Water Level Sensor Testing

November 2002/
December 2003
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Irrigation Training and Research Center

December 2003
EXECUTIVE SUMMARY

The findings presented here are the continuation of a series of studies begun in 1998 by the Irrigation Training and Research Center (ITRC) at California Polytechnic State University (Cal Poly), San Luis Obispo, California, on behalf of the Mid-Pacific Region of the United States Bureau of Reclamation (USBR) to test water level sensors under a variety of hydraulic conditions. This report is intended as a supplement to the original 1999 report, entitled “Water Level Sensor and Datalogger Testing and Demonstration” (ITRC Report No. R-01-010), which describes the testing processes in detail and presents detailed results for the first 17 sensors tested. The 1999 report can be accessed through the ITRC website (www.itrc.org). The 2003 research, summarized in this report, includes the testing of five new sensors.

The goals for the original project were to determine the best way to monitor water level, and to develop a fast method for appraising sensors considered for irrigation district applications. This research addresses the need for water level sensors that are relatively simple to use and are very accurate over a broad range of hydraulic conditions. The use of water level sensor technologies, including ultrasonic sensors, pressure transducers, bubblers, and float sensors, was investigated for applications in a range of canals, reservoirs, and stilling wells. The testing results have been summarized with decision flow charts and rating tables for cross comparison.

During laboratory testing conducted at the Cal Poly Water Delivery Facility, the water level sensors were installed in a portable monitoring demonstration unit built by ITRC. The sensors were tested under different hydraulic conditions and the data gathered was used to evaluate the performance of each of the water level sensors. The characteristics evaluated included long-term trending, time lag, output stability, linearity and hysteresis, drying effects, and the effects of air temperature.
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INTRODUCTION

Background

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University (Cal Poly), San Luis Obispo, was contracted on behalf of the USBR, Mid-Pacific Region to conduct research on water level measurement technologies that have potential applications in irrigation water distribution and delivery systems. ITRC began the first phase of this water level sensor study in 1999 by developing testing procedures and originally testing 17 water sensors. Since that time, additional sensors have been tested using the same procedures and the same equipment, in order to ensure comparable results with all tested products. This present report, which summarizes the findings of the more recent tests conducted at the Cal Poly Water Delivery Facility, was intended to be the first of several anticipated additions to the original study.

Sensors tested for this project are those commonly used in irrigation applications:
- ultrasonic sensors
- float sensors
- submersible pressure transducers
- bubbler sensors

As part of this study, ITRC has worked with selected manufacturers in the industry to obtain test units and evaluate their performances based on a standard set of specifications. The information and data contained in this report are being used to improve manufacturer specifications in order to increase the accuracy and reliability of the water level measurements provided by these devices, and to determine the feasibility, reliability and suitability of such technologies in their desired small-scale applications.
**METHODODOLOGY**

**Equipment Setup**

A testing setup was developed by ITRC in order to create a standard for a continuous sensor evaluation project. The setup includes a portable SCADAPak, a computer with the appropriate software, a sensor testing tank, a holding tank, two pumps, and the appropriate sensors connected to the SCADAPak. This simple setup makes it possible for ITRC to easily and quickly conduct similar studies in the future. The format of the evaluation procedure also allows for other sensors and updates to be added to the series of testing.

![Figure 1. Photo of water level testing setup](image)

In the testing procedure, two variables were monitored: the water level and the air temperature. Two sets of tests were performed. During the first set of tests, three new sensors monitored the water level: a Keller 46W pressure transducer, a BelTech BTS bubbler, and a Celesco PT1MA float. A Druck PTX 1230 water level sensor was used for control purposes during testing. The air temperature was monitored using three thermocouples. The second set of tests measured and compared two submersible pressure transducers: an Endress+Hauser Waterpilot FMX 167, and a Stevens PS600. During this test, the Druck PTX 1230 was used for the control, and a Druck PTX 1830 was run alongside the new sensors for comparison.

The software program LOOKOUT was used to display all sensor test results. The program was set up to log data (results) to a CSV (comma separated variable) file in Excel, and was subsequently analyzed. For further information on the SCADA setup or LOOKOUT, refer to the ITRC reports “Remote Monitoring and Control” and “LOOKOUT Instructions for a Portable SCADA System.”
Sensor Testing

For this study, float sensors, submersible pressure sensors, and bubbler pressure sensors were tested. Several ultrasonic sensors were evaluated for the 1999 report, but no new sensors in that category were tested for this phase.

All sensors were tested for mechanical characteristics such as power requirements, ease of installation, and simplicity of instructions. More importantly, the sensors were also tested for the following performance features:

- Long-term trending (reliability)
- Air and water temperature effects (performance during fluctuating temperatures)
- Drying effects
- Output stability
- Time lag (water level response time)
- Linearity and hysteresis

Several other characteristics, such as foam penetration effects, wave damping, DC power requirement, and others, were used in the testing of sensors for the 1999 report, but are no longer considered because there was either little or no variation among the sensors, or it was found that those characteristics did not affect the sensors’ performance. Only those characteristics listed above were tested for the current report.

Detailed explanations of characteristics and testing methods can be found in the 1999 ITRC report “Water Level Sensor and Datalogger Testing and Demonstration.” Below are brief descriptions of the features tested for the current research.

**Long-term Trending**

This test was set up to allow the pumps to maintain a high point setting and a low point setting for a certain amount of time. Three long-term stability tests were run so that the data could be compared. When all tests were complete the data was analyzed separately for each test and for each sensor, and graphs were developed. By examining and comparing the graphs it was possible to determine which sensors did well over long periods of time.

**Temperature Effects**

This test was set up to induce a change in the air temperature. A canvas tarp was used to cover the testing area, so that the heat would be focused towards the tank and the sensors. An electric (portable) heater was used to create heat under the tarp. On the first day of testing, the air temperature in the tank was raised and maintained for two hours. The enclosure was allowed to cool for two hours, and then heated again for two hours. Overnight, the temperature dropped to about 17 degrees Celsius. On the second day of testing, the air temperature was raised and maintained for six consecutive hours. Once testing was complete, a graph was developed for each sensor showing time (hours) versus water level (inches).
**Linearity and Hysteresis**

For this test the sensors were tested at eight different water levels. At each water level, a settling time of two minutes was used. Ten readings were taken at each water level at a poll rate of once per second. Therefore, the pumps were only off for two minutes and ten seconds at each level. The true water level was read off a metric staff gauge and recorded for each data point. The data was then analyzed by plotting sensor output (in raw numbers) versus the actual water depth in inches. **Hysteresis** is the maximum difference in output, at any measured value within the specified range, when the value is approached first with increasing and then with decreasing measurements. **Linearity** is the closeness of a calibration curve to a specified straight line.

**Time Lag**

For this test, the water was raised for a set amount of time, maintained at that level for five minutes, and then dropped back down to its original level. Once the original level was maintained, the second pump was instantly turned on to repeat the cycle. Individual graphs were developed for each sensor showing time (seconds) versus water level (inches). The graphs made it possible to analyze time lag by looking at how well the sensor readings matched the actual water levels as the pumps were raising or lowering the water depth.

**Output Stability**

For this test, the water level of 18 inches was maintained in the test tank for two hours. A plot of the output from each sensor was analyzed for stability (how much it oscillated around the average reading). The graphs were set up to show time (minutes) versus water level (inches). An ideal sensor would show a straight line (throughout the test) at the water level set point.

**Drying Effects**

This test allowed the sensors to be dried out for a short period of time in order to determine how well they reacted to drying. Data was logged for two hours before the sensors were removed from the tank to dry for five days. After the drying period the sensors were placed back into the water and data was logged for two hours after the drying period. The data was analyzed by plotting the water level versus time to see how drying each sensor affected the accuracy of its readings.
TEST RESULTS

Selecting a Sensor

Each of the sensors was rated on a scale from one to ten, based on the performance of all sensors, (one being the worst and ten being the best). The sensors were also rated on the ease of installation and calibration, each individual performance test, and overall accuracy. The flow chart below was developed to assist in the selection of a sensor type for various applications.

Figure 2. Water level sensor selection guide
Ultrasonic Sensors

General. Ultrasonic sensors transmit a series of cone-shaped sound waves through the air. These sound pulses reflect off the liquid surface and are in turn received by the sensor, which measures the time interval between the transmitted and received signal. Electronics then convert this time interval into a distance measurement using the speed of sound in air. No part of the sensor ever touches the water – a distinct advantage of this sensor type.

<table>
<thead>
<tr>
<th>General Advantages</th>
<th>General Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Non-contacting, so are not affected by dirty water, floating debris, or aquatic wildlife</td>
<td>- Affected by air temperature fluctuations</td>
</tr>
<tr>
<td>- Not affected by fluctuating water temperatures</td>
<td>- May reflect off floating foam or debris</td>
</tr>
<tr>
<td>- Not affected by high flow rates</td>
<td>- Must be aligned precisely</td>
</tr>
<tr>
<td>- Easy to calibrate</td>
<td>- May be affected by turbulent water (a stilling well may be required)</td>
</tr>
<tr>
<td>- Low maintenance</td>
<td>- May display misleading readings if echo is lost</td>
</tr>
<tr>
<td>- Excellent linearity and lack of significant hysteresis</td>
<td>- Large beam angles cannot be used in constricted spaces</td>
</tr>
<tr>
<td>- Can withstand freezing temperatures</td>
<td>- Some sensors damaged by flooding (i.e., they are not waterproof)</td>
</tr>
<tr>
<td>- Long-term reliability</td>
<td>- Some delay between the time when power is first applied and the first output</td>
</tr>
</tbody>
</table>

Figure 3. Flow chart for selecting an ultrasonic sensor
Evaluation results for all ultrasonic sensors tested by ITRC are found below. No new ultrasonic sensors have come on the market, so there have been no ultrasonic sensors tested by ITRC since the 1999 report.

Table 1. Evaluation results for all ultrasonic sensors tested by ITRC

<table>
<thead>
<tr>
<th>Sensor Brand</th>
<th>Sensor Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Compatibility with Other Brand Dataloggers</th>
<th>Water Level Display?</th>
<th>Performance During Fluctuating Air Temperature</th>
<th>Performance During Fluctuating Water Temperature</th>
<th>Foam Penetration</th>
<th>Durability in Dirty Water</th>
<th>Ability to Handle Freezing</th>
<th>Wave Damping</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>DC Power Requirement</th>
<th>Long Term Reliability</th>
<th>List Price</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badger 2500</td>
<td>9 8 9 10 Yes</td>
<td>3 10 10 10 10 A** 10 8 5 10 7 10</td>
<td>10 $1,600 8</td>
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<tr>
<td>Bailey-Fischer &amp; Porter 50US300 0</td>
<td>7 8 7 10 Opt. 4 10 2 10 10 9 10 7 10 10 10 AC only 10 $1,900 7</td>
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<tr>
<td>Endress + Hauser Prosonic T FMU 230</td>
<td>5 8 5 10 Opt. 2 10 2 10 10 10 A** 10 8 6 10 9 10 $585 7</td>
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<tr>
<td>Lundahl DCU-7110</td>
<td>10 8 9 10 On Laptop 1 10 1 10 1 10 7 8 10 7 10 $615 7</td>
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<tr>
<td>Miltronics The Probe</td>
<td>9 9 8 10 Yes 2 10 5 10 10 10 A** 10 2 8 10 9 NA $695 8</td>
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</tr>
</tbody>
</table>

* Error may have been introduced in the RS-232C to 4-20 MA output conversion.
** Increasing the wave damping effect will decrease the water level response time.
10 = excellent; 1 = horrible; NA = not available; A = adjustable, SW = stilling well required; SW? = stilling well recommended; Opt. = optional
**Float Sensors**

General. There are two basic types of float sensor, one which involves a pulley and counterweight and one which utilizes a spring to produce an upward force on the float cable.

![Pulley & Counterweight vs Spring-loaded](image)

**Figure 4. Two basic float sensor models**

In the pulley and counterweight version, a counterweight provides tension to a beaded cable. Notches in the pulley mesh with cable beads, forcing the pulley to turn as the water level rises or lowers and the float goes up or down. This version of the float sensor is the more difficult to install and calibrate. The pulley has a “travel stop” for both the clockwise and counterclockwise directions. During installation, the user must ensure that neither travel stop will be hit between the highest and lowest expected positions. Additionally, the float must be placed on the correct side of the pulley.

In the second model, the cable wraps and unwraps around a spring-loaded shaft inside the sensor. To install, simply hook a float to the cable and lower it to the water. If the distance between the highest expected water level and the sensor is more than about 20 cm, extra cable should be installed between the standard sensor cable and the float instead of purchasing a longer-range sensor. This will ensure the highest possible resolution across the measurement range.

Turns of the pulley or spring-loaded shaft change the resistance of a potentiometer within the sensor housing, changing the output electrical voltage or current. Though the electronics are less complex than in an ultrasonic sensor, they still must be mounted directly over the water. If the water level fluctuates around a certain level for an extended period of time (dithering), the potentiometer may wear out quickly.
General Advantages
- Not affected by dirty water
- Not affected by water temperature
- Not affected by foam
- Low effect of changing air temperatures
- Low maintenance
- Low cost
- Can withstand freezing temperatures
- No delay between the time when power is first applied and the first output

General Disadvantages
- Stilling well required
- Cable may slip (pulley and counterweight type only)
- Easily vandalized unless enclosed
- May wear if water level remains at one position for extended periods
- Salt build-up may freeze the pulley
- Some sensors damaged by flooding

The Celesco PT1MA was the only new float sensor tested. Therefore, it was the only new sensor incorporated into the selection guide below.

Figure 5. Float sensor selection guide

Some of the differences between the two Celesco sensors (tested) are listed below the flow chart. The Celesco PT420 is typically used for gate movement and calibration. It is common to find a PT420 used in combination with a SCADA system. The PT1MA is used in several districts and other applications for flow studies because of its reliability and low cost.
Evaluation results for all float sensors tested by ITRC are found below. The new sensor tested for this report is listed in bold.

**Table 2. Evaluation results for all float sensors tested by ITRC**

<table>
<thead>
<tr>
<th>Sensor Brand</th>
<th>Sensor Model</th>
<th>Sensor Type</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Base of Calibration</th>
<th>Compatibility with Other Brand Dataloggers</th>
<th>Water Level Display?</th>
<th>Performance During Fluctuating Air Temperature</th>
<th>Performance During Fluctuating Water Temperature</th>
<th>Foam Penetration</th>
<th>Durability in Dry Water</th>
<th>Ability to Handle Freezing</th>
<th>Wave Damping</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>DC Power Requirement</th>
<th>Long Term Reliability</th>
<th>List Price</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celesco</td>
<td>PT420</td>
<td>Float</td>
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<td>7</td>
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<td>Celesco</td>
<td>PT1MA</td>
<td>Float</td>
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<td>8</td>
<td>-</td>
<td>No</td>
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</tbody>
</table>

* Error may have been introduced in the RS-232C to 4-20 MA output conversion.
** Increasing the wave damping effect will decrease the water level response time.

10 = excellent; 1 = horrible; NA = not available; A = adjustable, SW = stilling well required; SW? = stilling well recommended; Opt. = optional
General. The PT1MA adds a 4 – 20 mA position feedback signal to Celesco’s compact line of cable-extension transducers. The PT1MA is available with full stroke ranges from as little as 2 inches up to 50 inches with adjustable zero and span settings to precisely match the full scale output to your exact measurement range. The PT1MA offers several options including forward and reverse 0–20 and 4–20 mA output signals, alternate measuring cable exits and a couple of different electrical connection options.

Test Results: The Celesco PT1MA rated well when compared to other float sensors. The overall rating on a scale from one to ten was a nine (Table 3). The sensor produced accurate readings when the water level was held constant for a period of time as well as when the water level was continuously changing. It earned its lowest rating (a 6) during the air temperature test. As shown in Figure 7, when the air temperature rose, the sensor’s reading dipped slightly. However, the Celesco PT1MA did well in its other areas. There were a few jumps in the water level during the output stability test reading (Figure 9) due to the resolution of the sensor, but other than those jumps, the graph showed a straight line at a constant water level.

Table 3. Evaluation ratings for Celesco PT1MA

<table>
<thead>
<tr>
<th>Sensor Brand and Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Performance During Fluctuating Air Temperature</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>Long Term Reliability</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celesco PT1MA</td>
<td>NA</td>
<td>9</td>
<td>8</td>
<td>6</td>
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<td>10</td>
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</table>

Figure 6. Celesco PT1MA
Figure 7. Celesco PT1MA temperature test results

Figure 8. Celesco PT1MA long-term test

Figure 9. Celesco PT1MA drying test results

Figure 10. Celesco PT1MA output stability test results
Submersible Sensors

General. At any given level, both liquids and gasses exert an equal pressure in all directions. Water pressure increases linearly with depth of submergence. For every 70 cm (2.31 ft) of water, pressure increases by 1 PSI. The pressure difference between the atmosphere and the water around the sensor head produces a force on a flexible diaphragm. Electronics convert the force on the diaphragm into a proportional electric signal. All submersible pressure sensors studied had a standard or optional 4 – 20 mA output signal.

![Figure 11. Basic submersible pressure sensor layouts](image)

The vent tube is an important component in submersible pressure transducer. Transducers measure the water and air pressure combined, and without a vent tube, the sensors cannot distinguish between a change in water pressure caused by water level, and changes in barometric pressure. For this study, all pressure sensors were equipped with vent tubes, and hourly atmospheric data for San Luis Obispo was compared with data from the tests for all sensors. No correlation was found between the sensor results and barometric pressure changes during testing.

Desiccant. The vent tube must remain dry, necessitating the use of a desiccant or bellows at the open end. Desiccant is a chemical that absorbs water vapor. Desiccants used with pressure sensors generally change color when in need of replacement. As an alternative to desiccant, bellows or an air bladder can separate the air within the vent tube from the atmosphere while allowing the pressures to equilibrate. Absolute pressure sensors do not have vent tubes and therefore require no desiccant and lower maintenance. However, some type of barometric sensor would be required to provide a reading to the datalogger or PLC, where the pressure sensor output can be corrected for changes in atmospheric pressure.

Installation. A submersible pressure sensor is very easy to install—simply lower it into a stilling well so that the water intake ports are about 10 cm below the lowest water level that is of interest to monitor. To avoid damage to the sensor, do not place it where it could go deeper than the overpressure rating. An overpressure rating of 3x for a 0 – 3-m range sensor means that it will be damaged at depths greater than 9 m.

If possible, install the sensor deep enough so that it will be below ice that may form on the surface. If the water could freeze around or inside the sensor, it must be removed from the water before any ice forms. A sensor can easily be crushed as water freezes around it.
When installing, lower the transducer slowly into the water. To avoid permanent damage to the diaphragm or electronics, do not drop the sensor or strike it against a hard object. Secure the cable so that it will not slip and change the depth of the sensor. Cable harnesses are available from some manufacturers. If the sensor is installed in a deep well, the large amount of cable may stretch over time due to its own weight. Druck includes a Kevlar cord inside the cable jacket to avoid stretching. Otherwise, some other type of support cable should be used.

<table>
<thead>
<tr>
<th>General Advantages</th>
<th>General Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to install</td>
<td>Damaged by ice</td>
</tr>
<tr>
<td>Electronics are hidden from view</td>
<td>Can clog in dirty water</td>
</tr>
<tr>
<td>Low power draw</td>
<td>Susceptible to malfunction if often allowed to dry</td>
</tr>
<tr>
<td>Not usually affected by air temperature fluctuations</td>
<td>May hang up debris</td>
</tr>
<tr>
<td>Not affected by foam</td>
<td>Adversely affected by water temperature fluctuations</td>
</tr>
<tr>
<td>Almost no time lag</td>
<td>Range is not adjustable</td>
</tr>
<tr>
<td>No delay between the time when power is first applied and the first output</td>
<td>Desiccant must be periodically replaced</td>
</tr>
<tr>
<td></td>
<td>Stilling well often required</td>
</tr>
<tr>
<td></td>
<td>Lightning protection recommended</td>
</tr>
<tr>
<td></td>
<td>Damaged if submerged much too deep</td>
</tr>
<tr>
<td></td>
<td>Easily damaged by aquatic wildlife</td>
</tr>
</tbody>
</table>
The Keller 46W, Endress+Hauser FMX 167, and Stevens PS600 have been incorporated into the selection guide.

Submersible pressure transmitter selection guide
Among irrigation districts and farmers, the most widely used sensor for flow measurement studies is the Druck 1230 (0-1 psi range). Evaluation results for all submersible sensors tested by ITRC are found below. The new sensors tested for this report are listed in bold.

Table 4. Evaluation results for all submersible sensors tested by ITRC

<table>
<thead>
<tr>
<th>Sensor Brand</th>
<th>Sensor Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Compatibility with Other Brand Data Loggers</th>
<th>Water Level Display?</th>
<th>Performance During Fluctuating Water Temperature</th>
<th>Foam Penetration</th>
<th>Water Level Display?</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Handle Freezing</th>
<th>Wave Damping</th>
<th>Long Term Reliability</th>
<th>DC Power Requirement</th>
<th>List Price</th>
<th>Overall Rating</th>
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<td>Automata</td>
<td>LEVEL-WATCH</td>
<td>10</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>Opt.</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>1</td>
<td>SW?</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>7</td>
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<td>Global Water</td>
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<td>10</td>
<td>No</td>
<td>9</td>
<td>3</td>
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<td>1</td>
<td>SW?</td>
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<td>9</td>
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<td>Stevens</td>
<td>PS600</td>
<td>10</td>
<td>9</td>
<td>10</td>
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<td>No</td>
<td>10</td>
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<td>10</td>
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<td>1</td>
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<td>10</td>
<td>9</td>
<td>1</td>
<td>SW?</td>
<td>10</td>
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<td>Hauser</td>
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<td>10</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>SW?</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>8</td>
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<td>10</td>
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<td>No</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>SW?</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>7</td>
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<td>Instrumentation Northwest</td>
<td>KPSI 210S</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>No</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>SW?</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>4</td>
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<td>SDT-II</td>
<td>10</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>No</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>SW?</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>NA</td>
<td>9</td>
<td>8</td>
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<tr>
<td>Keller 46W</td>
<td>Series 46</td>
<td>NA</td>
<td>9</td>
<td>9</td>
<td>-</td>
<td>No</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Error may have been introduced in the RS-232C to 4-20 MA output conversion.
** Increasing the wave damping effect will decrease the water level response time.
10 = excellent; 1 = horrible; NA = not available; A = adjustable, SW = stilling well required; SW? = stilling well recommended; Opt. = optional
Druck PTX 1230/1830

(203) 746-0400
http://www.druck.com/usa

General. For the current testing, a Druck PTX 1230 was used as the control sensor to measure the water level because of its proven reliability, as well as its excellent performance in the field and during earlier tests. Another sensor in the same series, the Druck PTX 1830, was tested for the 1999 report and performed well among the submersible pressure transducers, demonstrating especially impressive accuracy during fluctuating water temperatures. Because of its reliability, the PTX 1830 was tested alongside the new sensors in this phase as a standard against which the new sensors could be compared. The only difference between the PTX 1230 and 1830 is that the PTX 1230 is rated at ±0.25% full-scale accuracy, while the PTX 1830 is rated at ±0.1% full-scale accuracy.

Photos obtained at www.druck.com

Figure 13. Druck PTX 1230 (l.) and 1830 (r.)
Keller 46W Pressure Transducer

(877) 2-KELLER
http://www.Keller46W-Druck1230.com

General. The Keller 46W submersible water level transducer is marketed for its rugged build and good linearity. The Kavlico low pressure capsule measures the pressure generated by the head of water above it, and is enclosed in a sealed stainless steel housing with the diaphragm protected by a gold layer. A neoprene O-ring seals the sensing diaphragm to the housing. The transmitter circuit is based on the Keller “Progres” ASIC, and can be reprogrammed by the user before or after installation (programmable version only).

Test Results: This sensor did not perform well, despite nearly perfect linearity and hysteresis results and very little variation in output due to increased air temperature (Figure 15). Over the series of tests the Keller 46W slowly began reading higher than the actual water level. This problem started approximately 280 hours (11.7 days) after calibration, during one of the long-term stability tests. The higher reading continued throughout the remainder of the testing, as shown in Figures 16 and 18.

The high readings were apparent in the time lag and drying tests as well. After drying, the Keller 46W showed the same pattern as the long-term trending results. The readings started out at one level and slowly increased as time went on. The graph in Figure 17 shows the output from the sensor before and after the five-day drying period. Because of these progressively higher readings, the Keller proved to be unreliable over time.

Table 5. Evaluation ratings for Keller 46W

<table>
<thead>
<tr>
<th>Sensor Brand and Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Performance During Fluctuating Air Temperature</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>Long Term Reliability</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keller 46W</td>
<td>NA</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
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</table>
Figure 15. Keller 46W temperature test

Figure 16. Keller 46W long-term stability test

Figure 17. Keller 46W drying test

Figure 18. Keller 46W output stability test
Stevens PS600 Pressure Transducer

(800) 452-5272
http://www.stevenswater.com

General: It is important to note that the PS600 is no longer being manufactured by Stevens. The approximate cost listed in the sensor comparison chart at the beginning of this section is for the PS700, which is the latest in the series. The PS700 has the same specifications and can be substituted for PS600.

Test Results: The results for this sensor demonstrated very good performance. Overall (among the submersible pressure transmitters) the Stevens PS600 rated an eight on a scale from one to ten. The sensor gave nearly perfect linearity and hysteresis results and showed very little variation in output due to increased air temperature. During nearly every test, the Stevens’ output matched the output of the Druck 1230 control sensor, as shown in Figures 20 through 23.

Table 6. Evaluation ratings for Stevens PS600

<table>
<thead>
<tr>
<th>Sensor Brand and Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Compatibility with Other Brand Dataloggers</th>
<th>Performance during Fluctuating Air Temperature</th>
<th>Performance during Fluctuating Water Temperature</th>
<th>Foam Penetration</th>
<th>Durability in Dirty Water</th>
<th>Ability to Handle Freezing</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>DC Power Requirement</th>
<th>Long Term Reliability</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stevens PS600</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>10</td>
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<td>9</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>
Water Level Sensor Testing

Figure 20. Stevens temperature test results

Figure 21. Stevens long-term test results

Figure 22. Stevens drying test results

Figure 23. Stevens output stability test results
Endress+Hauser Waterpilot FMX 167 Pressure Transducer

(888) ENDRESS
http://www.us.endress.com

General: The Endress+Hauser Waterpilot FMX 167 pressure transducer is a submersible level transmitter with a ceramic pressure sensor for use in applications where coating and fouling can disable other submersible transducers. The Waterpilot is available with nine permanently calibrated measuring ranges from 3 to 600 ftH20 to ensure use in all standard applications (optional application specific range). Due to its compact outer diameter of only 0.87" (22mm), it is ideal for use in 1" well casings as well. As an option, a function permitting the simultaneous measurement of level and temperature is available (integrated temperature sensor Pt 100).

![Figure 24. Endress+Hauser Waterpilot FMX 167](image)

Benefits of the Waterpilot FMX 167 include permanent hermetically sealed cable probe, high mechanical resistance to overload and aggressive media, high-precision and long-term stability ceramic measuring cell, potted electronics and 2-filter pressure compensation system, which provide resistance to climatic changes. The FMX 167 has electronics comprising 4-20mA output signal and integrated overvoltage protection. Drinking water approvals include KTW, NSF, and (ACS in preparation). The sensor is certified to ATEX II 2 G/EEx ia, FM and CSA. Its rugged terminal housing (IP 66/IP 67) includes a GORE-TEX filter for pressure protection. Complete measuring point solutions are available through comprehensive accessories from Endress+Hauser.

Test Results: Overall (among the submersible pressure transmitters) the Endress+Hauser Waterpilot FMX 167 gave nearly perfect linearity and hysteresis results and showed little variation in output due to increased air temperature, other than a slight dip in readings when the air temperature spiked. After drying, the output was slightly elevated and stayed at this level (Figure 27). This reading was slightly more pronounced than with the other pressure sensors tested; however, the difference was only about five hundredths of an inch. Therefore, its rating in the drying test is consistent with other similar pressure transmitters.
### Table 7. Evaluation ratings for Endress+Hauser FMX 167

<table>
<thead>
<tr>
<th>Sensor Brand and Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Compatibility with Other Brand Dataloggers</th>
<th>Performance During Fluctuating Air Temperature</th>
<th>Performance During Fluctuating Water Temperature</th>
<th>Foam Penetration</th>
<th>Durability in Dirty Water</th>
<th>Ability to Handle Freezing</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>DC Power Requirement</th>
<th>Long Term Reliability</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endres Hauser Waterpilot FMX 167</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>10</td>
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<td>8</td>
<td>8</td>
<td>8</td>
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</tbody>
</table>
Water Level Sensor Testing
ITRC Report No. 04-005

Figure 25. Endress+Hauser FMX 167 temperature test
Long-Term Reliability

Figure 26. Endress+Hauser FMX 167 long-term test

Figure 27. Endress+Hauser FMX 167 drying test

Figure 28. Endress+Hauser FMX 167 output stability test

Irrigation Training and Research Center
Bubbler Sensors

General. Bubblers measure water level by sensing the pressure of one or more air-filled tubes or chambers that have an open, submerged bottom end. The higher the water level and therefore the higher the static pressure at the end of the bubbler tube, the more air pressure is needed to fill the tube. Air is often continually bled out of each tube for three reasons: 1) to keep dirt and debris out of the line, 2) to lower the effect of a leak, and 3) to keep the air in the tube from dissolving in the water. The pressure in the tube minus atmospheric pressure is proportional to water level. Figure 29 shows the three basic layouts for bubbler pressure sensors.

![Figure 29. Basic bubbler pressure sensor layouts](image)

Installation. Install the most shallow tube outlet about 15 cm below the lowest water level that is of interest to monitor. Bubbler lines must be securely installed to avoid any change in position of the submerged end. The tube may bend or curl over time, so secure it as close to the submerged end as possible. Some manufacturers provide a metal tube (which is connected to the end of the flexible plastic tubing) to help ease installation.

Seal the plastic tubing around the metal with a hose clamp or piece of heavy-duty wire to avoid leaks. If a metal end-piece is not supplied, cut the submerged end at a 45° angle (except for a captive air system). Use as little tubing as needed, and run it downhill the entire way from the electronics to the submerged end if possible. This will help to keep water vapor condensation from accumulating in the line. Mount the electronics above the high water line—tubing can be run for long distances if required. Since any plastic tubing can crack if exposed to the sun too long, it should be run through PVC pipe or conduit in long-term installations.
General Advantages
- Easy to install and calibrate
- Electronics can be installed away from the water
- Only inexpensive bubbler tubing contacts the water
- Not significantly affected by air or water temperature fluctuations
- Not significantly affected by drying
- Not affected by foam
- Not easily clogged by dirty water

General Disadvantages
- May hang up debris
- Requires one of the following:
  1. A large nitrogen tank, which must be periodically refilled
  2. A power-hungry air compressor with desiccant packs that must be periodically replaced
- High list price
- Sensor output may lag behind a changing water level

The BelTech BTS bubbler was incorporated into the flow chart below to assist in the selection of the appropriate sensor.

Figure 30. Bubbler selection guide

Several other differences exist between sensors that are not apparent in the flow charts above. With some further research, the differences can be determined and the perfect sensor for each application can be selected. Contact information for each of the sensors can be found in Appendix A of this report.
Evaluation results for all bubbler sensors tested by ITRC are found below. The new sensor tested for this report is listed in bold.

Table 8. Evaluation results for all bubbler sensors evaluated by ITRC

| Sensor Brand          | Sensor Model | Sensor Type | Simplicity and Correctness of Instructions | Base of Installation | Compatibility with Other Brand Data Loggers | Water Level Display? | Performance During Fluctuating Air Temperature | Performance During Fluctuating Water Temperature | Foam Penetration | Durability in Dry Water | Ability to Handle Freezing | Wave Damping | Water Level Response Time | Linearity and Hysteresis | Output Stability | Ability to Read Quickly After Extended Dry Period | DC Power Requirement | Long Term Reliability | List Price | Overall Rating |
|-----------------------|--------------|-------------|--------------------------------------------|----------------------|---------------------------------------------|----------------------|-----------------------------------------------|-----------------------------------------------|-----------------|-------------------------|-----------------------------|--------------|----------------------------|------------------------|-------------------|---------------------------------|-------------------------|------------------|-----------|----------------|}
| American Sigma        | 950          | Bubbler     | 6                                          | 7                    | 7                                           | 10                   | Yes                                          | 9                                            | 9               | 10                      | 10                          | 10           | 10                         | 10                     | 8                | 10                 | 8                       | 10             | $4,060    | 8         |                |
| Campbell Scientific   | DB1          | Double Bubbler | 1                                          | 1                    | 1                                           | 1                   | No                                           | 5                                            | 10              | 10                      | 10                          | 10           | 10                         | 10                     | 1                | 10                 | 5                       | 2               | $1,560    | 1         |                |
| Digital               | 12259        | Bubbler     | 9                                          | 7                    | 7                                           | 10                   | Yes                                          | 8                                            | 9               | 10                      | 10                          | 10           | 5                         | 10                     | 5                | 10                 | 10                      | 8               | $1,200    | 8         |                |
| Tesco                 | Captive Air  | Reactive Air System | 6                                          | 7                    | 9                                           | 10                   | Yes                                          | 7                                            | 7               | 10                      | 10                          | 10           | 5                         | 10                     | 9                | 10                 | 10                      | 1               | $2,075    | 8         |                |
| BelTech BTS           | BTS 103-001A | Bubbler     | NA                                         | 8                    | 9                                           | -                   | No                                           | 1                                            | -               | -                       | -                           | -            | 5                         | 9                      | 9                | -                  | 10                      | 10             | $995      | 7         |                |

* Error may have been introduced in the RS-232C to 4-20 MA output conversion.
** Increasing the wave damping effect will decrease the water level response time.
10 = excellent; 1 = horrible; NA = not available; A = adjustable, SW = stilling well required; SW? = stilling well recommended; Opt. = optional
BelTech BTS Bubbler

(727) 397-1805
http://www.beltechsystems.com

General. The BelTech BTS 103-001A was selected for testing. The Bubbler Level Monitor is designed for reliable operation in rigorous environments such as wastewater lift stations, lakes, irrigation, aquifers, and creek level monitoring. Its alternating dual compressor design ensures long life and provides redundancy; the unit will operate with only one working compressor. It operates by blowing air down the attached tube every 52 seconds and measuring the head of liquid with a high-performance pressure transducer. For this particular setup a compressor cycle of seven seconds was used.

![BelTech BTX Bubbler](image)

Figure 31. BelTech BTX Bubbler

Test Results: Overall the BelTech BTS bubbler earned a low rating in comparison to other sensors (7 on a 10-point scale), mostly due to its instability during the air temperature test (as seen in Figure 32). From the results of the six tests run it was apparent the BelTech BTS bubbler does not have tight resolution. At the beginning of the tests a certain range was selected to calibrate the sensor. Depending on the magnitude of the range, the bubbler can only output water levels in certain increments. Therefore, the results showed jumping around in the sensor readings. The graphs in Figures 32 and 34 show examples of the resolution problem.

In addition, the BelTech earned a six in the output stability category because its readings were much higher than the actual water level, and they bounced around considerably in the first 80 minutes. However, after that the readings leveled out and became unnoticeable during the long-term trending test, which measured the sensor for 48 hours (Figure 33). This accounts for the drastic difference in ratings for output stability and long-term reliability.
Table 9. Evaluation ratings for BelTech BTS Bubbler

<table>
<thead>
<tr>
<th>Sensor Brand and Model</th>
<th>Simplicity and Correctness of Instructions</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Performance During Fluctuating Air Temperature</th>
<th>Water Level Response Time</th>
<th>Linearity and Hysteresis</th>
<th>Output Stability</th>
<th>Ability to Read Quickly After Extended Dry Period</th>
<th>Long Term Reliability</th>
<th>Overall Rating</th>
</tr>
</thead>
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<tr>
<td>BelTech BTS 103-001A</td>
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<td>8</td>
<td>9</td>
<td>1</td>
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<td>9</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>7</td>
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</table>
Water Level Sensor Testing

Figure 32. BelTech BTS temperature test

Figure 33. BelTech BTS long-term test

Figure 34. BelTech BTS drying test

Figure 35. BelTech BTS time lag test
SUMMARY AND CONCLUSIONS

This set of tests was conducted as a continuation to the report developed by ITRC in February of 1999. The results (ratings) in this portion of the study were determined by a comparison of all sensors, including those previously tested by ITRC. A quick and easy procedure has been developed to test the performance of water level sensors. Therefore, additions and updates may be continually incorporated into the study.

The continuous testing method developed by ITRC has become a way for irrigation districts and farmers to select the appropriate sensors for their individual needs. As part of the selection process, the sensors were broken down into categories based on the operational type (bubbler, float, submersible, ultrasonic), installation requirements, performance, and cost. All sensors tested within each operational type category were compared and rated.
REFERENCES


Irrigation Training and Research Center. 2002. SCADA – Supervisory Control and Data Acquisition. Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, CA.


Yasutake, M. 2002. LOOKOUT Instructions for a Portable SCADA – Creating Object. Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, CA.
APPENDIX A

Contact Information
<table>
<thead>
<tr>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Fax</th>
<th>Email</th>
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<tr>
<td>ACR Systems</td>
<td>Unit 210, 12960 84th Ave. Surrey, B.C. Canada V3W-1K7</td>
<td>(800) 663-7845</td>
<td>(604) 591-2252</td>
<td><a href="mailto:acr@acrsystems.com">acr@acrsystems.com</a></td>
<td><a href="http://www.acrsystems.com">http://www.acrsystems.com</a></td>
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<td>AGM Electronics</td>
<td>P.O. Box 32227 Tucson, AZ 85751-2227</td>
<td>(520) 722-1000</td>
<td>(520) 722-1045</td>
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<td>American Sigma</td>
<td>P.O. Box 820 Medina, NY 14103-0820</td>
<td>(800) 635-4567</td>
<td>(716) 798-5599</td>
<td><a href="mailto:sigma@americansigma.com">sigma@americansigma.com</a></td>
<td><a href="http://www.americansigma.com">http://www.americansigma.com</a></td>
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<td>Automata</td>
<td>10551 E. Bennett Road Grass Valley, CA 95945-7806</td>
<td>(800) 994-0380</td>
<td>(530) 273-0381</td>
<td><a href="mailto:automata@automata-inc.com">automata@automata-inc.com</a></td>
<td><a href="http://www.automata-inc.com">http://www.automata-inc.com</a></td>
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<td>Badger Meter</td>
<td>P.O. Box 581390 Tulsa, OK 74158</td>
<td>(918) 836-8411</td>
<td>(918) 832-9962</td>
<td><a href="mailto:jjzimmer@badgermeter.com">jjzimmer@badgermeter.com</a></td>
<td><a href="http://www.badgermeter.com">http://www.badgermeter.com</a></td>
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<td>Bailey-Fischer &amp; Porter</td>
<td>125 East County Line Road Warminster, PA 18974</td>
<td>(215) 674-6000</td>
<td>(215) 674-6740</td>
<td><a href="mailto:Webmaster@bailey.com">Webmaster@bailey.com</a></td>
<td><a href="http://www.ebpa.com">http://www.ebpa.com</a></td>
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<td>BelTech BTS Systems Inc.</td>
<td>13000 98th Ave. N Seminole, FL. 33776</td>
<td>(727) 397-1805</td>
<td>(727) 595-4387</td>
<td><a href="mailto:donald.parker@beltechsystems.com">donald.parker@beltechsystems.com</a></td>
<td><a href="http://www.beltechsystems.com">http://www.beltechsystems.com</a></td>
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<td>Campbell Scientific</td>
<td>815 West 1800 North Logan, UT 84321</td>
<td>(435) 753-2342</td>
<td>(435) 750-9540</td>
<td><a href="mailto:info@campbellsci.com">info@campbellsci.com</a></td>
<td><a href="http://www.campbellsci.com">http://www.campbellsci.com</a></td>
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<td>Celesco PT1MA Transducer</td>
<td>7800 Deering Avenue Canoga Park, CA 91309</td>
<td>(800) 423-5483</td>
<td>(818) 340-1175</td>
<td>On website</td>
<td><a href="http://www.CelescoPT1MA.com">http://www.CelescoPT1MA.com</a></td>
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<td>Coastal Environmental Systems</td>
<td>820 First Avenue South Seattle, WA 98134</td>
<td>(800) 488-8291</td>
<td>(206) 682-5658</td>
<td><a href="mailto:pkelly@coastal.org">pkelly@coastal.org</a></td>
<td><a href="http://www.coastalenvironmental.com">http://www.coastalenvironmental.com</a></td>
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<td>Digital Control Corporation</td>
<td>10871 75th St. North Largo, FL. 33777</td>
<td>(800) 335-5219</td>
<td>(727) 547-1722</td>
<td><a href="mailto:dcc@gle.net">dcc@gle.net</a></td>
<td><a href="http://www.digitalcc.com">http://www.digitalcc.com</a></td>
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<td>4 Dunham Drive New Fairfield, CT 06812</td>
<td>(203) 746-0400</td>
<td>(203) 746-2494</td>
<td><a href="mailto:sales@Druck1230.com">sales@Druck1230.com</a></td>
<td><a href="http://www.Druck1230.com/usa">http://www.Druck1230.com/usa</a></td>
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<td>(907) 344-4995</td>
<td>(907) 344-8013</td>
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<td>Endress + Hauser</td>
<td>P.O. Box 246 Greenwood, IN 46142-0246</td>
<td>(888) ENDRESS</td>
<td>(317) 535-8498</td>
<td>On website</td>
<td><a href="http://www.us.endress.com">http://www.us.endress.com</a></td>
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<td>Global Water</td>
<td>11257 Coloma Road Gold River, CA 95670</td>
<td>(800) 876-1172</td>
<td>(916) 638-3270</td>
<td><a href="mailto:globalw@globalw.com">globalw@globalw.com</a></td>
<td><a href="http://www.globalw.com">http://www.globalw.com</a></td>
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<tr>
<td>Instrumentation Northwest</td>
<td>14972 NE 31st Circle Redmond, WA 98052</td>
<td>(800) 776-9355</td>
<td>(425) 867-0404</td>
<td><a href="mailto:info@inwusa.com">info@inwusa.com</a></td>
<td><a href="http://www.inwusa.com">http://www.inwusa.com</a></td>
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<tr>
<td>Intermountain Environmental</td>
<td>601 West 1700 South, Suite B Logan, UT 84321-6219</td>
<td>(800) 948-6236</td>
<td>(435) 755-0794</td>
<td><a href="mailto:info@inmtn.com">info@inmtn.com</a></td>
<td><a href="http://www.inmtn.com">http://www.inmtn.com</a></td>
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<td>KPSI</td>
<td>34 Research Drive Hampton, VA 23666</td>
<td>(800) 328-3665</td>
<td>(757) 865-8744</td>
<td><a href="mailto:kpsi@cts.com">kpsi@cts.com</a></td>
<td><a href="http://www.kpsi.com">http://www.kpsi.com</a></td>
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<td>Lundahl Instruments</td>
<td>429 South Main Logan, UT 84321</td>
<td>(888) 525-7300</td>
<td>(801) 753-7490</td>
<td><a href="mailto:solution@lundahl.com">solution@lundahl.com</a></td>
<td><a href="http://www.lundahl.com">http://www.lundahl.com</a></td>
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<tr>
<td>Milltronics</td>
<td>709 Stadium Drive Arlington, TX 76011</td>
<td>(817) 277-3543</td>
<td>(817) 277-3894</td>
<td><a href="mailto:raulc@milltronics.com">raulc@milltronics.com</a></td>
<td><a href="http://www.milltronics.com">http://www.milltronics.com</a></td>
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<td>Stevens Water Monitoring Systems</td>
<td>P.O. Box 688 Beaverton, OR 97075-0688</td>
<td>(800) 452-5272</td>
<td>(503) 469-8100</td>
<td><a href="mailto:info@stevenswater.com">info@stevenswater.com</a></td>
<td><a href="http://www.stevenswater.com">http://www.stevenswater.com</a></td>
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<tr>
<td>Tesco Controls</td>
<td>3434 52nd Avenue Sacramento, CA 95823</td>
<td>(916) 395-8800</td>
<td>(916) 394-1893</td>
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