BASELINE DATA FOR ASSESSING CLIMATE CHANGE AND FUTURE ENHANCED SURFACE WATER PASSAGE IMPACTS ON THE SALMON RIVER ESTUARY

Final Report

PROJECT SPR-719

Oregon Department of Transportation

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by

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16. Abstract:

The Oregon Department of Transportation (ODOT) monitored the surface waters in and around the Salmon River Estuary on the Pacific coast of Oregon for approximately ten years. Two ODOT highways are associated with this estuary. Oregon State Route 18 runs along a portion of the southern margin of the estuary while U.S. Route 101 runs directly across the estuary. Water level, conductivity, temperature, and dissolved oxygen measurements were collected at 10-minute intervals from 20 stations for varying periods from 2011 until 2021. Numerous researchers have been monitoring the flora and fauna in the estuary for decades. Comparatively little longitudinal data regarding the hydrology and water in and around the estuary has been published. This report documents the water data ODOT collected from 2011 through 2021. This report describes the data to make them usable by researchers from diverse disciples. It is hoped that many future publications will interpret these data.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
~NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

ACKNOWLEDGEMENTS

This project was, originally, the brainchild of Barnie Jones, Research Section Manager from 1998 to 2013. He attended a meeting in 2008 where the restoration of the Salmon River Estuary was discussed, and he learned of the existence of the "Cascade Head Experimental Forest" and the "Pacific Northwest Research Station." Barnie envisioned of a facility full of U.S. Forest Service researchers, on the site, doing great things to advance human knowledge and understanding. While a former U.S. Forest Service Ranger Station now bears the name Cascade Head Experimental Forest Research Station, its buildings stand vacant much of the time. The staff of the Pacific Northwest Research Station (80 researchers and 300 total staff) are scattered across Alaska, California, Oregon, and Washington. The headquarters are in Portland, Oregon. The Cascade Head Experimental Forest is just one small part of the work it does. None-the-less, Barnie came away with a desire to combine doing some sort of research regarding climate change with some sort of partnership with the Cascade Head Experimental Forest Research Station. His desire to do climate change research was tied to the interests of the then Chair of the Oregon Transportation Commission, Gail Achterman (Chair from 2007-2011). He gave the author of this report the assignment to come up with a research problem statement that would include climate change and collaboration with the USFS.

Long-time Research Section employee Eric Brooks helped with the installation of the monitoring instrumentation at the start of this project. This was one of Eric's last projects before retiring for real.

Apprentices in Science and Engineering (ASE) intern Daniel Garcia worked on this project in 2012 as the centerpiece of his internship. In the estuary, he learned that sometimes science is dirty business.

Because this project lasted 12 years (2009-2021), including delays due to capital equipment budget hurdles, most of the original TAC members have retired (or otherwise moved on) at this point. The original TAC members were: Kami Ellingson, USFS; Barbara Ellis-Sugai, USFS; Steve Gisler, ODOT; Rob Piehl, USFS; Dan Bottom, NOAA; Marjorie Lifsey, ODOT; Jerry Wolcott, ODOT. Their assistance with this project is much appreciated. Replacement TAC members were Geoff Cook, ODOT; Paris Edwards, ODOT; Daniel Ohrn, ODOT; and Kira Glover-Cutter, ODOT. There review comments regarding the final report were very helpful.

DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

In 1961 a new, straightened and shortened, portion of U.S. Route 101 along the Oregon coast was completed between Neskowin and Lincoln City. This new section of the highway moved Route 101 from a bridge over the Salmon River that was at the edge of the tidal influence on the river (now a Lincoln County bridge carrying "N. Old Scenic Highway 101") to a new bridge over the river located further west, in the heart of the Salmon River Estuary. The old route followed a narrow, winding road up the drainage of Deer and Toketa Creeks. The new route was much straighter, and of course wider, and followed Salmon Creek drainage. Figure 1.1 and Figure 1.2 show the original highway circa 1939 and in 2019. Figure 1.3 shows a map of the estuary in 1955 with the original alignment of US Route. The new route made travel between Neskowin and Lincoln City much quicker, hopefully safer, but the new highway left a heavy mark on the estuary.

Figure 1.1: A portion of the original US Route 101 north of the Salmon River Estuary, circa 1939.

Figure 1.2: The same portion of the original (now former) US Route 101 as shown in Figure 1.1, as it was in 2019.

This research project was intended to establish a thorough baseline of water conditions in the Salmon River Estuary to compare to future conditions that are likely to change due to climate change and the future construction of new passages for Salmon Creek and the Salmon River under US Route 101 in the estuary. This was done is the context of extensive previous and on-going research done by others in the estuary. This report documents the data collection during nearly 10 years of monitoring the water in the Salmon River Estuary. The report is intended to be descriptive, not interpretive. The expectation is that the data will be used for diverse interpretive purposes in the future.

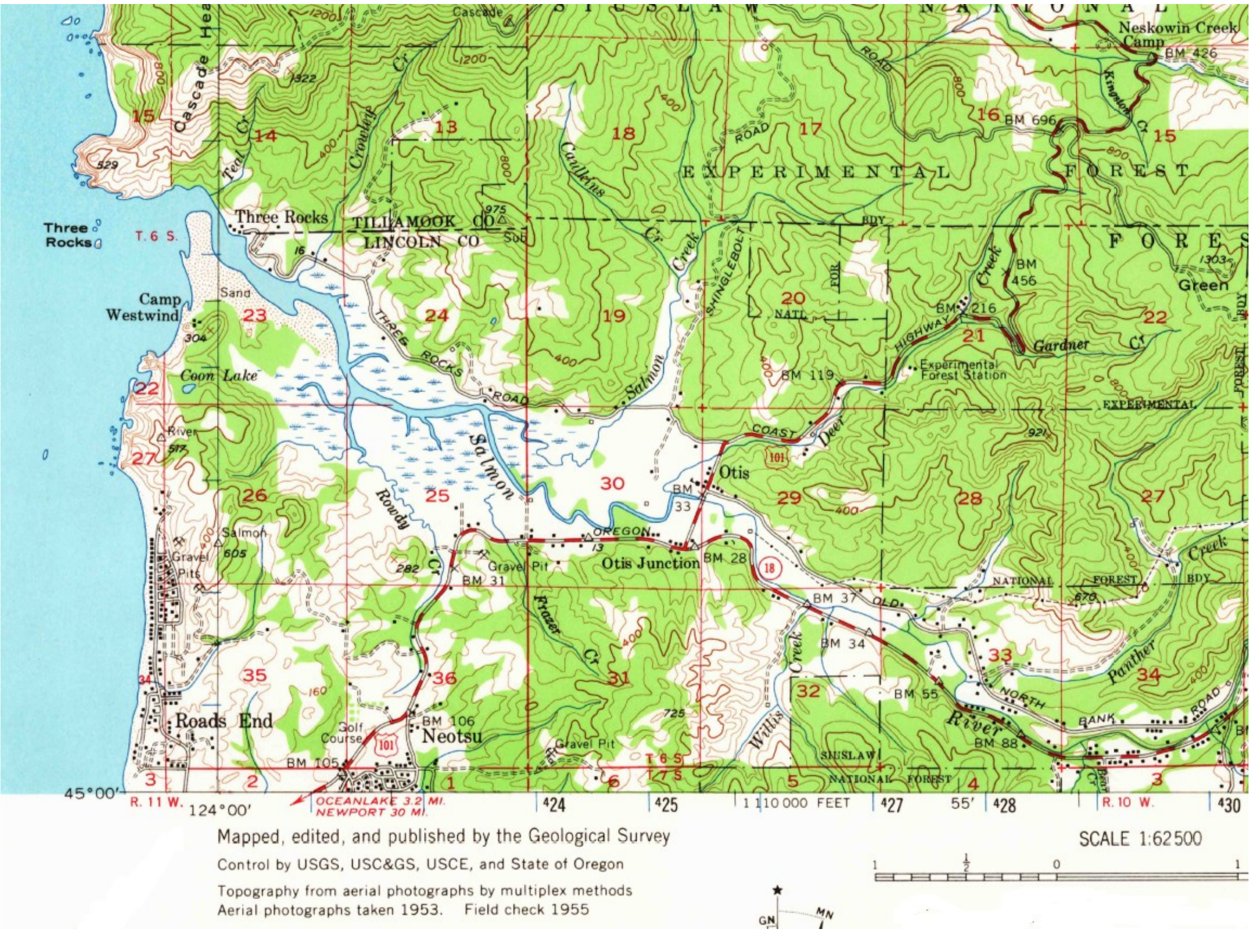

Figure 1.3: Excerpt of 1955 US Geological Survey Topographic Map showing the Salmon River Estuary prior to the construction of the new alignment of US Route 101.

1.1 THE SALMON RIVER ESTUARY

The Salmon River Estuary is far from the largest estuary on the Oregon coast, but it is similar to many estuaries up and down the coast. It is located in a drowned stream valley that has filled with sediment. The topographic map shown in Figure 1.3 does not have sufficient elevation resolution to establish precisely the outline of the estuary. However, the area around the Salmon River west of Otis that is white, lacking both brown topographic contours and forest cover (indicated by green) gives a fair sense of its extent. Three-Rocks Road marks the approximate limit of the estuary to the north. (Oregon) State Route 18 similarly approximates the boundary to the south. The current estuary is a product of the shift from the most recent sea-level low-stand 20,000 years ago, during the last ice age, into the current interglacial climate (Komar, 1997). The estuary is shielded from direct wave action by a sand-spit at the coast where the river empties into the open ocean through an outlet much narrower than the drowned stream valley.

The estuary has evidence of human habitation that extends back into prehistory, long before European colonization of North America (Ross, 1990). It was used as pastureland beginning in the 19th century (Zobel, 2002). To facilitate and extend grazing, portions of the estuary were diked to isolate them from tidal and stream flood inundation. Importantly, one portion of the estuary was never diked (Ellingson & Ellis-Sugai, 2014). This has allowed researchers to compare the conditions in the now restored areas of the estuary with the natural, relatively unimpaired conditions in the part of the estuary that was never diked.

The rerouted section of US Route 101 was built on an artificial fill embankment that acts as a dike running in a straight-line northeast to southwest across the estuary (see Figure 1.4). When built, the only hydraulic opening in this dike was under the bridge over the Salmon River. This bridge was constructed with a span length that coincides with the active channel width of the Salmon River. The position of the active channel of the river in the estuary has been stable since the time of the first maps in the mid-19th century. Two tributary creeks, Salmon Creek and Frazer Creek[1], were rerouted to run parallel to the new embankment. The relocated creeks joined the Salmon River upstream of the bridge instead of their natural course through the estuary (see Figure 1.5). Thus, the highway had clear impacts on the hydrology of the estuary. The rerouted section of US Route 101 was not the first human impact on the estuary, and it was not the last constructed. Subsequent to the construction of the new section of US Route 101, Pixieland amusement park and the Tamara Quays subdivision were also built in the estuary (Ellingson & Ellis-Sugai, 2014).

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[1] The name of Frazer Creek is found spelled both "Frazer" and "Fraser." This report uses the USGS Geographic Names Information System spelling of "Frazer."

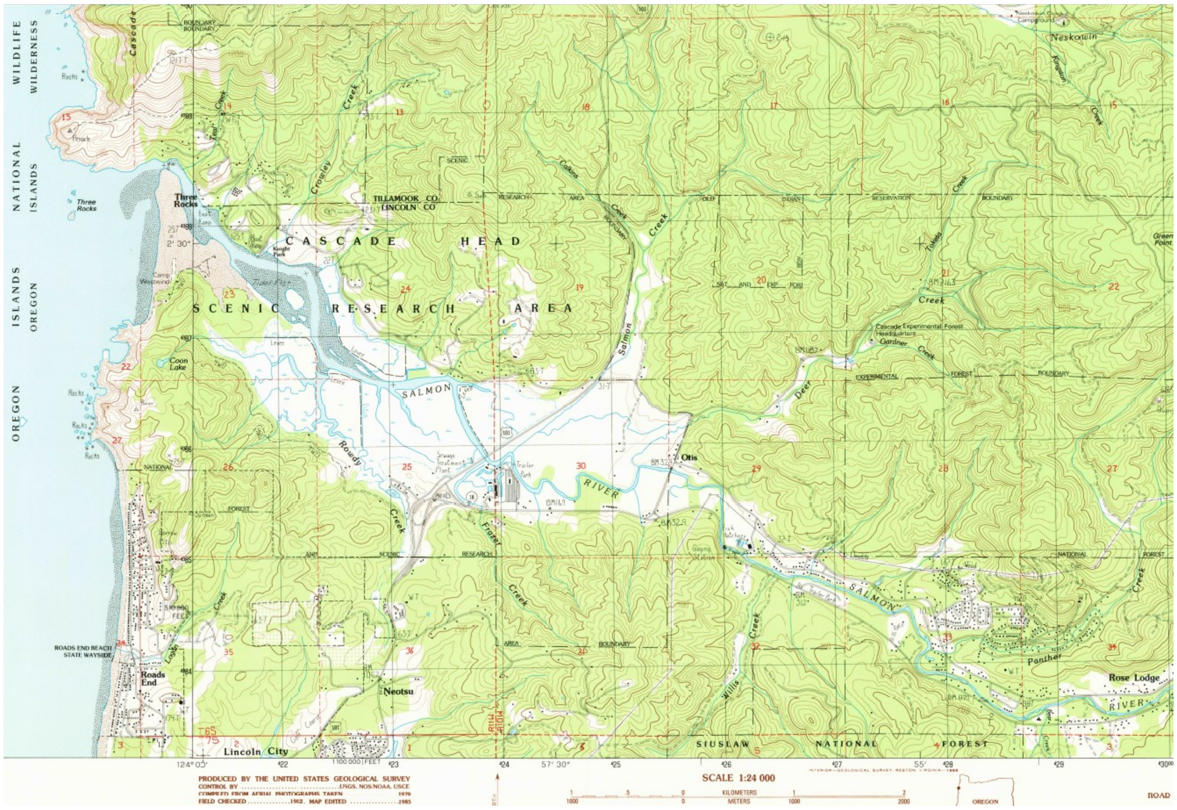


Figure 1.4: Excerpt of 1985 USGS topographic map of the Salmon River Estuary showing the “new” US Route 101 and changes to Frazer Creek and Salmon Creek (compare to Figure 1.3). Also shown are Pixieland amusement park (labeled “Trailer Park”) and Tamara Quays (adjacent to the pond on Rowdy Creek).

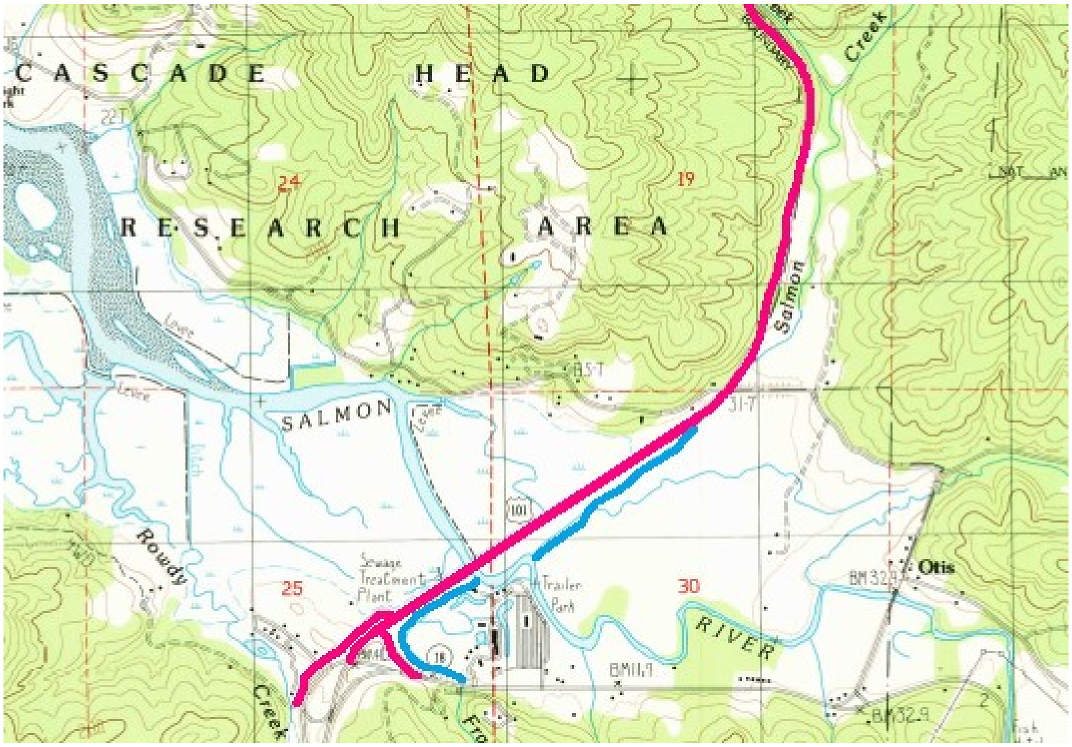


Figure 1.5: Map highlighting the relocated US 101 (wide pink lines) and changes to the course of Salmon Creek and Frazer Creek (wide blue lines)

Systematic deconstruction of these human modifications of the estuary began in the 1970s with the 1978 removal of the first set of dikes. Additional dikes were removed in 1987 and 1996. This coincidentally created an experiment with restorations spaced at 9-year intervals. The remnants of Tamara Quays were removed in 2008-2009 and those of Pixieland in 2010-2011 (Ellingson & Ellis-Sugai, 2014). As a result, US Route 101, Knight Park, a deteriorating dike for one small plot of private land, and the remnants of some ditches are the last human structures remaining on the Salmon River Estuary.

Estuaries on the Oregon coast have been in a continuous state of change for millennia. The two primary sources of change, apart from human impacts, are climate and tectonics. Changes in climate follow a wandering path, but climate change related to emergence from the last ice age has imparted a clear, long-term direction to this path and imposed a heavy imprint on the Salmon River Estuary (Komar, 1997). It would perhaps be more accurate to say climate change related to the current interglacial climate. These changes have affected the flora and fauna of the estuary directly, by changing the seasonal maximum and minimum temperatures and the balance of growing time versus dormancy. The estuary has also likely been affected by changes in the timing and volumes of freshwater moving through it from upland areas to the ocean. It is likely that the flora and fauna of the upland areas has also drifted with climate, and that these changes have influenced both the hydrology and the food web of the entire drainage basin, including the estuary.

Accompanying the changes in the local climate, have been changes in global sea level and thus the local sea level. As sea level has steadily risen, the estuary has certainly responded with changes in its function and features. Its existence in its current location is a result of sea-level rise. The magnitude of local sea-level change during the Holocene is much greater than the difference in elevation between sub-tidal bay areas and supra-tidal high marshes (Komar, 1997).

Finally, the coast of Oregon has experienced a steady cycle of tectonically driven uplift and subsidence. This process takes land along the northern Oregon coast from sub-tidal to supra-tidal and abruptly back again. This happens with a periodicity of a few hundred years. The Salmon River estuary is situated such that the estuary would be adjusting to slow gradual uplift for a few hundred years due to tectonic uplift (tempered by globally rising sea levels). The time of gradual adjustment would be followed by rapid subsidence during an earthquake (Komar, 1997). In addition to the resulting long-term decrease in elevation, the estuary would also have to respond in the short term to the disruption of tsunami waves carrying in sediments and debris from the ocean. The tsunami would also mobilize material within the estuary with local current velocities considerably higher than during normal flooding events. These tsunami currents also rapidly change directions (Peters & Jaffe, 2010).

These changes in water level, driven by climate and tectonics, which have been a natural part of the Salmon River Estuary for millennia, are considerably more dramatic than the agricultural and development impacts of the past century-and-a-half.

1.1.1 Previous Research in the Estuary

In conjunction with the Cascade Head Experimental Forest and the restoration of the estuary, a great deal of research has been done in the Salmon River estuary. What follows is not intended to be a comprehensive summary of that work, but rather a sampling of the nature of that research.

1.1.1.1 Flora

Mitchell (1981) documented soil and vegetation conditions in two undiked areas and a diked area prior to the removal of a portion of the dikes. These areas were monitored for two years following the dike removal to observe the changes in vegetation that resulted from the dike removal. Frenkel and Morlan (1991) report on the continued monitoring of the 1978 dike removal area. On more than one occasion, this author has encountered researchers out on the estuary that were continuing this vegetation monitoring and extending it to additional areas of the marsh.

1.1.1.2 Fauna

Gonzalez (1983) focused on the zooplankton in the Salmon River Estuary with an eye to understanding the interactions of estuaries with the open ocean along the Oregon coast. Gray (2005) assessed the recovery of the Salmon River Estuary, following the three phases of dike removal in 1978, 1987, and 1996. She made observations of not only Chinook salmon (Oncorhynchus tshawytscha) density, diet, and growth, but also looked at the invertebrate abundance across the marsh. During this project, this author encountered researchers continuing to collect data regarding the fauna of the estuary.

1.1.1.3 Hydrology

Asken, Hansen, Higgins, Nobel, & Pratt (1976) produced a thorough physical description of the Salmon River Estuary based on published information and three consecutive days' observations in mid-May. Their report focused almost exclusively on the main channel of the Salmon River. Their fieldwork was done over a three-day period in May 1976. Their data included measurements of salinity stratification in the river. Later, the U.S. Forest Service commissioned a report by Coulton, Philip Williams & Associates, Ltd., & Crane & Merseth (1995) on the hydrology of the Salmon River Estuary. The primary focus of the report was the flooding implications of changes to dikes and tide gates planned as part of the ongoing restoration of the estuary. This report provided detailed topographic information and flood frequency estimates. Their field work was done over six days in December 1994. Additionally, this report summarized a variety of information related to the estuary since the construction of the new alignment of US Route 101. Both of these hydrology focused reports captured moment-in-time observations relating to the waters of the estuary.

1.2 OBJECTIVES OF THE RESEARCH PROJECT

This research project was conceived in the context of the restoration work and research outlined above. In 2009, the US Route 101 bridge over the Salmon River was approaching the 50th anniversary of its completion. Therefore, replacement could be foreseen as a development in the future. Likewise, there was a desire to restore both the Salmon Creek and Frazer Creek tributaries of the Salmon River to something like their natural courses prior to the construction of the rerouted section of highway. Such future projects would be motivated, or shaped by, a desire to further the restoration of the estuary. Thus, an obvious research question is how will the functioning of the estuary be changed by these future changes aimed at a returning to a more naturally functioning estuary? Additional obvious questions are how climate change will affect the functioning of US Route 101 and how tectonic changes will affect US Route 101.

The objective of this research project was to document aspects of the water quality and levels in the estuary across changing weather, changing seasons, and inter-annual variations. Characterizing such variations well was important because the magnitude of these variations might be comparable to changes due to climate change or a new culvert. Having a thorough baseline would provide a clear frame of reference to assess future changes resulting from modifications to US Route 101 and changes due to climate change. With its 10-year duration, there was the possibility that changes due to climate change would be observable, or that significant changes to US Route 101 would occur. However, the project was designed to be useful for the study of changes occurring over an even longer time span.

The parameters of water level, temperature, and conductivity were selected as the primary observations because they relate directly to the movement of water in the estuary, its function as a location for the mixing of fresh and salt water, and to the aquatic habitat quality. Dissolved oxygen is another important parameter regarding habitat quality, oxygen being essential for most aquatic animals. When the opportunity to collect some continuous (meaning a reading every 10 minutes) data of dissolved oxygen presented itself, measurements of this parameter were added.

Eventually, a total of 21 water-monitoring stations were installed (only 20 successfully producing data). These were distributed in and around the estuary. The objective was to collect data regarding Salmon River, its tributary streams, and the tidal channels in the marsh. These could be compared to one another for current conditions and provide context for any shifts due to future climate change or construction.

The movement of water in streams and estuaries is influenced by weather. Precipitation influences stream flow, as do evaporation and transpiration. Storm systems influence tidal levels. To supplement existing weather stations in the region around the Salmon River estuary, two additional weather stations were installed. One was located on the estuary itself and the other was located near the headwaters of tributaries to the estuary.

Issues related to tectonics were beyond the scope of this project. However, the data collected might still be used for comparison to conditions following the next great earthquake on the Oregon coast.

2.0 INSTRUMENTATION

The objectives of this research project required two types of instrumentation. First, instruments to directly make and record observations of the water in the various channels of the estuary. Second, weather instruments to record observations of weather data, which indirectly influences the water in the estuary. The primary water measurement was water level. Water level governs not only the flow of water to and from the ocean and within the estuary, but also the extent of available habitat for aquatic organisms. The significant increases in water levels can also affect the highway infrastructure. The primary water level parameter was accompanied by measurements of temperature and conductivity. The temperature of water is important to aquatic organisms and influences what constitutes habitat for various species. The conductivity of the water shows where ocean water is reaching and also influences which vegetation and animals can utilize an area as habitat. In addition, shorter-term observations of dissolved oxygen were recorded at a few stations. Dissolved oxygen is essential to aquatic organisms and some species, such as salmon, are very sensitive to dissolve oxygen levels.

All of these parameters vary on time scales ranging from diurnal to millennial, and beyond. They are also influenced by episodic events such storm systems and heat waves. Long-term, continuous observations capture much more of the character of these variations than do single, moment-in-time observations. What follows is a description of the instruments used.

2.1 WATER LEVEL INSTRUMENTS

Water level measurements were made with logging devices equipped with pressure transducers. These directly measure the pressure of the water and air column above the pressure transducer. From this, the height of that water column can be derived.

2.1.1 Solinst LTC Levelogger Junior

There are numerous manufacturers of water level loggers that are based on pressure transducers. The Solinst LTC Levelogger Junior was selected at the start of this project because of the simplicity of combining the level, temperature, and conductivity measurements in a single instrument package. Cost was also a factor. The more affordable an instrument is, the more locations that can be instrumented.

Figure 2.1 shows an LTC Levelogger Junior. The hole visible in the black end on the left is an opening to the pressure transducer. On the right end is the black, screw-on cap that protects the optical data-download interface and provides an attachment point for suspending the instruments when deployed. The metal body of these instruments was stainless steel. The pressure transducers were piezoresistive silicon in 316L stainless steel. The manufacturer's specifications for the LTC Levelogger Junior are as follows:

- Level Sensor Accuracy: 1 cm (0.1% of full scale, which was 10 meters)

- Level Sensor Resolution: 0.2 cm
- Battery Life: 5 years (at 5-minute sampling rate)
- Maximum Number of Readings: 16,000 sets of readings (level, temperature, conductivity)
- Size: 2.2 cm x 19.0 cm (7/8” x 7.5”)

Figure 2.1: Solinst LTC Levelogger Junior devices.

During this decade long project, as the Solinst instruments needed to be replaced, the decision was made to switch to Onset HOBO U20 series water level loggers (paired with HOBO U24 series conductivity/salinity loggers).

2.1.2 Onset HOBO U20 Level Logger Series

The growing number of LTC Levelogger Juniors that needed repair or replacement presented the opportunity to reassess the equipment being used. The longevity of original instruments was not meeting expectations. The information in the manufacturer’s manuals supported the conclusion that the instruments were not designed for the corrosive environment in which they were deployed, although marketing materials specifically mentioned estuaries as an application. In later years, the manufacturer would release new models that addressed the corrosion issues encountered. At the time that replacement instruments were needed, those future models were not available. Thus, Onset HOBO U20 loggers were selected as replacements. In 2014, Onset introduced a lower cost version of their U20 series logger, the U20L. These lower cost units use a non-metallic case and all HOBO U20 units use a ceramic (versus metallic) pressure transducer.

A combination of U20L (see Figure 2.2) and U20Ti (which have a titanium case, see Figure 2.3) loggers were acquired.

Figure 2.2: Onset HOBO U20L Water Level Logger device.

Figure 2.3: Onset HOBO U20Ti Water Level Logger device.

The manufacturer's specifications for the HOBO U20 Water Level Loggers are as follows:

- Level Sensor Accuracy: U20Ti 0.5 cm (0.05% of full scale, which was 9 m) typical
  1.0 cm maximum
  U20L 1 cm (0.1% of full scale, which was 9m) typical
  2 cm maximum.

- Level Sensor Resolution U20Ti 0.21 cm
  U20L 0.21 cm

- Battery Life: 5 years (1 minute or greater sampling rate)
- Maximum Number of Readings: U20Ti ~21,700 sets of readings (level and temp.)
  U20L ~21,700 sets of readings (level and temp.)
- Size: U20Ti 2.46 cm x 15 cm (0.97 inches x5.9 inches)
  U20L 3.18 cm x 15.24 cm (1.25 inches x 6.0 inches)

2.1.3 Solinst Barologger Gold

Using absolute pressure measuring instruments to record water level requires correcting the data for barometric pressure variations. Two Solinst Barologger Gold devices were purchased to record barometric pressure for this purpose. Figure 2.4 shows one of these Barologgers. These devices can record 40,000 sets of values (barometric pressure and temp.) and have a published accuracy of 0.1 cm (0.002% of full scale, which was 1.5 m). By being deployed in the air above the water these instruments allow the varying atmospheric pressure to be subtracted from the total pressure recorded by the water level instruments.

Figure 2.4: Solinst Barologger Gold device.

In addition to the Barologgers, the two weather stations were also equipped with barometers for recording barometric pressure. Later in the project, a HOBO U20L with a 4 m range was also deployed in air to measure barometric pressure. This device had a published accuracy of 0.4 cm typical (0.1% of full scale, which was 4 m) and 0.8 cm maximum.

2.2 CONDUCTIVITY INSTRUMENTS

Initially, conductivity measurements were made by the conductivity sensors built into the Solinst LTC Levelogger Junior instruments selected. When the switch was made to a different water level logger, a different conductivity logger was needed. For the sake of simplicity in the field and the office, the HOBO U24 series of conductivity/salinity loggers were chosen to pair with the HOBO water level loggers. It is important to note that with the Solinst LTC Levelogger Junior instruments the conductivity sensor was located only a couple of centimeters above the level sensor. With the two separate device arrangement of the HOBO loggers, the conductivity/salinity sensor was positioned at least 25 centimeters higher than the level sensor.

This meant that as the water level would drop, measurement of conductivity was lost well before the water dropped below the level sensor.

2.2.1 Solinst LTC Levelogger Junior

The Solinst LTC Levelogger Junior conveniently packaged the conductivity sensor and logging with the water level logging in one, slim package. The conductivity sensor is four platinum electrodes (visible in the opening in the stainless-steel case seen in Figure 2.1). The manufacturer's specifications for the LTC Levelogger Junior conductivity logging were:

- Calibrated Range: 500 to 50,000 μS/cm
- Range: 0 to 80,000 μS/cm
- Accuracy: 2% of reading or 20 μS/cm
- Battery Life: 5 years (at 5-minute sampling rate)
- Maximum Number of Readings: 16,000 sets of readings (level, temperature, conductivity)
- Size: 2.2 cm x 19.0 cm (7/8 inches x 7.5inches)

The conductivity sensor portion of the LTC Levelogger Juniors seemed to endure the estuary environment well. However, because the instruments all failed during data collection, no end-of-use calibration measurements (as were made with the replacement instruments) could be completed.

2.2.2 Onset HOBO U24 Conductivity/Salinity Logger Series

The Onset HOBO U24 Conductivity Loggers were a compromise. Having the conductivity logging in a separate device had the downside of needing to deal with two instruments instead of one and resulted in a greater distance separating the level and conductivity sensors. However, the plus side of this was that if either the conductivity logger or the level logger failed, the other would continue to collect half of the desired data. The U24 series includes two versions. The U24-001 freshwater conductivity logger and the U24-002 saltwater conductivity/salinity logger. Some of both versions were purchased and used for this project. Both versions allow a user to configure the logger to record in "Low Range," "Full Range"/"High Range," or "Dual Range" modes. The U24 loggers had a very different, non-contact conductivity sensor with a Titanium Pentoxide coating. These sensors seemed to endure the estuary environment very well.

Figure 2.5 shows a HOBO Conductivity logger. The small silver-colored rectangle on the left is the conductivity sensor. The black cap on the right covers the optical data-download interface.

Figure 2.5: HOBO Conductivity Logger device.

The specifications for the U24 Conductivity Loggers were:

- Calibrated Range: U24-001 Low Range 0 to 1,000 μS/cm
  Full Range 0 to 10,000 μS/cm
  U24-002 Low Range 100 to 10,000 μS/cm
  High Range 5000 to 55,000 μS/cm

- Extended Range: U24-001 Low Range 0 to 2,500 μS/cm
  Full Range 0 to 15,000 μS/cm

- Accuracy: U24-001 Low Range 3% of reading or 5 μS/cm
  Full Range 3% of reading or 20 μS/cm
  U24-002 Low Range 3% or reading or 50 μS/cm
  High Range 5% of reading within +/-3,000 μS/cm of calibration point.

- Battery Life: 3 years (at 1 minute logging rate)

- Maximum Number of Readings: 18,500 sets of readings (conductivity and temperature.)
  14,440 sets of readings for dual range

- Size: 3.18 cm x 16.5 cm (1.25 inches x 6.5 inches)

None of the six options offered by the two versions and three range settings was ideal. At the 10-minute logging interval being used, the dual range option offered only 100 days of logging. It was very easy to exceed this period between download visits due to tides, weather, and work schedules. In retrospect, probably the best compromise would have been the U24-001 version, set to full range at all locations.

2.3 DISSOLVED OXYGEN INSTRUMENTS

Onset introduced their U26 Dissolved Oxygen loggers shortly after the start of this project. When the decision was made to switch to the Onset loggers for water level and conductivity loggers, we decided to try making some long duration dissolved oxygen observations. Four of these loggers were purchased and deployed for several months during the project at select water level stations that are described later in this report.

Figure 2.6 shows the HOBO Dissolved Oxygen Logger. To the left is the removable guard that protects the replaceable RDO® (Rugged Dissolve Oxygen) sensor. Water passes over the sensor through the openings that can be seen in the photo. To the right is a removable cap that covers the optical data download interface and provides an attachment point.

Figure 2.6: HOBO Dissolved Oxygen Logger

The manufacturer's specification for the U26 loggers are as follows:

- Measurement Range: 0 to 30 mg/L
- Calibrated Range: 0 to 20 mg/L
- Accuracy: 0.2 mg/L up to 8 mg/l, 0.5 mg/L from 8 to 20 mg/L
- Sensor Life: 6 months, cap expires and logging ceases 7 months after initialization
- Battery Life: 3 years (at 5-minute logging rate)
- Maximum Number of Readings: 21,700 sets (DO and temp.)
- Size: 3.96 cm x 26.67 cm (1.56 inches x 10.5 inches)

In addition to the sensor caps expiring 7 months after initialization, they also have a relatively short shelf life before initialization that is inconvenient when working with a cumbersome procurement process.

2.4 WEATHER INSTRUMENTS

Numerous options for weather recording equipment were considered. Project budget eliminated many of the options, such as installing a standard ODOT Road Weather Information System (RWIS) station. Ultimately, Onset Weather Station loggers with a broad set of weather sensors were selected for their data storage capacity and power requirements. Each location was equipped with a tipping-bucket rain gauge, a thermometer and relative humidity sensor in a solar radiation shield, an anemometer, wind direction, barometer, and a Photosynthetically Active Radiation (PAR) light sensor. With all these sensors, the logger could store several months of data collected at 10-minute intervals. The four AA batteries could run the logger, even in the cold of winter, for up to a year. Due to variations in alkaline battery behavior, we learned to replace the batteries more frequently than the theoretical one-year life.

3.0 STATIONS

There were two basic types of instrumentation stations installed for this project. The first, and most numerous, type was water monitoring stations. The second type was weather stations. Of this latter type, there were two.

3.1 WATER STATIONS

The Salmon River zigzags through the estuary marsh (see Figure 1.3). The term “meander” is intentionally not used due to the apparent stability of the channel location during the period of written history. Several tributary streams join the Salmon River within the area of the estuary. Named streams are Salmon Creek, Frazer Creek, Rowdy Creek and Crowley Creek (Deer Creek joins Salmon River at the upstream edge of the estuary). In addition to the named streams, there are drainages from upland areas that commonly, or constantly, have water running in a channel that drains into the estuary marsh. Usually these connect to one of the several tidal channels. Some tidal channels do not have any connection to an upland stream.

All of the instruments for the water stations were mounted in 2-inch diameter PVC pipe. With the exception of the dissolved oxygen loggers, the pipes were perforated by drilling several ¼-inch holes in the pipe starting at ground level and extending approximately 2.5 feet up the pipe. The water level pipes were capped, and the instruments were hung from the caps (see Figure 3.1) using either thin, stainless cable or Kevlar® cored cord. The original type of caps used were advertised as vented, but in some cases the venting was apparently not working correctly. In such cases a hole was drilled through the pipe just below the cap. Replacement caps acquired late in the project were not vented, and thus the vent holes were needed for the new style of cap. The size and number of holes represents a compromise. Each hole weakens the PVC. As will be demonstrated in the following station descriptions, the strength of the PVC was frequently called upon by conditions in the estuary. However, more, and bigger, holes allow for a more free and rapid exchange of water into and out of the pipe.

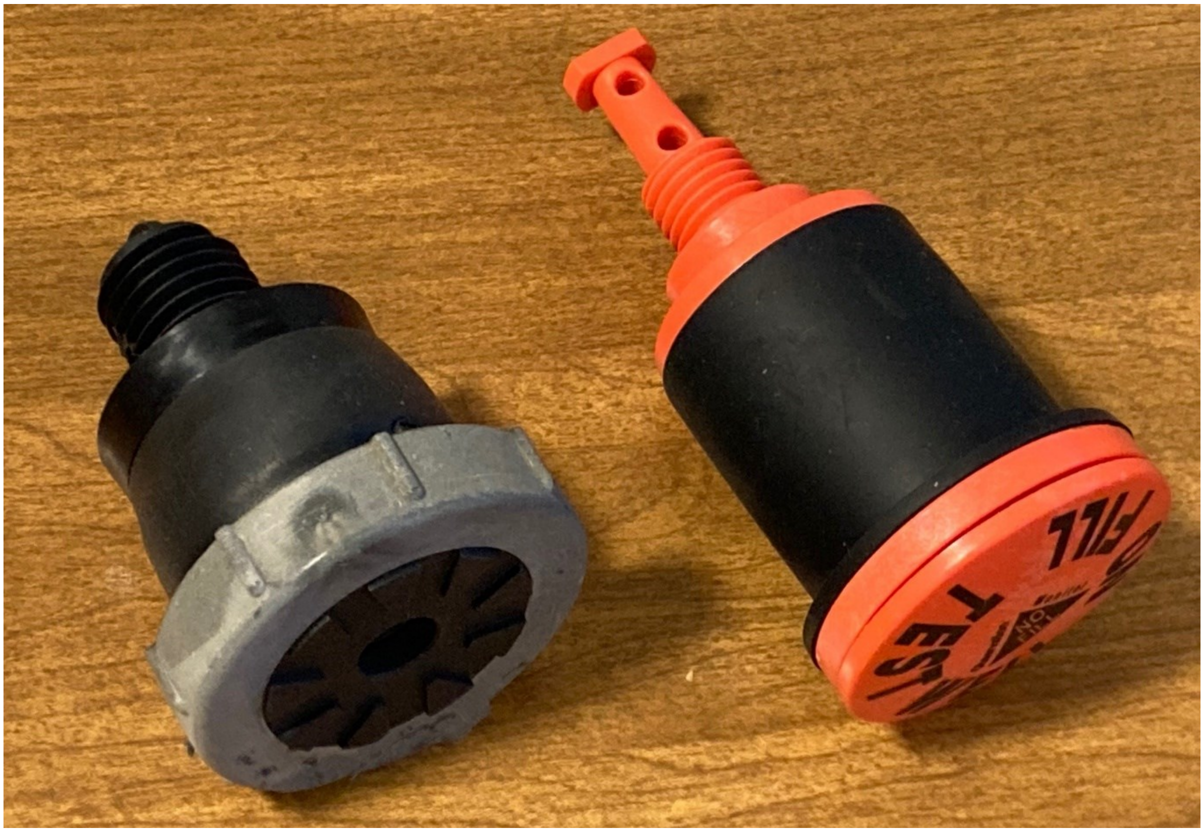


Figure 3.1: The two types of caps used for the water level stations. The cap on the left is the original type used. The cap on the right is the type used late in the project, after the original type were no longer available.

The 21 water level stations that were established were picked to observe the range of conditions for channels in and around the estuary. Some were in the Salmon River, some were in tributary creeks, and some were in channels without an upland connection. Table 3.1 lists the 21 stations with their latitude, longitude, and the elevation of the cap on the station's PVC pipe. Figure 3.2 shows the location of these stations on an aerial image of the estuary.

Table 3.1: Locations of Stations.

Station Name	**Latitude**	**Longitude**	**Cap Elevation**
70s Marsh	N45° 01.899’	W123° 58.757’	3.33 m
Former Salmon Creek Main	*N45° 01.784’*	*W123° 58.059’*	
Former Salmon Creek North	N45° 01.676’	W123° 57.857’	3.55 m
Former Salmon Creek South	N45° 01.601’	W123° 57.890’	3.60 or 3.15 m
Frazer Creek at Oregon Route 18	N45° 1.214‘	W123° 58.130‘	5.13 m
Frazer Creek at US Route 101	*N45° 1.373‘*	*W123° 58.248‘*	*3.37 m*
Reference Marsh North Downstream	N45° 01.626’	W123° 58.568’	*2.72 m*
Reference Marsh North Upstream	N45° 01.541’	W123° 58.372’	*3.26m*
Reference Marsh South Downstream	N45° 01.628’	W123° 58.797’	
Reference Marsh South Upstream	N45° 01.503’	W123° 58.594’	2.78 m
Rowdy Creek Culvert	N45° 01.159’	W123° 58.598’	4.20 m
Rowdy Creek Downstream	N45° 01.644’	W123° 59.147’	*2.89 m*
Rowdy Creek Upstream	N45° 01.368’	W123° 58.808’	2.92 m
Salmon Creek at Future Culvert	*N45° 1.581‘*	*W123° 57.691‘*	*4.82 m*
Salmon Creek near Three-Rocks Road	N45° 1.828‘	W123° 57.286‘	5.76 m
Salmon River at 70s Marsh	N45° 01.825’	W123° 58.652’	
Salmon River at Knight Park A	*N45° 2.405‘*	*W123° 59.490‘*	
Salmon River at Knight Park B	*N45° 2.434’*	*W123° 59.648‘*	*1.00 m*
Salmon River at Lincoln County Bridge A	*N45° 1.399‘*	*W123° 56.791‘*	*3.5 m*
Salmon River at Lincoln County Bridge B	*N45° 1.395‘*	*W123° 56.786‘*	*2.6 m*
Salmon River at Pixieland	*N45° 1.359‘*	*W123° 57.836‘*	
Salmon River at US Route 101	N45° 1.467’	W123° 58.051’	2.96 m
USFS Ditch	N45° 1.643‘	W123° 57.341‘	2.93 m

Latitudes and longitudes listed in Table 3.1 in standard font had locations established using GPS. Latitudes and longitudes in italics were derived by inspection on georeferenced aerial imagery. Cap elevations in standard font were established using RTK GPS and should have an accuracy of better than +/- 3 cm. The cap elevations in italics were derived from correlations of water levels to other stations. The accuracy of those elevations is around +/- 10 cm. Stations with no cap elevation were lost before the appropriate measurements were made. These stations do have estimates of the sensor elevations, which can be found in their data spreadsheets.

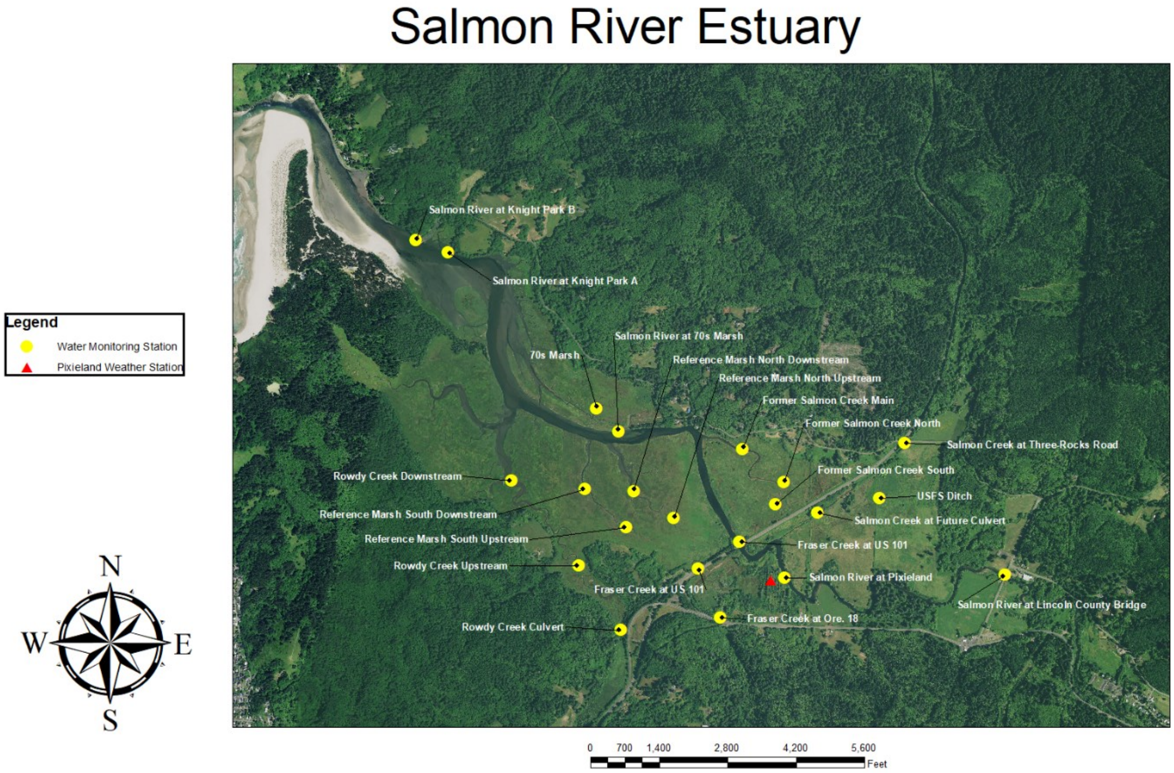


Figure 3.2: Map showing an aerial image of the Salmon River Estuary with the locations of the water level stations (and one weather station).

The following sections describe each of these 21 stations. The descriptions are grouped by the nature of their position in the estuary.

3.1.1 Stations in the Salmon River

Five stations were established in the Salmon River's main channel. Moving upstream, these were located at Knight Park, adjacent to the "70s Marsh," at the US 101 bridge, adjacent to Pixieland, and at the Lincoln County bridge. The Salmon River in the estuary is tidal, but it is a large river and maintains flow in its broad, deep channel throughout the summer. The large number of large tree snags that move down the Salmon River proved to be problematic for water level monitoring stations. All of these stations were wiped-out, presumably by driftwood, at some point during the project.

3.1.1.1 Salmon River at Knight Park

The first station at Knight Park was wiped-out after three downloads, or about 6 months, and the logger was lost. The first station at Knight Park was upstream of the boat ramp and dock and designed to be accessed at any tide (i.e., the PVC extended more than six feet above the riverbed that was exposed at low tide). A second station near Knight Park (referred to as Knight Park B) was established later 2016. Knight Park B was located downstream of the dock and could only be accessed at low tide because it only extended about 1.5 feet above the riverbed at low tide. This was intended to make it a smaller target for driftwood. Knight Park B survived until the end of the project. Figure 3.3 shows the Knight Park B station. No photograph was taken of the original Knight Park station before it disappeared.

Figure 3.3: Photograph of the Salmon River at Knight Park B station looking to the southwest.

3.1.1.2 Salmon River at 70s Marsh

The station adjacent to the 70s Marsh was wiped out before its first data download, but fortuitously the logger was found and recovered downstream. This station was abandoned at that point. No photo was taken of this station before it was destroyed.

3.1.1.3 Salmon River at US Route 101

The station at the US Route 101 bridge (referred to as “at ODOT bridge” in field notes and data files) lasted until the winter of 2019-2020, at which point it disappeared, presumably due to driftwood. In 2016 a second installation, attached to the actual bridge pier, was established and lasted until the end of the project (referred to as “on ODOT bridge”). This provided about 3-1/2 years of overlap between the two installations.

Figure 3.4 shows the station at the US Route 101 bridge. It should be noted that this station shows what was originally envisioned for all the station installations. The plan was to install two 4”x6” pressure treated posts with staff gauges attached. They were to be positioned at different elevations so as to cover the complete range of tides possible. The PVC pipe, which would act as a stilling well and protection for the logging devices was to either be attached to the lower post or driven into soft sediment. The soft nature of the sediments in the estuary made the posts with staff gauges impractical at most stations. At the lower position, a posthole would often not stand open long enough to allow a post to be properly set. At the US Route 101 bridge station, the upper post was immediately put into use by anglers as an aid to climbing the bank. It was quickly knocked out of position by the load and the erosion of the stream bank caused by their scrabbling. The lower post was washed away or knocked out of position by driftwood shortly thereafter. This same thing happened at several other stations where posts were installed. Driving the PVC into the soft sediment proved to be generally successful and very stable. In some locations, the sediments were gravel and attempts at driving the PVC did not succeed. The solution at those locations will be described later in this report.

Figure 3.4: Photograph of the Salmon River at US Route 101 station. Photograph taken looking downstream, facing north.

Figure 3.5 shows the station installation on the bridge. The PVC was secured to the bridge pier with adhesive. This mounting was less vulnerable to driftwood and streambed/stream-bank erosion, but it had the disadvantage of only being accessible by boat or very low river stage. Even at when the river was at low stage, reaching the pier on foot was difficult.

Figure 3.5: Photograph of the station installed on the bridge that carries US Route 101 over Salmon River. The photograph was taken looking upstream, facing southeast.

3.1.1.4 Salmon River at Pixieland

The station adjacent to Pixieland was lost after a single data download and the logger was never seen again. The station was also abandoned at this point. No photograph was taken of this station before it was destroyed.

3.1.1.5 Salmon River at Lincoln County Bridge

The station at the Lincoln County bridge was wiped out sometime after 15 downloads, or almost four years, and the logger was lost. A new installation was established at Lincoln County's bridge and remained stable until the end of the project. This second installation was placed in a slightly less vulnerable position, which meant that it could not record river levels at lower stages. Additionally, after the new PVC was installed, the river deposited several inches of sediment on the bank around the bridge abutment. The Lincoln County bridge station might be considered upstream of the estuary. The river stage at this bridge has long been considered tidally influenced (Hamilton, 1972) and data from this station affirm this. During the approximately four years that a conductivity logger was installed at the station, the conductivity seldom rose above 200 µS/cm. The maximum observed was 779 µS/cm during a brief spike during a high tide not associated with elevated river discharge on October 8, 2014. This indicates that little saltwater reaches the location and only rarely.

Figure 3.6 shows part of the original Lincoln County bridge station. The post is the upper post of the configuration described earlier. The lower post and PVC were adjacent to the column on the right. Either they were just outside the frame of this photo, behind the column, or they were submerged by the high water.

Figure 3.6: Photograph showing the original Lincoln County bridge station. Photograph taken facing southwest.

Figure 3.7 shows the location of the Lincoln County Bridge station prior to installation. The lower staff gauge post and PVC were installed to the left, and downstream of the column from the perspective of this photograph. The upper staff gauge was installed on the bank to the right of the column, at the edge of the photograph. The water level in Figure 3.6 was approximately at the level of the pour seam that can be seen in the column in Figure 3.7 and the post was installed in the water of the river for the stage shown in this photograph.

Figure 3.7: Photograph of Salmon River at Lincoln County bridge station location prior to installation. Photograph taken looking downstream, facing west.

Figure 3.8 shows the second PVC installation at Lincoln County's bridge. In this photo, the accreted sediment has been stabilized by reed canary grass (Phalaris arundinacea). When the station was installed, the location was active streambed, with the bed at an elevation several inches lower. It is likely that the bank had been eroded by the same high-water event that destroyed the original station. Riprap can be seen in the lower right of the photograph.

Figure 3.8: Photograph of the second installation of the Salmon River at Lincoln County Bridge station. The photograph is taken looking upstream, and the bridge pier is out of frame to the upper left. Photograph taken looking upstream, facing east.

3.1.2 Stations on the Periphery of the Estuary

Other stations were installed outside, or at the edge of, the estuary. The reason for having stations in such locations is to have a sense of the water entering the estuary in terms of volume, conductivity and temperature. They also provide information regarding how far upstream the effects of the tides extend. Specifically, they were at the Rowdy Creek Culvert under the ODOT frontage road near the former Tamara Quays, the Salmon Creek Culvert under Three-Rocks Road, and Frazer Creek Culvert under Oregon Route 18 adjacent to the former Pixieland.

3.1.2.1 Rowdy Creek at the Culvert

The Rowdy Creek Culvert station was installed at the downstream outlet of the recently completed streambed-simulation culvert on the ODOT frontage road that provides access to some private property. Figure 3.9 shows the station during a high-water event. At the time of this photograph, the vegetation at this location was still reestablishing itself.

Figure 3.9: Photograph of the station at the Rowdy Creek Culvert during a high-water period. Photograph taken looking upstream, facing southwest

The Rowdy Creek Culvert station was inundated with a standing pool of water that extended over the entire estuary on numerous occasions. The conductivity also rose above 10,000 µS/cm on numerous occasions, but the highest conductivity readings were not coincident with the highest water levels. A likely explanation, which needs testing and analysis, is that the highest water levels coincide to precipitation events that increase the discharge of fresh water in the streams, and this keeps the salt water from the rising tides from reaching this location. At lower stream discharge, the waters of high tides can reach the station.

Figure 3.10 shows the Rowdy Creek Culvert station during low water, but after a beaver had built a dam at the culvert outlet. The construction of this dam changed the flow conditions at the station and the streambed down-cut several inches at the PVC relative to where it was before the dam was built.

Figure 3.10: Photograph of the station at the Rowdy Creek Culvert showing the Beaver dam that was built and changed normal flow conditions. Photograph taken looking upstream, facing southwest.

These two figures show the station construction that was devised for locations with gravel that prevented the driving of the PVC pipe. A posthole was dug into the bank or streambed and a post was set into it. A staff gauge (not visible in these photographs) was then attached to the post. The PVC pipe for the logging instrument(s) was then cantilevered off the post, with the end of the vertical PVC set into the streambed a few inches. The second piece of PVC that is seen attached to the post in this photograph was used to house the Barologger installed at this station. It was hung just below the cap. In this position, it remained in the air, above the water, during even the highest high-water events. When the HOBO U20L 4m logger was added, it was installed directly under the cap of the PVC holding the level logger. This location also proved to be constantly above the highest high-water, but the HOBO U20L is designed to be submerged by up to 4 meters of water, unlike the Barologgers, which are designed to only be deployed in air. Thus, the fact that it was mounted approximately a foot lower was not a concern.

3.1.2.2 Salmon Creek at Three-Rocks Road

Initially, the station for Salmon Creek at Three-Rocks Road was built using the post method in a gravel bar. The post was washed away before a logger was even installed, even though immediately after that occurrence the gravel bar immediately grew back larger and persisted for the entire remainder of the project. Later, permission was granted to attach PVC to the culvert that carries Salmon Creek under Three-Rocks Road. Figure 3.11 shows this installation. This station is down in the vegetation above the culvert and the caps are not easy to remove without the specialized tool for loosening them. Despite this, on two occasions the logger disappeared from this station, presumably stolen.

Figure 3.11: Photograph of the Salmon Creek at Three-Rocks Road station. Photograph taken looking at the culvert outlet, facing northwest.

The station at the Three-Rocks Road culvert had a conductivity logger installed for about 4 years. During this period, the conductivity never rose above 120 µS/cm. This indicates that salt water does not reach this location on Salmon Creek.

3.1.2.3 Frazer Creek at Oregon Route 18

Figure 3.12 shows the station where Frazer Creek crosses under Oregon Route 18. This photograph was taken in March of 2019. This is when the leaning of the post was first observed. The blue and purple staining of the PVC cement and primer is evidence of the rebuilding of the station after the PVC was broken in the Spring of 2018, presumably due to debris that came through the culvert. The logger was recovered from downstream. In January of 2020, the station was discovered completely washed out. Again, the logger was recovered downstream. The station was not rebuilt after this.

Figure 3.12: Photograph of the Frazer Creek at Oregon Route 18 station.

The station at the Frazer creek culvert under Oregon Route 18 was in a location where the channel downstream had been recently reconstructed as part of the Pixieland estuary restoration project (completed in 2011, although some additional restoration activities have continued in the area of the former Pixieland). Later, the new Frazer Creek culvert under US Route 101 was constructed in 2015, and eventually the previous upstream connection (east of 101) to the Salmon River blocked off. Beavers then dammed the reconnected Frazer Creek channel, downstream of the new culvert. ODOT also performed maintenance related to the culvert under Oregon Route 18 on a few occasions. Thus, this station's channel and connection to tides was in a constant state of flux. While there were isolated data points with conductivity values of ~2700 μS/cm on two occasions in 2016, the cause of these high values is suspect because there is no transition up to, or down from, these two-point peaks and they are not associated with any unusual water levels. Otherwise, the conductivity is always less than 450 μS/cm, and most times is completely fresh. The restoration project planners had hoped that salt water would make it into the Pixieland area frequently enough, and in sufficient quantity, to suppress the reed canary grass (Phalaris arundinacea). All indications are that nowhere near enough saltwater makes its way into the area around this location to have any effect on the canary reed grass.

3.1.3 Stations within the Estuary in Smaller Channels

All but two of the remaining stations, ten to be precise, were all installed in channels within the estuary that cycle regularly through high and low water due to the tides. Some of these channels have very little water during low tide.

3.1.3.1 Estuary Stations in Rowdy Creek

The two stations in Rowdy Creek received a steady flow of fresh water. The upstream station is located just downstream of the area restored from the Tamara Quays subdivision. The downstream station is located near where Rowdy Creek begins to move away from the edge of the estuary towards its confluence with the Salmon River.

Figure 3.13 shows the Rowdy Creek Upstream station. This station was apparently struck by debris coming down Rowdy Creek shortly after installation and leaned slightly downstream from that point until the station was broken off during the winter of 2013-2014. The logger was lost at that point. New PVC was installed in April of 2016 and survived to the end of the project.

Figure 3.13: Photograph of the Rowdy Creek Upstream station. The photograph was taken looking in the upstream direction, facing north.

Figure 3.14 shows the Rowdy Creek Downstream station. This station remained in place for the entire duration of the project. The four data gaps in this station's record are due to the cleaning and calibration exercise in the summer of 2012, two logger failures, and one failure of the download device. The PVC pipe installed for the dissolved oxygen logger at this station is not shown in this photograph. This station was selected as one to host a dissolved oxygen logger because it is one of the channels in the estuary with a constant source of fresh water. This would be the situation for the area to the west of US 101 and north of the Salmon River if Salmon Creek were to be restored to its former course.

Figure 3.14: Photograph of the Rowdy Creek Downstream station. The photograph was taken looking in the downstream direction, facing west.

3.1.3.2 Estuary Station in 70s Marsh

The station within the marsh restored in 1978, or "70s Marsh," is located in the portion of the tidal channel where it has taken a 90-degree turn away from the Salmon River and heads toward the edge of the estuary. Some small, streams feed into this section of the estuary from the uplands. The principle tributary is named Mink creek (but only the newest digital USGS topographic map shows this name). It is a much smaller stream, with a much smaller drainage area, than the other named tributary streams that feed into the estuary at other locations. The 70s Marsh station survived the entire duration of the project without incident.

Figure 3.15 shows the 70s Marsh station. The second, shorter piece of PVC pipe next to the primary installation was added to house the dissolved oxygen logger that was described in section 2.3 Dissolved Oxygen Instruments. This station was selected as one to host a dissolved oxygen logger because it is one of the channels in the estuary with a constant source of fresh water. This would be the situation for the area to the west of US 101 and north of the Salmon River if Salmon Creek were to be restored to its former course.

Figure 3.15: Photograph of the 70s Marsh Station. The photograph was taken looking in the upstream direction, facing northeast.

3.1.3.3 Estuary Stations in the Reference Marsh

Four stations were established in what has been called the Reference Marsh. This name stems from the fact that this portion of the estuary was never diked. It thus represents a fair reference as to what the estuary would be like naturally, particularly in terms of flora. There are two main tidal channels, each with abundant branching, that carry water into, and out of, this portion of the estuary. Unlike the 70s Marsh, there are no freshwater channel sources that feed into this portion of the estuary. This influences the timing and duration of when there is fresh water in the channels and when there is salt water. It also influences how much water there is in the channels during low tide. The upland area around Tamara Quays partly drains into the Reference Marsh, but there are no apparent channels with flowing water like are seen entering the 70s Marsh. Two stations were installed in each of the two main tidal channels. Downstream stations were where the channels are broad and have direct connection to the Salmon River. Upstream stations were where the channels are narrow, have tortuous connection to the Salmon River, and are above the level of low tide. For reference purposes, the two channels were named Reference Marsh North and Reference Marsh South, referring to their positions relative to one another as one walked out onto the marsh from Tamara Quays. In retrospect, looking at them from an aerial perspective and where they join the Salmon River, it would have made more sense to call them east and west. The stations were first installed by hiking to them from Tamara Quays and in that context, the names made sense. The Reference Marsh South Downstream station was wiped out, presumably by driftwood, before the first data was downloaded. The logger was not recovered, and the station was abandoned. The other three stations, Reference Marsh South Upstream, Reference Marsh North Downstream, and Reference Marsh North Upstream all survived the entire duration of the project. This, even though some very large driftwood trees demonstrably passed by the stations based on the positions of logs observed during download visits.

Figure 3.16 shows the Reference Marsh South Downstream station. This location is such that the channel bottom is near the low water, low tide level of the Salmon River. The pipe was driven into the ground at the edge of the water at such a time. This means that there is frequently water in the channel throughout the day. However, at extremely low tides with extremely low water in the river the channel does become separated from the river. At the time of its installation, our presumption was that the large driftwood trees seen in the estuary moved rarely, in extreme flood events. This presumption was quickly disproven with the loss of this station. The station was not rebuilt in the belief that it was a vulnerable spot. In retrospect, at the end of this 10-year project, driftwood destroying the PVC pipes is a random event and all the stations with PVC in the midst of a channel were equally vulnerable.

Figure 3.16: Photograph of the Reference Marsh South Downstream station. Photograph was taken facing southeast.

Figure 3.17 shows the Reference Marsh South Upstream station. This station survived the entire duration of the project. The location had the advantage of being the most easily accessed of the Reference Marsh stations at low tide, being a short walk into the estuary marsh from the Tamara Quays high ground. Easiest, but not easy. There were two channels that had to be jumped and the ground in the estuary is generally very uneven and hidden by tall grasses, reeds, and sedges. At low tide, during low water in the river, this channel becomes just a trickle of water draining out of the marsh. The time between high tides is not sufficient for the marsh to ever completely drain, but the width of the flowing water becomes less than a foot and the depth becomes an inch or less.

Figure 3.17: Photograph of the Reference Marsh South Upstream station. Photograph was taken facing northeast.

Figure 3.18 shows the Reference Marsh North Downstream station. This station survived the entire duration of the project. It is located where the tidal channel's bed is at about the low tide, low water level of the Salmon River and thus there is almost always water in the channel, and it is often connected to the river throughout the day.

Figure 3.18: Photograph of the Reference Marsh North Downstream station. Photograph was taken facing south.

Figure 3.19 shows the Reference Marsh North Upstream station. This station survived the entire duration of the project. The station is located where the channel bottom is above the low tide, low water level of the Salmon River. Thus, at low tide on most days the water in the channel is reduced to the trickle of water draining out of the marsh. The time between high tides is too short for the marsh to drain completely and thus there is always some water in the very bottom of the channel, but it is narrow, shallow, and slow moving. During high water events on the Salmon River, it was possible to travel in a boat or kayak across the marsh, directly from the Reference Marsh North Upstream station to the Reference Marsh South Upstream station.

Figure 3.19: Photograph of the Reference Marsh North Upstream station. Photograph was taken facing southeast.

3.1.3.4 Estuary Stations in the 96 Marsh

There were three stations established in what has been called the 96 Marsh, where Salmon Creek flowed through the estuary prior to the construction of the current US Route 101. These stations will see the most direct affect if a culvert or bridge is built which allows Salmon Creek to reconnect with its former channel through the estuary. With a restored Salmon Creek course, this area will have a direct, sustained source of fresh water other than direct precipitation and runoff from US Route 101. In terms of fresh water supply, this marsh is currently most similar to the Reference Marsh. If Salmon Creek were to be reestablished, passing under US 101 through a culvert or bridge, then the freshwater availability for these stations would be more like the Rowdy Creek Upstream and Rowdy Creek Downstream stations

Figure 3.20 shows the Former Salmon Creek Main station. This station was roughly mid-way along the straight section of the tidal channel from where it joins the Salmon River. This station only produced data for two downloads before the logger failed. While the logger was out of the station for repairs, driftwood, presumably, wiped-out this station and it was abandoned.

Figure 3.20: Photograph showing the Former Salmon Creek Main station. Photograph taken facing north.

Figure 3.21 shows the Former Salmon Creek North station. This station was located at a branch in the channel of the former Salmon Creek where the channel of the former Salmon Creek turns and heads south and a secondary channel heads to the north. The station is a short distance up the smaller, north-directed channel. This station recorded data for two downloads before the logger failed. The logger was sent in for repairs and then reinstalled. It operated for one download and then failed again. A replacement logger (the repaired logger from Former Salmon Creek Main) was then installed. This logger produced data for four downloads before the logger failed. The station was unoccupied when it was destroyed, presumable by driftwood, in the winter of 2013-2014. It was abandoned at that point.

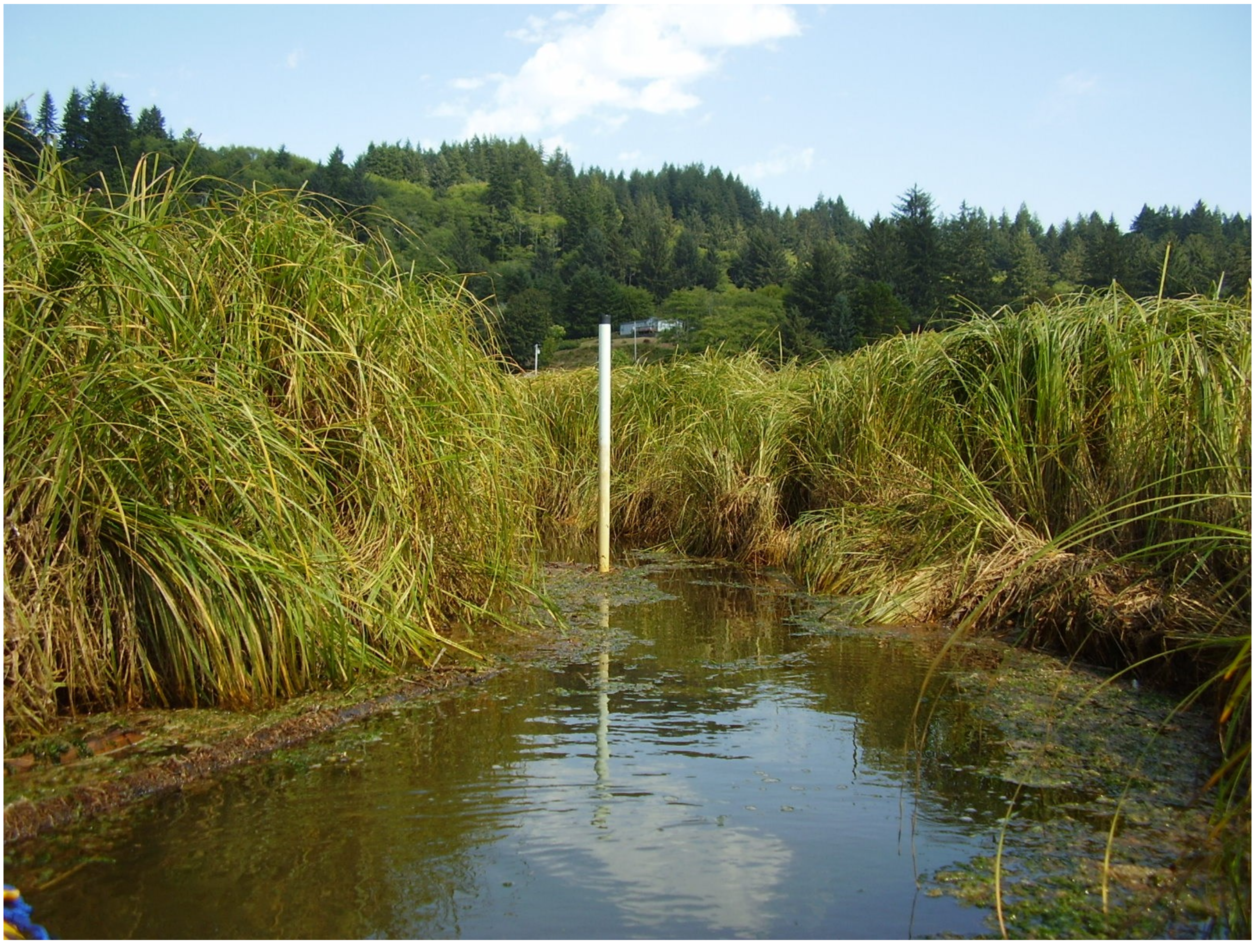


Figure 3.21: Photograph showing the Former Salmon Creek North station. Photograph taken looking northeast.

Figure 3.22 shows the Former Salmon Creek South station. This station was further along the former Salmon Creek where the channel is headed along a nearly straight course to the southeast. This means it is headed directly toward a nearly perpendicular intersection with US Route 101. This station was named Former Salmon Creek South. Even though large tree trunk driftwood moved in and around the area, this station survived for the entire project. As can be seen in the photograph, this station experiences an abundance of iron oxide deposition. While it was a constant concern with respect to the instruments, they seemed to endure it well and it seemed to be less of a problem than the corrosion that was present at all the stations within the estuary. In the photograph, a second, much shorter piece of PVC can be seen to the left. This, as was also indicated for the 70s Marsh station, was installed to house a dissolved oxygen logger. This station was selected to host a dissolved oxygen logger because it only receives significant volumes of water from water being forced up the channel from the Salmon River. It would be reconnected to a direct source of fresh water if Salmon Creek is restored to its former course.

Figure 3.22: Photograph showing the Former Salmon Creek South station. Photograph taken facing northwest

3.1.4 Other Stations

Finally, two stations were installed that were not on the Salmon River nor necessarily in the estuary. What constitutes the estuary to the east of US Route 101 is a matter of interpretation because of the influence of the highway on the current hydrology. These two stations' hydraulic connection to the estuary would be dramatically altered by reconnecting Salmon Creek to its former course. (The already described Salmon Creek at Three-Rocks Road station is at such an elevation that it likely would not see daily salt water even if US Route 101 was not present.)

3.1.4.1 Salmon Creek Near Future Culvert

The first of these "other" stations was installed in Salmon creek where it currently runs parallel to US Route 101, approximately where a future bridge or culvert might be built to reconnect Salmon Creek with its former channel. This station was occupied for approximately one year before the stream began to undermine the bank where the station was anchored, and the logger was proactively removed to prevent its loss. The station was never reoccupied or rebuilt. This station was named Salmon Creek Near Future Culvert, even though there were no firm plans for such a culvert or bridge.

Figure 3.23 shows the station on Salmon Creek near where a future culvert could be built. As can be seen, the cantilevered station construction was used. Salmon Creek has a gravel bed in this area, just as it did at Three-Rocks Road.

Figure 3.23: Photograph of station on Salmon Creek near future culvert. Photograph taken facing east.

3.1.4.2 USFS Ditch

The final station to be described was installed in a human-made ditch located to the east of US Route 101 in an area of pasture that sees bank overflow from Salmon Creek where it is unnaturally constrained parallel, and adjacent, to US Route 101. The station is on USFS land and so it is called USFS Ditch. This ditch connects with the current channel of Salmon Creek, through an unnamed stream, near the location of the Salmon Creek Near Future Culvert station (which can be seen in the background of Figure 3.23). This ditch's hydraulic connection to salt water is currently very different from what it was, and might once again be, with Salmon Creek connected to its former course through the estuary. Referring back to Figure 1.5, one can observe how restoring Salmon Creek, with its relatively small freshwater discharge, to its former course would bypass a long reach of the Salmon River, with its relatively large freshwater discharge. It is possible that this would allow greater access of salt water to the area east of US 101.

Figure 3.24 shows the USFS Ditch station. Access to this location requires crossing another branch of this ditch and thus it is only accessible at low water. The range of tidal variation is also smaller at this higher elevation. Thus, the PVC does not rise very high. The transition from water to earth in the ditch is very gradual and poorly defined. From the water surface moving downwards one encounters first vegetation that steadily increases in density. The vegetation then begins to be mixed with liquid muck and the muck increases in density until eventually becoming firm enough to be called earth or soil. Over 5 feet of PVC was easily driven down into this column of semi-solid material. This vague transition from water to earth presented a problem for choosing a positioning of the level logger within the PVC pipe.

This station survived the duration of the project.

Figure 3.24: Photograph of the station in the USFS ditch. The black cap and white pipe can be seen in the lower center of the photograph, at the edge of the grass. Photograph taken facing southwest. The fence runs slightly east of due south.

3.2 WEATHER STATIONS

Two weather stations were installed. One was installed at the location of the former Pixieland, and the other was installed in the highlands at the divide between the Salmon River Drainage and the Neskowin Creek drainage. This was an easy walk west of the Old Scenic Highway 101 where it crosses the divide (see Figure 3.25). Weather information is an important compliment to the water data because precipitation influences stream discharge, air temperature and sun influence water temperature and evaporation, and storm systems and winds influence tides.

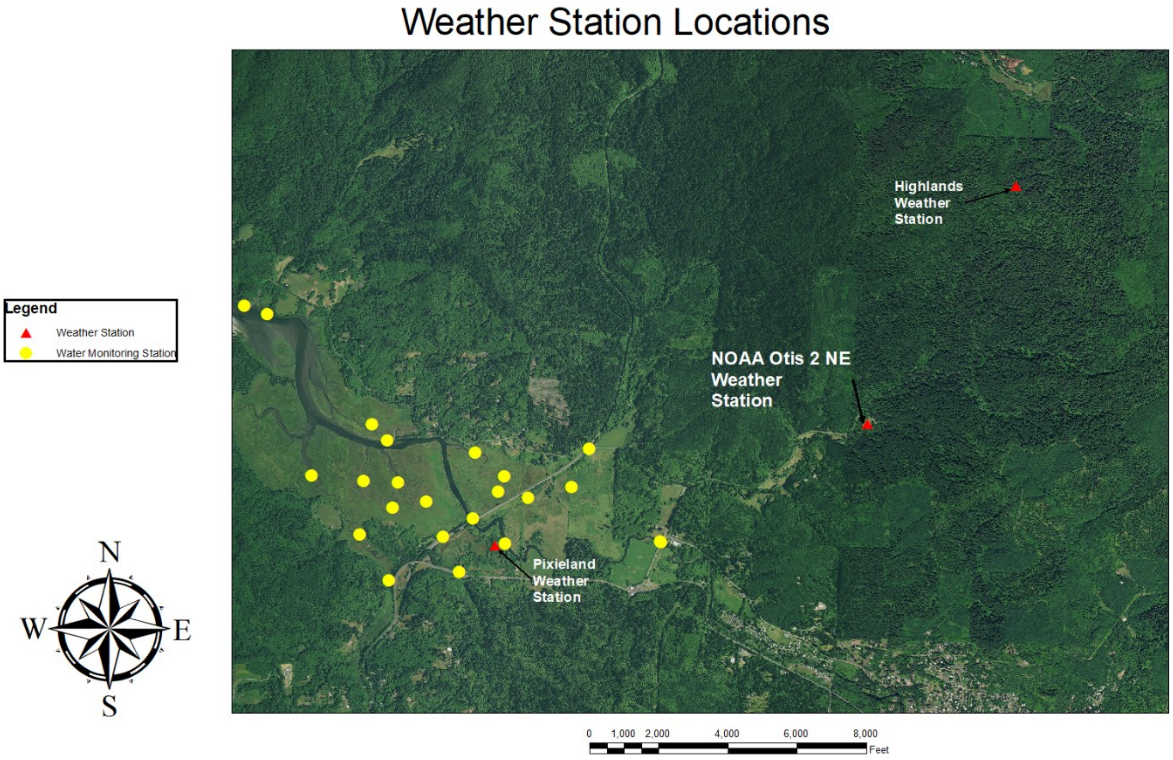


Figure 3.25: Map showing an aerial image of the Salmon River Estuary and part of the Cascade Head Experimental Forest with the location of the two project weather stations and the NOAA weather station (and the water level stations).

A weather station on the estuary was desired as a compliment to the various weather stations already installed in the region, such as in Rose Lodge, in Lincoln City, and the NOAA "Otis 2 NE" weather station at the Cascade Head Experimental Forest Research Station. Pixieland was convenient because it was easily accessed, out of sight of the average passer-by, not a location subject to driftwood, and there were large clearings in the trees. Other locations would either be easily visible, hard to reach, vulnerable to driftwood, too close to trees, or some combination of the foregoing. The Pixieland location worked out very well. This station was named the obvious: Pixieland Weather Station. It is located in the area of Pixieland that appears to have been the trailer park. Remnants of the pattern of roads and trailer pads can still be seen in aerial imagery from 2019. This is despite the extensive restoration efforts at the site.

A weather station was also desired at a higher elevation to try to capture the orographic effects on the weather. However, most of the high areas in the drainage basin are heavily timbered, in a scenic location, too close to the coast, or some combination of the foregoing. A small clearing was located in the Cascade Head Research Forest, but the clearing proved to be too small and the steady supply of shed needles from trees and dirty drip from the trees combined to cause troubles for the weather instruments, most especially for the rain gauge. The problems related to the small clearing surrounded by very tall trees were not unanticipated, but it was judged worth the try. This station was named Highlands Weather Station.

Figure 3.26 shows the Pixieland Weather Station. The broad, open clearing in which it stood is clearly evident in this photo.

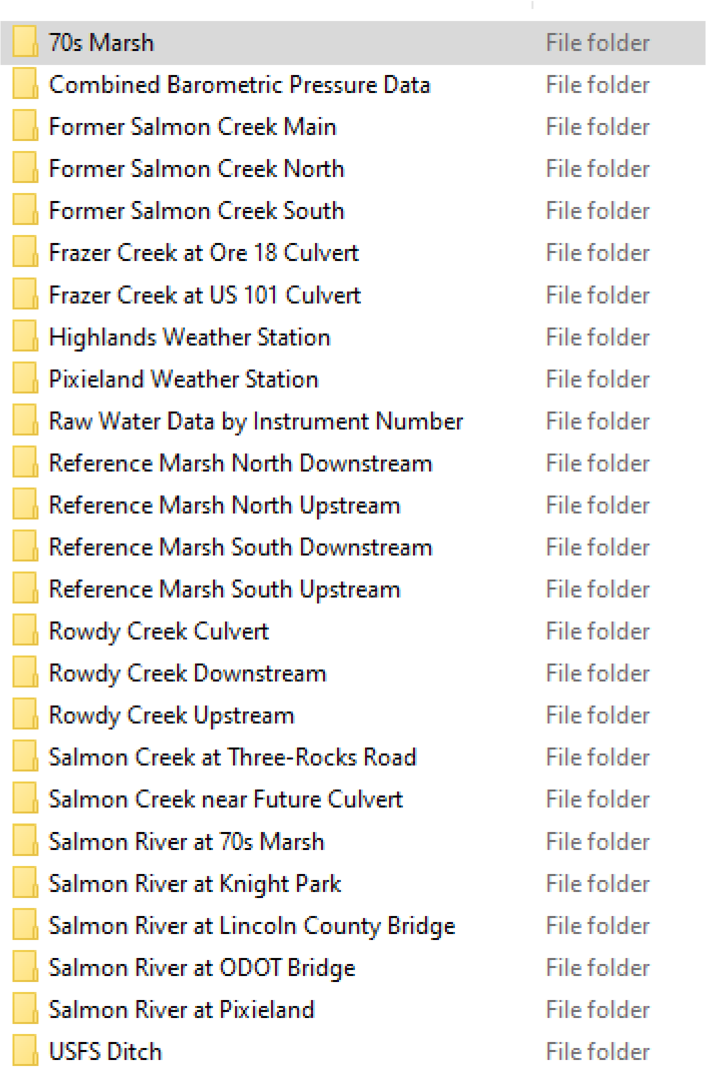
Figure 3.26: Pixieland Weather Station equipment.

Figure 3.27 shows the Highlands Weather station installed. The tall surrounding trees can be clearly seen in the background. It should also be noted that the lower vegetation, closer to the station, increased considerably in height over the duration of the project.

Figure 3.27: Highlands Weather Station equipment.

4.0 DATA ORGANIZATION

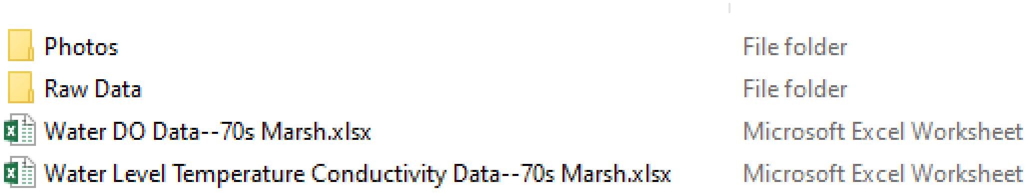
This section describes the organization of the data that accompanies this report. The data is primarily organized by station. The two exceptions to the station grouping are the grouping of all the barometric pressure data together in a single spreadsheet file and a folder where the raw water data is grouped by instrument number. Thus, there are twenty-five main folders with descriptive names. Twenty-one of these are for the water stations, two for the weather stations, one for the combined barometric pressure data, and one for the data grouped by instrument. Figure 4.1 shows what this station-oriented folder structure looks like.



70s Marsh	File folder
Combined Barometric Pressure Data	File folder
Former Salmon Creek Main	File folder
Former Salmon Creek North	File folder
Former Salmon Creek South	File folder
Frazer Creek at Ore 18 Culvert	File folder
Frazer Creek at US 101 Culvert	File folder
Highlands Weather Station	File folder
Pixieland Weather Station	File folder
Raw Water Data by Instrument Number	File folder
Reference Marsh North Downstream	File folder
Reference Marsh North Upstream	File folder
Reference Marsh South Downstream	File folder
Reference Marsh South Upstream	File folder
Rowdy Creek Culvert	File folder
Rowdy Creek Downstream	File folder
Rowdy Creek Upstream	File folder
Salmon Creek at Three-Rocks Road	File folder
Salmon Creek near Future Culvert	File folder
Salmon River at 70s Marsh	File folder
Salmon River at Knight Park	File folder
Salmon River at Lincoln County Bridge	File folder
Salmon River at ODOT Bridge	File folder
Salmon River at Pixieland	File folder
USFS Ditch	File folder

Figure 4.1: Folder structure for the project data.

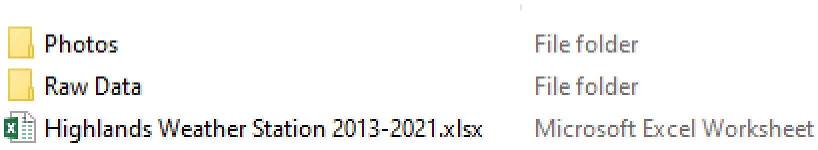
Within the water station folders, the primary file is a spreadsheet that combines that station's level, temperature, and conductivity data for the duration of the project. The organization of these spreadsheets will be described below. For those stations that also have dissolved oxygen data, there will be a second spreadsheet file. The second spreadsheet file holds all the dissolved oxygen data for that station for the duration of the project. In addition to the spreadsheet files, each folder contains two subfolders. One subfolder holds the photographs of the station. The other subfolder holds the data files for each individual data download for that station. Each data download is provided in both the native, proprietary format of the instrument manufacturer and in a plain text, comma separated value (CSV) file format. The Rowdy Creek Culvert station raw data includes the data for the Barologger and HOBO U20L 4m instruments that were installed at that station. Figure 4.2 shows an example of the subfolders and files in a water-station folder look like.



Photos	File folder
Raw Data	File folder
Water DO Data--70s Marsh.xlsx	Microsoft Excel Worksheet
Water Level Temperature Conductivity Data--70s Marsh.xlsx	Microsoft Excel Worksheet

Figure 4.2: Example of subfolders and files inside a water station folder.

Within the two weather station folders, the primary file is a spreadsheet that combines the various sensor readings for that station, for the duration of the project. The organization of these spreadsheets will be explained below. There are also two subfolders. One holds the photographs of the station. The other holds data files for each individual data download for that station. Each data download is provided in both the native, proprietary format of the instrument manufacture and in a plain text, comma separated value (CSV) file format. The Pixieland Weather Station raw data includes the data for the Barologger that was installed at that station. Figure 4.2 shows what the files and subfolders inside a weather station folder look like.



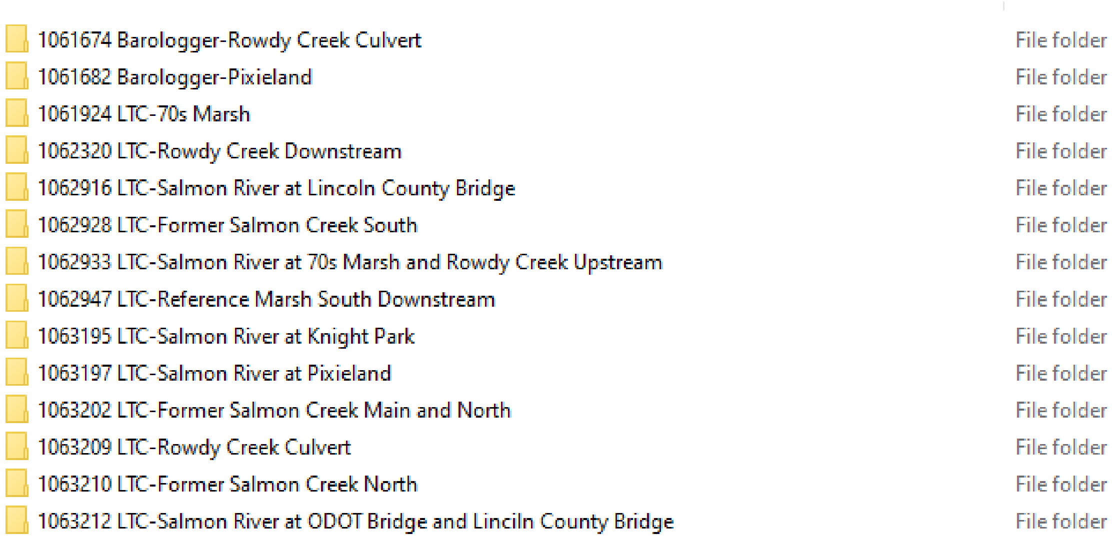
Photos	File folder
Raw Data	File folder
Highlands Weather Station 2013-2021.xlsx	Microsoft Excel Worksheet

Figure 4.3: Example of subfolders and file inside a weather station folder.

Within the "Combined Barometric Pressure Data" folder is a spreadsheet file that combines all the barometric pressure data recorded by this project's instruments. The organization of this spreadsheet will be explained below.

Finally, within the "Raw Water Data by Instrument Number" folder, there are 79 subfolders, one for every water instrument and Barologger acquired for this project. The names of the subfolders are created by combining the instrument serial number, the instrument model, and the name of the station(s) where the instrument was used. Some of the instruments were spares that were never deployed at a station, but they are included in this folder for completeness. Providing the data grouped by instrument number is done to facilitate potential analysis of the data produced by an individual instrument. For example, if an anomaly were to be discovered.

Figure 4.4 shows what a portion of the subfolders inside the Raw Water Data by Instrument Number folder looks like.



1061674 Barologger-Rowdy Creek Culvert	File folder
1061682 Barologger-Pixieland	File folder
1061924 LTC-70s Marsh	File folder
1062320 LTC-Rowdy Creek Downstream	File folder
1062916 LTC-Salmon River at Lincoln County Bridge	File folder
1062928 LTC-Former Salmon Creek South	File folder
1062933 LTC-Salmon River at 70s Marsh and Rowdy Creek Upstream	File folder
1062947 LTC-Reference Marsh South Downstream	File folder
1063195 LTC-Salmon River at Knight Park	File folder
1063197 LTC-Salmon River at Pixieland	File folder
1063202 LTC-Former Salmon Creek Main and North	File folder
1063209 LTC-Rowdy Creek Culvert	File folder
1063210 LTC-Former Salmon Creek North	File folder
1063212 LTC-Salmon River at ODOT Bridge and Linciln County Bridge	File folder

Figure 4.4: Excerpt of instrument subfolders in the Raw Water Data by Instrument Number folder.

4.1 SPREADSHEETS

As was previously mentioned, the individual stations' data and the barometric pressure data was combined into single spreadsheets. This was done to facilitate the viewing and working with the data collectively, rather than in discrete periods corresponding to time between data downloads.

4.1.1 Water Level-Temperature-Conductivity Data Spreadsheets

The water level-temperature-conductivity data spreadsheets are organized under six tabs listed below and shown in Figure 4.5:

1. Level, Temp, Cond. Data
2. Notes
3. Master Chart
4. Barometric
5. Level vs. Tide Gauge
6. Regional Tide Data

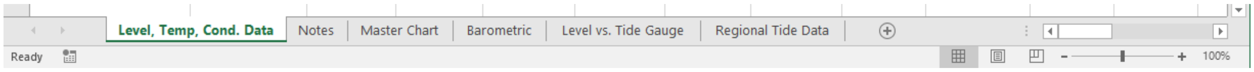
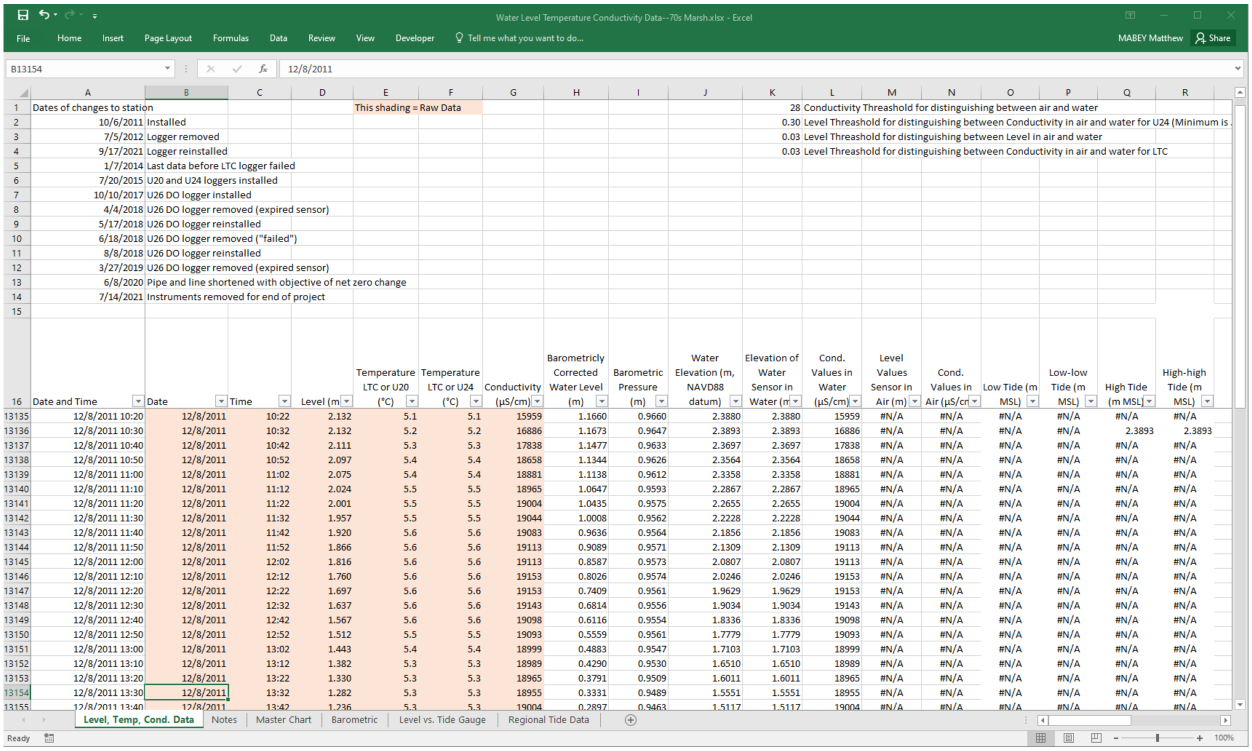


Figure 4.5: Spreadsheet tabs found in water level-temperature-conductivity data spreadsheets.

4.1.1.1 "Level, Temp, Cond. Data" Tab

The "Level, Temp, Cond. Data" tab corresponds to the worksheet that holds the measurements of water level, water temperature, and water conductivity. Figure 4.6 shows the top rows of the worksheet for the "Level, Temp, Cond. Data" tab in the spreadsheet for the 70s Marsh. In the upper left are the dates and descriptions of significant changes to the station. (This information is repeated here from the "Notes" tab for convenience.) In the upper right are values (adjustable) which are used to distinguish between data recorded when the sensors were in water and when they were in air. Row 16 contains the descriptive data column headings. Rows 17 onward are data. Worksheet cells for measured data are shaded tan, while the unshaded cells are values that are derived from the measured data by applying various adjustments.



	A	B	E	K	L
1	Dates of changes to station		This shading = Raw Data	28	Conductivity Threashold for distinguishing between air and water
2	10/6/2011	Installed		0.30	Level Threashold for distinguishing between Conductivity in air and water for U24 (Minimum is
3	7/5/2012	Logger removed		0.03	Level Threashold for distinguishing between Level in air and water
4	9/17/2021	Logger reinstalled		0.03	Level Threashold for distinguishing between Conductivity in air and water for LTC
5	1/7/2014	Last data before LTC logger failed			
6	7/20/2015	U20 and U24 loggers installed			
7	10/10/2017	U26 DO logger installed			
8	4/4/2018	U26 DO logger removed (expired sensor)			
9	5/17/2018	U26 DO logger reinstalled			
10	6/18/2018	U26 DO logger removed ("failed")			
11	8/8/2018	U26 DO logger reinstalled			
12	3/27/2019	U26 DO logger removed (expired sensor)			
13	6/8/2020	Pipe and line shortened with objective of net zero change			
14	7/14/2021	Instruments removed for end of project			
15					

16	Date and Time	Date	Time	Level (m	Temperature LTC or U20 (°C)	Temperature LTC or U24 (°C)	Conductivity (µS/cm)	Barometricly Corrected Water Level (m)	Barometric Pressure (m)	Water Elevation (m, NAVD88 datum)	Elevation of Water Sensor in Water (m	Cond. Values in Water (µS/cm)	Level Values Sensor in Air (m)	Cond. Values in Air (µS/cn	Low Tide (m MSL)	Low-low Tide (m MSL)	High Tide (m MSL)	High-high Tide (m MSL)
13135	12/8/2011 10:20	12/8/2011	10:22	2.132	5.1	5.1	15959	1.1660	0.9660	2.3880	2.3880	15959	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13136	12/8/2011 10:30	12/8/2011	10:32	2.132	5.2	5.2	16886	1.1673	0.9647	2.3893	2.3893	16886	#N/A	#N/A	#N/A	#N/A	2.3893	2.3893
13137	12/8/2011 10:40	12/8/2011	10:42	2.111	5.3	5.3	17838	1.1477	0.9633	2.3697	2.3697	17838	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13138	12/8/2011 10:50	12/8/2011	10:52	2.097	5.4	5.4	18658	1.1344	0.9626	2.3564	2.3564	18658	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13139	12/8/2011 11:00	12/8/2011	11:02	2.075	5.4	5.4	18881	1.1138	0.9612	2.3358	2.3358	18881	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13140	12/8/2011 11:10	12/8/2011	11:12	2.024	5.5	5.5	18965	1.0647	0.9593	2.2867	2.2867	18965	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13141	12/8/2011 11:20	12/8/2011	11:22	2.001	5.5	5.5	19004	1.0435	0.9575	2.2655	2.2655	19004	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13142	12/8/2011 11:30	12/8/2011	11:32	1.957	5.5	5.5	19044	1.0008	0.9562	2.2228	2.2228	19044	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13143	12/8/2011 11:40	12/8/2011	11:42	1.920	5.6	5.6	19083	0.9636	0.9564	2.1856	2.1856	19083	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13144	12/8/2011 11:50	12/8/2011	11:52	1.866	5.6	5.6	19113	0.9089	0.9571	2.1309	2.1309	19113	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13145	12/8/2011 12:00	12/8/2011	12:02	1.816	5.6	5.6	19113	0.8587	0.9573	2.0807	2.0807	19113	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13146	12/8/2011 12:10	12/8/2011	12:12	1.760	5.6	5.6	19153	0.8026	0.9574	2.0246	2.0246	19153	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13147	12/8/2011 12:20	12/8/2011	12:22	1.697	5.6	5.6	19153	0.7409	0.9561	1.9629	1.9629	19153	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13148	12/8/2011 12:30	12/8/2011	12:32	1.637	5.6	5.6	19143	0.6814	0.9556	1.9034	1.9034	19143	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13149	12/8/2011 12:40	12/8/2011	12:42	1.567	5.6	5.6	19098	0.6116	0.9554	1.8336	1.8336	19098	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13150	12/8/2011 12:50	12/8/2011	12:52	1.512	5.5	5.5	19093	0.5559	0.9561	1.7779	1.7779	19093	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13151	12/8/2011 13:00	12/8/2011	13:02	1.443	5.4	5.4	18999	0.4883	0.9547	1.7103	1.7103	18999	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13152	12/8/2011 13:10	12/8/2011	13:12	1.382	5.3	5.3	18989	0.4290	0.9530	1.6510	1.6510	18989	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13153	12/8/2011 13:20	12/8/2011	13:22	1.330	5.3	5.3	18965	0.3791	0.9509	1.6011	1.6011	18965	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13154	12/8/2011 13:30	12/8/2011	13:32	1.282	5.3	5.3	18955	0.3331	0.9489	1.5551	1.5551	18955	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13155	12/8/2011 13:40	12/8/2011	13:42	1.236	5.3	5.3	19004	0.2897	0.9463	1.5117	1.5117	19004	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Figure 4.6: Worksheet found in the "Level, Temp, Cond. Data" tab of the water level-temp-cond data spreadsheets.

Moving from left to right, the first column, "Date and Time," contains all the date-time combinations at 10-minute intervals from the beginning of project data collection until the end of project data collection. The next two columns, "Date" and "Time," contain the actual date and time, as recorded by the data logger, for recorded data values. These first three columns can differ from one another for several reasons. The first possible reason is that in the early stages of the project the importance of, and method to, have the instrument record at from-the-hour 10-minute intervals hadn't been discovered. Figure 4.6 shows the data was recorded every 10 minutes but shifted 2 minutes from the from-the-hour 10-minute times for the 70s Marsh station in early December 2011. Another reason is that occasionally the date and time in the logger were incorrect. Sometimes due to user error involving daylight savings time or time zone issues. Other times due to some sort of instrument glitch. However, through record keeping, and the times and dates of downloads before and after such problems, these issues could be confidently corrected.

The "Level" column contains the pressure reading of the water level logger (uncorrected for barometric pressure), expressed as meters of freshwater. The "Temperature LTC or U20" column contains the temperature as recorded by the LTC or U20 logger. The "Temperature LTC or U24" column contains the temperature as recorded by the LTC or U24 logger. The "Conductivity" column contains the conductivity.

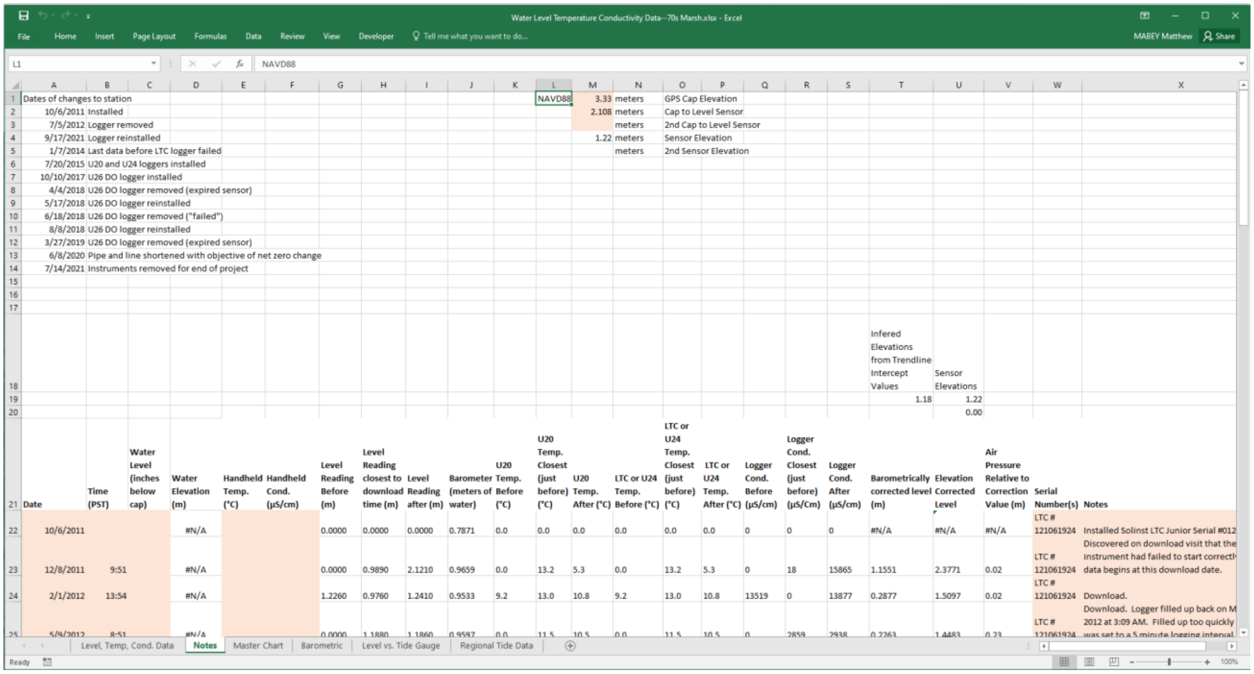
The next is "Barometrically Corrected Water Level." This is the recorded pressure (in meters of water) less the barometric pressure at the time. The barometric pressure used for this correction is found in the next column to the right. Continuing to the right, the "Water Elevation" is the approximate elevation of the water at the station, relative to the North American Vertical Datum of 1988. This value is calculated by adding the barometrically corrected water level to the elevation of the pressure transducer for the station. Note that these elevation values could be, but have not been, made less approximate by adjusting the water level for the density of non-fresh water using the conductivity readings.

The next four columns use the level and the conductivity readings to attempt to classify the readings as to whether they are measuring water or air. If the level reading is the same as the barometric pressure, then the level reading and the conductivity reading are evidently in air. If the conductivity drops low enough, then the conductivity sensor is evidently in air. In the case of the LTC loggers, the conductivity values reliably went to zero when the water level dropped below the conductivity sensor (approximately 4 cm above the level sensor). In the case of the U24 loggers, the distance between the level sensor and the conductivity sensor varied between station installations. Additionally, the nature of the small, contactless conductivity sensor meant that readings greater than zero often continued after the water had dropped below the sensor. The likely explanation for this is that drops of water clung to the sensor.

The final four columns on the right are crude attempts at identifying high and low tides. Because most of the stations are influenced by both tide and river stage, and because most of the stations' level sensors were installed at an elevation above the normal low-low tide level, the simple formulas used for these columns sometimes doesn't give the desired result.

4.1.1.2 "Notes" Tab

Figure 4.7 shows the top of the worksheet for the "Notes" tab. This worksheet includes both field notes from visits to the station as well as data recorded at the time of these visits.



Dates of changes to station	
10/6/2011	Installed
7/5/2012	Logger removed
9/17/2021	Logger reinstalled
1/7/2014	Last data before LTC logger failed
7/20/2015	U20 and U24 loggers installed
10/10/2017	U26 DO logger installed
4/4/2018	U26 DO logger removed (expired sensor)
5/17/2018	U26 DO logger reinstalled
6/18/2018	U26 DO logger removed ("failed")
8/8/2018	U26 DO logger reinstalled
3/27/2019	U26 DO logger removed (expired sensor)
6/8/2020	Pipe and line shortened with objective of net zero change
7/14/2021	Instruments removed for end of project

NAVD88			
	3.33	meters	GPS Cap Elevation
	2.108	meters	Cap to Level Sensor
		meters	2nd Cap to Level Sensor
	1.22	meters	Sensor Elevation
		meters	2nd Sensor Elevation

Infered Elevations from Trendline Intercept Values	Sensor Elevations
1.18	1.22
	0.00

Date	Time (PST)	Water Level (inches below cap)	Water Elevation (m)	Handheld Temp. (°C)	Handheld Cond. (µS/cm)	Level Reading Before (m)	Level Reading closest to download time (m)	Level Reading after (m)	Barometer (meters of water)	U20 Temp. Before (°C)	U20 Temp. Closest (just before) (°C)	U20 Temp. After (°C)	LTC or U24 Temp. Before (°C)	LTC or U24 Temp. Closest (just before) (°C)	LTC or U24 Temp. After (°C)	Logger Cond. Before (µS/cm)	Logger Cond. Closest (just before) (µS/Cm)	Logger Cond. After (µS/cm)	Barometrically corrected level (m)	Elevation Corrected Level	Air Pressure Relative to Correction Value (m)	Serial Number(s)	Notes
10/6/2011			#N/A			0.0000	0.0000	0.0000	0.7871	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	#N/A	#N/A	#N/A	LTC # 121061924	Installed Solinst LTC Junior Serial #012
12/8/2011	9:51		#N/A			0.0000	0.9890	2.1210	0.9659	0.0	13.2	5.3	0.0	13.2	5.3	0	18	15865	1.1551	2.3771	0.02	LTC # 121061924	Discovered on download visit that the instrument had failed to start correctl data begins at this download date.
2/1/2012	13:54		#N/A			1.2260	0.9760	1.2410	0.9533	9.2	13.0	10.8	9.2	13.0	10.8	13519	0	13877	0.2877	1.5097	0.02	LTC # 121061924	Download.
5/9/2012	8:51		#N/A			0.0000	1.1880	1.1860	0.9597	0.0	11.5	10.5	0.0	11.5	10.5	0	2859	2938	0.2263	1.4483	0.23	LTC # 121061924	Download. Logger filled up back on M 2012 at 3:09 AM. Filled up too quickly was set to a 5 minute logging interval.

Figure 4.7: Worksheet found in the "Notes" tab of the water level-temperature-conductivity data spreadsheet.

In the upper left is a brief listing of the significant changes that occurred at the station. These changes include events such as a new instrument being installed or an instrument failure. In the upper center of the worksheet are elevation data associated with the station. As with the previous worksheet, information recorded is shaded tan while derivative information is unshaded. As mentioned in chapter "3.0 Stations," the elevations of some station caps were measured with a survey grade GPS, while others were computed indirectly. The shading will reflect the type of cap elevation a station has. For some stations, the installation of new instruments, or conditions at the station, necessitate the raising or lowering of the water level sensor. In those cases, the various levels will be listed in this section of the "Notes" worksheet.

On row 21, or greater, are the column headings for the data from each station visit. The row number of the heading row may vary from station to station because the amount of space required for the significant station changes and elevation changes was greater for some stations. The first two columns are the data and time of the visit. A given station visit typically took anywhere from 10 to 30 minutes, with some being even longer. The time listed will be during the station visit but selected to facilitate the computation of the derived cell values in the columns to the right. The next column is the hand-measured distance from the top of the cap to the water surface. These measurements were not made for the first few years of the project. The next column is the water elevation derived from subtracting the cap to water distance from the cap elevation. In retrospect, on visits where the level logger was not in water at the time of visit, it may have been desirable to place the logger in a known depth of water (e.g., 0.5 m) as a calibration reference point. However, this would have been a time-consuming process and station visits were constrained by the ebb and flow of the tides.

The next two columns are handheld temperature and conductivity measurements of the water at the surface, outside the PVC pipe. These measurements were made with an Oakton ECTestr 11 Dual Range Conductivity Meter. This device has a maximum conductivity reading of 20,000 µS/cm. Thus, on many occasions the recorded value would be >20,000 µS/cm. In retrospect, the conductivity and temperature of the water inside the PVC at the level of the data logger differed considerably from those same parameters in the water, at the surface, outside the PVC. A sided-by-side measurement in the open channel should have been collected instead, or in addition to the measurements that were collected. Also in retrospect, placing the conductivity logger in a liquid of known conductivity would have been ideal. However, it would have been time consuming and logistically challenging to carry around a large volume of the reference solution. Again, the station visits were constrained by the timing of the tides.

The next fifteen columns are data pulled from the data on the “Level, Temp, Cond. Data” worksheet for times corresponding to the time of the station visit for comparison to the manual observations. The next column, “Air Pressure Relative to Correction Value” is computed by subtracting the barometric correction value from level logger’s reading in air while the data was being downloaded. The value in this column will not always be what the heading implies, because sometimes no logger reading was recorded in the air. This was typically due to inclement weather or other circumstances demanding haste.

The next column is “Serial Number(s).” This column records the serial numbers of instruments installed at the station after downloading and servicing. Thus, if an instrument were replaced during a visit, the serial number recorded on a given row would be that of the new instrument with the old instrument being recorded on the previous row. In addition to the serial number, the instrument type (i.e., LTC or U20L) is included for ease of interpretation. The instrument type could be derived from the serial number alone but listing the instrument type saves that effort.

Finally, the last column is the field notes transcribed from those written in a notebook at the time of the visit to the station. This information often includes data that is also recorded in the columns to the left (i.e., dates, times, temperatures, conductivities, and cap to water distances). Other observations are also common.

Beneath the rows of data from the station visits, there are three graphs of manual observations compared to data logger measurements. As has already been mentioned, the temperature and conductivity values often differed between the two sources, depending on how well the water in the PVC was equilibrated with the channel water.

4.1.1.3 Master Chart Tab

The "Master Chart" tab contains a chart (to use Excel's terminology for a graph) with date and time on the X-axis and level, temperature, and conductivity on one of the Y-axes. Figure 4.8 shows an example of this chart for the 70s Marsh station. In this figure all the data series included in this chart are displayed for the year 2018. Displaying all data series at once is not practical if for no other reason than the range of values for the various parameters are not mutually compatible. It is done here to illustrate that all the data series are included in the chart in the spreadsheet.

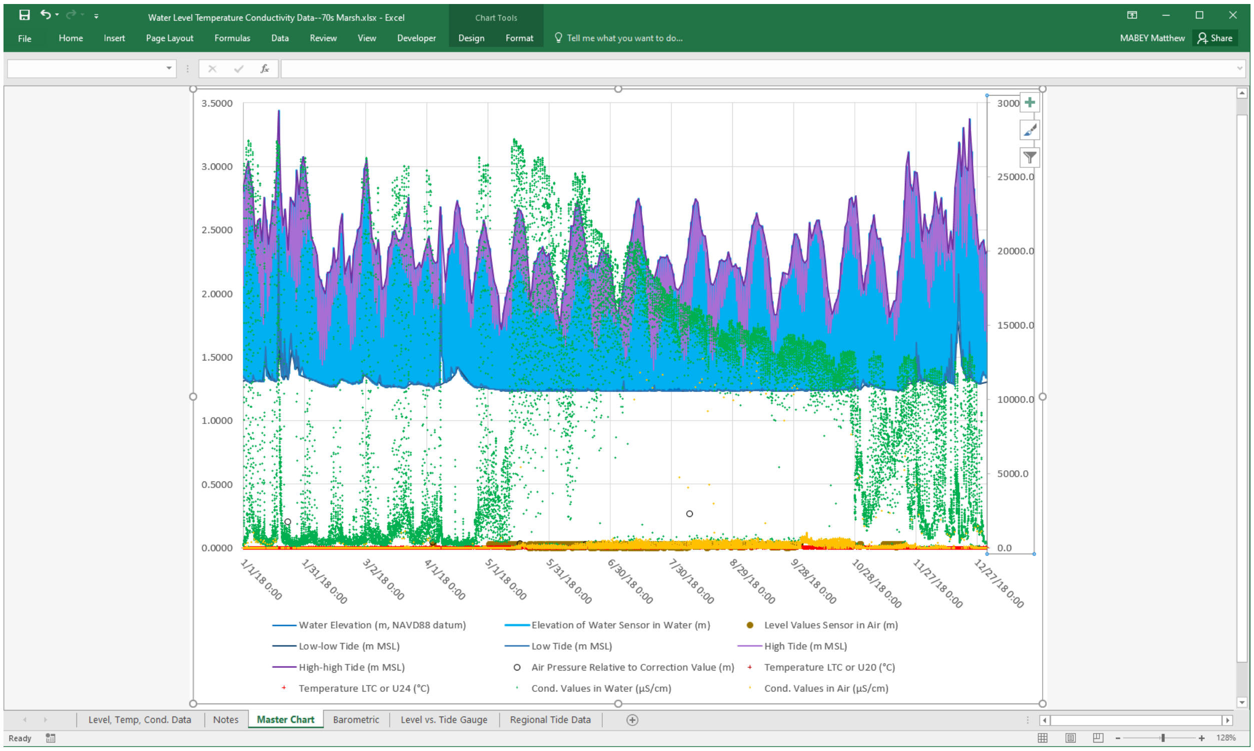


Figure 4.8: Worksheet found in the "Master Chart" tab of the water level, temperature, and conductivity data spreadsheet. All the data series are displayed in this image for the year 2018.

To be useful, one would select some subset of the data series (e.g., level in water and conductivity in water) by checking or unchecking items in the Data Series dialog box of Excel. One could then assign the selected data series to one of the two Y-axes, chose a range of dates, and adjust format settings for the display of the axes and the data series. Figure 4.9 shows the Master Chart configured to show level and conductivity data for a week in January 2018.

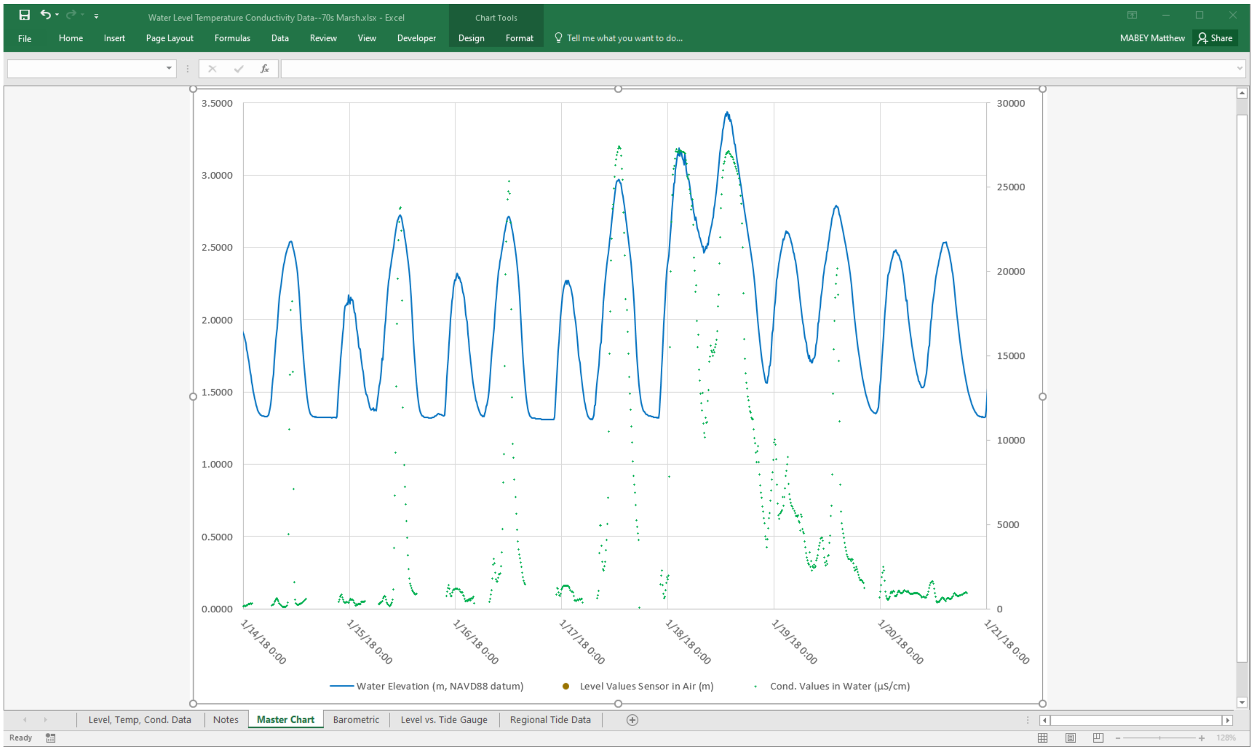


Figure 4.9: Master Chart with data series and formatting selections set for a focused view of water level and conductivity for a single week in January 2018.

Users of this data will clearly create their own graphs for data interpretation and presentation, but the "Master Chart" provides a method to explore many aspects of the data quickly.

4.1.1.4 "Barometric" Tab

The chart found in the "Barometric" tab graphs the recorded level pressure at the station on the X-axis and the measured barometric pressure used for barometric correction on the Y-axis. This graph is for quality control purposes. The measured station pressure will often be greater than the measured barometric pressure due to the water column. However, the measured pressure at the station should never be significantly lower than the measured barometric pressure (i.e., differences should be within the accuracy of the instruments.

Figure 4.10 shows the chart found in the "Barometric" tab for the 70s Marsh station. As can be seen, there are several instances where the measured level is more than 2 cm lower than the corresponding measured barometric pressure. On the worksheet of the "Level, Temp, Cond. Data" tab, the "Barometrically Corrected Water Level" column is set to zero when the result is less than 1 cm (i.e., the level value is less than the barometric pressure correction, which is the case when a point would be to the left of the 1:1 line). Therefore, the anomalously low-level values are included in the "Level" column but are not used for the water elevation values derived from raw level numbers. The "Level

Values Sensor in Air" column is included in the "Master Chart" and thus can be easily displayed there. That column does include all level values.

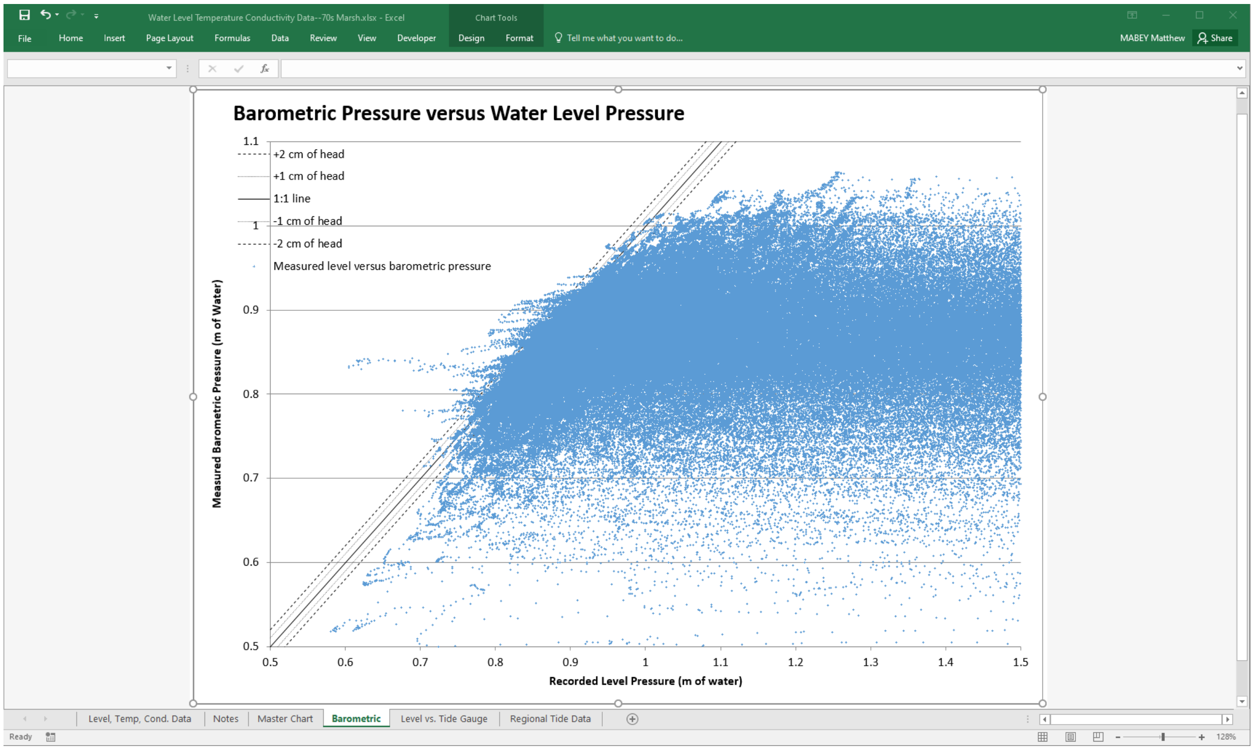


Figure 4.10: Graph of measured barometric pressure versus measured level at a station. A line of 1:1 with +/- 1 and 2 cm lines are included for reference.

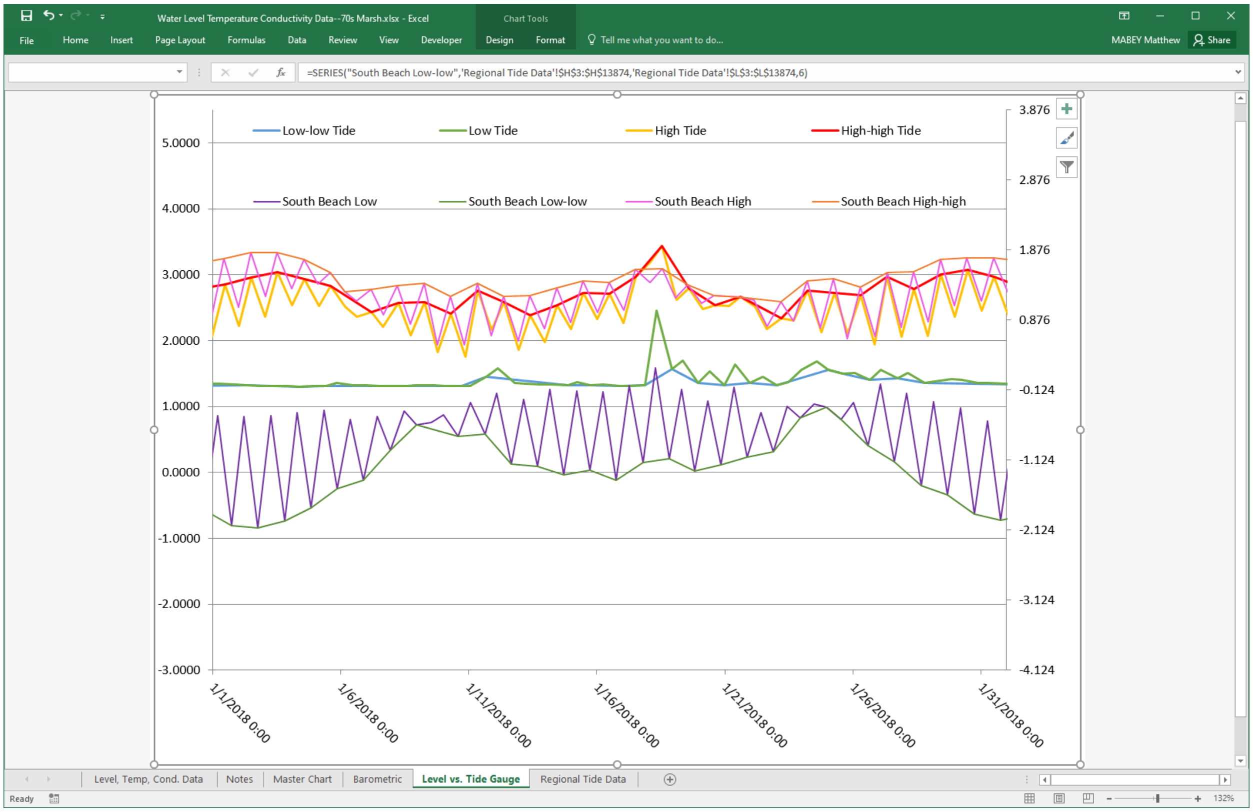
One possible explanation for such lower pressure excursions is drops of water clinging to the pressure transducer after the water level has dropped below the transducer. The weight of the water drop will exert a negative force on the membrane. All the level measurements recorded in air during data download for this station are slightly greater than the barometric pressure correction value. In addition, the calibration for the HOBO level logger at the end of the project showed the logger to be operating within the specifications. Therefore, it seems that whatever the actual explanation, it is not instrument inaccuracy or calibration drift of the HOBO level logger.

That said, Figure 4.10 clearly shows that the vast majority of the data points conform with the expected behavior of being to the right of the 1:1 line.

4.1.1.5 Level vs. Tide Gauge Tab

The chart found in the "Level vs. Tide Gauge" tab displays the water elevation data for the station along with the high and low tide values recorded at regional tide gauges. Specifically, the data from the tide gauges at Garibaldi, Oregon; South Beach (at Newport, Oregon); and Cascade Head (mouth of the Salmon River) are included. It should be noted that the Cascade Head tide gauge was only operated from late May 2013 to early October 2013. All the regional tide data is relative to a MSL datum, because only the South Beach gauge includes data relative to an NAVD88 Datum. The water elevations for the stations for this project are relative to the NAVD88 Datum. At the South Beach Tide gauge, the difference between NAVD88 zero and MSL zero is 1.124 meters (i.e., MSL zero is 1.124 m above NAVD88 zero)

Figure 4.11 Shows an example of the content of the “Level vs. Tide Gauge” tab with the X-axis configured to display one month of data for January 2018 for the 70s Marsh station and the South Beach Tide Gauge. The tide gauge data uses the secondary Y-axis on the right and the range has been set to adjust for the 1.124-meter difference between the NAVD88 datum and the MSL datum.



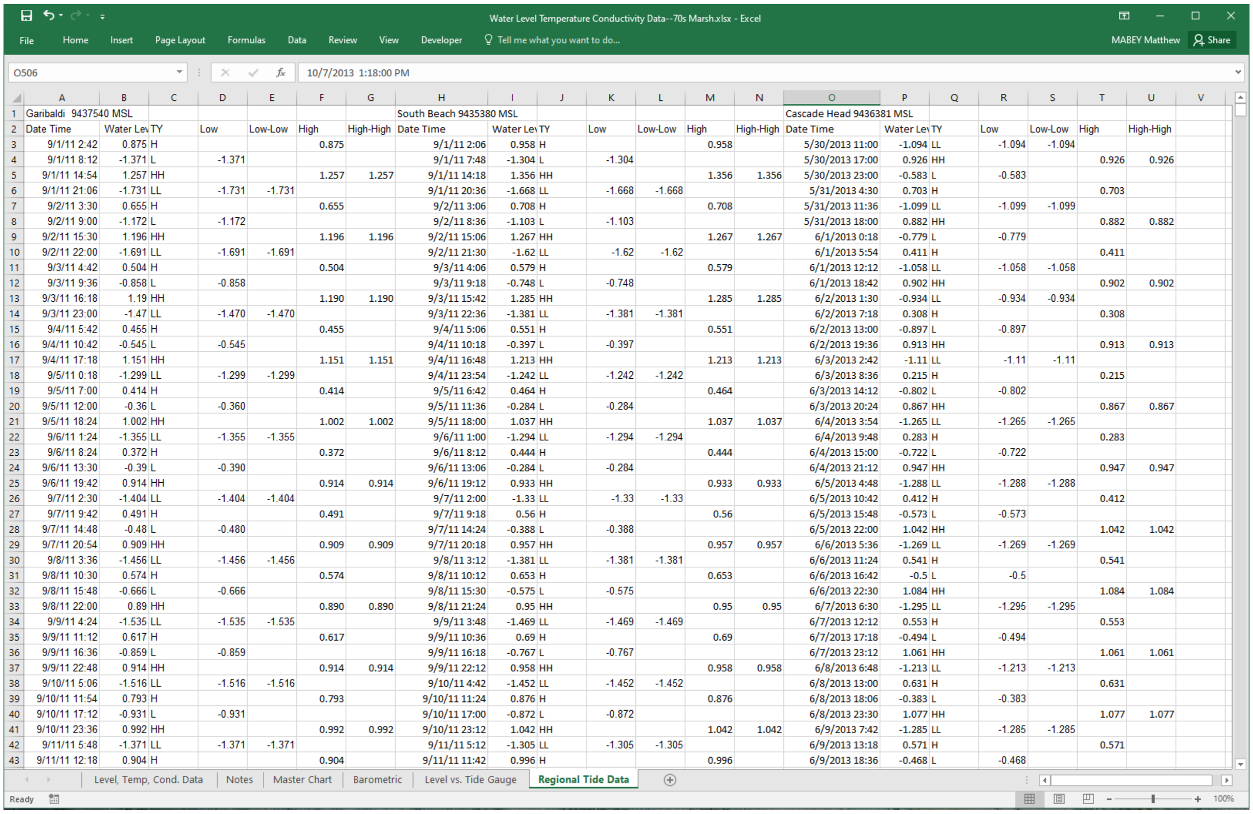
```
=SERIES("South Beach Low-low",'Regional Tide Data'!$H$3:$H$13874,'Regional Tide Data'!$L$3:$L$13874,6)
```

Figure 4.11: Example of Level vs. Tide Gauge tab showing January 2018 for 70s Marsh station.

4.1.1.6 Regional Tide Data

The worksheet in the “Regional Tide Data” tab contains regional tide data from three nearby National Oceanic and Atmospheric Administration (NOAA) tide gauges (the data is available at https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels). Namely the South Beach (Newport, OR), Cascade Head (mouth of the Salmon River), and Garibaldi (OR) gauges. The data included covers the project duration, beginning with September 1, 2011 and ending with June 30, 2021. The Cascade Head station was only operated from May 30, 2013 to October 7, 2013. Because neither the Garibaldi nor the Cascade Head station data is reported by NOAA for an NAVD88 Datum, all three gauges’ data are provided relative to a MSL datum. The correction from MSL to

NAVD88 at the South Beach gauge is +1.124 meters. Each station has seven data columns and the three stations' data are side-by-side in the worksheet. The first data column is Date-Time, in Pacific Standard Time. The next column is the recorded water level, in meters relative to an MSL datum. The next column is the classification of the water level as "H" for high tide, "L" for low tide, "HH" for high-high tide, and "LL" for low-low tide. The next column is the water level values for low tides, in meters. Subsequent columns contain the water levels for low-low tide, high tides, and high-high tides, respectively, all in meters. Figure 4.12 shows the contents of the top rows of the Regional Tide Data tab.



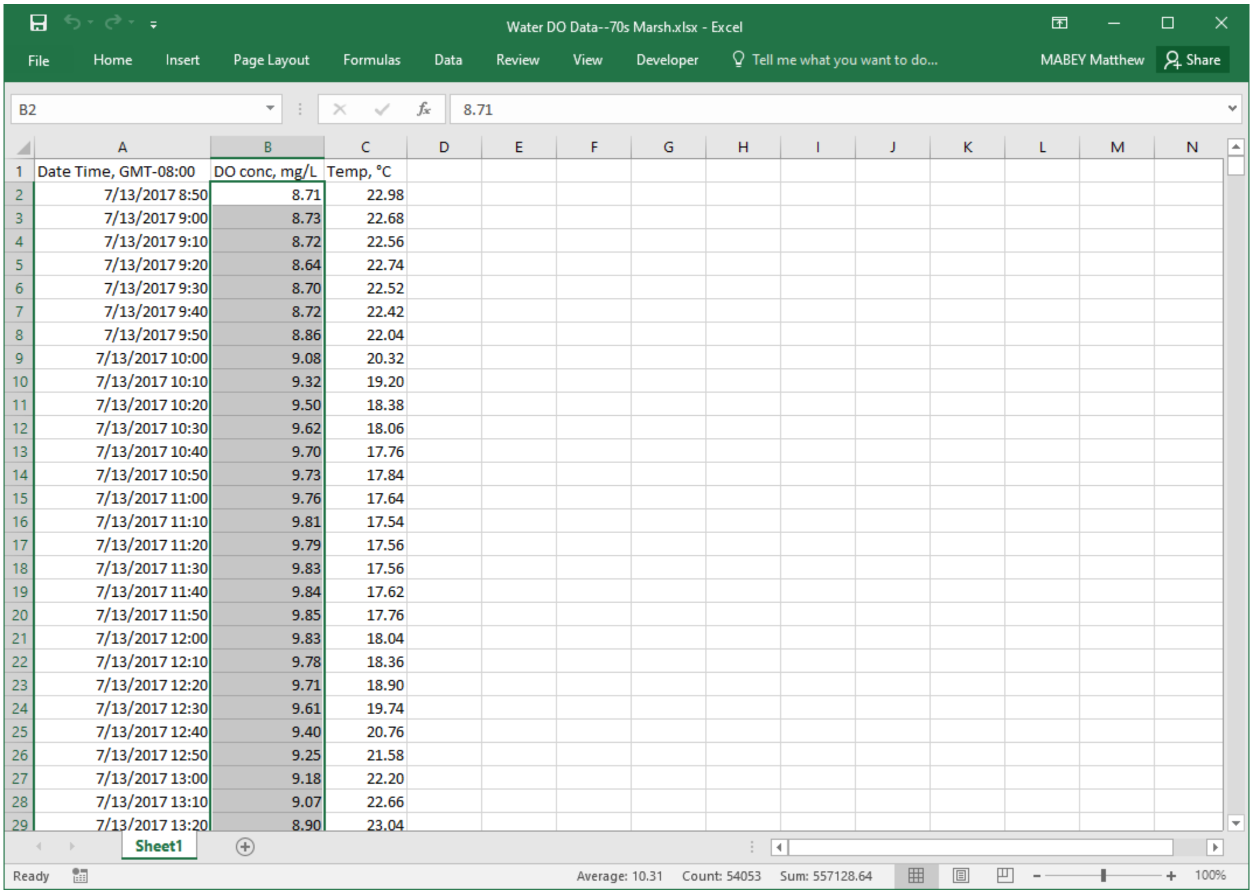
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Garibaldi 9437540 MSL							South Beach 9435380 MSL							Cascade Head 9436381 MSL						
2	Date Time	Water Lev	TY	Low	Low-Low	High	High-High	Date Time	Water Lev	TY	Low	Low-Low	High	High-High	Date Time	Water Lev	TY	Low	Low-Low	High	High-High
3	9/1/11 2:42	0.875	H			0.875		9/1/11 2:06	0.958	H			0.958		5/30/2013 11:00	-1.094	LL	-1.094	-1.094		
4	9/1/11 8:12	-1.371	L	-1.371				9/1/11 7:48	-1.304	L	-1.304				5/30/2013 17:00	0.926	HH			0.926	0.926
5	9/1/11 14:54	1.257	HH			1.257	1.257	9/1/11 14:18	1.356	HH			1.356	1.356	5/30/2013 23:00	-0.583	L	-0.583			
6	9/1/11 21:06	-1.731	LL	-1.731	-1.731			9/1/11 20:36	-1.668	LL	-1.668	-1.668			5/31/2013 4:30	0.703	H			0.703	
7	9/2/11 3:30	0.655	H			0.655		9/2/11 3:06	0.708	H			0.708		5/31/2013 11:36	-1.099	LL	-1.099	-1.099		
8	9/2/11 9:00	-1.172	L	-1.172				9/2/11 8:36	-1.103	L	-1.103				5/31/2013 18:00	0.882	HH			0.882	0.882
9	9/2/11 15:30	1.196	HH			1.196	1.196	9/2/11 15:06	1.267	HH			1.267	1.267	6/1/2013 0:18	-0.779	L	-0.779			
10	9/2/11 22:00	-1.691	LL	-1.691	-1.691			9/2/11 21:30	-1.62	LL	-1.62	-1.62			6/1/2013 5:54	0.411	H			0.411	
11	9/3/11 4:42	0.504	H			0.504		9/3/11 4:06	0.579	H			0.579		6/1/2013 12:12	-1.058	LL	-1.058	-1.058		
12	9/3/11 9:36	-0.858	L	-0.858				9/3/11 9:18	-0.748	L	-0.748				6/1/2013 18:42	0.902	HH			0.902	0.902
13	9/3/11 16:18	1.19	HH			1.190	1.190	9/3/11 15:42	1.285	HH			1.285	1.285	6/2/2013 1:30	-0.934	LL	-0.934	-0.934		
14	9/3/11 23:00	-1.47	LL	-1.470	-1.470			9/3/11 22:36	-1.381	LL	-1.381	-1.381			6/2/2013 7:18	0.308	H			0.308	
15	9/4/11 5:42	0.455	H			0.455		9/4/11 5:06	0.551	H			0.551		6/2/2013 13:00	-0.897	L	-0.897			
16	9/4/11 10:42	-0.545	L	-0.545				9/4/11 10:18	-0.397	L	-0.397				6/2/2013 19:36	0.913	HH			0.913	0.913
17	9/4/11 17:18	1.151	HH			1.151	1.151	9/4/11 16:48	1.213	HH			1.213	1.213	6/3/2013 2:42	-1.11	LL	-1.11	-1.11		
18	9/5/11 0:18	-1.299	LL	-1.299	-1.299			9/4/11 23:54	-1.242	LL	-1.242	-1.242			6/3/2013 8:36	0.215	H			0.215	
19	9/5/11 7:00	0.414	H			0.414		9/5/11 6:42	0.464	H			0.464		6/3/2013 14:12	-0.802	L	-0.802			
20	9/5/11 12:00	-0.36	L	-0.360				9/5/11 11:36	-0.284	L	-0.284				6/3/2013 20:24	0.867	HH			0.867	0.867
21	9/5/11 18:24	1.002	HH			1.002	1.002	9/5/11 18:00	1.037	HH			1.037	1.037	6/4/2013 3:54	-1.265	LL	-1.265	-1.265		
22	9/6/11 1:24	-1.355	LL	-1.355	-1.355			9/6/11 1:00	-1.294	LL	-1.294	-1.294			6/4/2013 9:48	0.283	H			0.283	
23	9/6/11 8:24	0.372	H			0.372		9/6/11 8:12	0.444	H			0.444		6/4/2013 15:00	-0.722	L	-0.722			
24	9/6/11 13:30	-0.39	L	-0.390				9/6/11 13:06	-0.284	L	-0.284				6/4/2013 21:12	0.947	HH			0.947	0.947
25	9/6/11 19:42	0.914	HH			0.914	0.914	9/6/11 19:12	0.933	HH			0.933	0.933	6/5/2013 4:48	-1.288	LL	-1.288	-1.288		
26	9/7/11 2:30	-1.404	LL	-1.404	-1.404			9/7/11 2:00	-1.33	LL	-1.33	-1.33			6/5/2013 10:42	0.412	H			0.412	
27	9/7/11 9:42	0.491	H			0.491		9/7/11 9:18	0.56	H			0.56		6/5/2013 15:48	-0.573	L	-0.573			
28	9/7/11 14:48	-0.48	L	-0.480				9/7/11 14:24	-0.388	L	-0.388				6/5/2013 22:00	1.042	HH			1.042	1.042
29	9/7/11 20:54	0.909	HH			0.909	0.909	9/7/11 20:18	0.957	HH			0.957	0.957	6/6/2013 5:36	-1.269	LL	-1.269	-1.269		
30	9/8/11 3:36	-1.456	LL	-1.456	-1.456			9/8/11 3:12	-1.381	LL	-1.381	-1.381			6/6/2013 11:24	0.541	H			0.541	
31	9/8/11 10:30	0.574	H			0.574		9/8/11 10:12	0.653	H			0.653		6/6/2013 16:42	-0.5	L	-0.5			
32	9/8/11 15:48	-0.666	L	-0.666				9/8/11 15:30	-0.575	L	-0.575				6/6/2013 22:30	1.084	HH			1.084	1.084
33	9/8/11 22:00	0.89	HH			0.890	0.890	9/8/11 21:24	0.95	HH			0.95	0.95	6/7/2013 6:30	-1.295	LL	-1.295	-1.295		
34	9/9/11 4:24	-1.535	LL	-1.535	-1.535			9/9/11 3:48	-1.469	LL	-1.469	-1.469			6/7/2013 12:12	0.553	H			0.553	
35	9/9/11 11:12	0.617	H			0.617		9/9/11 10:36	0.69	H			0.69		6/7/2013 17:18	-0.494	L	-0.494			
36	9/9/11 16:36	-0.859	L	-0.859				9/9/11 16:18	-0.767	L	-0.767				6/7/2013 23:12	1.061	HH			1.061	1.061
37	9/9/11 22:48	0.914	HH			0.914	0.914	9/9/11 22:12	0.958	HH			0.958	0.958	6/8/2013 6:48	-1.213	LL	-1.213	-1.213		
38	9/10/11 5:06	-1.516	LL	-1.516	-1.516			9/10/11 4:42	-1.452	LL	-1.452	-1.452			6/8/2013 13:00	0.631	H			0.631	
39	9/10/11 11:54	0.793	H			0.793		9/10/11 11:24	0.876	H			0.876		6/8/2013 18:06	-0.383	L	-0.383			
40	9/10/11 17:12	-0.931	L	-0.931				9/10/11 17:00	-0.872	L	-0.872				6/8/2013 23:30	1.077	HH			1.077	1.077
41	9/10/11 23:36	0.992	HH			0.992	0.992	9/10/11 23:12	1.042	HH			1.042	1.042	6/9/2013 7:42	-1.285	LL	-1.285	-1.285		
42	9/11/11 5:48	-1.371	LL	-1.371	-1.371			9/11/11 5:12	-1.305	LL	-1.305	-1.305			6/9/2013 13:18	0.571	H			0.571	
43	9/11/11 12:18	0.904	H			0.904		9/11/11 11:42	0.996	H			0.996		6/9/2013 18:36	-0.468	L	-0.468			

Figure 4.12: Example of the Regional Tide Data tab.

4.1.2 Dissolved Oxygen Data Spreadsheets

The dissolved oxygen spreadsheets are much simpler in structure than are the level-temperature-conductivity spreadsheets. Their purpose is simply to assemble all the dissolved oxygen data for a given station into a single, easily accessed file. The single worksheet in the spreadsheet includes three columns. The first column is data and time in Pacific Standard Time (GMT-8 hours). The second column is the dissolved oxygen concentration measured, in mg/liter. The third column is the Temperature measured in degrees Celsius. The 70s Marsh, Former Salmon Creek South, and Rowdy Creek Downstream stations have dissolved oxygen spreadsheets.

Figure 4.13 shows an example of the top rows of a dissolved oxygen data spreadsheet for the 70s Marsh.



	A	B	C
1	Date Time, GMT-08:00	DO conc, mg/L	Temp, °C
2	7/13/2017 8:50	8.71	22.98
3	7/13/2017 9:00	8.73	22.68
4	7/13/2017 9:10	8.72	22.56
5	7/13/2017 9:20	8.64	22.74
6	7/13/2017 9:30	8.70	22.52
7	7/13/2017 9:40	8.72	22.42
8	7/13/2017 9:50	8.86	22.04
9	7/13/2017 10:00	9.08	20.32
10	7/13/2017 10:10	9.32	19.20
11	7/13/2017 10:20	9.50	18.38
12	7/13/2017 10:30	9.62	18.06
13	7/13/2017 10:40	9.70	17.76
14	7/13/2017 10:50	9.73	17.84
15	7/13/2017 11:00	9.76	17.64
16	7/13/2017 11:10	9.81	17.54
17	7/13/2017 11:20	9.79	17.56
18	7/13/2017 11:30	9.83	17.56
19	7/13/2017 11:40	9.84	17.62
20	7/13/2017 11:50	9.85	17.76
21	7/13/2017 12:00	9.83	18.04
22	7/13/2017 12:10	9.78	18.36
23	7/13/2017 12:20	9.71	18.90
24	7/13/2017 12:30	9.61	19.74
25	7/13/2017 12:40	9.40	20.76
26	7/13/2017 12:50	9.25	21.58
27	7/13/2017 13:00	9.18	22.20
28	7/13/2017 13:10	9.07	22.66
29	7/13/2017 13:20	8.90	23.04

Figure 4.13: Example of the top rows of a dissolved oxygen data spreadsheet.

4.1.3 Barometric Pressure Data Spreadsheet

The recordings of barometric pressure from several different instruments, located in several different locations are gathered together in a single “Barometric Pressure Data--Combined” spreadsheet. This file is found in the “Combined Barometric Pressure Data” folder. More details about the instruments can be found in chapter “2.0 Instrumentation” and details about the use of the barometric pressure data can be found in section “6.1 Barometric Pressure Correction.”

The barometric pressure data spreadsheet includes nine tabs. The first tab is named “All Air Pressure & Temperature.” This tab holds the data worksheet (see Figure 4.14). The first fifteen rows are information about some data correction values used and some information about the various instruments. Row sixteen is the column headers for the data. The data begins on row seventeen. The first column is the date and time, in Pacific Standard Time. This value increments in 10-minute steps from a start of September 8, 2011 at 8:00 AM. The next column is the barometric correction used for all the water level data. The value in this column is the barometric pressure (in meters of water) recorded by the Pixieland Barologger, if a data value is available. If not then it is an adjusted barometric pressure recorded by the Rowdy Creek Culvert Barologger, if a data value is available. The adjustment to the Rowdy Creek Culvert Barologger value is a fixed value of 0.0009 m from September 29, 2011 through December 7, 2013 at 8:30

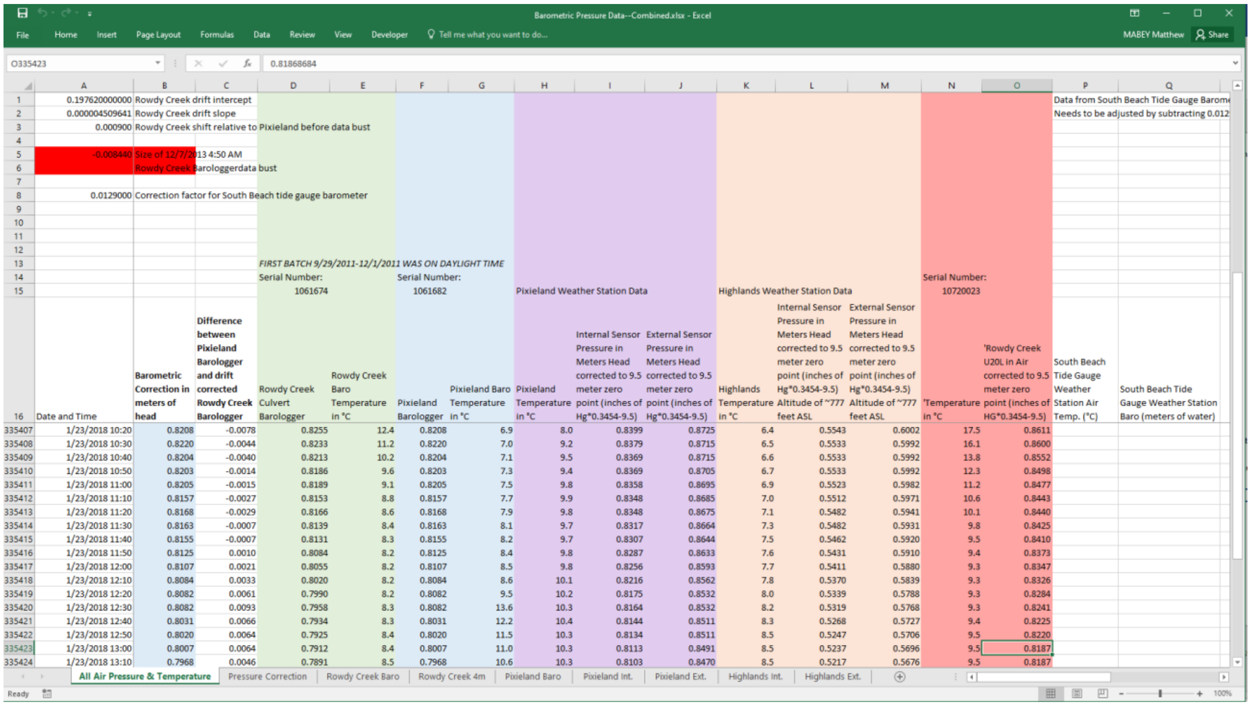
AM. This value adjusts for the average difference between the Pixieland and Rowdy Creek Culvert Barologgers. On December 7, 2013, there was a step jump in in the Rowdy Creek Culvert Barologger's data. This jump, and subsequent drift of the Rowdy Creek Culvert Barologger relative to the Pixieland Barologger were thereafter accommodated by applying a correction to the measured values derived from Equation 4-1.

$$-0.000004509641 \times datetime + 0.19762 \tag{4-1}$$

where:

"*datetime*" is the Excel date value for the date and time of the reading.

This results in an average difference of zero between the Pixieland values and the adjusted Rowdy Creek Culvert values. If neither Pixieland nor Rowdy Creek Culvert Barologger values are available, then the Pixieland Weather Station internal barometer was used, without adjustment. This only occurred once, from March 17, 2021 to April 6, 2021. For the 21 days before the Rowdy Creek Culvert Barologger was installed, the barometric pressure readings from the barometer at the South Beach tide gauge were used. Based on comparing readings from the days following the installation of the Rowdy Creek Culvert Barologger, the South Beach barometric pressure values were adjusted downward by 0.0129 m. Differences between the South Beach barometer readings and the readings gathered in the Salmon River Estuary are likely a combination of the differences between instruments and the geographic separation of the instruments. South Beach is over 25 miles straight-line distance from the Salmon River Estuary.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	0.197620000000	Rowdy Creek drift intercept														Data from South Beach Tide Gauge Barom	
2	0.000004509641	Rowdy Creek drift slope														Needs to be adjusted by subtracting 0.012	
3	0.000900	Rowdy Creek shift relative to Pixieland before data bust															
4																	
5	-0.008440	Size of 12/7/2013 4:50 AM															
6		Rowdy Creek Barologgerdata bust															
7																	
8	0.0129000	Correction factor for South Beach tide gauge barometer															
9																	
10																	
11																	
12																	
13				*FIRST BATCH 9/29/2011-12/1/2011 WAS ON DAYLIGHT TIME*													
14				Serial Number:		Serial Number:								Serial Number:			
15				1061674		1061682		Pixieland Weather Station Data			Highlands Weather Station Data			10720023			
16	Date and Time	**Barometric Correction in meters of head**	**Difference between Pixieland Barologger and drift corrected Rowdy Creek Barologger**	Rowdy Creek Culvert Barologger	Rowdy Creek Baro Temperature in °C	Pixieland Barologger	Pixieland Baro Temperature in °C	Pixieland Temperature in °C	Internal Sensor Pressure in Meters Head corrected to 9.5 meter zero point (inches of Hg*0.3454-9.5)	External Sensor Pressure in Meters Head corrected to 9.5 meter zero point (inches of Hg*0.3454-9.5)	Highlands Temperature in °C	Internal Sensor Pressure in Meters Head corrected to 9.5 meter zero point (inches of Hg*0.3454-9.5) Altitude of ~777 feet ASL	External Sensor Pressure in Meters Head corrected to 9.5 meter zero point (inches of Hg*0.3454-9.5) Altitude of ~777 feet ASL	'Temperature in °C	'Rowdy Creek U20L in Air corrected to 9.5 meter zero point (inches of HG*0.3454-9.5)	South Beach Tide Gauge Weather Station Air Temp. (°C)	South Beach Tide Gauge Weather Station Baro (meters of water)
335407	1/23/2018 10:20	0.8208	-0.0078	0.8255	12.4	0.8208	6.9	8.0	0.8399	0.8725	6.4	0.5543	0.6002	17.5	0.8611		
335408	1/23/2018 10:30	0.8220	-0.0044	0.8233	11.2	0.8220	7.0	9.2	0.8379	0.8715	6.5	0.5533	0.5992	16.1	0.8600		
335409	1/23/2018 10:40	0.8204	-0.0040	0.8213	10.2	0.8204	7.1	9.5	0.8369	0.8715	6.6	0.5533	0.5992	13.8	0.8552		
335410	1/23/2018 10:50	0.8203	-0.0014	0.8186	9.6	0.8203	7.3	9.4	0.8369	0.8705	6.7	0.5533	0.5992	12.3	0.8498		
335411	1/23/2018 11:00	0.8205	-0.0015	0.8189	9.1	0.8205	7.5	9.8	0.8358	0.8695	6.9	0.5523	0.5982	11.2	0.8477		
335412	1/23/2018 11:10	0.8157	-0.0027	0.8153	8.8	0.8157	7.7	9.9	0.8348	0.8685	7.0	0.5512	0.5971	10.6	0.8443		
335413	1/23/2018 11:20	0.8168	-0.0029	0.8166	8.6	0.8168	7.9	9.8	0.8348	0.8675	7.1	0.5482	0.5941	10.1	0.8440		
335414	1/23/2018 11:30	0.8163	-0.0007	0.8139	8.4	0.8163	8.1	9.7	0.8317	0.8664	7.3	0.5482	0.5931	9.8	0.8425		
335415	1/23/2018 11:40	0.8155	-0.0007	0.8131	8.3	0.8155	8.2	9.7	0.8307	0.8644	7.5	0.5462	0.5920	9.5	0.8410		
335416	1/23/2018 11:50	0.8125	0.0010	0.8084	8.2	0.8125	8.4	9.8	0.8287	0.8633	7.6	0.5431	0.5910	9.4	0.8373		
335417	1/23/2018 12:00	0.8107	0.0021	0.8055	8.2	0.8107	8.5	9.8	0.8256	0.8593	7.7	0.5411	0.5880	9.3	0.8347		
335418	1/23/2018 12:10	0.8084	0.0033	0.8020	8.2	0.8084	8.6	10.1	0.8216	0.8562	7.8	0.5370	0.5839	9.3	0.8326		
335419	1/23/2018 12:20	0.8082	0.0061	0.7990	8.2	0.8082	9.5	10.2	0.8175	0.8532	8.0	0.5339	0.5788	9.3	0.8284		
335420	1/23/2018 12:30	0.8082	0.0093	0.7958	8.3	0.8082	13.6	10.3	0.8164	0.8532	8.2	0.5319	0.5768	9.3	0.8241		
335421	1/23/2018 12:40	0.8031	0.0066	0.7934	8.3	0.8031	12.2	10.4	0.8144	0.8511	8.3	0.5268	0.5727	9.4	0.8225		
335422	1/23/2018 12:50	0.8020	0.0064	0.7925	8.4	0.8020	11.5	10.3	0.8134	0.8511	8.5	0.5247	0.5706	9.5	0.8220		
335423	1/23/2018 13:00	0.8007	0.0064	0.7912	8.4	0.8007	11.0	10.3	0.8113	0.8491	8.5	0.5237	0.5696	9.5	0.8187		
335424	1/23/2018 13:10	0.7968	0.0046	0.7891	8.5	0.7968	10.6	10.3	0.8103	0.8470	8.5	0.5217	0.5676	9.5	0.8187		

Figure 4.14: A screenshot of the header rows for the Barometric Pressure Data—Combined spreadsheet showing the header rows and several rows of data.

The next column is the difference between the Pixieland Barologger readings and the Rowdy Creek Culvert readings. The next two columns appertain to the Rowdy Creek Culvert Barologger and give barometric pressure and the temperature, in that order, without adjustments. The next two columns appertain to the Pixieland Barologger and give the barometric pressure and the temperature, in that order. The next three columns appertain to the Pixieland Weather Station and its two barometers. The first of the three columns contain the temperature, the second is the internal barometer, and the third is the external barometer. The internal barometer was installed for nearly the entire duration of data gathering while the external barometer was only installed for the latter half of the project. The next three columns appertain to the Highlands Weather station. The first of the three columns contain the temperature, the second the internal barometer, and the third the external barometer. It should be noted that the Highlands Weather Station is located at an elevation of ~777 feet above sea level. As such, the pressure readings are approximately 0.285 meters lower due to the decrease in barometric pressure with altitude. The next two columns appertain to the 4m U20L HOBO level logger that was installed in air at the Rowdy Creek Culvert Station. The first column contains the temperature and the second the pressure. The last two columns are the data from the South Beach tide gauge barometer. The first contains temperature readings and the second contains the pressure.

The remaining eight tabs are for graphs of this data. The first of these is the "Pressure Correction" tab that contains a plot of the barometric pressure correction that was used for correcting all the water level values. This graph clearly shows how the barometric pressure correction has a range of nearly 0.6 meters of water.

The next seven tabs are for each of the barometric pressure instruments and are named "Rowdy Creek Baro," "Rowdy Creek 4m," "Pixieland Baro," "Pixieland Int.," "Pixieland Ext.," Highlands Int.," and Highlands Ext." Each of these tabs contains a graph of the barometric pressure data for the corresponding instrument. These graphs include a trend line for the data. The intercept values of these trend lines are not meaningful, because they refer to an arbitrary day zero at the end of the year 1899. However, the values of the slopes of the lines represent meters per day of apparent drift. As can be seen, all represent drifts of less than a centimeter per year. In the case of the Barologgers and the internal barometers, the apparent drift is less than 2 centimeters over the duration of the 10-year project. For further discussion of the barometric pressure data, see section "6.1 Barometric Pressure Correction."

4.1.4 Weather Data Spreadsheets

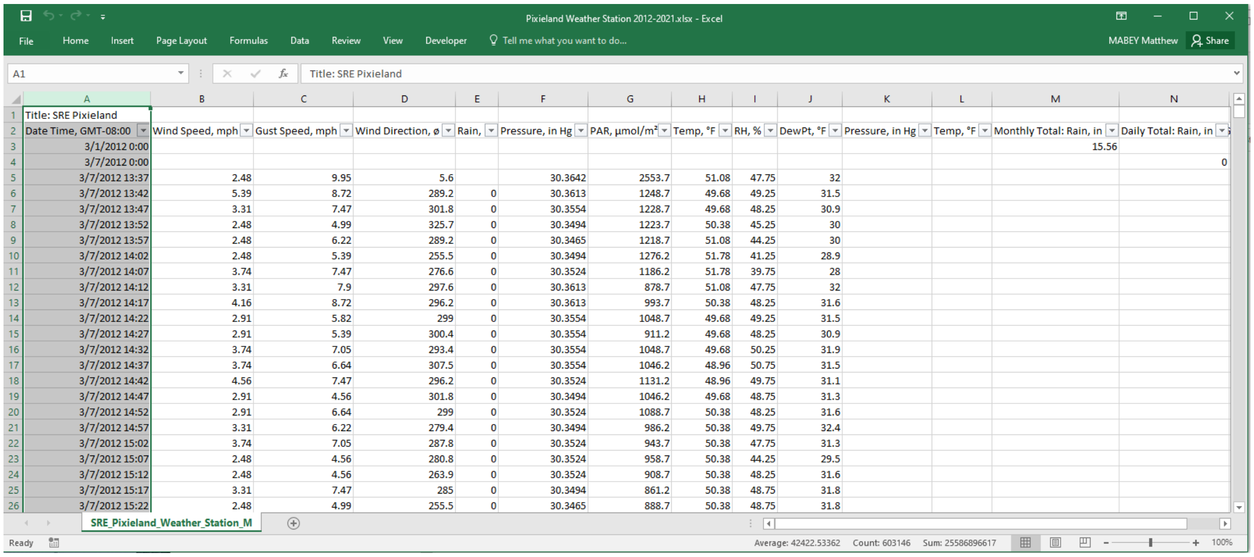
The folders for the two weather stations each contain a spreadsheet where the data from the numerous data downloads are combined together. The files are named "Highlands Weather Station 2013-2021.xlsx" and "Pixieland Weather Station 2012-2021.xlsx." These spreadsheets contain a single worksheet where the readings of the various sensors are in individual columns. The first column contains the date and time (Pacific Standard Time) for the readings in each row. The subsequent columns are:

- Wind Speed

- Gust Speed

- Wind Direction
- Rain
- Pressure (internal sensor)
- PAR (photosynthetically active radiation)
- Temperature (combined with relative humidity sensor)
- Relative Humidity
- Dew point
- Pressure (external sensor)
- Temperature (separate sensor)

These columns are followed by summary columns for total monthly rainfall and total daily rainfall. Figure 4.15 shows the top rows of the Pixieland Weather Station spreadsheet.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Title: SRE Pixieland													
2	Date Time, GMT-08:00	Wind Speed, mph	Gust Speed, mph	Wind Direction, ø	Rain,	Pressure, in Hg	PAR, µmol/m²	Temp, °F	RH, %	DewPt, °F	Pressure, in Hg	Temp, °F	Monthly Total: Rain, in	Daily Total: Rain, in
3	3/1/2012 0:00												15.56	
4	3/7/2012 0:00													0
5	3/7/2012 13:37	2.48	9.95	5.6		30.3642	2553.7	51.08	47.75	32				
6	3/7/2012 13:42	5.39	8.72	289.2	0	30.3613	1248.7	49.68	49.25	31.5				
7	3/7/2012 13:47	3.31	7.47	301.8	0	30.3554	1228.7	49.68	48.25	30.9				
8	3/7/2012 13:52	2.48	4.99	325.7	0	30.3494	1223.7	50.38	45.25	30				
9	3/7/2012 13:57	2.48	6.22	289.2	0	30.3465	1218.7	51.08	44.25	30				
10	3/7/2012 14:02	2.48	5.39	255.5	0	30.3494	1276.2	51.78	41.25	28.9				
11	3/7/2012 14:07	3.74	7.47	276.6	0	30.3524	1186.2	51.78	39.75	28				
12	3/7/2012 14:12	3.31	7.9	297.6	0	30.3613	878.7	51.08	47.75	32				
13	3/7/2012 14:17	4.16	8.72	296.2	0	30.3613	993.7	50.38	48.25	31.6				
14	3/7/2012 14:22	2.91	5.82	299	0	30.3554	1048.7	49.68	49.25	31.5				
15	3/7/2012 14:27	2.91	5.39	300.4	0	30.3554	911.2	49.68	48.25	30.9				
16	3/7/2012 14:32	3.74	7.05	293.4	0	30.3554	1048.7	49.68	50.25	31.9				
17	3/7/2012 14:37	3.74	6.64	307.5	0	30.3554	1046.2	48.96	50.75	31.5				
18	3/7/2012 14:42	4.56	7.47	296.2	0	30.3524	1131.2	48.96	49.75	31.1				
19	3/7/2012 14:47	2.91	4.56	301.8	0	30.3494	1046.2	49.68	48.75	31.3				
20	3/7/2012 14:52	2.91	6.64	299	0	30.3524	1088.7	50.38	48.25	31.6				
21	3/7/2012 14:57	3.31	6.22	279.4	0	30.3494	986.2	50.38	49.75	32.4				
22	3/7/2012 15:02	3.74	7.05	287.8	0	30.3524	943.7	50.38	47.75	31.3				
23	3/7/2012 15:07	2.48	4.56	280.8	0	30.3524	958.7	50.38	44.25	29.5				
24	3/7/2012 15:12	2.48	4.56	263.9	0	30.3524	908.7	50.38	48.25	31.6				
25	3/7/2012 15:17	3.31	7.47	285	0	30.3494	861.2	50.38	48.75	31.8				
26	3/7/2012 15:22	2.48	4.99	255.5	0	30.3465	888.7	50.38	48.75	31.8				

Figure 4.15: Example of the top rows of a weather station spreadsheet.

4.2 RAW DATA

Each station folder includes a subfolder named “Raw Data.” This these subfolders contain the individual data files from the loggers, as downloaded from the devices. The Solinst instruments produce a file with the extension “.xle” at the end of the file name. The HOBO U series loggers produce a file with the extension “.hobo” at the end of the file name. The weather stations produce a file with the extension “.dtf” at the end of the file name. In addition to the files as downloaded from the instruments, there are complimentary files in a human readable, comma separated value file format with the extension “.csv” at the end of the file name. Further information can be found on the manufacturer's websites, and in their software that can be downloaded from those websites. (https://www.solinst.com/, http://www.onsetcomp.com)

All of these files have file names constructed of the serial number of the instrument, the station name, and the beginning and end dates of the data in the file. To this is attached the extension based on the file type, as listed above. For example, the data for the Solinst Levelogger LTC Junior logger for the 70s Marsh in the winter of 2011-2012 has a file name of "1061924 70s Marsh 2011_12_08 to 2012_02_01.xle." A few files include an additional note in the file name that explains anything out-of-the-ordinary about the file. For example, on a few occasions loggers started with an incorrect, or default, time and date as opposed to the actual time and date. An example of a file name for such a file is "10710619 70s Marsh Cond 2019_12_02 to 2020_03_26 LOG DATES OFF.hobo" indicating that the log dates in the file are incorrect. The correct dates and times can be deduced from preceding and subsequent logs, or field notes from the download visit. The results of such deductions can be found in the spreadsheet for a station. Further explanations about such notes in file names can be found in the station spreadsheets under the "Notes" tab.

In addition to the raw data found in each station's folder, the raw data files are repeated in a folder named "Raw Data by Instrument Number." In this folder, there are 79 subfolders (see Figure 4.4). The subfolder names are the instrument serial number followed by the instrument type (LTC, U20Ti, U20L, U24S, U24F, or U26DO) and the names of the stations where it was deployed. The data files in these subfolders are the same as are found in the station folders. They are repeated with the instrument grouping to facilitate analysis of the data and performance of individual instruments, independent of the location of their deployment.

4.3 PHOTOS

Each station folder includes a "Photos" subfolder. These subfolders contain digital photographs of the station. The number of photographs varies from station to station. The image files include embedded metadata that gives the date the photo was taken. In some cases, the metadata also includes location information, depending on what device was used to take the photograph. Some stations did not last long enough to have photographs taken (i.e., Salmon River at 70s Marsh, Salmon River at Pixieland, and the original Salmon River at Knight Park).

The "Photos" subfolders also include a small number of videos taken at some stations.

5.0 WEATHER DATA

The intention was to collect continuous weather data for the 10-year duration of the project (the instrumentation used is described in section 2.4). However, there are data gaps at each of the stations. These are the result of equipment failure, or, perhaps on one or two occasions, human error. These data were always intended to be a supplement to the weather data collected at various other weather stations in the area.

5.1 PIXIELAND WEATHER STATION DATA

The Pixieland Weather Station was installed, and began collecting data, on March 7, 2012. Data gaps exist for the following periods:

- July 8, 2013 to October 10, 2013 (logger failure),
- May 21, 2014 to December 30, 2014 (data would not download following battery failure),
- August 5, 2019 to January 30, 2020 (data file is only readable to August 5, 2019)

The individual weather sensors at the Pixieland Weather Station all performed well, with the exception of the relative humidity sensor. This sensor began to malfunction in the fall of 2012 by recording unrealistically long periods of 100% humidity. By May of 2013 the readings seemed to be reasonable. Following the data gap in 2013, the long periods of 100% humidity returned and continued until the data gap of 2014. It is possible that these long periods of 100% humidity are correct, but the absence of similarly long periods following the installation of the new sensor in 2017 casts doubt on that. Following the data gap of 2014, the long periods of 100% humidity continued through the summer of 2015. These values are clearly not believable. Through the winter of 2015-2016 the values are predominantly 100%. Moving into the spring the values are predominantly 0% or 100%. By April of 2016, the readings were exclusively 0% or 100%. On July 20, 2017, a new combination temperature and relative humidity sensor was installed. This new sensor performed without any apparent problems until the end of the project, four years later.

5.2 HIGHLANDS WEATHER STATION DATA

The Highlands Weather Station was installed, and began collecting data, on April 29, 2013. The installation occurred much later than for the Pixieland station because the permitting process for areas within the Cascade Head Experimental Forest is much more complicated, and the fact that it was a separate process was not discovered until the Pixieland permit was nearly complete. Data gaps exist for the following time periods:

- December 4, 2014 to December 30, 2014 (logger memory filled)

- January 26, 2015 to July 22, 2015 (Wind sensor failure triggered logger failure)
- February 13, 2017 to March 1, 2017 (logger memory filled)
- March 18, 2018 to April 4, 2018 (logger memory filled)
- April 13, 2018 to June 18, 2018 (Download produced a corrupted file)

While the relative humidity sensor for the Highlands Weather station also had long periods of 100% humidity in the winter months, there are longer periods of <100% humidity than were seen at Pixieland. Following the 2015 data gap, the relative humidity sensor began to have numerous readings of -888.88%. This was replaced by predominantly readings of 100% in the winter of 2015-2016 with only brief periods with values slightly below 100%. In the spring of 2016, the relative humidity reading became exclusively either 0% or 100%. In the spring of 2017 this was replaced with a constant reading of -888.88%. During the period May 24, 2017 to July 20, 2017 the relative humidity sensor was not connected to the logger. A new relative humidity sensor was in installed on July 20, 2017. During the fall of 2017 and winter 2017-2018, there were extended periods of 100% humidity, but again these were combined with extended periods of values less than 100%. In February of 2018 there was a three-day period where the relative humidity was reading -888.88. In spring 2018 jumps from 100% humidity to 0% humidity began to appear. Following the bigger data gap of 2018, the relative humidity data seemed to be normal. In the fall of 2018, long periods of 100% humidity returned, again paired with long periods of <100% humidity. Data through the winter into the spring appears credible. In fall of 2019, the humidity value plunge down to being long periods of 0% humidity with interspersed periods of >0% humidity. In January, the values climb back up to realistic values that did not drop to 0%. For the rest of the winter and into early spring 2020 the relative humidity values look plausible. Late spring into summer 2020 has long periods of 100% humidity, but the summer data transitions to data that looks more normal, although with too much 100% humidity for summertime. Fall 2020 to spring 2021 again has long periods of 100% humidity interspersed with periods of <100% humidity.

Other sensors at Highlands Weather Station also had problems. The wind sensor, which combined the speed and direction in a single unit, failed. This failure also brought the logger down with it. The logger restarted just fine at the next download, but the wind sensor stayed dead.

The temperature sensor (combined with relative humidity) began giving intermittent readings of -888.88 following the failure of the wind sensor. However, most of the readings appeared to be fine and the -888.88 readings became less frequent over time in 2015. In 2016 the readings of -888.88 became dominant to the point of being exclusively -888.88.

In January of 2017, the barometric pressure sensor switched to all values of -888.88. Thus, by the data download visit in March of 2017, the only sensors operating correctly at the Highlands Weather Station were the PAR sensor and the rain gauge, with the latter being regularly compromised by the abundant falling debris from the surrounding trees.

In July of 2017 a new barometer, in addition to the new thermometer/relative humidity sensor mentioned above, was installed. The process of installing these new sensors resulted in the old barometer beginning to work properly too. Later, in August of 2017 a new, combination anemometer and wind direction sensor was installed too. Problems soon reappeared. In addition to the relative humidity issues already discussed, the new wind sensor began reading -888.88 on February 22, 2018, and that was the last data recorded from it. The older barometer and rain gauge recorded -888.88 for much of two days in April 2018. Some sort of data logger problem caused a download to give unreadable data from April 13 to June 18, 2018. On May 9th, the older barometer again started reading -888.88 until the next download. It resumed reading following the download on July 8, 2019. The last rain that the rain gauge recorded was on January 7, 2020. When all the weather sensors were bench tested at the end of the project, the rain gauge was not recording any data when the tipping bucket would tip. On June 22, 2020, the old barometer returned to reading -888.88 until the next download. The old barometer, having resumed following the download on September 22, 2020, returned to -888.88 on November 14, 2020. The pattern repeated and the old barometer returned at the March 17, 2021, download only to go back to -888.88 on May 29,2021. The old barometer worked without incident or problem during the end-of-project bench testing.

6.0 WATER DATA

6.1 BAROMETRIC PRESSURE CORRECTION

The barometric pressure correction is key to being able to extract meaningful data from records of absolute water pressure from the water level loggers used for this project. At the very beginning of data collection on September 8, 2011, the Barologgers were not yet installed. Therefore, barometric pressure from the weather station associated with the South Beach tide gauge at Newport, Oregon was used. On September 29, 2011, the Barologger at Rowdy Creek Culvert was installed. By the end of the project, there were 7 sensors recording barometric pressure. With many sources of the same measurement, the problem of which to treat as the reference presented itself. Based on an assessment of all the data sources, how continuous their data was and how their values compared to one another, it was decided to use the Pixieland Barologger as the primary barometric pressure source. During data gaps in the Pixieland Barologger's record, the Rowdy Creek Culvert Barologger was used, with correction of -0.0009 m for the average difference between the readings of the two during the period April 11, 2012 to December 7, 2013. This is a trivial correction, given the accuracy of the instruments and the other sources of error. The Rowdy Creek Culvert Barologger had a step change in its values on December 7, 2013. The cause is unknown. Following this data step, when the Rowdy Creek Culvert Barologger values were used, they were adjusted by Equation 4-1.

This equation corrects for the observed drift between the two devices over the period from December 7, 2013 through June 30, 2021. On December 7, 2013, this correction was .0100 m, slightly more than the amplitude of the step. On June 30, 2021, this correction was -.0025 m. Relative drift of just over 1 cm over a period of more than 7 years. On the one occasion when data from both the Pixieland and Rowdy Creek Culvert Barologgers were missing, the internal barometer in the Pixieland Weather Station was used. This only occurred when a download-equipment malfunction prompted bringing the Barologgers back from deployment from March 17, 2021 to April 6, 2021. All the raw barometric data download files are provided. Thus, the barometric correction can be repeated by any desired, alternative approach.

Figure 6.1 is a plot of the barometric pressure correction used for the entire duration of the project. The barometric pressure recordings are gathered together in the spreadsheet named "Barometric Pressure Data—Combined.xlsx." This figure illustrates that the influence of the variation in atmospheric pressure is equivalent to over 0.5 meters of water level variation. Figure 6.2 shows just one week of this same data. Together these figures demonstrate that the changes to barometric pressure occur over a broad range of time scales.

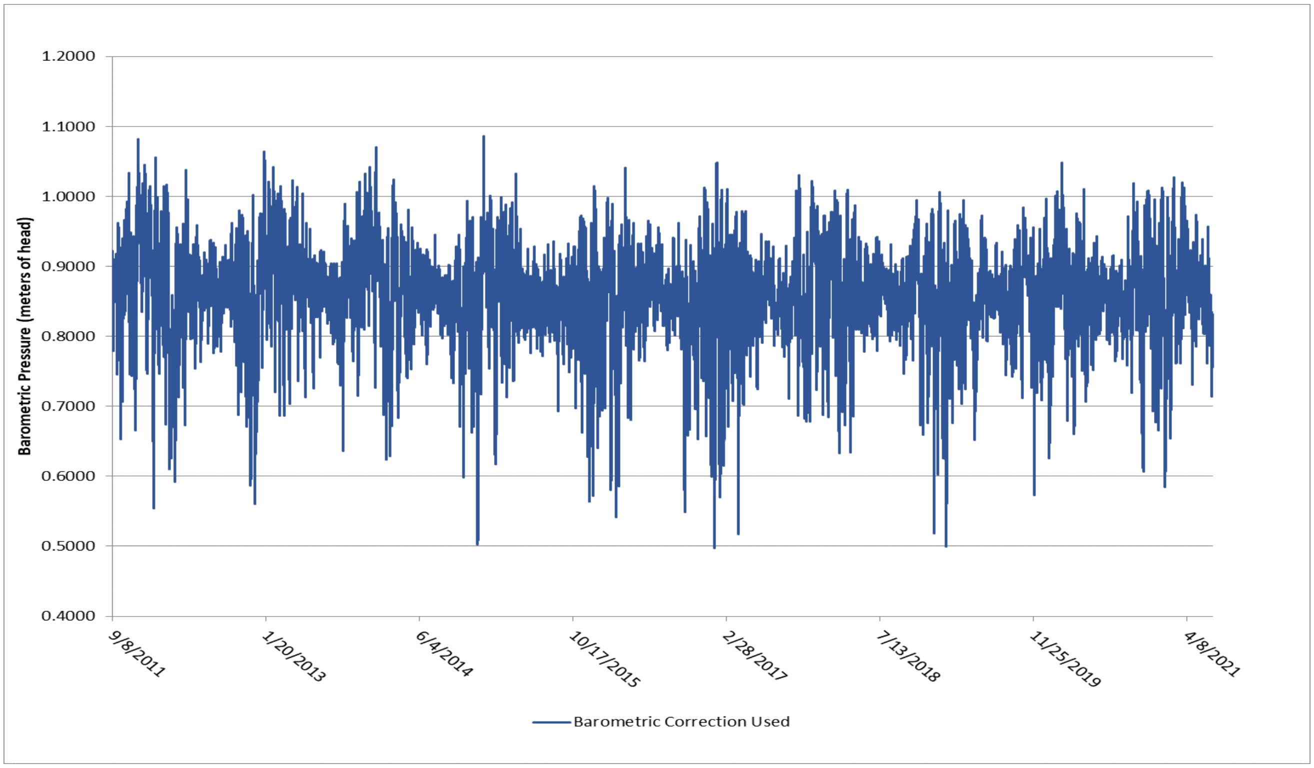


Figure 6.1: Plot of the barometric pressure correction that was used to convert absolute pressures to water elevations. This plot covers the entire duration of water level data collection.

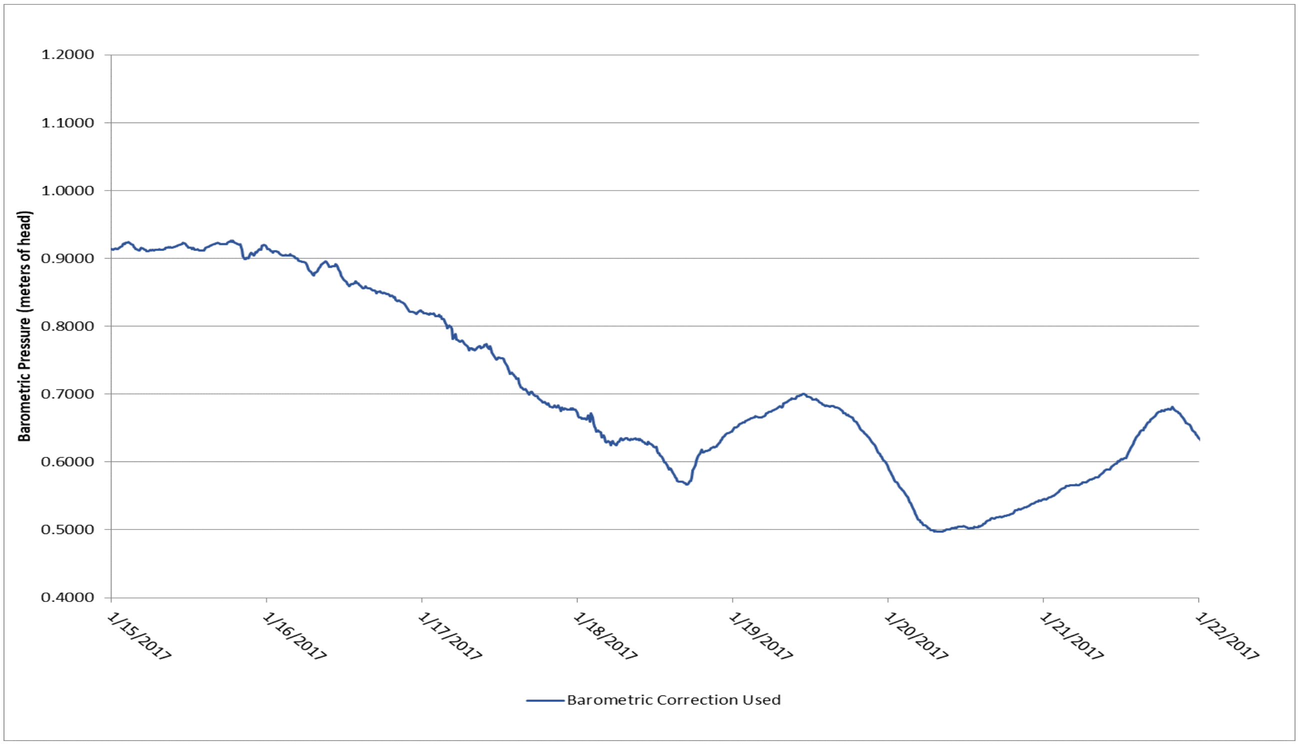


Figure 6.2: Plot of barometric pressure correction used. This plot shows data of one week.

Figure 6.3 is a plot of a week's worth of barometric pressure data from all seven sensors deployed during the project. This graph shows that the sensors track each other well, but that there are small variations between them. The data from the Highlands Weather Station is shifted because the station is located at a higher elevation (~237 m above sea level) than the other sensors, which are within a few meters of sea level. Both the Pixieland and Highlands external barometers consistently gave higher readings than their internal companions did. The lesser difference between the Pixieland Barologger and the Rowdy Creek Culvert Barologger is also shown. Likewise, the difference between the two Barologgers and the 4m U20L is shown.

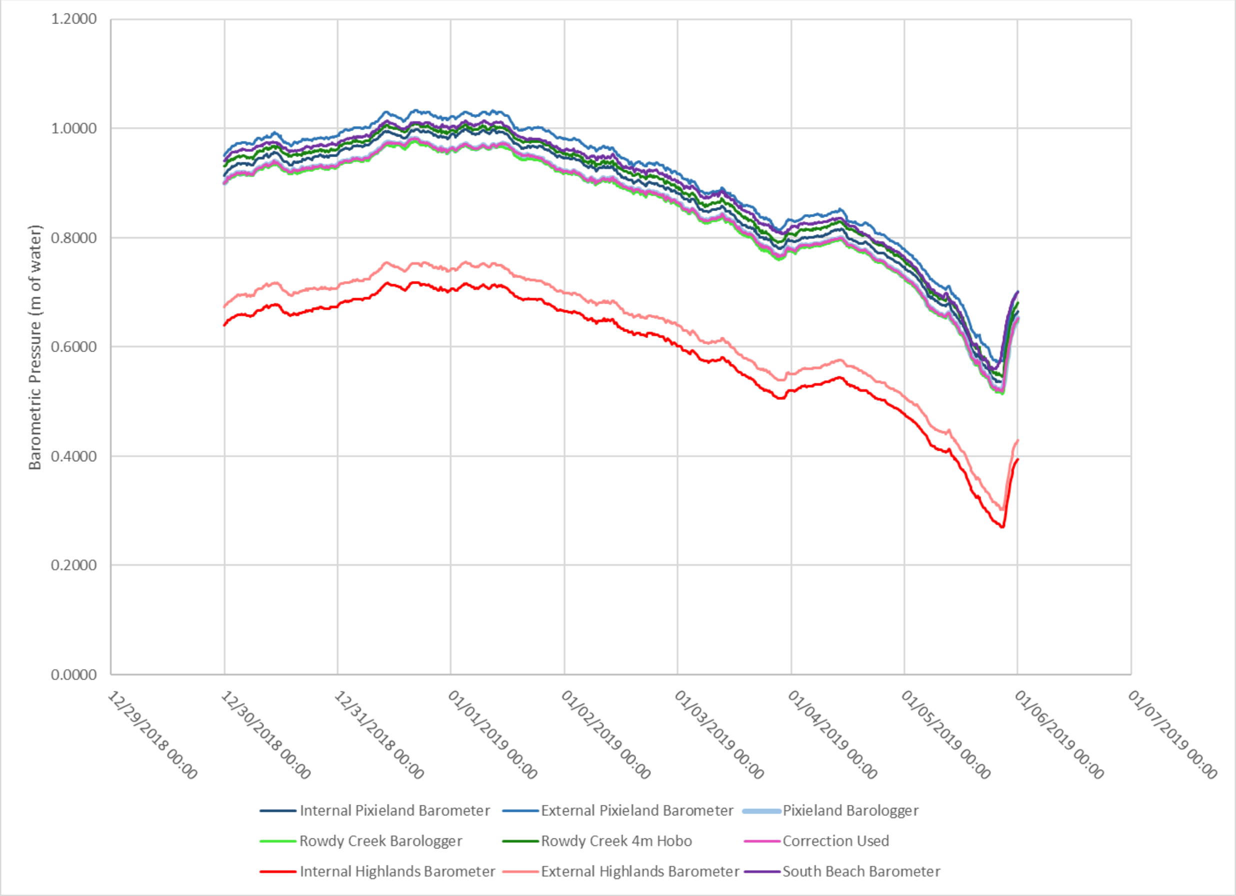


Figure 6.3: Plot of barometric pressure readings for all instruments. This plot shows data for one week. The Highlands Weather Station pressures are lower due to the elevation difference. The barometer readings from the weather station at the South Beach tide gauge are included for comparison.

Figure 6.4 shows one month of data for the two Barologgers, combined with a plot of the difference between the two (using the right-hand vertical axis). While the two Barologgers closely track one another, there is variation in the difference between the two. The difference is less than 1 cm, but more than the stated accuracy of 0.1 cm. It also shows that there is a periodicity to this difference.

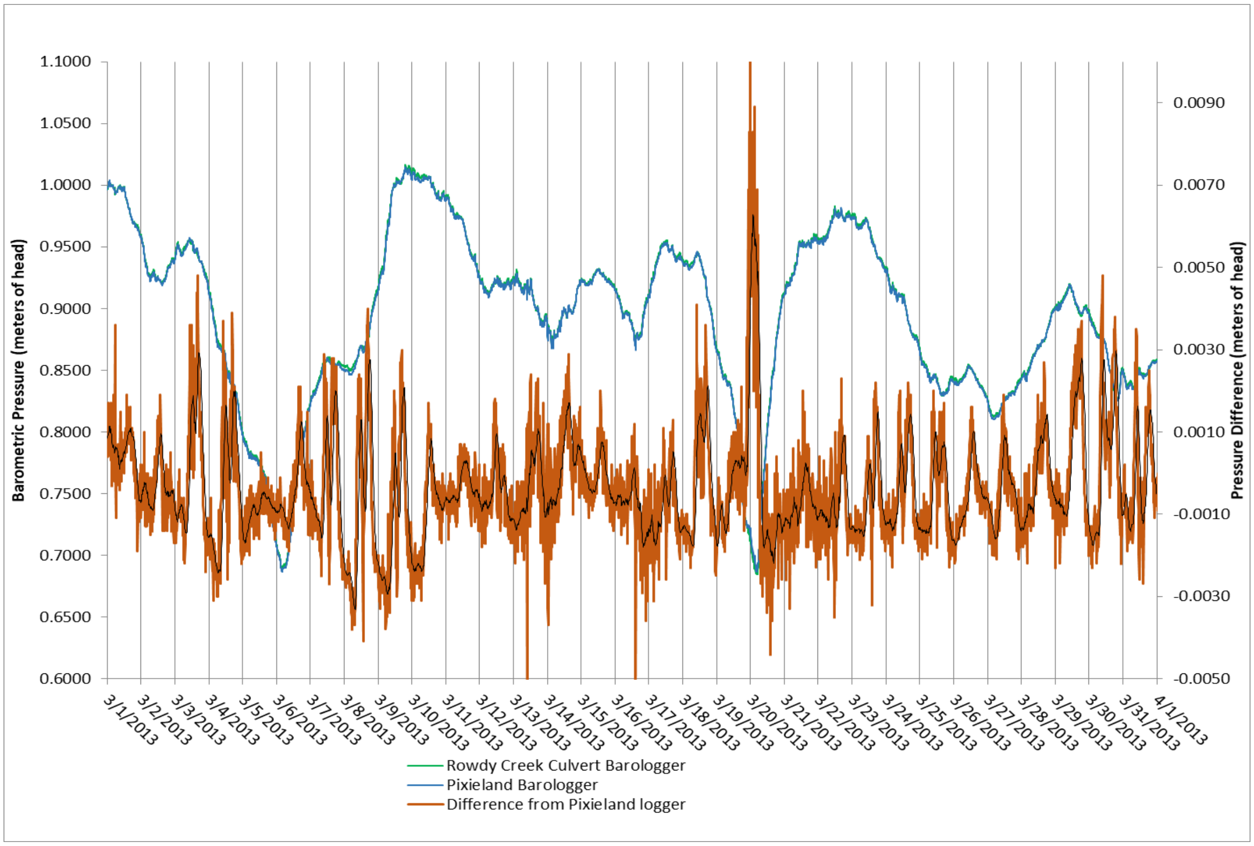


Figure 6.4: Plot of Pixieland Barologger and Rowdy Creek Culvert Barologger data for one month with a plot of the difference between the two instrument's readings (the black line is a running average of the difference).

Figure 6.5 adds the temperatures recorded by the Barologgers to the difference data in Figure 6.4. This shows the correlation between the periodicity of the difference between the two Barologgers and temperature. The main driver of the temperature difference during this month of data is the diurnal variation in temperature with the highest temperature occurring in the afternoon of each day. Figure 6.6 is a graph of 8 days of this same data.

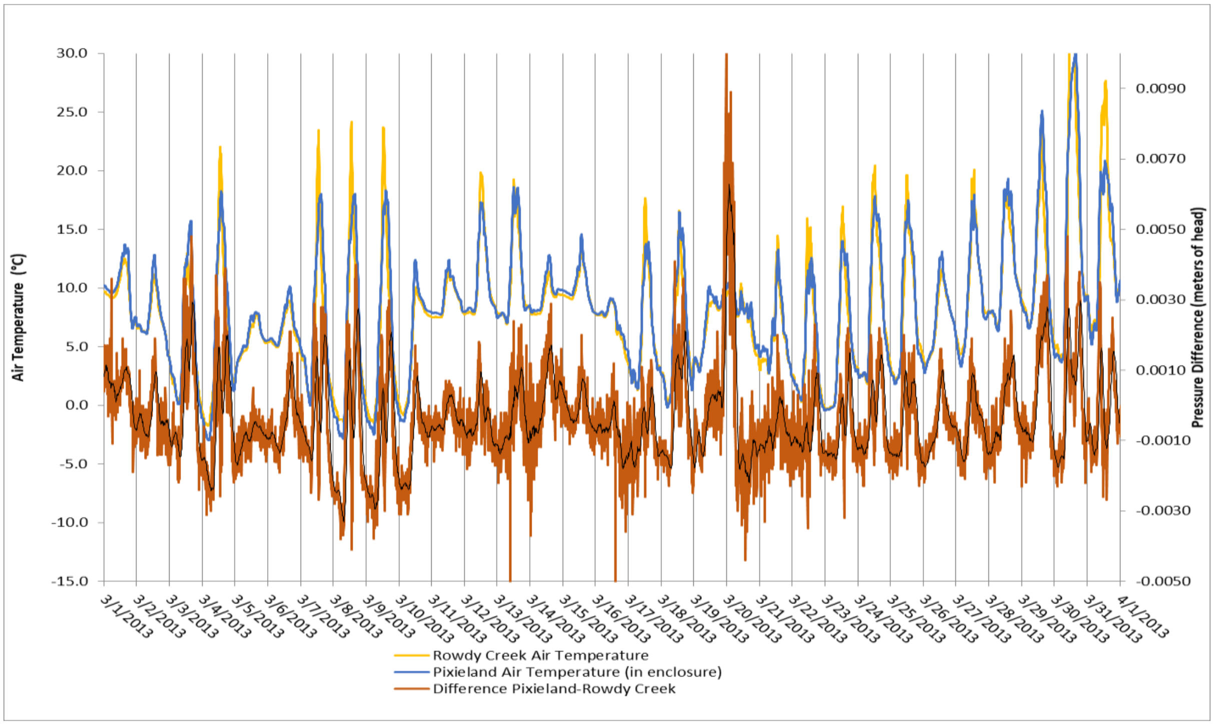


Figure 6.5: Plot showing a correlation between the temperatures recorded by the Barologgers and the pressure difference between the two Barologgers.

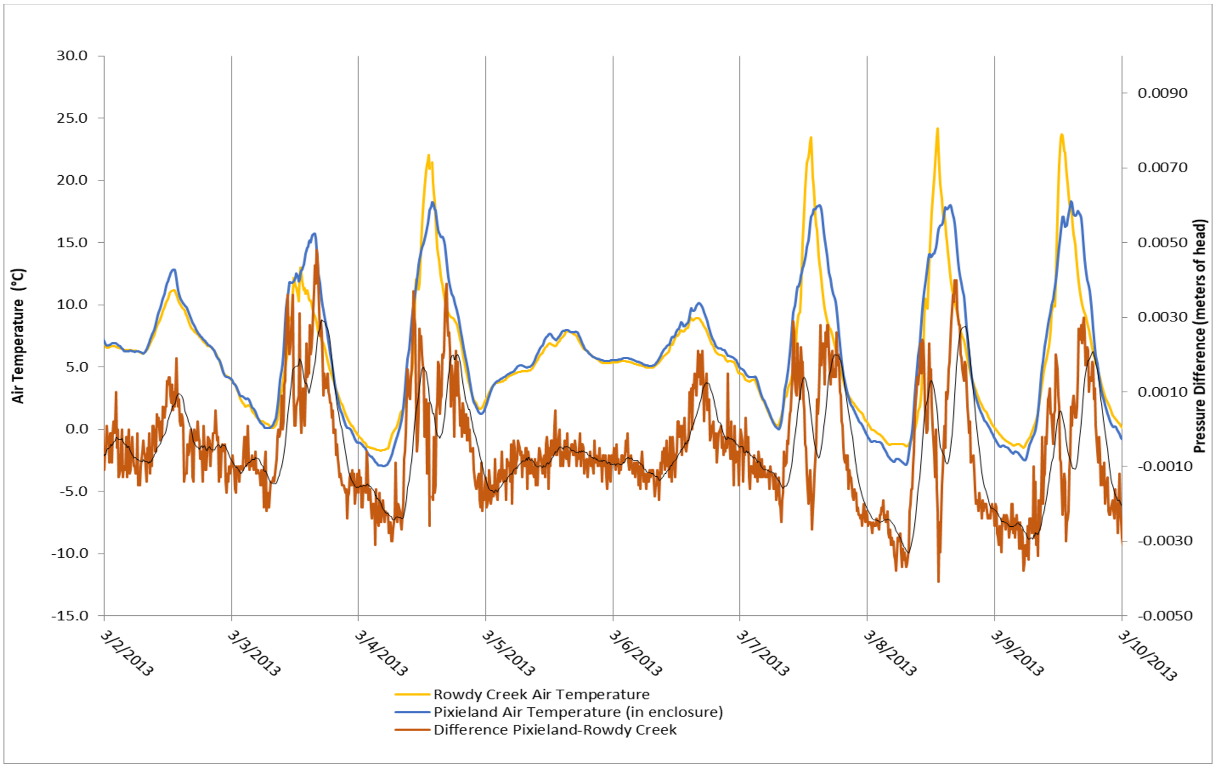


Figure 6.6: Plot of eight days of data showing diurnal temperature cycle's effect on difference in pressure measured by two Barologgers

At the end of the project, all seven barometric pressure devices were run sitting side-by-side on a workbench for 24 hours. Figure 6.7 shows the results of this comparison. Unfortunately, the Pixieland internal barometer sensor was bumped, and this caused it to fall onto its side (having been set in the position it had while deployed). The effect of this abrupt change in orientation can be seen in the graph. The graph shows that the absolute pressure readings for the seven sensors differs by a few centimeters of water column, but the difference remains relatively steady over the 24-hour period with the exception of the Pixieland internal barometer for the reason explained. The 4m U20L logger is grouped in between the two external barometers while the two internal barometers group with the two Barologgers. In the graph, the two Barologgers and the 4m U20L were left logging for more than the 24 hours to use for correcting the level logger calibrations that will be discussed later in this report.

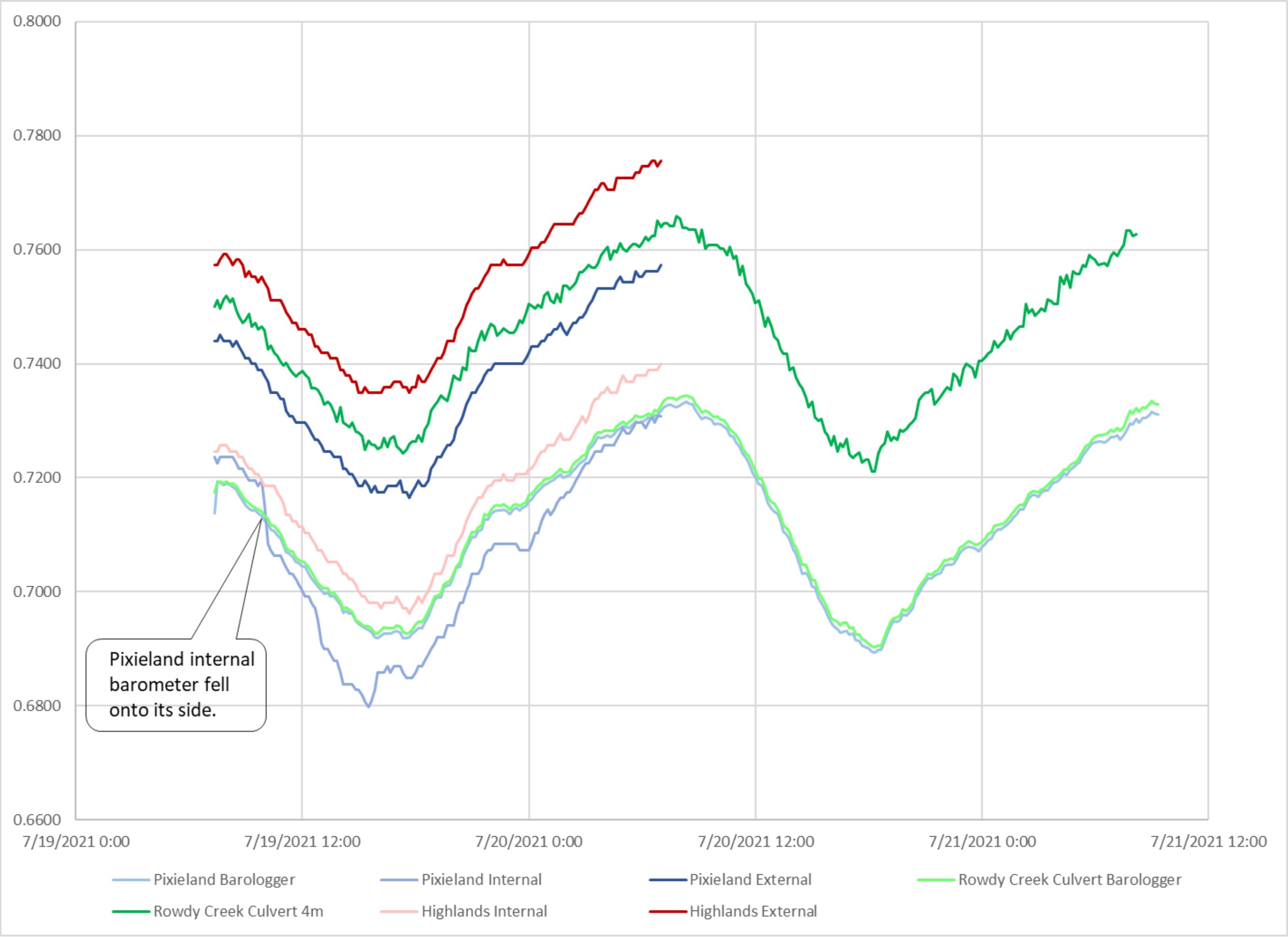


Figure 6.7: Comparison of side-by-side readings at conclusion of project

The difference between the two Barologgers and the 4m U20L bears further exploration, because the water level logging instrumentation was switched from Leveloggers to U20 series instruments during the project. Figure 6.8 shows a plot of the difference between the Rowdy Creek Barologger and the 4m U20L during the first week the U20L was deployed. These two loggers were located less than 1 meter horizontally apart and at essentially the same elevation. The 4m U20L consistently read about 3 cm higher that the Barologger.

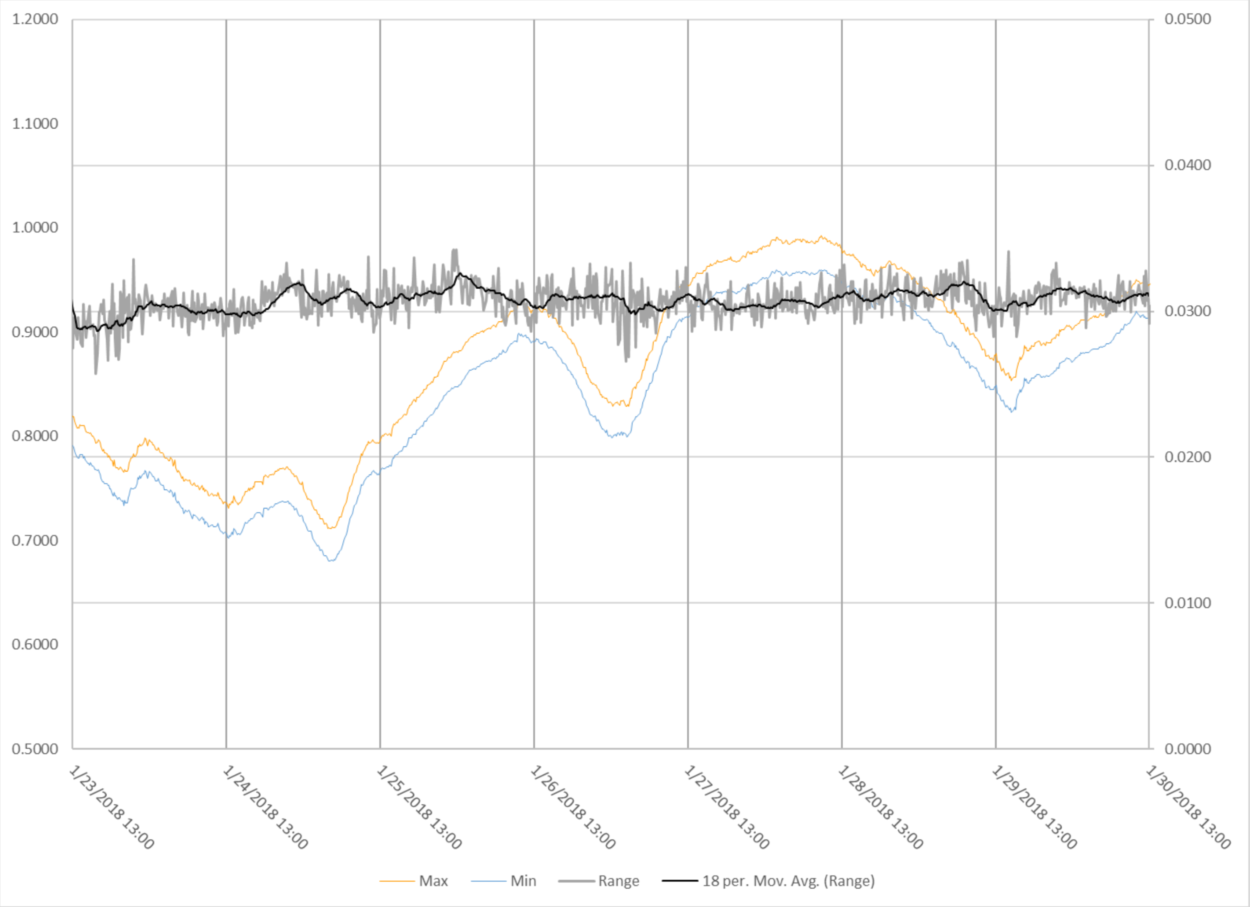


Figure 6.8: Difference between Rowdy Creek Barologger and 4m Hobo U20L, first week of deployment of U20L.

While the several barometric pressure sensors can be compared to one another, the "true" pressure value is unknown. The unequal times of deployment further complicate comparisons. Figure 6.9, Figure 6.10, Figure 6.11, Figure 6.12, Figure 6.13, Figure 6.14, and Figure 6.15 are plots of each of the various barometric pressure sensors' data recorded during the project. Also shown are linear regression trend lines fitted to the data. The equations of the trend lines are shown on the graphs. Since barometric pressure is constantly varying at many different time scales, it should not be expected that data in any given time window would have no trend. The longer the time window, the more variations will be canceled out, but it is possible that there were slight trends in "true" barometric pressure over the various durations of deployment. Thus, these trend lines should be considered as apparent drift and not absolute drift. The coefficient (slope of the line) corresponds to the apparent drift rate in meters per day because Excel assigns date and time values as a count of days since 1900, with January 1, 1900, 0:00 being 1.0. The constant (intercept of the line) is meaningless, because the zero it corresponds to is the arbitrary December 31, 1899, 0:00.

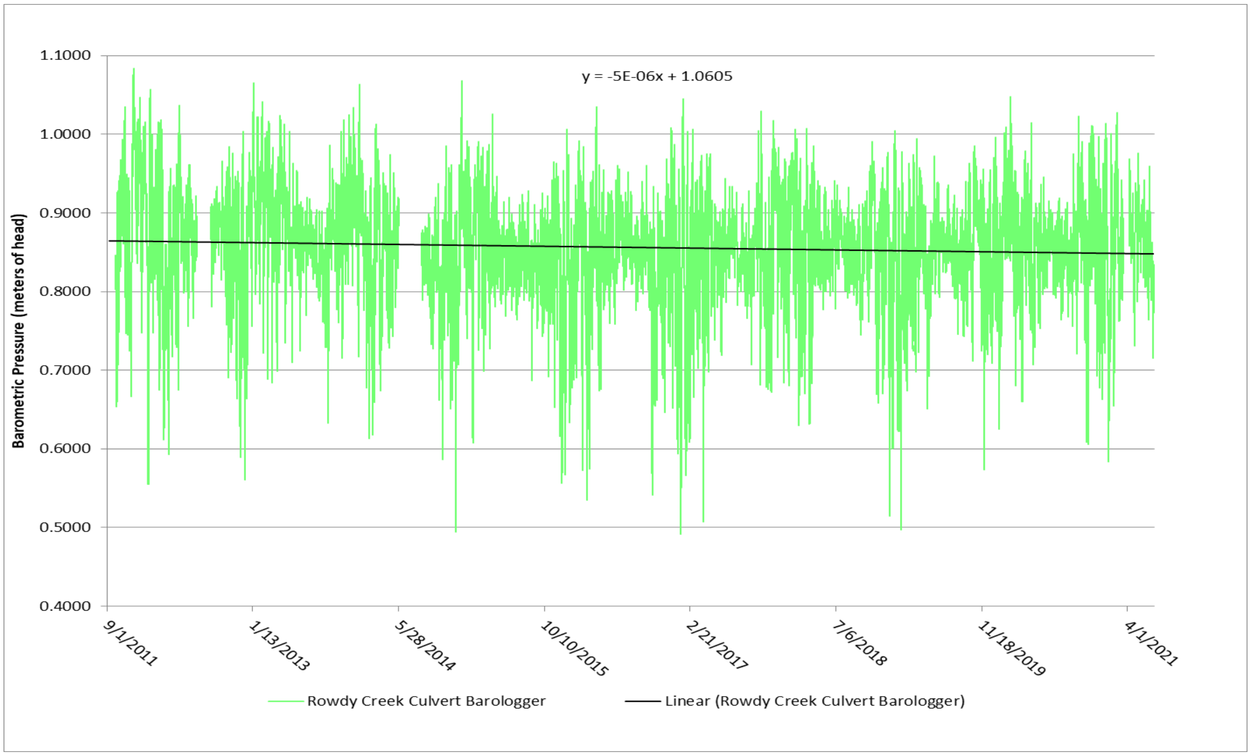


Figure 6.9: Rowdy Creek Culvert Barologger Drift

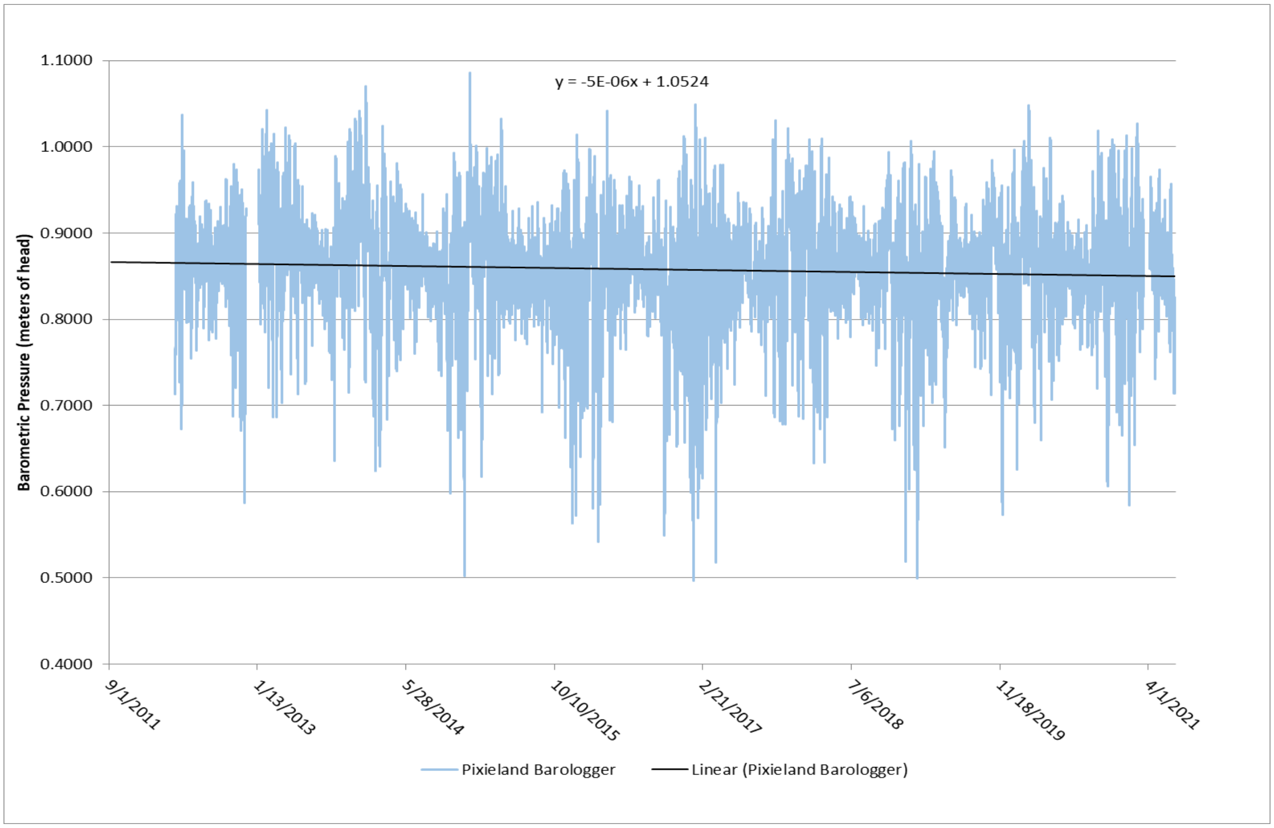


Figure 6.10: Pixieland Barologger Drift

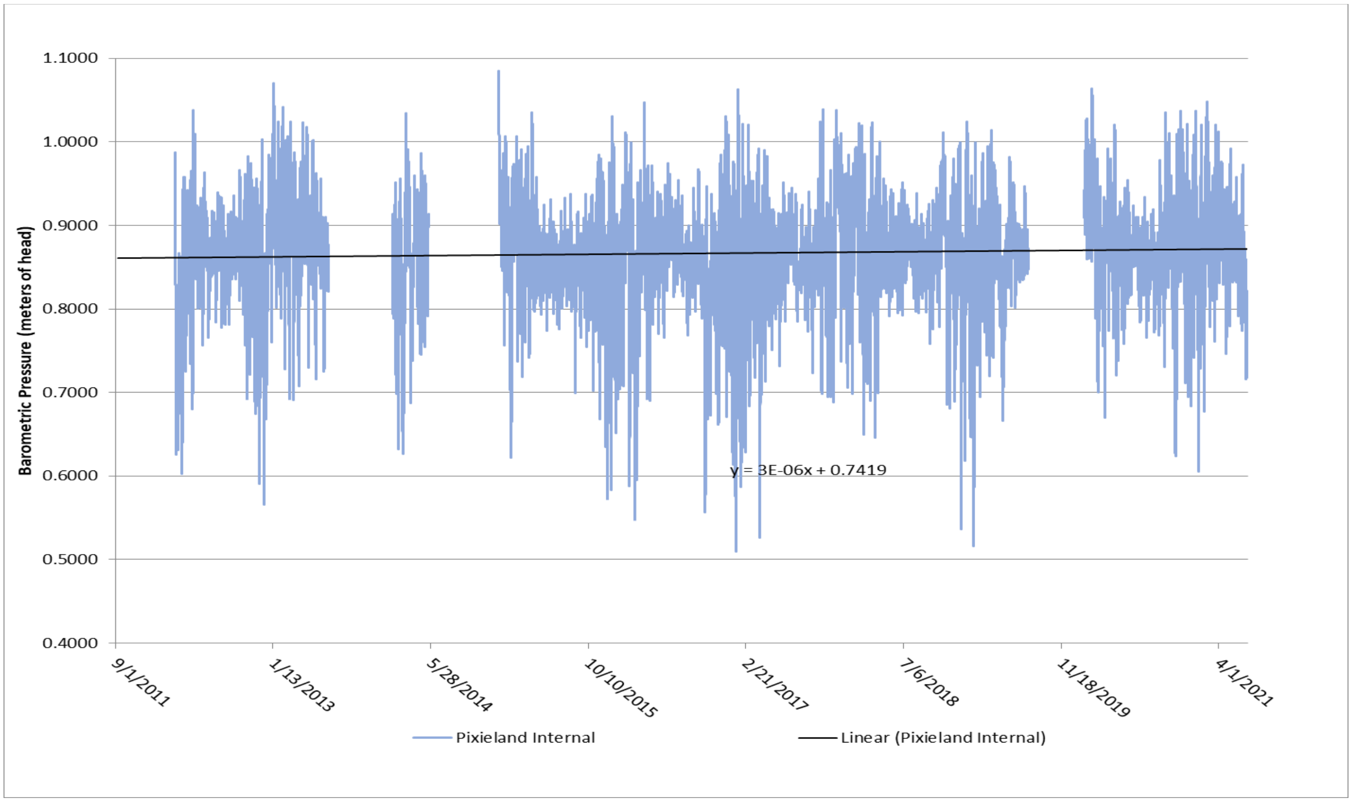


Figure 6.11: Pixieland Internal Barometer Drift

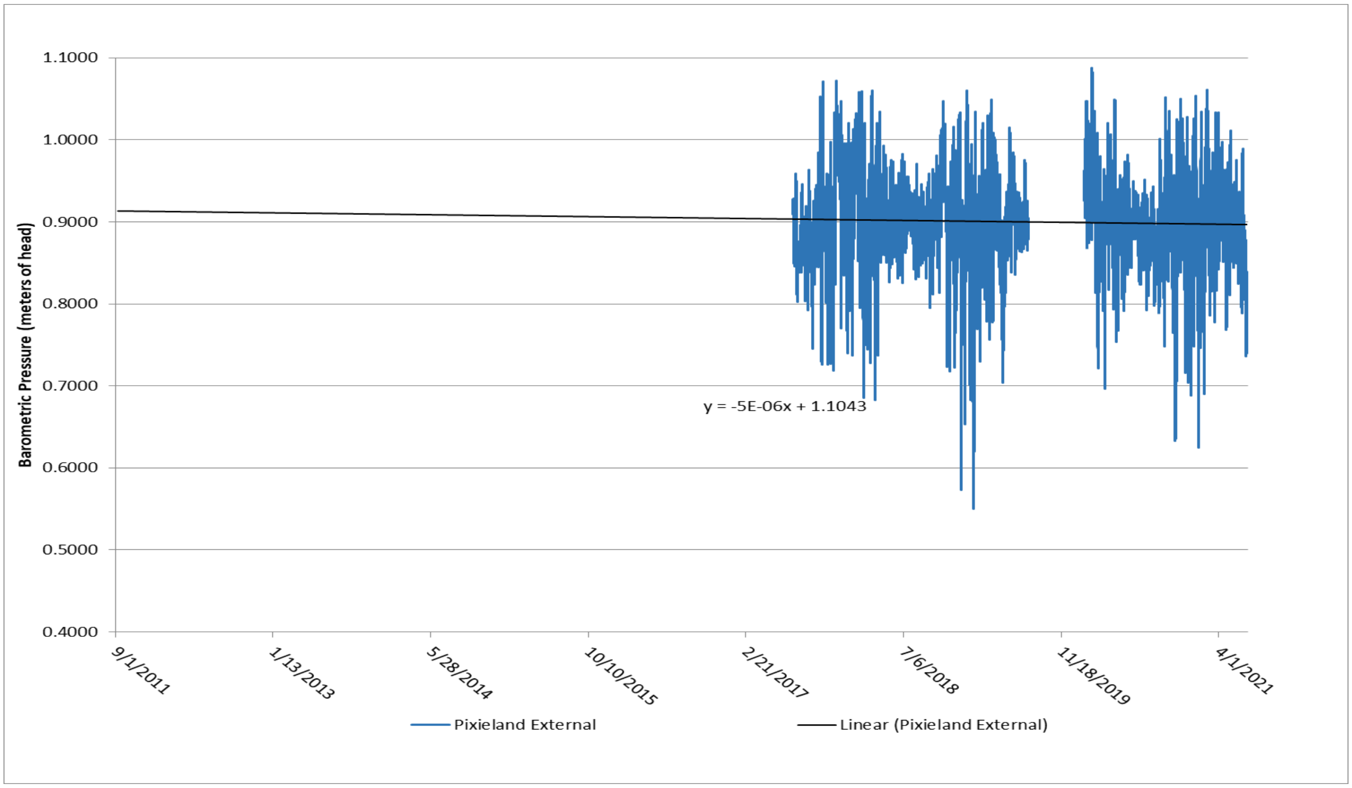


Figure 6.12: Pixieland External Barometer Drift

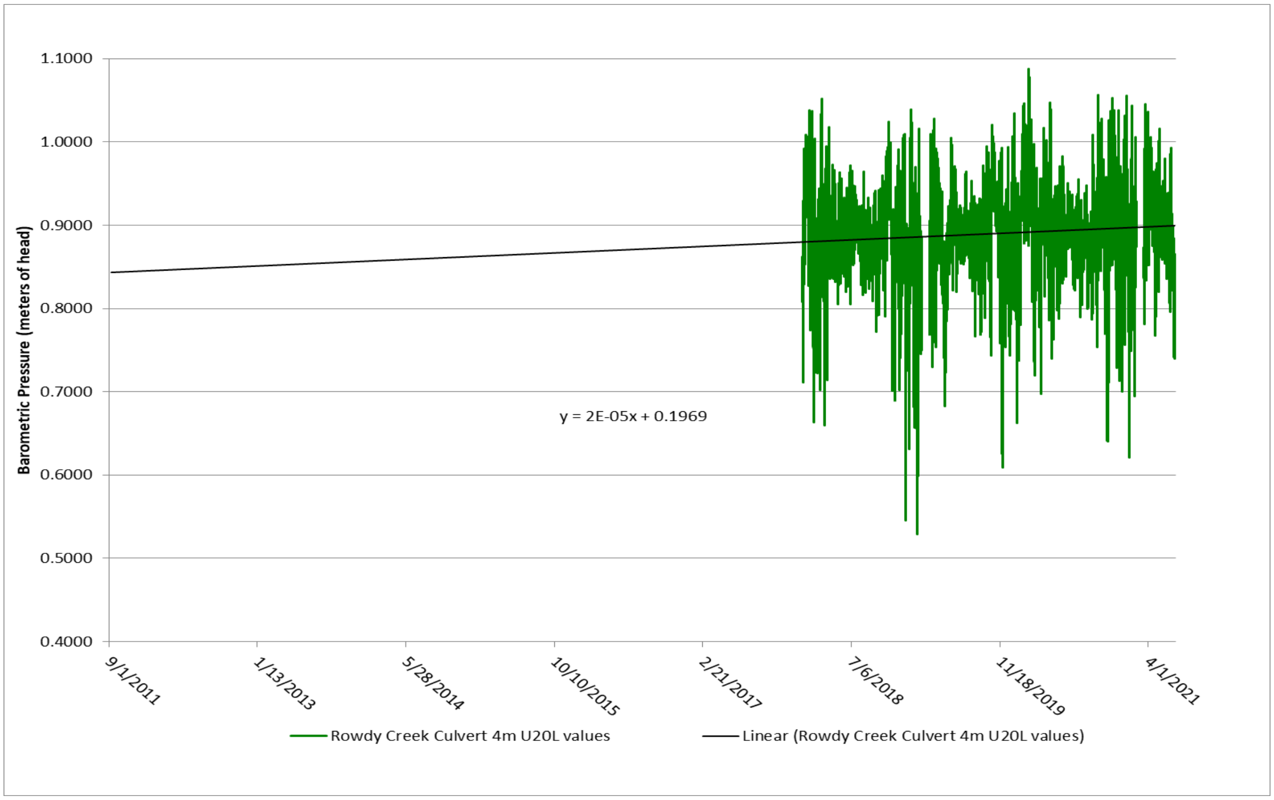


Figure 6.13: Rowdy Creek Culvert 4m U20L Drift

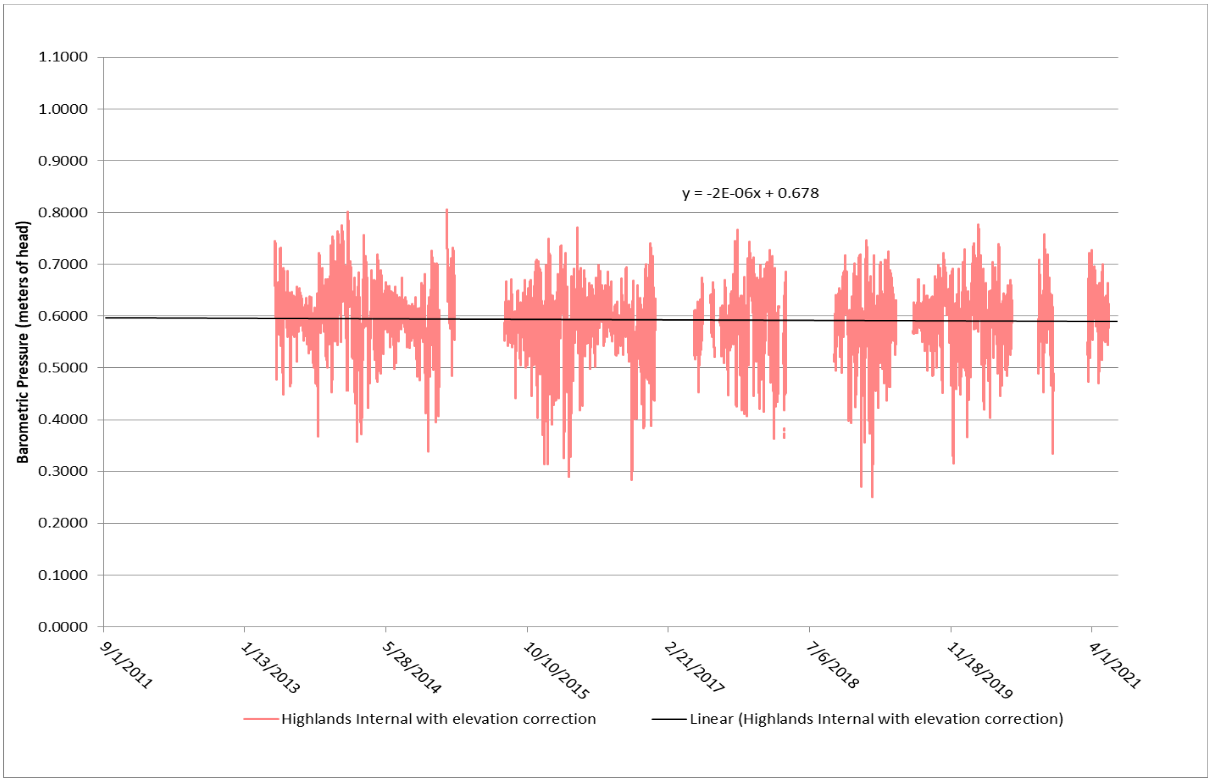


Figure 6.14: Highlands Internal Barometer Drift

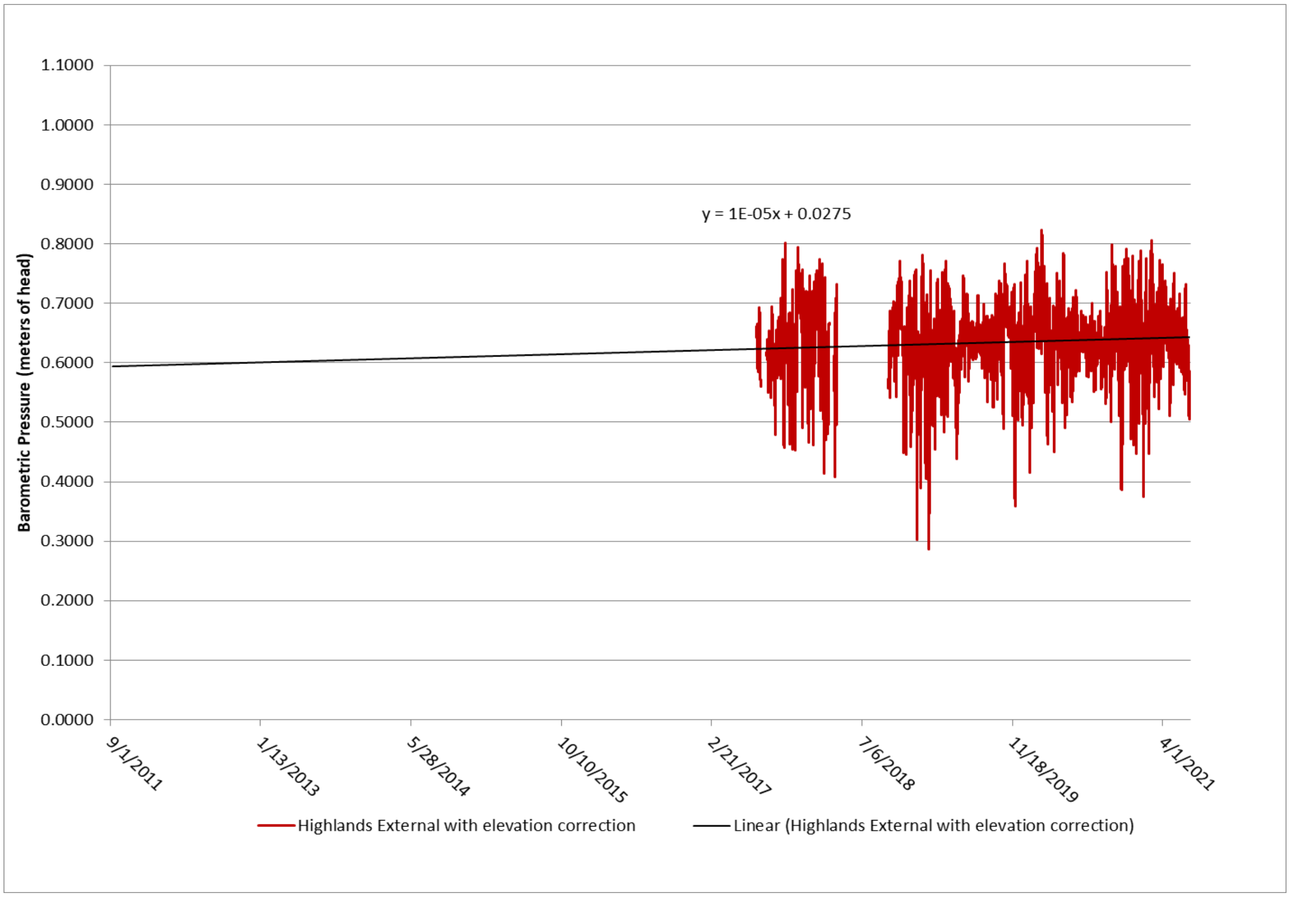


Figure 6.15: Highlands External Barometer Drift

Table 6.1 is a tabulation of the apparent drift values for all the sensors with the deployment dates and durations. In all cases, the apparent drift rate is less than 1 cm per year. The two Barologgers have apparent drift of less than 2 cm over the nearly 10 years of this project. The magnitude of drift is small when compared to the variation in the difference between the various sensors. The two sensors with the greatest apparent drift are also two with the shortest period of deployment (3.4 years and just under 4 years). Future analysis of this data might include looking at apparent drift for the sensors over matching time intervals without data gaps.

Table 6.1: Apparent Drift Data for the Barometric Pressure Sensors

Sensor Name	Apparent Drift Rate (cm/year)	Duration of Deployment (days)	Beginning Date of Deployment	Ending Date of Deployment
Rowdy Creek Culvert Barologger	-0.175	3562	Sept. 29, 2011	June 30,2021
Pixieland Barologger	-0.166	3367	April 11, 2012	June 30, 2021
Pixieland Internal Barometer	+0.107	3402	March 7, 2012	June 30, 2021
Highlands Internal Barometer	-0.073	2952	April 29, 2013	May 29, 2021 (last data)
Pixieland External Barometer	-0.171	1441	July 20, 2017	June 30, 2021
Highlands External Barometer	+0.507	1441	July 20, 2017	June 30, 2021
Rowdy Creek Culvert 4m U20L	+0.577	1254	Jan. 23, 2018	June 30, 2021

6.2 WATER LEVEL DATA

The water level data for the 20 stations for which data was recorded each have a folder that contains the data and other information about the station. The raw data files in the proprietary format of the manufactures are provided. These can be opened with Solinst Levelogger software or Onset's HOBOware software. The Solinst *.xle file format seems to be a slight variation on an XLM format and can be opened with Excel. The raw download data in Onset's proprietary, closed *.hobo file format can only be opened with Onset's HOBOware software. In addition, for each of these download files there is an exported file in Comma Separated Value (*.CSV), human-readable, ASCII text file format. These files can be opened in a spreadsheet for analysis or imported into other programs. The data for all downloads from each station have been merged together into a single Excel spreadsheet file for each station. The spreadsheet files include notes regarding the data collection and maintenance of the stations. They also have water level data that has been processed from absolute pressure readings to elevation readings using information about barometric pressure and the elevation of the level logger sensor. These processed data have *not* been corrected for the variability of the water density due to varying salinity. This is a further refinement that remains to be done. While some of the stations have GPS measurements of the elevations of the caps on the PVC pipe at the station, other stations have been corrected to a sea level datum elevation using the relative water elevation during prolonged high-water periods when the estuary becomes a standing pond of water with its own approximation of a potentiometric surface.

Numerous factors affect the accuracy, precision, completeness, and quality of the water level data.

- Corrosion
- Logger failures
- Delays in visiting stations for downloads or redeployment
- Driftwood
- Sediment/debris accumulation (both inside the pipes and in the perforation holes)

One important factor is that corrosion of the pressure transducer can affect the calibration of the sensor. This is based on the manufacturer reporting that several of the LTC Levelogger Juniors that were sent in for repair needed new pressure transducers due to corrosion. It is also based on observations of the pressure transducers on failed loggers that were not sent in for repair. Because the LTC Levelogger Juniors all died during the project, they were not available for the end of project calibration test that was done on the surviving U20 series level loggers at the end of the project. The same is true for the few U20 series level loggers that died before the end of the project.

Some stations had obvious problems produced by either corrosion or a similar instrument problem. An example of this is the LTC Levelogger Junior data from the Rowdy Creek Downstream station. Figure 6.16 shows the data recorded at Rowdy Creek Downstream for the period September 2011 through December 2013. In 2011 and January 2012, the level regularly drops to ~-2.0 m, relative to the station cap, at low tide. Beginning around February 2012, the minimum level recorded begins a steady rise until July of 2012 when the minimum values observed never drop below -0.5m. All loggers were removed from the field for cleaning and calibration in July of 2012, and the Rowdy Creek Downstream logger was not reinstalled until October of 2012. (Relocation of the ODOT Research Section offices delayed reinstallation longer than originally intended.) It can be seen that the readings of atmospheric pressure had dropped considerably, but not down to corresponding to the barometric pressure logger readings. The calibration done during the summer was for the conductivity sensor, the manufacturer stating that the factory pressure calibration was permanent. During the continued deployment, the steady increase in the readings at atmospheric pressure resumed and continued until the logger failed. The replacement logger did not exhibit this same drift during the 7 months it was operating at this station. Corrosion is the preferred hypothesis for this because representatives of the manufacturer reported that the pressure transducers for several failed LTC Levelogger Juniors were corroded and would need to be replaced as part of rehabilitating the level logger. Other causes are possible. For example, the level loggers inside the PVC tended to attract numerous copepods that crawled into the openings that lead to the pressure transducer. It is possible that growing populations of these copepods' gradual exerted more and more gentle pressure on the pressure transducer. This is less likely because of the linear nature of the drift. To try to protect the loggers from aquatic life, we began sliding nylon stockings over the entire instrument and secured the stocking to the line suspending the instrument with a plastic clip.

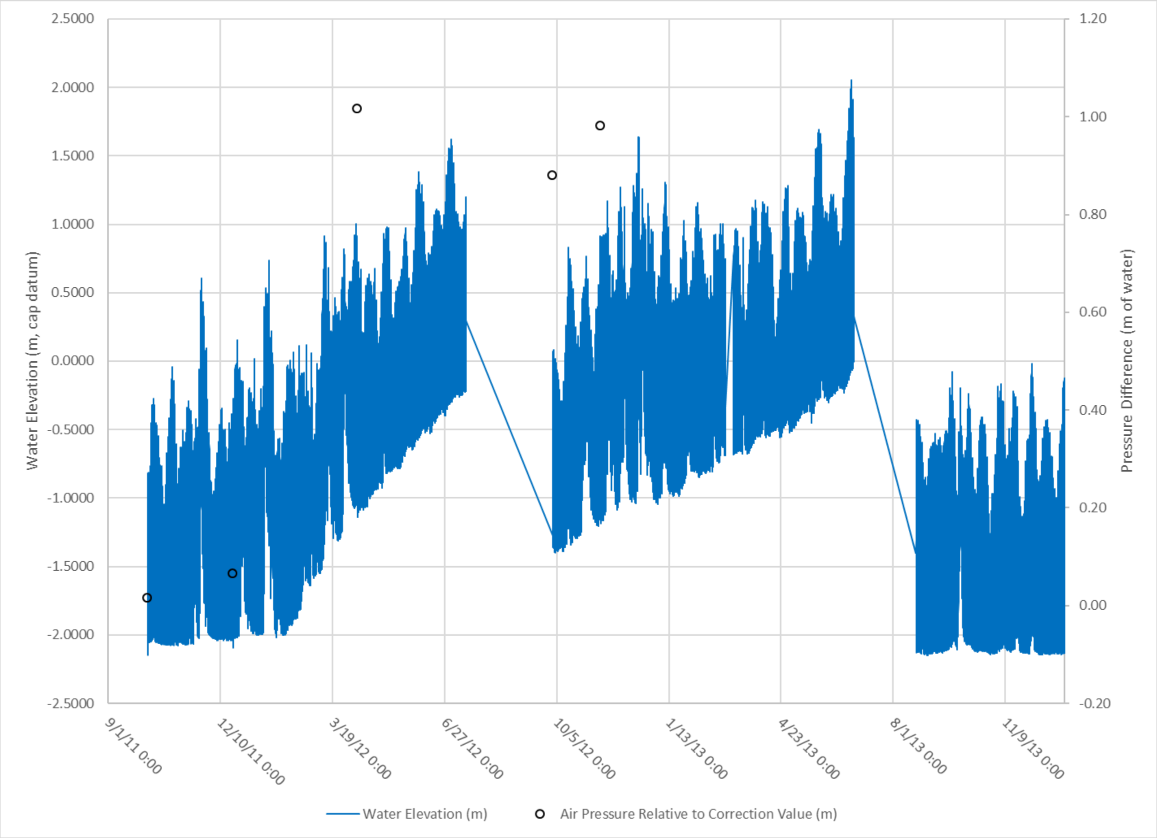


Figure 6.16: Graph of the Rowdy Creek Downstream water level data from 2011-2013, with barometric pressure compensation, showing data drift beginning in February 2012.

The U20L level logger installed at the Rowdy Creek Upstream station experienced odd data jumps at the time of almost every download from November of 2016 on. There was only one instance where there was not some sort of jump when the logger had not filled before the download (and thus made it impossible to detect a jump). While adjustments for these jumps can be applied, it is uncertain what the cause of the jumps is. The currents in Rowdy Creek are strong and it was observed that the PVC pipe at both Rowdy Creek Upstream and Rowdy Creek Downstream would begin a pronounced, processional oscillation in response to the turbulent flow of the water around the pipe. It is possible that this oscillation inflicted physical shock to the sensor that somehow affected it.

6.3 WATER TEMPERATURE DATA

Water level and water conductivity loggers include temperature measurements because they are important for adjusting the raw readings related to level and conductivity. Yet temperature itself is an important water quality parameter because it is related to aquatic habitat. When looking at the records of temperature recorded by the instruments in this project, there are two important points to keep in mind. First, due to fluctuating water levels (due to tides and changes in stream discharge) the instruments were regularly cycling in and out of water. Thus, some of the measurements are of air temperature and some are of water temperature. The conductivity and level data must be combined with the temperature data to determine what is being measured at each point in time. Second, the instruments have a certain degree of thermal inertia and thus the temperature readings do not change as quickly as the actual temperature can. The instruments were also enclosed in PVC pipes. This enclosure limits the speed with which changes in the temperature of water in the open channel can affect the readings of the instrument. This is especially true going from water to air, because of the lower heat capacity of air compared to water

Figure 6.17 shows the effects of a sensor cycling from air, into water, and then back into air with the falling and rising of the tides. Low tides in the afternoon show temperature peaks, due to warm afternoon air temperatures. Low tides at night, or in the early morning, lack the high temperatures. Note that not all afternoons are warm.

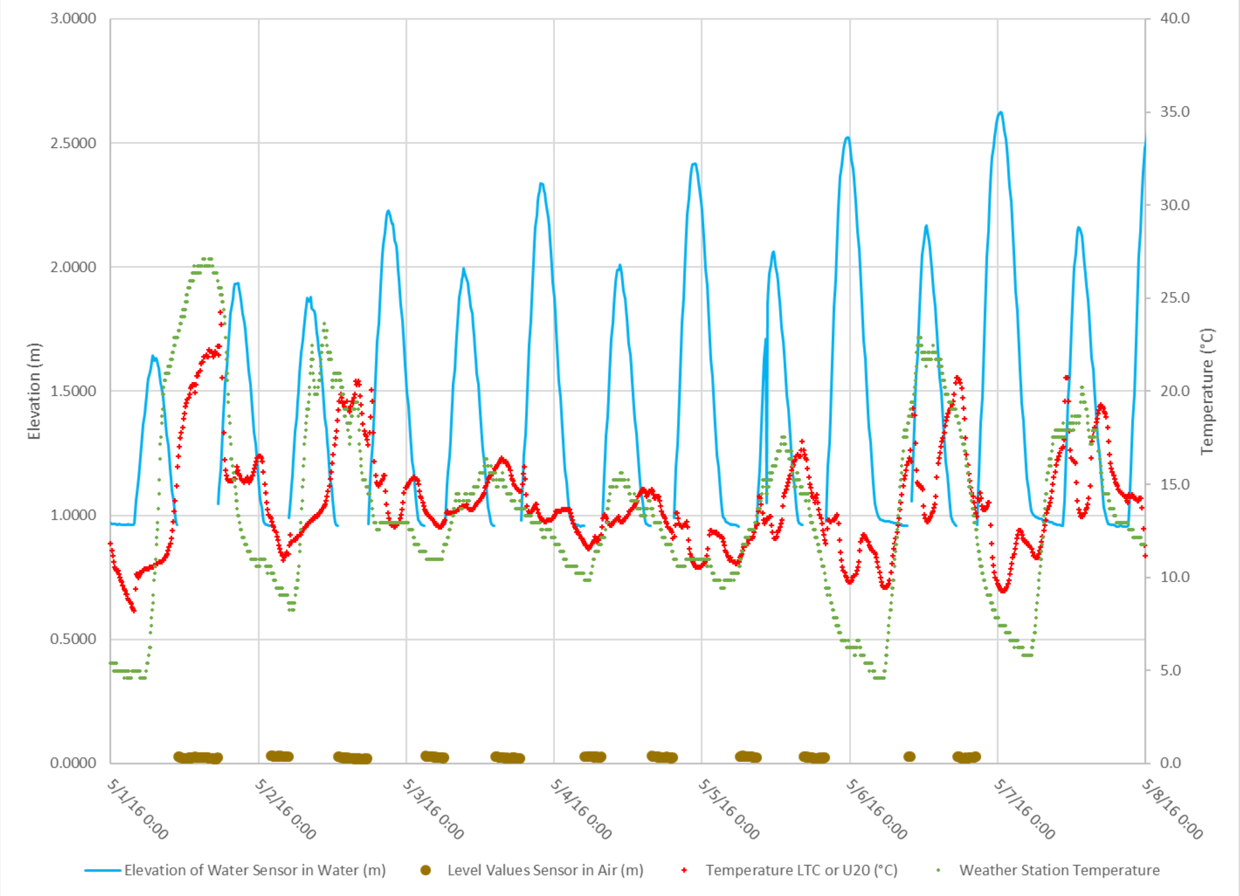


Figure 6.17: Graph of Reference Marsh South Upstream showing the effect of the logger going from air to water and back.

The water temperatures that occur at any given station are a combination of the ocean temperature, the river and creek temperatures, the stage of the streams, and the magnitudes of the high and low tides. Figure 6.18 shows the variation of temperature with the rising and falling tide as well as the changing air temperature during winter conditions. Note how the high tides bring higher temperatures, even when the air temperature is colder than the water.

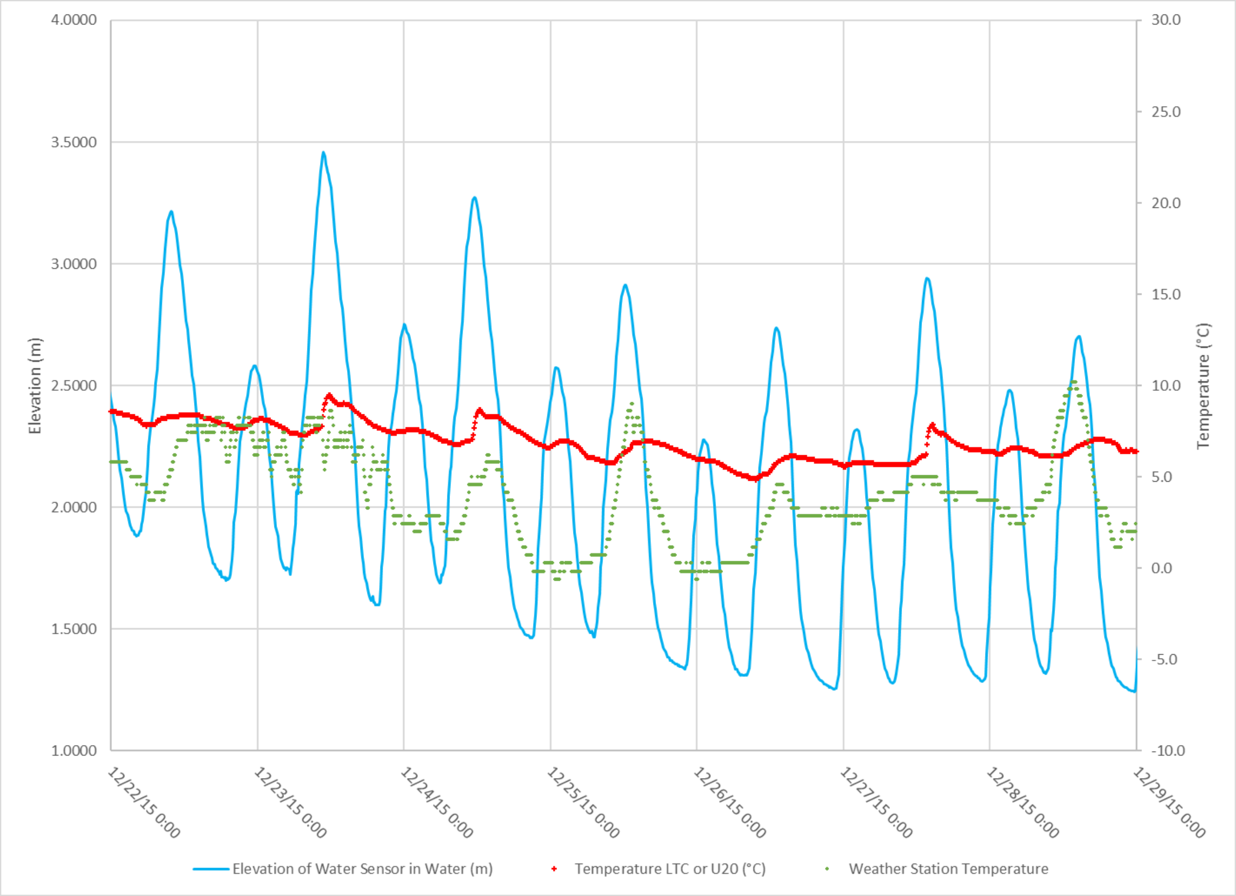


Figure 6.18: Graph of Former Salmon Creek South showing temperature fluctuation with the tides for one week in winter.

Figure 6.19 shows how, in the summer, the relatively colder ocean water causes pulses of cooler temperatures at high tides. Note that the water levels are lower during the dry summer when the discharge in the Salmon River drops (compare the water levels in Figure 6.18 and Figure 6.19).

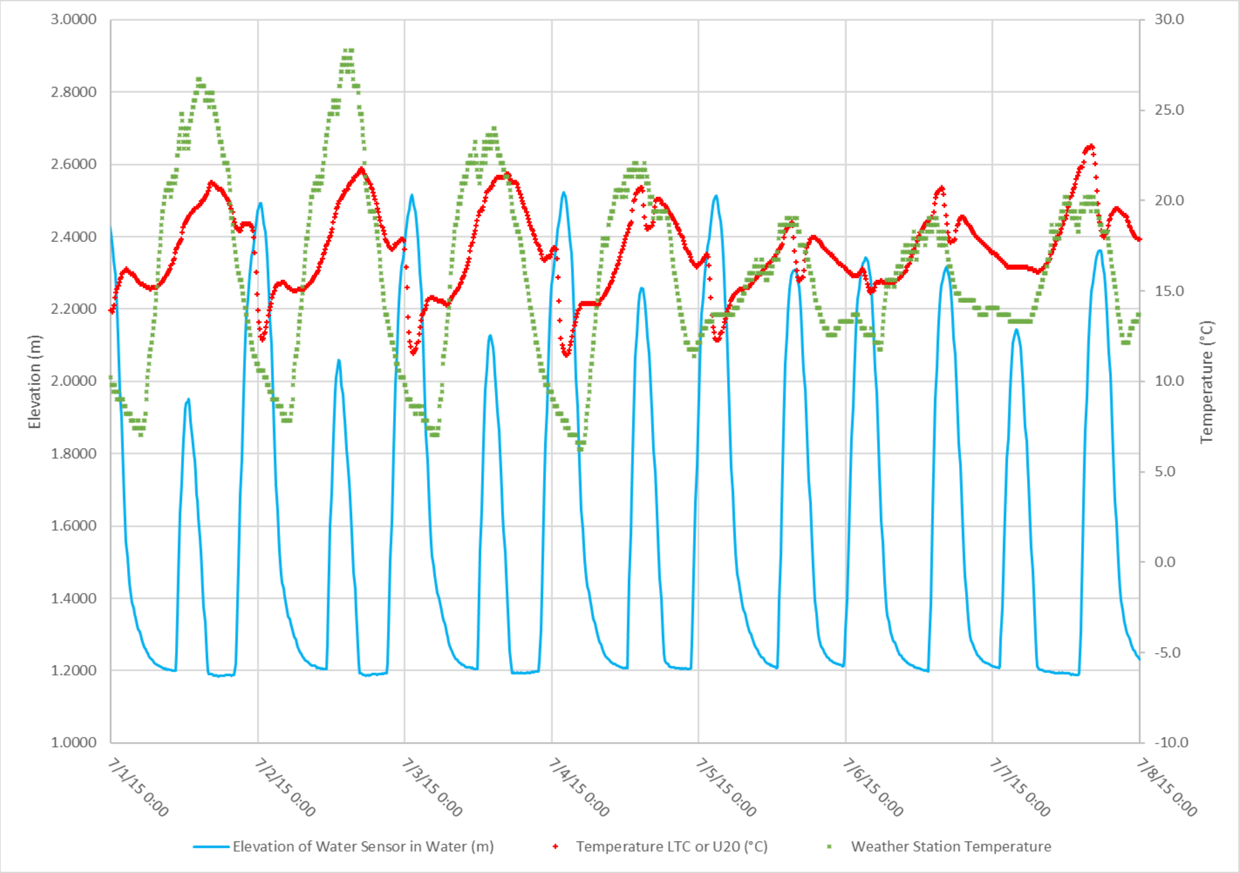


Figure 6.19: Graph of Former Salmon Creek South showing temperature fluctuation with the tides for one week in summer.

6.4 WATER CONDUCTIVITY DATA

Because estuaries are, by definition, areas where saltwater and freshwater mix, a wide range of conductivities are to be expected. The conductivity measurements of water in the Salmon River Estuary give an indication of whether the water, at a given point in time, came from the low-conductivity freshwater flowing from upland areas in one of the many streams, or from the high-conductivity Pacific Ocean, or some mix of the two. Similar to the water temperature values, care must be taken to combine the conductivity readings with the water level readings to determine if a given data point represents a reading taken in water or in air. The Levelogger LTC Junior instruments' conductivity sensor operates in such a way that when the water level dropped below the level of the sensor the conductivity would almost always drop to zero. The HOBO U24 conductivity sensors worked in a different way and thus they would quite often continue to give a non-zero reading after the water level dropped below the position of the sensor. This is presumed to be due to the influence of drops of water clinging to the non-contact sensor face, or perhaps due to the water in the nylon stocking around the loggers.

As mentioned previously, the conductivity sensors for the Levelogger LTC Juniors were located less than two inches above the water level sensor. Thus, the conductivity readings would drop to zero shortly before the water level would drop to zero. The combination of the HOBO U20(L) level loggers and the HOBO U24 conductivity loggers meant that the conductivity would drop when the water level was still well above the level of the water level sensor. This is because the diameter of the PVC pipe meant the two instruments could not be hung side-by-side in the pipe. The water level pressure sensor is located at the bottom of the U20 loggers, while the water conductivity sensor is located at the top of the U24 loggers. Thus, the minimum separation between the sensors was approximately 10 inches (25 cm). In practice, the hanging of the instruments on wire or Kevlar cord resulted in the separation being larger and was as much as 24 inches (61 cm) in the case of the Rowdy Creek Downstream station. The separation should be relatively constant for a given installation.

Figure 6.20 shows the conductivity and level data for a winter week at the Former Salmon Creek South station. Note how the lower high tides have fairly stable conductivity values around 4000 µS/cm that indicate a mix of salt water and fresh water. The higher high tides have much more variable conductivities that include values greater than 12,000 µS/cm, indicating a considerable fraction of ocean water in the mix.

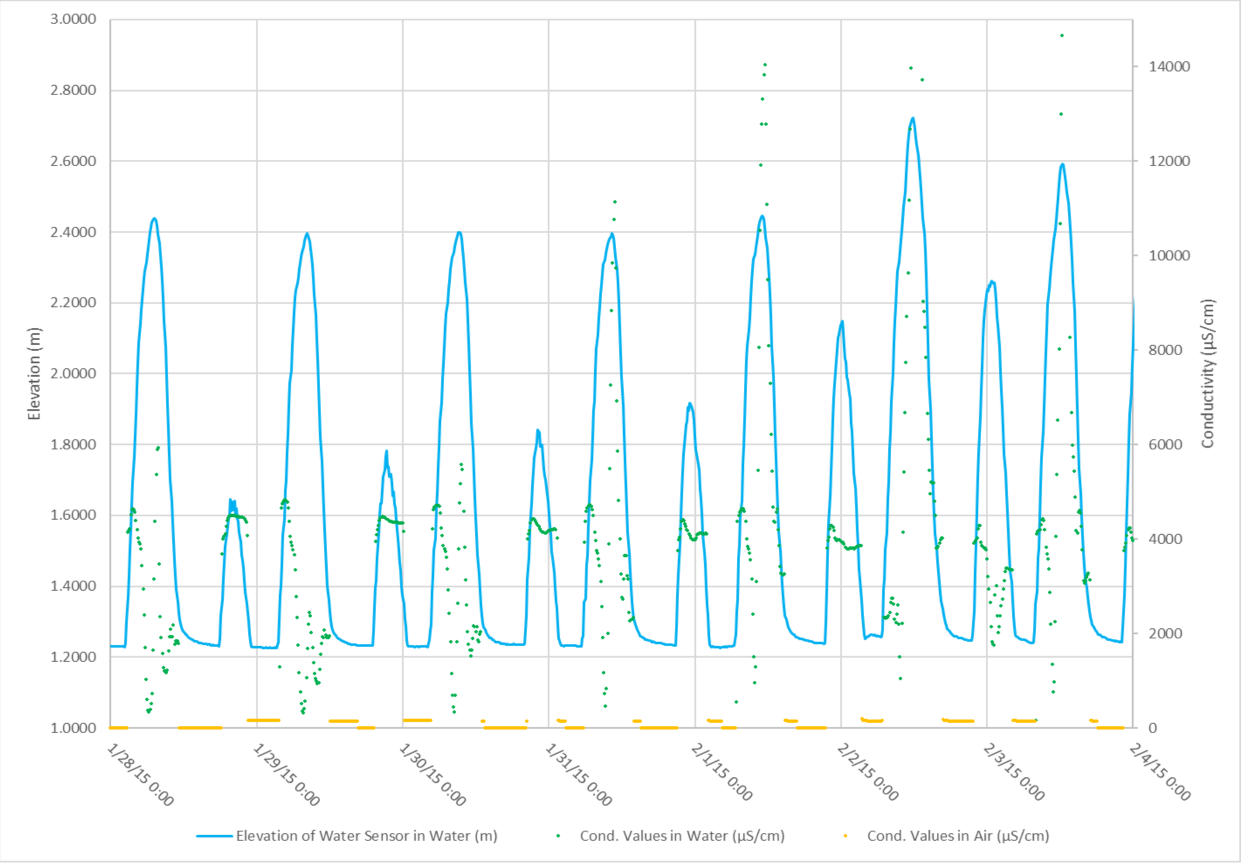


Figure 6.20: Conductivity and level data for one winter week at the Former Salmon Creek South station.

Figure 6.21 shows conductivity and level data for the same station, only for one week in the summer. With the lower peaks for the higher high tides, the conductivity values are less variable. The conductivity values are greater than the ~4000 µS/cm low tide values seen in winter, but do not include any values greater than 8000 µS/cm.

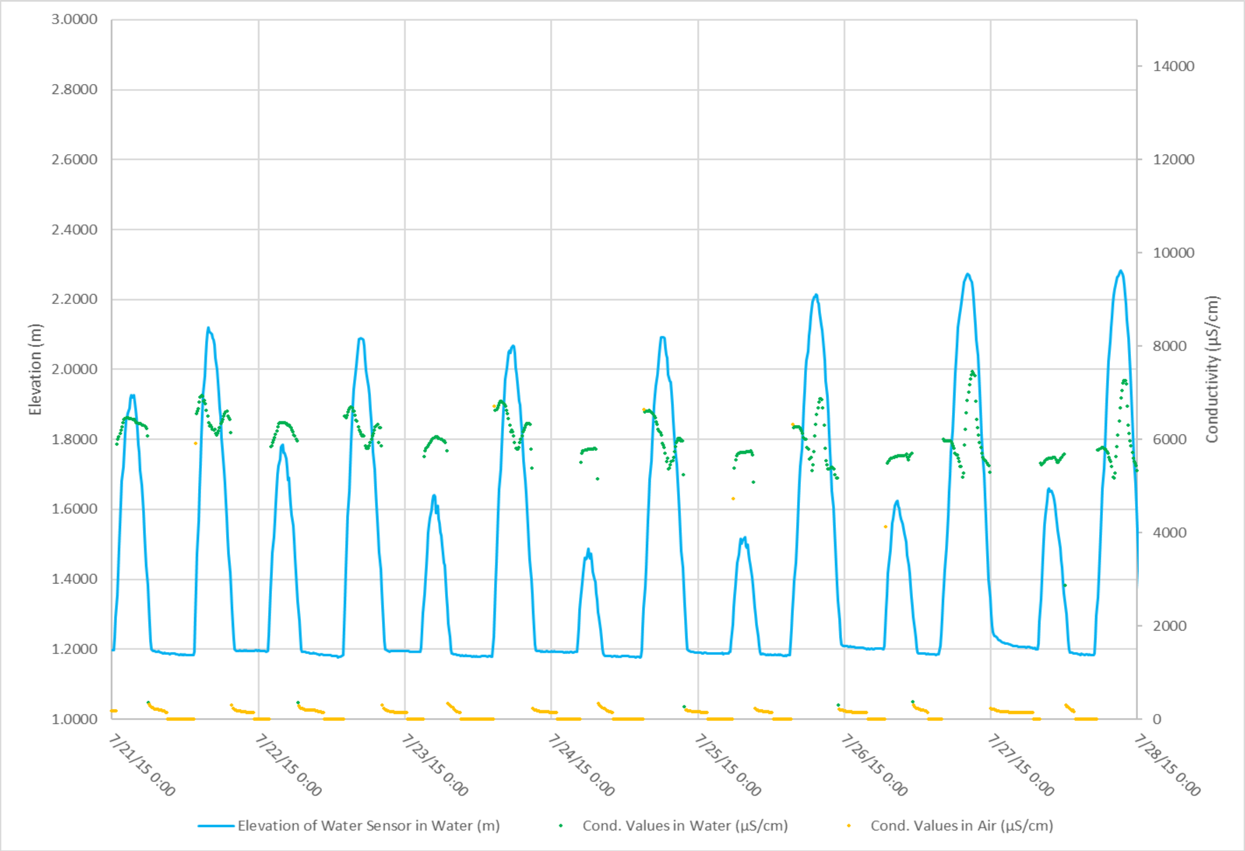


Figure 6.21: Conductivity and level data for one summer week at the Former Salmon Creek South station.

The conductivity data has not been converted to specific conductance values. Conductivity is a useful parameter in its own right and a user desiring specific conductance can use the data provided to compute specific conductance.

6.5 WATER DISSOLVED OXYGEN DATA

As mentioned previously, during this project the manufacturer of the level and conductivity loggers introduced a long-duration dissolved oxygen logger. Four such loggers were acquired. They were deployed at the Former Salmon Creek South, 70s Marsh, and Rowdy Creek Downstream stations. The reason these three stations were selected is to compare the DO in channels that have fresh water sources with the DO in the former Salmon Creek before its fresh water source is restored (this report) and after its fresh water source is restored (data to be collected in the future).

Unlike some dissolved oxygen measuring technologies that use a semi-permeable membrane and electrodes to measure dissolved oxygen, the RDO technology does not require that the sensor stay wetted. However, the manual for the HOBO instruments used for this project indicated, “make sure the logger is fully submerged.” Thus, in order to balance keeping the dissolved oxygen logger submerged with the need for well-mixed water, the dissolved oxygen loggers were installed in short pieces of PVC pipe. These pipes extended above channel bottom only a little higher than the length of the logger itself. Figure 3.22 shows the Former Salmon Creek South station with a second, shorter, piece of PVC pipe installed beside the taller water level and conductivity logger pipe. The idea was to have the logger be inside a pipe that would hold water while the tide is out and thus keep the logger submerged. This is less than ideal, but the hope was that the current of the water flowing inward on the rising tide and outward with the falling tide would induce a fair amount of mixing in the PVC.

In addition to the restriction of the water circulating around the logger, this also restricts access to the logger to only during low tide, for the purposes of downloading data. While the short pieces of pipe do hold water for a period of time, it is not certain that the sensor stayed wetted at every station for every low tide. The water may have been able to seep out of the pipe through the soil at the bottom during some low tides.

In retrospect, the recommendation regarding submergence could have been ignored and the loggers could have been installed in a PVC pipe exactly as was used for the level loggers.

Figure 6.22 through Figure 6.25 show dissolved oxygen data for weeklong periods in January and August of 2018. Figure 6.22 and Figure 6.23 show the January and August data paired with water elevation. These figures show how the dissolved oxygen values are disrupted by the transitions from high tide to low tide and low tide to high tide.

Figure 6.24 and Figure 6.25 are the dissolved oxygen data for the same weeklong periods but paired with the temperatures recorded by both the dissolved oxygen logger and the water level logger. In the summer data, the two temperature recordings track each other quite closely. The water level dropped below the level logger during low tide during the dry summer. In the winter data, there are several low tide periods where the two temperatures diverge considerably. The dissolved oxygen logger, being located in a pipe that is exposed to the surrounding air, diverges from the temperature of the level logger, which stays in communication with channel water throughout this example week.

Together, these figures once again demonstrate the importance of understanding the interplay of air temperature, water level, water temperature, and water conductivity for understanding what is being measured at any point in time.

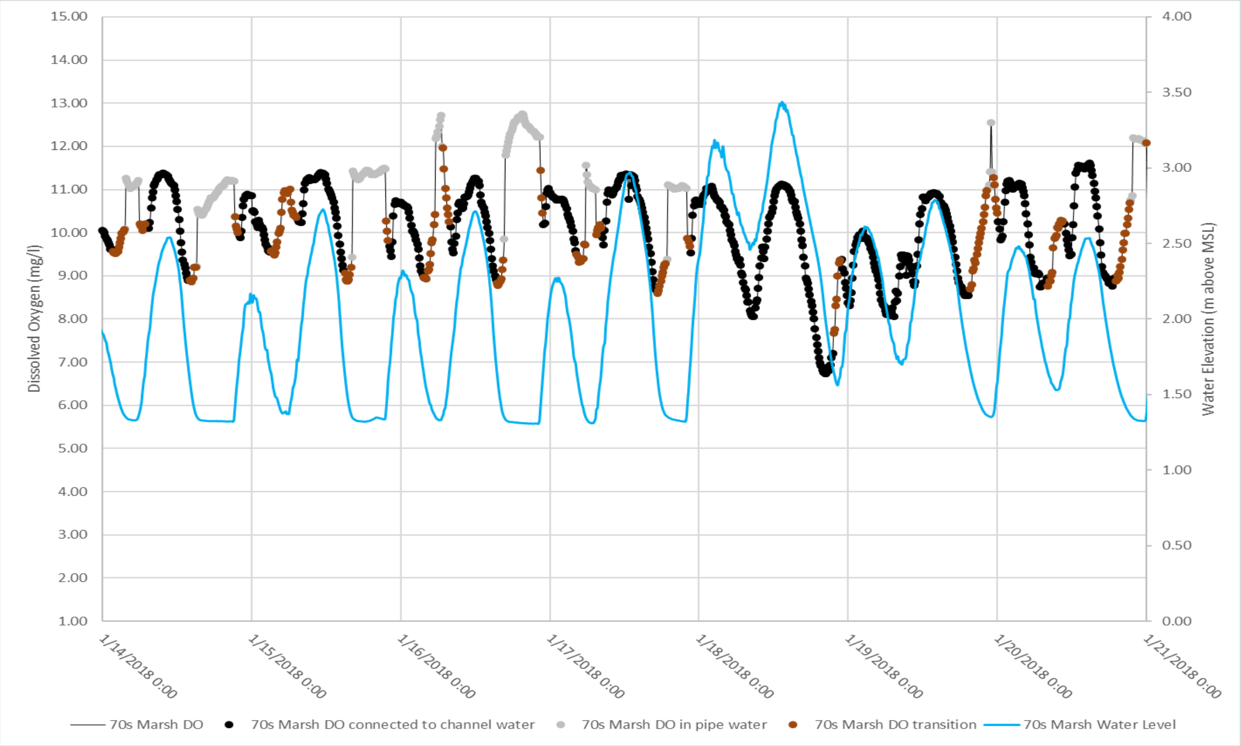


Figure 6.22: 70s Marsh Dissolved Oxygen and Water Level data for one week in January 2018.

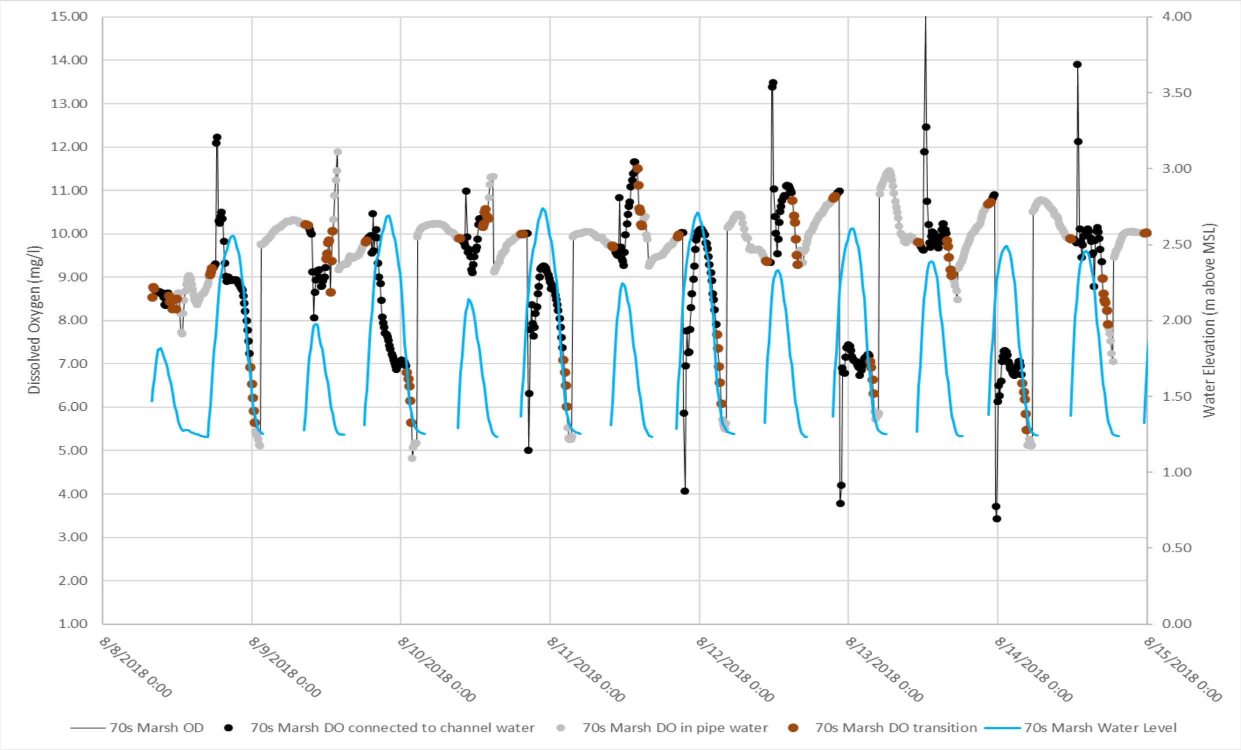


Figure 6.23: 70s Marsh Dissolved Oxygen and Water Level data for one week in August 2018.

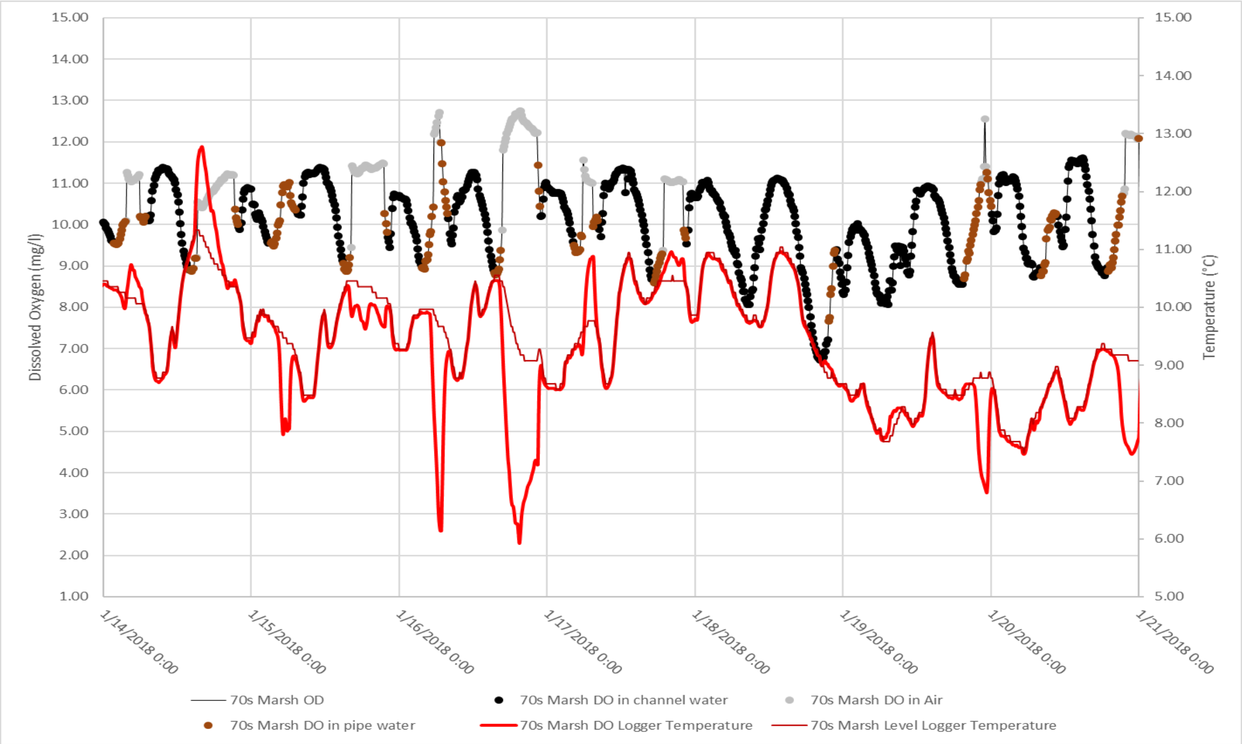


Figure 6.24: 70s Marsh Dissolved Oxygen and Temperature data for one week in January 2018.

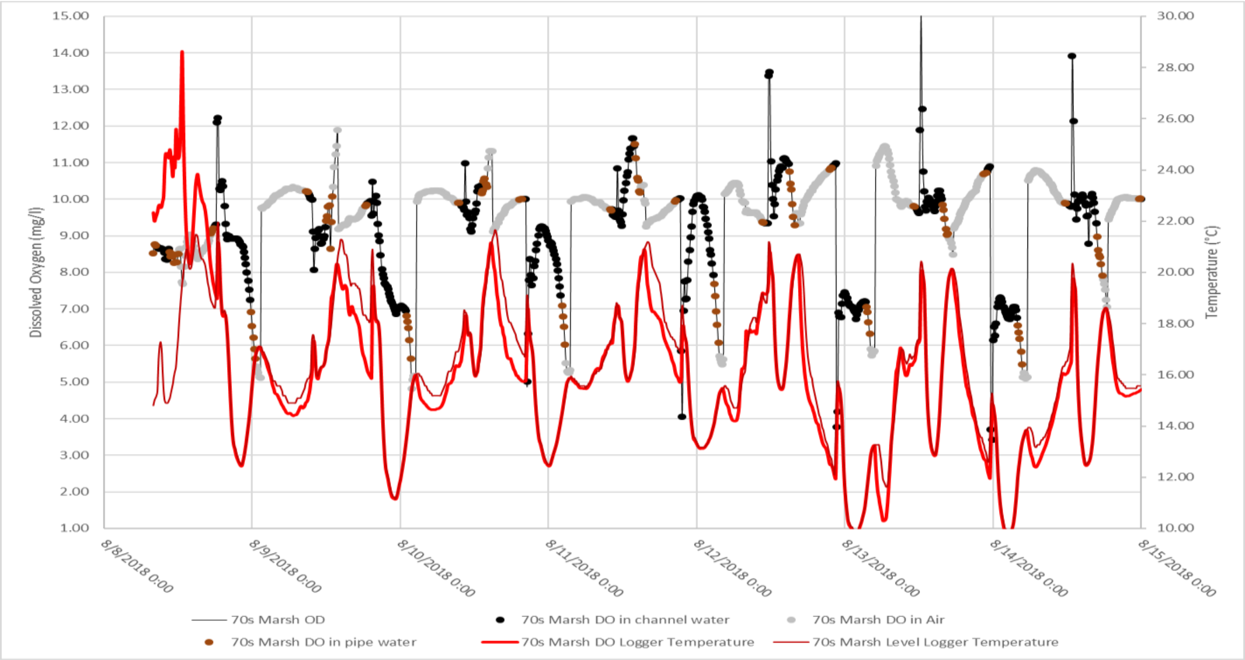


Figure 6.25: 70s Marsh Dissolved Oxygen and Temperature data for one week in August 2018.

The dissolved oxygen data in the spreadsheets has not been corrected for salinity.

7.0 CONCLUSION

A long-term water monitoring effort was conducted in the Salmon River Estuary. From September 2011 through June 2021, water level, conductivity, and temperature measurements were collected at 10-minute intervals using continuous logging instruments. This was done for varying periods at 20 stations in the Salmon River estuary. While some stations were occupied nearly continuously, with interruptions for instrument maintenance, other stations were occupied for shorter periods. To complement the water data, a weather station situated within the estuary was also operated during most of this approximately 10-year period. Dissolved oxygen measurements were also collected at three stations for several months in 2017 and 2018. This report describes the methods and instruments used to collect this data. It is intended to facilitate the use of this extensive data set.

The primary objective in collecting this data was to establish baseline observations that can be used in the future to assess the impacts of the addition of new, or larger, culverts or bridges under US Route 101, and the effects of future climate change. Such a long before treatment baseline allows for a more thorough understanding of the natural variations that occur within a complex natural system like the Salmon River Estuary. It is hoped that someone within ODOT will take the initiative to perform follow-up studies at the appropriate time in the future. For example, following construction of a new bridge or culvert.

These data also have the potential to be used to analyze water quality and movement within the estuary and to evaluate the nature and quality of habitat over a range of time scales and through variations with tides, weather, seasons, and other changes.

8.0 REFERENCES

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