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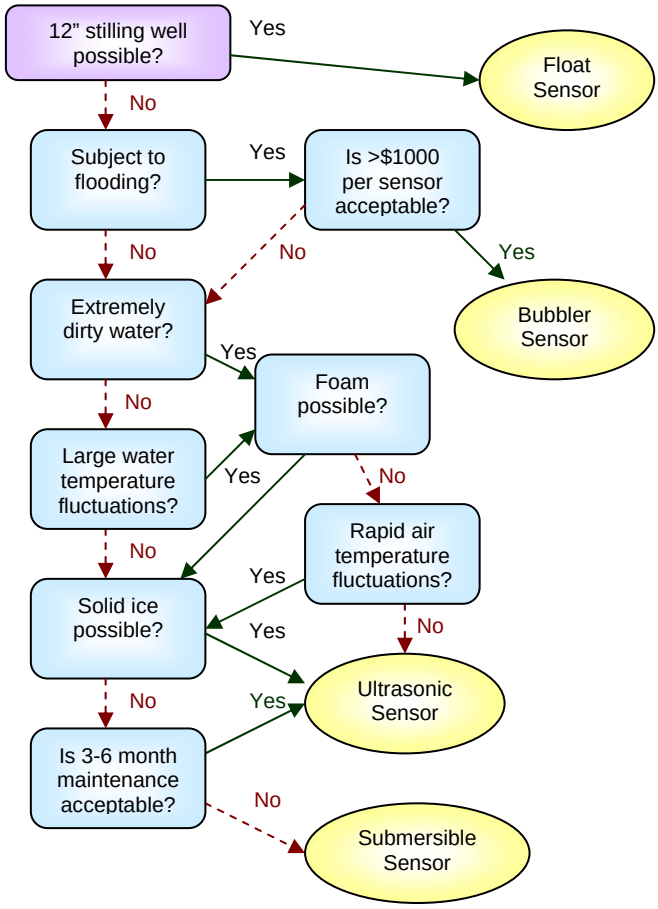
Water Level Sensor Testing

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.

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.

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 testing results have been summarized with decision flow charts and rating tables for cross comparison.



Selecting a Sensor

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
- output stability
- drying effects
- time lag
- linearity and hysteresis
- effects of air temperature

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.

For more details on methodology and results of individual sensors, please refer to this project's previous reports, which can be found online at: www.itrc.org/projects/waterlevelsensor.htm.

Ultrasonic Sensors

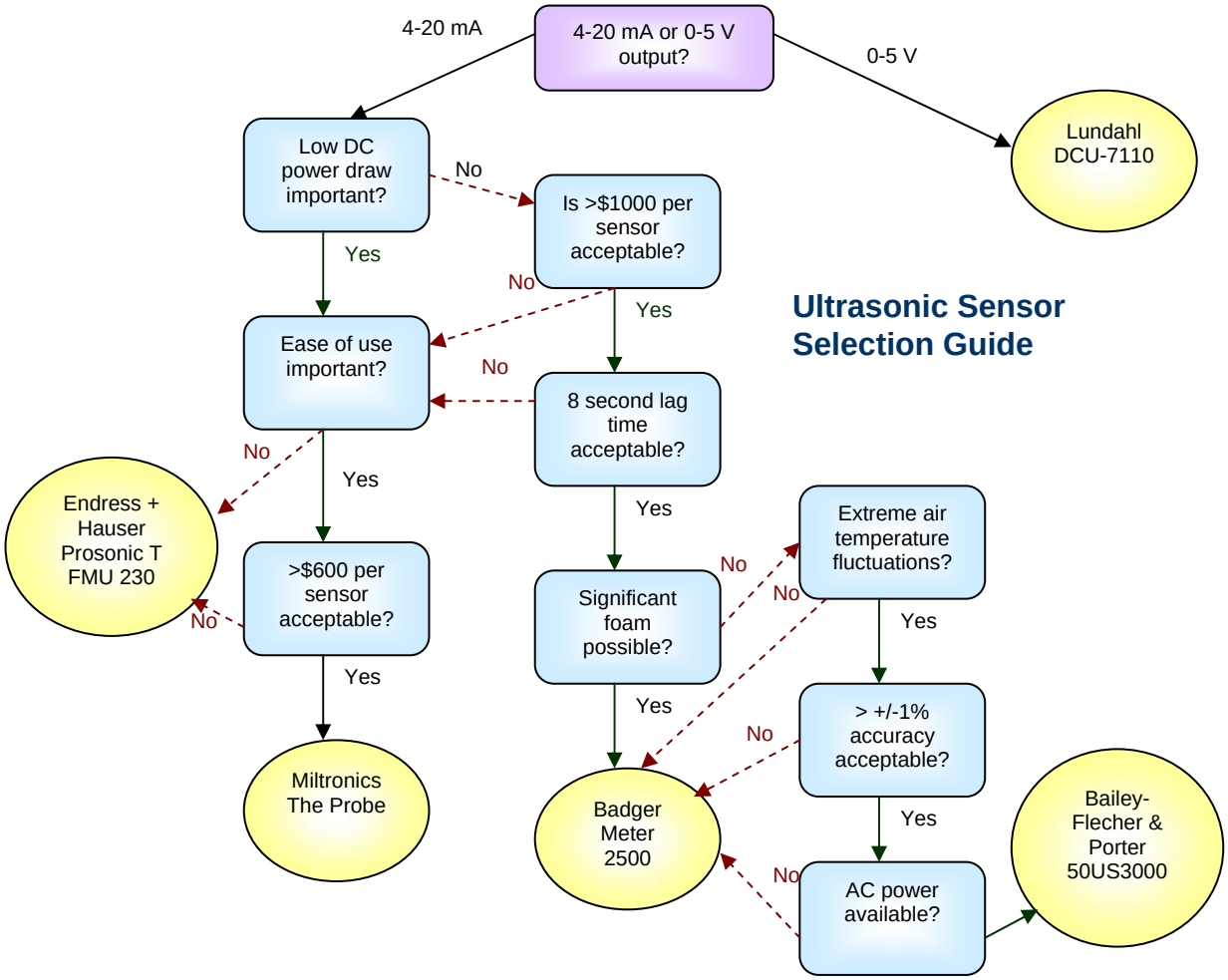
Ultrasonic sensors transmit a series of cone-shaped sound waves through the air. These sound pulses reflect off the liquid surface and are in turn received by the sensor, which measures the time interval between the transmitted and received signal. Electronics then convert this time interval into a distance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

General Advantages

- Non-contacting, so are not affected by dirty water, floating debris, or aquatic wildlife
- Not affected by fluctuating water temperatures
- Not affected by high flow rates
- Easy to calibrate
- Low maintenance
- Excellent linearity and lack of significant hysteresis
- Can withstand freezing temperatures
- Long-term reliability

General Disadvantages

- Affected by air temperature fluctuations
- May reflect off floating foam or debris
- Must be aligned precisely
- May be affected by turbulent water (a stilling well may be required)
- May display misleading readings if echo is lost
- Large beam angles cannot be used in constricted spaces
- Some sensors damaged by flooding (i.e., they are not waterproof)
- Some delay between the time when power is first applied and the first output



Evaluation results for all ultrasonic sensors tested by ITRC

Sensor Brand	Sensor Model	Simplicity and Correctness of Instructions	Ease of Installation	Ease of Calibration	Compatibility with Other Brand Dataloggers	Water Level Display?	Performance During Fluctuating Air Temperature	Performance During Fluctuating Water Temperature	Foam Penetration	Durability in Dirty 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
ULTRASONIC SENSORS																				
Badger	2500	9	8	9	10	Yes	3	10	10	10	10	A**	10	8	5	10	7	10	$1,600	8
Bailey-Fischer & Porter	50US3000	7	8	7	10	Opt.	4	10	2	10	10	9	10	7	10	10	AC only	10	$1,900	7
Endress + Hauser	Prosonic T FMU 230	5	8	5	10	Opt.	2	10	2	10	10	A**	10	8	6	10	9	10	$585	7
Lundahl	DCU-7110	10	8	9	10	On Lap-top	1	10	1	10	10	1	10	7	8	10	7	10	$615	7
Miltronics	The Probe	9	9	9	10	Yes	2	10	5	10	10	A**	10	2	8	10	9	NA	$695	8

* 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

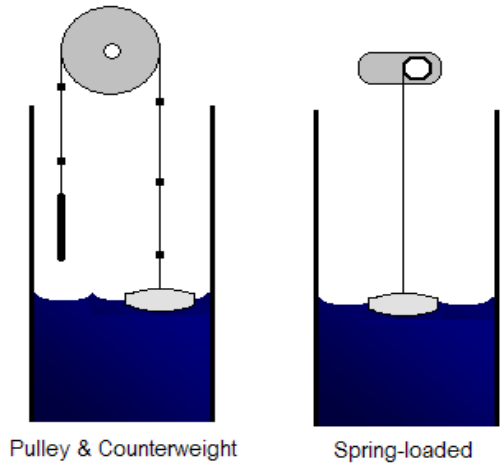
Float Sensors

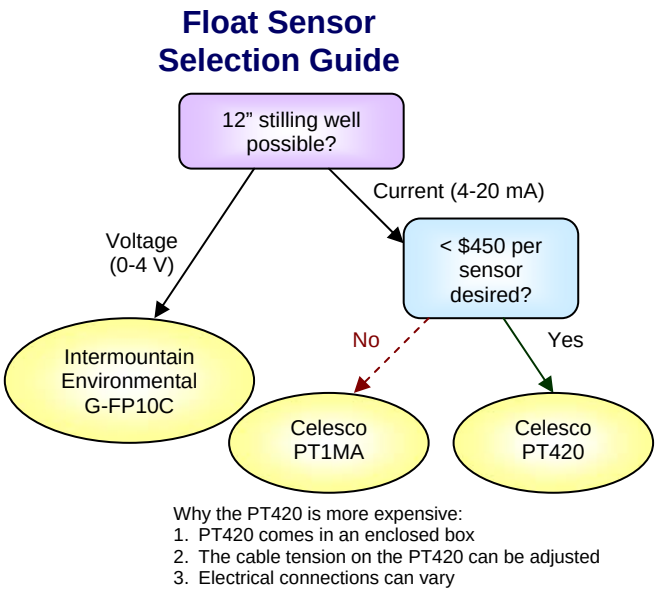
There are two basic types of float sensor: one that involves a pulley and counterweight and one that utilizes a spring to produce an upward force on the float cable. In the pulley and counterweight version, a counterweight provides tension to a beaded cable. Notches in the pulley mesh with cable beads, 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.

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.





General Advantages

- 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

General Disadvantages

- 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

Celesco PT1MA

Photo obtained at www.intertechnology.com

Evaluation results for all float sensors tested by ITRC

Sensor Brand	Sensor Model	Sensor Type	Simplicity and Correctness of Instructions	Ease of Installation	Ease of Calibration	Compatibility with Other Brand Dataloggers	Water Level Display?	Performance During Fluctuating Air Temperature	Performance During Fluctuating Water Temperature	Foam Penetration	Durability in Dirty 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
FLOAT SENSORS																					
Celesco PT420	PT420	Float	10	7	10	10	No	9	10	10	10	10	SW	10	9	10	10	9	NA	$485	10
Intermountain Environmental	G-FP10C	Float & Pulley	10	6	8	10	No	7	10	10	10	10	SW	10	8	9	10	10	10	$350	9
Celesco PT1MA	PT1MA	Float	NA	9	8	-	No	6	-	-	-	-	-	10	10	10	8	-	9	$389	9

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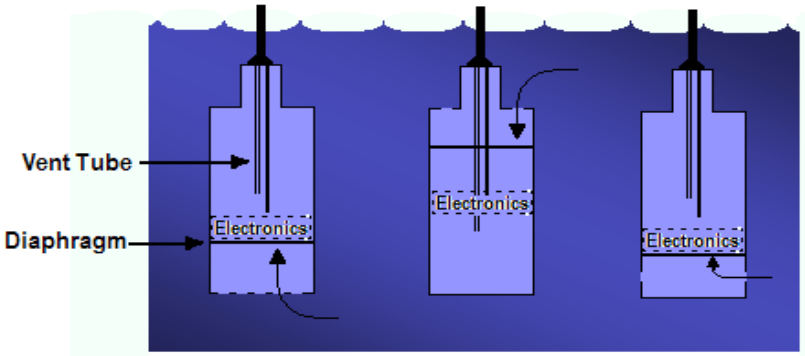
Submersible Sensors

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.



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.

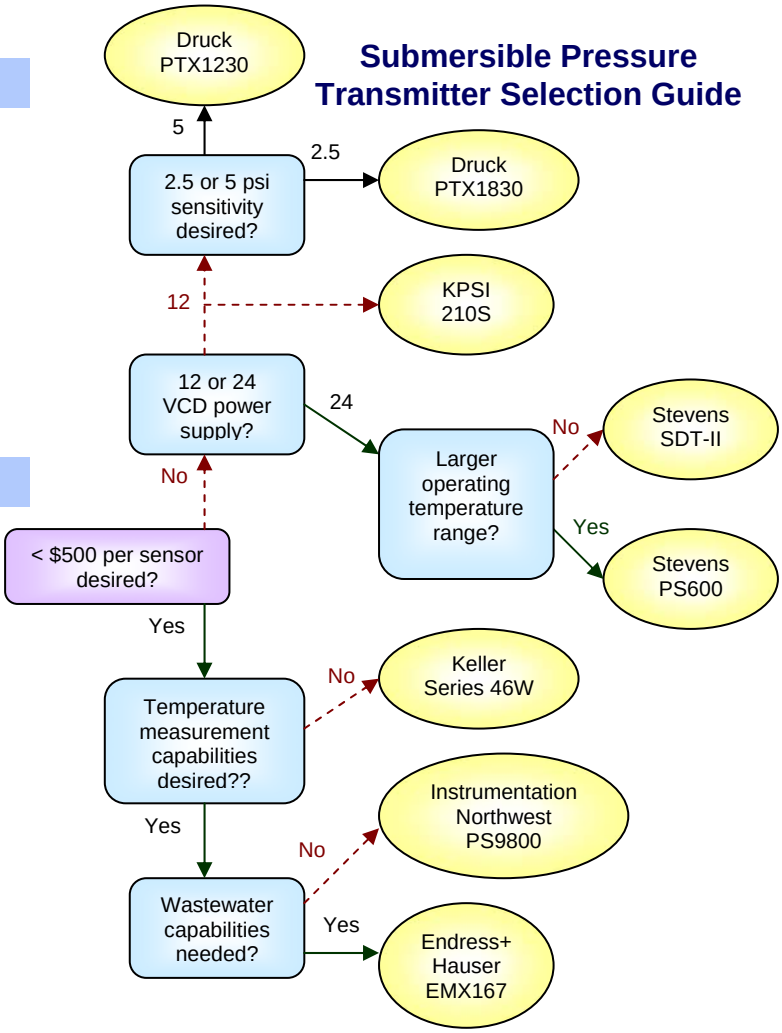
The vent tube must remain dry, necessitating the use of a desiccant or bellows at the open end. Desiccant is a chemical that absorbs water vapor. Desiccants used with pressure sensors generally change color when in need of replacement. As an alternative to desiccant, bellows or an air bladder can separate 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.

General Advantages

- Easy to install
- Electronics are hidden from view
- Low power draw
- Not usually affected by air temperature fluctuations
- Not affected by foam
- Almost no time lag
- No delay between the time when power is first applied and the first output

General Disadvantages

- Damaged by ice
- Can clog in dirty water
- Susceptible to malfunction if often allowed to dry
- May hang up debris
- Adversely affected by water temperature fluctuations
- Range is not adjustable
- Desiccant must be periodically replaced
- Stilling well often required
- Lightning protection recommended
- Damaged if submerged much too deep
- Easily damaged by aquatic wildlife



Endress+Hauser Waterpilot FMX 167

Photos obtained from manufacturers' websites

Evaluation results for all submersible sensors tested by ITRC

Sensor Brand	Sensor Model	Simplicity and Correctness of Instructions	Ease of Installation	Ease of Calibration	Compatibility with Other Brand Dataloggers	Water Level Display?	Perfomance During Fluctuating Air Temperature	Perfomance During Fluctuating Water Temperature	Foam Penetration	Durability in Dirty 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
SUBMERSIBLE SENSORS																				
Automata	LEVEL-WATCH	10	7	10	10	Opt.	7	3	10	1	1	SW?	10	2	9	1	9	7	$328	4
Global Water	WL300	10	9	10	10	No	9	3	10	1	1	SW?	10	9	5	1	9	2	$495	5
Stevens	PS600	10	9	10	10	No	10	10	10	9	1	SW?	10	8	9	7	9	8	$790	8
Endress + Hauser	FMX 167	10	9	10	10	No	10	10	10	9	1	SW?	10	8	9	7	9	8	$730	8
Druck	PTX 1830	10	9	10	10	No	10	10	10	9	1	SW?	10	8	9	7	9	8	$685-$1135	8
Instrumentation Northwest	PS9800	10	9	10	10	No	10	5	10	9	1	SW?	10	8	9	10	9	7	$479	8
KPSI	210S	10	9	10	10	No	10	6	10	9	1	SW?	10	10	10	10	9	4	$778	8
Stevens	SDT-II	10	7	10	10	No	10	5	10	9	1	SW?	10	8	9	NA	9	8	$707	8
Keller 46W	Series 46	NA	9	9	-	No	7	-	-	-	-	-	8	9	5	2	-	2	$495	6

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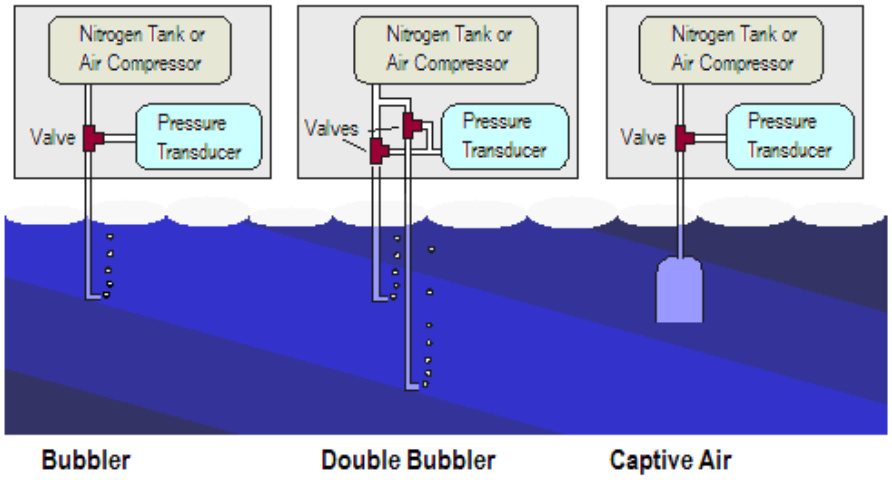
10 = excellent; 1 = horrible; NA = not available; A = adjustable, SW = stilling well required; SW? = stilling well recommended; Opt. = optional

Bubbler Sensors

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.



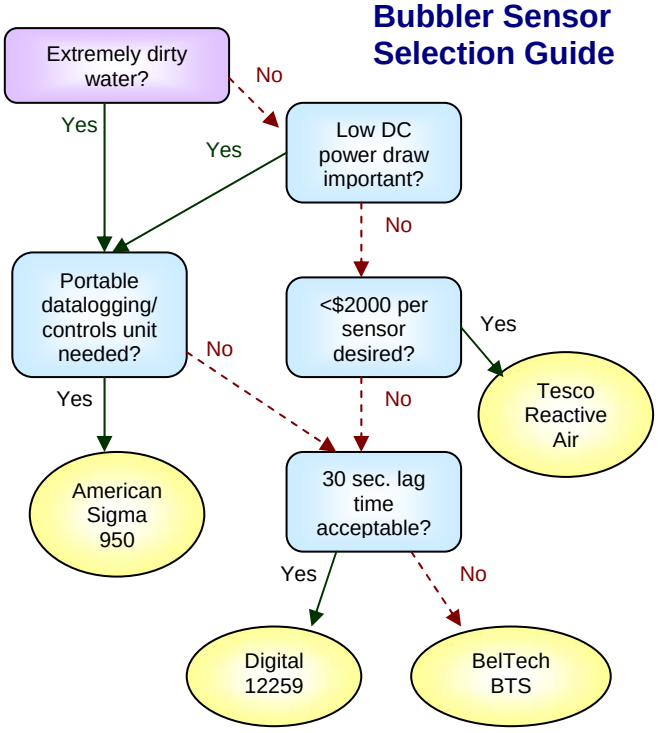
General Advantages

- 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

Bubbler Sensor Selection Guide



BelTech BTX Bubbler

Evaluation results for all bubbler sensors evaluated by ITRC

Sensor Brand	Sensor Model	Sensor Type	Simplicity and Correctness of Instructions	Ease of Installation	Ease of Calibration	Compatibility with Other Brand Dataloggers	Water Level Display?	Performance During Fluctuating Air Temperature	Performance During Fluctuating Water Temperature	Foam Penetration	Durability in Dirty 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
BUBBLER SENSORS																					
American Sigma	950	Bubbler	6	7	7	10	Yes	9	9	10	10	10	-	10	9	7	10	8	NA	$4,060	8
Campbell Scientific	DB1	Double Bubbler	1	1	1	1	No	5	10	10	10	10	-	1	1*	1	10	5	2	$1,560	1
Digital	12259	Bubbler	9	7	7	10	Yes	8	9	10	10	10	-	5	8	9	10	5	10	$1,200	8
Tesco	Reactive Air System	Captive Air	6	7	9	10	Yes	7	7	10	10	10	-	10	9	10	10	1	NA	$2,075	8
BelTech BTS	BTS 103-001A	Bubbler	NA	8	9	-	No	1	-	-	-	-	-	5	9	6	9	-	10	$995	7

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Company	Web Site
ACR Systems	http://www.acrsystems.com
AGM Electronics	http://www.agmelectronics.com
American Sigma	http://www.hach.com
Automata	http://www.automata-inc.com
Badger Meter	http://www.badgermeter.com
Bailey-Fischer & Porter	http://www.baileyfp.com
BelTech BTS Systems Inc.	http://www.beltechsystems.com
Campbell Scientific	http://www.campbellsci.com
Celesco PT1MA Transducer Products	http://www.Celesco.com
Coastal Environmental Systems	http://www.coastalenvironmental.com
Digital Control Corporation	http://www.digitalcc.com
Druck 1230	http://www.Druck.com
Dryden Instrumentation	http://www.drydenalaska.com
Endress + Hauser	http://www.us.endress.com
Global Water	http://www.globalw.com
Instrumentation Northwest	http://www.inwusa.com
Intermountain Environmental	http://www.inmtn.com
Keller 46W	http://www.kelleramerica.com
KPSI	http://www.kpsi.com
Lundahl Instruments	http://www.sti.com
Milltronics	http://www.milltronics.com
Stevens Water Monitoring Systems	http://www.stevenswater.com
Tesco Controls	http://www.tescocontrols.com

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moving water in new directions