

OFFICE MEMO

TO: Watermasters	DATE: January 1, 2010
FROM: Shawn Pike Senior Engineer Chief, Watermaster Service Section	SUBJECT: Department of Water Resources Watermaster Service Section Flow Measurement, Selection of Devices, Weir Considerations, Recommendations

INTRODUCTION

This memorandum discusses flow measurement by the Department of Water Resources, Northern District Watermaster Service. Subjects covered include:

- Watermaster experience
- Flow measurement at weirs
- Practical considerations of flow measurement device selection
- Economics of flow measurement devices
- Evaluation of installed flow devices
- Response to the Department of Fish and Game (DFG) memo of October 20, 2008
- Recommendations



Shasta Valley, Siskiyou County



**Eddy Creek Diversion No. 12 weir,
Siskiyou County, installed 2005**

Purpose and Benefits

The purpose of watermaster service is to distribute water according to established water rights. This is done by apportioning the available supplies in streams to the rightful users. This service is only provided to water users who are in a Watermaster Service Area (WMSA) and under watermaster service.

Distribution of water in watermaster service areas is the duty of the Department of Water Resources (DWR) as directed in Division 2, Part 4, Chapter 7 of the California Water Code (CWC). Under watermaster service, water right holders are assured that their rights are protected without having to take legal action against other water users.

One benefit of watermaster service to water users and the State is that litigation and violent conflict over water issues are rare. Also, available supplies of water are better used, as waste is reduced through careful management.

Although this work is done efficiently, considerable public funds are used to augment watermaster service during the decreed irrigation season and to maintain administrative support. Most clients find that the benefits of watermaster service include fairness, reliability, and reduced anxiety. This service is superior in comparison to being without State Watermaster Service.

Determination of Water Rights

Many of the streams under State Watermaster Service have had their water rights defined by the courts under one of three adjudication procedures. These judgments establish each water right holder's rights in terms of rate of source, rate of diversion, season of use, point of diversion, and place of use. They also establish priorities where each person's water rights are ranked according to the rights of all other decreed water right holders. Under this system, all rights of any one priority must be satisfied before water can be diverted to the owners of lower priority rights. The determinations of the courts are called decrees.

Water rights decisions necessary for establishing WMSAs are accomplished by the following methods: (1) a statutory adjudication which defines all water rights on the stream; (2) a court adjudication which results when two or more parties have their water rights defined; or (3) a court reference where the State Water Resources Control Board makes an investigation and reports to the court regarding water rights of the parties involved.

DWR Authority to Regulate Flows in Watermaster Service Areas

DWR regulates adjudicated, permitted and licensed flows within WMSAs. WMSAs are created by order of the Director of DWR, per CWC Sections 4025 – 4032. "Director" and "Department" are defined in Sections 22 – 23:

22. "Department," unless otherwise specified, means the Department of Water Resources.

23. "Director," unless otherwise specified, means the Director of Water Resources.

Water right holders are required to install dams, headgates and measurement devices to the satisfaction of DWR, per the following CWC Sections 4100 – 4104:

4100. The owner of every conduit subject to regulation by a watermaster shall construct and maintain to the satisfaction of the department a substantial and serviceable diversion dam or works in the channel of the stream from which the water is diverted.

4101. The owner of a conduit shall construct and maintain to the satisfaction of the department a substantial and serviceable headgate in the conduit through which the water is diverted at or near the diversion dam or works.

4102. The headgate shall be of such construction that it can be locked and kept closed by the watermaster.

4103. The owner of a conduit shall construct and maintain such water flow measuring devices at such points along the conduit as may be required and approved by the department for the purpose of assisting the watermaster in determining the amounts of water which are being diverted and applied to beneficial use.

4104. If the owner of any conduit refuses or neglects to construct and maintain the diversion dam or works, the headgate, or the measuring devices provided for in this article after 30 days' notice by the department so to do, the watermaster may close the conduit, and it shall not be opened or any water diverted from the source of supply until the requirements of the department as to the diversion dam or works, the headgate, or the measuring devices have been complied with.

DWR WATERMASTER SERVICE

DWR Watermaster Experience

The first WMSAs were created by the predecessor to DWR, the Division of Water Resources, in September 1929. Before then, some watermaster service was provided in accordance with the Water Commission Act of 1913. There are eleven WMSAs in Northern California regulated by DWR, including the Napa River Watermaster Service Area established in 2008.

Watermasters receive training in order to do their work. This training includes:

- Water Resources Engineering Technology, an 80-hour class taught by experts in DWR and including all aspects of technical work with precipitation, runoff, flow measurement, irrigation, and structure and system design
- DWR surface water flow measurement class (24 hours)
- Vendor-led classes for various flow measurement devices including pre-built flumes, Price Meters, SonTek Flow Trackers, and gaging station components
- Field training by experienced, registered DWR engineers within and outside the Watermaster Service Section

Currently there are over 80 years of combined watermaster and flow measurement experience among assigned watermasters. This experience includes:

- Flow measurement in open channels using a variety of devices including Price meters, electronic Flow Trackers, weirs, orifices, in-line meters, flumes and stream gages
- Calibration of in-place flow measurement devices
- Real-world, non-laboratory operation of large to small diversions with problems including:
 - Varying flows
 - Debris
 - Sediment (gravel, sand and mud)
 - Changing stream channels
- Adjustment of diverted flows to stop diversions that result in nonbeneficial use (e.g., flows that do not reach decreed lands)
- Adjustment of diverted flows to account for total volumes diverted, diurnal fluctuations, and operational changes (haying, flooding, rotation, etc.)
- Design, construction, operation, maintenance, repair, evaluation and replacement of headgates and measurement devices
- Use and application of the USBR Water Measurement Manual, King's Handbook of Hydraulics, various manufacturers' manuals for hydraulic structures, headgates, flow measurement devices, etc.
- Supervision at Senior and Supervising level by a Professional (registered) Engineer

One current watermaster, Keith Dick, has 30 years of experience in various WMSAs and is still assisting on the Shasta River.

Measurement of Head at Weirs in WMSAs

Watermasters measure the head over weirs in one of three ways. The first is to install a staff gage in the weir box at the specified distance upstream of the weir flashboards. The second is to use a stilling well at the specified distance upstream. The third is to use a weir stick. Because watermasters install different weir flashboards as flow conditions change, it is usually most convenient and accurate to use weir sticks. Weir sticks are described in the USBR Water Measurement Manual, 3rd Edition, 2001, Page 13-4:

9. Weir Sticks

Weir sticks are commercially calibrated stick or staff gage type devices which may be placed by hand upon the crest of a weir. In principle, the sticks show depth of flow plus velocity head or the runup of water above the water surface at the weir blade. This device gives an indication of the head that would have been measured at conventional weir measurement stations. Readings are taken at the top of the runup of water to indicate the rate of flow. Some sticks contain a piezometer and manometer to average the pulsations in the head reading. Turning the stick to an angle will not improve accuracy unless the stick has been calibrated in this position.

At best, the sticks can only approximate the potential accuracy of weirs when head is carefully measured in the normal manner. Weir sticks are designed to measure unit discharge along the crest of rectangular suppressed weirs. Thus, the gage indicates the discharge per unit length of weir. The design intent was to make weir measurements simpler without need for staff gage zero setting. Also, poor distribution of velocity of approach at the crest could be accounted for by multiple stick measurements and averaging along the crest because the weir stick measures the depth on the crest and the corresponding velocity head. Thus, they compensate for velocity of approach, such as caused by sediment deposits ahead of the weir blade.

In addition, the Irrigation Training and Research Center (ITRC) at California Polytechnic State University (Cal Poly) evaluates and reports on flow measurement devices. ITRC Report No. R 03-008 (ITRC Weir Stick) discusses the modern use of weir sticks to measure the flow over sharp-crested and flashboard weirs. The report recommends the use of the weir sticks and recommends an adjusted-scale "ITRC weir stick". However, the physics and measurement techniques of this and conventionally scaled weir sticks are the same.

Over the years, watermasters have checked head elevations obtained by weir sticks against upstream staff gages and stilling wells. Our findings have been that weir stick measurements are almost always the same as upstream measurements, with no difference to the hundredth of a foot (0.00 feet). The net result is that the same flows are determined whether heads are measured upstream or at the weir flashboards.

Practical Considerations

Measurement devices have a useful life lasting from two to 50 years. In rare cases, extreme flood events have destroyed devices soon after they were constructed, as large boulders and debris have moved swiftly downstream. On the other hand, well-built concrete structures in locations with little or no sediment movement have lasted half a century. Whatever the lifespan, devices eventually wear out and have to be repaired. Eventually, devices have to be replaced because of one or more of the following factors:

- movement of sediment and debris wearing or breaking concrete,
- cracking due to heat and cold (expansion/contraction) cycles,
- concrete spalling (pieces breaking off) due to impact,
- undermining causing breakage, tilting or collapse due to inadequate base material compaction, removal of fines, and rodent burrowing,
- backwater submerging the device, caused by sedimentation and/or vegetation accumulation in the ditch downstream of the device, and
- chemical wear.

Watermasters have found that the more expensive and time-consuming the installation of a measuring device, the harder it is to get agreement and cooperation from the landowner and/or water right holder to install the device. This is aggravated by the history of watermaster service in that many expensive flumes were installed by water right holders with State help 50 to 60 years ago. These have nearly all worn out and

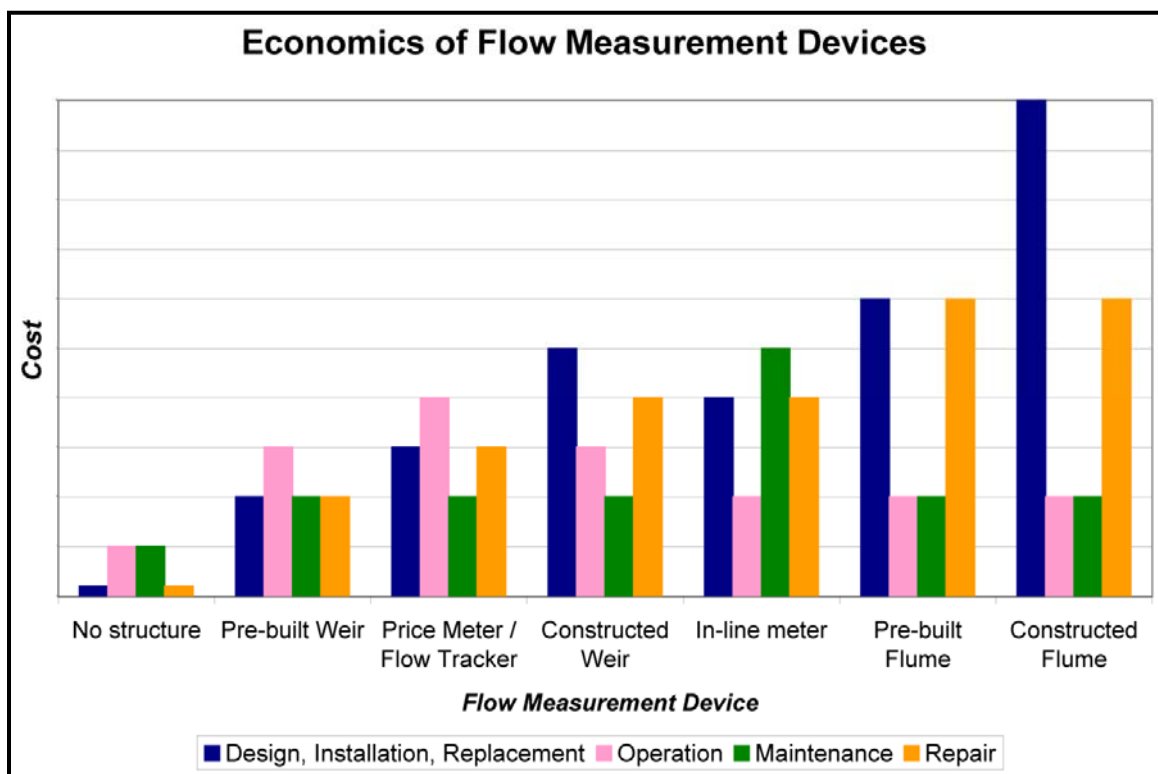
need to be replaced. Water right holders are very resistant to constructing new, expensive versions of the old devices for several good reasons:

- Devices may cost proportionately more because permits may be required.
- Many large ranches have been subdivided and it is considerably harder to organize construction with and obtain payment from multiple parties.
- Most water right holders have little expertise in this kind of construction.
- Younger landowners often prefer a modular or pre-built option of known cost.

Economics of Flow Measurement Devices

DWR watermasters have assisted water right holders with installation and have operated a variety of structures over the last eight decades. Selection of an appropriate flow measurement device must consider the costs of design, installation, replacement, operation, maintenance and repair.

The following chart shows the relative costs that the watermaster service and water right holders have experienced for various devices. The chart shows that pre-built weirs are the least expensive to install and repair. Flumes are the least expensive to operate, but are the most expensive to design and construct or install. Watermasters consider these facts when convincing water right holders to install devices.



Watermasters keep the USBR Water Measurement Manual with them and refer to it often while performing flow measurements and checking the operation of devices. In addition, watermasters review documents on the Internet to check measurement procedures.

Evaluation of Installed Flow Measurement Devices

Watermasters perform field testing of the operation of flow measurement devices. This testing includes:

- Checks of device integrity (wall smoothness, level, location in flow path, elevation, available head, etc.)
- Operating range of head for weirs (minimum of 0.25 feet on weir for flashboard weirs, 0.7 feet total elevation difference from upstream pool to downstream pool)
- Checks for submergence and adequate upstream water elevation of flumes, which are the devices most subject to error caused by submergence from backwater
- Checks for seepage under or around devices
- Sealing of gaps around and between flashboards
- Level of installed weir flashboards

There are many potential sources of error when designing, installing or operating flow measurement devices. All measurements of flow have errors and it is the watermaster's job to recognize and minimize errors.

Weir Considerations

DWR has heard some objections to the use of weirs as flow measurement devices:

1. Weir flashboards are leaky.
2. The 1.5 inch (milled 2 inch lumber) flashboards are too wide.
3. The nappe is not properly aerated in suppressed weirs.
4. The head is not measured properly.
5. Errors in flow measurement delivers more water than calculated to water right holders.

These objections do not apply to DWR Watermaster Service use of weirs, for the following reasons:

1. Watermasters always seal leaky flashboards with sediment, horse manure if available, and if necessary, sheet plastic. Watermasters are trained in these techniques from the first day in the field. Newer flashboards are used, and may be trimmed on site to reduce gaps prior to use.
2. Use of 1.5 inch flashboards rather than sheet or plate metal for sharp edges provides no practical or measurable error in measured flows, provided that the head on the weir is great enough to cause separation of the water from the upstream edge of the flashboard. The minimum required head has been calculated by the watermaster to be around 0.25 feet.

As an example, DWR watermasters compared the use of flashboards to sharp-crested weirs on November 20, 2008, as they have done several times in the past. Differences were recorded and weirs with flashboards had calculated flows that were both slightly less and slightly more than the flows calculated from sharp-edged weirs. Any difference is well below the margin of error when taking into account all possible errors. In summary, 1.5-inch flashboards provide results indistinguishable from sharp-crested weirs for the use of measuring diverted flows.

3. DWR designed the Briggs-manufactured “rice boxes” with two flashboard slots. The upstream flashboard slot holds the nominal 2-inch wide weir flashboards. The downstream slot provides the air gap, as specified in the USBR Water Measurement Manual, 3rd Edition, 2001, in Figure 7-8 on Page 7-13.
4. DWR measures weir heads with weir sticks, as specified in the USBR Water Measurement Manual, 3rd Edition, 2001, on Page 13-4. DWR has checked the use of weir sticks numerous times and found the difference between the head measured with a weir stick and that at a staff gage nearly always to be 0.00 feet.
5. DWR delivers flow up to the legal diversion amount to the head of the ditch to water right holders. The amount delivered may occasionally be somewhat more than the water right as streamflows vary due to diurnal fluctuation, changes in upstream diversions, and from increased flows due to storm events. However, more than half the time when flows are not at the legal amount, they are reduced or are shut off completely. The reasons include the following:
 - a. If diverted flows are insufficient to reach adjudicated lands, then this is not beneficial use of water and the watermaster shuts off the diversion.
 - b. Floating debris sometimes accumulates on the upstream side of a diversion headgate, reducing flow.
 - c. Water right holders who grow hay shut off their diversions to cut, dry, bale and haul hay for several days, reducing their total volume of diversion.
 - d. Irrigation season damage to ditches requires diversions to be reduced or stopped during repairs.
 - e. Weed growth or sediment in the ditch reduces the hydraulic capacity of ditches.

Recommendations

1. Water right holders and other agencies should work with the DWR Watermaster to plan, design, install, repair or replace flow measurement devices. The CWC specifies that flow measurement devices must be maintained “to the satisfaction of the Department.” Water right holders risk rejection of a device installation if they or an agency install an inadequate device.
2. If another agency has any question about DWR procedures, then management or staff needs to ask DWR questions about the procedures. The answers may be readily known.
3. Agencies other than DWR should not advise water right holders on diverted flows, diversion works, headgates or measurement devices, except for dams over which such agencies may have jurisdiction.
4. DWR will continue to use pre-built weirs as well as other flow measurement devices most of the time because of the following factors:
 - Weirs are usually the least expensive device to design and install.
 - Weirs are easy to operate.
 - Weirs can accurately measure a range of flows from the design flow down to very low flows (with a flashboard cut to serve as a contracted weir).
 - Weirs are easy to maintain.
 - Flashboard weirs can be easily adjusted to accommodate sedimentation caused by backwater, or vegetation growth in the ditch downstream of the weir.

- Weir flashboards can be removed after the irrigation season so that the full conveyance capacity can be maintained. Many ditches also convey high flows during storm events.
- Weirs provide the best opportunity to obtain landowner cooperation leading to water right holders complying with the CWC.