RECLAMATION
Managing Water in the West

Field Performance Evaluation of Water Level Sensors

Research and Development Office
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Hydraulic Laboratory Report HL-2017-07

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Mission Statements

Protecting America's Great Outdoors and Powering Our Future

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Field Performance Evaluation of Water Level Sensors

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Executive Summary

The impetus for this field performance monitoring project was to address requests Reclamation engineers have repeatedly encountered from irrigation districts and other water conveyance system operators: “Is there any information available documenting the long-term accuracy and reliability of water level sensors?” Water level sensors are a key element in electronic monitoring and control networks for open channel water conveyance systems. Failure of a water level sensor can readily lead to damage costs that are orders of magnitude greater than the cost of the failed instrument. This project – funded through Reclamation’s Science and Technology Program and carried out with support from Reclamation’s Yuma Area Office and Western Colorado Area office (along with in-kind contributions from cooperating irrigation districts) – was conducted by Reclamation’s Hydraulic Investigations and Laboratory Services Group (HILS) to document the field performance of a range of water level sensing instruments as an information source for interested parties.

Commercially available water level sensors were purchased from a variety of sources. Sensors were required to have an analog output and have a relatively low upfront cost. A technique for calibrating water level sensors both in the lab and in the field was developed which allowed for accurate and repeatable calibrations over a wide range of water levels throughout the duration of the project. Test sites were identified at three different projects including South Platte Ditch Company (SPDC), Orchard-Mesa Irrigation District (OMID) and Gila Gravity Main Canal (GGMC) to install the sensors and monitor their performance over several irrigation seasons. Recalibration of the sensors were completed at random intervals during service and showed that slopes were unaffected for the majority of the sensors over the testing period. Offsets to the sensors were a different situation, which appeared to change over time.

Contents

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Water Level Sensors Instrument Selection

Water level sensors included in this study were selected using the following criteria:

- Analog output instruments (0-5 V or 4-20 mA) with linear outputs that are compatible with a wide range of programmable control and/or data logging equipment.
- Low to moderate purchase cost (target of ~$1,000 or less per unit).
- Simple setup (not requiring sensor programming) with setup tasks limited to calibration for slope and offset.

In order to keep the range of instruments to be included within a manageable number, the equipment selected for evaluation were either products the HILS staff has had experience with or products recommended for inclusion by entities that the HILS staff have worked with in the field. Types of level sensing technologies in this project include submersible pressure transducers, ultrasonic ("down looking") level sensors, and bubbler level sensors. At some of the field sites, these sensor technologies are installed alongside previously installed float level sensors.

Sensor Calibration

A protocol was devised for initial calibrations (and for periodic recalibration) of the level sensing instruments. This included configuration of a portable calibration apparatus that enabled calibrations to be performed in the field with accuracy to within ±0.005 foot (1/16 inch). The calibration system that was developed may be configured with a water column for calibrating submersible pressure transducers or bubbler sensors, or with a reflective surface for calibration of ultrasonic sensors. Figures 1 and 2 show the calibration system setup for the water column and reflective surface, respectively.

For uniformity purposes the same type of programmable remote terminal unit (RTU), manufactured by Control Design Inc. was utilized at each field location. The signal output of each sensor included in the project varies either in voltage output (0-5 volts) or current (4-20 mA). This information is transmitted to an analog to digital (A-D) module in the RTU where it is converted to a digital value. The RTU units are configured with 12-bit A-D converters that translate the selected sensor output signals (voltage or current) to a digital value over a range of 2^{12} (4096) discrete values varying from 0 to 4095.

The calibration process enables the variations in signal output from a level sensor to be accurately mapped to the corresponding actual change in water level in the desired unit of measure (i.e., feet in this case). Since these instruments provide a linear output signal, the mathematical tool for conversion of a sensor signal's A-D value into a water level is simply the equation for a line:

$$y = mx + b \qquad \text{Equation 1}$$

Where: y = the unknown quantity (water level); *m* = the *slope* of the correlation line; *x* = the known quantity – the A-D value; *b* = the *offset* – the [positive or negative] value that, when added to the product of the x (sensor signal) value and the slope, produces the observed *y* (water level) value.

Figure 1. Calibration with water column

Appropriate slope values for each sensor were determined using the calibration apparatus. The appropriate offset values are a function of the position at which each sensor is subsequently installed at the field site. The offset values must be determined after installation of each sensor by correlating the sensor reading to a surveyed water level or an on-site staff gage reading.

For calibration using the water column setup, the submersible pressure transducers (or bubbler outlet port) remain in a stationary position while water is pumped into or drained from a ten foot section of clear 2-in PVC pipe positioned vertically. A target of ten readings were taken as the water column depths were increased in steps, followed by a target of ten additional readings taken as the water column was decreased in steps. At each reading level the measured water depth (to $^{1}/_{16}$ inch resolution) was recorded along with the sensor's A-D signal value read from the RTU.

Figure 2. Calibration with reflective surface

For the ultrasonic sensor calibration, a reflective surface (a plywood section with laminated vinyl surface) was placed and leveled in a horizontal position near the ground. Ultrasonic sensors were attached to a mount in a sliding track that enabled the sensor to be raised or lowered over a maximum range of ten feet. In a manner similar to that used for the water column setup, separate data sets were taken for first increasing distances from the sensor to the reflective surface, followed by decreasing distances.

Slope calculation was accomplished using available utilities embedded in the Excel spreadsheet software. For each sensor the data sets recorded for increasing and decreasing depth (or for increasing and decreasing distance from the reflective surface) were plotted independently using the Excel "x-y scatter" plotting function. A visual assessment of the plotted data served as a preliminary screening to detect whether any significantly non-linear points were present in the data record. Non-linear points close to min/max values would be investigated as potential range-limit outputs from the sensor. If this were the case, these points were discarded. Non-linear points appearing within the sensor range were investigated for data-entry errors. If an error appeared likely, a new data set was collected.

Following an acceptable visual assessment of a data set plots, two options for Excel utilities may be used to determine the calibrated slope. The Excel "add trend line" (the "Linear" trend line option along with the "Display equation on chart" and "Display R-squared values on chart" selected) will calculate and display sensor slope values. The multiplier associated "x" term in the displayed equation is the sensor slope for scaling changes in the sensor output signal into the corresponding observed change in water depth (or changes in distance from ultrasonic sensor to reflective surface). [The offset term appearing in the equation is a function of sensor position in the calibration apparatus relative to the calibration measurement datum and is of no use once a sensor is removed from the calibration setup.] Sensor slope may also be determined using the Excel LINEST() utility directly from the calibration data arranged in a table. Figure 3 is an example sensor calibration plot.

From the example sensor calibration in Figure 3, the slope determined from the calibration data set is 0.001776. This means that each unit of increase in A-D signal value represents an increase of 0.001776 feet in water level. The R^2 value provides an indication of the degree of linearity between sensor output and observed change in water level, with a value of 1.0 being perfectly linear. The 0.999996 R^2 value shown on the plot indicates that the output from this sensor is highly linear.

From both data sets with each sensor, increasing and decreasing water column depth or increasing and decreasing distance from the reflective surface, two sensor slope values were computed independently. The degree of agreement between the two computed slope values may be considered as one aspect of performance consistency for a given sensor. The average of the two computed slope values was used for field installations.

For all current loop (4-20 ma) output sensors an excitation voltage of 24 V was supplied. All voltage output sensors (0-5 volt) operated using a 5 V excitation. A table of calibrated slope values for all sensors along with a list of sensors and approximate cost are included in Appendix A of this report.

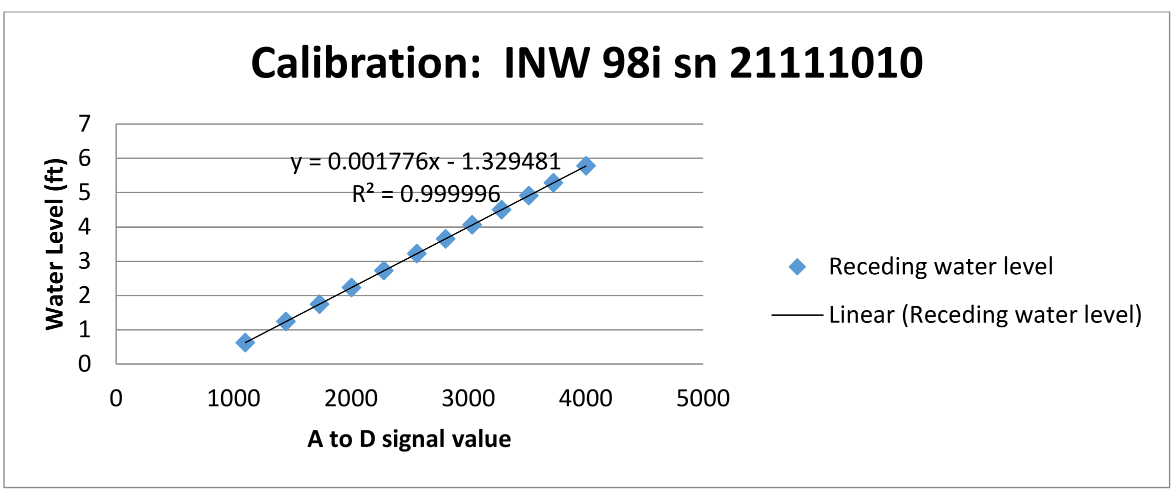

Figure 3. Example sensor calibration plot

Field Test Sites

Targeted field test sites were located to provide a broad range of operating environments. In order to minimize project expenditures on system hardware, the sites were locations where data logging and telemetry equipment was already in place or where new installations provided shared functionality with other concurrent projects. Three cooperating entities were ultimately selected: South Platte Ditch Company (SPDC), Orchard-Mesa Irrigation District (OMID) and Gila Gravity Main Canal (GGMC) shown on the Figure 4 map.

Figure 4. Performance monitoring field locations

The SPDC is located near the town of Merino in northeastern Colorado. This system has existing data collection and telemetry systems to which additional level sensing units could be readily added. Other aspects of SPDC operations included the fact that the SPDC has the most senior diversion right on the South Platte River in Colorado Water District 64 and thus is constantly in operation during the irrigation season. The SPDC also has one of the most senior recharge diversion rights on the South Platte meaning that the system is frequently in service during the non-irrigation season. This location allowed the opportunity to monitor performance of level sensing equipment under off season low temperature conditions in addition to typical summer conditions.

OMID is located near Palisade CO. An original feature of OMID is the hydro-pumping plant that uses hydropower to lift irrigation water up onto the mesa south and west of Palisade. The OMID Power Canal delivers water diverted upstream from the Colorado River to the hydro-pumping plant with a head differential of almost 80 feet between the Colorado River and the pumping plant. A second hydro plant which generates electricity was subsequently constructed adjacent to the pumping plant. The capability to generate electricity extends the utility of the power canal infrastructure beyond the irrigation pumping season through the entire calendar year. Level sensors were installed both upstream and downstream of trash rack structures near the inlets of the respective hydro plant penstocks to monitor head differential across the trash racks. As with the SPDC sites, the OMID power generation plant offers the opportunity to monitor level sensor performance over a wide range of seasonal conditions.

The third field location, GGMC is in Southwestern AZ. Level monitoring stations have been established along the upper reach of the GGMC beginning at Imperial Dam and extending to the bifurcation with the Welton-Mohawk Canal. Seven level monitoring stations have been established along this reach of approximately 15.3 miles. Data from the monitoring stations is being collected and analyzed to track the rate at which flow adjustments progress through the monitored canal reach as part of an effort to develop a daily operations planning tool. This field site provides an opportunity to observe year around sensor performance under the desert conditions where many canals and streams are of critical importance.

Setup of Field Sites

Multiple sensors were installed at each field site to enable monitoring of comparative performance. Where feasible, three (or more) sensors were installed at each site. To the extent that it was practical, the goal was to install at least two sensor technologies (among submersible pressure transducers, ultrasonic down lookers and bubbler sensors) at each site.

South Platte Ditch Company Sites

An existing level monitoring and data collection network was in place at the SPDC prior to this project. A PC linked to the base unit at the company office on which collected data is stored is set up as a file transfer protocol (FTP) site that enables password-protected internet access to the collected data. Level sensors were installed at three measurement structures (all Parshall flumes) on the SPDC system. Each of the SPDC sites had been previously equipped with multi-turn potentiometer/float sensors installed in stilling wells. The uppermost SPDC instrumentation is located in the main flume (Figure 5).

Submersible pressure transducers were installed in the stilling well (arrow 1) at the SPDC Main Flume. Two ultrasonic sensors were installed at the site, a Judd Communications depth sensor (arrow 2) and an Engineering and Manufacturing Services (EMS) SR6 ultrasonic senor (arrow 3). Submersible pressure transducers installed in the stilling well include an Instrumentation Northwest (INW) and a Stevens Water SDX. A shop-fabricated float and pulley apparatus utilizing a Bourns 3540 10K ohm 10 turn potentiometer had previously been installed in the stilling well.

Figure 5. SPDC Main Flume

The second SPDC field site is the Company Lateral flume shown in Figure 6. Submersible pressure transducers installed in the stilling well (arrow 1) at this site include a Keller Levelgage and an INW 98i. The stilling well also houses a previously installed shop-fabricated float and pulley apparatus utilizing a Bourns 3450 10K ohm 10 turn potentiometer A Siemens 7ML12011EF00 ultrasonic sensor (arrow 2) is seen in Figure 6 installed over the flume.

The SPDC Smart Lateral flume is shown in Figure 7. Submersible pressure transducers were installed in the stilling well (arrow 1) at this site are an Endress Hauser FMX21 and an Automata Level-Watch. An Automata Ultra-Ultra ultrasonic sensor is installed above the flume (arrow 2).

Figure 6. SPDC Company Lateral Flume

Figure 7. SPDC Smart Lateral Flume

Orchard Mesa Irrigation District Sites

Penstock intakes for the OMID hydropower and hydro pumping plants are located approximately 140 feet apart on the OMID Power Canal. Figure 8 shows the after bay in the foreground of the hydropower plant (left) and the hydro pumping plant (right) with the penstocks leading from the Power Canal to each facility in the background.

Figure 8. OMID Hydropower and Hydro Pumping Plants

Figure 9 shows the placement of sensors in the power canal upstream of the hydropower trash rack. At this site, an INW 98i submersible pressure transducer and a bubbler port linked to a Control Design CD103-2 bubbler are installed in a stilling well (arrow 1). A Siemens "The Probe" ultrasonic sensor is installed on an arm extending over the water surface (arrow 2).

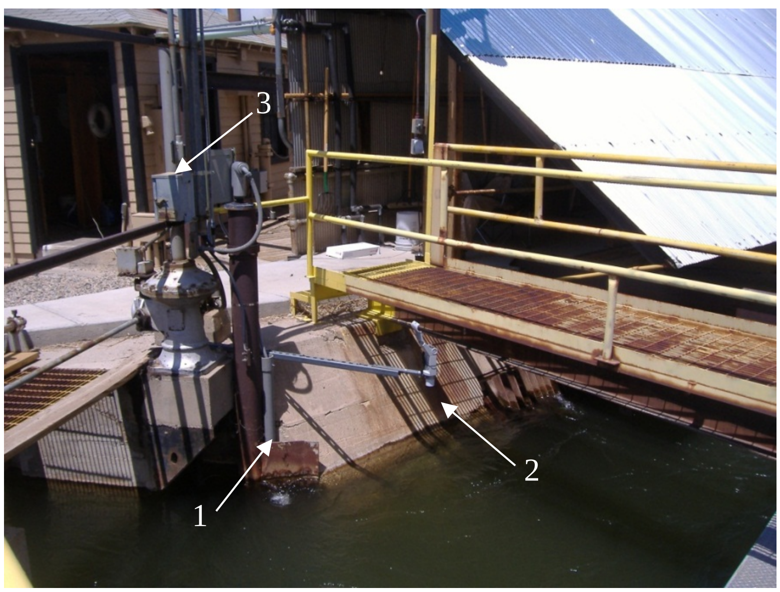

Figure 9. Sensor placement upstream of the OMID hydro power plant trash rack

Sensors monitoring the water level downstream from the trash rack are installed under the decking between the trash rack and the valve house seen in the background of Figure 9 (arrow 3). A closer view is shown in Figure 10.

Figure 10. Sensor installation downstream from the OMID hydropower trash rack

An Endress-Hauser submersible pressure transducer and a bubbler outlet tube linked to a CD 103-2 bubbler sensor are installed in the stilling well seen in Figure 10. An EMS ultrasonic sensor is installed below the wooden deck at this site.

Locations of level sensors installed for the OMID hydro pumping plant are shown in of Figure 11. Upstream of the trash rack a Druck PTX 1732 submersible pressure transducer and a bubbler outlet line linked to a CDI CD103-2 bubbler sensor are installed in a stilling well affixed to the concrete wall in the foreground (arrow 1). A Judd Communications Depth Sensor ultrasonic is attached to an arm extending over the channel (arrow 2). Downstream of the trashrack an AGP PT500 submersible pressure transducer and a bubbler outlet line linked to the CDI CD103-2 bubbler sensor are installed in a stilling well under the deck behind the trashrack (arrow 3). An AGP IRU 2005 ultrasonic sensor is also installed under this deck.

Figure 11. Sensor installation upstream of the OMID hydro pumping trash rack

Gila Gravity Main Canal Sites

Level sensing stations have been established at seven sites along the Gila Gravity Main Canal over a reach that starts at the canal headworks at Imperial Dam and extends downstream to the major bifurcation where the Welton-Mohawk canal splits off from the Gila Gravity canal. Each of these level monitoring sites was established at an existing canal structure.

Level sensors are installed immediately above and immediately below the trash rack at the heading of the Gila Gravity Main Canal at Imperial Dam on the Colorado River. Figure 12 is a view of the trash rack. This photo was taken in November of 2012 during the once-every-three-years maintenance/inspection outage for the canal. During this outage, the stilling well (arrow) was installed that now houses a Druck PT1732 submersible pressure transducer and a bubbler outlet tube linked to a CDI CD103-2 bubbler sensor. In addition, a Judd Depth Sensor ultrasonic sensor has subsequently been installed at this site.

Figure 12. Upstream view of GGMC trash rack

Figure 13 is a photo just downstream from the GGMC trash rack also taken during the November 2012 outage. An Endress-Hauser FMX21 submersible pressure transducer and a bubbler outlet tube linked to the CDI 103-2 bubbler sensor are installed in the stilling well (arrow). An Automata "Ultra-Ultra" ultrasonic sensor has also been installed at this site (not shown in Figure 13).

Proceeding downstream, the next level monitoring station on the GGMC is the long-throated flume (approximately 0.9 canal miles below Imperial Dam) shown in Figure 14. At this site an APG IRU-9423 ultrasonic sensor is installed on a mount extending over the water surface (arrow 1). Two submersible pressure transducers, a Stevens SDX and a Keller Levelgage are installed in a stilling well pipe (arrow 2) attached to a walkway support leg.

The GGMC has three mechanically operated automated spill structures. The uppermost of these spill structures (approximately 5.5 canal miles downstream from Imperial Dam) is the third level monitoring station in this project. This site is shown in Figure 15.

At the upper spill structure seen in Figure 15, a Judd Depth Sensor ultrasonic sensor is installed on a mount over the water (arrow 1). An Automata Level Watch submersible pressure transducer and a Global Water WL400 submersible pressure transducer are installed in a stilling well at the site (arrow 2). HILS engineer Bryan Heiner is seen examining the sensor installations.

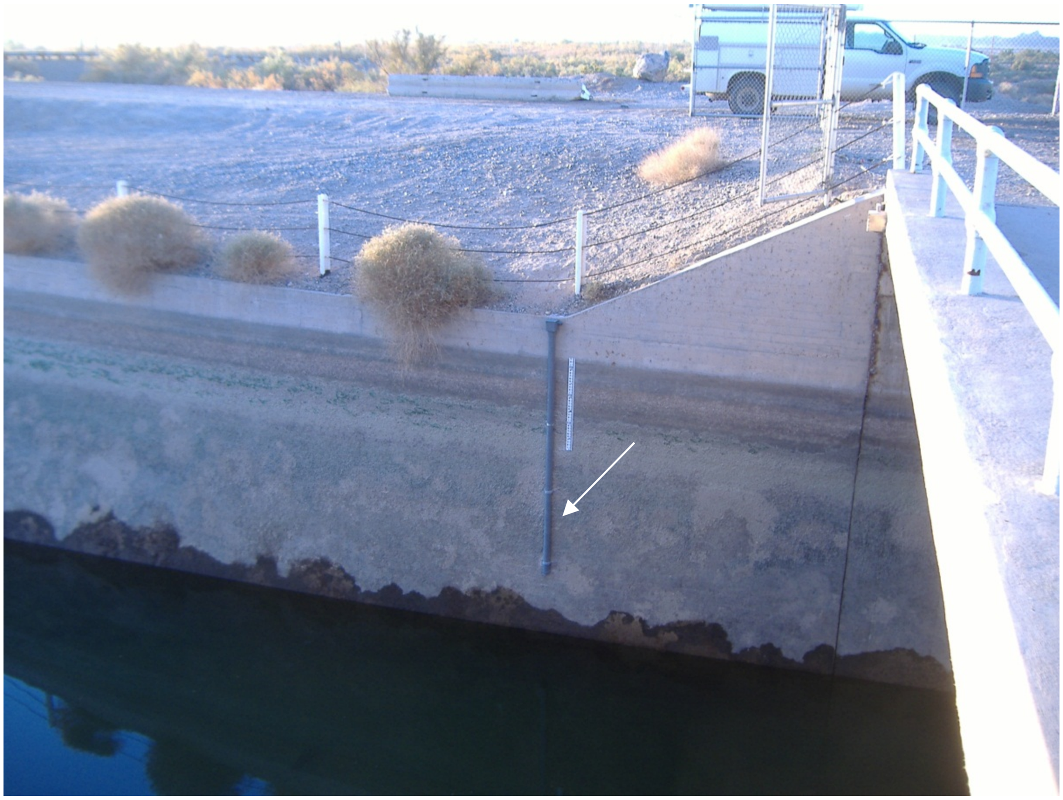

Figure 13. Sensor location immediately below the GGMC trash rack

Figure 14. GGMC long-throated flume site

Figure 15. GGMC upper spill structure level monitoring site

The fourth GGMC level monitoring station is the North Gila #1 head gate. Between this site and the GGMC upper spill structure, the canal passes through two tunnels. The North Gila is located approximately 7.9 canal miles from Imperial Dam. Figure 16 shows the North Gila #1 head gate site. An APG PT500 submersible pressure transducer and an Automata Level Watch submersible pressure transducer are installed in a stilling well (out of view behind the canal bank just to the right of the fenced area seen in Figure 16) at this site.

The fifth GGMC site is the North Gila #2 head gate. This site is located approximately 11.5 canal miles downstream from Imperial Dam. Figure 17 shows the North Gila #2 head gate site.

A Keller Levelgage submersible pressure transducer is installed in a stilling well (arrow 1) at the North Gila #2 head gate site shown in Figure 17. Two Flowline ultrasonic sensors, a DX10 and a DL10 are installed on a mount arm extending over the water surface (arrow 2).

The sixth GGMC level monitoring station is the entrance structure for the invert siphon that carries flow under the Gila River channel. The siphon entrance is approximately 14.9 canal miles from Imperial Dam. Figure 18 shows the siphon entrance site.

Figure 16. The GGMC North Gila #1 headgate level monitoring site

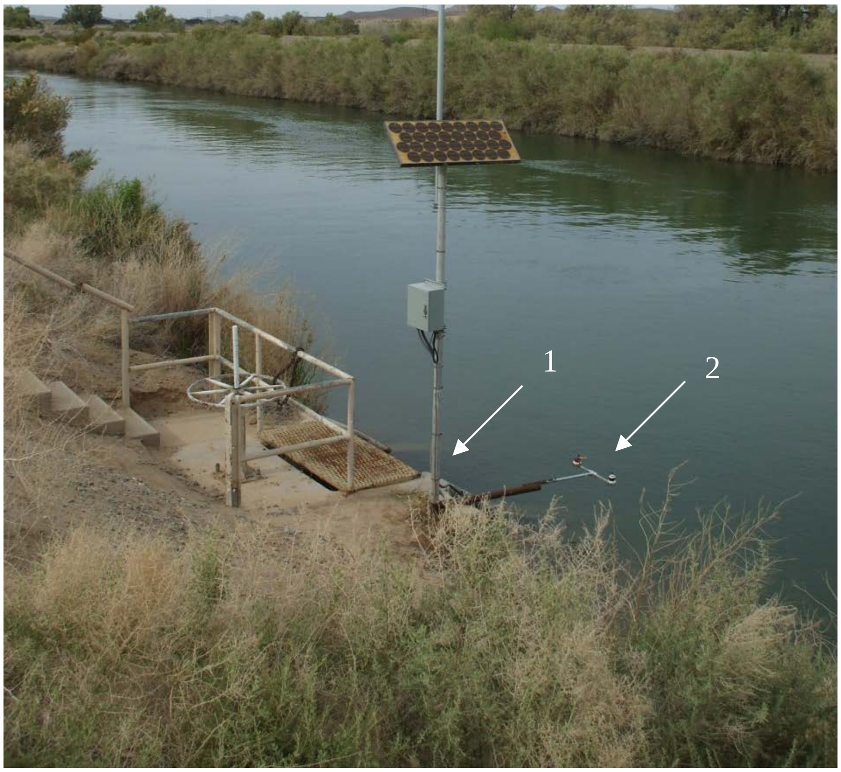

Figure 17. The GGMC North Gila #2 head gate level monitoring site

Figure 18. The GGMC Gila River invert siphon entrance site

Two submersible pressure transducers, a Keller Acculevel and a Stevens SDX are installed in a stilling well (arrow) at the Gila River invert siphon entrance site shown in Figure 18. The project team plans to add an OTT Compact Bubbler Sensor (CBS) to the existing sensors at this site. The bubbler outflow tube will be installed in the stilling well along with the submersible pressure transducers.

The seventh GGMC level monitoring site is a buffer pond at the “Y” bifurcation location at which the Welton-Mohawk canal splits off from the Gila Gravity Main. This site is immediately downstream from the Gila River invert siphon. The buffer pond is about 720 feet long with a mean width of about 150 feet. This site is approximately 15.3 canal miles downstream from Imperial Dam. Figure 19 shows the sensor installations at the Y site.

Figure 19. GGMC sensor installation at the Y buffer pond

Four level sensors are installed at the Y site shown in Figure 19. Submersible pressure transducers installed include an INW 98i and a Sevens SDX installed in a stilling well (arrow 1). Ultrasonic sensors at the site include an APG 2005 (arrow 2) and an EMS SR6 (arrow 3).

An additional level monitoring site was established near the end of the canal at the South Gila (Yuma Irrigation District) headgate during 2014. An office base unit is set up at the Yuma Irrigation District office. Software on a PC linked to the office base radio/control unit directs collection of logged data from each of the field sites. The collected data is stored on the PC hard drive. The cooperating irrigation districts are planning to get set up for this PC to function as a file transfer protocol (FTP) site that will allow password-protected access to the recorded data via the internet.

Data Collection

Getting data collection networks into operation has proven to be a challenge for this project. Data is logged on-site at each location in a circular buffer. The systems are set up for data to be collected via a wireless communications network and stored on the hard drive of a PC linked to the base unit at the office of each of the cooperating irrigation districts. A number of issues have been encountered in attempting to get each data network fully functional.

At the South Platte Ditch Company where data collection had been in service for multiple seasons prior to this project, radio transmissions from their remote sites began operating sporadically after the additional sensors were installed. SPDC personnel suspected communications issues might be linked to 12-24 V DC-DC converters that were installed to provide excitation voltage for current loop sensors. SPDC personnel report that communication issues cleared up after the district disconnected the DC-DC converters (which cut power to 4-20 mA output sensors).

During June 2014, the manufacturer of the radio/control units which are used at all project field locations made a site visit to SPDC to investigate communications issues apparently associated with equipment added to SPDC sites as part of this project. A Fluke 124 ScopeMeter Oscilloscope was used to measure voltage oscillations during times the DC-DC converters (and thus when all current loop output level sensors) are energized. At the SPDC sites, no voltage spikes associated with operation of the DC-DC converters themselves could be detected that would have a potential effect on operation of communications or other equipment. Voltage spikes of a questionable RTU were detected relating to the operation of specific level sensor units.

On the Gila Gravity Main Canal, the base unit is located in the Yuma Irrigation District Office. Following each site visit the data collection system had functioned for a time interval ranging from a few days to a few weeks but then would shut down. It was eventually learned from district personnel that YID obtains its electric power from either of two sources. At times when the energy source is being changed, the district office is without power for a few moments. A battery-backup power supply has since been installed to keep the PC powered up during YID power source switching events.

Another problem encountered at specific sites on the GGMC project was the inability to communicate with the modems of the radio/control field units when linked via RS232 serial cable to a laptop PC during field setup. The manufacturer of the radio/control equipment was able to track this problem to the 12V DC to 120V AC power inverter being used to power the laptop PC. The particular inverter being used was causing memory in the modems to lose programmed settings. This problem was addressed by running on the PC battery while communicating with the RTU modem. Use of a true sine wave inverter may also eliminate this problem.

The RTU units installed at Orchard Mesa Irrigation District were initially configured with VHF license-free radios that operate in the 151-154 MHz frequency range. Electronic background noise (EMF) from the power generation facility corrupted this frequency and blocked radio operation. After the radios were replaced with UHF radios that operate in the 450-470 MHz frequency range, the communications system functioned well.

There are also persistent issues with keeping the PC linked to the office base unit running at OMID, similar to problems seen at YID. A battery backup power supply was purchased to power the PC in an attempt to eliminate this problem. Issues at SPDC and at OMID are being worked on as the project team has opportunity to make site visits.

Discussion

Water level sensing instruments representing the array of the technologies commonly utilized by water delivery entities have been installed at field sites on the three cooperating water districts. In each case the level sensing stations will serve a dual purpose of providing feedback to the cooperating entity (both real time and time-record logged data) plus meeting the objective of this project in providing a comparative observation of field performance of the various instruments.

Over the period of this project it became abundantly clear to the researchers that all manufacturers and styles of water level loggers are prone to issues. Some of the biggest issues encountered with the sensors can be summarized as follows:

- Spider webs blocking ultrasonic signals from reaching the intended target
- Power failure at remote sites
- Drift of the sensor offset when left in place over extended periods of time
- Overheating causing sensor malfunction
- Poor temperature compensation resulting in a non-linear calibration with temperature fluctuations
- Corrosion, buildup and plugging of sensor ports

Issues that were anticipated but not realized were:

- Slope calibration changes over repeated seasons. All sensors that were recalibrated held the same calibration slope over repeat calibrations and time intervals

Several of the sensors installed in the field went dead for no apparent reason. There did not seem to be a consistent nature to the failure or, as shown in Appendix A, any particular sensor that frequently failed. Reclamation recommends finding a sensor that fits within project budgets, that has shown to work well for your application. If you have not found a sensor that fits your liking please contact the Authors to discuss your options.

Because sensors seem prone to failure in agricultural applications it is highly recommended that redundant sensors be placed at all critical measurement locations. Programming an RTU to read both two sensors and have one set to primary and one set to secondary is fairly straight forward. It is important to take it the next step and have an error message or alarm trigger if the values exceed a certain threshold.

Examination of Collected Data Examples

As discussed above, each of the level sensing instruments evaluated during this project provide a linear analog output signal. The required calibration tasks were presumed to be limited to identifying the sensor slope and offset. Any additional functions (i.e., temperature compensation required for ultrasonic sensors) were presumed to be internal to the instrument and pre-calibrated by the manufacturer. Slope calibration is discussed in detail above. Offset values were determined by direct surveys referenced to elevation monuments or by reference to surveyed staff gages at the respective sites. As part of the initial setup, offsets for the individual instruments were adjusted until all sensors at a site generated identical readings to within ±0.01 feet during consecutive polling cycles.

A sampling of collected data in the form of twenty-four hour plots for data recorded at 15 minute intervals on February 22, 2014 is shown below for three of the GGMC level gaging stations. To aid in making comparative observations among the plots, each plot has a vertical range of 1.2 feet. Figure 20 shows water level data from the long-throated flume near the upper end of the canal.

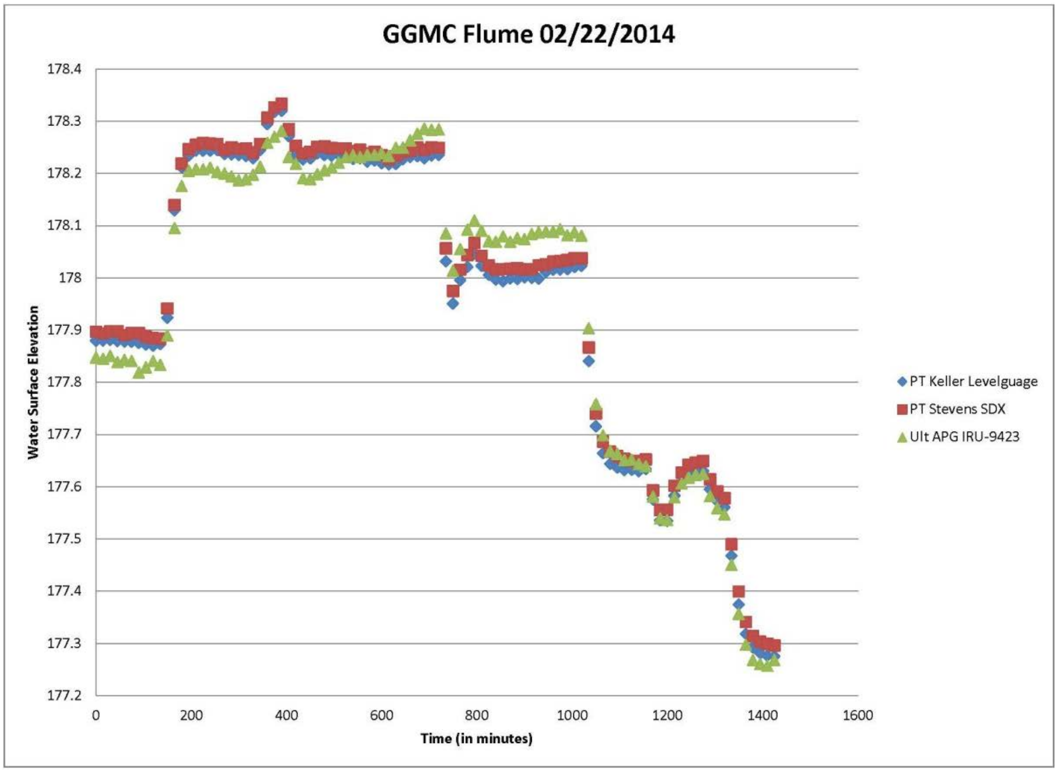

Figure 20. Water level data at the GGMC flume on 02/22/2014

As indicated in the legend of Figure 20, there are two submersible pressure transducers (PT) and an ultrasonic sensor (Ult) at this site. The two submersible pressure transducers track closely throughout the day with the level computed from the Keller Levelgage consistently just below the level computed from the Stevens SDX. It appears there is a general trend for levels computed with the APG IRU-9423 ultrasonic sensor to be less than the others prior to about 450 minutes (8:00 AM) and after 1100 minutes (7:00 PM), but tending to produce a higher reading level between 8:00 AM and 7:00 PM.

The observation of a slight offset between the submersible pressure transducers, while tracking each other uniformly throughout the day indicates that one of the offsets may have been incorrectly installed or that one of the sensors has drifted away from its original offset.

The comparative outputs between the ultrasonic sensor and the submersible pressure transducers might bring into question how well tuned the temperature compensation function is in the ultrasonic sensor, as temperature increase at the site (with the rising of the sun) it appears the ultrasonic sensor output changes with a fairly constant water surface elevation (according to the pressure transducer data).

Figure 21 shows the water level data record over the same time frame for the Upper Spill site which is also instrumented with two submersible pressure transducers and an ultrasonic sensor. It is interesting to note that as flow adjustments (and associated changes in water level) move down the canal between these sites, the rates of change (steepness of plotted data slopes) is, as expected, visibly dampened.

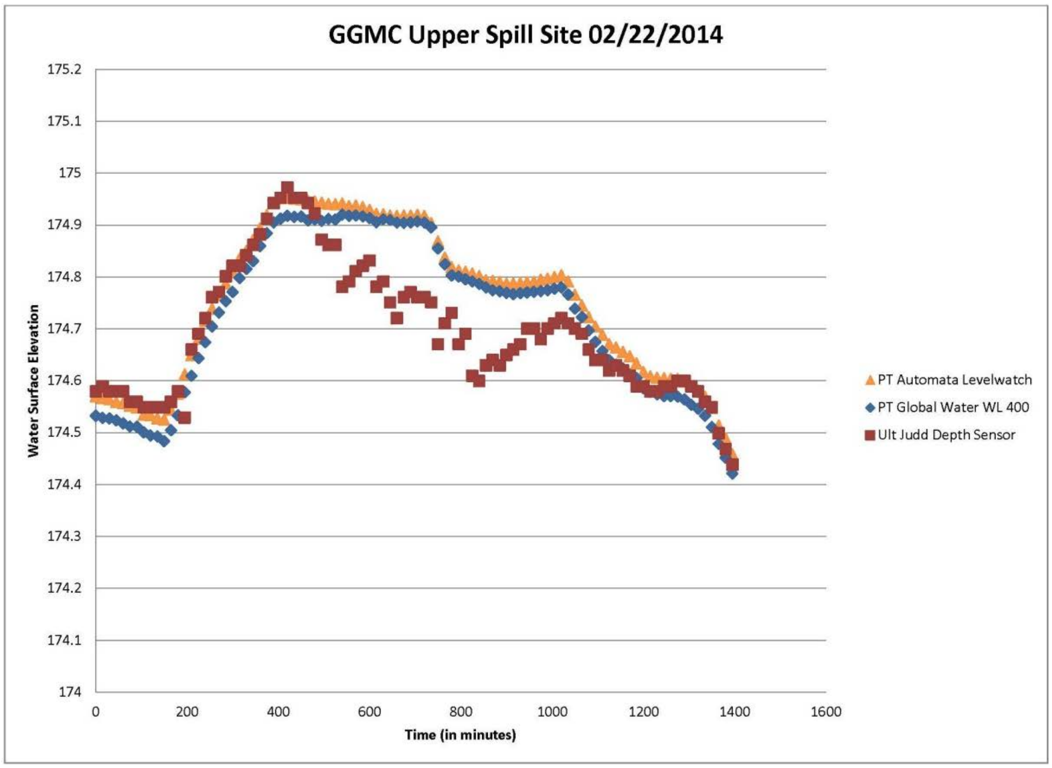

Figure 21. Water level data at the GGMC Upper Spill on 02/22/2014

Interesting similarities with the Figure 20 data are seen in Figure 21. At both sites the two submersible pressure transducers track reasonably close. From Figure 21 water levels computed from the Global Water WL 400 are slightly lower in value than levels computed with the Automata Levelwatch. The degree of agreement between the Judd ultrasonic sensor and the submersible pressure transducers at this site are better before 8:00 AM and after 7:00 PM with notably greater variance between the ultrasonic sensor and the submersible pressure transducers during the warmest part of the day.

In contrast to the performance of the APG ultrasonic sensor at the flume (Figure 20) which output higher level values during the warmest part of the day the Judd sensor readings during the daylight hours are noticeably below that of the other sensors at the upper spill site. This would appear to be a function of how temperature corrections are processed in by the different ultrasonic sensor manufacturers.

Recorded data from the same time period at the GGMC bifurcation is shown in Figure 22. The apparent discontinuities in the data plotted in Figure 22 appear to be a function of gate adjustments at the headworks of the Welton-Mohawk canal at this site. “Abrupt” level changes on the order of up to 0.02 feet are seen from one 15 minute polling cycle to the next at multiple times during the day at approximately 6 hour intervals.

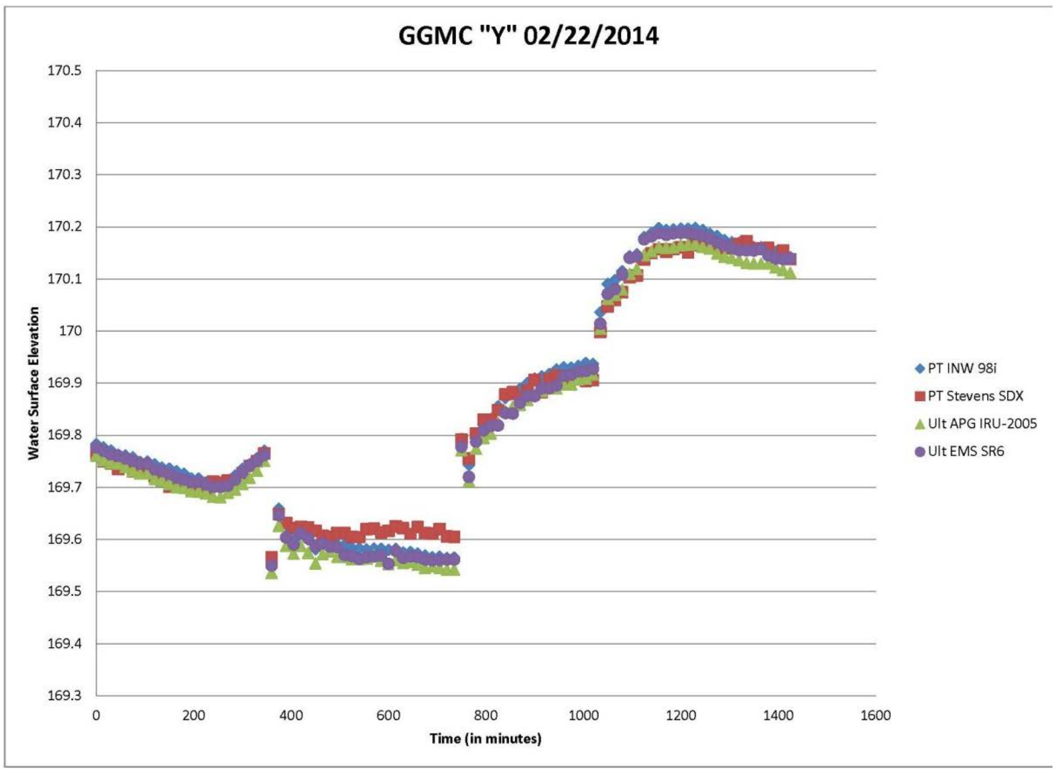

Figure 22. Water level data at the GGMC Upper Spill on 02/22/2014

Four level sensors are installed at this site, two each submersible pressure transducers and ultrasonic sensors. At this site three of the four sensors appear to be tracking in reasonably close agreement. The INW 98i submersible pressure transducer readings appear to be consistently slightly higher than readings from the EMS SR6 ultrasonic sensor with readings from the APG IRU-2005 ultrasonic sensor coming in with slightly lower values than the EMS unit. In this data set, a submersible pressure transducer appears to exhibit the greatest degree of variation from the “consensus” level being sensed. Later in the season it was noticed that the Stevens SDX pressure transducer had failed un-expectantly and would not output any data.

Minimal inference with respect to level sensing performance of the various instruments should be drawn from these 24 hour data record. These examples serve to illustrate some of the performance factors the project team is monitoring to assess troubleshooting issues that arise in this level sensor field evaluation. It was the researchers' intent to have irrigation district personal or remote cameras record a fixed staff gauge reading and time stamp to compare with the digital data. This did not occur during the testing but would be recommended to anyone performing similar analysis. If this data were available the researchers could have compared electronically sensed data against the staff reading to determine which sensors were reading accurate, if any. It is entirely possible that output from a sensor that does not appear to be tracking as close to others at a given site may well be providing output closer to the physical staff gage readings.

Project Summary

At the conclusion of this project, many of the field sites have been turned over to the respective districts. Any that have not been turned over have been removed from service.

The resources required for equipment installation and troubleshooting significantly exceeded projections at the beginning of this project. The travel distance from the Denver Federal Center to the field sites has to some degree been a limiting factor in being able to meet some of the goals for this project. Specifically, the body of level sensing data that has been acquired is a fraction of the information that had been anticipated during this project. However useful information has been determined during the data collection. The sensor technologies included in the project can provide interested parties with a sense of comparative performances of instruments that perform in a wetted (submersible pressure transducers) or non-wetted (ultrasonic and bubbler sensors) environment.

A key project objective was to monitor performance of the various level sensors over an extended period of time. A reasonable performance life expectation for the instruments in the study might be several years. A performance record over a time frame on the order of ten years is envisioned by the project team as a product that would represent significant value for Reclamation (and other) irrigation systems in assessing robustness and long-term affordability of electronic water level monitoring instrumentation. The project team will continue to explore any possibilities that might provide means of meeting this objective, including continued communication with districts that still have equipment installed.

Appendix A – Sensor Database Containing Calibrated Slope Values and Approximate Cost for Each Tested Sensor

Table A-1 contains a list of all the sensors that were tested during this project, with the approximate cost of each of the sensors at time of purchase. It should be noted that sensor pricing is adjusted regularly by individual manufacturers and no attempt will be made to keep the costs up-to-date. Many of the sensors were not calibrated a second time due to budget and or logistics in visiting the site. Those values are entered with a NA in the Cal 2 column.

Table A 1.

	Manufacturer	Model	Approximate Price	Have
Pressure Transducer	AGP	PT-500	460	3
	AutoMata	Level-Watch	280	3
	Endress Hauser	FMX21	955	2
	Endress Hauser	FMX167	1045	1
	GE Druck	PTX 1730	525	2
	Global Water	WL400	590	2
	Instrumentation Northwest	98i	540	4
	Keller	Acculevel	480	2
	Keller	Levelgage	315	4
	Stevens	SDX	355	4
Ultrasonic Downlooker	Judd Communications	-	655	4
	AGP	IRU-2005	495	3
	AutoMata	Ultra-Ultra	720	2
	EMS	SR6	250	5
	Flowline	EchoPod DL10-00	255	2
	Flowline	EchoPod DX10-00	235	2
	Global Water (EMS)	WL700	665	2
	Nova Lynx (APG)	IRU 9423	475	2
	Seimens "The Probe"	7ML12011EF00	860	3
Other	Float, Pully and Poteniometer	Custom USBR Design	150	3
	Bubbler - Control Design	CD 103-1	595	4
	Bubbler - OTT	CBS - Std Accuracy	1690	1

Table A 2.

Manufacturer:	Type:	Model:	S/N:	Range:	Cal 1 Slop	Cal 1 Date	Cal 2 Slop	Cal 2 Date
APG	Press Trans	PT-500	Y7687	0-5 psi	0.00354	2/10/2012	0.00355	6/11/2015
Automata	Press Trans	Level Watch	1202-194302-1.1	0-5 psi	0.00355	2/22/2012	0.00354	6/11/2015
Endress-Hauser	Press Trans	Waterpilot FMx21	F1009F001122	0-6 psi	0.00408	2/10/2012	0.00409	6/11/2015
Inst NW	Press Trans	98i	21111021	0-2.5 psi	0.00176	1/20/2012	0.00177	6/11/2015
Global Water	Press Trans	WL400-003	1113109867	0-3 ft	0.00099	1/20/2012	NA	
GE - Druck	Press Trans	PTX-1730	3357075	0-5 psi	0.00354	2/9/2012	NA	
Judd	Ultra	Judd	3746	0-34 ft	-0.00999	6/22/2011	0.01000	6/11/2015
EMS	Ultra	SR6	113012	0.8-6 ft	-0.00154	6/22/2011	-0.00156	6/11/2015
APG	Ultra	IRU 2005	I200500223	1-6 ft	-0.00153	2/22/2012	-0.00153	6/11/2015
Automata	Ultra	Ultra-Ultra	1202-194302-2.2 (4-20)	8-168 in	-0.00405	2/22/2012	-0.00407	
Siemens	Ultra	The Probe	PDB/C1162020	1-6 ft	-0.00152	2/13/2012	-0.00153	6/11/2015
APG	Ultra	IRU-9423	I942300025	1-8 ft	-0.00214	2/10/1012	NA	
Keller	Press Trans	Acculevel	59327	0-5 ft	0.00153	1/20/2012	DEAD	
Keller	Press Trans	Levelgage	59335	0-5 ft	0.00153	1/20/2012	DEAD	
Inst NW	Press Trans	98i	21111020	0-2.5 psi	0.00178	6/22/2011	0.00178	6/11/2015
Stevens	Press Trans	SDX	202322	0-5 ft H20	0.00178	6/22/2011	DEAD	
Flowline	Ultra	DLP10-0	110218-003664	2-49.2 in	0.00123	1/20/2012	DEAD	
Keller	Press Trans	Levelgage	91117	0-10 ft	0.00245	2/12/2015	NA	
APG	Press Trans				0.00282	2/12/2015	NA	
EMS	Ultra	SR6			-0.00123	2/12/2015	NA	
Keller	Press Trans	Levelgage	69932	0-5 ft	0.00154	2/9/2012	NA	
Flowline	Ultra	DLP10-0	110218-003662	13.5-49.2 in	-0.00091	1/20/2012	DEAD	
Inst NW	Press Trans	98i	21111017	0-2.5 psi	0.00177	1/20/2012	NA	
Siemens	Ultra	The Probe	PBD/X7130090	1-6 ft	-0.00151	6/1/2012	NA	
EMS	Ultra	SR6	121004	0.8-6 ft	-0.00155	2/13/2012	NA	
Endress-Hauser	Press Trans	FMX167	C7019C0108E	0-3 psi	0.00211	6/1/2012	NA	
Control Design	Bubbler	CD103-1	JK3538	0-5 psi	0.00358	6/27/2012	NA	
Keller	Press Trans	Levelgage	69921	0-5 ft	0.00153	2/9/2012	DEAD	
Judd	Ultra	Judd	3935	0-34 ft	-0.00997	6/1/2012	NA	
Control Design	Bubbler	CD103-1	LA3002	0-5 psi	0.00357	6/1/2012	NA	
APG	Press Trans	PT-500	Y7686	0-5 psi	0.00354	2/10/2012	NA	
APG	Ultra	IRU 2005	I200500224	1-6 ft	-0.00153	2/22/2012	DEAD	
Control Design	Bubbler	CD103-1	LA3002	0-5 psi	0.00357	6/1/2012	NA	
Automata	Press Trans	Level Watch	1202-194302-1.2	0-5 psi	0.00353	2/22/2012	0.00355	12/15/2015
Global Water	Press Trans	WL400-015	1113109866	0-15 ft	0.00396	1/20/2012	0.00400	12/15/2015
Judd	Ultra	Judd	3745	0-34 ft	-0.01008	1/20/2012	-0.00993	12/15/2015
Keller	Press Trans	Levelgage	59325	0-5 ft	0.00153	1/20/2012	DEAD	
Stevens	Press Trans	SDX	205648	0-5 ft	0.00167	2/9/2012	DEAD	
APG	Ultra	IRU-9423	I942300026	1-8 ft	-0.00214	2/10/1012	DEAD	
Endress-Hauser	Press Trans	Waterpilot FMx21	F6009C01122	0-6 psi	0.00411	9/26/2012	DEAD	
Automata	Ultra	Ultra-Ultra	1202-194302-2.1 (4-20)	8-168 in	-0.00405	2/22/2012	-0.00405	12/15/2015
GE - Druck	Press Trans	PTX-1730	3357074	0-5 psi	0.00354	2/9/2012	0.00349	12/15/2015
Judd	Ultra	Judd	3936	0-34 ft	-0.00997	6/1/2012	-0.00992	12/15/2015
Control Design	Bubbler	CD103-1	LA3004	0-5 psi	0.00356		0.00356	12/15/2015
APG	Press Trans	PT-500	Y7685	0-5 psi	0.00354	2/10/2012	0.00359	12/15/2015
Automata	Press Trans	Level Watch	1202-194302-1.3	0-5 psi	0.00356	2/22/2012	0.00355	12/15/2015
Flowline	Ultra	DX10-0	120112-002107	2-49.2 in	0.00102	2/13/2012	NA	
Keller	Press Trans	Acculevel	59352	0-5 ft	0.00153	1/20/2012	0.00153	12/15/2015
Stevens	Press Trans	SDX	202323	0-5 ft	0.00159	1/20/2012	DEAD	
Inst NW	Press Trans	98i	21111019	0-2.5 psi	0.00177	1/20/2012	0.00176	12/15/2015
Stevens	Press Trans	SDX	205647	0-5 ft	0.00158	2/9/2012	DEAD	
APG	Ultra	IRU 2005	I200500222	1-6 ft	-0.00153	2/22/2012	-0.00153	12/15/2015
EMS	Ultra	SR6	121006	0.8-6 ft	-0.00156	2/13/2012	NA	
Siemens	Ultra	The Probe	PDB/C1162021	1-6 ft	-0.00160	2/13/2012	-0.00159	12/15/2015
Control Design	Bubbler	CD103-1	LA3001	0-5 psi	0.00356	6/1/2012	NA	
EMS	Ultra	SR6	113013	0.8-6 ft	-0.00156	1/20/2012	NA	
EMS	Ultra	SR6	121005	0.8-6 ft	-0.00155	2/13/2012	NA	
Flowline	Ultra	DX10-0	120112-002106	2-49.2 in	0.00102	2/13/2012	NA	
Global Water (EMS)	Ultra	SR35	1113109872	1.5-35 ft	-0.01024	1/20/2012	NA	
Global Water (EMS)	Ultra	SR6	1104108287	0.8-6 ft	-0.00154	1/20/2012	NA	
APG	Press Trans		z4751	4-20 mA	NA		0.00282	12/15/2015
Keller	Press Trans	Levelgage	91117	4-20 mA	NA		0.00245	12/15/2015
APG	Press Trans	PT500	Z4750	4-20 mA	NA		0.00282	12/15/2015