SBx7 Flow Rate Measurement Compliance for Agricultural Irrigation Districts

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Irrigation Training & Research Center

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GROUPED DELIVERIES

Senate Bill x7-7 (SBx7-7) requires documented volumetric accounting to individual turnouts for water deliveries. Section 597.3 of the bill lists two very different requirements for devices (bold, underlined, italics have been added for emphasis):

- Section 597.3(a) discusses measurement devices that must be used at points where there is a reasonable degree of flow rate control.

- Section 597.3(b) states that "An agricultural water supplier may measure water delivered at a location upstream of the delivery points or farm-gates of multiple customers using one of the measurement options described in §597.3(a) if the downstream individual customer's delivery points meet either of the following conditions:

  A. The agricultural water supplier does not have legal access to the delivery points of individual customers or group of customers to install, measure, maintain, operate, and monitor a measurement device.

  Or,

  B. An engineer determines that due to small differentials in water level or large fluctuations in flow rate or velocity that occur during the delivery season at a single farm-gate, accuracy standards of the measurement options in §597.3(a) cannot be met by installing a measurement device or devices (manufactured or on site built or in-house built devices) with or without additional components (such as gauging rod, water level control structure at the farm-gate, etc.).

This last section (B) in essence defines the most downstream point of measurement to be located at the "hand-off point".

The "hand-off point" can be defined as the location, moving downstream in the branching hydraulic network, below which the irrigation district no longer has good control over the flow rates that go to individual farm-gates.

For example, one might consider using a ditch or pipeline with a rotation delivery schedule, with one "head" or delivery at a time. That single "head" or flow rate is rotated among users, one at a time. There is no control over flow rates at individual turnouts (along that ditch or pipeline); the flow rate is controlled at the head of the ditch or pipeline.

This is also true of ditches or pipelines with a rotation delivery schedule, with two or three "heads" or deliveries. These systems typically have little or no precise flow control downstream of the heading. In some districts, the delivery points are not even to a field; the distribution pipelines have alfalfa valves for each border strip that is irrigated. When there is an internal splitting of two "heads", it is done without the benefit of the structures that provide good water level or pressure control.

While it may be possible in many cases to install flow measurement devices within these pipelines or canals, the measurement would be of uncontrolled flows unless the pipelines or canals were substantially modified. In other words, "additional components" besides the flow measurement devices would be required.
Rice systems are a special category, as good water management of rice irrigation is premised on maintaining a target water level in the fields, rather than on delivering a specific volume to a specific field.

That said, with traditional rice laterals, or with traditional rotation laterals, it is entirely reasonable to require farmers with new pressurized systems on such ditches/pipelines to install magnetic meters or propeller meters on their systems. Such flow measurement installations are rather typical and do not represent technical or fiscal challenges for implementation.

**Conclusions**

1. The wording of SBx7 appears to clearly indicate that the proper, most downstream flow measurement location would be at the head of any "community ditches". "Community ditches" (sometimes called "improvement districts") are defined as privately owned distribution systems that receive water from the irrigation district. The distribution, partitioning, and scheduling of water deliveries within the "community ditch" is not done by irrigation district personnel.

2. Irrigation district ditches and pipelines that are operated on a rotation schedule need an accurate flow measurement device at the head of the ditch or pipeline, but not at individual delivery points within/along the ditch or pipeline that receives water on a rotation schedule. This pertains to ditches and pipelines that are owned either by improvement districts or by irrigation districts.

3. Individual delivery points with pressurized irrigation systems that receive water from an irrigation district ditch or pipeline that is primarily a "rotation" system must be individually metered.

*Note: The phrase "irrigation district" encompasses a wide range of district types including reclamation districts (e.g., RD108), water districts (e.g., Coachella WD), irrigation districts (e.g., Modesto ID), and Water Storage Districts (e.g., Buena Vista WSD).*
FLOW RATE VS. VOLUMETRIC ACCURACY

SBx7 requires the verification of the accuracy of annual volumes provided at delivery points.

- For devices with totalizers, it can be assumed that:
  \[
  \text{Flow rate accuracy} = \text{Volumetric accuracy}
  \]

- For devices such as meter gates and orifice plates that do not have totalizers, the flow rate accuracy may only be part of the total desired 12% volumetric accuracy. The annual volumetric accuracy of any such single turnout depends upon errors due to:
  - IFR – Instantaneous flow rate error
  - CWLF – Canal water level fluctuations, or pipeline pressure fluctuations over time. The impact of these fluctuations are mostly self-canceling over the course of an irrigation season. This is discussed later in this report.
  - CBP – Changes in “backpressure”. Backpressure is the pressure on the downstream side of the flow measurement device.
  - ARD – Accuracy of the recording of durations. For example, if an actual delivery lasts for a total of 25 hours but it is recorded and billed as a 24-hour delivery, this would be an error of one hour, or 4.2%

These inaccuracies must be mathematically combined to determine the total volumetric accuracy.

\[
\begin{align*}
\text{Volumetric accuracy} &= 100 \times \left[ 1 - \sqrt{(\text{IFR})^2 + (\text{CWLF})^2 + (\text{CBP})^2 + (\text{ARD})^2} \right]
\end{align*}
\]

For example, assume the following errors expressed as decimals rather than as percentages. These are plus/minus errors (“within 5%” means “within +/- 5%”):

- IFR is within 5% (IFR = .05)
- CWLF = .02
- CBP = .03
- ARD = .04

Then,

\[
\begin{align*}
\text{Volumetric accuracy (VA)} &= 100 \times \left[ 1 - \sqrt{(.05)^2 + (.02)^2 + (.03)^2 + (.04)^2} \right] \\
VA &= 92.7 = 93\%
\end{align*}
\]

The errors are independent of each other. Therefore, the total error does not equal the sum of the errors (14%), which would incorrectly indicate an 86% accuracy.

The maximum acceptable flow rate measurement error (expressed as a decimal) equals:

\[
\text{Max. acceptable device flow rate error} = \sqrt{(1 - \frac{VA}{100})^2 - ARD^2 - CBP^2 - CWLF^2}
\]

For example, if the required volumetric accuracy (VA) = 88% (88) (i.e., within 12%) and:

- ARD = .04
- CBP = .03
- CWLF = .02

Then, the maximum acceptable device flow rate accuracy error = 0.107 = 10.7%

That is, this specific device, when tested at a specific representative flow rate, must be within 89.3% accuracy.
IMPACT OF CANAL WATER LEVEL CHANGES ON ANNUAL VOLUMETRIC ACCURACY

Background
The volume delivered through flow measurement devices without totalizers is computed as:

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

The flow rate is typically checked once per day, and a new flow rate is either noted on the records, or the flow rate control device is re-adjusted to provide the target flow rate.

During any 24-hour period, the canal water levels will fluctuate, resulting in a delivery of more or less flow rate than was originally set.

The question addressed in this section is: Over the course of an irrigation season with ten, twenty, or thirty 24-hour irrigation events, do these minute-to-minute fluctuations cancel out? If they do, this will remove the "CWLF" (discussed in the previous section) from consideration.

To examine this, ITRC obtained water level data from multiple locations throughout San Luis Canal Company, over a time period from June 8 to July 11, 2012. Canal levels were recorded automatically on an hourly basis. The total change in water level across the turnout [(water surface in the canal) - (water surface in the downstream ditch)] was also recorded at the start of each datalogging session. The irrigation district has typical flashboard check structures to maintain water levels in the majority of its locations.

A series of 22 sites were analyzed for 48-72 hours. It is believed that these sites are representative of the range of conditions throughout the district. No special management of the check structures was involved; the canal operators were unaware that the levels were being recorded.

Error Analysis

Water Level Error Model
In order to assess the error of volumetric flow rate measurement in the canal system, first the fluctuations in water level must be computed. A model was constructed to measure the percent error of the water level over a 24-hour period from a given starting point in the sample set.

The raw data was normalized so that canal fluctuations would be represented as a percentage of the head difference. In this way, all the data points could be accumulated to create a contiguous set of hourly fluctuations for the model data set. The resulting model contains a total of 5500 hourly data points.

Sample Set
A sample set was generated from the model. The sample set contained three different blocks. Each block had 30 different seasons with varying numbers of irrigations events per season. Block 1 had 30 seasons of ten 24-hour irrigations, Block 2 had 30 seasons of twenty 24-hour irrigations, and block 3 had 30 seasons of thirty 24-hour irrigations.
The starting points for the irrigation events in each season were selected by a random number generator. The error was recorded for each hour from the starting point for a total 24 hours. Thus, each irrigation event consisted of 24 data points, resulting in a total of 21,600 data points sampled for all of the seasons in all 3 blocks.

**Results**

If the present water level for a moment during an irrigation event in the model is equal to the starting water level for that event, then the percent error at that moment is zero. The percent error at each recorded time during an irrigation is calculated by the following equation:

\[
\text{\% Error at a moment} = \frac{\text{Present Water Level} - \text{Initial Water Level}}{\text{Initial Change in Head}} \times 100
\]

Where "Initial Water Level" is the water level when the 24-hour irrigation began.

The characteristics of the population of "errors" in water level are shown in the figure below.

![Hourly % Error in Water Level During a 24-hr Irrigation vs. Frequency](image)

Figure 1. Sample distribution for hourly % error in water level vs. frequency

The variation in relative water levels over time is interesting, but of more interest is the impact on turnout flow rates. There are two possible situations, described below:

1. The flow measurement device is operated under "free flow". That is, the water jets out from it, and the flow rate through the orifice device is not affected by changing downstream water levels. The variation in flow rate over time can be computed, based solely on the upstream water level change. In this case, the sensitivity of the turnout flows to canal water levels is computed as:

   \[
   \text{Free Flow Error} = (1 + \text{Level Error})^{0.5} - 1
   \]

2. The flow measurement device operates under a "submerged" condition. In this case, what happens is that if the canal water level changes, the flow through the measurement device increases. But that also results in a rise in the downstream water level. This provides a "pressure compensating" effect. The total head change is less than the change in the canal water level. ITRC has examined a number of possible downstream channel conditions, and uses the following equation to estimate the effect of a change in canal water level:

   \[
   \text{Submerged Flow Error} = (1 + \text{Level Error})^{0.38} - 1
   \]
For each block (group of 30 randomly selected seasonal irrigation cycles), the mean and standard deviation of the error were computed. **Figure 2** shows the results of the analysis. The mean error is plotted for each block along with the standard deviations. The red bars are 1 standard deviation above the mean, and the green bars are 1 standard deviation below the mean.

![Figure 2. Means and standard deviations for each block](image)

**Conclusion**

For the condition of 10 irrigations per season, the seasonal flow rate error due to fluctuating canal water levels averages less than 0.2%, regardless of whether the turnout is free flow or submerged flow. The average seasonal error for 20-30 irrigations per season is almost 0.0%.

Because most irrigation districts deliver more than 10 irrigations per season, it appears that a reasonable estimate of the annual volumetric error due to a fluctuating canal water level is about +/- 0.5%, when one considers one standard deviation from the mean.

While this data originated in a single district, ITRC believes that the conditions are representative of "typical" canal districts, based on experiences in about 150 irrigation districts in the western U.S. The exception would be the few irrigation districts that have a very extensive distribution of long-crested weirs or ITRC flap gates throughout the canals. An extreme example would be Modesto ID, in which case almost every check structure is a long-crested weir. In that case, the seasonal impact of fluctuating canal water levels is likely 0.0%, for all practical purposes.
SELECTED OF A REPRESENTATIVE SAMPLE FOR VERIFICATION OF ACCURACY

California Legislature SBx7 requires flow measurement devices to be within a required level of accuracy. For existing flow measurement devices, the acceptable error for volumetric flow measurement is ±12% as stated in §597.3(a)(1). Initial certification of existing devices requires a random and statistically representative sample set or an accepted statistical methodology as described in §597.4(a)(1) and §597.4(b)(1). This document defines a statistical methodology that can be used to provide good information that meets both the intent of SBx7 and the needs of the irrigation districts.

Background

Representative Sample

Irrigation districts have turnouts with flow measurement devices that supply water to areas with correspondingly varying annual delivered volumes. The selection process defined below is intended to define how to select a representative sample set of flow measurement devices for verification of volumetric measurement quality in the district as whole.

In an irrigation district with a wide range of acreages downstream of flow measurement devices, a simple random selection of measurement devices would statistically over-emphasize the importance of small delivery points. The sampling may only represent a very small percentage of all the water delivered in the district. The volume delivered through a turnout is related to the size of the area irrigated. Therefore, it is better to weigh the importance of each measurement device according to the area it services, rather than weighing all turnouts equally. Thus, the sample of flow measurement devices to be tested will be constructed using a probability-proportional-to-size (PPS) sampling method so that the likelihood of inspection for a given flow measurement device will be proportional to the acreage served by that device.

Considerations for Availability

Ideally, all the devices would be randomly selected by the PPS sampling process mentioned above, and then the selected devices would be evaluated for accuracy. However, only some percentage of the turnouts will be operating at a given time. Therefore, if a turnout is selected in a purely random manner, the customer served by that turnout may not be ready to irrigate, prohibiting evaluation of the flow measurement device at that turnout. It is also clear that even if farmers are scheduled to receive water from a turnout on a specific date/time, they do not always irrigate on that schedule; this makes advance and careful scheduling of field evaluations problematic.

A solution to this is to use opportunity sampling in combination with sampling quotas. An opportunity sample is composed of samples taken as they are available or convenient. Since device availability will be an issue, devices should be inspected when they are available.

Point #1: To ensure that the data set is representative of the district’s overall volumetric flow measurement, a minimum of 10% of the district’s service area (or volume) should be represented by the combined service acreage for the turnouts in the sample set.

Point #2: To meet the SBx7 requirements, the minimum sample size of 5 and maximum of 100 for a particular device type should be evaluated.

Point #3: Two scenarios for sampling are described in this document:
- Advance Probability-Proportional-To-Size (PPS) Sampling
- Opportunity Sampling with a consideration of PPS
**Scenario 1: Acreage-Based Sampling Using Probability-Proportional-to-Size (PPS)**

Scenario 1 is the ideal situation, where at any given time all turnouts will be available for inspection.

**Background**

**Representative Sample Selection**

Flow measurement devices in a district will be assigned a number range based on the acreage (or known annual volume) that the devices serve (e.g., a turnout servicing 10 acres may be assigned 10 numbers such as 61-70). This numbering will have a logical sequencing that is appropriate for the given district. A random number generator will then be used to select a device from the developed sequence. In this way each device will be weighted in selection by the acreage it serves. Specifically, the sample will be skewed favoring devices that measure greater volumes of water. This will ensure that the random sample will be statistically representative of the overall accuracy of flow measurement within the district.

**Random Selection Process**

A random number generator will be used to select a device to be tested. If the number produced by the random number generator is within the range assigned to a device, then that device will be tested. Once a device has been tested, its range will no longer be considered in the selection process, and numbers randomly generated in its range will be ignored. This procedure will be improved from the example given in §597.4(b)(1), in that devices providing at least 10% of the district volume or acreage (rather 10% of the devices) will be tested, with a minimum of 5 devices, and not to exceed 100 individual devices of a certain type.

**Device Types**

It is important to take note of device types for this legislation. If 25% of existing devices (as estimated from the properly selected sample) of a particular type are not in compliance with ±12% accuracy requirements, the district must develop a plan to test another sample of measurement devices of this type as stated in §597.4(b)(2). This document interprets the intent of the legislation as applying to 25% of water delivered, rather than 25% of existing devices. For illustration, in the extreme case of a district with the following:

- 100 garden plots of 0.25 acres each, each with a measurement device (25 acres total)
- 50 larger fields of 80 acres each, each with a measurement device (4000 acres total)

Certainly, careful irrigation water management would not focus on the large number of very small plots that represent less than 1% of the total acreage. This document therefore assumes that the proper interpretation is to focus on reasonable measurement of at least 25% of sample water volume, rather than 25% of the sample devices.
Step 1: Assign Sequence Range Numbers to Each Turnout

Table 1 describes a sample scenario and shows a sequence range of number assignments for each turnout. The district in the sample scenario has one lateral with 10 turnouts serving a varying array of acreage.

<table>
<thead>
<tr>
<th>Turnout #</th>
<th>Acreage Served</th>
<th>Sequence Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>1-10</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>11-20</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>21-35</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>36-50</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>51-52</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>53-54</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>55-59</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>60-64</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>65-114</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>115-164</td>
</tr>
</tbody>
</table>

Each turnout is assigned sequence range numbers based on their acreage. Turnout 1 is assigned the sequence range from 1 to 10 because it has 10 acres, and Turnout 2 is similarly assigned 11 to 20. Turnout 3 is assigned a longer sequence range, from 21 to 35, because it has 15 acres. Turnouts are continued to be assigned sequence range numbers in this fashion. As a result of this sequence range numbering, each turnout will represent a portion of the total 164 acres.

Step 2: Use a Random Number Generator to Select Turnouts

Use a random number generator to choose a number between 1 and the total acreage of the district. A random number generator can be a software program or simply pulling numbers out of a hat. In the example above the random number generator would pick a number between 1 and 164. If the number produced by the random number generator is between the sequence range numbers assigned to a device, then that device will be tested.

Repeat this process until devices representing 10% of the acreage served (or volume delivered) have been selected with a minimum of 5 and a maximum of 100 per device type.

Continuing with the example data set above, assume that the first numbers selected by the random number generator were: 17, 24, 157, 156, 53, 42, 41, 36, 2, 12, and 52.

Eliminate duplicate turnouts, starting from the first random number.

With this random selection of numbers, the following turnouts are selected:

2 (selected by number 17; 12 is a duplicate)
3 (selected by number 24)
10 (selected by number 157; 156 is a duplicate)
6 (selected by number 53)
4 (selected by number 41; 41 and 36 are duplicates)

This provides the minimum number of 5 turnouts. Now, the acreage must be checked to verify that the selection represents more than 10% of the acreage (or volume).
Table 2. Example of randomly selected sample set

Green rows indicate the selected devices for the sample set

<table>
<thead>
<tr>
<th>Turnout #</th>
<th>Acreage Served</th>
<th>Sequence Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acres</td>
<td>% of Total</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>6%</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>30%</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>164</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

The five turnout samples represent 55% of the total acreage.

Therefore, this sample set meets the criteria of:
- greater than or equal to 10% of the acreage, and
- a minimum of 5 turnouts of a particular type - assuming all are the same device.

Note: If there is more than one device, this process would be repeated by device. The final criteria to be met are:
- Including all device sample sets, at least 10% of the district acreage (or volume) must be accounted for.
- A minimum of 5 turnouts of a particular device, for each device.
- No more than 100 of any particular device.

**Step 3: Evaluate Selected Turnouts and Record Data**

Once the turnouts have been selected, evaluate each flow measurement device for accuracy. Record gate type, total acreage serviced by the device, and measured accuracy. This data will need to be retained for ten years or two Agricultural Water Management Plan Cycles as per 597.4(c).

To continue the example, Table 3 shows how data should be recorded for the example district. For simplicity, it is assumed that all devices are meter gates.

Table 3. Sample data collection for selected turnouts

Red rows indicate devices that do not meet the required standard

<table>
<thead>
<tr>
<th>Turnout #</th>
<th>Device Type</th>
<th>Acreage Served</th>
<th>Flow Accuracy Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Meter Gate</td>
<td>10</td>
<td>15%</td>
</tr>
<tr>
<td>3</td>
<td>Meter Gate</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>4</td>
<td>Meter Gate</td>
<td>15</td>
<td>6%</td>
</tr>
<tr>
<td>6</td>
<td>Meter Gate</td>
<td>2</td>
<td>8%</td>
</tr>
<tr>
<td>10</td>
<td>Meter Gate</td>
<td>50</td>
<td>4%</td>
</tr>
</tbody>
</table>

Total acreage sampled: 92
Step 4: Determination of Compliance

SBx7 requires an annual volumetric accuracy of within 12% on existing devices. Table 3 addresses flow rate accuracy, not volumetric accuracy.

If 25% or more of the sampled area for a particular device type exceeds the 12% annual volumetric allowable error, then a second round of testing must be conducted. This second round of testing should be conducted in the same manner as the first, but only for the device type(s) that did not meet the required accuracy standard.

Compliance of this particular example. Table 3 is repeated below for illustration.

<table>
<thead>
<tr>
<th>Turnout #</th>
<th>Device Type</th>
<th>Acreage Served</th>
<th>Flow Accuracy error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Meter Gate</td>
<td>10</td>
<td>15%</td>
</tr>
<tr>
<td>3</td>
<td>Meter Gate</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>4</td>
<td>Meter Gate</td>
<td>15</td>
<td>6%</td>
</tr>
<tr>
<td>6</td>
<td>Meter Gate</td>
<td>2</td>
<td>8%</td>
</tr>
<tr>
<td>10</td>
<td>Meter Gate</td>
<td>50</td>
<td>4%</td>
</tr>
</tbody>
</table>

Total acreage sampled: 92

Assuming that the minimum required flow rate accuracy is 10.7% (using the example), then only one turnout measurement device does not meet the requirement. No re-testing is needed, because:

1. Ninety-two acres were tested out of the total 164 acres. This is much greater than the 10% sample size required.
2. Five devices were sampled, which meets the minimum because all devices are of the same basic design.
3. The one device with greater than 10.7% error only represents 10 acres, which is 11% of the acreage sampled. This is below the allowable 25%.
Scenario 2: Limited Availability of Turnouts and Opportunity Sampling

Turnouts may not be available for inspection due to fluctuations in irrigation scheduling. Therefore, opportunity sample can be used to select devices to be evaluated. As opposed to the PPS random sample set, this sample will be based on availability and service size rather than a weighted random sampling.

Background

Representative Sample Selection

To ensure the sample is representative of the district as a whole, evaluators need to ensure that the area serviced by the devices evaluated is at least 10% of the district’s entire area. Furthermore, when given a choice between devices of equal convenience, devices servicing a larger acreage should be given priority for inspection. Additionally, a minimum of 5 devices must be inspected. In this way each device will be weighted in selection by the acreage it serves. Specifically, the sample will be skewed favoring devices that measure greater volumes of water. This will ensure that the opportunity sample will be statistically representative of the overall accuracy of flow measurement within the district.

Selection Process

Devices will be selected as they are available to be tested. Priority for evaluation will be given to devices that service greater acreage. Once a device has been tested, it will no longer be considered in the selection process. A minimum of 5 devices will be tested, and all evaluated devices (summation of all types) will service a combined 10% of the district’s total area (or delivered volume), not to exceed 100 individual devices of a certain type.

Step 1: Choose a Currently Available Turnout

Select a turnout that is available for testing based on the size of the turnout, giving priority to turnouts that serve greater acreage. Do not test the same device more than once. Table 4 shows an example of the selection process for two days. On the first day Turnout 10 serves the largest acreage out of the available turnouts. On day two, Turnout 5 is chosen because it serves the largest area and has not yet been tested. The district in this example has one canal lateral with 10 turnouts, and the turnouts have limited availability for testing.

Table 4. Device selection on two separate days

Green rows indicate the selected turnout. Grey rows indicate a turnout that has been tested.

<table>
<thead>
<tr>
<th>Turnout #</th>
<th>Currently Available</th>
<th>Acreage Served</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>yes</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>yes</td>
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</tr>
<tr>
<td>3</td>
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<td>9</td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
<td>5</td>
<td>no</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
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<td>1</td>
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<tr>
<td>7</td>
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<td>1</td>
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<td>50</td>
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<td>10</td>
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<td>50</td>
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Day 2

<table>
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<tr>
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<th>Acreage Served</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>no</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>yes</td>
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<tr>
<td>3</td>
<td>no</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>yes</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>yes</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>no</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>yes</td>
<td>1</td>
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<tr>
<td>8</td>
<td>yes</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>no</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>yes</td>
<td>50</td>
</tr>
</tbody>
</table>

Continue testing devices until the following criteria have been met:

- At least 10% of the total district acreage is serviced by the devices tested
- At least 5 devices have been tested
- Test no more than 100 devices of a particular type

Steps 2–4: Follow the Previous Scenario Instructions
FLOW MEASUREMENT DEVICES

Background
This section is intended to provide useful information on several common flow measurement devices that might be considered for traditional, non-pressurized turnouts. Often, the problems with some of the devices (meter gates, orifice plates, and propeller meters) are largely associated with improper measurement, or improper installation or maintenance. If properly designed and maintained, all three of these measurement devices will generally fall well within required SBx7 requirements.

Meter Gates
Meter gates are one of the most common devices used in California irrigation districts to both measure and control flow rates. There is no doubt that many of these devices provide accurate results. However, as with all devices, certain rules must be followed. Typical physical inaccuracies associated with meter gates include:

1. Incorrect “zero” measurement of gate opening, as determined by the vertical movement of the threaded shaft.
   a. There are four primary reasons operators might measure the opening from an incorrect "zero" mark on the threaded shaft:
      i. The zero point is affected by "slop" in the connection between the shaft and the gate plate.
      ii. Wedges are used to force the plate against the gate frame during gate closure. These wedges are often adjusted in the field, so there is no standard stopping distance (vertically) for the plate.
      iii. When the plate begins to move, it may overlap the opening (by 0.5 - 2"). Although water may begin to leak as the plate moves out of the wedge constraint, the true zero is the opening at which the bottom of the plate is exactly at the bottom of the frame opening.
      iv. The "zero" point should always be determined while the gate is being raised.
   b. Once the zero point is known, a notch should be scribed into the shaft to note the location of the zero mark. Then the gate opening should always be measured as the gate is being opened, rather than being closed.

2. Incorrect downstream water level measurement.
   a. The stilling well must be placed over a full pipe, at a specific distance downstream of the meter gate.
   b. Many existing stilling wells were actually designed to be air vents, and have such a small diameter that there is constant surging. A large diameter stilling well, fed by a relatively small access hole at its bottom (about 1/6th the diameter of the stilling well), is needed to "still" the water surface so it can be measured downstream of the gate. The problem with a small access hole is that it can plug up easily. A good combination is a 2" access hole (connecting the stilling well to the top of the pipe) and a 12" stilling well.
   c. The pipe must be full at all flow rates. This may require the placement of a small obstruction downstream, in the pipe, similar to what is done with well pump discharges to keep propeller meters full. Various entities, including ITRC, have successfully designed side contractions in pipes to create "Replogle flumes" that have very little loss, and that pass bottom loads of silt. Something similar could be used downstream of the meter gates.
Another technique used in some districts to maintain a submerged condition on a gate is to install "bumps" in the bottom of a canal or ditch downstream of the turnout. These should be permanent "bumps" which, at low flows, will keep the water level high. The rule for building these "bumps" is:

Build up the restriction from the bottom of the ditch/canal so that at high flow rates, the upstream water surface (relative to the bump) is only raised by about 0.1' or less. In other words, its presence will hardly be noticeable.

If farmers move downstream in their canal, setting siphons at a different place, this "bump" will keep the backpressure on the meter gate almost constant, and minimize the flow rate change that would normally occur.

3. **Incorrect gate opening geometry.** Since the plate has a larger outside diameter than the inside diameter of the pipe, the ratio of the open area between the two openings must be taken into account. Almost everyone uses tables that were developed decades ago. ITRC is not certain if the gate dimensions have changed since then, or if different manufacturers use different gate dimensions. ITRC is planning to verify this in the future.

4. **Non-standard entrance and exit conditions.** The flow rate is associated with a measured opening and head loss. The head loss will be different (at the same flow rate) with different entrance conditions. Various manuals, such as the USBR Flow Measurement Manual, provide recommended dimensions.
Orifice Plates

The following is an explanation of the characteristics of a submerged (on both sides) rectangular orifice plate.

According to the U.S. Bureau of Reclamation *Water Measurement Manual*, conditions for achieving accurate flow measurement of ± 2% for a fully contracted submerged rectangular orifice are:

- The upstream edges of the orifice should be straight, sharp, and smooth.
- The upstream face and the sides of the orifice opening need to be vertical.
- The top and bottom edges of the orifice opening need to be level.
- Any fasteners present on the upstream side of the orifice plate and the bulkhead must be countersunk.
- The face of the orifice plate must be clean of grease and oil.
- The thickness of the orifice plate perimeter should be between 0.03 and 0.08 inches. Thicker plates would need to have the downstream side edge chamfered at an angle of at least 45 degrees.
- Flow edges of the plate require machining or filing perpendicular to the upstream face to remove burrs or scratches and should not be smoothed off with abrasives.
- For submerged flow, the differential in head should be at least 0.2 feet.
- Using the dimensions depicted in Figure 4 below, P > 2Y, Z > 2Y, and M > 2Y

The equation for determining the flow through a submerged orifice plate is:

\[ Q = C_d A \sqrt{2 g \Delta h} \]

Where:
- \( Q \) = Flow Rate, CFS
- \( C_d \) = Coefficient of Discharge, 0.61
- \( A \) = Area of the orifice, ft\(^2\)
  \[ A = W \times Y \]
- \( W \) = Orifice opening width, ft
- \( Y \) = Orifice opening height, ft
- \( g \) = Acceleration due to gravity, 32.2 ft/s\(^2\)
- \( \Delta h \) = Change in head, ft

**Figure 4. Flow through a submerged orifice plate**

For a sharp-edged rectangular orifice where full contraction occurs from every side of the orifice, the coefficient of discharge is 0.61.
It is recommended that “Y” be smaller than “W”, so that a good depth “Z” can be maintained. This helps keep the orifice entrance submerged all the time regardless of upstream water level fluctuations, and also provides for the proper entrance conditions.

It is assumed that the flow control gate will be located downstream of the orifice plate. The particular dimensions of that gate would rarely influence the performance of an orifice plate.

Typical problems include:

1. Inaccurate measurement of the difference in head.
   
   **Solution:**
   
   a. Careful relative calibration of pressure transducers, if used. They do not need to read a correct "elevation", but at zero flow rate must read the same "elevation".
   
   b. Install a horizontal reference steel plate on a bulkhead wall, so operators use the same reference elevation for both measurements if they manually measure the head difference.

2. The distances P, Z, or M are not greater than 2 times the smallest opening dimension (usually “Y”). In reality, it is rare that this "2 times" criteria is met in irrigation districts, except with very small flows.
   
   **Solution:**
   
   a. If only one side is suppressed (typically the bottom entrance, which might have no convergence), adjust the discharge coefficient, C_d as follows:

<table>
<thead>
<tr>
<th>W/Y</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_d</td>
<td>0.63</td>
<td>0.64</td>
<td>0.65</td>
</tr>
</tbody>
</table>

   b. We do not know exactly how much to adjust the C_d if the distances P, Z, or M are less than two times the smallest opening dimension. Therefore, it is recommended that the orifice be installed in a plate that is wide enough and tall enough to approximately meet those required distances – even if the plate must be extended beyond the inlet to the turnout. See the figure below.

![Figure 5. Installation of orifice](image-url)
3. A single orifice size has a limited flow rate range. This is illustrated in the tables below. At too low a flow rate, the measured head difference is very small, often resulting in major errors in head difference. At too high a flow rate, the measured head difference is excessive, and may well exceed the available head. For this reason, it is common to have a moveable plate that can be adjusted up and down, varying the "Y" dimension.

The addition of the moveable plate (often a rectangular sluice gate) creates the commonly known "CHO" or "constant head orifice". The device certainly does not create a "constant head", but it does provide an adjustable orifice. It provides the flexibility needed for a turnout to supply different flows at different times, with reasonably accurate head measurements. The opening should be adjusted so that the minimum head difference is greater than 0.2'. A 1' head loss across the orifice plate is more than what is attainable in many California irrigation district turnouts.

Table 5. Orifice size values

<table>
<thead>
<tr>
<th>Width of Orifice Opening, ft</th>
<th>Height of Orifice Opening, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Change in Head, ft</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Flow Rate, CFS

<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>5.0</th>
<th>4.5</th>
<th>4.0</th>
<th>3.5</th>
<th>3.0</th>
<th>2.5</th>
<th>2.0</th>
<th>1.5</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Head, ft</td>
<td>1.0</td>
<td>1.0</td>
<td>0.8</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>1.5</th>
<th>1.0</th>
<th>0.8</th>
<th>1.0</th>
<th>1.2</th>
<th>1.4</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Head, ft</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>6.0</th>
<th>5.0</th>
<th>4.5</th>
<th>4.0</th>
<th>3.5</th>
<th>3.0</th>
<th>2.5</th>
<th>2.0</th>
<th>1.5</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Head, ft</td>
<td>1.0</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>1.1</th>
<th>1.0</th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
<th>0.4</th>
<th>0.3</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Head, ft</td>
<td>1.0</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>1.0</th>
<th>0.5</th>
<th>0.3</th>
<th>0.2</th>
<th>0.1</th>
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</thead>
<tbody>
<tr>
<td>Change in Head, ft</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
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</tr>
</tbody>
</table>
If steel theft is a concern, a marine plywood frame could be used to support a steel orifice opening frame. Fasteners used to connect the steel orifice to the plywood frame would need to be countersunk to minimize debris getting caught on them.

<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>Width of Orifice Opening, ft</th>
<th>Change in Head, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>0.6</td>
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<td>20.0</td>
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<td></td>
<td>0.8</td>
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<tr>
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<td>1.0</td>
<td>0.7</td>
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<tr>
<td>7.0</td>
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<tr>
<td>5.0</td>
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<tr>
<td>4.5</td>
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<tr>
<td>3.5</td>
<td>0.5</td>
<td>0.4</td>
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<table>
<thead>
<tr>
<th>Flow Rate, CFS</th>
<th>Width of Orifice Opening, ft</th>
<th>Change in Head, ft</th>
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<tr>
<td></td>
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</table>

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**Trash Shedding Propeller Meters**

For several decades there has been interest in "trash shedding propeller meters". ITRC examined the "cloggability" of an early design about 20 years ago. Boat propellers are sold with "weed shedding" features, which include specially designed propellers as well as fixed vanes upstream of the propeller that are intended to pass the weeds below or to the side of the boat propeller. McCrometer sells a saddle meter with the trash shedding options.
McCrometer will also mount a reverse-facing propeller on a standard open flow meter, which can be mounted on stands above low pressure pipelines.

A commercially available package that includes a reverse propeller meter and trash-shedding fixed vane, plus flow straighteners, is available from RSA.
Rubicon Transit Time Flow Meter

The Rubicon Sonaray flow meter is an interesting addition for larger turnouts with a canal supply, in that it also has a totalizer. The Rubicon literature cites a flow test in California, but it is unclear if the magmeter used for flow rate verification was recently calibrated. ITRC has found that new magmeters with guaranteed accuracies can be off by several percentage points. The device appears to be new, without substantial field testing in the USA.

![Rubicon Sonaray flow meter](image-url)