FLOW MEASUREMENT CAPABILITIES OF DIVERSION WORKS IN THE RIO GRANDE PROJECT AREA

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ABSTRACT

Releases from Rio Grande Project storage are made on demand by the U.S. Bureau of Reclamation for diversion into Elephant Butte Irrigation District (EBID), El Paso County Water Improvement District No.1, and Republic of Mexico canals and laterals. The diversions are charged against each district and Mexico's annual diversion allocation. As the Rio Grande Project implements and refines new operating procedures and the State of New Mexico continues efforts to implement Active Water Resource Management in the Lower Rio Grande, it is essential to have a high degree of confidence in the measurements of the water diverted from the Rio Grande.

With this mission in mind, the New Mexico Interstate Stream Commission (NMISC) initiated a study to evaluate the Rio Grande Project diversion works, flow measurement facilities, and flow measurement methodologies in the Rincon and Mesilla Valley portions of the Rio Grande Project. More specifically, the NMISC was interested in understanding the measurement accuracy limitations presented by the diversion structures themselves, and whether improvements to those structures and/or methods could improve measurement accuracy. WEST Consultants, Inc. (WEST) evaluated flow measurement techniques at Elephant Butte Dam, Caballo Dam, Percha Diversion Dam, Arrey Main Canal, Leasburg Diversion Dam, Leasburg Canal, Mesilla Diversion Dam, the East Side Canal, the West Side Canal, and the Del Rio Lateral. EBID is making a significant effort to accurately measure flows despite the advanced age of many of the structures in the Rio Grande Project. All measurements in these areas were made following typical protocols and standards.

This paper outlines the accuracy estimations, describes the flow measurement techniques used and analyses conducted, and provides suggestions for improving the flow measurements in some difficult locations.

INTRODUCTION AND BACKGROUND

Up until the 1980s, the Rio Grande Project was operated as a single project and was not concerned with state boundaries (i.e., determining the amount of water diverted by each state was not important). Now, releases from Rio Grande Project storage at Caballo Dam are made on demand by the U.S. Bureau of Reclamation for diversion into Elephant Butte Irrigation District (EBID), El Paso County Water Improvement District No.1, and Republic of Mexico canals and laterals. The diversions are charged against each district and Mexico's annual diversion allocation. As the Rio Grande Project implements and refines new operating procedures and the State of New Mexico continues efforts to

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implement Active Water Resource Management in the Lower Rio Grande, it is essential to have a high degree of confidence in the measurements of the water diverted from the Rio Grande. Allowable groundwater diversions are a function of annual surface water allocations made by the U.S. Bureau of Reclamation (USBR), and calculation of a comprehensive Lower Rio Grande water budget for administrative purposes necessarily depends on accurate diversion data for both surface water and groundwater.

Personnel from WEST and NMISC inspected the diversion works, flow measurement facilities, and flow measurement methodologies in the Rincon and Mesilla Valleys. WEST assessed the current flow measurement methodologies used at various sites and made suggestions to improve the measurements. A field visit was conducted on June 8-9, 2006. The site visit started at Elephant Butte Dam and preceded downstream to Caballo Dam, Percha Diversion Dam, Leasburg Diversion Dam, and Mesilla Diversion Dam (see Figure 1).

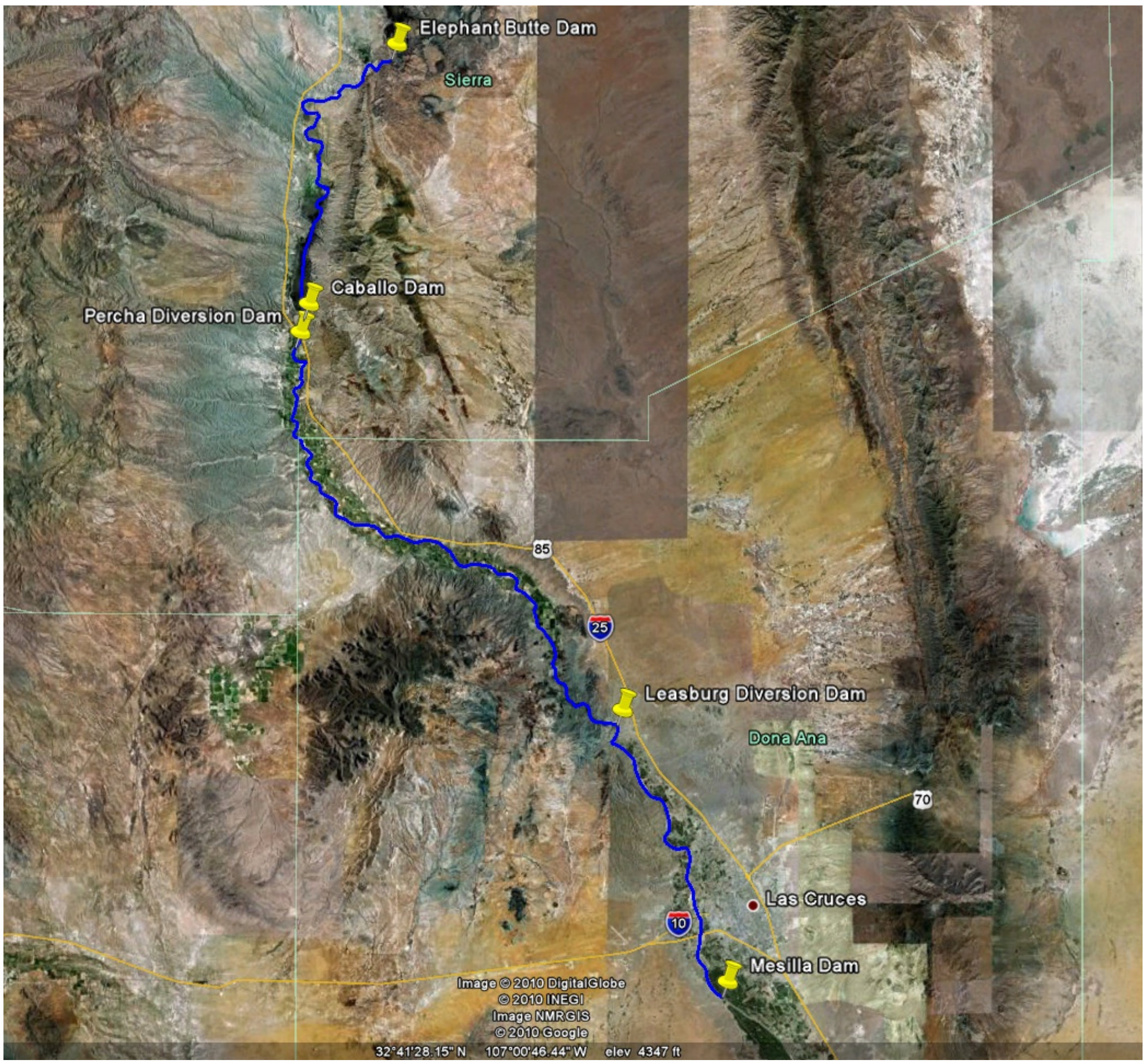

Figure 1. Project location map

ELEPHANT BUTTE DAM

The Elephant Butte Dam (originally called Engle Dam) is on the Rio Grande River, 125 miles north of El Paso, Texas. A concrete gravity dam, it is 301 feet high, 1,674 feet long (including the spillway), and contains 618,785 cubic yards of concrete. It was completed in 1916, but storage operations began in 1915. The resulting Elephant Butte Reservoir can store up to 2,210,000 acre-feet of water to provide irrigation supply and year-round power generation.

Flow is measured downstream of Elephant Butte Dam at the Rio Grande Below Elephant Butte Dam, NM stream gaging site (ID 08361000) that is operated and maintained by the U.S. Geological Survey (USGS). This gage has been in operation since 1916. A measurement is performed once every two weeks when releases are made from Elephant Butte Dam. While a stream gage measurement is being performed, flows are also measured using the sluice gates (it was not possible to observe these sluice gates during the field visit). The flow measured by the sluice gates and the stream gaging typically agree with each other. However, there can be additional releases from Elephant Butte Dam that are not passed through the sluice gates. In these cases, the two measurements do not agree.

The Elephant Butte stream gaging site appears to be in a very good location for maximizing measurement accuracy (see Figure 3). The approach channel is straight and there is no noticeable debris to obstruct the flow. The cobbled canal bed is relatively smooth and stable. The only problem with this site is that weeds often become entangled with the current meter (see Figure 2) and must be removed by hand. The USGS uses a 3-foot vertical spacing when performing the stream gaging and start their verticals 6 feet from the bank.

For the most part, the flows are measured using the guidelines provided by the USGS for accurate stream gaging measurement (Rantz, 1982). Based on previous studies [Sauer and Meyer (1992) and Clemmens and Wahlin (2006)], an individual current-meter discharge measurement at this site will be accurate to approximately 2-3%.

Figure 2. Weeds can be an issue at the Elephant Butte stream gaging site

Figure 3. Stream gaging site downstream of Elephant Butte Dam

CABALLO DAM

Caballo Dam, constructed by the USBR and completed in 1938, is located 25 miles downstream from Elephant Butte Dam. The dam is an earthen structure 96 feet high and 4,590 feet long with a capacity of 343,990 acre-feet of water. Water discharged from the Elephant Butte Power Plant during winter power generation is impounded at Caballo Dam for irrigation use during the summer. Caballo Reservoir also serves an important flood control role, particularly in the summer. The reservoir receives inflow from several significant tributaries which drain large areas between the Rio Grande River and the crest of the Black Range Mountains to the west.

Flow is measured downstream of Caballo Dam at the Rio Grande Below Caballo Dam, NM stream gaging site (ID 08362500). This stream gaging site is operated and maintained by the USBR since 1938. A measurement is performed once a week. In addition, EBID also performs stream gagings at this site twice a week. The measured flow at the site is used to set the opening on the radial gates at the Percha Diversion Dam, as explained in the next section. The Caballo stream gaging site appears to be in a very good location to maximize measurement accuracy (see Figure 4). The approach channel is straight and there is no noticeable debris or vegetation to obstruct the flow. The canal bed appears to be smooth and stable. The USBR uses a 5-foot vertical spacing when performing the current-meter discharge measurement, and they appear to be following the streaming gaging guidelines defined by the USGS (Rantz, 1982).

Figure 4. Stream-gaging site downstream of Caballo Dam

One problem with this site is that backwater effects can extend to this site from the Percha Diversion Dam downstream, resulting in extremely low velocities, which makes flow measurement less certain. Regardless, the methodology itself used to measure flows at Caballo Dam stream gaging site is acceptable. For the most part, the USBR is following the guidelines provided by the USGS for accurate stream gaging measurement (Rantz. 1982). Based on previous studies (Sauer and Meyer, 1992, and Clemmens and Wahlin, 2006), an individual current-meter discharge measurement will be accurate to approximately 2-3%, although this does not account for the potential complications resulting from the backwater effects.

PERCHA DIVERSION DAM

The Percha Diversion Dam is located about two miles downstream from Caballo Dam (see Figure 5). It was constructed by the USBR from 1914-1919 and diverts water into the Arrey Main Canal along the west bank of the Rio Grande River. Although the dam is still owned by the USBR, it is operated by EBID. The diversion dam is a concrete ogee weir with embankment wings. There are two radial gates on the west side of the diversion dam. Based on the observed water marks on the downstream side of the radial gates, it appears that the radial gates are always in the free-flow condition. Although some flow goes through the radial gates, most of the flow in the Rio Grande River goes over the diversion dam. The exception to this is when there are no releases from Caballo Dam in which case the entire Rio Grande River flows through the gates. The radial gates are not currently being used to measure the flow rate in the river. Instead, they are being used to keep the water level upstream of the Percha Diversion Dam at a given elevation so that the flow Q (cfs) into the Arrey Main Canal will be constant. Once a stream gaging has been made at the Caballo gaging station, the gate openings on the two radial gates on the Percha Diversion Dam are set according to the following rules:

- If Q < 300 cfs, then open one radial gate 6 inches.
- If 300 cfs <= Q < 700 cfs, then open both radial gates 6 inches.
- If 700 cfs <= Q < 2,500 cfs, then open both radial gates 14 inches.
- If Q >= 2,500 cfs, then open both radial gates 16 inches.

The origin of these rules is unknown. They are attached to the controls for raising and lowering the radial gates. Once the gate opening is set on the radial gates, this information is called into EBID headquarters and recorded.

Figure 5. Percha Diversion Dam with radial gates in the foreground

ARREY MAIN CANAL (OFF OF PERCHA DIVERSION DAM)

The Arrey Main Canal, which carries water for the irrigation of 16,260 acres in the Rincon Valley, is 28.1 miles long and has a capacity of 350 cfs. The head gates to the Arrey Main Canal consist of 10 submerged sluice gates. Near the head of the canal, the bottom width is 12 feet and the side slopes are 2.5:1. The channel depth is 6 feet. The canal extends 4 miles downstream from the Percha Diversion Dam where it connects to the Garfield Canal.

Currently, there appears to be no flow measurement devices at the head of the Arrey Main Canal. The submerged sluice gates at the head of the Arrey Main Canal will not provide very accurate flow measurements. Installing a Replogle flume in the Arrey Main Canal will be an economical way to achieve accurate flow measurements. The Replogle flume is accurate to within about 2% and can be easily and inexpensively constructed in a concrete-lined or earthen canal. These flumes can easily pass floating debris and can be designed to pass sediment transported by open channels with subcritical flow. Head loss is minimal. Each flume can be computer calibrated, producing an accurate rating table even if the flume is not constructed exactly to the design dimensions. For more details on Replogle flumes, see Clemmens et al. (2001).

It has been reported that a flow measurement device is available approximately 100 yards downstream of the head gates in a concrete portion of the canal. Unfortunately, the existence of this site was not known until after the field visit, and hence no assessment was made of its effectiveness.

LEASBURG DIVERSION DAM

The Leasburg Diversion Dam is located on the Rio Grande 62 miles north of El Paso at the head of Mesilla Valley. The USBR started construction of this dam in 1906 and completed it in 1908. The Leasburg Diversion Dam is a concrete ogee weir with embankment wings (see Figure 6). This structure diverts water into the Leasburg Canal for the upper 31,600 acres of the Mesilla Valley irrigation system. There are submerged sluice gates on the east bank of the Rio Grande. Water passes through these gates and enters the Leasburg Canal.

The Leasburg Canal, constructed in conjunction with the Leasburg Diversion Dam, conveys irrigation water to Mesilla Valley, is 13.7 miles long and has a capacity of 625 cfs. On average, the bottom width of the canal is approximately 34 feet, the side slopes are 1:1, and the depth is about 4 feet. The canal is deeper and wider near the head gates. There are 7 highly submerged sluice gates at the head of the Leasburg Canal as shown in Figure 7. The water level in the Leasburg Canal is typically very high as shown in Figure 8. There are significant sediment problems that occur near the head of the Leasburg Canal. To alleviate the sediment problem, the Leasburg Canal Wasteway 1-A was installed approximately a mile downstream of the head gates.

The highly submerged nature of the diversion head gates makes flow measurement difficult and inaccurate using the sluice gates. Indeed, there are instrumentation casings installed upstream and downstream of the head gates that probably once held pressure transducers to measure depth but that were subsequently abandoned when the method was found to be unreliable and inaccurate. Thus, both known limitations and field evidence suggest that using the highly submerged head gates to measure the flow is not a viable option.

Figure 6. Leasburg Diversion Dam

Figure 7. Submerged sluice gates at the head of the Leasburg Canal

Figure 8. Leasburg Canal from the head gates

One way to measure flows in the Leasburg Canal would be to install a Replogle flume somewhere along the canal. However, because the water depths in the canal are so high, care would need to be taken to ensure that the flume operates correctly and that the canal does not overtop.

In addition, installation of a Replogle flume may cause excessive sediment accumulation upstream of the flume. To reduce sediment problems, several steps can be taken (including minimizing upstream backwater effects, minimizing head loss, limiting the Froude number to 0.5 at maximum flow and maximizing it at low flows, and contracting the flume from the sides only (Clemmens et al., 2001). Even with all of these measures, however, sediment may still accumulate upstream of the flume, which would require the sediment to be removed at regular intervals.

Unfortunately, a preliminary Replogle flume design for this location indicated that it is not a viable option. The Froude numbers at the flume are predicted to be near 0.1, which is not high enough to actively pass the sediment. Even at the lowest flume height possible, the Froude numbers do not approach 0.5 in this slow moving canal. Of course, additional data are needed to verify this conclusion.

Another alternative is to further investigate the area to look for a more appropriate flow measurement location farther downstream past the Leasburg Canal Wasteway 1-A. Other locations may have higher Froude numbers allowing a Replogle flume to be installed without causing sediment accumulation.

A more viable option may be to use the bridge shown in Figure 8 to perform stream gaging measurements. While the section around the bridge appears to be significantly influenced by backwater, thus limiting flow measurement accuracy by stage-discharge relationship development, accurate flow measurements could be made using standard stream gaging techniques. Further investigation is needed to determine whether or not a reliable record could be obtained at this site using stream gaging.

Finally, there may be ways to reduce the sediment load in the Leasburg Canal using settling tanks, sediment ejectors, vortex sand traps, or vortex chambers. Details of these devices are described by Raudkivi (1993). Further study is necessary to determine if any of these devices could be feasibly implemented on the Leasburg Canal.

MESILLA DIVERSION DAM

The Mesilla Diversion Dam is located on the Rio Grande 40 miles north of El Paso, TX. It was constructed by the USBR during the same time period as the Percha Diversion Dam (1914-1919). The Mesilla Diversion Dam consists of a low concrete weir with 13 radial gate structures, 22 feet high, flanked by levees as shown in Figure 9. This structure diverts water into the East Side and West Side Canals (also constructed from 1914-1919) for the lower 53,650 acres of the Mesilla Valley irrigation system. The structure also diverts water in to a smaller lateral called the Del Rio Lateral. Under normal operating conditions, only 2 of the 13 radial gates on Mesilla Diversion Dam are opened. The remaining 11 gates are kept closed unless sediment needs to be flushed through the structure or there is a flood event. Unlike the other diversion dam structures on the Rio Grande River, all of the flow goes through the radial gates; none of the flow goes over the diversion dam.

Gate 1 is located on the east side of the Mesilla Diversion Dam. This gate is typically kept at a constant opening and the gate position is not changed. Gate 2 is located on the west side of the diversion structure. This gate is adjusted up and down depending on the flow in the Rio Grande River. According to Wayne Treers, then of the USBR, who was interviewed during the field visit, there is a local flow controller on Gate 2 that automatically adjusts the gate opening to maintain a constant flow through Gate 2. According to a ditch rider for EBID, who was interviewed during the field visit, the local upstream water level controller on Gate 2 operates according to the following rules:

- If the water level upstream of Mesilla Diversion Dam is greater than 7 feet, then Gate 2 is opened.
- If the water level upstream of Mesilla Diversion Dam is less than 6.75 feet, then Gate 2 is closed.
- If the water level upstream of Mesilla Diversion Dam falls in between 6.75 and 7 feet, then the gate position is not changed.

Figure 9. Upstream face of the Mesilla Diversion Dam

Further investigation is needed to know exactly what type of controller is actually being used on Gate 2. Gate 2 transmits data (i.e., gate opening, water level, and flow rate) back to EBID's headquarters automatically. EBID can monitor Gate 2 remotely, but they cannot control it remotely (as of 2006). Thus, if EBID wants to make additional changes to Gate 2 (besides the local controller changes), a ditch rider must be sent out to manually adjust the gate.

Both Gate 1 and Gate 2 appear to be operating under free-flow conditions. The high water marks on the downstream sides of the gate suggest that these radial gates are never submerged or in the transition zone. Because of this, accurate flow measurements are possible using Gate 1 and Gate 2. Currently, EBID calculates the flow through the radial gates by assuming that one inch of gate opening is equal to 28 cfs. It is uncertain how this rule was initially developed. To obtain more accurate flow measurements, it is suggested that the USBR's WinGate program be used to calculate the flow through the gates. This program uses a newly developed algorithm for calculating flows through radial gates based on research performed by the U.S. Arid Land Agricultural Research Center, which is part of the Agricultural Research Service in the U.S. Department of Agriculture. A summary of the methodology used in this new radial calibration appears in a paper by Wahl (2005).

If WinGate is used to calculate the flows through Gates 1 and 2, a further investigation would be needed to ensure that the upstream head is measured correctly. Currently, the head is measured using a stilling well on the west bank of the Rio Grande. The stilling well appears to be in a good location. However, the stilling well should be examined to verify that the zero is set correctly and that the stilling well is installed correctly (e.g., pipes not clogged, taps drilled correctly, properly zeroed). This is probably routinely done by EBID, but was not verified.

EAST SIDE CANAL (OFF OF MESILLA DIVERSION DAM)

The East Side Canal is 13.5 miles long and has a capacity of 300 cfs. The head gates are sluice gates. The flow passes under the sluice gates and into a concrete rectangular box before transitioning into the canal. The flow in the concrete box is quite turbulent as can be seen in Figure 10. Near the head gates, the canal bottom is approximately 40 feet wide and its depth is 9.5 feet. The canal side slopes are 1.15:1.

It appears the flow measurement using the East Side Canal head gates would be difficult. Another option would be to install Replogle flumes just downstream of the head gates but still inside the rectangular concrete box. This option would require some flow conditioning to reduce the turbulence after the gate and improve the flow distribution so that the flume would measure flow accurately. Some possible flow conditioning devices include flow straightening vanes and wave suppressors (Replogle, 1997). A third alternative would be to install a Replogle flume about 500 feet downstream of the head gates, where an abandoned concrete structure could be converted into a Replogle flume.

WEST SIDE CANAL (OFF OF MESILLA DIVERSION DAM)

The West Side Canal is 23.5 miles long and has a capacity of 650 cfs. The head gates on the West Side Canal are submerged sluice gates. Just downstream of the head gates, there is a 90° bend in the canal. Water shoots out from the sluice gates and it is extremely turbulent as shown in Figure 11. There is a strong jet of water that runs along the north side of the West Side Canal which hits the side of the canal where it bends, causing even more turbulence. The canal has a bottom width of approximately 58 feet and a depth of 8.2 feet. The side slopes are 0.67:1.

Flow measurement accuracy is unlikely using the sluice gates at the head of the canal because the water downstream of the gates is so turbulent, making it difficult to obtain a downstream water level. An equipment casing housing had been installed in an attempt to measure the downstream water level; however, the EBID ditch rider reported the measurements obtained were not good and so the measurement site had been abandoned. An alternative would be to install a Replogle flume downstream of the bend in the canal near where the stream gaging station is located as shown in Figure 12.

DEL RIO LATERAL (OFF OF MESILLA DIVERSION DAM)

Very little information was available on the Del Rio Lateral. This canal receives water from the east bank of the Rio Grande upstream of the Mesilla Diversion Dam. The canal passes under the East Side Canal via a siphon before it continues south parallel to the Rio Grande River. It has a bottom width of 6 feet, a depth of 7.25 feet, and side slopes of 1.5:1. The Del Rio Lateral is an earth lined canal; however, there is a short portion that was concrete lined in an attempt to measure the flow using stream gaging techniques (see Figure 13). There was a PVC pipe installed on the side of the concrete portion of the Del Rio Lateral. This pipe was probably used to get a measurement of the stage in the lined section in order to develop a rating curve for this canal.

This canal is problematic from a flow measurement standpoint because sediment accumulates in the short lined portion of the canal. Installation of a Replogle flume may result in excessive sediment accumulation upstream of the flume. While the Clemmens et al. (2001) methods could be implemented to reduce the accumulation (see the Leasburg Canal section), it would probably not completely alleviate the problem, and sediment would still need to be removed at regular intervals.

The PVC pipe along the sides of the lined portion of the Del Rio Lateral (see Figure 13) is a static pressure tube that can be used to determine the depth of water. Note the pressure taps on this tube (shown in a close up view in Figure 14) are drilled such that the holes face upstream. As a consequence, the depth of water inside the pipe will be influenced by the energy of the water directly hitting the pressure taps. This will lead to water surface elevations inside the pipe that are higher than the water surface elevation outside the pipe. An alternative design for a static pressure tube that avoids such problems is shown in Figure 15 (from Replogle, 1997).

Figure 10. Turbulent flow under the sluice gates at the head of the East Side Canal

Figure 11. Turbulence downstream of the head gates on the West Side Canal

Figure 12. West Side Canal near the stream gaging bridge

SUMMARY

In general, flow measurements are made on the Lower Rio Grande following standard procedures despite the advanced age of some of the structures. Accuracy of the individual stream gage measurements is in the 2-3% range. Most of the laterals off of diversion dams are not gaged. It is would be desirable to have some sort of flow measurement information at the heads of each of these laterals. At some sites, such as the Arrey Main Canal, a flow measurement device would be relatively straightforward. At other sites, such as the Leasburg Canal and the Del Rio Lateral, installing a flow measurement device will be tricky. Suggestions as to possible flow measurement devices to use on these canals were given.

Figure 13. Concrete lined section of the Del Rio Lateral

Figure 14. Close up view of pressure taps

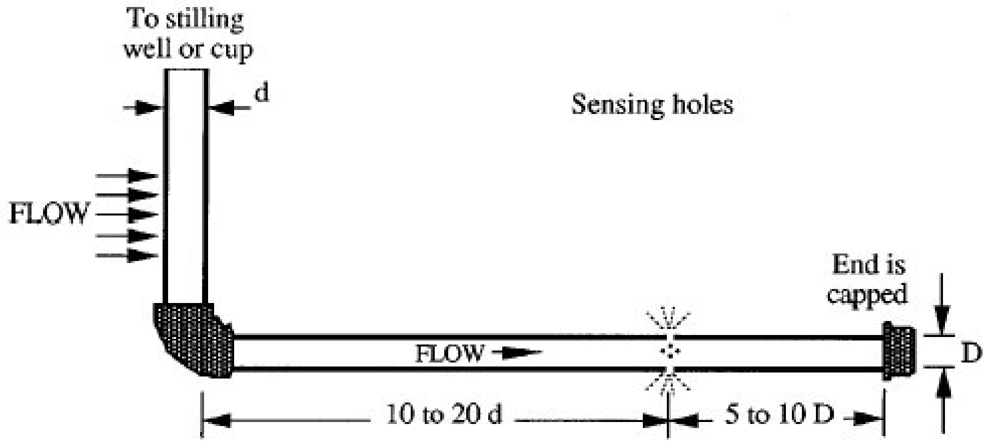

Figure 15. Suggested design for a static pressure tube (from Replogle, 1997)

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