# MEMORANDUM

**Date:** October 3, 2018

**To:** Marie Winkowski, Marc Hayes, Tim Quinn, Keith Douville, Julie Tyson, Mara Zimmerman, and Tim Kramer, Washington Department of Fish and Wildlife; Chrissy Bailey and Diane Butorac, Washington Department of Ecology; Janelle Leeson and Bob Thomas, U.S. Army Corps of Engineers

**From:** Matt Kuziensky, Tim Stone, Matt Wilson, Greg Summers, Bob Montgomery, and Ben Johnson, Anchor QEA, LLC

**Cc:** Heather Page, Anchor QEA

**Re:** Chehalis River Off-Channel Habitat Hydrologic Monitoring Project

## Introduction

The Chehalis River Off-Channel Habitat Hydrologic Monitoring Project (Project) was designed to evaluate hydrologic conditions and interactions between the Chehalis River and selected off-channel sites along the main channel that have been identified by the Washington Department of Fish and Wildlife (WDFW) as providing important aquatic habitat for amphibians and other wildlife. The goal of this analysis is to gain a better understanding of how the Chehalis River may interact hydrologically with those habitats, both in terms of flooding and subsurface connection, to provide a baseline from which to assess the potential impacts of implementing a flood retention dam alternative as part of the Chehalis Basin Strategy. This information will be used in the calibration of hydraulic models being developed by Watershed Science and Engineering (WSE) for the Chehalis River 100-year floodplain (floodplain). Additionally, the monitoring data will be used to inform the downstream floodplain wetland impact analysis that is being prepared for the Project.

This memorandum is intended to provide WDFW, the Washington Department of Ecology (Ecology), and U.S. Army Corps of Engineers with documentation of the Project, including the following:

- Project objectives
- Monitoring site selection
- Field monitoring equipment implementation and installation
- Data collection and quality control procedures
- River flow measurements
- Monitoring data summary and analysis
- Project discussion and conclusions

## Project Objectives

The purpose of the Project is to gain a better understanding of hydrologic interactions between off-channel areas and the Chehalis River. Specifically, the Project focused on determining the degree to which floodwater, direct precipitation, and groundwater contribute to the hydrology of these off-channel habitats. The data collection effort occurred over 2 years and included collecting the following information to gain a better understanding of the primary hydrologic sources that support these habitats:

- Water surface elevations and water temperature in the mainstem Chehalis River both upstream and downstream of the monitoring sites
- Water surface elevations and water temperature in the off-channel ponds at each monitoring site
- Groundwater levels and water temperature upgradient of each monitoring site
- River flow measurements in the mainstem Chehalis River near two of the monitoring sites

Water surface elevation and flow data collected during this study will be used to help calibrate and refine the hydraulic models being developed for the Chehalis River by WSE. This will allow for more confidence in the simulation of surface water connections between the channel and floodplain, and for much more detailed and accurate mapping of floodplain inundations (area and depth) and velocities. Temperatures in the upper and lower water columns of the off-channel areas will also be compared to upgradient groundwater temperatures and downgradient river temperatures to assess potential groundwater contributions to the off-channel ponds.

Groundwater and river surface elevation data collected during the Project will also be used to support a separate study being conducted to analyze the potential effects of implementing a flood retention dam alternative in the upper Chehalis River Basin on the hydrology of downstream floodplain wetlands. Groundwater elevations collected at Project monitoring sites and other groundwater wells within the 100-year floodplain of the mainstem Chehalis River will be compared to river elevations for the data available to inform the relative elevation difference and potential hydrological interaction between the Chehalis River and groundwater levels in the floodplain. That information will be used to characterize the relative hydrologic contributions of river levels to floodplain wetlands. Existing data on groundwater levels before and after the 2007 flood will also be evaluated to identify possible groundwater recharge contributions to wetlands that occur on a less frequent basis.

## Monitoring Site Selection

Monitoring sites were selected by WDFW to reflect a range of conditions along three types of gradients (Hayes 2017):

- Proximity to the proposed flood retention dam
- Presence and abundance of non-native aquatic species
- Connectivity with the Chehalis River

Accessibility and the willingness of landowners to participate in the study were also considered during the site selection process. All potential sites considered for the Project are regularly monitored by WDFW for off-channel aquatic biota, especially amphibians and fishes, as part of a separate study.

A total of six sites were initially selected for the Project. Of these, one site was later dropped when the landowner declined to participate in the study. The remaining five sites are shown on Figure 1 and described in this section (in order of increasing distance from the proposed dam).

### Site 007

Site 007 is an excavated, s-shaped water treatment pond located outside of the Chehalis River 100-year floodplain near river mile (RM) 107.5 (Figure 2). Site 007 is located near the Weyerhaeuser Pe Ell Tree Farm headquarters to the south of Pe Ell and occurs on top of a steep bluff above the river in a semi-open (i.e., partially-shaded) area along the edge of a large gravel parking lot. Site 007 was specifically designed to receive runoff from the parking areas and roofs of the adjacent Weyerhaeuser facility. It is the closest monitoring site to the proposed dam and the only site that is not located in the floodplain (i.e., not connected to the river). Site 007 does not contain non-native aquatic species (Hayes 2017).

### Site 004

Site 004 is an oxbow pond on private property in the Chehalis River floodplain approximately 5 miles downstream of Doty near RM 93.5 (Figure 3). The site is separated from the river by an old railroad grade that is now used as the Willapa Hills Trail (Willapa Hills Trail embankment). The pond at Site 004 is connected to the river by an existing 36-inch concrete culvert located in the southwest corner of the pond. Nicholson Creek, a small perennial stream, flows into the northeastern corner of the pond from an existing 18-inch diameter corrugated metal culvert under Meskill Road. Other surface water inputs include an existing culverted intermittent drainageway that enters the northwest corner of the pond and the outlet of an existing roadside ditch along Meskill Road that enters the south end of the pond. Site 004 contains a mix of native and non-native aquatic species (Hayes 2017).

### Site 068

Site 068 is an oxbow pond on private property on the north side of the Chehalis River approximately 1 mile downstream of the Washington Route 603 bridge near RM 76.5 (Figure 4). Site 068 has an overland connection with the Chehalis River during floods, starting from the downstream side with eventual connection to the river on the upstream side as the site fills with water. The landowner also reported that water levels in the pond are influenced by groundwater and possibly a spring. Site 068 is directly across the river from Site 020. Site 068 supports a high level of non-native aquatic species relative to other sites along the Chehalis River monitored by WDFW (Hayes 2017).

### Site 020

Site 020 is across the river from Site 068 on the south side of the Chehalis River channel near RM 76.5 and consists of two features: a larger oxbow pond and a smaller, shallower pond located between the oxbow pond and the river (Figure 5). Both features occur within former river channels and are mostly separated from one another by an area of higher ground, although they can connect through a narrow area on their southern ends. The larger pond also has an overland connection with the river on its northern end via a low-lying swale, which, according to the digital elevation model (DEM) developed from Light Detection and Ranging (LiDAR) data, appears to contain a small earthen check dam near its connection with the pond. According to WDFW, the larger pond also receives drainage from a very old (100 plus years) agricultural drainage tile that enters from the south (Douville 2018). Site 020 is regularly inundated by overbank flow from the Chehalis River with the larger oxbow pond remaining seasonal or intermittently flooded throughout much of the year. The Chehalis-Centralia railroad line and Willapa Hills Trail intersect south of this site, forming an x-shaped berm that, under certain conditions, can funnel overbank floodwaters from the Chehalis River into this site from upstream areas. Site 020 is known to support relatively low levels of non-native aquatic species (Hayes 2017).

### Site 086

Site 086 is approximately 2 miles upstream of Porter near RM 36.5 and consists of an off-channel pond within a former river channel along the east bank of the Chehalis River (Figure 6). The pond is regularly connected to the mainstem Chehalis River via overland connections on both its northern and southern ends. An existing beaver dam is present on its northern end. The fields to the east of the pond are managed by WDFW for waterfowl and flood every year from either upstream creek flow or artificial impoundment. Site 086 represents the opposite end of the proximity and connectivity gradients from Site 007; it is the furthest away from the proposed dam with the highest level of connectivity to the Chehalis River. Site 086 contains a mix of native and non-native aquatic species (Hayes 2017).

## Field Monitoring Equipment Implementation and Installation

The following sections describe the installation of monitoring wells and equipment at each of the monitoring sites selected by WDFW. Photographs of the monitoring wells and equipment are provided in Appendix A.

### Monitoring Locations

At each of monitoring sites, three types of monitoring locations were established to collect water level elevation and temperature data: groundwater monitoring locations (GMLs), river monitoring locations (RMLs), and oxbow monitoring locations (OMLs). These locations are shown for each site in Figures 1 through 6.

#### *Groundwater Monitoring Installation and Instrumentation*

Three new piezometers were installed as GMLs at Sites 007, 004, and 086 as shown on Figures 2, 3, and 6. At Site 020 an existing domestic well was used as the GML, and at Site 068 an existing City of Chehalis monitoring well adjacent to the site was used as the GML. In the areas of new well installation, soil borings were advanced and soil cores recovered by a driller licensed in the State of Washington, using direct-push drilling technology methods (Appendix A, Photo A-1). Soil recovered at each core section was described in the field to develop a lithologic boring log, with all description and observations recorded on field boring log forms. Soil characteristics were described in accordance with American

Society for Testing and Materials International (ASTM) D-2488, including color, structure, texture, mineral composition, moisture, and percent recovery.

After the completion of drilling and logging activities, piezometers were installed in the resulting boreholes (Appendix A, Photos A-1 through A-4). All wells were constructed in accordance with Washington Administrative Code 173-160-451 under the oversight of an Anchor QEA geologist licensed in the State of Washington. Piezometers were constructed using 2-inch outer diameter Schedule 40 PVC pipe with a 5- or 10-foot pre-packed screen with 0.010-inch slots. The lithology observed during the soil coring process and the relative elevation difference between the ground surface at the boring and surface water were used to determine the appropriate screen zone elevation for the piezometer installation. The driller advanced a larger-diameter casing before installing the well components to allow installation of a filter pack, filter pack seal, and annular seal around the well pipe. A filter pack equivalent to 10/20 or 20/40 sand was placed in the bottom of the borehole to 2 feet above the top of the screen. A filter pack seal (bentonite chips or very fine sand) was placed directly on the filter pack to isolate it from the bentonite backfill. The annular bentonite backfill was installed to near ground surface and completed at the surface with a cement seal and protective monument. Wells were secured by either a flush protective monument or a protective stick-up monument, depending on site characteristics. Well completion details were documented on well detail data forms (Appendix B), which were submitted to Ecology.

Well logs for the two existing groundwater wells could not be found at the time of monitoring initiation. For the well at Site 068, a depth-to-bottom reference measurement was obtained using an electronic water level indicator. The field crew was unable to get a similar measurement for the well at Site 020 due to the presence of an in-well pump. The well log for Site 068 was later found with Ecology's Washington State Well Report Viewer and is included in Appendix B.

After well installation, Anchor QEA field staff developed each well by surging, bailing, and/or pumping (Appendix A, Photo A-2). Surging was conducted across the entire screened interval of the well. Well development was considered complete when 10 times the well volume was removed, when field parameters stabilized, or when the well purged dry (whichever occurred first). Field parameters (pH, conductivity, and temperature) were measured and recorded after each casing volume had been removed from the well. Field parameters were considered stable when three consecutive measurements showed differences of less than 10% for each parameter. Field parameter measurements and general observations were recorded on well development log data forms.

Each GML well was equipped with temperature/pressure loggers installed to the approximate bottom elevation of the screened interval for the continuous measurement of groundwater elevation and temperature (see Data Logger Deployment).

### River Monitoring Installation and Instrumentation

Two RMLs were established at Sites 004, 068, 020, and 086, with one upriver and one downriver of the off-channel feature at each site (Figures 3 through 6). RMLs were not installed at Site 007 because of the lack of connection between the Chehalis River and the pond feature at that site. Because Sites 068 and 020 are located directly across the channel from each other, one set of RMLs was established to service both sites.

Each RML consisted of a stilling well installed to collect temperature and river elevation data (Appendix A, Photos A-5 through A-8). Stilling wells were constructed of perforated galvanized pipe threaded together with a drive point attached to the end. Each RML stilling well was manually driven into the river sediment from the shoreline until the piping could not be driven any further or the piping was securely embedded in the sediment, whichever came first. Solid galvanized pipe was extended from the top of the perforated piping to near the top of the riverbank and stabilized with a shoreline anchor (e.g., driven T-post or similar, existing shoreline structures).

RML stilling wells were equipped with pressure/temperature loggers installed at or near the river mudline elevation to continuously measure and record river temperature and water level elevation (see Data Logger Deployment).

### Oxbow Monitoring Installation and Instrumentation

Two OML stilling wells were installed in the off-channel ponds at all five monitoring sites (Figures 2 through 6). The OML stilling wells were constructed of the same perforated galvanized pipe and drive points used for the RML stilling wells (Appendix A, Photos A-9 and A-10). They were manually driven into the sediment at each site from a small boat until the piping could not be driven any further or the piping was secure in the sediment, whichever came first. Non-perforated galvanized piping was then extended from the top of the perforated piping to above the water surface elevation.

Temperature/pressure loggers were installed in each OML stilling well to continuously measure and record water level elevation and temperature approximately 12 inches above the mudline (Appendix A, Photos A-9 and A-10). The pressure/temperature logger interface cables were extended beyond the top of each well and secured to buoys to access and service the instrumentation when the water level was above the stilling well structure. Surface temperature loggers were also attached to buoys and tethered to the stilling well to allow for variable water surface elevations to be continuously measured and to record water temperature approximately 12 inches below water surface.

## Surveying Monitoring Locations

Upon completion of well installation, GMLs and OMLs were surveyed by Foresight Surveying, Inc., a surveyor licensed in the State of Washington, to establish vertical and horizontal positioning using the Project coordinate system and the selected horizontal and vertical datums (Washington State Plane Coordinates South Zone; North American Datum of 1983, U.S. feet; North American Vertical Datum of

1988, U.S. feet) to the nearest hundredth. Additional benchmarks were established at each monitoring location for use as instrument calibration references and to verify accuracy of water level monitoring equipment at each GML, OML, or RML. Vertical and horizontal positions were established at each benchmark by the surveyor.

### *Groundwater Monitoring Elevations*

At the time of instrument installation and during each monthly site visit, the depth-to-water (DTW) from the surveyed top-of-casing (TOC) mark was measured using an electronic water level indicator. The time and measurement were recorded on the field log and used to calculate the water level elevation. The technician connected to the data logger to read the instrument elevation and compare to the manually measured elevation. If the difference between the manually measured elevation and elevation indicated by the instrument was greater than 0.1 foot, the instrument reference elevation was reset to the measured water level elevation.

### *River Monitoring Elevations*

Because many of the RMLs could have periodically been inundated during monthly monitoring events, benchmarks for elevation reference were established during the initial site survey (Appendix A, Photo A-6). These benchmarks allowed the field team to measure the water level using basic survey equipment (Appendix A, Photo A-8). When collecting data at these sites, the field crew set up the survey instrument with line of sight to a known benchmark and to the water surface at a given RML. The stadia rod was then held at the water's edge and a stadia measurement taken. This measurement was compared to the benchmark elevation to calculate the water surface elevation at each RML. The manually measured water level elevation and instrument elevation were also compared to evaluate instrument accuracy. If the difference between the manually measured elevation and instrument elevation was greater than 0.1 foot, the instrument reference elevation was reset to the measured water level elevation.

### *Oxbow Monitoring Elevations*

Water levels at the OMLs were monitored using the same procedures used for the RMLs. Measurements to the water surface were made from the surveyed TOC mark of the OML stilling well using an electric water level indicator. When the TOC of a given OML could not be accessed due to high water, a survey instrument was set up with line of sight to a known benchmark and to the water surface at a given OML. The stadia rod was held at the water's edge and the stadia measurement was taken and compared to the benchmark elevation to calculate the water surface elevation at each OML. The time, DTW, and calculated elevation were recorded and then compared to the instrument elevation. If the difference between the manually measured elevation and instrument elevation was greater than 0.1 foot, the instrument reference elevation was reset to the measured water level elevation.

## Data Logger Deployment

The following sections describe the deployment procedures used for the temperature/pressure loggers and temperature loggers. Instruments were programmed to record measurements at 15-minute intervals. Data logger details are shown in Table 1.

### *Temperature/Pressure Logger Deployment*

As indicated in Table 1, In-Situ Rugged Troll 200 combined pressure/temperature loggers were deployed at each GML, RML, and OML. Each Rugged Troll was connected to direct-read cables and installed to the depths previously described in the monitoring locations section. Because the Project area is prone to flooding, non-vented Rugged Trolls were selected for all monitoring locations. In addition, because these types of instruments require correction to account for changes in atmospheric pressure, an In-Situ BaroTroll pressure logger was installed at each monitoring site to provide reference data. These instruments were installed above the anticipated water high water mark or in a protected area selected based on site conditions. Data were downloaded from the BaroTroll loggers approximately every 90 days. Water level elevation data recovered from temperature/pressure loggers were corrected using the ambient atmospheric data recovered from the BaroTroll instruments.

**Table 1**
**Number of Field Monitoring Equipment Deployed at Each Monitoring Site**

| | | GML | RML | OML | |
|---|---|---|---|---|---|
| SITE | BAROTROLL DATA LOGGER[a] | RUGGED TROLL 200 DATA LOGGER | RUGGED TROLL 200 DATA LOGGER | HOBO PRO V2 DATA LOGGER | RUGGED TROLL 200 DATA LOGGER |
| 007 | 1 | 1 | None | 2 | 2 |
| 004 | 1 | 1 | 2 | 2 | 2 |
| 068 | 1[b] | 1 | 2[c] | 2 | 2 |
| 020 | None[b] | 1 | None[c] | 2 | 2 |
| 086 | 1 | 1 | 2 | 2 | 2 |

Notes:
BaroTroll data logger records atmospheric barometric pressure for compensation of water surface elevation data.
Rugged Troll 200 data logger non-vented transducer records water temperature and pressure.
HOBO Pro v2 data logger records water surface temperature.

a. One BaroTroll data logger was installed at each site to record variations in atmospheric barometric pressure to correct the pressure/elevation data of the Rugged Trolls.
b. Sites 068 and 020 share a BaroTroll to record atmospheric compensation data.
c. Because of the relative locations of Sites 068 and 020, river data are collected at a shared pair of RMLs.

### *Temperature Logger Deployment*

Onset HOBO Pro v2 temperature loggers were installed at each OML to record surface water temperature within areas of off-channel inundation (Table 1). Each temperature logger was suspended from a floatation device to approximately 1 foot below water surface and tethered to the stilling well with a cord of sufficient length to accommodate fluctuations in water level elevation.

# Quality Assurance

## *Data Logger Calibration*

The following sections describe the calibration procedures used for the temperature/pressure data loggers. All instruments were calibrated based on field measurements relative to surveyed benchmark elevations.

### *Temperature/Pressure Logger Set-Up and Calibration*

For all monitoring locations with a Rugged Troll, calibration occurred at deployment and was checked during each monthly site visit. Each Rugged Troll was installed using a cable that extends from the TOC to the base of the screened interval at GML wells and at the approximate mudline elevation at RML or OML stilling wells. The cable allows for real-time calibration of instrument elevation set points.

The following procedure was used to install and calibrate the Rugged Trolls:

1. Each Rugged Troll was connected to a communication cable of the appropriate length.
2. The instrument was calibrated to zero in ambient air conditions.
3. A lead line measurement was taken to confirm depth to mudline of the stilling wells.
4. The instrument and cable were slowly fed down into the well to approximately 0.5 foot from the bottom of the well screen (GMLs) or mudline (OMLs and RMLs).
5. The installer used a portable field computer to connect to the instrument cable.
6. The installer used an electric water level probe to measure the water level elevation and entered the result into the instrument as a real-time reference value.
7. The installer programmed the instrument to collect one measurement of temperature and water level elevation at 15-minute intervals.
8. The above ground connector on the cable was protected by a dust cap or similar protection device to protect against moisture based on site conditions.
9. Each data logger was checked to confirm data were being logged.

## *Monitoring*

Monitoring of the GMLs, RMLs, and OMLs occurred monthly to assess site conditions and download data from the data loggers.

### *Site Condition Assessment*

During each site visit, field staff performed visual inspection of the site conditions and noted any accessibility issues (e.g., high water, impassable access roads) that could affect monitoring or other observable changes to the monitoring sites, including damage that may have occurred to the monitoring equipment due to natural (e.g., flooding) or human-induced (e.g., vandalism) events. All damage was documented on field logs and photographs were taken. Based on these observations, recommendations to replace or repair damage were then made to the Project team.

### *Temperature/Pressure Logger Monitoring*

During the installation of the temperature/pressure loggers, manual water level measurements were made at all monitoring locations before and after the water level data loggers were installed. These manual measurements were used as reference points for the data generated by the level logging equipment. Levels were measured to the nearest 0.01 foot and recorded immediately on a water level data sheet with the date, time (on a 24-hour clock), reference point, and initials of the person who made the measurements. If differentials of more than 0.1 foot were observed between manual and instrument elevation measurements, the instrument's reference elevation was adjusted. Logged data were then retrieved using Win-Situ software on a portable computer or appropriate equipment. Each data file was opened in the field to verify that data records were complete

### *Temperature Logger Monitoring*

During each site visit, the surface water temperature loggers were retrieved and connected to the HOBO Waterproof Shuttle by a coupler that facilitates download and transfer of the stored data. The Waterproof Shuttle was also used to program and start new tests. Each data file was opened in the field to verify data records were complete. Upon completion of data retrieval, the temperature loggers were redeployed.

### *Barometric Correction Monitoring*

During each site visit, barometric pressure data were collected from each BaroTroll data logger and used to correct for the effect of barometric pressure on water level data collected by the temperature/pressure loggers (Appendix A, Photo A-11).

## *Quality Control*

This section summarizes the accuracy of the monitoring equipment selected for use on the Project. These accuracies have readily quantifiable uncertainty that have been well studied and documented in the literature.

### *Rugged Troll Accuracy*

The Rugged Troll water level accuracy is plus or minus (±) 0.1% of the measurement range of the data logger. Data logger drift was examined when data were downloaded and compared to manually measured water level elevations. When drift was identified, data were reasonably adjusted by assuming a linear correction over the time interval from the previous data download. When incidents of large drift were encountered, the data logger was replaced.

### *HOBO Accuracy*

The HOBO temperature sensor accuracy is ±0.21°C, and the system clock accuracy is ±1 minute per month.

### *Depth-to-Water Probes*

An electric water level probe was used to manually check the instrumentation DTW measurements. The accuracy of a graduated electric tape is ±0.01 feet for DTW of less than 200 feet (Cunningham and Schalk 2011). Field accuracy was periodically verified by conducting multiple measurements and/or by repeated measurements by multiple field crew members.

## River Flow Measurement

To support the calibration of WSE's Chehalis River hydraulic models, measurement of discharge at a given river water level along an established reach of the river was collected. This was accomplished through an acoustic Doppler current profiler (ADCP) flow survey. ADCP technology uses hydroacoustic principles to determine water current velocities using soundwaves scattered off particles in the water column. To determine river discharge, an ADCP unit was mounted to a boat and moved along a transect perpendicular to flow (Appendix A, Photo A-12). Throughout the transect, the ADCP unit took measurements of velocity, depth, and distance. These measurements were then used to calculate discharge, as shown in Equation 1.

**Equation 1**

$$Q = \sum (A \times V)_1 + (A \times V)_2 + (A \times V)_i$$

Where:
A = Area
Q = Discharge
V = Velocity

The ADCP survey was conducted on April 24, 2017, using a Teledyne RiverRay ADCP. During this survey, three sets of transects were performed to determine the relationship between discharge and stage in the Chehalis River near Chehalis. Two sets of transects were completed at different locations between Sites 020 and 068. One set of transects was completed at the Washington Route 603 bridge.

For each set of transects, at least five individual transects that were within ±5% of the calculated average discharge were completed. The results of these individual and averaged discharge measurements were paired with water level elevation data for the Chehalis River collected from the stilling wells at RML1 and RML2, both of which are located in the Chehalis River between Sites 020 and 068. Water level elevation and discharge data from the U.S. Geological Survey (USGS) gage at Adna (No. 12021800; Adna gage) were also included in this comparison.

## Monitoring Data and Analysis

As shown in Table 2, most of the monitoring sites were monitored for period of approximately 26 months between late March 2016 to late May 2018. The only exception is Site 086, which was monitored for only 18 months because the monitoring wells at that site were installed later than the other sites due to issues with site access and delays in securing landowner permission. Monitoring instrumentation problems encountered during the Project are summarized in Table 3, which includes a list of the monitoring sites and locations where problems occurred, a description of each problem, the date the problem was discovered, the action taken to correct the problem, and the date of correction. Many of the problems encountered during the monitoring period did not result in data collection interruptions, although there were multiple instances of stilling well damage or complete destruction at RML sites (especially Site 004, RML2) due to river-borne debris or bank erosion that did create some data gaps (Table 2). A data gap also occurred at the beginning of the monitoring period at Site 068 because the initial stilling well location for RML1 did not extend far enough into the river. Although this well was later moved, the data logger was stolen before the first set of data could be downloaded. Other commonly encountered problems included data logger malfunction or failure, which occurred in nearly all monitoring location types, and cable damage at the OML sites by either animals (beaver) or floating debris.

**Table 2**

**Monitoring Well Installation Dates and Monitoring Periods**

| | GROUNDWATER MONITORING LOCATION | | RIVER MONITORING LOCATION | | OXBOW MONITORING LOCATION | |
|---|---|---|---|---|---|---|
| SITE | INSTALLATION | MONITORING | INSTALLATION | MONITORING | INSTALLATION | MONITORING |
| 007 | 3/2/2016 | 3/3/2016 to 5/23/2018 | Not applicable[1] | Not applicable[1] | 3/24/2016 | 3/24/2016 to 5/23/2018 |
| 004 | 3/4/2016 | 3/4/2016 to 5/23/2018 | 3/22/2016 | RML1: 3/22/2016 to 1/30/2017[2]<br>RML1: 3/30/2017 to 5/23/2018[3]<br>RML2: 3/22/2016 to 7/27/2016[4]<br>RML2: 11/2/2016 to 6/27/2017[5]<br>RML2: 10/26/2017 to 11/12/2017[6]<br>RML2: 2/15/2018 to 4/18/2018[7] | 3/22/2016 | 3/24/2016 to 5/23/2018 |
| 068 | Not applicable[8] | 5/25/2016 to 5/24/2018 | 3/23/2016 | RML1B: 6/29/2016 to 5/24/2018[9]<br>RML2: 3/23/2016 to 5/24/2018 | 3/28/2016 | 3/28/2016 to 5/24/2018 |
| 020 | Not applicable[8] | 5/25/2016 to present | 3/23/2016 | RML1B: 6/29/2016 to 5/24/2018[9]<br>RML2: 3/23/2016 to 5/24/2018 | 3/23/2016 | 3/23/2016 to 5/24/2018 |
| 086 | 6/28/2016 | 6/28/2016 to present | 6/28/2016 | 6/29/2016 to 5/22/2018 | 6/28/2016 | OML1 6/29/2016 to 5/22/2018<br>OML2 6/29/2016 to 2/13/2018[10] |

Notes:
1. No RMLs were established at Site 007.
2. Stilling well at RML1 for Site 004 was destroyed by river debris in late January 2017; no data were collected between 1/31/2017 and 3/29/2017.
3. Stilling well at RML1 for Site 004 was replaced in on 3/29/2017; data collection continued uninterrupted until 5/23/2018.
4. Data logger for RML2 at Site 004 stopped working in late July 2016; no data were collected between 7/28/2016 and 11/1/2016.
5. Data logger for RML2 at Site 004 replaced with new data logger on 11/2/2016, which operated until 6/27/2017 when stilling well was destroyed by river debris; no data were collected between 6/28/2017 and 10/25/2017.
6. Stilling well for RML2 at Site 004 replaced on 10/25/2017, which operated until 11/12/2017 when stilling well was again destroyed by river debris; no data were collected between 11/13/2017 and 2/14/2018.
7. Stilling well for RML2 at Site 004 replaced on 2/14/2018, which operated until 4/18/2018 when bottom half of stilling well broke off; data between 4/18/2018 and 5/23/2018 were recovered but determined to be unusable.
8. The GMLs for Sites 068 and 020 used existing wells; no new groundwater monitoring wells were installed.
9. Initial stilling well at RML1 for Sites 068 and 020 was placed too far from the water's edge and had to be moved; monitoring continued with new RML (RML1B) slightly upstream of previous monitoring site on 5/24/2016. Data from 5/24/2016 to 6/28/2016 were lost when data logger was stolen. New data logger installed on 6/29/2016 and continued to collect data until 5/24/2018 when stilling well was decommissioned.
10. No temperature data were collected at OML2 from 2/13/2018 until the end of the monitoring period due to a faulty data download from the temperature logger.

**Table 3**

**Monitoring Equipment Problems Encountered During the Chehalis River Off-Channel Habitat Hydrology Monitoring Project**

| SITE | MONITORING LOCATION | PROBLEM | DATE OF DISCOVERY | REMEDY | DATE REMEDY IMPLEMENTED |
|---|---|---|---|---|---|
| 020/068 | RML1 | Stilling well installed too far from water's edge | 5/24/2016 | Abandoned RML1; established a new RML (RML1B) upstream of previous monitoring site | 5/24/2016 |
| 020/068 | RML2 | Lower portion of stilling well silted in | 5/24/2016 | Adjusted elevation of data logger in stilling well and recalibrated | 5/24/2016 |
| 020/068 | RML1B | Data logger stolen | 6/29/2016 | Moved data logger from abandoned RML1 to RML1B | 6/29/2016 |
| 068 | GML | Temperature sensor malfunctioned | 7/27/2016 | Replaced data logger and cable | 7/27/2016 |
| 004 | OML1 | Data logger cable severed | 11/1/2016 | Replaced cable | 11/1/2017 |
| 004 | RML2 | Data logger connectivity failed | 11/1/2016 | Replaced data logger | 11/1/2016 |
| 007 | GML | Data logger connectivity failed | 12/27/2016 | Replaced data logger | 12/27/2016 |
| 004 | RML1 | Benchmark compromised by slope failure | 1/5/2017 | Reestablished benchmark in different location | 1/31/2017 |
| 004 | RML1 | Stilling well destroyed by river debris during flood; upper section of stilling well and data logger washed away | 3/1/2017 | Installed new stilling well, data logger, and cable | 3/29/2017 |
| 020/068 | RML1 | Ground adjacent to benchmark eroded away | 3/2/2017 | Added additional concrete to stabilize benchmark monument | 3/29/2017 |
| 020/068 | RML2 | Benchmark buried by up to 2 feet of sediment | 3/2/2017 | Reestablished benchmark in different location | 3/29/2017 |
| 068 | OML1, OML2 | Data logger cables severed | 4/24/2017 | Replaced cables | 4/24/2017 |
| 020 | OML2 | Data logger cable severed | 4/24/2017 | Replaced cable | 5/24/2017 |
| 004 | RML2 | Stilling well location shifted downslope due to erosion | 5/23/2017 | Adjusted data logger location in stilling well and recalibrated | 5/23/2017 |
| 004 | OML2 | Data logger cable tangled in large floating tree caused data logger to be lifted in well when water receded | 5/23/2017 | Attempted to correct for elevation change by measuring distance data logger was lifted | 5/23/2017 |

| SITE | MONITORING LOCATION | PROBLEM | DATE OF DISCOVERY | REMEDY | DATE REMEDY IMPLEMENTED |
|---|---|---|---|---|---|
| 004 | RML2 | Bottom of stilling well broken off by floating debris in river | 6/28/2017 | Installed new stilling well; installed recovered data logger and cable | 10/25/2017 |
| 086 | OML1, OML2 | Data logger cables severed | 10/24/2017 | Replaced cables | 10/24/2017 |
| 068 | OML2 | Data logger cable severed | 10/25/2017 | Replaced cable | 10/25/2017 |
| 086 | RML2 | Benchmark lost due to bank erosion; continuing bank erosion affected future access to stilling well | 2/13/2018 | Benchmark reestablished, and 7-foot riser added to stilling well to extend well further up bank to maintain accessibility | 2/15/2018 |
| 004 | RML2 | Stilling well broken by debris in river | 2/14/2018 | Installed new stilling well | 2/14/2018 |
| 004 | OML1 | Surface water temperature logger stuck out of water on tree stump | 2/14/2018 | Freed logger | 2/14/2018 |
| 004 | OML2 | Surface water temperature logger stuck under water by woody debris | 2/14/2018 | Freed logger | 2/14/2018 |
| 004 | OML2 | Data logger cable stuck under tree trunk, pulling cable up about 3 feet. Cable could not be freed. | 2/14/2018 | Reset data logger elevation in stilling well | 2/14/2018 |
| 020/068 | RML1 | Stilling well riser pipe bent by fallen tree and knocked loose of its support | 2/15/2018 | Reattached stilling well to t-post and recalibrated data logger; bent pipe left on well string | 2/15/2018 |
| 004 | RML1 | Stilling well destroyed when tree it was attached to fell into the river after riverbank was eroded | 5/23/2018 | Abandoned and decommissioned well | 5/23/2018 |
| 004 | RML2 | Data logger connectivity failed | 5/23/2018 | Sent data logger to manufacturer for data retrieval | 5/30/2018 |
| 086 | OML2 | Temperature logger data download failed | 5/22/2018 | No remedy available; data were lost | 5/22/2018 |

## Monitoring Results

Graphical depictions of the water elevation and temperature monitoring results for each monitoring site are included in Appendix C and Appendix D, respectively. On each water elevation and temperature graph, precipitation and daily high and low temperature data were also included for the monitoring period. This information was obtained from Washington State University's AgWeatherNet automated weather station network from either Station 53–Chehalis (Sites 007, 004, 068, and 020) or Station 49–Montesano Station (Site 086). River flow data from the USGS Doty, Ground Mound, and Porter gages were also examined for the monitoring period. These gages were selected to provide upstream, midstream, and downstream flow measurements for the portion of the mainstem Chehalis River that encompassed the monitoring sites.

For river flow measurements, the monitoring period covered a portion of Water Year 2016, all of Water Year 2017, and a portion of Water Year 2018.[1] During that period, there were seven flow events that exceeded 19,000 cubic feet per second (cfs) at Porter gage (USGS 2018). This flow threshold was chosen because it was just below the highest flow observed during the March to April 2016 late spring period when the monitoring period began. In addition to the one exceedance in spring 2016, three events from October 2016 to April 2017 and three events from October 2017 to April 2018 exceeded the 19,000 cfs threshold at the Porter gage. Table 4 details the flows and estimated recurrence interval for the seven high flow events at USGS Doty, Grand Mound, and Porter gages (USGS 2018). As shown, the highest flow occurred during a February 2017 event and was between a 2-year to 5-year event. In 2016, the highest flow (in the March 2016 event) was around 60% of a 2-year event. In November and December 2017, peak flow was about 80% of a 2-year event.

A discussion of the collected data and general trends noted at each monitoring site is provided in the following sections. For sites where overbank flows from the Chehalis River are known or thought to contribute to site hydrology, a brief discussion of the estimated river connection points and their associated elevations is provided. Such information was determined using the preliminary Hydrologic Engineering Center River Analysis System (HEC-RAS) modeling for the Chehalis River Basin along with a DEM developed from LiDAR data to determine topography and associated elevations. The likelihood that a 2-, 10-, and 100-year flood frequency event would trigger such a connection is also discussed. Those flood events were estimated using information obtained from the 2014 *Chehalis Basin Ecosystem Restoration General Investigation Study Baseline Hydrology and Hydraulics Modeling* (USACE 2014), which used available gage data for the Chehalis River from Water Year 1929 through Water Year 2011.

[1] The USGS defines Water Year as the 12-month period from October 1 for any given year through September 30 of the following year (USGS 2016).

**Table 4**

**Chehalis River High Flow Events Occurring During the Off-Channel Habitat Hydrology Monitoring Period**

| | | CHEHALIS RIVER AT DOTY GAGE | | CHEHALIS RIVER AT GRAND MOUND GAGE | | CHEHALIS RIVER AT PORTER GAGE | |
|---|---|---|---|---|---|---|---|
| DATES | WATER YEAR | PEAK FLOW (CFS) | ESTIMATED RECURRENCE INTERVAL | PEAK FLOW (CFS) | ESTIMATED RECURRENCE INTERVAL | PEAK FLOW (CFS) | ESTIMATED RECURRENCE INTERVAL |
| ***3/10/2016 to 3/11/ 2016*** | ***2016*** | ***5,990*** | ***60% of 2-year event*** | ***15,700*** | ***60% of 2-year event*** | ***19,100*** | ***65% of 2-year event*** |
| 11/25/2016 to 11/26/2016 | 2017 | 9,730 | 2-year event | 23,900 | 90% of 2-year event | 26,900 | 90% of 2-year event |
| ***2/9/2017 to 2/11/2017*** | ***2017*** | ***15,100*** | ***5-year event*** | ***30,800*** | ***Between 2-year and 5-year event*** | ***31,900*** | ***Between 2-year and 5-year event*** |
| 3/10/2017 to 3/11/2017 | 2017 | 5,330 | 55% of 2-year event | 17,400 | 70% of 2-year event | 20,700 | 70% of 2-year event |
| 11/22/2017 to 11/24/2017 | 2018 | ***8,360*** | ***85% of 2-year event*** | 18,800 | 75% of 2-year event | ***23,000*** | ***80% of 2-year event*** |
| 12/29/2017 to 12/31/2017 | 2018 | 6,060 | 60% of 2-year event | ***20,100*** | ***80% of 2-year event*** | 21,600 | 75% of 2-year event |
| 4/15/2018 to 4/16/2018 | 2018 | 5,200 | 50% of 2-year event | 18,800 | 75% of 2-year event | 22,900 | 80% of 2-year event |

Notes:
Source: USGS 2018
Bolded, italicized event is highest event of the water year.
In Water Year 2018, the highest event for Grand Mound gage was different than the highest event for Doty and Porter gages

Where applicable, the water elevation data for each monitoring site were also compared to the locations of expected gaining and losing reaches in the mainstem Chehalis River as mapped by USGS in September 2007 (Ely et al. 2008; Appendix E). Gaining reaches are those where the predominant interaction between stream flow, groundwater, and surface water is discharge to streams, while losing reaches are those where the predominant interaction between stream flow, groundwater, and surface water is discharge to groundwater. While a gaining or losing state may be common within certain reaches, such conditions are not uniformly fixed and may fluctuate seasonally or between years depending on varying factors.

## Site 007

### Water Elevation Data

A graph of the groundwater and surface water levels measured at Site 007 during the monitoring period is provided in Figure C-1 in Appendix C. Precipitation volumes measured at Station 53–Chehalis are also included on the graph.

Over the 26-month monitoring period, groundwater elevation patterns at Site 007 were annually consistent and typically followed recorded rainfall with a slight lag. Groundwater elevations fluctuated on the order of 5 to 6 feet over the course of a year with the lowest elevations (442 to 443 feet NAVD88) typically occurring in August and the highest elevations (447.5 to 448.25 feet NAVD88) occurring in November. Groundwater elevations were higher than the water elevations in the pond with a 2 to 3-foot difference observed during the dry season and up to a 5 to 7-foot difference observed during the rainy season. The seasonal decline in groundwater levels that occurred in spring/summer of 2016 was greater than that associated with the spring/summer period of 2017 by about 1 to 1.5 feet. During that period, the pond elevation also dropped below 440.75 feet NAVD88 for an extended period.

Site 007 is outside of the 100-year floodplain of the Chehalis River and lies about 55 feet higher in elevation than the upper river bank (Figure 2). As such, Site 007 is not affected by changes in river levels or overbank flooding. Due to the steepness of the riverbank in this location, no river level monitoring was performed at Site 007. The river reach containing Site 007 was not included in the USGS study of gaining and losing reaches in the Chehalis River mainstem (Appendix E).

Surface water elevations recorded at the two pond monitoring locations at Site 007 were nearly identical throughout the duration of the monitoring period. The surface water elevation in the pond is controlled by a weir and typically remains around 440.75 feet NAVD88, with occasional peaks of up to 441.0 feet NAVD88. Most of these peaks appear to correspond with rainfall events. As noted above, an extended drop in the pond elevation occurred during March to October 2016. During this period, water levels appeared to be below the elevation of the controlling weir and groundwater elevation seemed to have an observable effect on the water elevation in the pond. Although there were several rainfall events during this period, the pond elevation remained below 440.75 feet NAVD88 until mid-October 2016.

### *Temperature Data*

Groundwater, surface water (pond), and mudline temperatures measured at Site 007 during the monitoring period are shown on Figure D-1a (Appendix D) along with the daily low and high temperatures recorded at Station 53–Chehalis. Figure D-1b presents the mudline temperatures at each of the OMLs along with the daily low and high temperatures. As shown on the graphs, ambient air temperatures during the monitoring period varied between -10°C and 37°C with the lowest temperatures typically occurring between December and February and the highest temperatures occurring in June and August.

Groundwater temperatures during the monitoring period showed limited variability across all seasons and typically ranged from approximately 9°C to 12°C. The lowest groundwater temperatures occurred in early summer (May and June) and the highest temperatures occurred in mid-winter (December and January), which is the reverse of the ambient air temperature pattern.

Surface water temperatures at the two OMLs in the off-channel pond at Site 007 varied seasonally with ambient air temperatures and ranged from 3°C in the winter to 23°C at the height of summer (Appendix D, Figure D-1a). Pond water temperature was typically between 0°C to 15°C (average 5°C) higher than the daily low ambient air temperature and 0°C to 20°C (average 6°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes. Recorded temperatures at the two OMLs exhibited similar patterns but typically differed by 1 to 5 degrees in the summer months with the greatest differences occurring between June and September. Surface water temperatures at Site 007's upstream site (S007-OML2) were typically warmer than those at the OML site located closer to the outlet weir (S007-OML1). This difference is likely related to the pond depth because the portion that contains S007-OML1 is considerably deeper than the portion that contains S007-OML2.

Mudline temperatures at S007-OML1 and S007-OML2 ranged from 5°C to 20°C and typically followed the ambient air temperatures (Appendix D, Figure D-1b). Mudline temperatures were typically between 1°C to 17°C (average 7°C) higher than the daily low ambient air temperature and 1°C to 24°C (average 20°C) lower than the daily high ambient air temperature, with the biggest differences observed with the seasonal temperature extremes. As with the surface water temperatures, S007-OML2 was typically warmer than S007-OML1 by between 1 to 5 degrees in the summer months. Groundwater does not appear to overly influence surface water or mudline temperatures in the pond.

### *Site Hydrology Summary*

Based on the water elevation data, groundwater appears to be the primary hydrologic source for the pond at Site 007 with additional inputs from direct precipitation (rainfall that falls directly in the pond or flows into the pond as runoff from the immediate surrounding area) and runoff from the parking areas and roofs of the adjacent Weyerhaeuser facility. Throughout the monitoring period, groundwater levels were between 3 to 7 feet higher than surface water elevations in the pond (Appendix C, Figure C-1).

Given these elevations and the proximity of the GML to the pond (approximately 40 feet away from the edge of the pond, 190 feet away from OML1, and 140 feet away from OML2), it is likely that groundwater influences the water elevation in the pond. Because water elevation in the pond is controlled by a weir, the monitoring data do not show an obvious corresponding change in pond elevation in response to fluctuations in groundwater level. However, the fact that the pond remained full or near full throughout the monitoring period, despite several extended periods of relatively high temperatures during the summer, suggests that the pond is primarily fed by groundwater. Further evidence of this occurs between August and October 2016 when pond levels dipped below full for an extended period. During that time, water elevations in the pond closely followed the groundwater elevation, which had also decreased by an equal amount. Although groundwater seems to be the primary hydrologic source, direct exposure to sunlight and the ambient air temperature appear to have more of an influence on water temperatures than groundwater. This is likely due to the relatively shallow condition of the pond and its location in a mostly open (i.e., unshaded) setting.

## *Site 004*

### Water Elevation Data

Graphs of the groundwater and surface water elevations measured at Site 004 during the monitoring period are provided in Figures C-2a through C-2d in Appendix C. Precipitation volumes measured at Station 53–Chehalis are also included on these graphs.

Groundwater elevation patterns at Site 004 were seasonally consistent across the monitoring period with the lowest elevations recorded at approximately 243 feet NAVD88 between late summer and early fall (August to October) and the highest elevations recorded at 250 to 254 feet NAVD88 in the late fall and early spring (November to March). Throughout much of the monitoring period, groundwater elevations were above the river level and either at or above the elevation of the water in the pond. However, as shown on Figures C-2b and C-2d (Appendix C), there were a few instances (e.g., between November 22 and 29, 2016; between October 15 and 29, 2017; between November 12 and 26, 2017) where the recorded river water level upstream from the site was above the groundwater elevation by up to approximately 2 feet. All these occurrences were of relatively short duration with the river level quickly receding back below the groundwater level within a few days. There were also several instances (e.g., five times between November 22 and December 27; twice between October 15 and 29, 2017; and three times between November 12 and 26, 2017) where the water elevation in the pond peaked higher than the groundwater elevation by less than a foot to nearly 5 feet (Appendix C, Figures C-2b and C-2c). During these occurrences, the pond level typically stayed above the groundwater level for up to a week or more.

As shown in Figure C-2a (Appendix C), the river water elevation data for Site 004 have some gaps due to multiple incidents of equipment damage, particularly with the downstream monitoring location (S004-RML2; Table 3). The data show that the river water level pattern was typically mirrored by both the up- and downstream water surface elevation data with a consistent water level difference of approximately 5 feet due to the presence of an instream rock outcropping located between the up- and downstream monitoring sites. Overall, river elevations were seasonally consistent, with the lower and least variable water surface elevations occurring in the summer and the higher and more variable water surface elevation changes occurring in the winter. Recorded river elevations at the upstream monitoring site (S004-RML1), ranged from a low of around 238 feet NAVD88 in August and September2017 to a high of around 248 feet NAVD88 in November 2016. It is likely that the river reached an even higher elevation at S004-RML1 in mid-February 2017 when the stilling well at the site was destroyed by river debris (Table 3). During that period, a peak river water level of nearly 250 feet NAVD88 was recorded at S004-RML2. Based on the typically observed difference between the up- and downstream monitoring sites, it is likely that the mid-February 2017 flow at S004-RML1 resulted in river elevation of nearly 255 feet NAVD88. Recorded river elevations at S004-RML2 exhibited the most data gaps with the lowest water elevation recorded in July 2016 at approximately 234 NAVD88 and the highest in February 2017 at just under 250 feet NAVD88. It is interesting to note that most of the equipment failures at S004-RML2 occurred during periods of lower river flows while the one major equipment failure at S004-RML1 occurred during a high flow event. In comparing peak water elevation occurrences to precipitation, many of river water elevation peaks correlated well with precipitation events recorded at Station 53–Chehalis; however, there were a few occasions where river water elevation peaks did not seem to track well with the recorded rainfall (e.g., February 2017). These occurrences could be the result of precipitation events that occurred upstream of this site in the Willapa Hills.

Water surface elevations measured at the two pond monitoring stations at Site 004 (S004-OML1 and S004-OML2) were seasonally consistent and essentially identical for most of the monitoring period (Appendix C, Figures C-2a through C-2d). The lowest recorded elevation occurred in July 2016 at approximately 243 feet NAVD88 and the highest recorded elevation occurred in February 2017 at approximately 258 feet NAVD88. With few exceptions, water levels in the pond were nearly always higher than water levels in the Chehalis River and were often about 1 foot or less below groundwater levels. Only one incident was recorded where the river level was higher than the pond level. This occurrence happened between October 15 and 29, 2017, when the river level at S004-RML1 quickly rose 2 to 3 feet higher than the pond level in response to a precipitation event. This peak quickly receded to below the pond elevation within a few days (Appendix C, Figure C-2c). On that occasion, and during most peak elevation events in the pond, the pond elevation would rise above the groundwater elevation by up to 5 feet or so for a short duration before dropping back below groundwater levels within a week or so. One occasion where water elevations at the two pond monitoring sites differed noticeably occurred in early January 2018 when the water elevation of S004-OML1 registered about 0.5 feet lower than that at S004-OML2 for an extended duration following a period of receding water levels in all the monitoring wells (Appendix C, Figure C-2d). As described in Table 3, this occurrence was caused by a downed tree that floated into the pond and came to rest on top of the exposed section of data logger cable for S004-OML2. As the water level in the pond receded, the tree settled onto the cable and lifted the data logger in the well causing it to record a series of incorrect elevation readings. Although the monitoring crew attempted to correct this difference by off-setting the measurements by the length that the data logger had been lifted, the elevations were still different enough to be noticeable on the graph. The elevation recorded by S004-OML1 should be considered the more accurate reading during that period with both elevations essentially the same.

### *Temperature Data*

Groundwater, surface water (river and pond), and mudline temperatures measured at Site 004 during the monitoring period are shown on Figure D-2a (Appendix D) along with the daily low and high temperatures recorded at Station 53–Chehalis. Figure D-2b presents the mudline temperatures at each of the OMLs along with the daily low and high temperatures. As shown on the graphs, ambient air temperatures during the monitoring period varied between -10°C to 37°C with the lowest temperatures typically occurring in December and the highest temperatures occurring in August.

Groundwater temperature was consistently between 10°C to 11°C throughout the monitoring period with the most frequent fluctuations occurring in the summer months. Groundwater temperatures did not appear to have much influence on surface water or mudline temperatures in the pond at Site 004.

River water temperature varied from around 0°C in December 2016 up to a little over 25°C in July 2016 Figure D-2a (Appendix D). Water temperature in the river was typically between 0°C to 18°C (average 6°C) higher than the daily low ambient air temperatures and 0°C to 24°C (average 6°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes. Temperatures recorded at the up- (S004-RML1) and downstream (S004-RML2) monitoring locations were nearly identical until April 2017 when recorded temperatures at the upstream site began to vary noticeably (up to 5 degrees or more) from those recorded at the downstream site. This shift occurred about the same time that a new stilling well was installed at S004-RML1 to replace the original well that was destroyed by river debris (Table 3). Based on the data that were returned for S004-RML1 during this period, it appears that the temperature sensor on that data logger was faulty.

Surface water temperatures recorded at the two OMLs in the off-channel pond at Site 004 varied seasonally with ambient air temperatures and ranged from a low of around 1°C in January to a high of approximately 25°C in August (Appendix D, Figure D-2a). The range and timing of pond water temperatures recorded at the OMLs were much the same as those observed at the RMLs for the Chehalis River. Pond water temperature was typically between 0°C to 15°C (average 7°C) higher than the daily low ambient air temperatures and 0°C to 19°C (average 4°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes. Recorded temperatures at the two OMLs exhibited similar patterns but typically differed in temperature by 1 to 2 degrees with temperatures ranging from a low of around 2°C in December 2016 to a high of approximately 27°C in August 2016 (Appendix D, Figure D-2a). Surface water temperatures at the more northern of the two sites (S004-OML) were often warmer than those that at the OML closer to the Nicholson Creek inlet (S004-OML2; Figure 3).

Mudline temperatures at S004-OML1 and S004-OML2 ranged from approximately 3°C in the winter to 22°C in late summer and typically followed the ambient air temperatures (Appendix D, Figure D-2b). Mudline temperatures were typically between 0°C to 13°C (average 6°C) higher than the daily low ambient air temperature and 0°C to 20°C (average 6°C) lower than the daily high ambient air temperature, with the biggest differences observed with the seasonal temperature extremes. As with the surface water temperatures, S004-OML1 was typically warmer than S004-OML2 by 0.5 to 1 degree.

### *Site Hydrology Summary*

The primary hydrology sources for Site 004 are direct precipitation, flow from Nicholson Creek, and groundwater. Water entering the pond from the river via overbank flooding is unlikely in this location due to the height of the former railroad (i.e., constructed) embankment that separates the pond from the river. Based on the preliminary HEC-RAS modeling for the Chehalis River, the 100-year flow event would not overtop the river bank in this location. However, an overbank connection could occur about 1,000 feet upstream of the site in the location where a tributary enters the Chehalis River near RM 93.9, allowing floodwaters to enter the Site 004 pond from the northwest via overland flow. In that upstream location, the overtopping elevation would be about 260 feet NAVD88. In the HEC-RAS modeling, a 20-year event water surface elevation is approximately 258.7 feet NAVD88 and a 100-year event water surface elevation is approximately 263.1 feet NAVD88, so Site 004 is unlikely to be affected by overland flow from the Chehalis River until somewhere above a 20-year flood event.

In the absence of an overbank or overland connection, the primary point of interaction between the Site 004 pond and the Chehalis River occurs through the existing 36-inch diameter concrete culvert that extends under the Willapa Hills Trail embankment at the southwest end of the pond (Figure 3)[2]. The inlet and outlet elevations and slope of that culvert, which is sometimes referred to as the Nicholson Creek culvert, are unknown[3]. Given that measured water levels in the pond never dropped below approximately 243 feet NAVD88, even during the driest times of the monitoring period when river levels were below 240 feet NAVD88, the culvert invert may be at or slightly above that elevation. When river levels rise above 243 feet NAVD88, the water elevations at the two monitoring locations in the pond appear to respond in time and magnitude. This could either be a situation where the increasing water elevation in the pond is caused by the same precipitation events affecting the river (via direct precipitation and surface inflow from Nicholson Creek and other sources) or potentially an instance where the river is pushing water through the culvert and into the pond.

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[2] Based on information from a June 17, 2014 subsurface exploration and geotechnical assessment conducted for the replacement of the existing 36-inch diameter concrete culvert by Associated Earth Sciences, Inc., for the Washington State Parks and Recreation Commission, water from the pond may also be seeping through the Willapa Hills Trail embankment in certain locations (AES 2014).

[3] The 2014 Associated Earth Sciences report lists the culvert inlet and outlet elevation as 281.38 feet and 279.57 feet, respectively based on an unspecified project datum (AES 2008). Because those elevations are nearly 30 higher than the elevations shown on the LiDAR surface being used for the Chehalis Basin modeling work (Figure 3) and the monitoring well and benchmark survey work that Foresight Surveying, Inc. performed for Anchor QEA for the Project, they were determined to be unusable for the Project.

A potential example of the elevations being affected by the same precipitation event occurs around November 15, 2016, when a relatively large precipitation event (approximately 0.4 inches of rainfall in 15 minutes) was followed within a day or two by a steep rise in both the river and pond water surface elevations (Appendix C, Figure C-2b). Figure C-2b shows the pond elevation increased along with the river elevation but remained around 2 to 3 feet higher than the river level. Given the limited conveyance capacity of the culvert and the fact that it is known to be further compromised by debris blockages around the inlet and possibly by a previous internal repair (Douville 2017), it seems unlikely that the river alone would be responsible for elevated water level in the pond. Rather, the increase water elevation is more likely attributable to inflow from Nicholson Creek and to a lesser degree, the other surface inlets that discharge to the pond (Figure 3). Similar instances occur between November 22 and December 27, 2016, (Appendix C, Figure C-2b) and November 12 and 26, 2017 (Appendix C, Figure C-2c).

One event captured between October 15 and 29, 2017, (Appendix C, Figure C-2c) could be indicative of the scenario where the river could be pushing water into the pond through the culvert. In that instance, both the river and pond water levels rose rapidly, seemingly in response to two relatively heavy precipitation events in Chehalis area. While the pond elevation peaked at around 246 feet NAVD88, the water level in the river continued to rise to around 248 feet NAVD88. Under such conditions, it might be possible for river water to backflow into the pond through the culvert. Again, such an interaction would be limited by the conveyance capacity of the culvert, which could explain the difference in the peak elevations. However, because this type of situation only occurred once during the monitoring period and the volume of water contributed to the pond by Nicholson Creek is unknown, there is insufficient data to prove that river level influenced the pond elevation through the existing culvert on that occasion.

Overall, the data collected at Site 004 during the monitoring period suggest that the off-channel pond at Site 004 is not reliant on the Chehalis River for hydrology. Occasions when water in the pond was higher than groundwater appear to correspond with periods when the river water level was above approximately 244 feet NAVD88, which could indicate rainfall events that cause river levels to rise with additional input from Nicholson Creek. Instances where the river water level extended above the groundwater elevation could represent short-term flood events where Nicholson Creek rose due to localized rainfall, resulting in an increase in pond level but little effect on groundwater levels. Or, such instances could be short-term events where water levels in the Chehalis River receded more quickly than groundwater could respond.

In their seepage study of the mainstem Chehalis River, USGS identified the section of river that includes Site 004 as a losing reach (Ely et al. 2008; Appendix E). In losing reaches, the typical surface-to-groundwater interaction is discharge of surface water to groundwater. The data collected during the monitoring period seem more indicative of a gaining reach where groundwater is discharging to surface water. However, the reach length studied in the USGS report was approximately 4 miles long and conditions could vary within that reach both due to location and seasonality.

## Site 068

### Water Elevation Data

Graphs of the groundwater and surface water elevations measured at Site 068 during the monitoring period are provided in Figures C-3a through C-3d in Appendix C. Precipitation volumes measured at Station 53–Chehalis are also included on these graphs.

Groundwater elevation patterns at Site 068 varied seasonally across the monitoring period with the lowest levels typically observed during late summer or early fall and highest levels during the late fall and winter (Appendix C, Figures C-3a through C-3d). The lowest groundwater level recorded was approximately 172 feet NAVD88 in mid-October 2016 and the highest was nearly 190 feet NAVD88 in mid-February 2017. The seasonal groundwater elevation range was more typically about 10 feet during the monitoring period. Throughout the monitoring period, groundwater elevation was consistently 2 to 5 feet higher than pond water levels and usually higher than the water level in the river. Groundwater levels appear to be closely associated with river levels once the river elevation rose above about 172 feet NAVD88.

River elevations recorded at Site 068 during the monitoring period varied from around 153 feet NAVD88 to 185 feet NAVD88 and were nearly identical at both RMLs (Appendix C, Figures C-3a through C-3d). The lowest levels occurred between June and September and the highest between October and May. Data collected at the downstream RML (S068-RML2) included two periods where the stilling well was essentially dry. These occurrences appear as straight lines on the graph and generally occurred between June and September 2016 and July and September 2017. Once the river water level surpasses approximately 176 feet NAVD88, overbank flooding begins to occur through the low-lying swale that connects the river with the downstream end of the pond. This occurred several times during the monitoring period, with the largest event occurring in early February 2017 (Appendix C, Figure C-3c). Both groundwater and pond elevations also peaked during this occurrence with groundwater rising to about 190 feet NAVD88, about 5 feet higher than the river elevation, and the pond elevation rising to nearly the same elevation as the river. As the river level receded, both pond and the groundwater levels declined at about the same rate to within 1 to 2 feet of one another with the groundwater always at a higher elevation than the pond.

During the monitoring period, surface water elevations measured at the OMLs in the off-channel pond at Site 068 were nearly identical and varied consistently with the seasons. The lowest water level recorded at both sites was just under 170 feet NAVD88 between late July and late October of both monitoring years. The highest water level recorded was approximately 184 feet NAVD88 in February 2017. The pond did not completely dry during the monitoring period and is likely supported by groundwater much of the year as groundwater levels are consistently 2 to 5 feet higher than pond water levels. Based on a review of DEM developed from the LiDAR data, the pond begins receiving overbank flows from the river once the river water elevation tops about 176 feet NAVD88. At that elevation, water from the river begins entering the site from the low-lying swale that extends between the pond and the river near RM 76.4. As the water elevation in the river recedes, the pond elevation steadily drops until it reaches approximately 175 feet NAVD88. Below 175 feet NAVD88, the pond water level recedes more slowly staying at a higher elevation than the river, typically retaining between 1 to 5 feet of water until mid-summer. According to the preliminary HEC-RAS model, the pond at Site 068 can also receive floodwater from an upstream connection at RM 76.7 when river levels reach approximately 182 feet NAVD88. According to the monitoring data, that elevation was exceeded twice during the monitoring period, in November 2016 and February 2017. During these events (i.e., river water levels above 176 feed NAVD88) water levels in the river and pond are essentially the same.

### *Temperature Data*

Groundwater, surface water (river and pond), and mudline temperatures measured at Site 068 during the monitoring period are shown on Figure D-3a (Appendix D) along with the daily low and high temperatures recorded at Station 53–Chehalis. Figure D-2b presents the mudline temperatures at each of the OMLs along with the daily low and high temperatures. For both graphs, temperature data for days when the monitoring wells were dry (i.e., when data loggers were not submersed in water) for extended periods[4] were removed from the temperature graphs. Under such conditions, the temperature sensors do not provide measurements of water temperature but ambient air temperature within the stilling well pipe. As such, they were not considered to be useful for the analysis. As shown on the graphs, ambient air temperatures during the monitoring period varied between slightly below -10°C to around 37°C with the lowest temperatures typically occurring in January 2016 and the highest temperatures occurring in August 2016.

As shown in Figure D-3a (Appendix D), groundwater temperature was consistently about 12°C throughout the monitoring period with the most frequent but still small fluctuations occurring around the same time as the coldest recorded air temperature (January 2016). Groundwater temperatures did not seem to be greatly influenced by ambient air or surface water temperatures.

River water temperatures recorded at the up- (S068-RML1) and downstream (S068-RML2) monitoring locations were essentially the same throughout the monitoring period and ranged from just above 0°C in January 2016 to a peak of around 26°C in July 2016. River water temperature varied seasonally and in response to ambient air temperature, with river water temperatures being typically between 0°C to 15°C (average 6°C) higher than the daily low ambient air temperatures and 0°C to 21°C (average 5°C) lower than the daily high ambient air temperature (Appendix D, Figure D-3a). As expected, the biggest differences observed between ambient air and river temperature occurred during the seasonal temperature extremes.

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[4] Extended dry periods for Site 068 included the following:

- RML2: 5/6/2016 to 5/24/2016, 6/29/2016 to 10/19/2016, and 7/18/2017 to 10/19/2017

Surface water temperatures recorded at S068-OML1 and S068-OML2 varied seasonally with ambient air temperatures from a low of around 3°C in January 2016 to a high of approximately 27°C in June 2016 (Appendix D, Figure D-3a). Surface water temperature in the off-channel pond was typically between 0°C to 17°C (average 8°C) higher than the daily low ambient air temperatures and 0°C to 16°C (average 4°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes. Both sites exhibited similar seasonal patterns but typically differed in temperature by 2 to 3 degrees with slightly higher temperatures recorded at S068-OML1 (Figure D-3a Appendix D). This may be explained by S068-OML1 being located in a shallower section of the pond than S068-OML2 (Figure 4).

Mudline temperature measurements at S068-OML1 and S068-OML2 varied seasonally with ambient air temperature during the monitoring period (Appendix D, Figure D-3b). Mudline temperatures recorded at S068-OML1 ranged from a minimum of about 5°C in January 2017 to a maximum of about 18°C in July 2016 while those recorded at S068-OML2 ranged from a minimum of about 3°C in January 2017 to a maximum of about 17°C in late August 2017. Mudline temperatures recorded at S068-OML2 were consistently cooler than S0068-OML1 by up to 5 degrees. In comparison to ambient air temperatures, mudline temperatures at both monitoring locations were typically between 0°C to 16°C (average 6°C) higher than the daily low ambient air temperature. Variation from the daily high ambient air temperature was notably different at each monitoring location with mudline temperatures at S068-OML1 being between 0°C to 21°C (average 13°C) lower than the daily high ambient air temperature and mudline temperatures at S068-OML2 being between 0°C to 35°C (average 13°C) lower than the daily high ambient air temperature. Again, the water and mudline temperature differences between the two OMLs may be due to the differing surface water depths at each location but could also indicate the groundwater influence of a spring in the vicinity of S068-OML2.

### *Site Hydrology Summary*

Site 068 receives water from direct precipitation, groundwater, and overbank flooding. Groundwater appears to discharge to both the river and pond in this location, which is consistent with the gaining reach designation assigned to this section of the river by USGS (Ely et al. 2008; Appendix E). While groundwater is a primary input to the pond, contributions from overbank flooding seem to be necessary to fill the pond to its capacity during the winter months. Based on the preliminary HEC-RAS model and the DEM developed from LiDAR data, the river first connects with the downstream end of the Site 068 pond at river levels of above approximately 176 feet NAVD 88 via a swale near RM 76.4 (Figure 4). Overbank connection can also occur on the upstream end of the pond when the river level is above 182 feet NAVD88. Based on the preliminary HEC-RAS model, the 176-foot NAVD88 elevation equates to a flow event of approximately 13,000 cfs, which could be expected to occur during a less than 2-year flood event. The 182-foot NAVD88 elevation equates to a flow event of approximately 20,900 cfs, which could be expected to occur at some point during a 2- to 10-year flood event. It appears that once fully filled, the pond drains relatively slowly, retaining some of water throughout the year.

## Site 020

### *Water Elevation Data*

Graphs of the groundwater and surface water elevations measured at Site 020 during the monitoring period are provided in Figures C-4a through C-4d in Appendix C. Precipitation volumes measured at Station 53–Chehalis are also included on these graphs.

The groundwater monitoring well at Site 020 is an actively pumped domestic well, as indicated by the repeated daily drawdowns in groundwater elevation shown on the data graphs (Appendix C, Figures C-4a, C-4b, and C-4c). The recovery elevations shown on the graph are assumed to define the static water level in the well. During the monitoring period, groundwater levels under non-pumping conditions ranged from a low around 164 feet NAVD88 in September 2016 to around 176 feet NAVD88 in February 2017. Overall, the seasonal pattern of observed groundwater levels appears to be consistent with the seasonal patterns for precipitation. However, data collected during the monitoring period indicate that elevated water levels in the river can cause the groundwater level to rapidly rise. For example, in November 2016, the river water level rose rapidly from around 160 feet NAVD88 to around 183 feet NAVD88, an approximate change of 23 feet (Appendix C, Figure C-4a). During this same period, groundwater levels rose quickly from around 168 feet NAVD88 to around 175 feet NAVD88 and remained in that elevated state for several months. Similar examples of this response were observed in late January 2017, March 2017, between September and December 2017, and between April and May 2018 (Appendix C, Figures C-4a through C-4d). Groundwater levels were typically below the bottom elevation of the off-channel ponds from early summer (June) through late fall (November) during both monitoring years, but at or above pond water elevations from early winter (December) through spring (May).

Site 020 shared the same set of river monitoring locations with Site 068, so the minimum and maximum river elevation observations noted under Site 068 are also applicable to this site. Figures C-4a through C-4d (Appendix C) show the river elevation monitoring data overlain with the groundwater and off-channel pond data collected at Site 020. According to LiDAR topography, water from the river can potentially flow into the northern end of larger pond via what is presumed to be a former river channel near RM 76.5. This connection appears to form when river levels rise past 175 feet NAVD88, flows through the former channel, and crests a small earthen check dam located at the northern end of the pond. Once the larger pond fills to above approximately 173 feet NAVD88, water can flow into the smaller pond via a low-lying area at its southern end. It appears that both ponds can also be inundated by overbank flows from a location further upstream near RM 76.9 when river flow elevations exceed approximately 182 feet NAVD88. Based on the preliminary HEC-RAS model, the 175-foot NAVD88 elevation equates to a flow event of approximately 12,300 cfs, which could be expected to occur during a less than 2-year flood event. The 182-foot NAVD88 elevation equates to a flow event of approximately 20,900 cfs, which could be expected to occur some point between a 2- to 10-year flood event.

Unlike the other Project monitoring sites, the OMLs at Site 020 are located in ponds that are separated during lower water levels essentially creating two ponds. S020-OML1 is located in a smaller, shallower pond, and S020-OML2 is located in the larger oxbow pond (Figure 5). As previously stated in the site description section, these ponds are separated from one another by an area of higher ground, although they can connect through a narrow area on their southern ends during high water events. As such, the water elevations collected in these areas were different from one another but were still consistent with seasonal variations (i.e., water elevations are lower in the summer and higher in the winter). As shown in Figures C-4a through C-4d (Appendix C), data collected at S020-OML1 indicate that water levels in the smaller pond ranged from a minimum elevation of about 169 feet NAVD88 to a maximum elevation of around 175 feet NAVD88, a difference of about 6 feet. The presence of the straight horizontal line on the graph at the 169-foot NAVD88 elevation between May and November 2016 and June and October 2017 is indicative of a lack of surface water and is assumed to be the approximate bottom elevation of the pond in the location of the monitoring well. As shown on the graph, the water level in the smaller pond dropped as groundwater levels declined in the summer. This decline continued until the pond went dry. The smaller pond remained dry into the fall until groundwater levels rose above 169 feet NAVD88 in response to increased precipitation and rising river levels. Above 169 feet NAVD88 the pond elevation tracked the groundwater elevation fairly closely and again declined to a dry state as groundwater dropped below 169 feet NAVD88. If river levels rise above 175 feet NAVD88, the pond may also receive some surface water flow from the larger oxbow pond through the low-lying area at its southern end or if river levels rise above 185 feet NAVD88, it could receive overbank flow directly from the river.

Water levels in the larger pond at S004-OML2 ranged from approximately 167 feet NAVD88 to approximately 173 feet NAVD88, a difference of about 6 feet. Again, the straight horizontal line at 167 feet NAVD88 between June and October 2016 is likely indicative of near dry conditions in the larger pond. From this dry condition, pond elevations started to rise with rising groundwater in the fall in response to increased precipitation and rising river levels. When river levels rose past approximately 175 feet NAVD88, flows from the river moved into the oxbow pond through the former channel to the north. Once flooded, the pond continued to be refreshed by the river when elevations were sufficient to form the connection. With these repeated recharges, the oxbow pond retained water for a longer period than the smaller pond, even as groundwater levels dropped below the pond elevation. When it is full, the oxbow pond may connect with the smaller pond if water elevations in it rise above 175 feet NAVD88. Groundwater appeared to influence the smaller pond (S020-OML1) more often than the larger pond (S020-OML2) whose hydrology seems more closely tied to river water level. The larger pond also receives water from an older drain tile that enters from the south, the hydrologic contribution of which is largely unknown.

### *Temperature Data*

Groundwater, surface water (river and pond), and mudline temperatures measured at Site 020 during the monitoring period are shown on Figure D-4a (Appendix D) along with the daily low and high temperatures recorded at Station 53–Chehalis. Figure D-4b presents the mudline temperatures at each of the OMLs along with the daily low and high temperatures. As with Site 068, temperature data for days when the monitoring wells were dry (i.e., when data loggers were not submersed in water) for extended periods[5] were removed from the temperature graphs. Under such conditions, the temperature sensors do not provide measurements of water temperature but ambient air temperature within the stilling well pipe. As shown on the graphs, ambient air temperatures during the monitoring period varied between slightly below -10°C to around 37°C with the lowest temperatures typically occurring between November and March and the highest temperatures occurring between June and September.

Groundwater temperature was consistently between 10°C to 11°C throughout the monitoring period with more frequent and larger fluctuations occurring throughout the monitoring period than observed at the other sites. These small changes may be associated with the operating domestic water pump at this site, which changes the groundwater elevation by up to 10 feet on a daily basis.

River water temperatures recorded at the up- (S020-RML1) and downstream (S020-RML2) monitoring locations were essentially the same throughout the monitoring period and ranged from just above 0°C in January 2016 to a peak of around 26°C in July 2016. River water temperature varied seasonally and in response to ambient air temperature, with river water temperatures being typically between 0°C to 15°C (average 6°C) higher than the daily low ambient air temperatures and 0°C to 21°C (average 5°C) lower than the daily high ambient air temperature (Appendix D, Figure D-3a). As expected, the biggest differences observed between ambient air and river temperature occurred during the seasonal temperature extremes. Surface water temperatures recorded at S020-OML1 varied from a low of around 2°C in early January 2017 to a high of near 21°C in late May 2018. The pond containing S020-OML1 was dry or near dry between early June and mid-November (the periods of the highest ambient air temperature) during both monitoring years so there were no accurate water temperatures recorded during those periods. Surface water temperatures at S020-OML2 varied from a low of around 3°C in mid-January 2017 to a high of approximately 20°C in late June 2016. The pond containing S020-OML2 was dry from mid-June to late-October during 2016 and for about 3 consecutive days in September 2017; pond water temperatures were not available during those periods. Both monitoring sites exhibited similar seasonal patterns but typically differed in temperature by 5 to 15 degrees with the more extreme temperatures recorded at S020-OML1 in the small shallow pond. This is likely explained by the fact that the smaller pond is smaller, shallower, and does not hold water as long as the larger pond (Figure 5). Pond water temperature was typically between 0°C to 14°C (average 6°C) higher than the daily low ambient air temperatures and 0°C to 20°C (average 6°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes.

[5] Extended dry periods for Site 020 include the following:

- RML2: 5/6/2016 to 5/24/2016, 6/29/2016 to 10/19/2016, and 7/18/2017 to 10/19/2017
- OML1: 4/25/2016 to 11/24/2016 and 6/4/2017 to 11/20 2017
- OML2: 6/27/2016 to 10/26/2016 and 9/4/2017 to 9/6/2017

Surface water temperatures measured at S020-OML2 typically exhibited a larger range of variation with ambient air temperatures than S020-OML2.

Mudline temperature measurements at S020-OML1 and S020-OML2 also varied seasonally with ambient air temperatures with S068-OML1 being slightly warmer than S068-OML2 in the spring/summer and cooler than S068-OML2 in the fall and winter (Appendix D, Figure D-4b). Again, this is likely due to the presence of lengthy dry periods in the smaller pond. Mudline temperatures recorded at S020-OML1 ranged from a minimum of about 4°C in February 2017 to a maximum of around 22°C in May 2017 while those recorded at S020-OML2 ranged from a minimum of about 4°C in mid-January 2017 to a maximum of about 20°C in late June 2016. Mudline temperatures were typically between 0°C to 18°C (average 6°C) higher than the daily low ambient air temperature and 0°C to 23°C (average 6°C) lower than the daily high ambient air temperature, with the biggest differences observed with the seasonal temperature extremes. As with surface water, mudline temperatures measured at S020-OML2 typically exhibited a slightly larger range of variation with ambient air temperatures than S020-OML2.

### *Site Hydrology Summary*

Based on the monitoring data, Site 020 receives hydrology from both groundwater, drainage tile, and overbank flows with the smaller pond being primarily driven by groundwater and the larger pond being more influenced by the river and drain tile input. Both ponds go dry during the summer with the smaller pond remaining dry for a much longer period than the larger oxbow pond, possibly due to input from the drain tile. Following this dry period, groundwater influences water elevations in the oxbow pond until the river elevation rises enough to form an overland connection with that pond. The larger pond can also form an overland connection to the smaller pond. In addition to a seasonal connection to the ponds, groundwater appears to discharge to the river throughout most of the year, along with discharge from the ponds as they drain, which is consistent with the gaining reach designation assigned to this section of the river by USGS (Ely et al. 2008; Appendix E).

## *Site 086*

### *Water Elevation Data*

Graphs of the groundwater and surface water elevations measured at Site 086 during the monitoring period are provided in Figures C-5a and C-5b in Appendix C. Precipitation volumes measured at Station 49–Montesano Station are also included on these graphs.

Groundwater elevation patterns at Site 086 were seasonally consistent across the monitoring period with the lowest elevations recorded at approximately 43 feet NAVD88 in August and September and the highest elevations recorded at approximately 56 feet NAVD88 in early November and late January (Appendix C, Figure C-5a). Throughout much of the monitoring period, groundwater elevations were either at or above the elevation of the water in the pond by less than a foot. However, as shown on Figure C-5b (Appendix C), there are several instances (e.g., between November 15, 2016 and December

20, 2016; between November 12 and 26, 2017) where the water elevation in the pond peaked higher than the groundwater elevation and a few instances between mid-October and late November where the pond elevation peaked above the groundwater level for very short durations.

As shown in Figure C-5 (Appendix C), the river elevation data for the upstream and downstream monitoring location at Site 086 are nearly identical and vary as expected with the seasons (lower flow in the summer and fall and higher flows in the winter and spring). Recorded river elevations range from a low of around 41 feet NAVD88 in August 2016 to a high around 56 feet NAVD88 in January 2016. Elevations measured at the downstream site (S086-RML1) tended to be up to a foot lower than the elevations measured at the upstream site (S086-RML2).

Water elevations recorded at the OMLs follow the groundwater elevation closely, with groundwater being up to 1 foot higher during the wetter time of the year (September to May). During both monitoring years, river elevations rose in late September/early October and inundated the pond. According to the preliminary HEC-RAS model, the connection that facilitates this initially occurs on the downstream of the site near RM 35.8 when river elevations exceed 45 feet NAVD88. An upstream connection also forms near RM 37.1 at 56 feet NAVD88. These conditions correspond to flows of 6,000 cfs and 23,000 cfs, respectively. Of those flows, the 6,000 cfs flow occurs an average of about 75 days per year and the 23,000 cfs flows would be expected to occur under a less than 2-year flood event. The river elevation data collected during the monitoring period indicate that the downstream connection was likely maintained throughout most of the winter while the upstream connection occurred less frequently.

#### *Temperature Data*

Groundwater, surface water (river and pond), and mudline temperatures measured at Site 086 during the monitoring period are shown on Figure D-5a (Appendix D) along with the daily low and high temperatures recorded at Station 49–Montesano Station. Figure D-4b presents the mudline temperatures at each of the OMLs along with the daily low and high temperatures. As shown on the graphs, ambient air temperatures during the monitoring period varied between a low of around -8°C to a high of around 36°C with the lowest temperatures typically occurring in late December of both years and the highest temperatures occurring in mid-August of both years.

Groundwater temperature typically varied between 10°C to 14°C throughout the monitoring period with one sudden 5-degree drop down to about 8°C occurring sometime in February 2017 (Appendix D, Figure D-5a). The reason for this dip is unknown; it may be a recording error. In general, groundwater temperatures at Site 086 seemed to fluctuation more than was observed at the other monitoring sites, but there were no obvious relationships observed between these temperatures and the ambient air or surface water temperatures.

River water temperature typically varied from a low of around 2°C in January 2017 up to around 25°C in July 2016 and August 2017 Figure D-4a (Appendix D). Temperatures recorded at the upstream river monitoring site (S086-RML2) were often up to 5 degrees cooler than those measured at downstream river monitoring site (S086-RML1) during the summer and up to 7 degrees warmer during the winter months. This could be caused by differing water depths. For example, a relatively shallow area in the river might show a greater temperature variation than a deeper area under both hot and cold conditions. The downstream monitoring site is located in an eddy where there is reverse current flow and more stagnant water. In contrast, the upstream monitoring site is located in a section of river that receives relatively steady downstream flow.

Surface water temperatures recorded at the OMLs were nearly identical until February 2017 when the temperature sensor in S086-OML2 failed (see Table 3). Low and high temperatures recorded in these locations ranged from 3°C to around 29°C, with the coldest temperature occurring in January 2017 and the warmest in July 2016. Pond water temperature at both monitoring sites was typically between 0°C to 16°C (average 8°C) higher than the daily low ambient air temperatures and 0°C to 12°C (average 3°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes.

Mudline temperature measurements at S086-OML1 and S086-OML2 followed the same pattern with a slight difference of less than one degree up until October 2017 (Appendix D, Figure D-5b). After that point, they consistently diverge from one another by 1 to 3 degrees (S086-OML1 recording cooler temperatures) until March 2018 when they again begin to track each other closely. This period of greater variation between the two sites may be associated with the OML2 data logger being hung up on debris and out of the water for an extended period (see Table 3). When compared to ambient air temperatures, mudline temperature measured at S086-OML1 and S086-OML2 were typically between 0°C to 16°C (average 6°C) higher than the daily low ambient air temperatures and 0°C to 21°C (average 5°C) lower than the daily high ambient air temperature, with the biggest differences occurring with the seasonal temperature extremes.

### *Site Hydrology Summary*

The primary hydrology sources for Site 086 include both groundwater and overbank flow from the river. The off-channel pond at this site typically retains water year-round with water levels supported by groundwater during the drier months and by overbank flow during the wetter months. The pond initially connects to the river on the downstream end at river elevations of above approximately 45 feet NAVD88, which corresponds to a flow of approximately 6,000 cfs. It can also connect on the upstream end when river elevations exceed 56 feet NAVD88 or a flow of about 23,000 cfs. Of those flows, the 6,000 cfs flow occurs an average of about 75 days per year and the 23,000 cfs flows would be expected to occur under a less than 2-year flood event. Groundwater elevations remain higher than river elevations throughout most of the year, indicating the groundwater likely discharges to the river, which is consistent with the gaining reach designation assigned to this section of the river by USGS (Ely et al. 2008; Appendix E).

### River Flow Measurement Results

The results of the ADCP survey are summarized in Appendix F, Table F-1. This table includes the discharge and velocity measurements made during the three sets of ADCP transects, water level elevation data from stilling wells S068/S020-RML1 and S068/S020-RML2, and the water level elevation and discharge data from the Adna gage. Overall, ADCP transects presented from a given set were found to be within 3% of the average discharge calculated by the ADCP unit and the discharge recorded at the Adna gage for the given period. When looked at together, this variation in flow values was not consistently greater than or less than the flow measurements recorded at the Adna gage. When considered separately, however, the downstream set of ADCP transects did show consistently higher flow rates than those measured at the gage; on average these flows were 2% higher than those recorded the Adna gage. The other two sets of transects varied between being slightly above and slightly below the flow measured at the Adna gage.

On April 24, 2017, discharge and water level elevations in the Chehalis River increased over the course of the day in response to precipitation throughout the Chehalis Basin. Discharge measured by the ADCP at the different transect locations and times ranged from 1,774 to 2,143 cfs. Despite increasing flows, there was agreement between the discharge measurements made by the ADCP and the upstream Adna gage. This indicates there were only minor contributions to flow between the Adna gage and the location of the transects during this time. These data were given to WSE for incorporation into their hydraulic model. Future ADCP surveys under higher discharge conditions may further benefit the model. Decisions regarding the need for this work will be made in consultation with the Office of Chehalis Basin.

## Summary

Based on the ground- and surface-water elevation and temperature data collected during the Project, notable observations include the following:

- All monitoring sites are reliant on groundwater as a hydrologic input to some degree
- Sites 004 and 007 are primarily supported by groundwater and non-Chehalis River surface water inputs (e.g., Nicholson Creek, runoff from the parking areas and roofs of the Weyerhaeuser facility) with limited (Site 004) to no (Site 007) input from the Chehalis River
- At Site 004, the contribution of river flow to pond hydrology via the existing 36-inch diameter culvert is not fully understood due to limited information on the culvert and how it behaves under elevated river levels. The amount of flow that Nicholson Creek and the other pond inlets contribute is also unknown but are primary sources of hydrology that help sustain water levels in the pond.

- For Sites 068, 020, and 086, groundwater provides a sustaining hydrologic source during the summer and fall, but overbank flows from the Chehalis River in the spring and winter are required to recharge and fully inundate the off-channel ponds.
- The off-channel ponds at Sites 068, 020, and 086 will all receive overbank flow from at least one connection point with the Chehalis River during the 2-year flow event, and from at least two connection points during the 10-year flow event.
- The off-site pond at Site 004 would likely receive overbank flow from the Chehalis River during a 100-year flow event; flow would not overtop the Willapa Hills Trail embankment at that site but would come in from a connection at an upstream location.
- Site 020 appears to have the most complex hydrology. It can potentially receive water from multiple sources and nearly all directions including groundwater, overbank flow from multiple locations along the Chehalis River, overland flow from Newaukum River flooding, and possibly piped flow from an agricultural drainage tile and overland flow down existing roads.
- The off-channel ponds at Sites 007, 004, 068, and 086 likely contain standing water all year long; the off-channel ponds at Site 020 likely dry up in the mid- to late-summer during most years.
- Surface water temperatures in the off-channel ponds fluctuate daily and seasonally similar to Chehalis River water temperatures.
- Mudline temperatures were observed to fluctuate seasonally, but do not fluctuate much daily.
- Groundwater temperatures remain fairly constant with slight seasonal variations.
- Surface water temperature in the off-channel ponds appears to be more strongly influenced by ambient air temperature than groundwater.
- Seasonal surface water temperature variations in the off-channel ponds are influenced by water depth, as demonstrated by pond temperatures often being higher than river temperatures during summer.
- River flow data calculated using ACDP were found to be within 3% of the average discharge amounts recorded at the Adna gage for the period of survey.

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# Figures

**Figure 1**
**Site Locations Map**

**Figure 2**
**Monitoring Locations at Site 007**

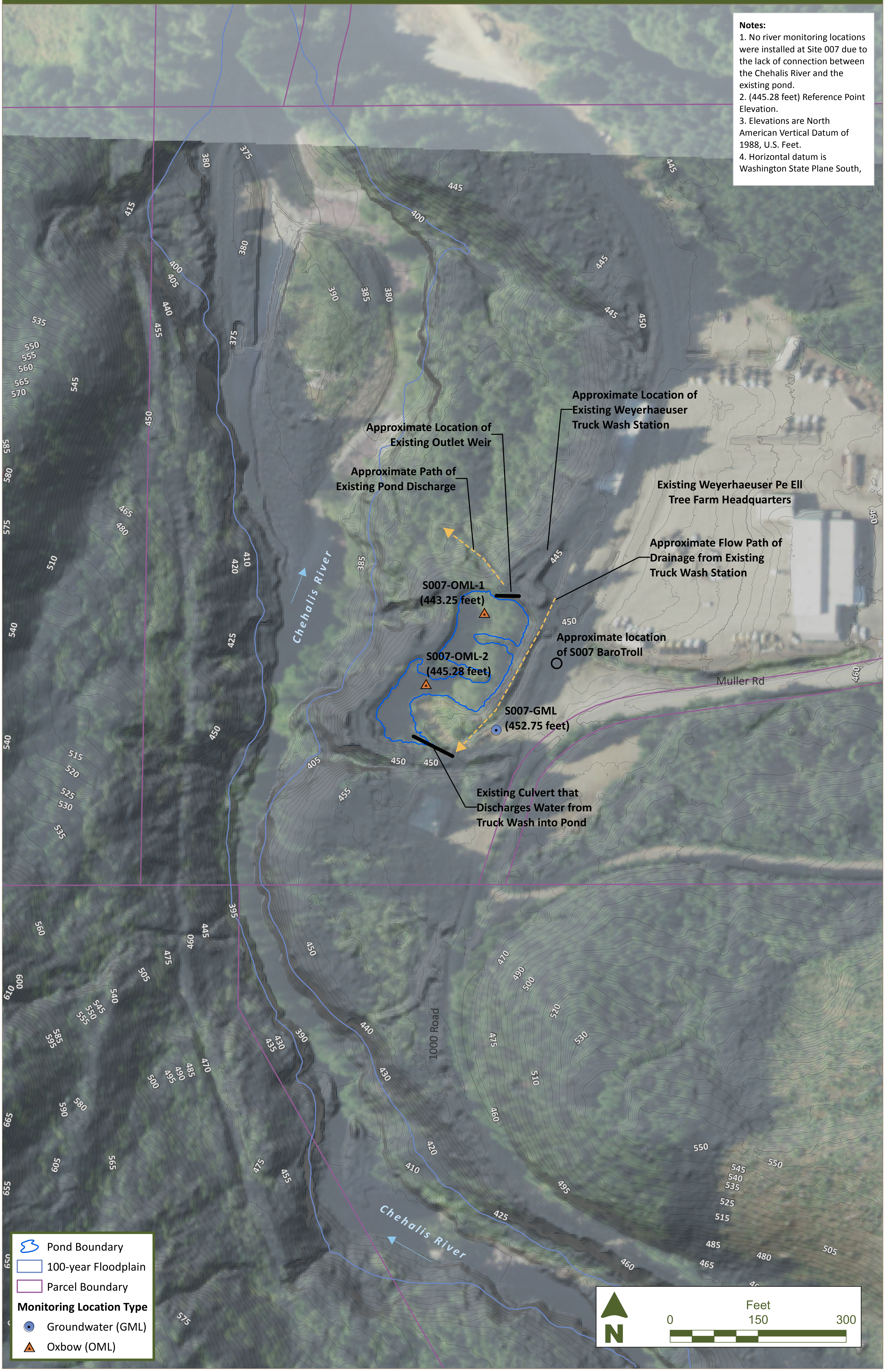
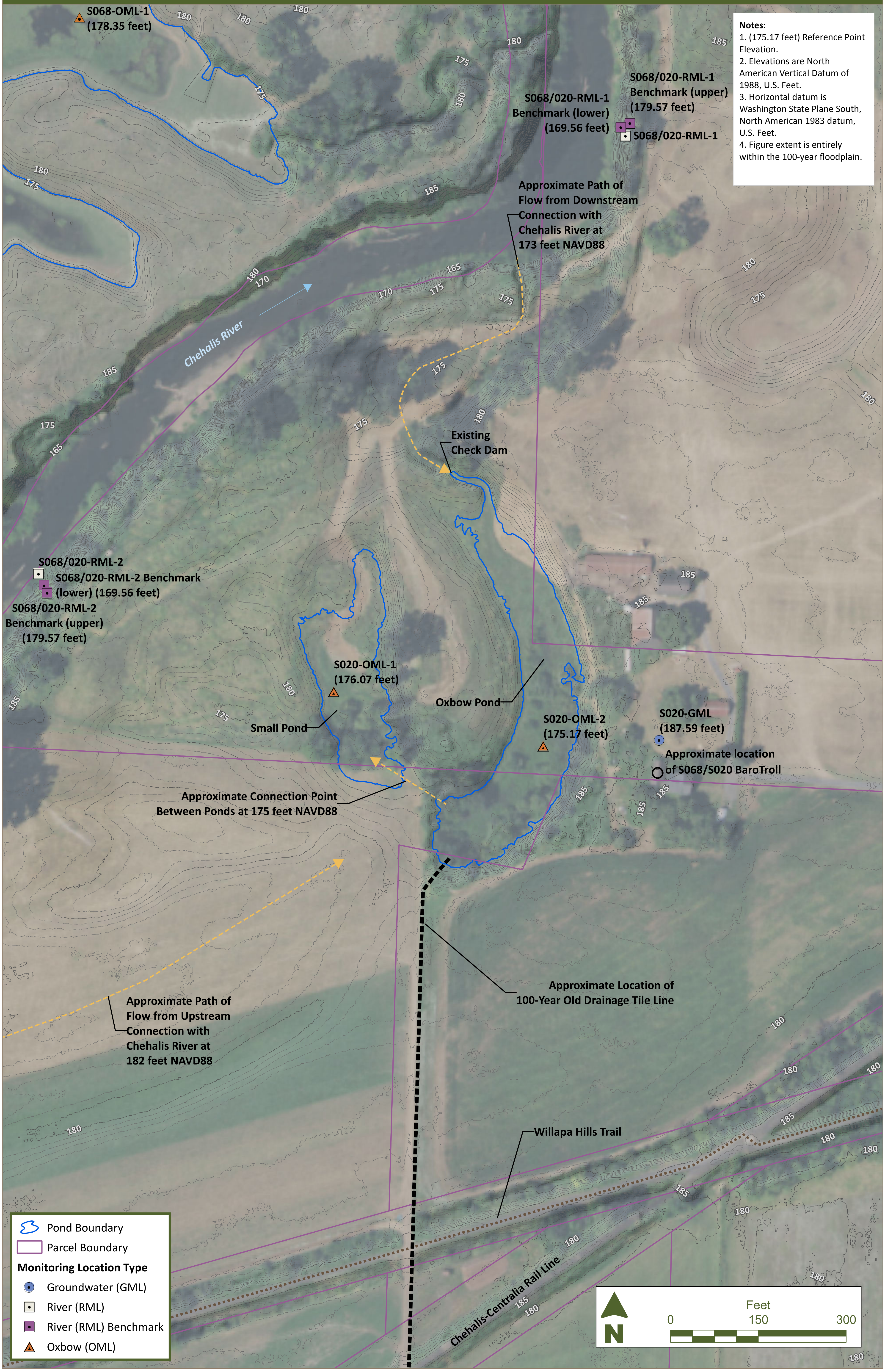


**Figure 3**
**Monitoring Locations at Site 004**

**Figure 4**
**Monitoring Locations at Site 068**

## Figure 5
## Monitoring Locations at Site 020



## Figure 6
## Monitoring Locations at Site 086