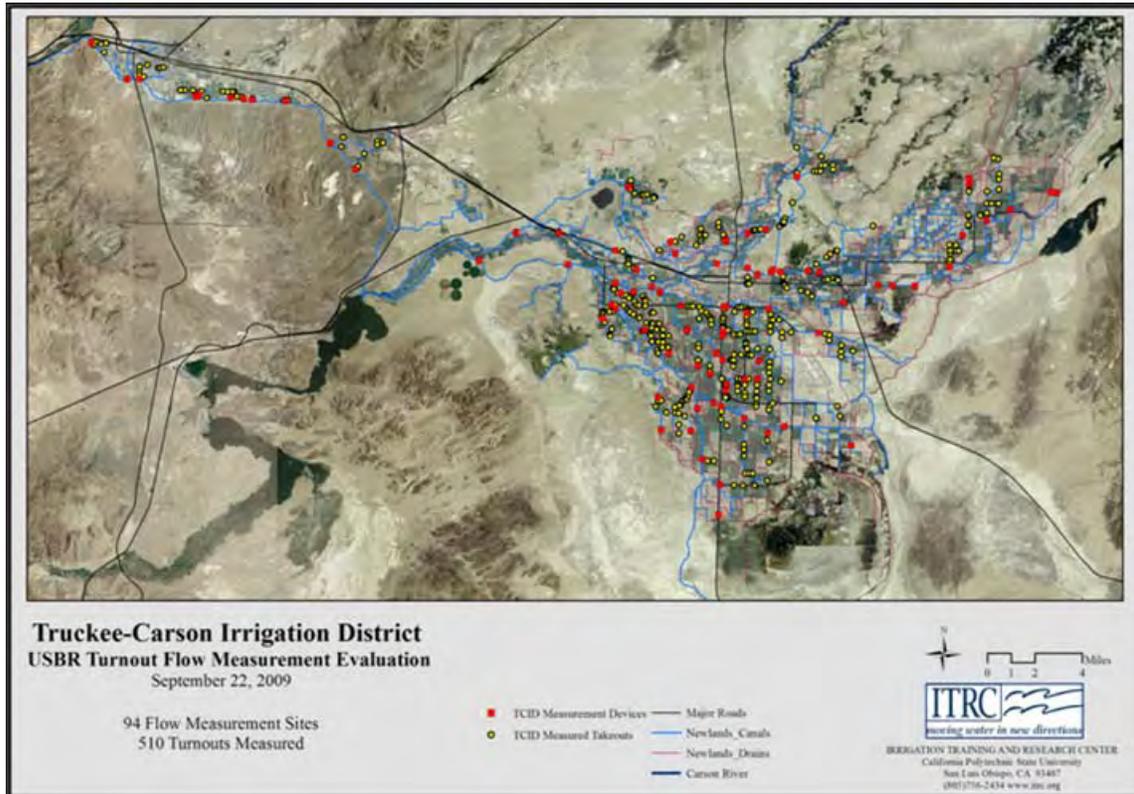


Figure 1. Locations of TCID Flow Measurement Sites

The types of devices are listed in **Table 6**.

Table 6. Numbers and Types of Flow Measurement Devices

Type of Measurement Device	# of Devices	Datalogger?
Broadcrested 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

TCID noted that the meters above measured 67% of the total delivered volume. Eight percent of the volume remained to meet the 75% volume target.

In 2009, TCID performed a "Meter Audit". For all of the metered laterals, the following values were computed:

Total metered flow (through the flumes, weirs, or propeller meters) = 148,516 AF
 Total charges to turnouts downstream of those points: = 100,404 AF
 % of metered flow that is charged to fields = 67%

There were many reasons for the difference in values, including:

1. TCID does not include as "charges" some turnouts that are at the extreme downstream ends of some of the metered laterals. In other words, TCID does not feel that there is sufficient backup data to use the measurement device at the head of the lateral to estimate some deliveries.
2. Some of the measurement devices pass substantial return flows while deliveries are not being made. Therefore, the total metered flow is greater than the charged flows.
3. Seepage losses occur between the meter and the turnouts.
4. The charges are based on the duration of the delivery to the farm turnouts. The farm turnout may be closed at the end of an irrigation, but water continues to flow through the meter at the head of the canal.

Starting in 2009, TCID began to systematically organize information for each field turnout in spreadsheets. This information provides documentation on how each individual delivery event's volume is calculated before it is entered as a "charged" value. For each event and each turnout, the following are considered:

1. Seepage estimates that have been made. Different seepage values are used for different times of the irrigation season.
2. The flow rate through the lateral at the time of the delivery. This impacts the seepage rate.
3. Ditchrider records of on/off times for the turnout.
4. Ditchrider records of Poly weir stick measurements upstream and downstream of turnouts.
5. Datalogger flow measurements, adjusted for lag times to the turnout.
6. Complaints by users, and subsequent checks of seepage or other values.

8. Recommendations

8.1 Water Measurement Program (WMP)

1. The existing Water Measurement Plan, with some modifications, appears to be functional, reasonably accurate, and reasonably cost-effective to administer.
2. TCID should take responsibility for the construction, maintenance, and operation of all flow measurement devices within TCID that are used for the purpose of billing

(charging) individual field turnouts. The TC Canal measurement devices, in particular, need major improvements.

3. Verification of flow rates (or inversely, seepage), whether by TCID or a USBR representative, must be done with a standardized procedure that is mutually agreeable to both parties. Currently, TCID current metering procedures (including verification of a steady flow rate) are different from those used by USBR representatives. Even if procedures are identical, there will be differences in measured flow rates; different procedures can cause unnecessary conflict.
4. TCID must improve the transparency of its accounting process for estimating individual turnout volumes. Most districts have conditions which require only limited, occasional interpretation of field data before assigning values of delivered volumes. TCID does not have a combination of hardware and delivery gate access and personnel that can provide this simplified volumetric accounting.

TCID has elected to substitute a fairly complex procedure to compute the delivered volume for each individual delivery event. The procedures are difficult to understand and explain, and training a new employee to duplicate the process would be problematic. An external auditor must listen to a verbal description of procedures on an event-by-event basis.

The computation and background data collection procedures must be modified so that they are very transparent to both insiders and outsiders, with very standard and well documented protocols. Aspects of an improved accounting process should include:

- a. Written general procedures for computing volumes to delivery gates.
 - i. All the procedures would not be used for all delivery locations.
 - ii. They should be described in a detailed background document. This document would define all procedures (and the techniques and mathematics) used for items such as:
 1. Seepage (there may be 3 or 4 different procedures)
 2. Pass-by flow in the lateral canal
 3. Start time
 4. End time
 5. Adjustments at a later date for the correction of errors
- b. Written specific procedures and values that apply to each individual delivery gate throughout the season. This document (likely a spreadsheet) would define:
 - i. Which of the general procedures were used
 - ii. Details of each procedure – for example, when and where things are measured. In the case of seepage, the date and details the seepage tests should be supplied.
 - iii. Constant values that are used for each delivery gate
- c. A worksheet that provides explanations for values that have special computations on specific dates for each turnout. These should be coded to enable simple display in a readable summary table at the end of the season.

- d. Linked or readily available worksheets and/or databases that provide input for the computation of each component.
- e. Description of how the computed volume is transferred to a charged value for billing.
- f. A written flow chart that shows the procedures, locations of files, file names, etc.

The end result of this documentation would be that anyone interested in understanding the procedures and source of numbers for a single delivery event could quickly (within a few minutes) learn from the written backup information/procedures without needing to talk to someone. It is assumed that it would take longer for the visitor to understand the linkages.

5. The procedures listed in (4) above are more complicated and inaccurate if there are large numbers of field turnouts serviced by one flow measurement device a long distance from the meter. TCID staff members recognize this problem, and have plans to install more “intermediate” flow measurement devices in such situations. ITRC provides the following specific recommendation:
 - *The hydraulic travel distance between the meter and a turnout cannot exceed 1.25 miles. Any exceptions to this rule must be documented and justified in writing and be approved by a joint USBR/TCID technical committee.*
6. If either one of the following conditions occurs during a delivery event, that volume cannot be counted toward the required metered volume for the district. However, the user must be billed for every delivery volume, even though the volume for a specific event is not counted toward the district metering requirement. The two conditions are:
 - a. A submerged weir/flume, or one temporarily inaccurate for any of many reasons.
 - b. Simultaneous multiple deliveries from the canal/lateral which would require an estimate of what percentage of the flow is being delivered to a delivery gate.
7. TCID must provide, at the end of every irrigation season, a clear table that provides the following information for each delivery gate that is included in the metering program:
 - a. Delivery gate ID
 - b. Meter used to measure the flow rate
 - c. Acres supplied by that delivery gate
 - d. Acre-feet that were billed and were counted as part of the metering program.
 - e. Acre-feet that were billed but were not counted as part of the metering program, plus code(s) describing what problems were encountered.
 - f. A summary of:
 - i. Total AF billed under the metering program
 - ii. Total AF billed for turnouts that would normally fall under the metering program, but which were not counted this year.
 - iii. Total AF billed for turnouts outside the metering program
 - iv. Total AF billed to all fields in TCID (i + ii + iii)

8. TCID must re-check the zero elevations/settings for its data collection at flumes and weirs, where errors greater than 2% were noted during the November 2009 site review, plus at the sites that were not visited. Written documentation of the results should be maintained on file.

9. All flow measurement weirs and flumes must have dataloggers and water level sensors for automatic recording of levels, with the minimum logging interval at least as good as is specified in the 1997 report. It is recommended that any new dataloggers have at least 16-bit resolution.

10. For future policy, individual flow measurement devices must be within $8\% \pm$ accurate in measuring flow rate. The average accuracy of all measurement devices used for determining water charges must be within $5\% \pm$. Volume estimates at individual turnouts must be within $10\% \pm$, with an average accuracy of $7\% \pm$ for all of the turnouts used to calculate water charges.

8.2 Water Conservation Plan

The OCAP agreement provides a target project efficiency. The Water Measurement Plan (WMP) is one element that is useful in achieving the goal. Improving and expanding the WMP beyond the 75% measurement target, and stressing even more accuracy than is recommended in this update, would likely have limited success in achieving or exceeding the efficiency target.

In districts with a similar hydrology, it is common to improve project efficiency through a combination of improved canal control (including regulating reservoirs) and recirculation of good quality drainage water. That also appears to be a reasonable approach for this project.