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Hydrometric Field Manual

Measurement of Stage

Water Survey of Canada
National Hydrological Services
Environment and Climate Change Canada
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Version aussi disponible en français.

Front Cover
Left: Direct water level measurement (photo by Pat Maltais)
Middle: Water Level at 07AF014 June 20, 2023 (photo by Carl Steenbergen)
Right: Obtaining the elevation of the orifice/sensor (photo by Wade Hanna)

Back Cover
Left: Radar stage sensor (photo by Malyssa Maurer)
Middle: Historical photo (source unknown)
Right: Ben Lambert setting the rod for a reference water level (photo by Aaron Donohue)

Revision History

Version	Date	Source	Description/Rationale for Change
1.0	1983	IWD, WRB, EC	Initial publication
1.1	2008	HQ-WSC, EC	Reformatting as electronic document
2.0	2019	National Office	Updated to include current technology and methods
3.0	2023	National Office	Section changes: -Added Section 5 on reference water level requirements during field visits. This guidance supersedes all older statements on the subject, in all WSC SOPs. - added table of key points - updated dual tubing - added requirements for comparison of inside and outside water level for wells - removed required accuracy of sensors as it is covered in instrument specifications

Foreword

The Water Survey of Canada (WSC) is the operational arm of the National Hydrological Service, responsible for the collection, interpretation and dissemination of standardized hydrometric data and information in Canada. It has been the main operator of the National Hydrometric Program for over 115 years. The Water Survey of Canada is an International Organization for Standardization 9001 certified organization committed to the principle of continuous improvement. We endeavour to develop standards that prioritize data integrity and usefulness.

This document is an update to "qSOP-NA008-02-2019 - Hydrometric Field Manual - Measurement of Stage", which it supersedes. It outlines the field methods used by the Water Survey of Canada for stage measurement activities. It covers continuous monitoring with automated stage sensors, acquiring reference water level measurements to validate sensor data, requirements for mean gauge height calculations for discharge measurements, and various methods for acquiring peak stage data. During recent internal WSC audits, it was found that our various procedures contained conflicting and ambiguous requirements for water level data collection for the purpose of calculating mean gauge heights, a new section clarifying these requirements was therefore added to this document. The guidance in this section supersedes all guidance in existing procedures.

Many of our colleagues enabled the development of this document through discussions and contributions. We thank the following recent reviewers for their contributions Wayne Beaton, Zachary Bishop, Amber Brown, Marcena Croizier, Tom Davie, Derek Elliot, Steven Falconer, Jean-Pascal Faubert, Virginia Fleming, Christina Nussbaumer, Scott Palfreyman, Ryan Seibel, Leigh Sinclair and Curtis Waiting. We thank everyone for their effort in contributing to these procedures and are confident their work will help to unify, stabilize, and modernize the program.

R.W. Jenkins

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Executive Director, National Hydrological Service
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November 2023

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Table of Key Points

The following is a table of the main rules and standards found within this document. Some sentences have been shortened for brevity and the **should** statements were not included as they are too numerous. Context for all items is found within the main body of the text. In this document, the terms **must** and **should** are used intentionally. **Must** statements are requirements, while **should** statements are best practices. If **must** and **should** statements cannot be followed, the reasoning behind the choice to do something else **must** be documented.

Continuous Monitoring of Stage	Water Survey of Canada reports stage in meters above the operating datum with millimeter precision.
	Regardless of the type of sensor used, stage **must be** measured and logged at 5-minute intervals.
	Stilling well intakes, bubbler orifice lines and submersible pressure sensors **must be** positioned perpendicular to the flow so that only the static pressure is measured.
	Stilling wells **must** meet the requirements listed in Section 3.2.1
	[Orifice lines] **must be** properly anchored to the streambed to prevent movement.
	[The footprint of radar stage sensors] **must be** completely clear of obstacles at all stages.
	When selecting a stage sensor, refer to qREC-NA020- List of Approved Devices.
Reference Water Level Measurements	The observed surge in water level **must be** noted, even if it is zero.
Station Visit Requirements for Stage Measurements	Readings from the stage sensor **must be** compared to a reference water level (surveyed or reference gauge) at least once during each site visit.
	A minimum of two water level values, **must be** used to calculate mean gauge height, one at the beginning and one at the end of the discharge measurement.
	Reference water levels **must be** measured before and after any station maintenance that may affect the stage sensor to confirm whether logged values are accurate.
	To ensure the well is functioning correctly, a comparison of the water level *inside the well* and *outside the well* **must be** conducted before and after work that affects the intakes or valves of a well (flushing, maintenance, etc.).
Methods for Measuring Peak Stage Between Visits	Crest Stage Gauges: At each visit, the wooden rod **must be** inspected. If necessary, it **must be** cleaned, and the cork dust container **must be** refilled before the rod is replaced in the pipe.
Troubleshooting	[If the stage sensor and the reference gauge] are not within the same pool, the elevation of the water surface can differ, so too can the hydraulic conditions. This situation **must be** avoided at all costs.

Glossary

Bubbler system: A non-submersible pressure sensor that uses a compressed gas-purge system.

Crest stage gauge: A non-recording gauge used to measure the peak stage since it was last set.

Discrete measurement: A measurement performed manually during a station visit.

Drawdown: The condition where the water level in a stilling well is lower than the level in the connected stream, or equivalently when the water level detected by a pressure sensor is less than the actual water level.

Effective stage: Height of water above the orifice, water intake, or pressure sensor.

Float system: A gauge that consists of a float that rises and falls with the water surface. The float's movements are transmitted to a sensor.

Gauge correction: A correction that is applied to recorded water levels to account for vertical movement of the reference gauge.

Gauge height: Synonym of stage. The elevation of the water level above the operating datum.

Gauging pool: Area in the river reach where the station’s reference gauge and stage sensor are located and where the water level is assumed to rise or fall uniformly with changes in flow conditions.

Inclined gauge: A staff gauge consisting of a graduated plate or rod set on an incline that is mounted on the shore.

Operating datum: The surface to which gauge height elevations are referenced. It is sometimes referred to as the gauge datum.

Reference gauge: The gauge to which the automated stage sensor is set.

Sensor reset: Setting the stage sensor value to the water level from the reference gauge.

Staff gauge: A graduated plate or rod which is set vertically in a streambed or attached to a solid structure.

Stage: Synonym of gauge height. The elevation of the water level above the operating datum.

1. Introduction

Hydrometric stations are sites at which water level (i.e. stage) data are systematically collected, recorded, and published. Water Survey of Canada reports stage in meters above the operating datum with millimeter precision (e.g. stage = 4.326 m). Stage is used to calculate discharge at most stations; therefore, the accuracy of stage data directly impacts discharge data. Accurate stage measurements are essential to the integrity of the Water Survey of Canada (WSC)'s data. This document provides the standard operating procedures for stage measurement, focusing on both continuous monitoring and discrete measurements.

2. Station Design and Planning

When establishing a new site, the following factors **should** be considered:

- There **should** be a pool for the gauge, preferably above a riffle. This enables data to be collected for the entire range of stage and avoids high velocities which can adversely affect stage data.
- There **must be** suitable locations for installing a stable benchmark network and reference gauge - see the *Hydrometric Field Manual - Levelling* (qSOP-NA005).
- Stilling wells and shelters **should** be located where they will not sustain damage during floods. The shelter **should** be above the 200-yr flood level if possible.
- The well intakes or orifice **should** be low enough to record the lowest expected stage. In cold climates, try to place them below the frost line to protect them from freezing.
- The reference water level measurement (i.e. reference gauge observation) **should** be in the same pool as the stage sensor, intakes, or orifice to ensure they are subject to the same conditions.
- If the site is located at or near a bridge, the hydraulic impact of the bridge **must be** considered, such as scour and deposition of sediment, and drawdown and pileup of water.
- If the site is near the outlet structure of a lake or reservoir, make sure the gauge intakes, or orifice are located upstream of the zone of drawdown of the outlet structure.
- If a stage-discharge rating will be developed, consider the requirements for sensitive controls and stable rating curves, and avoid locations affected by variable backwater, including backwater from other water bodies downstream.

3. Continuous Monitoring of Stage

A stage sensor is a device used to measure the height of the free water surface (i.e. water level). The sensor output can be referenced to the gauge's operating datum to determine the gauge height. The three types of stage sensors currently in use at the Water Survey of Canada are float systems, pressure systems (submersible and non-submersible) and non-contact systems. All three systems are described in this document. At the time of writing (2023), approximately 21% of WSC stations use float systems, 61% use gas pressure systems, 16% use submersible pressure sensors, with the remaining 2% consisting of non-contact and acoustic sensors. Tips for sensor selection are provided in Section 3.6 and details on their operation can be found in instrument-specific manuals.

3.1.Measurement and Logging Frequency

Regardless of the type of sensor used, stage **must be** measured and logged at 5-minute intervals. In addition to simplifying the programming of sensors and the management of data acquisition, this time interval allows for notable events such as flood peaks to be captured with sufficient accuracy.

Some sensors report instantaneous measurements while others can report time-integrated values by averaging multiple readings. Many dataloggers can internally average instantaneous values from a stage sensor. Either instantaneous measurements or time-integrated measurements are acceptable as logged stage values. Time averaging smooths out minor fluctuations in the water surface caused by wind or non-steady flow, thereby reducing noise in the data. For example, some sensors take measurements over twenty seconds and average the results (20-s integration time). Integration time **should** be adjusted to local conditions to improve the representability of recorded water levels, with 10-30 s generally being sufficient.

3.2.Float Systems

A float system consists of a float connected to a beaded or non-beaded wire with a counterweight balanced on the other side. The wire rides over a 0.375-m circumference pulley which is attached to the shaft of a shaft encoder. A shaft encoder converts the angular position of a shaft to a digital signal. The float rides on the water surface and the shaft encoder determines the stage. Users need to be aware that for proper operation, the tape or beaded cable needs to move freely, and the float and counterweight need to be properly sized for the job. When installing a new shaft encoder, ensure that the stage readings increase as the float rises and decrease as the float sinks.

The float system is mounted within a stilling well that is connected to the stream by intake pipes so that the water level in the well reflects that of the stream (Figure 1). The well reduces fluctuations in water level caused by wind or flow turbulence by controlling the volume of water entering the well.

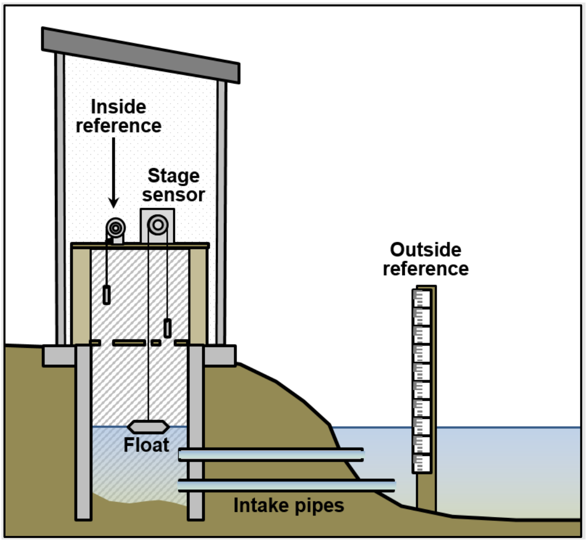

Figure 1: Stilling well with float system showing water intake pipes connected to the river.

3.2.1. Stilling Well and Intake Requirements

Wells can house other sensor types, but they predominately house float systems. All stilling wells **must**:

- Have intakes that are deep enough to cover all ranges in stage.
- Be equipped with a flushing system so that the intake pipes can be flushed to remove sediment.
- Be equipped with a means of removing sediment from the well.
- Be operable throughout the winter, if necessary.
- Have both an inside and outside water level reference in order to validate stage sensor data.

In many cases, two intakes are necessary to cover the entire range of stage. Ideally, the intakes **should** be installed in a region where water velocities are low and where sediment deposition is unlikely. Intakes **should** be positioned at right angles to the flow so that the water level in the well is the result of static pressure only. If they face into the flow, the level in the well will be higher than the stream since it will reflect a combination of static pressure and the dynamic pressure of the flowing water.

Note that the direction of flow past the intake pipe may vary with flow conditions and stage. At times, flow past the intake may cause drawdown, which results in a lower water level in the well than in the river. At other times, it may cause pile-up, which results in a higher water level in the well than in the river. Readings from the inside and outside gauges are used to determine whether drawdown, pile-up or partial/full blockage is occurring. If the intake is partially blocked, there will be a lag between water level changes in the stream and in the well as shown in Section 7. To limit drawdown or pileup of the water in the stilling well, one can add a static tube to the streamside of the intake as shown in Figure 2.

A static tube is a short length of perforated pipe through which water enters and leaves. It is attached to an elbow or T that extends from the intake pipe downstream and is capped at the end. If a static tube is properly positioned and in working order, the water level in the well **should** be identical to the water level in the stream. Since static tubes can quickly fill with sediment or be colonized by biological material, they need to be accessible and cleaned frequently to ensure unobstructed flow between the well and the stream.

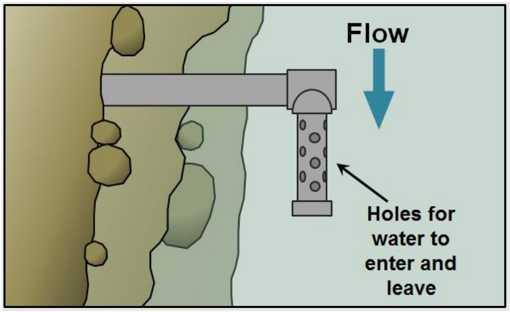

Figure 2: Example of a static tube attached to a stilling well intake pipe.

3.3.Pressure Sensors

The pressure at a point below the water surface depends on the height of the water above it (i.e. effective stage). Reference water level measurements are used to relate the effective stage measured by a pressure sensor to the water level above the operating datum (see Section 4). This is known as the stage or gauge height.

Pressure sensors are designed to measure either absolute pressure or differential pressure. Absolute pressure is the pressure measured with respect to an absolute vacuum. It is the sum of the pressure due to the atmosphere, p_{atm}, and the pressure due to the water, ρgz:

$$p_{absolute} = p_{atm} + \rho gz$$

where ρ is the density of the water, g is gravitational acceleration and z is the effective stage. This second term is known as the gauge pressure.

Differential pressure is the difference in pressure between two points. If the side of the pressure sensor diaphragm opposite the water is exposed to the atmosphere by a vent line, the difference in pressure is the gauge pressure. Almost all submersible and non-submersible pressure sensors used by WSC measure gauge pressure. If using a sensor that only measures absolute pressure, a barometer is required to measure the atmospheric pressure and the gauge pressure is calculated as follows:

$$p_{gauge} = p_{absolute} - p_{atm}$$

This calculation is typically be done within a data logger.

3.3.1. Non-submersible Pressure Sensors

Non-submersible pressure sensors require a gas-purge system (bubbler system) located in the gauge house. Desiccated compressed air or nitrogen gas is fed through a system of valves, regulators and tubing, and escapes through a submerged orifice line. At the end of the orifice, the pressure exerted by the water on the escaping gas is transferred back through the line to the pressure transducer type sensor that is mounted in the shelter. The sensor converts the pressure into an electronic signal from which the effective stage is calculated. Reference water level measurements are used to relate this value to the gauge height. An example of this type of system is shown in Figure 3.

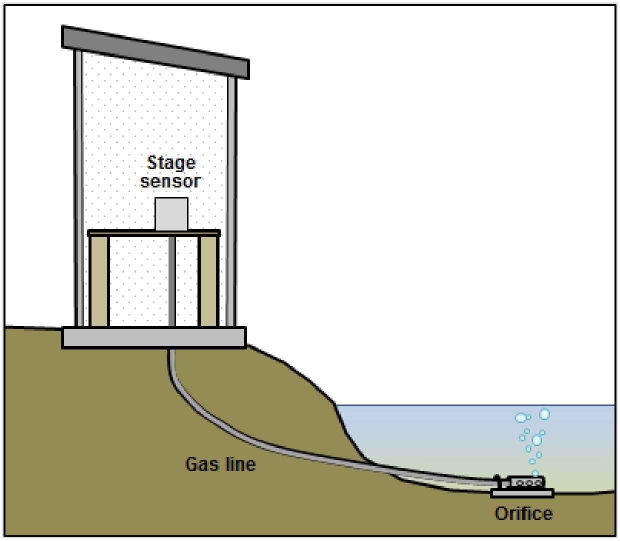

Figure 3: Example of a site equipped with a non-submersible pressure sensor.

As with stilling well intakes, the orifice **must be** positioned perpendicular to the flow so that only the static pressure is measured. If possible, it **should** also be in a pool or in a slow-moving region. Studies have shown that having the orifice facing, but not touching, the riverbed can improve data quality by reducing the possibility of sediment accumulating within the line and ensuring no flow is incident on the orifice. If high velocities are expected, the orifice can be installed in an orifice static tube.

The friction of the gas flowing in the purge system is a function of the bubble rate, the gas density (which varies with temperature), and the inside diameter of the orifice line. Friction created by the flow of gas through the bubble tubing results in the pressure at the sensor being slightly higher than that at the orifice. Variations in the bubble rate caused by temperature fluctuations cause variations in gas friction that may be significant for long lengths of tubing. The significance of gas friction can be determined by adjusting the bubble rate and observing the effect, if any, on the stage reading. Increasing the bubble rate will tend to increase the stage reading if gas friction is significant. If, for a given length of orifice line, a difference of greater than 0.003 m results from a 100 percent increase (doubling) in bubble rate, dual tubing **should** be considered to mitigate the problem. One line is used to feed gas to the orifice, and the other line, joined near the orifice with a T-connector, is used as a static return line to the instrument. Using larger inside-diameter single tubing can also reduce the problem. Additional details on the role of gas friction and the use of dual tubing can be found in Rantz *et al*., 1982 and Smith, 1991.

A further consideration for bubbler systems is that when there is a large difference in elevation between the orifice and the pressure sensor, and there are large changes in stage, the weight of the gas in the line needs to be accounted for. Variation in weight of the gas in the line with changing stage will cause the pressure sensor to read low (under register) at high stages. These errors generally vary linearly with stage and can be corrected for by determining the linear relationship between stage and the error. Depending on the pressure sensor model, it may also be possible to adjust the sensor to compensate for the variation in the weight of the gas column with stage.

The principal sources of error inherent in bubbler systems are variation in gas friction, variation in weight of gas column with stage, and variation in required bubble-feed rate with rate of increase in stage. Some models of non-submersible pressure sensors allow adjustments to compensate for the variables that influence the calculation of stage (include water density, gas density, local gravity, and elevation changes of the orifice). WSC is not in the habit of performing these adjustments.

Finally, it is important that the bubbler feed rate be set appropriately for the station conditions. If the bubbler rate is set too low, then large and rapid stage rises can result in a lag in sensor readings.

The standard orifice line is made of plastic tubing with an inside diameter of 3 mm (1/8 in.) and an outside diameter of 9.5 mm (3/8 in.). It is recommended that this line be protected from crushing or cutting forces as well as animals that may gnaw on it. Depending on the level of protection required it can be encased in conduit or heavy armoured line. The orifice line **must be** continuously sloped from the station shelter to the orifice end. This will prevent condensation from accumulating in a low point, which can cause problems with pressure readings. Burying the line prevents debris or ice from catching on and moving or destroying it during times of fast flow. If the line cannot be buried, rocks **should** be placed over it, or anchor pins used to hold the line in place and make it less tempting to vandals.

The line **must be** properly anchored to the streambed to prevent movement since any vertical movement of the orifice end results in an apparent change in stage. Various types of anchors exist, such as the orifice blocks seen in Figure 4 a, b. Orifice blocks **should** be shaped so that there is minimal erosion of the streambed underneath and around the block. An example of a streamlined anchor is shown in Figure 4 b. Since large objects can be easily moved by the force of water, using an anchor with as small a cross section as possible will decrease the chance of movement. Therefore, when feasible, anchoring with rebar or a pipe with a cross fitting or a T fitting is advisable (Figure 4 d). The length of rod required will depend on the substrate and degree of bed mobility.

Another type of anchoring system is a well point orifice, which involves burying the orifice within a bubble of sand or gravel (Figure 4c). This is a good option when the velocity past the orifice is high, when there is a risk of the orifice freezing into the ice cover or when the stream is silt laden. While the gravel bubble can reduce silt deposits in the orifice, it does not prevent them entirely. When the orifice or the space around an orifice is partially blocked by debris or silt, the stage trace gives the illusion of a surging water level and is often described as exhibiting erratic painting. Section 7 contains detailed information on equipment troubleshooting for all installation types used by the WSC.

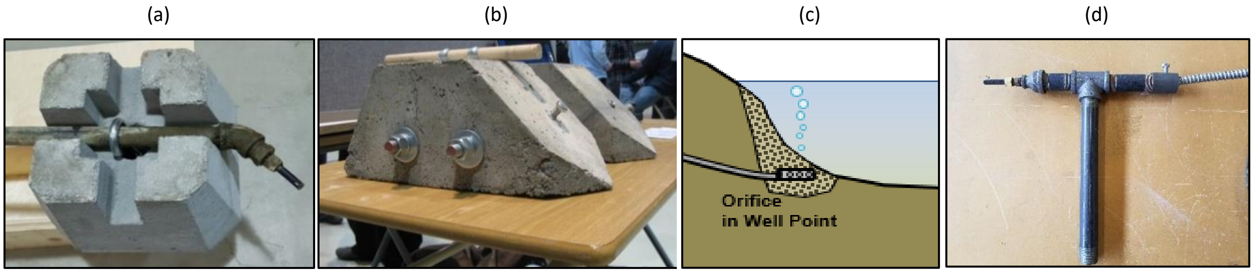

Figure 4: Anchor systems for orifice lines. (a) Orifice block, the orifice line is angled towards the bed when deployed; (b) a streamlined orifice block; (c) a well point orifice; (d) orifice and pipe anchor with a T fitting.

3.3.2. Submersible Pressure Sensors

Submersible pressure sensors are self-contained units that are installed on the streambed as depicted in Figure 5. If the sensor is equipped with a vent tube, the sensor measures gauge pressure. If it does not have a vent line, it measures absolute pressure and data from an atmospheric pressure sensor is required to calculate the gauge pressure from the sensor reading. Sub-zero temperatures can damage and destroy some sensor models, so it is important to select the right sensor for each site.

Some recent models of submersible pressure sensors measure and account for changes in water temperature. Accounting for water temperature can be important because water density is a function of temperature, so if extreme temperature changes are unaccounted for, the sensor may over or underrepresent the effective stage. Pressure sensors that do not account for water temperature **should** only be installed in a location where temperature changes throughout the year are minimal; this would typically be in a deep shaded section. Some sensor models can also account for user-defined values of water density and gravitational acceleration.

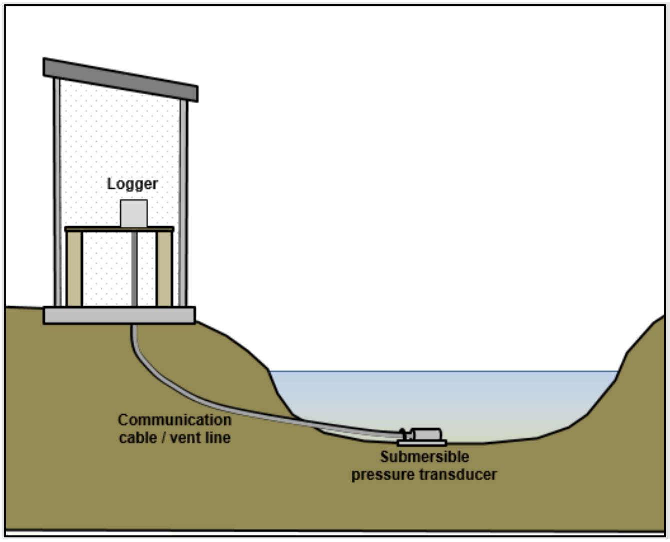

Figure 5: Example of a site with a submersible pressure sensor.

The techniques for positioning and anchoring orifice lines described in Section 3.3.3.3.1 also apply to anchoring submersible sensors. Notably, if a pressure transducer faces into the flow, the stage readings will be biased high, and this bias will increase with increasing flow speed. To avoid this potential source of error, submersible pressure sensors **must be** installed perpendicular to the direction of flow. In addition, they can also be installed facing the riverbed. Tips on troubleshooting data acquired with submersible pressure sensors are presented in Section 7.

3.4. Non-contact Sensors

In rivers that experience high levels of sediment transport or debris, non-contact instruments may be the ideal stage sensor since they are installed above the river on a bridge handrail or other stable structure facing the water surface. Depending on the technology, they determine the distance to the water using either electromagnetic waves (radar or laser) or acoustic waves (sound). At the time of publishing, there were no acoustic or laser stage sensors in the WSC network, therefore only radar sensors are discussed below.

3.4.1. Radar Stage Sensors

Radar sensors emit and receive radio waves, measuring the distance to the water in a circular area on the surface (Figure 6). The size of this footprint increases as the distance between the radar and the water increases. The diameter of the footprint is calculated from the distance to the water, i.e., the air gap, and the radar's beam angle, θ:

$$Diameter = Distance * \tan\theta$$

For example, a sensor with a 10° beam angle will have a 0.35 m diameter footprint when it is 2 m above the water, and a 1.76 m diameter footprint when it is 10 m above the water. The sensor's footprint **must be** completely clear of obstacles at all stages. If something other than water is within the field of view, the sensor cannot interpret the reflected signal properly, though some radar models can suppress false signals. This means that radar sensors do not provide meaningful stage data when there is ice or snow covering the water.

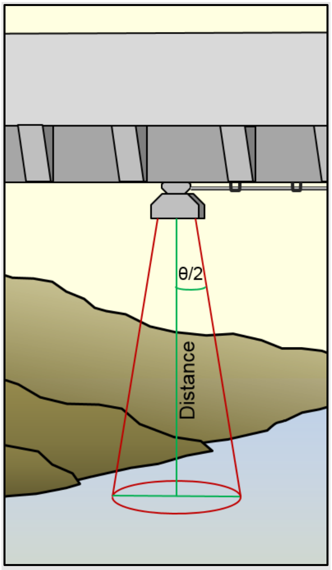

Figure 6: Example of a radar stage sensor

Radar sensors typically have a minimum required air gap of ~0.5 m and a maximum range of 20 - 40 m, depending on the model. They are not impacted by ambient temperature or weather (snow or rain) and the emitted radiation is harmless to humans and wildlife. They can be mounted on bridges or other infrastructure directly above the water, but any vibrations of the structure influence the stage readings. Bridges can move by several centimeters due to temperature fluctuation and vibrations from traffic, so the sensor **should** be mounted on, or near, a stable pillar. The face of the sensor **should** be as parallel as possible to the water, and it **should** be positioned over a smooth patch of water. Foaming water, surging, or standing waves below the radar are to be avoided.

3.5.Stage Sensors on Acoustic Doppler Velocity Meters

Acoustic Doppler Velocity Meters are often used to monitor flow at sites that experience variable backwater, highly unsteady flow, and/or reverse flow. Most models are equipped with two means of measuring water level: a low accuracy pressure sensor and a higher accuracy upward-facing acoustic beam. The pressure data are typically used by the instrument to determine stage from the backscatter data acquired with the vertical beam. Under ice conditions, the effective stage measured by the vertical beam corresponds to the distance to the underside of the ice and the stage measured by the pressure sensor is generally greater than this value. Therefore, the combination of these two measures of stage can be used to track the evolution of the ice cover. It is not advisable to use these instruments as primary stage sensors for two reasons. Firstly, the range to the surface measured by the acoustic beam will be greater than the effective stage if the instrument is not perfectly level and this difference will increase with increasing stage. Secondly, their specified accuracy does not meet WSC standards and typically exceeds 0.003 m.

3.6.Selecting a Stage Sensor

Four methods for monitoring stage were presented: submersible pressure sensors, non-submersible pressure sensors, float systems in stilling wells, and non-contact systems. These methods provide data of comparable accuracy if properly installed and maintained. The choice of sensor is site-specific, and technologists **should** consider the advantages and limitations presented in Table 1, choosing the solution that best meets operational realities. When selecting a stage sensor, refer to qREC-NA020- List of Approved Devices.

Table 1: Options for continuous stage monitoring.

Method	Advantage	Limitations
Submersible pressure sensor	• Relatively inexpensive • Easy installation	• With some exceptions, most models are susceptible to damage when encased in ice • Accuracy decreases with increasing effective stage • The sensor is in the water, leaving it vulnerable to damage and loss • Narrow diameter vent lines may be susceptible to blockage from moisture • Sensor can move during floods or ice breakup, often drifting to shore • Require desiccant to keep vent tube dry
Non-submersible pressure sensor (bubbler system)	• Only the orifice line is in the water, not the sensor itself, meaning less risk of sensor damage	• Expensive • Requires an orifice line and a source of pressurized gas • Orifice block can move during floods or ice breakup, often drifting to shore • Orifice can routinely be blocked by sediment, algae, calcium or other material • Can be affected by humidity in gas • Accuracy decreases as effective stage increases • Require desiccant to keep orifice line dry • Susceptible to leaks in the system
Float with shaft encoder	• Fluctuations from wind and waves are	• Requires a stilling well

	dampened by stilling well • Less frequent errors during floods than other sensors • No risk of sensor damage during floods	• Well **must be** protected from freezing if site is operated year-round. • Intakes require regular flushing to ensure interior/exterior levels match. • Can be errors due to drawdown and pileup if intakes are not perpendicular to the flow
Radar stage sensor	• Equipment is not in contact with the water • Useful at sites with heavy silting, high velocities or debris • Immune to snow and rain • Low maintenance	• **Must be** installed at least ~0.5 m above the water • Bad or unusable data if anything other than water is in their footprint (e.g. rocks or ice) • Waves on surface decrease accuracy • Installation on an unstable platform decreases accuracy

3.6.1. Dual Sensors

Some monitoring sites may be equipped with two stage sensors. In some cases, the second sensor is a redundancy requirement stipulated by a partner. When this is the case, the secondary sensor may be the same model as the primary sensor. In other cases, a different model of sensor may be used. This might be the case at a site where one sensor type is not appropriate for all conditions or ranges of stage. Having two stage sensors at a site can improve continuity in records and station reliability, providing a backup if one sensor fails. When there is more than one stage sensor at a site, the purpose of the secondary sensor **should** be noted in the station description. The secondary sensor **should** be installed in a location that will record the same water level as the primary sensor but that is not likely to experience the same problems. For example, you would not want two sensors tied together as they would both give erroneous data if one sensor's cable were moved by ice. Be sure to note any difference in water level between the locations since two points within the same pool can have different water levels, and this difference can change under different hydraulic conditions.

In some cases, a secondary sensor may be used to track beaver activity or to validate peaks or the shape of the time series. If there is a different flow control at the secondary sensor, the time series **should** be adequately labelled, and the different controls described in the data computation system.

4. Reference Water Level Measurements

Reference water levels are of utmost importance, as they are required to set, validate, and correct stage sensor data. The various methods of obtaining this information are described within this section. Readings from the reference gauge are referred to as discrete water level measurements. The various types of reference gauge are described below, they include direct water levels, staff gauges, inclined staff gauges, measuring points, tape and weight gauges, wire weight gauges, electric tape gauges and electric contact gauges. Details on instrument operation and maintenance can be found in instrument-specific manuals.

The reference gauge **should** be as close as is practical to the stage sensor, inlet pipe or orifice and in the same pool to ensure they are subject to similar conditions. For example, you would not want the stage sensor immediately upstream of a bridge pier and the reference gauge downstream of the pier because hydraulic conditions would differ in these locations. The reference gauge **should** also be in a zone of minimal local turbulence. If the water surface is surging, take several observations, preferably at the crest and trough of the waves, and average the results to obtain as accurate an average reading as possible. The observed surge in water level **must be** noted, even if it is zero.

The elevation of the reference gauge, relative to the operating datum is determined and documented following the procedures outlined in the *Hydrometric Field Manual - Levelling* (qSOP-NA005). When conditions are such that there is no reference gauge that is accessible at all stages a site may have more than one reference gauge. However, if possible, gauge corrections and sensor reset corrections are only applied using readings from one reference gauge. This will maximize record consistency and avoid confusion.

4.1.Direct Water Level

When stage is observed by differential levelling from a benchmark or measuring point, it is referred to as a direct water level. To simplify calculations and avoid confusion when accounting for gauge corrections, levelling **should** begin at the same reference point (benchmark) at every site visit. Ideally, measurements **should** be made at the same location in the river every visit to avoid introducing uncertainty due to spatial variation in the local water level. Take the reading as close to the orifice, intake, or submersible pressure sensor as possible, ensuring you do not influence the water level during the reading.

When the surface of the water is choppy or surging, a temporary stilling well can be constructed from a bucket with holes at the bottom. This bucket will stabilize the water surface at the point where the rod is read (Figure 7). Refer to the *Hydrometric Field Manual - Levelling* (qSOP-NA005) for instruction on obtaining direct water level measurements.

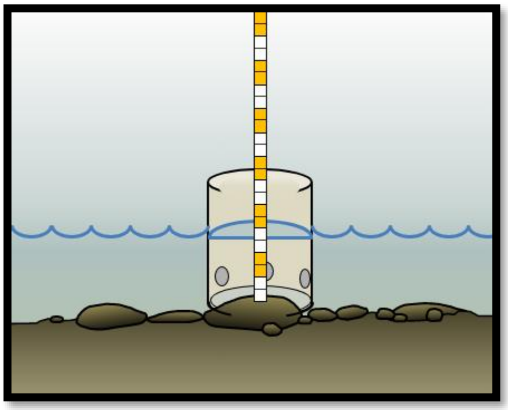

Figure 7: Temporary stilling well to stabilize the water surface while obtaining a water level reading from the survey rod.

4.2. Staff Gauge

A staff gauge is essentially a large ruler composed of sections of enamelled steel plate fastened to a backing board and attached to a structure that may be in the streambed or inside a stilling well. Staff gauges **should** be installed so that they are protected from damage by floating ice or debris and are not affected by local drawdown or pile-up of water. Small local effects may be reduced by mounting the face of the plate parallel to the current and by streamlining the backing board.

When reading a staff gauge, the observer **should** try to be at eye level with the meniscus of the water and the gauge **must be** read at the bottom of the meniscus, as shown in the green solid line in Figure 8. The staff gauge **should** be cleaned regularly so that it is clearly legible. It **should** be replaced when necessary.

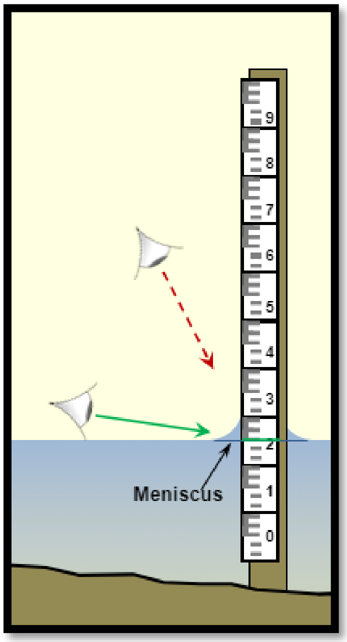

Figure 8: Correct (solid green arrow) and incorrect (dashed red arrow) examples of reading a staff gauge.

4.3. Inclined Staff Gauge

Inclined staff gauges (Figure 9) may be used where gently sloping riverbanks make it impractical to install a vertical staff gauge or where a vertical gauge would be endangered by floating debris during high flow. An inclined staff gauge provides better resolution than a vertical staff gauge because the distance up the slope is greater than the corresponding vertical height. A conversion table produced by levelling at various points along the length of the inclined gauge is required to convert the numerical readings to the stage. This makes the inclined gauge a more complicated and less desirable reference gauge than the other options. Furthermore, inclined gauges can be moved by frost heaves, so special care **must be** used upon installation.

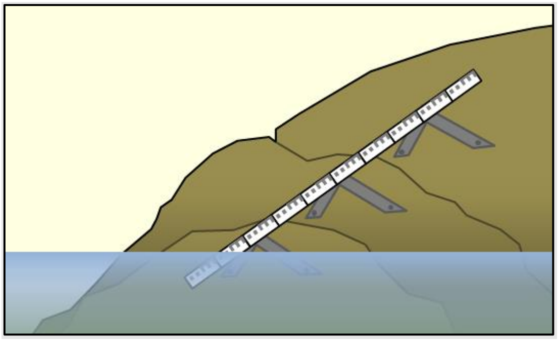

Figure 9: Inclined staff gauge.

4.4. Measuring Points

A measuring point is a stable, accessible point on a bridge, pier, abutment or stilling well from which one measures the vertical distance to the surface of the water. Measurements can be made using a levelling rod or a weighted tape such as a wire weight gauge. Alternatively, some sites may have in-stream measuring points located near the pressure sensor, orifice, or well intake. These measuring points are often metal rods driven in the river, and the reference water level is obtained by measuring the distance above or below the measuring point to the water surface.

4.5. Wire Weight Gauge

Wire weight gauges are typically used to obtain readings from bridges, but they can also be attached to cantilevered arms connected to the shore. A wire weight gauge consists of a weighted cable with graduated markings. The weight is lowered from a reel down to the water surface (Figure 10).

For this and all other tape-type measurements:

- Readings are obtained when the weight first touches the water surface as it is lowered. This will help avoid surface tension effects because once contact with the water surface has been made the weight can be raised as much as 6 mm without breaking the contact.
- The bottom of the weight **should** be visually inspected at every reading to verify it is at the zero of the tape or determine a correction if necessary, and to ensure there is no debris or ice on it.

It is important to note that during periods of high wind, the accuracy of readings will be degraded by wind drag on the wire. A kinked or bent tape also leads to error.

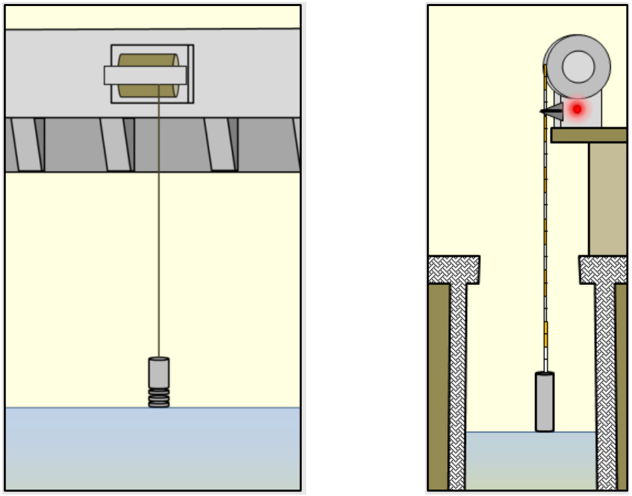

Figure 10: Measuring water level using a wire weight gauge (left) and an electric tape gauge (right).

4.6. Electric Tape Gauge

An electric tape gauge or electric contact gauge is an electrified wire weight gauge permanently installed in a stilling well (Figure 10). It consists of a reel with a graduated stainless-steel tape attached to a weight, an electrical power source, and a device to indicate when the electric circuit is completed, usually a voltmeter or indicating light. The weight is lowered until it contacts the water surface, thus completing the electric circuit and illuminating the light or moving the needle on the voltmeter. The bottom of the contact surface is concave to prevent observation errors due to water droplets on the weight bottom. Electric tape gauges can be affected by moisture in the shelter, so they **should** be visually inspected routinely to ensure there is no corrosion on the weight or in the electric circuit. Replace batteries when required.

5. Station Visit Requirements for Stage Measurements

Guidance in this section supersedes guidance in all older standard operating procedures regarding station visit requirements for stage measurements.

Readings from the stage sensor **must be** compared to a reference water level (surveyed or reference gauge) at least once during every site visit. The reference water level **should** be compared to the sensor reading using the closest logged 5-minute reading which **should** be recorded on the field note. While "forced" reading are useful for station diagnostics, they cannot be confirmed during the data review process and are not recommended as reference water levels. If a sensor reset correction is large or atypical for the station, a second reference water level measurement **should** be obtained to confirm the value. In addition to validating the sensor readings and determining sensor reset corrections, reference water levels are important for calculating the mean gauge height during discharge measurements, and for comparison to sensor readings before and after station maintenance.

5.1.Mean Gauge Height

For station visits that include discharge measurements, a mean water level, representative of the water level during the discharge measurement, is required for building and validating the stage-discharge rating model. A minimum of two water level values **must be** used to calculate mean gauge height, one at the beginning and one at the end of the discharge measurement.

Operational Note: The electronic hydrometric survey note (eHSN) allows for the calculation of mean gauge height using either average or time weighted methods. The time-weighted method **must be** used for periods when the water level changes > ±0.003m between the measurement start and end time. Using the time-weighted method in all conditions **is recommended** for consistency.

The three acceptable ways to calculate mean gauge height are presented below.

- Use one reference water level from before the start, and one from after the end, of the discharge measurement to calculate the mean gauge height. When operationally possible, this is the preferred method. This method **must be** used when logged stage values are unusable or unavailable.
- Use a reference water level to confirm stage sensor values are accurate, then measure the discharge. Use logged sensor values corresponding to the start and end times of the discharge measurement to calculate mean gauge height.
- Measure the discharge. Then use a reference water level to confirm stage sensor values are accurate. Apply appropriate corrections to corresponding logged values for the start and end times of the discharge measurement and use these values to calculate the mean gauge height. This method can only be used when logged stage values are available and reliable.

The choice of method depends on operational realities, including proximity of the discharge measurement cross section to the gauge house and reference gauge, and the validity of the stage sensor data. Independent of the method used, in cases where the stage is rapidly changing and the trend is not linear (measurement encapsulated a peak or a trough in the stage record), additional water level values (reference or logged) between the measurement start and end times **should** be used in the calculation of mean gauge height.

5.2.Before and after station maintenance

Reference water levels **must be** measured before and after any station maintenance that may affect the stage sensor to confirm whether logged values are accurate. Examples of such maintenance are included in Section 7 of this document. If the maintenance work takes less than 5 minutes (the standard time at which stage values are recorded), and the water level is not rapidly changing, it is acceptable to compare the post-work logger reading to the pre-work reference water level.

To ensure that stilling wells function correctly, a comparison of the water level *inside the well* and *outside the well* **must be** conducted before and after work that affects the well intakes or valves (flushing, maintenance, etc.).

6. Methods for Measuring Peak Stage between Visits

Stage sensors may occasionally stop working or incur damage at times when data are most needed such as during floods or ice break-up. At these times, alternative methods to determine peak stage may be used to fill gaps in the stage record or to corroborate data from the stage sensor. Methods for obtaining peak stage are presented in the following subsections. Peak stage data and high-water marks can also be used to calculate discharge with indirect methods such as the slope-area method. When using such a method, the appropriate literature **should** be consulted. The United States Geological Survey has several useful publications on the subject.

6.1. Crest Stage Gauge

Crest stage gauges are simple devices for measuring the height of flood crests. The three types of crest stage gauges shown in Figure 11 are discussed in this document. Note that at the time of writing, less than a handful of crest stage gauges were employed in WSC's hydrometric network.

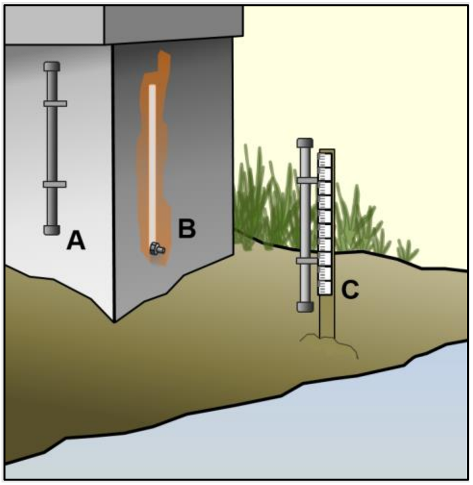

Figure 11: Three types of crest stage gauges: (A) cork dust and rod in tube; (B) chalk mark; and (C) tube and staff gauge.

One type of crest stage gauge is made from a galvanized pipe that is capped at both ends (A in Figure 11 and Figure 12). Holes are drilled in the bottom cap, to permit entry of water while keeping surge effects to a minimum, and a vent hole is drilled in the top cap. A wooden or aluminum rod with a small cup containing cork dust attached at the lower end is placed inside the pipe so that it cannot float (Figure 12). As the water rises in the pipe, the cork dust floats free of the container and adheres to the rod at the point to which the water has risen. The entire assembly is firmly fixed to a bridge or pier and levelled to the operating datum so that the elevation of the cork dust line on the rod can be noted. At each visit, the wooden rod **must be** inspected. If necessary, it **must be** cleaned, and the cork dust container **must be** refilled before the rod is replaced in the pipe to ensures it can be used to measure peak stage between visits.

The second type of crest stage gauge consists of a length of transparent tubing attached to a backing board, usually alongside a staff gauge (C in Figure 11). Inside the tube there is a cylindrical piece of foam. The bottom and top of the tube are drilled to permit entry of water and venting of air. As the water level rises inside the tube, the foam floats upward following the rise in stage. The foam sticks to the tube and does not drop when the water level recedes. The height of the midpoint of the float is read on an adjacent staff gauge or it can be determined by levelling from a benchmark. The gauge is easily reset by removing the top plug from the tube and dislodging the float. Errors can occur if the crest gauge is subjected to vibration or if humidity is very low, preventing the float from adhering to the tube.

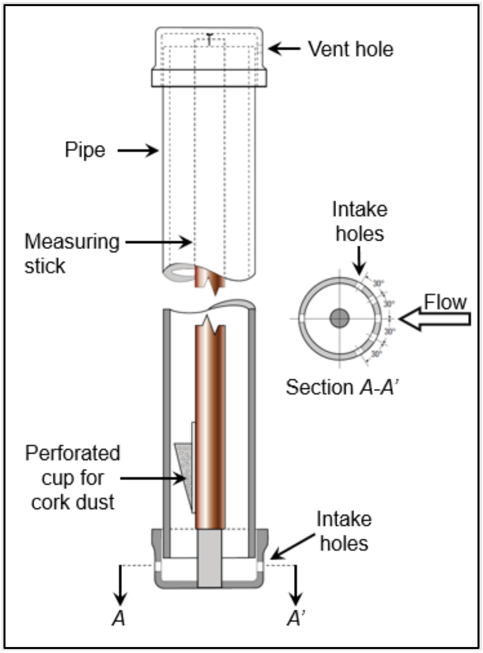

Figure 12: Example of a crest stage gauge using cork dust with holes drilled in the top and bottom (source: Sauer and Turnipseed 2010).

A third type of crest stage gauge is a simple vertical paint line and chalk mark drawn above a reference point of known elevation (B in Figure 11). First, a thick line of paint is applied to a smooth vertical surface and a vertical line is drawn in chalk on top of the dry paint. The bottom of the chalk line **must** coincide with a reference point of known elevation. In a flood situation, water will wash away the chalk up to the highest water level reached and the elevation of the high-water mark is determined from the remaining chalk. If the chalk line can be sufficiently protected from wind and blowing rain, the high-water mark will be visible at the next site visit.

6.2.High Water Marks

High-water marks (HWMs) are evidence of the highest stage left behind after the water has receded. They can be used to verify or dismiss a logger value. For example, a spike in the stage record (especially during freeze-up or break-up) could be dismissed as invalid if there is no visible high-water mark. These marks can also help determine when to apply sensor reset corrections. High-water marks can include debris lines on the riverbanks, or in a gauge house, as shown in Figure 13.

Ice ledge elevations are a specific type of high-water mark that **should** also be considered and surveyed (Figure 14). They are the highest point on the bank where the ice remains fixed to the ground, i.e., where it is shore fast. Ice ledge elevations indicate the elevation at which the ice and presumably water once were. They usually form during the winter months after freeze-up events. While these high-water levels usually do not produce the maximum discharge values, they are helpful information for data analysis and computation.

Figure 13: Examples of recording and surveying high water marks.

Noting the elevation at which ice is present along the shore can help in determining the ice-affected period at a site. This can be done by working backwards, comparing the ice ledge elevation to the stage record. The absence of an ice ledge is also useful information. For example, if the stage sensor recorded 4.104 m two weeks ago during a cold snowy spell, yet there was no ice on the bank at or near 4.104 m, it would be reasonable to assume that the site was not ice affected during that time.

Figure 14: Examples of surveying ice shelves.

Due to their extreme usefulness, field notes **should** include detailed comments about the presence or absence of high-water marks as well as their type, quality, and location in relation to the gauge. Some examples of observations include "excellent leaf litter HWM surveyed at 3.23m", "fair HWM of rubble ice noted at 3.23m", "no apparent recent HWM above current water level."

Some best practices for identifying high water marks and avoiding pitfalls are to:

- Understand the purpose – knowing why you need high water marks will help you find them.
- Act quickly – identify marks as soon as possible after an event because they morph and degrade with time.
- Find locations with still water – ineffective flow areas or the inside of structures such as stilling wells often have the best high-water marks because they collect fine debris in thin lines that are well preserved (not exposed to the elements).
- When in doubt, collect more data – look carefully along each bank for the greater of 150 m or five times the river width upstream and downstream of the stage sensor. Remember, you do not have to use it, but if you did not collect it in the field, you can never use it.
- Look up – there may be multiple high-water marks. When you think you have found one, look above it for another.
- Take a step back – a wider view may show patterns that were invisible up close.
- Take pictures – high-water marks **should** always be photographed.
- Note your findings and erase the marks after their elevations have been noted to prevent confusion in the future.

Proper identification of high-water marks requires experience and an understanding of how floodwaters create them, see Koenig et al. 2016 for details.

6.3. Water Level by Stakes and Images

When the stage is so high that the reference gauge cannot be accessed, the water level can be identified with stakes placed at the water's edge. All stakes **should** be marked with a line drawn at the water level and the date and time **should** be written on each stake. The elevation of the water line can be determined via levelling when the water has receded.

Images can also be used to determine the stage. The best and simplest may be a photo of the water against a staff plate, but a photo of any object at the water surface is sufficient as long at the object’s elevation is known or can be determined later. All photos and videos **should** be dated and the point from which they are taken **should** be referenced to permanent site features such as bridges or gauge houses. Some sites are equipped with telemetry-enabled cameras that capture images of the gauging pool. These images may help confirm trends observed in the stage record and may also indicate whether a station is facing problems.

7. Troubleshooting and Sources of Error

The accuracy of stage data depends on several factors including temporal fluctuations in stage, measurement error, the accuracy with which reference gauge elevations are determined, and the accuracy of the stage sensor. The following tables are designed to help troubleshoot and improve stage data, listing symptoms, possible causes and solutions. Figures illustrating some of the symptoms follow the tables. In addition to the symptoms and causes listed below, the reference water level may disagree with the stage sensor data if they are subject to different hydraulic conditions. If they are not within the same pool, the elevation of the water surface can differ, and so too can the hydraulic conditions. This situation **must be avoided** at all costs.

Furthermore, it is important to note that even if the stage time series exhibit the symptoms listed below, there may be no issue and the record may reflect the actual water levels.

Table 2: Troubleshooting data from float systems in stilling wells.

Symptom	Possible cause	Action
Flat line in trace (Figure 15, left image)	Float or beaded float wire caught on shelf or gauge house floor	Enlarge shelf/floor holes or remove floorboards (potential freezing issues with this solution).
	Counterweight resting on bottom of well	Shorten float line.
	Counterweight hitting underside of floor or shelf	Lengthen beaded line or tape to accommodate full range of stage.
	Frost catching tape or wire	Heat gauge house, enlarge holes in floor and shelf or surround them with felt soaked in antifreeze.
	If shaft encoder has a beaded line, beads may be slipping, preventing wheel from rotating properly	Reposition the beaded line to ensure the beads sit in the divots.
	Intakes blocked or frozen	Flush pipe or steam pipe to thaw. If intake is buried, expose it. Add a riser to the end to keep intake just off the streambed.
	Water in well freezes because heat lamp burns out or there is oil loss from a frost tube due to flooding.	Manually break ice. If using a heat lamp, replace bulb and adjust its height. If using a frost tube, thaw ice using salt and then replace oil.
	Float catching on intake pipes or corrugated pipe of well	Move float to other side of encoder or move encoder to a new position on the shelf.
	Bottom intake not low enough	Install a second stage sensor for low water conditions.
	Silt in well	Remove silt.
	Minor fluctuations in stage may not be detected by the encoder	Check that the starting torque of the encoder is minimal, and that the float is an appropriate size. Confirm that the encoder responds adequately.
Discontinuity in trace on rise or fall in stage	Float or counterweight caught on obstruction or each other	Check path of float and counterweight through range in stage and enlarge floor and shelf holes if required.

	Thin layer of ice forming on water surface in the well	Check heating system or use a frost tube (i.e. marine-safe oil cylinder) at sites without power.
Water level in well lags water level in river (Figure 16)	Clogged intake	Flush intake.
Water level in well differs from water level in stream	Pulley may be the wrong dimension.	Verify that the pulley circumference is 0.375m.
Water level in well differs from water level in stream and data are noisy	Float pulley is loose	Tighten pulley.
	Beaded cable or float tape disengaged	Re-engage and check for cause, e.g., dirt in tape hole.
	Animals resting on float periodically	Remove animal.
Random fluctuations and false surges (i.e., painting), particularly at high water	Intakes are too large	Close intake valves slightly.
	Velocity effects on intakes	Install static tubes on intake pipes.

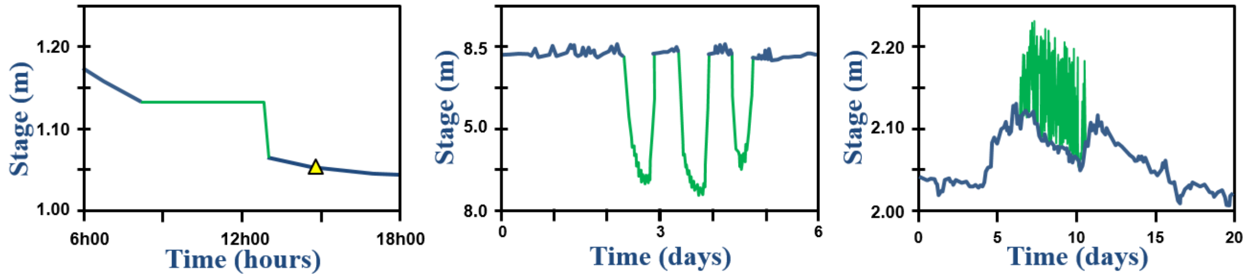

Figure 15: Raw (green) and corrected (blue) stage data with field visits shown in yellow. Left: flat-lining trace due to a stuck float system. Middle: gas leaks resulting in temporary drops in measured stage. Right: painting caused by sediment blocking the orifice line.

Table 3: Troubleshooting data from bubbler systems with non-submersible pressure sensors.

Symptom	Possible cause	Action
Painting (Figure 15, right image)	Water in line (uniform painting)	Purge line, try slightly higher bubble rate. Reinstall line to eliminate any low points.
	Silicone oil in gas line (Conoflow system only)	Check oil level in sight feed to see if it is too high. Dismantle and clean sight feed and line.
	Calcium, algae, mussels, etc. on orifice end	Clean line and purge.
	Silt deposits on orifice leading to erratic painting	Remove silt or reinstall orifice.
	Water velocity effects. Painting typically increases with increasing flow speed.	Ensure orifice is perpendicular to flow. Move orifice closer to riverbed. Add a static tube to orifice or use a well point orifice.

	Slush on orifice, often in early winter. Very erratic painting.	The slush may clear on its own, if not, reposition orifice.
Drop and recovery in stage trace (false troughs) which may be confused with diurnal fluctuations	Intermittent leaks caused by temperature changes (Figure 15, middle image)	Check for leaks and repair.
	Gas supply exhausted	Replace gas tank.
Erratic bubble rate in sight feed (Conoflow system only)	Metal particles or oil in needle valve assembly of regulator	Increase feed pressure to see if bubble rate increases. Replace regulator or dismantle carefully and clean.
	Particles caught in needle valve tip	Check for particles in the bottom of the sight-feed glass. Replace regulator or dismantle and clean.
Erratic bubble rate or bubble size in the stream	Orifice fouled	Purge line. Cut off the end if it is a bare orifice. Clean the orifice.
Stage at instrument's maximum full-scale reading	Orifice completely blocked or frozen	Clear the orifice line, dig it out or install a new line.
Stage biased high (Figure 17)	Orifice partly buried in silt	Purge the line. If still biased high, the anchor may have settled into the bed due to scouring, which is not in itself problematic. Perform a sensor reset.
Large sensor resets required after a high-water event	Water in line because bubble rate was too low. Orifice moved during fast flow	Purge line with a high feed pressure and allow to restabilize. If needed, increase bubble rate. Reposition orifice. Use different anchor system.
Sudden jump in stage followed by erratic/ fluctuating stage	Orifice line severed below the water line	Replace orifice line.
Sudden jump in stage followed by flat lining	Orifice line severed above the water line	Replace orifice line.
Sensor reads low at high water	Drawdown at orifice	Ensure orifice is perpendicular to flow. Move orifice closer to riverbed where velocity effects are lower or add a static tube. Secure the orifice end against rotation.
Unrealistic stage trace	Problems with the line slipping or moving.	Check the state of the line and repair or reposition if necessary.

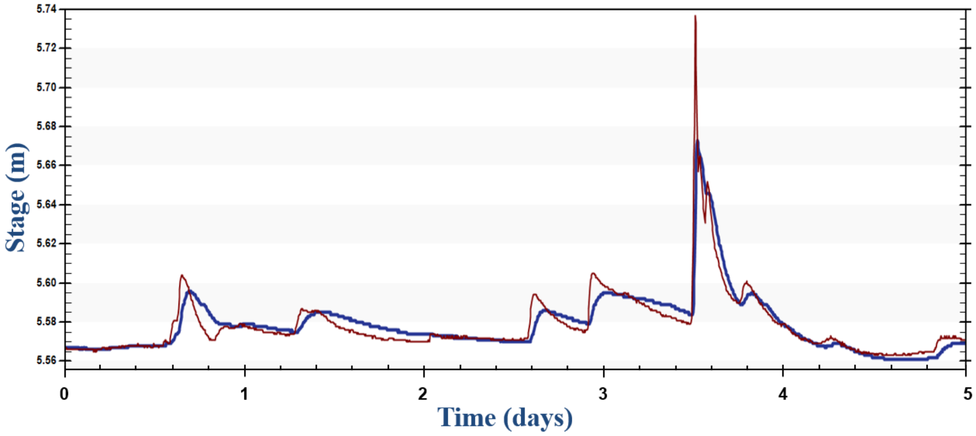

Figure 16: Stage measured in the stream (red) and in the well (blue) demonstrating lag due to partial blockage of the well intake.

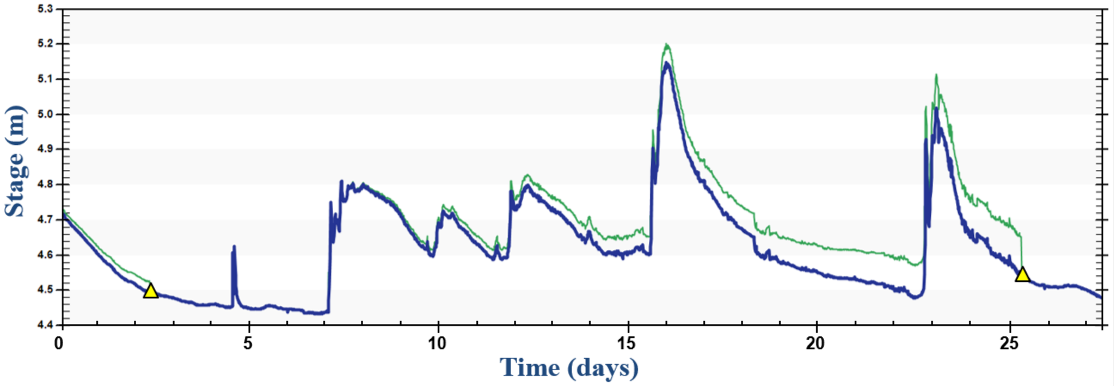

Figure 17: Raw (green) and corrected (blue) stage data when orifice is partly buried in silt. Field visits are shown in yellow.

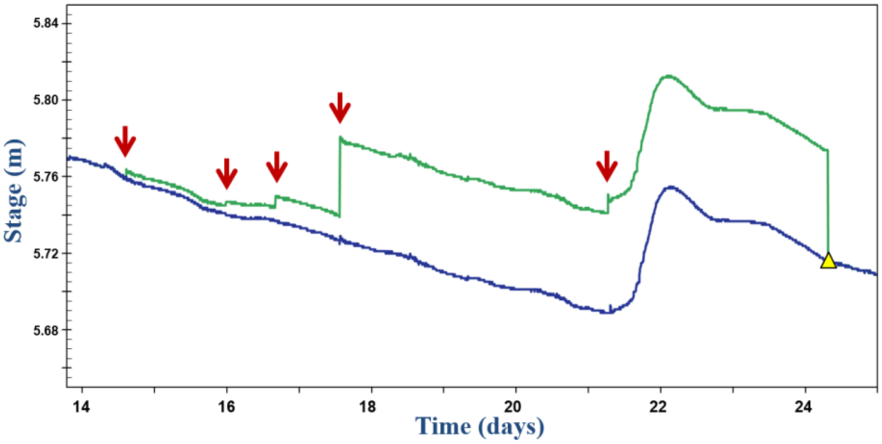

Figure 18: Raw (green) and corrected (blue) stage data when orifice line is moving as the clamp is slipping (times indicated by red arrows).

Table 4 Troubleshooting data from submersible pressure sensors

Symptom	Possible cause	Action
Painting	Deposits on sensor	Clean sensor.
	Velocity of flow past the sensor is affecting pressure measured by the sensor (problem worsens with increasing velocity).	Ensure the sensor is perpendicular to the flow, add a static tube to the sensor.
Flat line in trace	Sensor failure	Replace sensor.
Sensor drifting	Moderate drift is inevitable over time. If problem is severe, it could be an instrument failure.	Perform a sensor reset, i.e., set the sensor value to the reference water level measurement. Replace the instrument if the unit seems to be malfunctioning.
Slope of stage trace does not match reality	User-specified units set incorrectly in data logger (e.g. feet instead of meters)	Correct units.
Stage biased high	Sensor buried in silt	Clean sensor.
Stage does not agree with reference water level measurement and difference is a function of stage	different hydraulic conditions at the two locations	Ensure reference gauge is as close as possible to the sensor or at least at the same streamwise position.
	Velocity effects	Ensure sensor is perpendicular to the flow. Add a static tube.

Table 5: Troubleshooting data from radar water level sensors.

Symptom	Possible cause	Action
Stage does not agree with reference water level measurement	Debris caught in the radar footprint	Remove obstruction. If debris accumulates regularly in this location, move sensor.
Sensor values vary for a steady stage or are not present	Sensor dirty	Carefully clean.
	Sensor not aligned at right angles to water surface	Correct sensor alignment.
	Movement of the mounting location (e.g. bridge vibrations or expansion and contraction with changing temperature)	Optimize mounting location.
	Large metal surfaces near the sensor beam	Optimize mounting location.
Trace fluctuates wildly at a time when ice is suspected. (Figure 19)	Ice cover in part of the field of view	Do not use the data during affected period

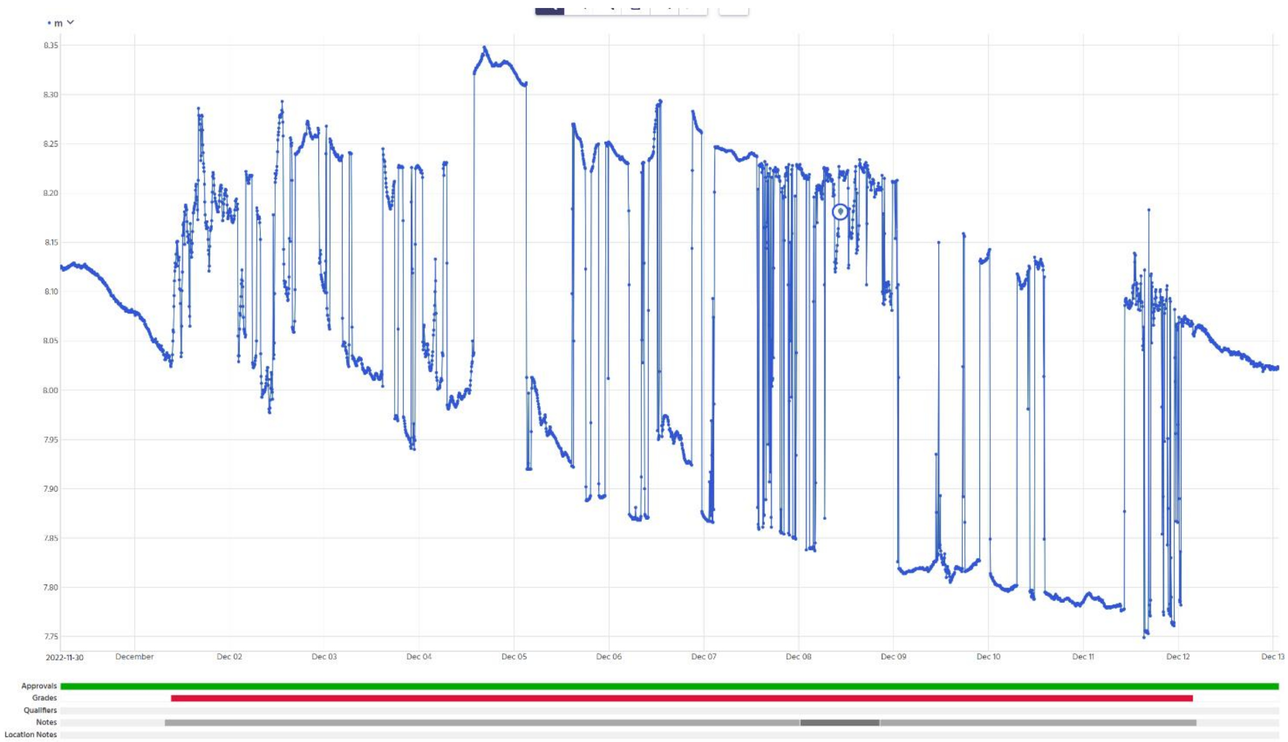

Figure 19: Radar stage sensor data a period with ice in the field of view (December 1-12).

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