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Beavers, Hydrology, and Wapato: A Baseline for Monitoring Franz Lake National Wildlife Refuge

Justine Casebolt
Portland State University

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By: Justine Casebolt

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Project Committee:
Jen Morse, Ph.D.
Geoffrey Duh, Ph.D.
Sarah Kidd Ph.D.
Juliette Fernandez (FWS)

Department of Environmental Science and Management
Portland State University

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Abstract

Located in the lower Columbia River floodplain, Franz Lake National Wildlife Refuge is a unique landscape with a complex land use history. For thousands of years, Indigenous tribes lived on this land. In the early 1990s, U.S. Fish and Wildlife Service acquired the land, after it was identified as a mitigation site following the construction of the Bonneville Lock and Dam. Franz Lake Refuge was once known for its prevalent Wapato (*Sagittaria latifolia*) population, an emergent plant with edible tubers and an important food source for Indigenous people. With specific growth requirements and hydrologic conditions for germination and establishment, *S. latifolia* is susceptible to environmental changes. American beavers (*Castor canadensis*) can dramatically alter a landscape to suit their needs, such as digging channels, rerouting water, and through direct consumption of vegetation. To better understand the hydrology in Franz Lake Refuge, water elevation data was collected continuously, and historical lake surface water and beaver dams were evaluated using remote sensing. Wetland vegetation transect surveys were performed and used for an image classification of the Franz Lake Refuge floodplain. The results suggest that there are many factors influencing the hydrology and wetland plant community within Franz Lake Refuge. The Columbia River has a significant influence on Franz Lake Refuge, especially during large flooding events; however, the effects from beaver dam building activity on Franz Lake hydrology were inconclusive. In addition, reed canary grass (*Phalaris arundinacea*) has become a dominant species and is likely encouraging on *S. latifolia* habitat. This project was designed to create a baseline for future monitoring and anticipated habitat restoration.

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1. Introduction

Designated as a refuge exclusively for wildlife and preservation, Franz Lake National Wildlife Refuge (referred to from here as Franz Lake Refuge) provides ample opportunity for conducting ecological research in the lower Columbia River basin. Located in southwest Washington (river mile; rm 137) less than 10 miles below the Bonneville Dam (rm 147), Franz Lake Refuge is a unique natural area within the lower Columbia River floodplain where human disturbance has been limited since the U.S. Fish and Wildlife Service (FWS) acquisition in 1990 (FWS, 2004). Franz Lake Refuge supports a diversity of wildlife including amphibians, reptiles, small mammals, American beaver (*Castor canadensis*), coyotes (*Canis latrans)*, songbirds, black tailed deer (*Odocoileus hemionus*), and is an important wintering area for tundra swans (*Cygnus columbianus*) and other waterfowl (FWS, 1991). Franz Lake Refuge was once known as “the largest and most intact Wapato, spike rush, and bulrush marsh remaining on the lower Columbia River,” (FWS, 2004) yet there is a lack of a more recent characterization of the wetland plant community within Franz Lake Refuge.

Sagittaria latifolia (also known as Wapato or broad-leaf arrowhead) is a native wetland plant that improves water quality and is a vital food source for Indigenous tribes and wildlife (Marburger, 1993; Darby, 2005: 194, 212). According to the previous landowner and FWS land managers, the *S. latifolia* population in Franz Lake appears to be in decline (Price, 2022, pers. comm.; Fernandez, 2022, pers. comm.). The former landowner, Tom Price, suggested that the decline in *S. latifolia* is attributed to beavers building dams in the slough, which connects Franz Lake to the Columbia River, and increasing the water levels in the lake over time. However, the site has a complex history of land use legacies, hydrological, and ecological interactions that could also explain a shift in the plant community. To shed light on aspects that are relevant to

FWS needs, this project focuses on characterizing the overall landscape of Franz Lake Refuge, quantifying the vegetation community, and investigating the hydrological conditions related to the Columbia River and suggested beaver activity to establish a baseline for future research.

The Lower Columbia Estuary Partnership (LCEP) has performed long-term monitoring of the slough in Franz Lake Refuge since 2008 (Kidd et al., 2022); however, a complete characterization of the plant community and hydrology of the Franz Lake Refuge has not been completed before. Therefore, the primary goals of this project are 1) to characterize the historic trajectory of beaver dams, the existing vegetation composition, and hydrologic conditions of the entire Franz Lake Refuge, and 2) to investigate the current water depths and variations over time.

2. Background

2.1. Overview and History of Franz Lake Refuge

Franz Lake Refuge is in Skamania County, Washington, approximately 30 miles east from the Portland-Vancouver metropolitan area (Figure 1). Franz Lake Refuge is part of the Ridgefield National Wildlife Refuge Complex, which also contains Pierce Refuge and Steigerwald Lake Refuge located along the lower Columbia River, below Bonneville Dam. Located within the Columbia River floodplain, Franz Lake Refuge is a 695-acre property consisting of forested upland habitat, grasslands, freshwater wetlands, and two freshwater lakes: Arthur and Franz (FWS, 1991; 2004).

Figure 1: Ridgefield National Wildlife Refuge Complex located throughout southwest Washington

Indigenous communities occupied this region for thousands of years. The Watlala, also known as Cascade Indians, once resided along the Columbia River from Hood River, Oregon to the Willamette River in Portland, and likely inhabited what is now the Franz Lake Refuge (Hines, 1991: 69). As Lewis and Clark made their journey through the Pacific Northwest from 1805 to 1806, they estimated the Watlala population at 2,800; however, by 1854, their population had dropped to 80, most likely due to an influenza outbreak (Hines, 1991: 70). Kalliah Tumulth (1854-1906), also known as Indian Mary, was part of the Watlala Band (Williams, 2022). She was known as an independent woman who resisted relocation to reservation land after the treaties of 1855, and she was able to stake claim to her ancestral homeland on what is now Franz Lake Refuge (Williams, 2022). Her land remained in the family until it was acquired by FWS

(Williams, 2022; FWS, 1991). Indian Mary Creek, which flows into Franz Lake from the north, and Indian Mary Road, the primary road to access the Refuge, were both named after Kalliah (Williams, 2022).

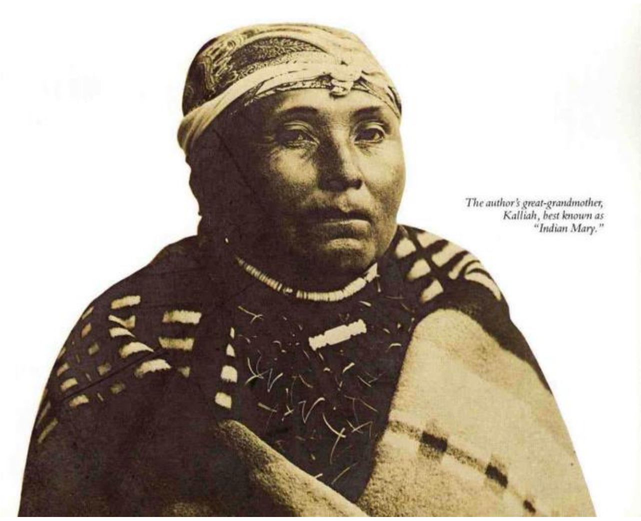

Photo: Kalliah Tumulth courtesy of Chuck Williams from Oregon Encyclopedia

Following Euro-American settlement, the history of the Franz Lake Refuge land ownership is fragmented; however, previous public records from the 1850s state that the initial titles to the property were owned by John W. Stevenson, John B. Woodward, Kenzy Marr, and Kalliah Tumulth (FWS, 1991). The Franz Lake namesake is credited to Jacob Franz, who acquired the property in 1908 (FWS, 1991). Among many other landowners, the more recent include R.T. Strong, who acquired the property in 1910 and grew sweet potatoes and other root crops on the property, followed by the Price family, who purchased the property in the 1930s and remained on the land until the FWS acquisition (Price, 2022, pers. comm.; FWS, 1991). Throughout this period, Franz Lake Refuge was used for a variety of purposes including residency, timber, hunting, fishing, grazing, and even a small private airstrip (FWS, 1991).

In 1977, Franz Lake Refuge was identified as a mitigation site for wildlife habitat lost during the construction of Bonneville Lock and Dam (FWS, 1990). It was deemed a Special

Management Area and was protected under the Columbia River Gorge National Scenic Area Act, which was established in 1986 by President Ronald Reagan (FWS, 2004). In 1990, FWS acquired 552 acres (79 percent) of the property, and since then, management practices have been limited to research and monitoring, with human disturbance kept to a minimum (FWS, 2004). In addition, LCEP, a public-private organization, assists in the management and monitoring of Franz Lake Refuge and other natural areas along the Columbia River, from the Pacific Ocean to Bonneville Dam (FWS, 2004). The LCEP sampling site is located approximately 350 meters from the Franz Slough mouth, which is primarily a high marsh and spans an area impacted by beaver dams both upstream and downstream (Kidd et al., 2022).

In general, the Western Mountains and Valleys within this region receive abundant rainfall or snow with an average annual precipitation of 500mm (>20 in.) and the streams and rivers are often perennial (ACE, 2010). According to the Natural Resources Conservation Service Custom Soil Resource Report of Franz Lake Refuge, the floodplain consists primarily of McBee silt loam soil (date accessed April, 2024). McBee silt loam is found in floodplains with a slope of 0 to 3 percent and is moderately well drained. The depth of the water table is about 36 to 48 inches and does not have a hydric soil rating. The Western Mountains and Valleys are known to have continuous water tables with deeper groundwater (ACE, 2010). The upland areas within Franz Lake Refuge consist of a variety of soil types, typically found in higher elevations and in areas with greater slopes, such as Skamania very fine sandy loam, Skoly stony loam, and Steever stony clay loam.

2.2. Ecology and Significance of Sagittaria latifolia

S. latifolia, a native freshwater plant typically found in aquatic and semiaquatic habitats (Darby, 2005: 194), was first documented by The Nature Conservancy on the north shore of Franz Lake in 1977 (FWS, 1991). As a perennial emergent forb, *S. latifolia* is characterized by its arrowhead shaped leaves, which emerge from underground rhizomes with edible tubers (Guard et al., 1995: 70). *S. latifolia* leaves emerge in the summer, flowering occurs from September to October, and the achenes are shed throughout fall and winter (Guard et al., 1995: 70; Kaul, 1985). *S. latifolia* is typically found in perennial wetlands and in shallow freshwater surrounding lakes, pools, ponds, and sloughs (Guard et al., 1995: 70; Darby, 2005: 199). In a lake environment, *S. latifolia* can be found on the edges of the water between the areas of high and low water lines (Darby, 2005: 199). It generally requires exposed mudflats for successful seed germination and establishment (Kaul, 1985), but can grow in water depths of up to 50 centimeters deep and in a variety of soil types, including sandy loam and silty clay soils (Clark and Clay, 1985, as cited in Marburger, 1993).

Furthermore, *S. latifolia* is known as a cultural keystone species (Garibaldi & Turner, 2004) due to its value as a First Food for Indigenous communities (Darby, 2005: 194). Throughout the lower Columbia River region, *S. latifolia* once grew in prolific homogeneous fields, providing a staple starchy food source to the Northwest tribes for thousands of years, such as the Chinookan people (Darby, 2005: 194). The tubers are said to resemble the white potato (*Solanum tuberosum*) in taste and texture (Darby, 2005: 195). The plant tubers and achenes are also consumed by wildlife, such as tundra swans (*Cygnus columbianus*), other waterfowl, American beavers (*Castor canadensis*), and muskrat (*Ondatra zibethicus*) (Darby, 2005: 212). Historically, to increase *S. latifolia* productivity, efforts were made to control these potential consumers of *S. latifolia* by the Indigenous communities (Darby, 2005: 212).

Today, *S. latifolia* is frequently used in wetland construction and restoration. It can improve water quality in wetlands due to its exceptional ability to increase dissolved oxygen levels and remove pollutants (Marburger, 1993; Reddy et al., 1990). Aquatic plants, such as *S. latifolia*, typically growing in anaerobic sediments and anoxic water, can transport oxygen through their foliage to their roots, which in turn stimulates organic matter decomposition and increases nitrifying bacteria (Reddy et al., 1990). While testing the effectiveness of using aquatic macrophytes for wastewater treatment, Reddy et al. (1990) found that *S. latifolia* tolerated high nutrient loading from primary sewage, increased dissolved oxygen, and decreased the biological oxygen demand and ammonia-nitrogen concentrations.

Although *S. latifolia* was once widespread throughout the Pacific Northwest, populations across the region are in decline due to numerous factors. It is important to note, as European settlement began, Indigenous tribes and the *S. latifolia* they managed began to disappear (Darby, 2005: 213). Flood management strategies, the drainage of wetlands for agriculture, grazing, climate change, and the introduction of invasive species, such as reed canary grass (*Phalaris arundinacea*) and carp (*Cyprinus carpio*), are all potential contributors to the decline in *S. latifolia* (Guard et al., 1995: 70; Darby, 2005: 214). Franz Lake Refuge was formerly used for cattle grazing, but once *S. latifolia* was discovered on the property in 1977, all grazing ceased (FWS, 1991). *P. arundinacea* has become pervasive on the Refuge and is likely encroaching on primary *S. latifolia* habitat. Also, carp, an herbivorous fish species that consume *S. latifolia*, are prevalent throughout wetland ecosystems of the lower Columbia River (Darby, 2005: 213) and have been observed in Franz Lake Refuge (Kidd et al., 2022).

2.3. Hydrologic Conditions

With specific growth requirements that depend on some level of inundation throughout the *S. latifolia* lifecycle, it is essential to identify the factors influencing the hydrology in Franz Lake to better understand the *S. latifolia* population within the lake. Long term data is needed to monitor the changes in the wetland plant community, so this research provides a framework for future research and monitoring in Franz Lake Refuge. It is accepted that the lower Columbia River hydrology has been drastically altered due to the construction of the many hydroelectric dams and other flood control measures. According to the U.S. Army Corps of Engineers Northwestern Division (date accessed May, 2024), the Columbia River Basin drains about 250,000 square miles and contains over 250 reservoirs and about 150 hydroelectric projects, including 18 mainstem dams. Bonneville Dam alone has impacted approximately 20,749 acres of wildlife and wetland habitat along the Columbia River (FWS, 1991). Indeed, Franz Lake Refuge has seen a drastic change in the flow regime due to the alteration of the natural regime on the Columbia River as shown in Appendix A containing images of the lake surface water extent from 1930 (pre-Bonneville Dam) to 2022.

According to the *Franz Lake National Wildlife Refuge Management Plan* (1991), releases from Bonneville Dam determine the levels in the lower Columbia River, which ultimately influences the extent and levels of water in both Franz Lake and Arthur Lake. In addition, Franz Lake is fed by Indian Mary Creek, from the northeast, and several other natural springs (FWS, 1991). Franz Lake flows west into Arthur Lake, which is fed by additional springs and empties into the Columbia River (FWS, 1991). The extent of surface water in Arthur Lake can vary greatly from a narrow stream to many acres in extent (FWS, 1991); however, since the early 1990s, beaver dams have influenced the amount of ponded water in Arthur Lake.

Notably, the landscape and hydrology in Franz Lake Refuge has been modified throughout time by beaver activity (Kidd et al., 2022; Price, pers. comm. 2022). As ecosystem engineers, beavers alter habitats through their dam-building activity, which influences the availability of resources for other species, both directly and indirectly (Jones et al., 1994). By impounding water, beaver dams shift the annual streamflow regime, decrease stream velocity, and redistribute groundwater (Naiman et al., 1988; Pollock et al., 2015). In Acadia National Park, Cunningham et al. (2006) observed an 89% increase in the total number of ponded wetlands between 1944 and 1977 due to creation of new wetlands by beavers. Furthermore, beavers can affect lacustrine vegetation by altering the water regime, through direct consumption, and digging channels (Bashinskiy, 2020). In addition, beaver dams increase sediment and organic matter retention, which can provide carbon and nutrient storage (Naiman et al., 1988). Considering the various ecosystem services that beavers provide, there is strong interest in learning to collaborate with beavers to help maintain and restore natural systems.

3. Project Objectives

As previously mentioned, the goals of the project are: 1) to characterize the historic trajectory of beaver dams, the existing vegetation composition, and hydrologic conditions of the entire Franz Lake Refuge, and 2) to investigate the current water depths and variations over time. To meet the expectations of this project, the following objectives will be addressed:

1) Establish a baseline for hydrologic monitoring in Franz Lake Refuge.

2) Determine the current composition of vegetation communities, including *S. latifolia* and *P. arundinacea*, in Franz Lake Refuge.

3) Use remote sensing data to analyze current and historical imagery to assess temporal changes in lake surface water extent and beaver activity.

To establish a baseline for hydrologic monitoring in Franz Lake, seasonal water variability was measured throughout the time frame of this project (March 2023 to July 2024). In addition, long term water temperature and stage were evaluated from the slough data provided by LCEP. To determine the current composition of vegetation communities, transect surveys were performed to determine the number and percent coverage of each plant species surrounding Franz Lake. Finally, historical aerial imagery provided by the U.S. Army Corps of Engineers (ACE), Google Earth Pro (version 7.3.6.9796), and National Agriculture Program (NAIP) aerial imagery were used to assess the changes in water surface area and beaver dam activity over time. Additionally, ESRI ArcGIS Pro (version 3.2.2) and data collected in situ were used to produce maps to provide an overall characterization describing the vegetation composition, hydrology, and beaver activity of Franz Lake Refuge.

4. Methodology

4.1. Baseline for Hydrologic Monitoring

To establish a baseline of the hydrology in Franz Lake Refuge, Hobo Onset Water Level Loggers (pressure transducer sensors or data loggers) were installed in March 2023 to continuously measure water levels and determine the water level variability. Three pressure transducers were provided by LCEP. The pressure transducer sensors were installed in various locations in the lake and slough to measure the variations in water levels across the system. As previously mentioned, LCEP has been monitoring the Franz Slough since 2008 using the same Hobo Logger and methods, which were used in the analysis for long term comparison of the slough and Columbia River. Figure 2 below shows the locations of the slough logger and the

2023 loggers, labeled 1-3 from west to east. Logger one was positioned just above an over 100-meter (334 ft) long beaver dam, logger two was installed where Franz Lake ends and the Franz Slough begins, and logger three was installed on the east side of the lake, just below the outlet of Indian Mary Creek. These loggers are expected to remain in place to provide continuous long-term water surface elevation and temperature data of Franz Lake Refuge.

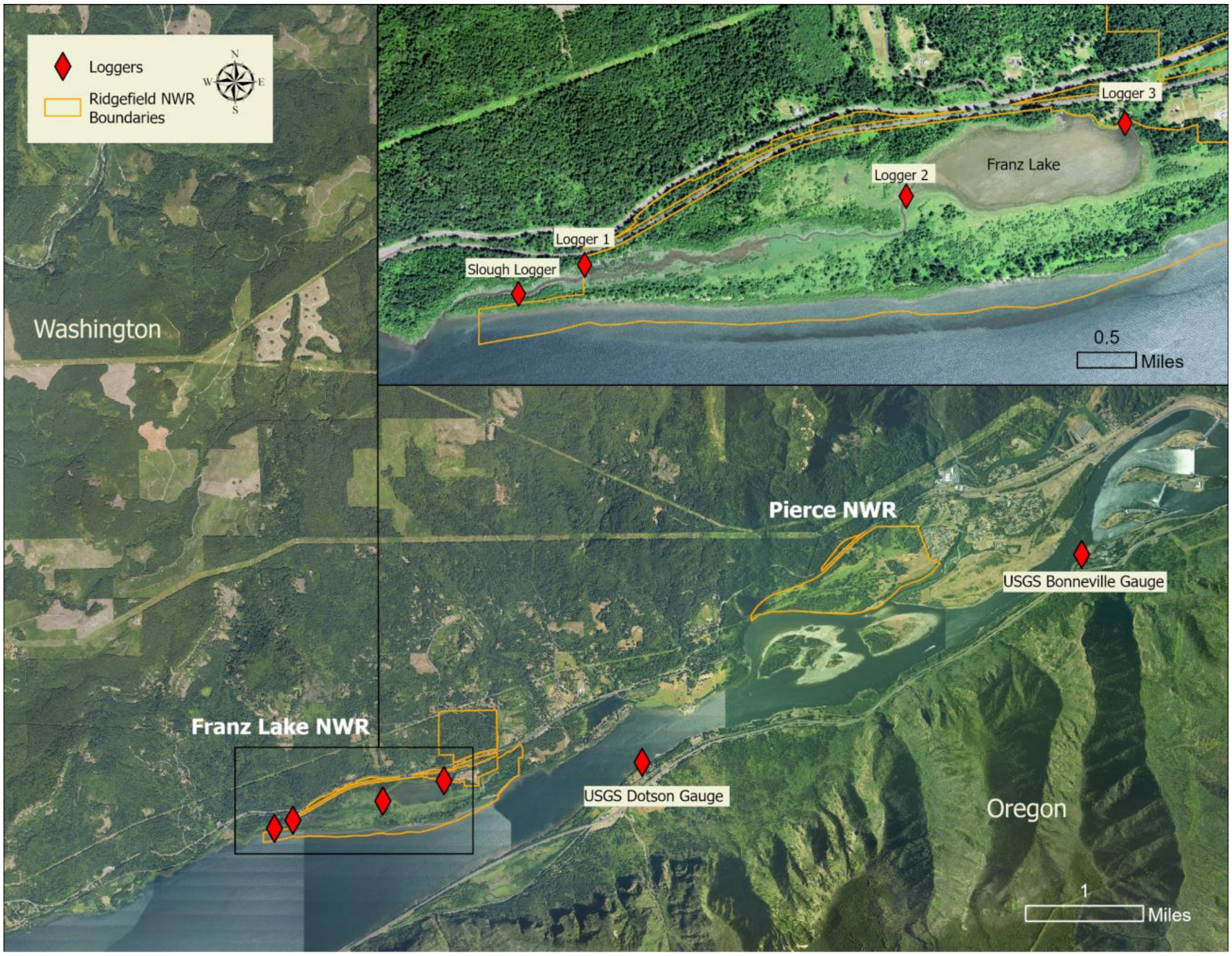

Figure 2: Map of USGS Bonneville Dam and Dotson Creek gauge locations and Franz Lake Refuge loggers. Imagery data source: NAIP Compressed County Mosaics, 2023, USDA Geospatial Data Gateway. Inset map NAIP, 2020. Earthexplorer.usgs.gov.

Upon installation, the sensors were surveyed for elevation using Real-Time Kinematic (RTK) GPS allowing the water depth data to be converted to water surface elevation (Kidd et al., 2022). RTK can measure elevation within an accuracy of 1-5 centimeters (United States Geological Survey, USGS, 2012). This water surface elevation monitoring protocol, used by

LCEP, is based on Roegner et al. (2009) methods for measuring hydrology. Measurements were automatically recorded every hour from the time of installation (March 2023) to data retrieval (July 2023). Post retrieval, the data was processed by Wolf Water Resources, an engineering consulting firm in Portland, Oregon. The RTK data and barometric pressure from the National Oceanic and Atmospheric Administration (NOAA) Scappoose Station was used to calculate the final water surface elevation (or stage) for each data logger to North American Vertical Datum of 1988 (NAVD 88).

Based on data availability, the stage and water temperature from the Franz Lake data loggers were compared to two USGS gauges along the Columbia River. For water surface elevation, or stage, the USGS gauge below Bonneville Dam, Oregon (gauge number: 14128870), was obtained from the USGS ‘dataRetrieval’ package in RStudio (RStudio version 2023.12.0.369 and R version 4.3.2). Originally in North American Datum of 1983, the Bonneville stage was adjusted to NAVD 88 by adding 3.34 feet (Boudreau et al., 2021). All stage data previously in feet was then converted to meters by dividing by 3.281. For water temperature, the USGS gauge near Dotson Creek, Oregon (gauge number: 45360122021400) was used for comparison to the Franz Lake water temperatures, also obtained from the USGS ‘dataRetrieval’ package in RStudio. Using RStudio Software, linear regressions were used to analyze the statistical relationship of these variables between Franz Lake Refuge and the Columbia River. A threshold regression model (Fong et al., 2017; Fong, 2020) from the ‘chngpt’ R package was used for comparing all the stage data from loggers one, two, and three to Bonneville after a simple linear regression model was determined to be an unfit model. More specifically, a continuous two-phase segmented model was used (Fong, 2020). Threshold regression models are non-regular models that depend on a change point, or threshold, and are useful when there is a non-linear relationship between the predictor variable and the response variable (Fong et al., 2017).

In addition, satellite and aerial imagery were used to measure the changes in the extent of surface water of Franz Lake over time. In total, 23 images from 1930 to 2023 were derived from NAIP imagery, Google Earth Pro, and ACE aerial images. NAIP is a U.S. Department of Agriculture (USDA) program designed to acquire aerial imagery during the peak agricultural season (Earth Resources Observation and Science Center, 2017). The NAIP pilot program started in 2002, originally offering 1-meter spatial resolution with an acquisition schedule of every 5 years. In 2019, 0.6-meter resolution NAIP imagery was acquired in Washington, and in 2022 0.3-meter resolution was acquired. NAIP data is orthorectified four-band imagery, offering red, green, blue, and near-infrared bands and is freely available through USGS Earth Explorer (https://earthexplorer.usgs.gov). In color-infrared imagery, vegetation appears in variations of red due to its high infrared response, and water appears as shades of black and blue (Richards and Jia, 2006; 69), allowing for ease of identification of these features. The ACE images were originally acquired by LCEP for 1930, 1948, 1959, 1983, and 1995 in PDF format. Since ArcGIS Pro does not accept PDFs, the images were converted to JPG using the Adobe Acrobat export PDF to JPG function. These images were then georeferenced in ArcGIS Pro to NAD 1983 UTM Zone 10N coordinate system using at least seven control points. Due to the limited availability of NAIP imagery, Google Earth Pro historical images in both natural color and grayscale were used to substitute missing years when available (i.e. 1993, 2005, 2006, 2010, 2023).

All 23 images were visually analyzed to create polygons of the surface water, or open water, to assess the change in surface water extent, using methods adapted from Johnson-Brice et al. (2021). However, this analysis focused on open water rather than ‘deep marsh’ wetland classes defined by Cowardin et al. (1979) due to the difficulty in distinguishing upland boundaries from ‘deep marsh’ boundaries in the imagery obtained. In ArcGIS Pro, the Create Feature Class geoprocessing tool was used to create a new feature class for each year, and the Create Tool was used to create the polygons of lake water extent. Open water without emergent vegetation was the primary focus due to the difficulty in distinguishing the water extent with mixed vegetation, especially for the ACE images that were in grayscale. In ArcGIS Pro, the areas of the polygons were automatically calculated in meters squared, found within the feature’s Attribute Table. The areas from the Google Earth Pro images were gathered from the Properties of each polygon. The areas were transcribed into an Excel spreadsheet for further analysis.

Global solar radiation (Langley’s cumulative), precipitation (non-heated tipping bucket in cumulative inches of water) and average ambient temperature data (average degree Fahrenheit) was acquired from the Bonneville Dam Washington Weather Station from the Bureau of Reclamation AgriMet Cooperative Agricultural Weather Network (https://www.usbr.gov/pn/agrimet/webagdayread.html). The data was collected starting from July 16, 2013 to August 3, 2022 and averaged to daily values to provide a long-term comparison of the Franz Slough data logger. In addition, the 2023 Franz Lake loggers (1-3) were averaged together, allowing a short-term comparison to the weather data from March 15, 2023 to July 26, 2023. Before analysis, ambient temperature was converted to degrees Celsius using the formula $°C = (°F - 32) \times 5/9$. A correlation matrix was created for each dataset to assess the relationship between Franz Lake stage and water temperature to the weather variables. The correlation matrix provides the Spearman Rank Correlation Coefficient, displayed in the top right corner of the graph, which shows the strength of the relationship between the two variables. In the bottom left corner of the graph is the pairwise scatter plot with a curved line showing the relationship between the variables using locally estimated scatterplot smoothing (LOESS). The histograms of each dataset are on the diagonal within the matrix.

4.2. Beaver Dams

Ground surveys were conducted in March 2023 along the Franz Lake Slough to characterize the present beaver activity. The data collected included the number, location, elevation, hydraulic height (water level difference upstream from downstream of dam), width, and other features of each dam. These survey methods were adapted from The Wetlands Conservancy and Johnson Creek Watershed Council, Beaver Survey Project (2019). The elevation data was estimated using a hand-held Garmin GPS (model eTrex 10) in situ. Additionally, the geographic locations, elevation, and lengths from the 2023 ground surveys beaver dams were used to validate the satellite imagery.

Working backwards in time, Google Earth Pro historical images were used to identify and map the historical beaver dams throughout Franz Lake Refuge. Historical beaver dams are easily identified through careful observations of the pond morphology and riparian vegetation (Zhang et al., 2023). All the beaver dams were mapped from 1993 to 2023, and the data was transcribed in Excel, which included file name, dam elevation, date (year, month, day), latitude, longitude, and dam length (meters). The locations of the beaver dams and lodges were mapped primarily in Google Earth Pro, and for missing years the rest were mapped in ArcGIS using the NAIP imagery used for water extent polygons. In ArcGIS, beaver dams (lines) were mapped using the Create Feature Class tool. The beaver dam data was collected to align with the water extent polygons so that a linear regression could be performed to evaluate the relationship of beaver dams to lake area. Using RStudio, lake areas were compared to the total number of dams for each year. A Shapiro-Wilk's test was used to check if the data were distributed normally, and an F-test was used to check that the data had equal variance.

4.3. Wetland Vegetation

In October 2023, wetland vegetation surveys were performed primarily in the area surrounding Franz Lake. Belted-transect surveys were performed to assess percent coverage, which were methods adapted from Rapid Wetland Vegetation Assessment from FWS (Chmielewski & Khem, 2023 unpublished). To select locations for the surveys, a vegetation survey boundary and lake boundary were created in ArcGIS using 2020 and 2022 NAIP imagery to provide a target area for surveying the emergent and aquatic wetland community surrounding Franz Lake. These boundaries were then used to generate unstratified, equal probability, spatially balanced samples of transect points using the Generalized Random Tessellation Stratified (GRTS) survey design (Stevens & Olsen, 2004; Olsen et al. 2012), which is available in 'spsurvey' RStudio library. Initially, a total of 60 base sites were created along with 40 oversample sites and 100 replacement sites using nearest neighbor, with a minimum of 10 meters distance between each point and a 10-meter buffer from the vegetation survey boundary. Oversample points were created in case more data was needed post-surveying, and replacement points were created as a precaution in case accessibility was an issue, knowing this area had not been thoroughly surveyed in situ before.

A total of 58 transects were surveyed on October 7th and 8th, 2023 on foot and using an inflatable kayak to navigate to the north side of the lake. With the survey points used as a midpoint, belted transects measuring 10 meters by one meter, running east to west (using a compass), were surveyed for percent coverage of vegetation. The ESRI Field Maps application (for iPhone 11 version iOS 17.4.1) was used for data entry. Plants were identified to genus and species (when possible). The categories for percent coverage were: <10%, 11-25%, 26-50%, 51-75%, 75-100%. It is important to note that with this survey method, the transect could have coverage of over 100%. Data was collated into an Excel spreadsheet, and Pivot Tables were used to assess the patterns in the data. The data was transformed for analysis by converting the surveyed percentages to averages (A+B)/2. The categories were converted to the following <10% to 5%, 11-25% to 18%, 26-50% to 38%, 51-75% to 63%, 75-100% to 88%.

Using the 58 transect points, training polygons where created based on the dominant vegetation class and a supervised image classification was performed using the Image Classification Wizard in ArcGIS Pro. In remote sensing, supervised classification utilizes algorithms to label pixels as ground cover types, or classes, (Richards and Jia, 2006; 193). With the supervised method for classification, the outcome depends on the training samples provided, which are representative of the classes defined by the user (ERSI, accessed 2024). Training polygons were created based on the dominant vegetation type derived from the vegetation transect surveys. The classification system was adapted from Cowardin et al. System of Wetland Classification (1979) used by the U.S. Department of Interior and FWS to inventory wetlands and deepwater habitats. Table 1 below shows the classes used. Since *P. arundinacea* was a dominant species, it was given its own category.

Table 1: Classes defined for Franz Lake in the image classification analysis

Classes:	Cowardin System
1	Water
2	Forested Uplands
3	Mixed Forested Wetland
4	P. arundinacea (RCG) Dominant
5	Emergent Wetland Non Persistent
6	Aquatic and Submerged

Planet (3-meter resolution) satellite imagery captured on Oct. 7, 2023, within the same day the transect surveys were completed, was used for the image classification. Two raster images were downloaded from Planet (https://www.planet.com/), and the Mosaic tool in the Raster Dataset toolset from ArcGIS was used to merge the images. Then, the Extract by Mask tool was used to create the area of interest for the image classification. The training polygons were used for a pixel-based Maximum Likelihood Classifier to create the final classification map for Franz Lake. The Reclassifier function was used to improve the accuracy of the image classification for the pixels that were misclassified.

5. Results

5.1. Hydrologic Influences

To define the relationship between Franz Lake and the Columbia River, several linear regressions were performed in RStudio. Table 2 provides a summary of the stage and water temperatures from the data loggers in Franz Lake Refuge. In the time series hydrograph (Figure 3) of the 2023 Franz Lake loggers (1-3) and the Bonneville logger, there appears to be a clear influence on the lake levels of all three loggers from May to June. However, outside of that period there appears to be minimal influence. A simple linear regression was found to be poor fit when comparing the stage data of all three loggers (1-3) to Bonneville, so a threshold regression was used instead (Figure 4). In the threshold regression analyses, a change point was estimated at 6.69 meters (Confidence Intervals or CI: 6.66, 6.72) for logger one, 6.72 meters (CI: 6.70, 6.74) for logger two, and 6.75 meters (CI: 6.73, 6.78) for logger three. There was a slight negative relationship between Franz Lake and the Columbia River at Bonneville until this change point, then there was a positive relationship between Franz Lake and Bonneville for all three loggers. Table 3 provides a summary of the results from the threshold regression analysis for loggers one, two, and three.

Table 2: Summary statistics of Franz Lake Refuge data loggers 1-3, with the slough logger being furthest downstream and L3 the furthest upstream.

Stats	Slough Stage (m)	Slough Temp (°C)	L1 Stage (m)	L1 Temp (°C)	L2 Stage (m)	L2 Temp (°C)	L3 Stage (m)	L3 Temp (°C)
Min	3.50	-0.10	4.93	6.47	5.04	4.62	5.02	6.37
Q1	4.18	7.28	5.08	9.77	5.19	11.53	5.18	8.58
Median	4.58	12.01	5.13	14.71	5.22	16.43	5.22	10.36
Mean	4.94	12.70	5.53	16.05	5.61	16.43	5.60	10.67
Q3	5.44	17.67	5.19	22.43	5.28	20.42	5.29	12.50
Max.	10.31	32.29	8.04	22.26	8.08	30.26	8.09	17.00

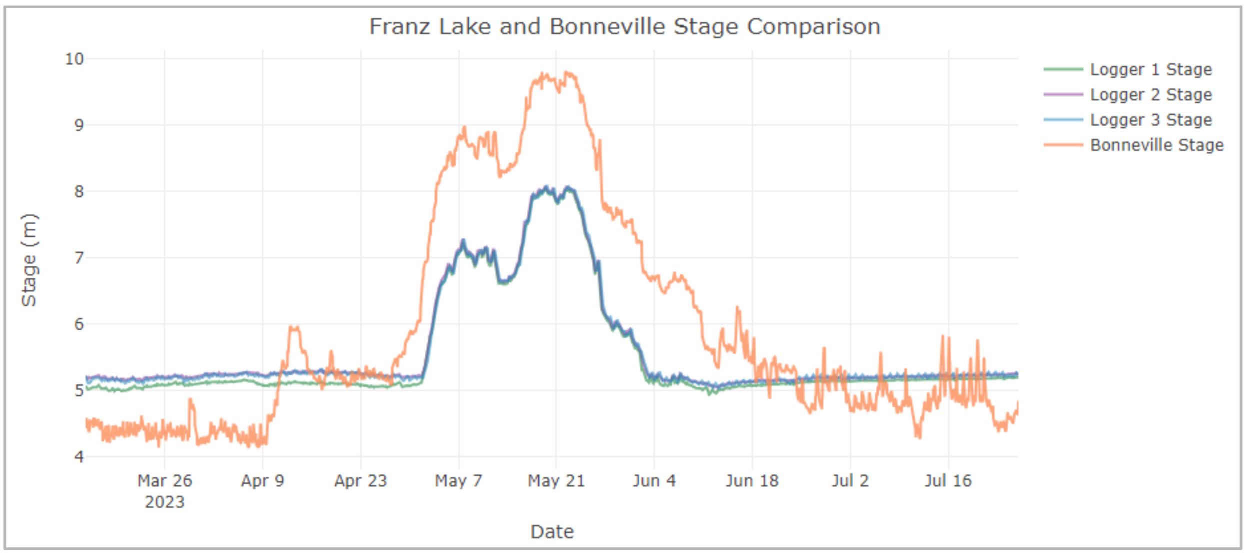

Figure 3: Hydrograph of Franz Lake loggers 1-3 stage and Bonneville stage, adjusted to NAVD 88, from March 15, 2023 to July 27, 2023

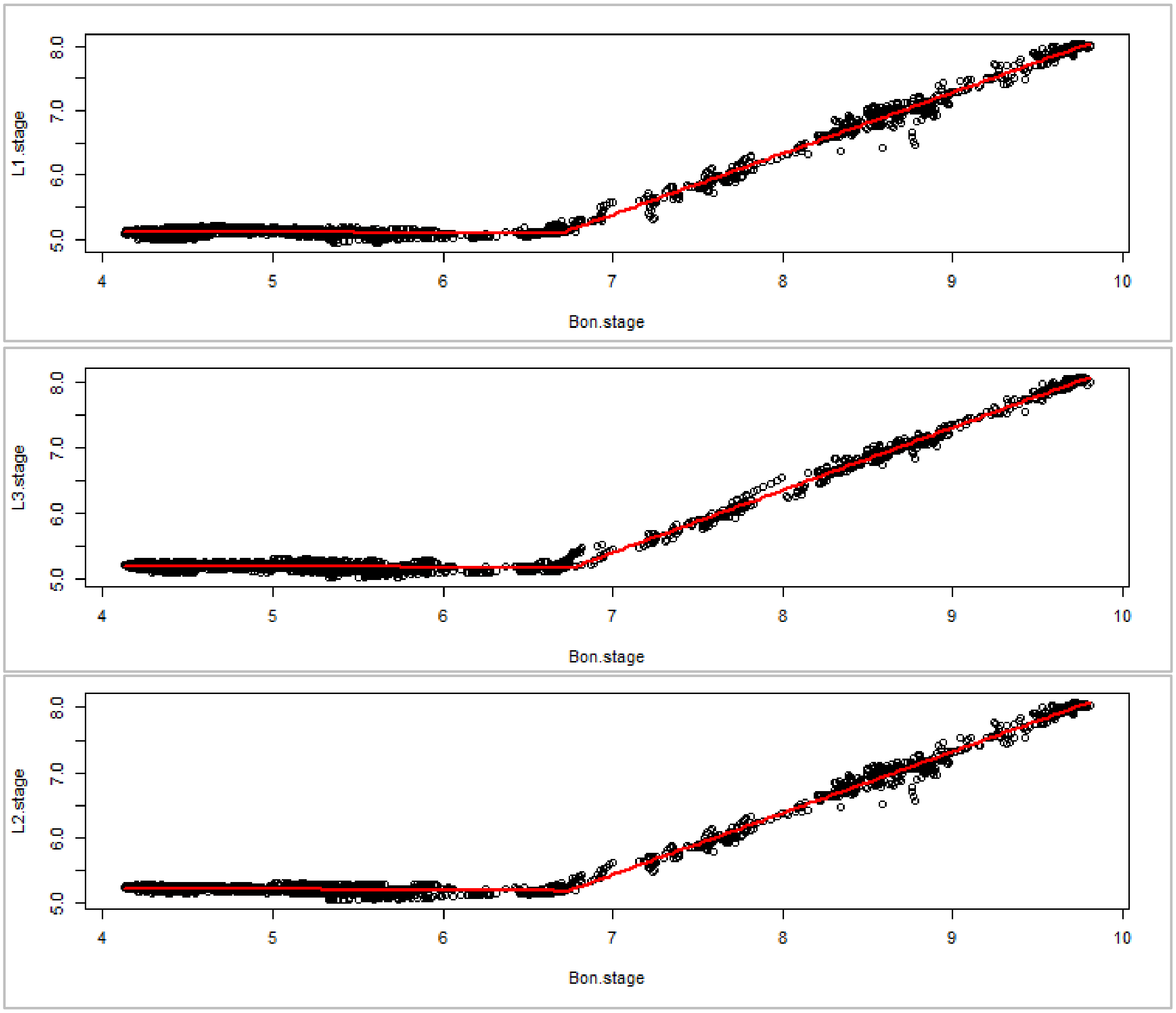

Figure 4: Threshold regression of Franz loggers 1-3 (top to bottom) and Bonneville stage from March 15, 2023 to July 27, 2023

Table 3: Results of threshold regression analysis for loggers 1-3 and Bonneville stage from March 15, 2023 to July 27, 2023. Coefficient est. are the estimated coefficients, Std. error is the standard error for each coefficient, CI lower is the lower confidence interval, CI upper is the upper confidence interval. 'chngpt' stands for change point.

Logger 1	Coefficients est.	Std. error	CI lower	CI upper
Intercept	5.14	0.01	5.12	5.17
Bon Stage	-0.01	0	-0.01	0
(Bon Stage-chngpt)+	0.96	0	0.95	0.97
Logger 2	**Coefficients est.**	**Std. error**	**CI lower**	**CI upper**
Intercept	5.29	0.01	5.28	5.31
Bon Stage	-0.02	0	-0.02	-0.01
(Bon Stage-chngpt)+	0.96	0	0.96	0.97
Logger 3	**Coefficients est.**	**Std. error**	**CI lower**	**CI upper**
Intercept	5.25	0.01	5.23	5.27
Bon Stage	-0.01	0	-0.02	-0.01
(Bon Stage-chngpt)+	0.97	0	0.96	0.97

Conversely, when the data was parsed out, the results vary from the initial analysis of the combined data (Figure 4). Three categories were created to assess the relationship further, which are defined as pre-freshet (March 15-April 30, 2023), freshet (May 1-June 15, 2023), post-freshet (June 16-July 27, 2023). In the pre-freshet period (Figure 5), logger one, which was just above the large (greater than 100-meter long) beaver dam, had an R-squared value of 2% (p-value < 0.05), so only 2% of the variance in logger one stage can be explained by the Bonneville stage. Logger two stage ($R^2 = 0.27$; p-value < 0.05) and logger three stage ($R^2 = 0.26$; (p-value < 0.05) indicated a similarly weak relationship to the Bonneville stage. All the loggers in this category had a slightly positive relationship with the Bonneville stage in the pre-freshet period.

During the freshet period (Figure 6), Franz Lake stage and Bonneville stage have a strong statistically significant relationship. Logger one ($R^2 = 0.96$; p-value < 0.05), logger two ($R^2 =$

0.96; p-value < 0.05), and logger three ($R^2 = 0.96$; p-value < 0.05) indicated a strong positive relationship between Franz Lake stage and Bonneville stage. Then, during post-freshet period (Figure 7) there was a negative, weak statistically significant relationship between Franz Lake stage and Bonneville stage with logger one ($R^2 = 0.41$; p-value < 0.05), logger two ($R^2=0.38$; p-value < 0.05), and logger three ($R^2=0.37$; p-value < 0.05).

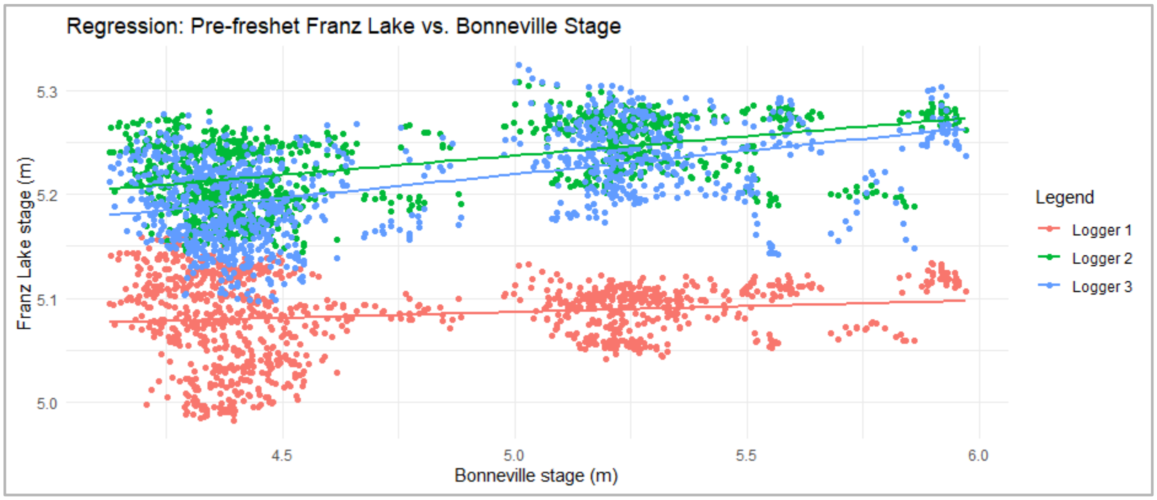

Figure 5: Linear regression of Franz Lake loggers 1-3 stage and Bonneville stage pre-freshet from March 15 to April 30, 2023

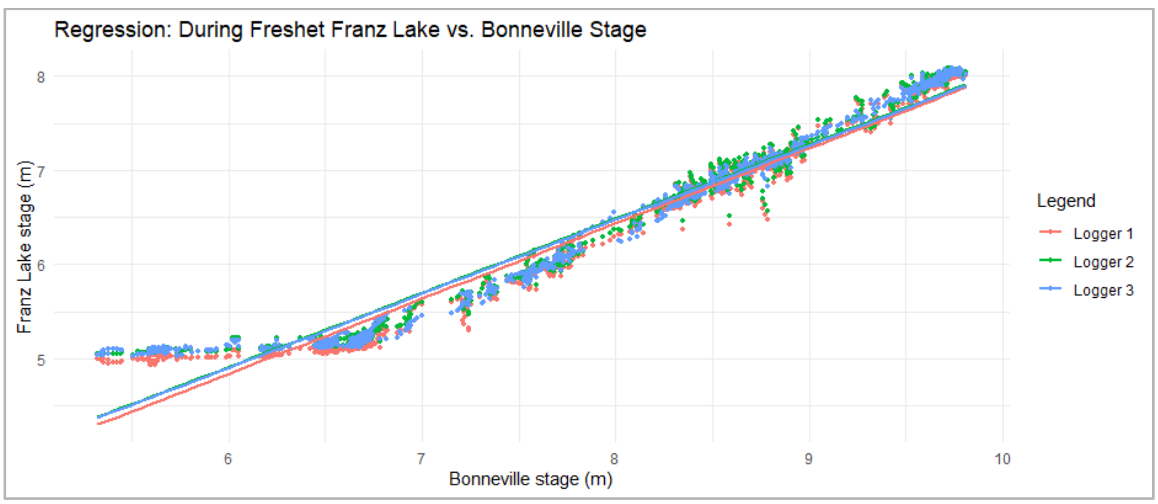

Figure 6: Linear regression of Franz Lake loggers 1-3 Stage and Bonneville stage during freshet from May 1 to June 15, 2023

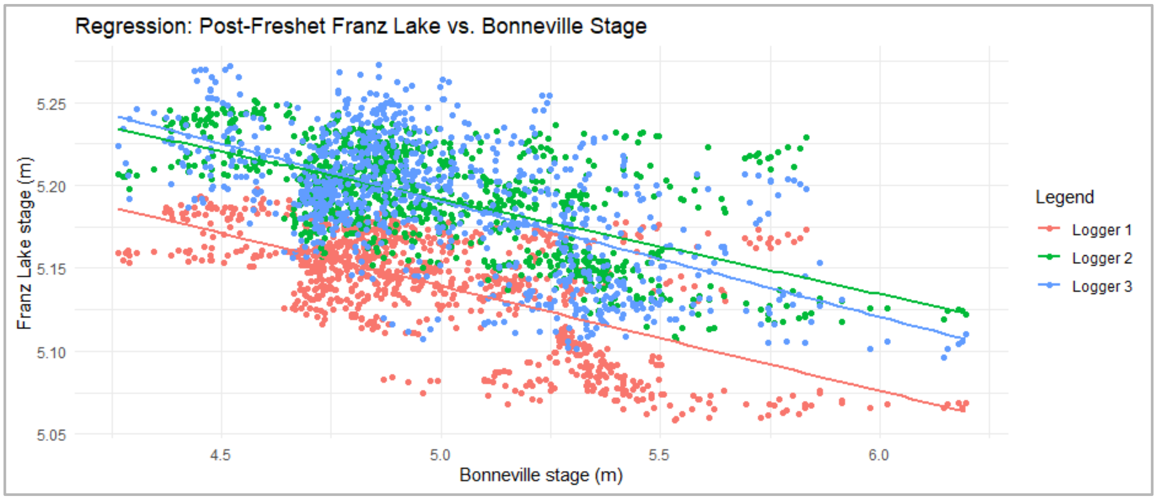

Figure 7: Linear regression of Franz Lake loggers 1-3 Stage and Bonneville stage post-freshet from June 16 to July 27, 2023

In the time series hydrograph (Figure 8), it is apparent that the Bonneville water elevations and the Franz Slough water elevations track together. Appendix C provides a time series graph of the Franz Slough and Bonneville daily average stage by year from 2008 to 2022. In the regression analysis of the long-term (Figure 9), seasonal water stage data (2008-2022) from the slough logger, which was lowest in elevation in the Franz Lake system and closest to the Columbia River, there was a strong statistical relationship between the slough logger and the Bonneville logger. Based on the R-squared value of 0.77 ($p < 0.05$), it can be determined that 77% of the variance in Franz Lake Slough stage can be explained by the Bonneville stage.

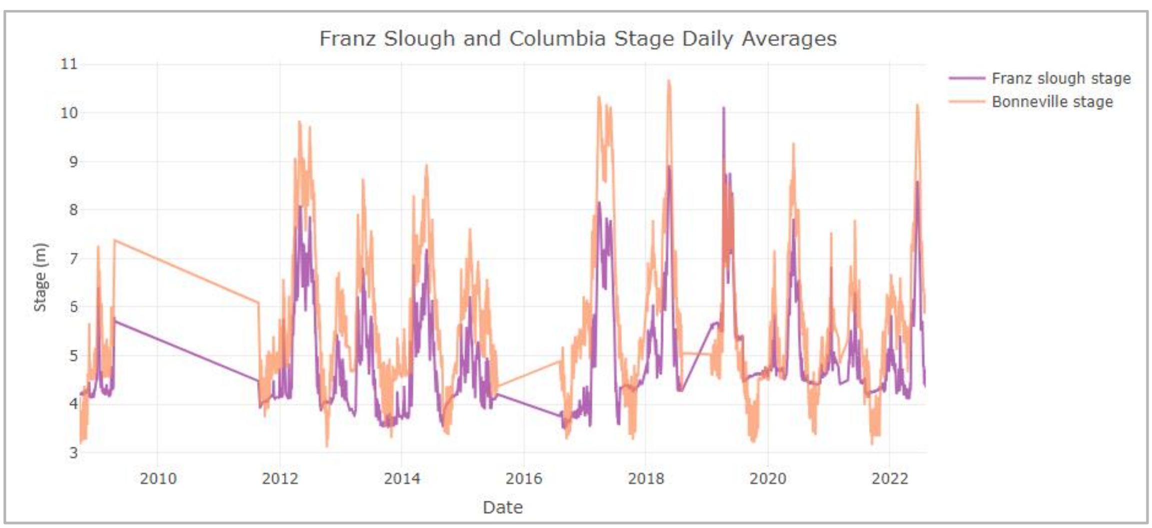

Figure 8: Hydrograph of Franz Slough and Bonneville daily average stage from 2008 to 2022

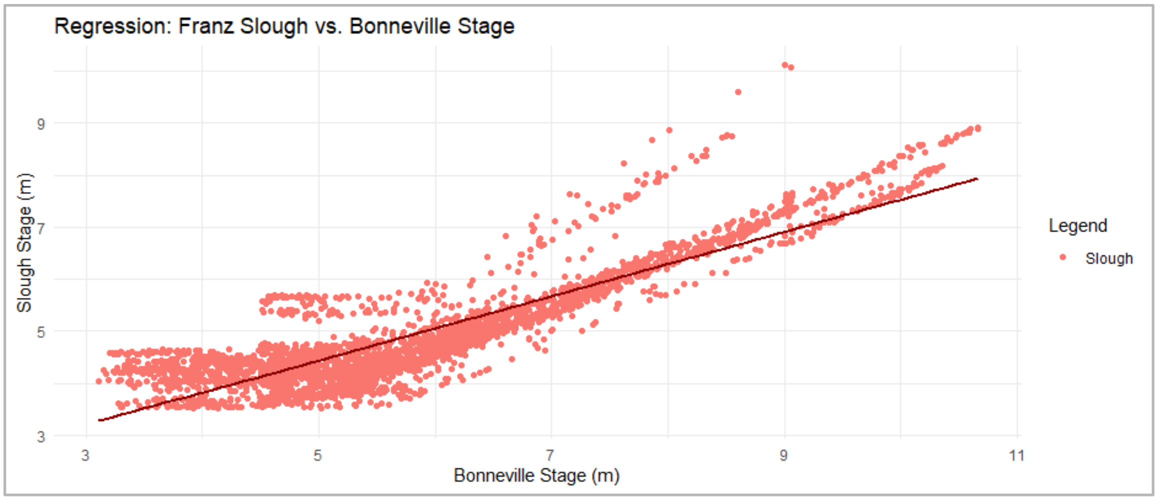

Figure 9: Linear regression of Franz Slough and Bonneville stage daily averages 2008 to 2022

Moreover, the differences in water temperature between Franz Lake loggers (1-3) and the Columbia River at the Dotson Creek USGS gauge also produced interesting results. In the time series graph (Figure 10), there was a steady increase in water temperature from April through July, 2023 in loggers one and two and at Dotson Creek, but in logger three the water temperature decreases in June and remains consistently lower than all the other loggers. This may likely be due to the location of the logger, which was located just below Indian Mary Creek on the east side of Franz Lake, a primary water source of Franz lake. In the regression analysis comparing all the temperature data (Figure 11), logger one ($R^2 = 0.90$; p-value < 0.05) and logger two ($R^2 = 0.76$; p-value < 0.05) water temperatures are highly influenced by the Columbia River with a positive relationship, while in logger three there was a weaker relationship ($R^2 = 0.55$; p-value < 0.05).

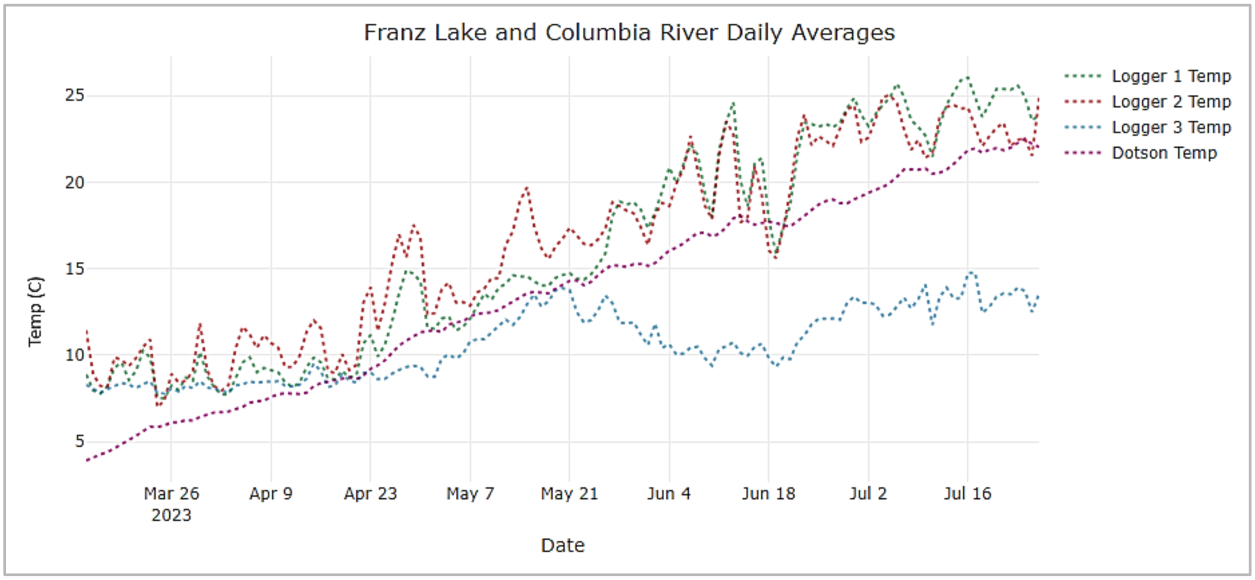

Figure 10: Time series of daily average water temperatures of Franz Lake Refuge loggers 1-3 and Columbia River at Dotson Creek from March 15 to July 27, 2023

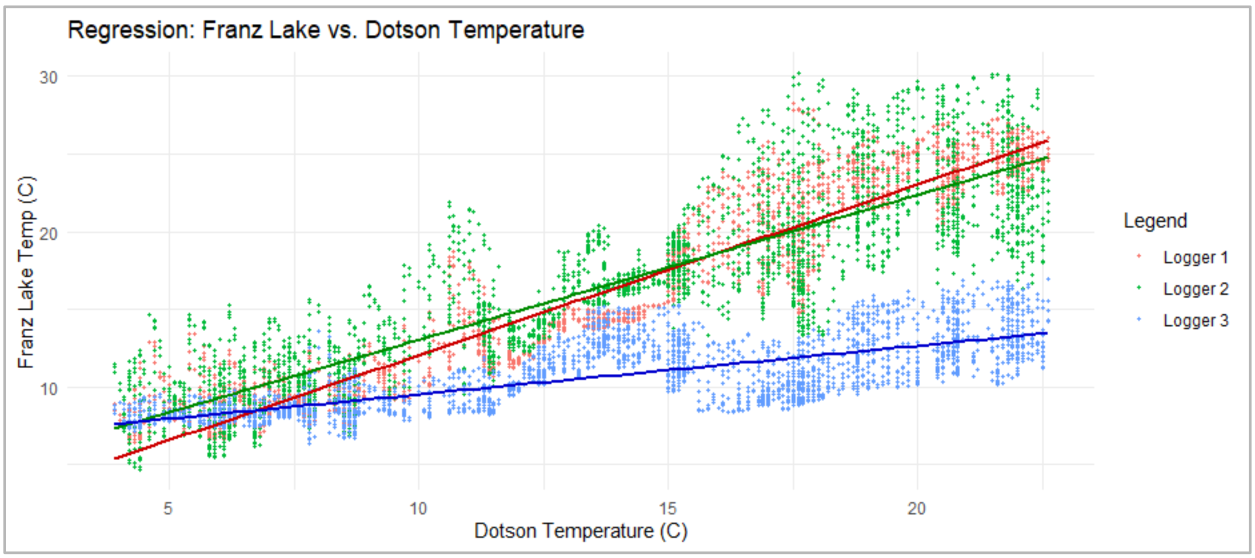

Figure 11: Linear Regression of Franz Lake loggers 1-3 and Columbia River at Dotson Temperature from March 15 to July 27, 2023

Pre-freshet (Figure 12), the water temperature throughout the Franz Lake system showed a weak, statistically significant relationship to the Columbia River temperature. Logger one (R^2=0.34; p-value < 0.05), logger two (R^2=0.37; p-value < 0.05), and logger three (R^2=0.15; p-value < 0.05) all showed a weak, positive relationship between the Columbia River temperature. During the freshet period (Figure 13), the temperature results between the Franz Lake loggers vary. Logger one had a strong positive relationship (R^2=0.81; p-value < 0.05) with the Columbia

River, logger two had a weaker relationship than logger one (R^2=0.51; p-value < 0.05) (Figure 14), and logger three had almost no relationship (R^2=0.01; p-value < 0.05) with the Columbia River. Since logger three was highest in elevation in the Franz Lake system and located just below a main water source (Indian Mary Creek), this regression analysis shows that it was highly influential on keeping the water temperature lower. However, as the water moves through the lake, from east to west, through the slough, the water temperature increases. During post-freshet (Figure 14), there was a weak, statistically significant relationship between Franz Lake water temperature and the Columbia River overall. All the loggers had a low R-squared value of less than 0.50 (p-value < 0.05), with logger two with the lowest R-squared of 0.06 (p-value < 0.05). In these regression analyses of water temperature, the influence of Indian Mary Creek on Franz Lake appears even more influential.

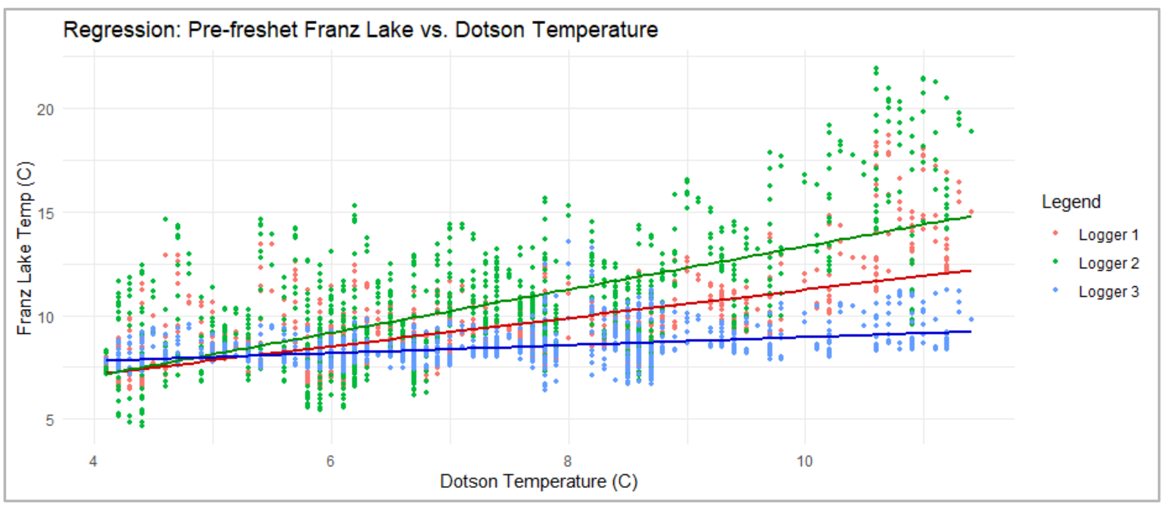

Figure 12: Linear regression of Franz Lake Refuge loggers 1-3 and Columbia River at Dotson Creek temperature pre-freshet from March 15 to April 30, 2023

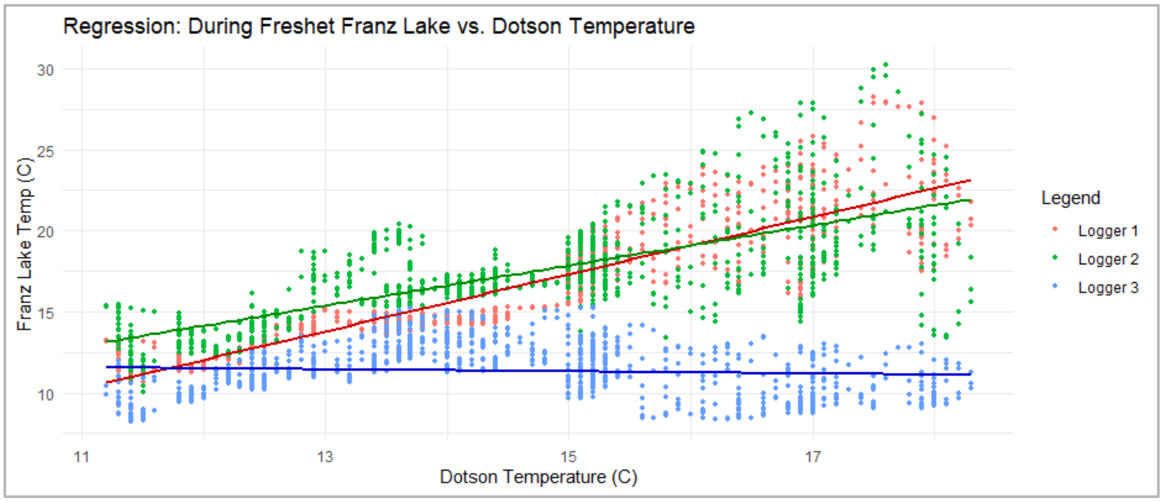

Figure 13: Linear Regression of Franz loggers 1-3 and Columbia River at Dotson Creek temperature during freshet period from May 1 to June 15, 2023

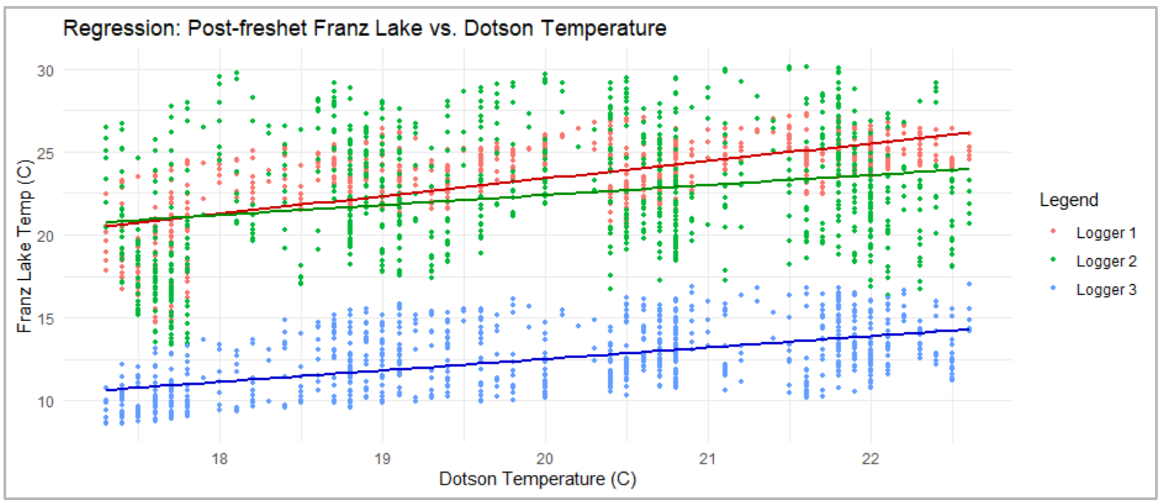

Figure 14: Linear regression of Franz loggers 1-3 and Columbia River at Dotson Creek temperature post-freshet from June 16 to July 27, 2023

In the time series graph from 2008 to 2022 (Figure 15), the Franz slough temperature and Columbia River at Dotson Creek data loggers appear closely aligned. Appendix D provides a time series of the Franz Slough and Columbia River at Dotson Creek daily water temperature averages for each year from 2008 to 2002. Upon further assessment using a linear regression analysis, a strong and statically significant relationship was found between the slough logger and the Dotson Creek logger (Figure 16). The R-squared value was 0.84 (p-value < 0.05); therefore, 84% of the variance in Franz Slough water temperature can be explained by the Columbia River water temperature. This may likely be due to the location of the logger and its proximity to the

Columbia River. During high water periods in the Columbia River, it is likely that water changes its direction of flow in the slough contributing to this strong relationship.

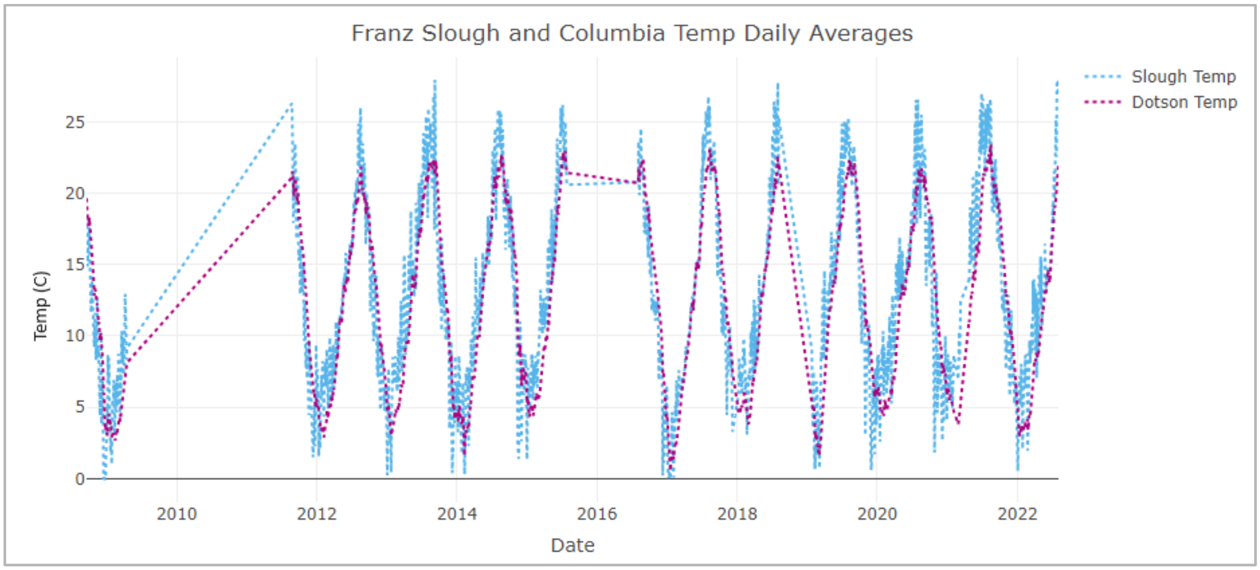

Figure 15: Time series graph of Franz slough water temperature and Columbia River at Dotson Creek from 2008 to 2022

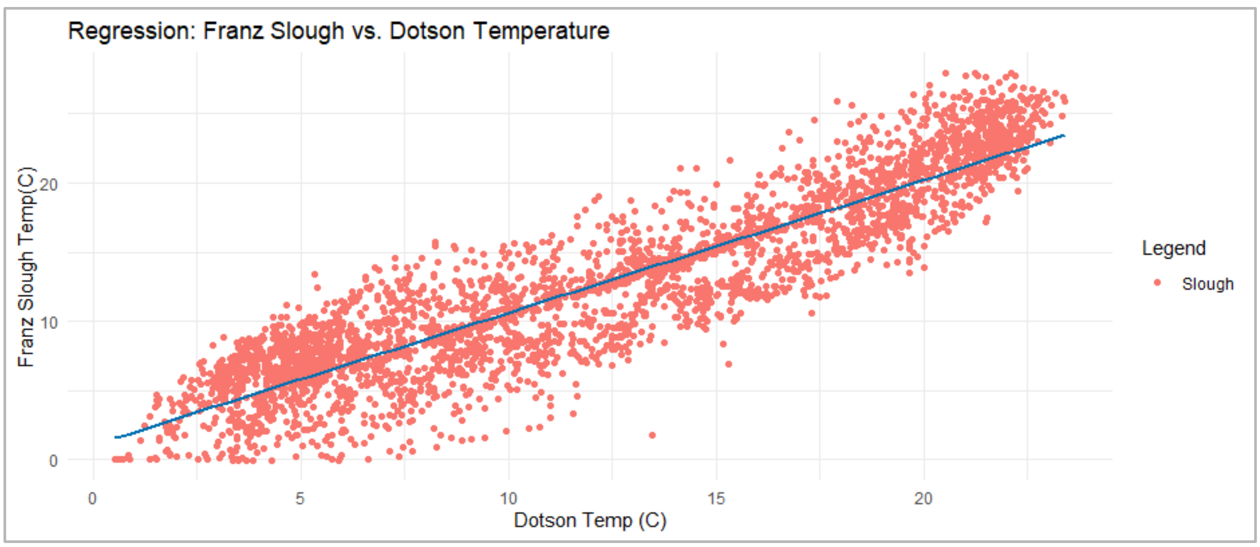

Figure 16: Linear regression of Franz Slough and Columbia River at Dotson Creek water temperature from 2008 to 2022

A correlation matrix (Figure 17) revealed that in the long-term data from the slough logger, water temperature and air temperature ($\rho = 0.96$) are highly correlated based on the Spearman Rank Correlation Coefficient. Water temperature and solar radiation ($\rho = 0.72$) are also highly correlated based on the Spearman Rank Correlation Coefficient. Conversely, there was a weak relationship between precipitation and slough logger stage and between precipitation and water temperature. The pair-wise scatter plot indicates a positive relationship between slough water temperature and air temperature as well as between water temperature and solar radiation.

Similarly, in the correlation matrix of loggers 1-3 (Figure 18), the Spearman Rank Correlation Coefficient showed a strong relationship in all three loggers between water temperature and precipitation and between water temperature and air temperature ($\rho = 0.92$). The pair-wise scatter plot showed a positive relationship between water temperature and precipitation and between water temperature and air temperature in all three loggers. Conversely, there was a weak relationship between water temperature and solar radiation in all three loggers. Similarly to the slough logger, there was a weak relationship between water stage and precipitation for all three loggers. This may be an indication that the water levels in Franz Lake are less dependent on rain and snow melt compared to water levels in the Columbia River. Air temperature also had a significant effect on water temperature throughout the entire Franz Lake system. Interestingly, there was a strong correlation with precipitation and water temperature in the three loggers ($\rho = 0.84$), but this was not found to be the case in the slough logger.

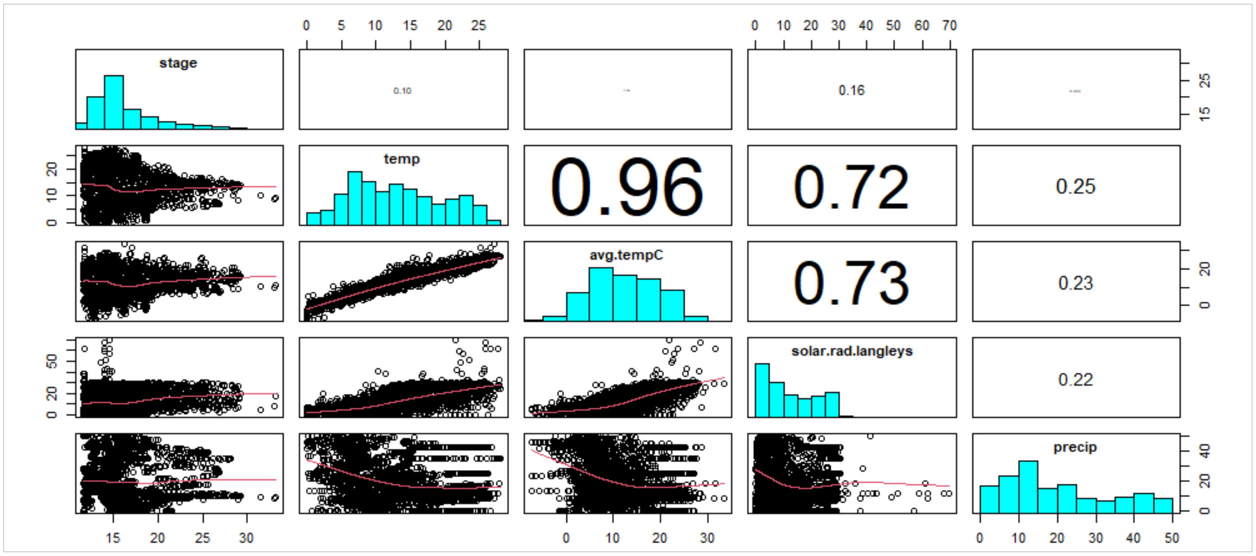

Figure 17: Correlation matrix of Franz Slough logger and weather data 2013-2022. The histograms of each dataset are on the diagonal within the matrix. 'Stage' is slough stage, 'temp' is slough water temperature, 'avg.temp.C' is ambient temperature, solar.rad.langleys is solar radiation, and precip is average precipitation. The Spearman Rank Correlation Coefficient is displayed in the top right corner of the matrix. A pair-wise scatter plot with a curved line showing the relationship between the variables using locally estimated scatterplot smoothing (LOESS) is displayed in the bottom left corner of the matrix.

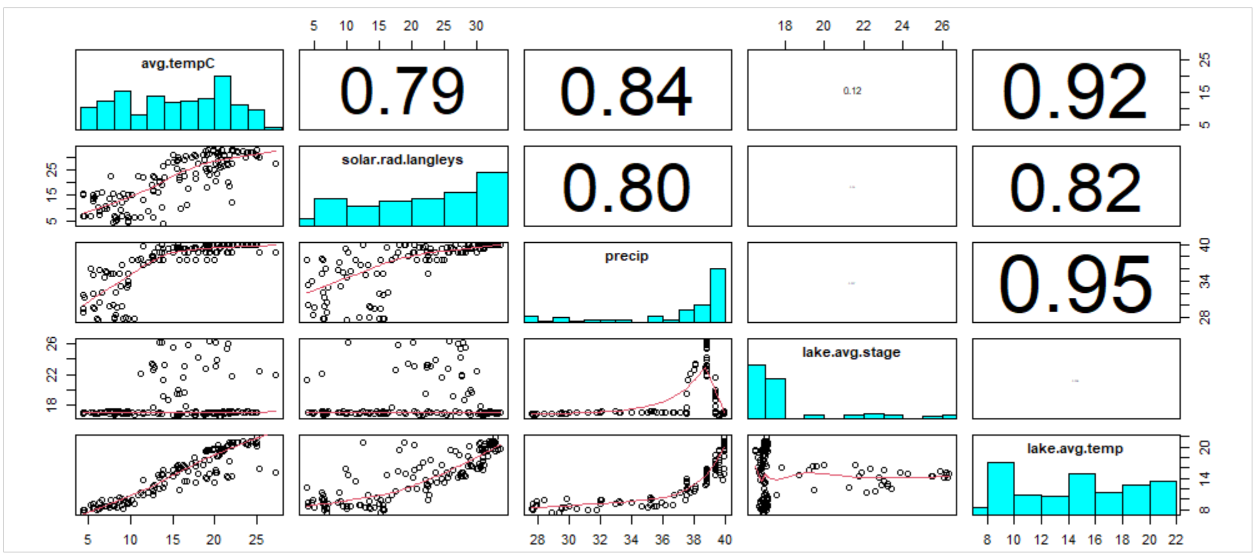

Figure 18: Correlation matrix of Franz Lake loggers 1-3 averaged and weather data from March 15 to July 27, 2023. The histograms of each dataset are on the diagonal within the matrix. 'Avg.temp.C' is ambient temperature, 'solar.rad.langleys' is solar radiation, and 'precip' is average precipitation, 'lake.avg.stage' is the stage of loggers 1-3 averaged together, and 'lake.avg.temp' is the water temperature of loggers 1-3 averaged together. The Spearman Rank Correlation Coefficient is displayed in the top right corner of the matrix. A pair-wise scatter plot with a curved line showing the relationship between the variables using locally estimated scatterplot smoothing (LOESS) is displayed in the bottom left corner of the matrix.

5.2. Lake Area and Beaver Dams

Ground surveys in March, 2023 revealed that there are two active beaver dams at Franz Lake. Beaver dams were considered active if there was freshly packed mud, grass, and other newly added vegetation and chewed sticks. The lower dam (latitude: 45.60030, longitude: -122.10625) on the slough was approximately 20 meters (64 feet) in length, 4 meters (13 feet) in elevation, and the water level difference between downstream and upstream (or hydraulic height) was approximately 0.5 meters (1.5 feet). The lower dam was wider than the main channel and was primarily composed of wood, grass, and mud. There was overflow of water at the dam; over, under, through, and around the dam. The upper dam was approximately 102 meters (335 feet) in length, 5 meters (17 feet) in elevation, and the hydraulic height was approximately 0.67 meters (2.2 feet). The upper dam (latitude: 45.60130, longitude: -122.09998) was wider than the channel and was composed of wood, grass, mud, and cobble (stones). There was overflow of water at the dam, both over and through the dam. There was also an area that was blown out, but the rest of the dam was intact and holding water. High water marks on the rock nearby indicated that the water had dropped at least 0.3 meters (1 foot) recently at the upper dam, possibly following the dam blow out.

Additionally, the ground surveys revealed that there were three lodges, one inactive and two active (Figure 19) Similarly to beaver dams, lodges were considered active if there was freshly packed mud, grass, and chewed sticks on and surrounding the lodge. One active beaver lodge (latitude: 45.60048, longitude: -122.10492) was located upstream (east) of the lower dam on the south bank of the slough. It was noted to have two entrances facing the stream side. The second active beaver lodge (latitude:45.60124, latitude: -122.09884) was located east of the large upper dam in the middle of Arthur Lake. The third lodge (latitude: 45.60228, longitude: -

122.09525) was located on the north bank of Arthur Lake. The entrances were not underwater, and there was no fresh packed mud or sticks, so this lodge was considered abandoned or inactive. Based on satellite and aerial imagery, beavers began building dams in Franz Lake Refuge in 1993. One dam was recorded in 1993 (latitude: 45.60145, longitude: -122.100715) at 36 meters in length (117 feet). Since 1993, the number of dams has varied from zero dams in 2012 to as high as five in 2006. Beaver dams have remained consistent throughout Franz Lake Refuge from 2012 to 2023. Bank lodges are difficult to identify from aerial views, but the 2023 lodge located in the middle of Arthur Lake was observed dating back to 2009.

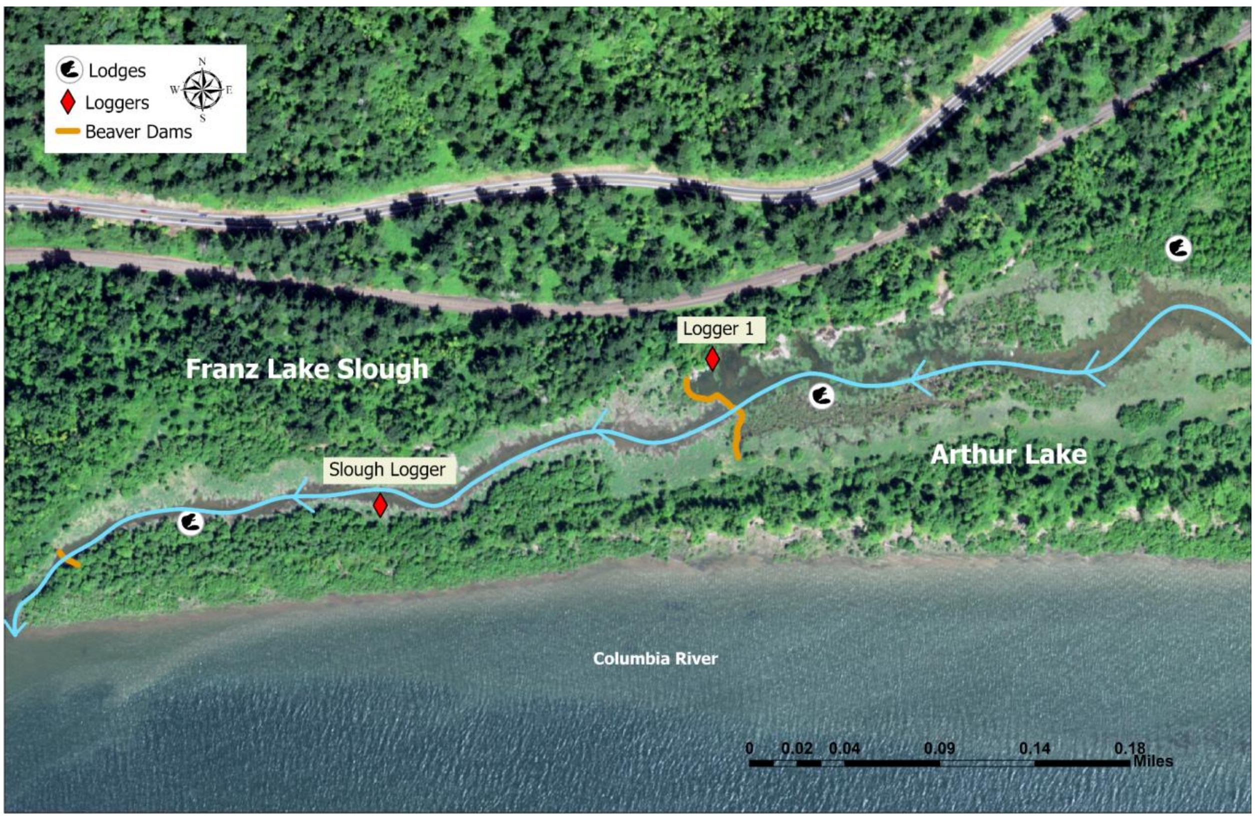

Figure 19: Franz Lake Refuge beaver dams and lodges identified in 2023 ground surveys. The blue lines indicate the direction of water flow. Imagery data source: NAIP, 2020, Earthexplorer.usgs.gov.

Franz Lake surface area was assessed using a combination of satellite and aerial imagery from 1930 to 2023. Bonneville Dam was constructed in 1938, resulting in a highly modified and actively managed hydrologic regime in the lower Columbia River floodplain. In the hydrograph with the hourly stage data from Bonneville Dam (Figure 3), the water levels downstream of the Bonneville Dam were found to be highly variable. In the lake area time series graph (Figure 20) derived from the remote sensing imagery, the surface water extent in Franz Lake was also highly variable; however, since 2017, there has been a leveling off and the variability has diminished. In Figure 20, when visually comparing the lake area extent to the peak water stage from the Bonneville gauge on the same day the remote sensing image was captured, it appears that they are closely aligned, suggesting the Columbia River stage is largely influencing the surface water extent within Franz Lake.

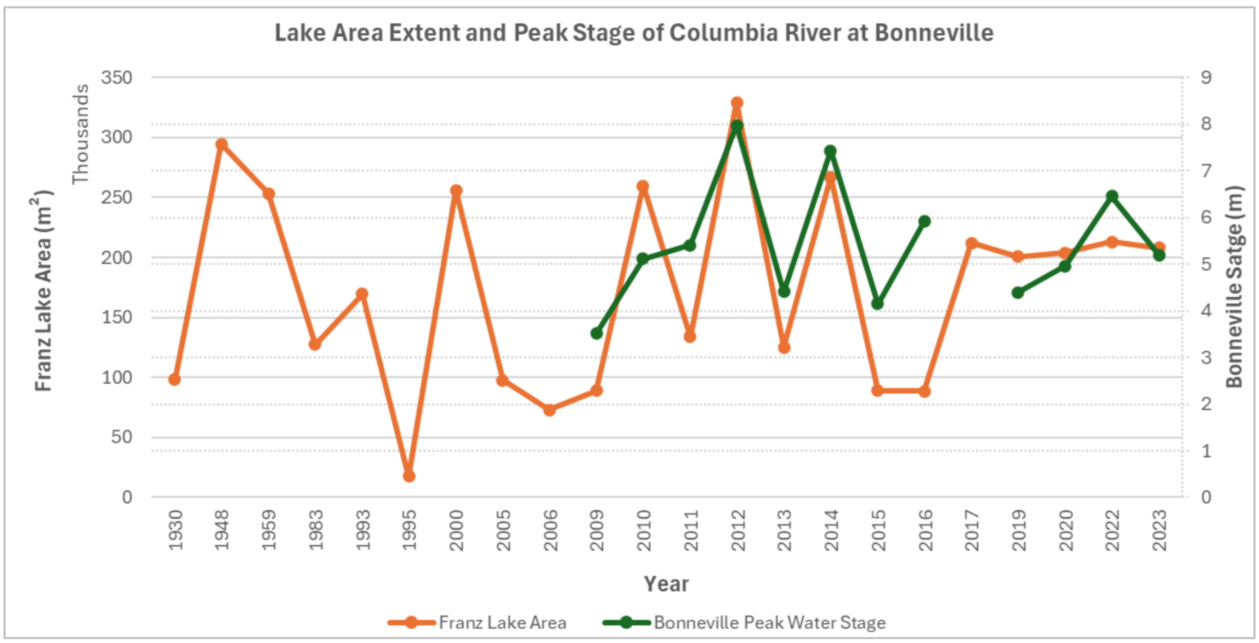

Figure 20: Time series graph of Franz Lake surface water areas and the peak water elevation (stage) at the USGS gauge below Bonneville Dam from 1930 to 2023

Furthermore, in the linear regression analysis (Figure 21), the relationship between the number of beaver dams and lake area was negative and weak with an R-squared value of 0.21 (p-value = 0.03); therefore, only 21% of the variance in lake area can be explained by the number of beaver dams. Table 4 provides a summary of the linear regression results from the lake area and beaver dam analysis. As previously mentioned, there was a strong relationship found between the Franz Lake loggers (1-3) stage and Bonneville stage during the freshet period (May 1-June 15), but outside this period, the relationship between Franz Lake loggers and Bonneville was found to be statistically weak. This may be an indication that the beaver dams in Franz Lake do have influence on the water levels in Franz Lake to a certain extent, outside of flooding periods, but further analysis is needed.

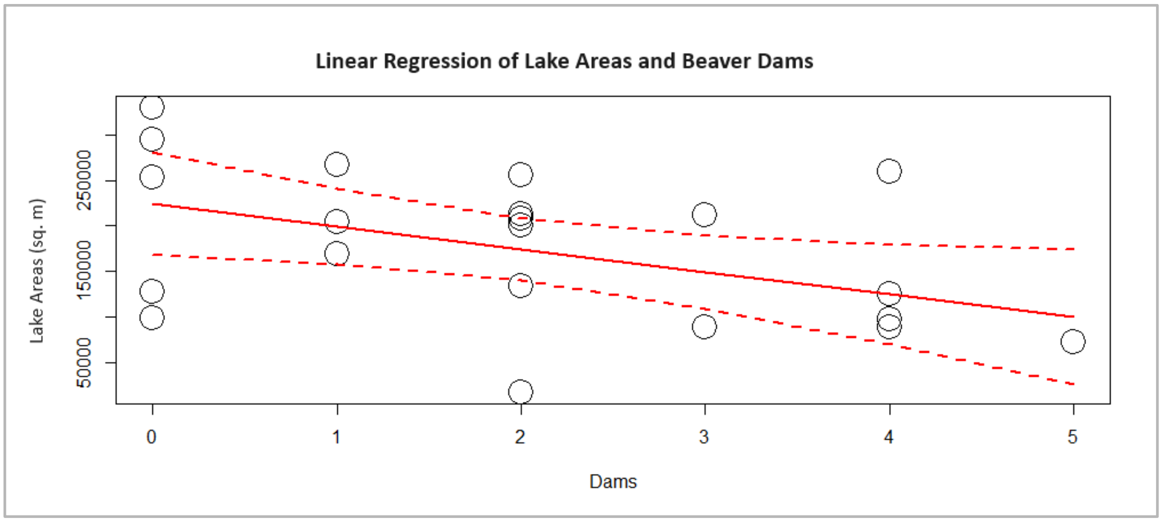

Figure 21: Linear regression model (solid red line) with 95% confidence intervals (segmented red line) of the relationship between Franz Lake ponded areas and number of beaver dams from 1930 to 2022.

Table 4: Linear regression model results of lake area (m^2) and number of beaver dam from 1930 to 2022 with coefficient estimates, 95% confidence intervals, and p-values

	Lake Water Area		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	223990.67	167229.68 – 280751.65	**<0.001**
Dams	-24870.21	-47133.70 – -2606.72	**0.030**
Observations	22		
R^2 / R^2 adjusted	0.214 / 0.174		

5.3. Vegetation Composition

The ground surveys revealed that *P. arundinacea* is the dominant species surrounding Franz Lake based on total percent coverage (Figure 23). However, the surveys also revealed that there is substantial plant diversity, with 60% of other species when compared to 33% *P.*

arundinacea. *S. latifolia* makes up approximately 7% of the total percent coverage in Franz Lake after the open water categories were removed (Figure 22). *S. cypernius*, *P. dilatatum, Eleocharis* species were among other species with the most percent coverage. The highest number of species identified at a single site was 10. The dominant species type found was to be emergent wetland, non-persistent based on the Cowardin et al. Wetland Classification System (1979). Other types included scrub-shrub wetland, aquatic, submerged, and forested wetland species. Of the top five most abundant species identified, two are considered introduced, invasive species; *P. arundinacea* and *P. dilatatum.* Table 5 below summarizes the plant species identified in Franz Lake Refuge, although this list is not all inclusive, given that the percent coverage transect surveys focused on the floodplains of Franz Lake and not the upland habitat.

In the image classification performed in ArcGIS Pro (Figure 24), the total area analyzed was approximately 138 hectares, which primarily focused on the lower floodplain area in order to assess the emergent and aquatic vegetation. A total of 6 classes were used in the image classification: open water, forested uplands, mixed forest wetland, *P. arundinacea* (RCG) dominated, emergent non-persistent wetland, and aquatic/submerged species. The classified area comprises 7.86% open water, 13.48% forested uplands, 36.30% mixed forested wetland, 18.17% *P. arundinacea* dominant, 16.11% emergent wetland, and 8.07% aquatic and submerged vegetation.

Table 5: Franz Lake observed vegetation in 2023, including growth habit and classification status

Scientific Name	Common Name	Growth Habit	Image Classification Status
Amorpha fruticosa	False Indigo bush	Perennial shrub (introduced)	Forested wetland
Apocunum androsaemifolium	Spreading dogbane	Perennial herb	Forested wetland/uplands
Bidens cernua	Nodding beggarticks	Annual forb	Emergent wetland
Callitriche stagnalis	Pond water-starwort	Aquatic perennial floating herb	Aquatic/submerged
Carex feta	Green-sheathed sedge	Perennial herb-sedge	Emergent wetland
Carex aquatalis	Water sedge	Perennial herb-sedge	Forested wetland
Eleocharis Spp.	Spikerushes	Annual emergent grass-like	Emergent wetland
Elodea canadensis	Canadian waterweed, ditchmoss	Perennial submerged forb	Emergent wetland
Equisetum spp.	Horsetails	Perennial herb	Forested wetland
Fraxinus latifolia	Oregon ash	Native tree	Forested wetland
Leersia oryzoides	Ricecut grass	Perennial grass	Emergent wetland
Ludwigia palustris	Water purslane	Aquatic perennial herb	Emergent wetland
Paspalum dilatatum	Knotgrass, Dallis grass	Perennial grass	Emergent wetland
Patamogeton natans	Pondweed	Aquatic perennial herb	Aquatic/submerged
Phalaris arundinacea	Reed canary grass	Perennial grass (introduced)	RCG dominant
Polygonum amphibium	Water smartweed	Perennial emergent forb	Emergent wetland
Polygonum hydropiperoides	Swamp smartweed, pepperweed	Perennial emergent herb	Emergent wetland
Populus balsamifera	Black cottonwood	Native tree	Forested wetland
Rubus armeniacus	Himalayan blackberry	Vine (Introduced)	Forested wetland/uplands
Sagittaria latifolia	Wapato, duck potato	Perennial emergent forb	Emergent wetland
Salix spp.	Willows	Native woody shrub	Forested wetland
Scirpus arutus	Hardstem bulrush, tule	Perennial emergent herb	Emergent wetland
Scirpus cyperinus	Woolgrass	Perennial emergent herb	Emergent wetland
Scirpus tabernaemontani	Softstem bulrush, tule	Perennial emergent herb	Emergent wetland
Spiraea douglasii	Douglas spiraea	Woody shrub	Forested wetland

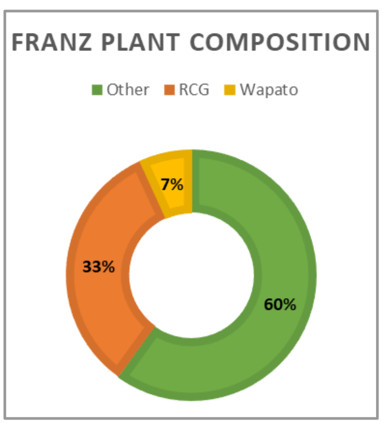

Figure 22: Pie chart from Franz Lake plant composition in 2023 displaying of reed canary grass (RCG) dominant, Wapato, and all other species combined

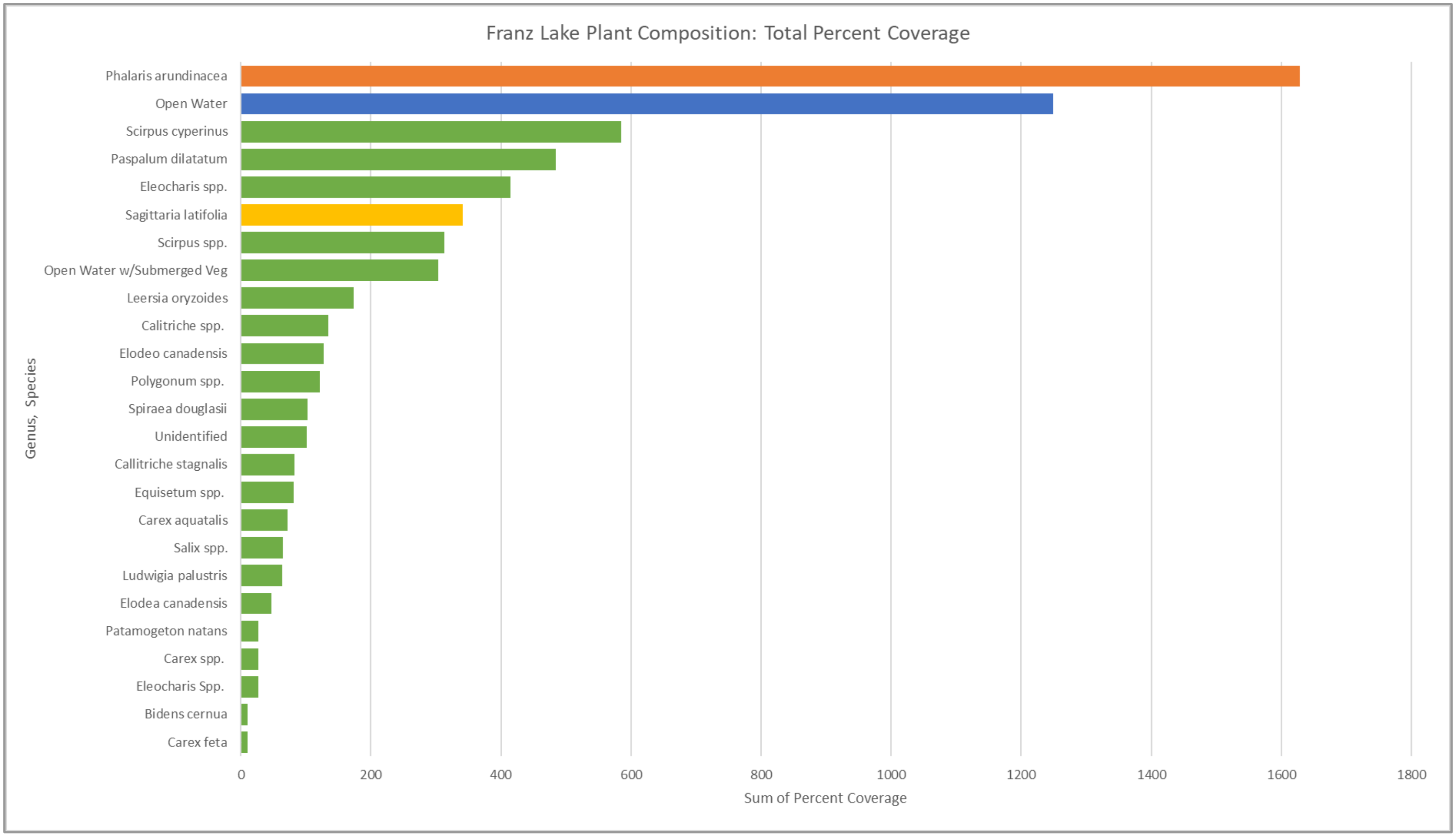

Figure 23: Bar chart of total percent coverage of each plant species and open water in Franz Lake during October, 2023

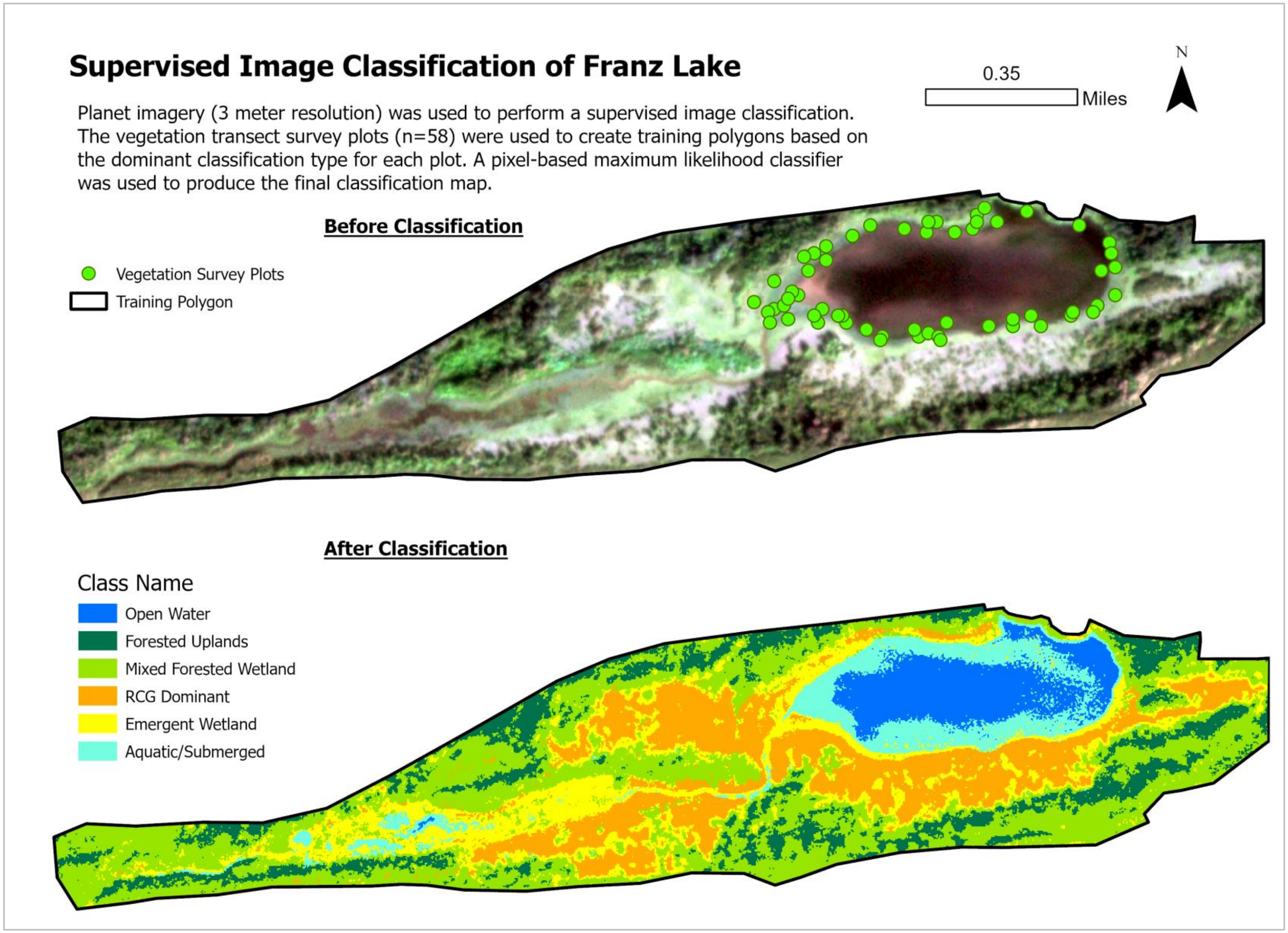

Figure 24: Supervised image classification of Franz Lake Refuge floodplain performed in ArcGIS Pro. Top image displays the vegetation plots surveyed in October 2023. Bottom image displays results from image classification. Imagery data source: Planet.com, Oct. 2023.

6. Discussion

6.1. Hydrologic Factors in Franz Lake

With over 250 reservoirs and about 150 hydroelectric projects, including 18 mainstem dams (ACE, 2024), the Columbia River basin's natural hydrology has been highly altered by anthropogenic activity. Upon initial analysis, Franz Lake and the slough both appear to be largely influenced by the Columbia River, especially during flooding periods. However, outside of the flooding period, the influence of the river on stage in the lake is insignificant, pointing to other sources of influences on water surface elevation within the lake system, such as beaver dams, natural springs, creeks, and climatic shifts. In the slough, being the lowest in elevation in the system, the long-term data suggests that the water elevation and temperature are highly influenced by the Columbia River during all times of the year, even outside of major flooding periods. Since the lake is higher in elevation than the slough there is less of an influence from the Columbia River outside of the freshet period. The results of this research suggest that precipitation has little effect on the water stage in both the lake and slough.

Moreover, the water temperature in Franz Lake Refuge is highly influenced by various factors. Indian Mary Creek provides consistently lower water temperatures to the lake, but as the water flows through the lake system, a steady increase in water temperature was found in the slough. The water temperature in Franz Lake Refuge is affected by other factors such as exposure to solar radiation and ambient temperature. While Franz Lake is under the influence of a flooding event, like the spring freshet, the lake system appears to be influenced strongly by the Columbia River; however, as the water elevations decrease back to a steady state, the water temperatures in the slough remain consistently high, even above the average Columbia River water temperatures. In the summer months of 2023, the daily average water temperatures in the slough, above the main beaver dam in Arthur Lake, remained consistently higher than the Columbia River.

6.2. The Role of Beavers in Franz Lake Refuge

Beavers were non-existent in Franz Lake Refuge from the 1930s to the 1990s based on the lack of beaver dams found in the imagery obtained in this study. The evidence suggests that beavers have been actively building dams in Franz Lake Refuge for more than 30 years. Since establishing in Franz Lake Refuge, the beavers have experienced both boom and bust years, with some years as many as five dams throughout the system. In 2023, there were two active lodges found during the ground surveys of Franz Lake Refuge, which are typically determined by the presence of fresh mud and newly chewed sticks (Johnston and Windels, 2015). There are likely at least two beaver colonies living on Franz Lake Refuge, since the density of beaver populations is regulated in part by intraspecific competition, or territoriality (Aleksuik, 1968). Beavers use scent mounds consisting of mud and anal secretions to mark their territories along streams, the movement of the colony, and to deter non-resident beavers (Aleksuik, 1968; Collins, 1976). Each colony size is assumed to be one mated pair and one to two generations of offspring (Collins, 1976).

Based on this research, the presence of beaver dams in Franz Lake Refuge was shown to have minimal effect on the extent of surface water within Franz Lake. The statistical analysis showed that there was a negative relationship between the lake water surface area and the number of beaver dams; therefore, the lake areas decrease as the number of beaver dams increases. In the imagery, there were five years recorded with zero beaver dams in Franz Lake, and the lake areas were higher than when there were the most beaver dams found in the area (4-5 dams). This is counter to other research findings that beaver presence would increase the amount of open water, since beaver dam complexes create ponded water. In Alberta, Canada beaver presence (i.e. beaver lodges) was correlated with a ninefold increase in open water in wetland complexes (Hood and Bayley, 2008). In northwestern Alaska, beaver dammed lake outlets led to a 26% increase in the surface water area in thermokarst lakes (Jones et al., 2020). However, the decrease in lake surface area with an increase in beaver dams in Franz Lake Refuge suggests that there are additional factors influencing the hydrology in this setting.

On another note, although herbivory of *S. latifolia* was not quantified in this research, anecdotal evidence suggests that beavers may be contributing to the decline in *S. latifolia.* Beaver herbivory can significantly reduce the amount of aquatic vegetation and alter the composition of plant species (Parker et al., 2007). When consuming more palatable, preferred species and avoiding less preferential species, herbivores can both directly and indirectly change the plant abundance and composition within a landscape (Parker et al., 2007; Huntly, 1991). While conducting transect surveys in October, 2023, there was evidence of herbivory of *S. latifolia*, which was noted by leafless stems and whole plants pulled from the substrate (see picture to left). There is little information on the role of animal herbivory, particularly beavers, on populations of *S. latifolia* (Marburger, 1993; Darby, 1996).

Picture: *S. latifolia* stems with no leaves, evidence of herbivory

6.3. Sagittaria latifolia and Phalaris arundinacea

As previously mentioned, beavers had been suggested as the cause of the decline in *S. latifolia* due to increasing the water levels in Franz Lake; however, based on the evidence, there are many compounding factors contributing to the suspected decline in *S. latifolia* in Franz Lake Refuge. It is important to consider that there was no scientific record of *S. latifolia* in Franz Lake Refuge before 1977 (FWS, 1991). Considering this area was used for a variety of purposes, including grazing cattle that are known for eating *S. latifolia* leaves (Darby, 1996), there is the possibility that the *S. latifolia* was present, but the achene and tubers remained dormant underground until provided with the right conditions for emergence and decreased pressure from herbivory. Kaul (1985) found that the germination rates of *Sagittaria* species achene contained in a laboratory refrigerator only dropped by five percent after 7 years, which suggests the long-term viability of the species. Kenow et al. (2018) found *Sagittaria* is highly tolerant to flooded conditions and average mortality of *Sagittaria* species with large tubers was only 2% and 7% for seedlings. Others have found similar results with *Sagittaria* species in varying flooding conditions (Martin & Shaffer, 2005; Marburger, 1993).

S. latifolia is known to survive in a variety of conditions. As a perennial species with underground storage organs (i.e. tubers and rhizomes), *S. latifolia* can survive drastic fluctuations in the environment, such as floods, droughts, and wavering water and soil conditions (Kaul, 1985). For instance, if the water is low during dry conditions during the flowering in the late summer into fall, *S. latifolia* can become dormant, not producing flowers, but can be revived by fall rains (Kaul, 1985). The length of time that *S. latifolia* tubers and achene can remain dormant, yet viable underground, is unknown. As previously mentioned, *S. latifolia* has been harvested by Indigenous people for thousands of years and was once a staple food and trade commodity for the tribes of the lower Columbia River (Darby, 2005; 194). Darby (2005; 213-214) suggests that the disappearance of *S. latifolia* in the lower Columbia River is attributed to the impacts of European settlement in the area, starting in the 1830s, and the elimination of the people that once protected and valued this valuable resource.

In ideal conditions along lake shores, *S. latifolia* requires exposed mudflats in May and June to germinate and for seedlings to establish, and is typically widespread after periods of dryness, suggesting that the dryness weakens the seed coats which may be inhibiting germination (Kaul, 1985). Kidd et al. (2022) found that in the lower Columbia River floodplains, low discharge years are attributed to the increase in *S. latifolia* the following year. This delayed response to the Columbia River discharge and requirement of exposed substrate for germination may be affecting the ability of *S. latifolia* to establish, especially with the pervasiveness of *P. arundinacea* in Franz Lake Refuge. However, low water levels can also favor *P. arundinacea*, especially when *S. latifolia* is crowded out (Kaul, 1985). As suspected, *P. arundinacea* has become pervasive in Franz Lake Refuge, composing approximately 18 percent of the lower floodplain landscape based on the field survey in 2023 and digital image classification results. *P. arundinacea* is likely encroaching on primary *S. latifolia* habitat, among other native emergent species within Franz Lake Refuge. From 2018 to 2021, LCEP recorded an increase in *P. arundinacea* at their Franz Slough monitoring site from 11% to 30% (Kidd et al., 2022). Additionally, Kidd et al. (2022) found a strong correlation of the Columbia River discharge and site-specific water levels with the annual shifts in *P. arundinacea* percent coverage.

Invasive plant species pose a major threat to endemic plant ecosystems and are a significant contributor to the loss of biodiversity (Lavergne and Molofsky, 2004; Vitousek et al., 1996). In Washington, *P. arundinacea* is listed as a Class C noxious weed that is detrimental to wetland ecosystems due to its ability to rapidly form dense monocultures. (Washington State Noxious Weed Control Board, 1995; Apfelbaum and Sams, 1987). *P. arundinacea* can both inhibit the growth and eliminate other competing species (Apfelbaum and Sams, 1987). Several factors can contribute to the spread of *P. arundinacea* including, but not limited to, land use disturbance, altered hydrology, and excessive nutrient runoff (Lavergne and Molofsky, 2004). If unconstrained in bare sediment conditions, *P. arundinacea* invades rapidly via vegetative spread of underground rhizomes and dominating other native wetland plant species (Adams & Galatowitsch, 2005). This is problematic for *S. latifolia* since it requires exposed soil and mud to establish.

6.4. Study Limitations and Recommendations for Future Research

This research examined only one location within the lower Columbia River floodplain, which represents a small portion of the entire Columbia River basin and a small sample size of the characteristics of vegetation, beaver dams, and lake area extent within one location. Future research would benefit from including a greater number of areas within the lower Columbia River floodplain with beaver presence to better understand the complex interactions between beaver activity, hydrology, and wetland vegetation communities. Also, future research would benefit by including elevation data into the survey design to understand the influence of land elevation on wetland species distribution and hydrology. This could be accomplished with topographic surveys using RTK GPS technology and existing Light Detection and Ranging (LiDAR) datasets. With a greater understanding of the variations in land elevation, this could provide more information into the intricacies of the relationship between *P. arundinacea* and *S. latifolia* and the environmental factors that influence plant species dominance within floodplain ecosystems (Kidd, 2024, pers. comm.).

Moreover, the beavers' influence on the hydrology of Franz Lake needs further analysis. This research considers the effects of the number of beaver dams on lake water surface areas over time; however, the relationship of beaver dam elevations to the long-term water elevations from the data loggers installed throughout Franz Lake 2023 should be further evaluated. There are limitations with using remote sensing imagery, considering the images used to calculate lake water surface area are one snapshot in time, with most of the images taken in late summer, and do not consider the variability in hydrology within this complex system. In beaver dam complexes, the water levels are a balance between the volume of water entering (i.e. stream flow, precipitation, groundwater), volume of water exiting (i.e. stream flow, groundwater) and evaporation (Gurnell, 1998). Also, RTK GPS technology and LiDAR datasets would be useful in evaluating the long-term changes in beaver dam elevations and their relationship to the water level elevations. With one data logger above a large beaver dam (over 100 m) and the other two loggers upstream, this provides ample opportunity for long-term analysis of the effects of the beaver dams on water surface elevation.

Additionally, the image classification of the Franz Lake floodplain performed using remote sensing imagery could be further improved by using higher resolution imagery and an accuracy assessment of the classification results. Due to the limitations in funding for this project, Planet imagery with three-meter resolution was used to create the training polygons; however, this spatial analysis would benefit from access to high resolution imagery from an unmanned aerial vehicle (UAV) or other high resolution (<50 cm) remote sensing imagery. UAV photography is capable of "generating high accuracy top-down ortho mosaics" that can be used to characterize vegetation composition (Kidd et al., 2022). The image classification accuracy assessment is determined empirically and will allow a confidence level of the assessment to be attached to the classification results (Richards and Jia, 2006; 303). This can be performed by selecting a random sample of pixels and checking their classes against reference data that is ideally collected during site visits (Richards and Jia, 2006; 303).

Furthermore, given the dynamic nature of Franz Lake Refuge, future research should consider assessing the seasonal variations of water flow, or discharge, within the Columbia River over time, which can significantly influence wetland hydrology, and the health and extent of vegetation communities (Kidd, 2024, pers. comm.). Future research should evaluate the discharge and hyporheic, or groundwater, exchange within Franz Lake to better understand the relationship between Franz Refuge and the Columbia River and the effects of building activities of beaver. In eastern Oregon, Lowry (1993) found that beaver dams increased aquifer recharge and that groundwater storage potential from a beaver dam and pond was 446 m^3. In northern Utah, beaver presence was found to increase discharge at the reach scale, but when considering a smaller sub-reach there was variability in the losses and gains in discharge due to the complexity of water flow that beaver dams create within a stream system (Majerova et al., 2015). A comprehensive, long-term analysis of these factors affecting the hydrology within Franz Lake Refuge could provide more insight into how beaver dams affect lake water elevation and water extent seasonally.

6.5. Implications for Land Management

For land intended for preservation, maintaining biodiversity is essential. To maintain biodiversity within the wetland ecosystem, the management and control of *P. arundinacea* is essential. This can be done through many different avenues such as prescribed burning, herbicide application, mechanical removal, and controlled management of hydrology. Considering this research focus is on hydrology, the following habitat management recommendations will focus primarily on hydrological management. In floodplain ecosystems, like Franz Lake Refuge, water fluctuations can help increase biodiversity because periods of low water allow germination of buried or submerged seeds and periods of high water create gaps in the vegetation so that species can colonize (Farrelly, 2012). In Smith and Bybee Wetlands, located between the Columbia Slough and Columbia River in northwestern Oregon, Farrelly (2012) evaluated changes in wetland vegetation from an altered hydrologic regime by using linear transect surveys and elevation data. Farrelly found that areas experiencing a minimum of 0.6 meters (about 2 feet) of inundation had reduced *P. arundinacea* coverage and increased native plant coverage. Considering Farrelly's conclusions from a similar floodplain ecosystem, manipulation of the water elevations in Franz Lake Refuge could be a strategy to limit the growth of *P. arundinacea* and promote native species.

For *S. latifolia* the timing of inundation is important for both germination and establishment. In a controlled experiment, Kenow et al. (2018) evaluated *Sagittaria* species survival and plant biomass using three levels of timing of inundation, three levels of duration of inundation, and four levels of various water depths. They found that controlled flooding treatments had a positive effect on seedling biomass production of *Sagittaria* species, more specifically, when the flooding treatments occurred early, were shallow, and for a short duration. In 2023, major flooding occurred from May to June with the highest water elevations recorded around eight meters (NAVD88) in Franz Lake Refuge. Outside of this flooding period, water levels within Franz Lake remained fairly level, which may be attributed to both beaver activity and the human altered hydrologic regime. Due to the many dams built throughout the Columbia River basin, natural hydrologic activity has been dramatically altered within the lower Columbia River, which is likely influencing the wetland vegetation composition. Since the 1800s, dam regulation has reduced the peak summer flows and increased the winter low flow periods, "flattening" the seasonal hydrological patterns (Water Science and Technology Board, 2004). Adjusted to the demands for electric power, daily flow patterns below a hydroelectric dam are shown to vary substantially (WSTB, 2004), as evidenced by the hydrograph of Bonneville Dam water elevations in Figure 3.

Without implementing policy changes, it is difficult to say if changes to the flow management of hydroelectric dams are possible, especially as human populations continue to increase and the demand for electricity grows. Assuming historic flow conditions cannot be achieved, it is still possible to enhance biodiversity through habitat restoration in Franz Lake Refuge. As previously mentioned, assessing the elevation gradient within Franz Lake Refuge will provide more insight into the relationship between the hydrology and vegetation community. Restoration strategies should consider changing the elevation gradient within Franz Lake to better fit the existing hydrologic conditions to both promote native species and suppress invasive species (Kidd, 2024, per. comm.). In the ACE historical imagery from 1930 (Appendix A), Franz Lake had multiple connections to Columbia River, so restoring those connections could be a valuable first step to restoration. This project provides ample opportunities for future restoration efforts by providing a baseline for data collection and monitoring, which can be used as a measurement for success post-restoration.

Since beavers are well established in Franz Lake Refuge, they are likely influencing the emergent plant diversity through direct consumption as observed in the field surveys. Future research should consider the direct effect of beaver herbivory on *S. latifolia.* Parker et al. (2007) found that beavers reduced aquatic plant biomass by 60%, dramatically shifting the composition of plant species in benthic freshwater ecosystems. Future restoration and land management within Franz Lake Refuge should consider exclusion strategies to protect *S. latifolia* from animal herbivory. This can be done by using exclusion fencing or even strategic planting of unpalatable species to deter beaver herbivory. For instance, *Scirpus cyperius* has been shown to provide associational defense, protecting palatable species from animal herbivory (Parker et al., 2007: Levine, 2000). Interestingly, *S. cyperius* was among the top five most common species found in the 2023 transect surveys.

Finally, future restoration goals should consider: 1) making changes to the elevation gradient and reconnecting Franz Lake to the Columbia River to help increase water fluctuations to allow for the necessary drawdown so that *S. latifolia* and other native emergent species can establish, 2) the control and regular maintenance of *P. arundinacea*, and 3) selective planting to both protect plants from animal herbivory and to outcompete *P. arundinacea.*

7. Conclusions

Although human disturbance has been kept to a minimum since the FWS acquisition in 1990, Franz Lake Refuge is not immune to the indirect effects of anthropogenic activity. The hydrology within Franz Lake has been dramatically altered. The changes in lake water surface area over an almost 100-year period showed that there is considerable variability in the lake system from year to year. Altered hydrology and a lack of management are likely contributing to the spread of invasive plant species like *P. arundinacea.* As an introduced species, *P. arundinacea* has become a dominant species within the floodplains of Franz Lake Refuge, encroaching on native emergent species habitat. When unmanaged, as seen in Franz Lake, it can form dense monocultures that have detrimental effects on biodiversity within wetland communities.

In protected areas, such as Franz Lake Refuge, climate change is a major concern due to their primary role in the conservation of threatened species and preservation of biodiversity (Hood and Bayley, 2008). Increased global temperatures, caused by the release of greenhouse gasses into Earth's atmosphere due to the combustion of fossil fuels, have been linked to extreme heat waves, droughts, heavy precipitation, and other severe weather events (Intergovernmental Panel on Climate Change, 2023). Appendix B is a schematic that displays the complexity of factors and impacts to Franz Lake Refuge, including the potential impacts of climate change. The IPCC (2023) recognizes that restoring wetlands and rivers can reduce climate change threats, such as flood risks and urban heat effects. If future restoration is to be conducted in Franz Lake Refuge, the data collection from this research will offer a useful comparison for post-restoration monitoring.

Lastly, as an important food for Indigenous tribes and as a beneficial plant to water quality, *S. latifolia* has ecological and cultural significance. Once protected and managed by Indigenous tribes for thousands of years, the disappearance of *S. latifolia* coincided with Euro-American colonialism and the movement of tribes from their ancestral lands (Darby, 2005; 213-214). Future research should consider the traditional ecological knowledge of the people who acknowledge the reciprocal relationship between the land and people. To honor and respect the Watlala people who once inhabited Franz Lake Refuge, it is critical to acknowledge the value of protecting this land for generations to come.

8. References

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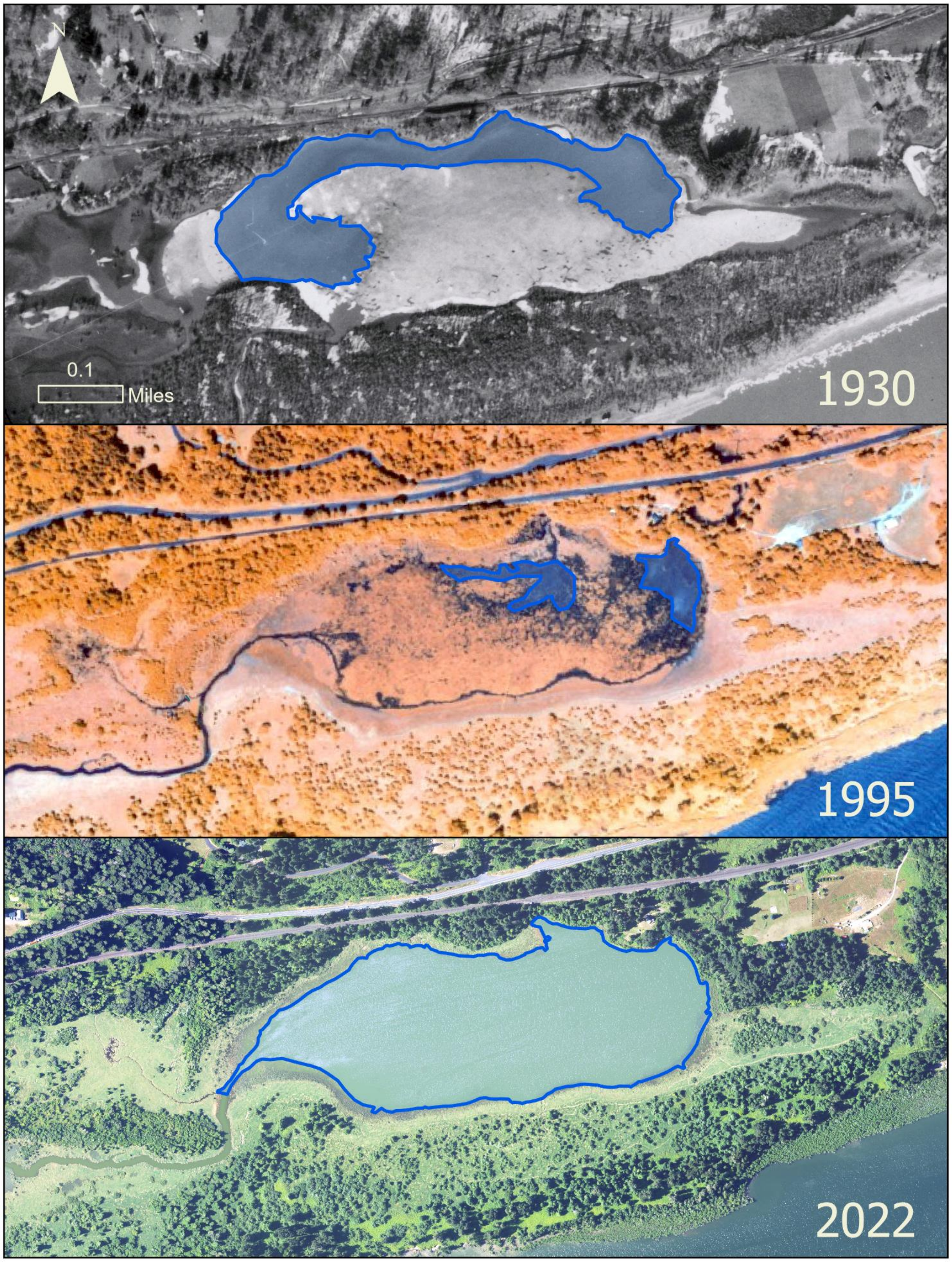
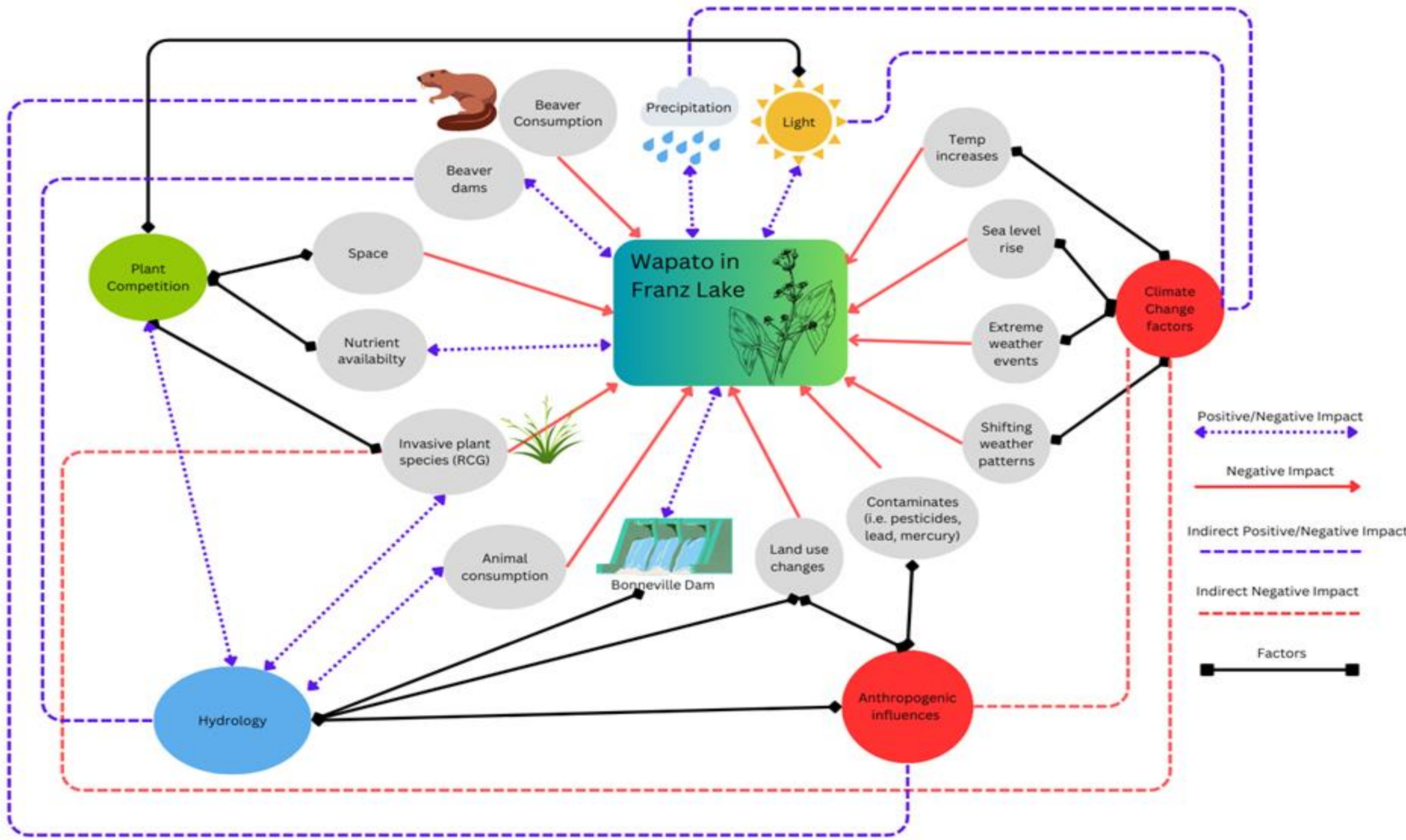
Appendix A: Map of Examples of Franz Lake Water Extent from 1930, 1995, and 2022 using Different

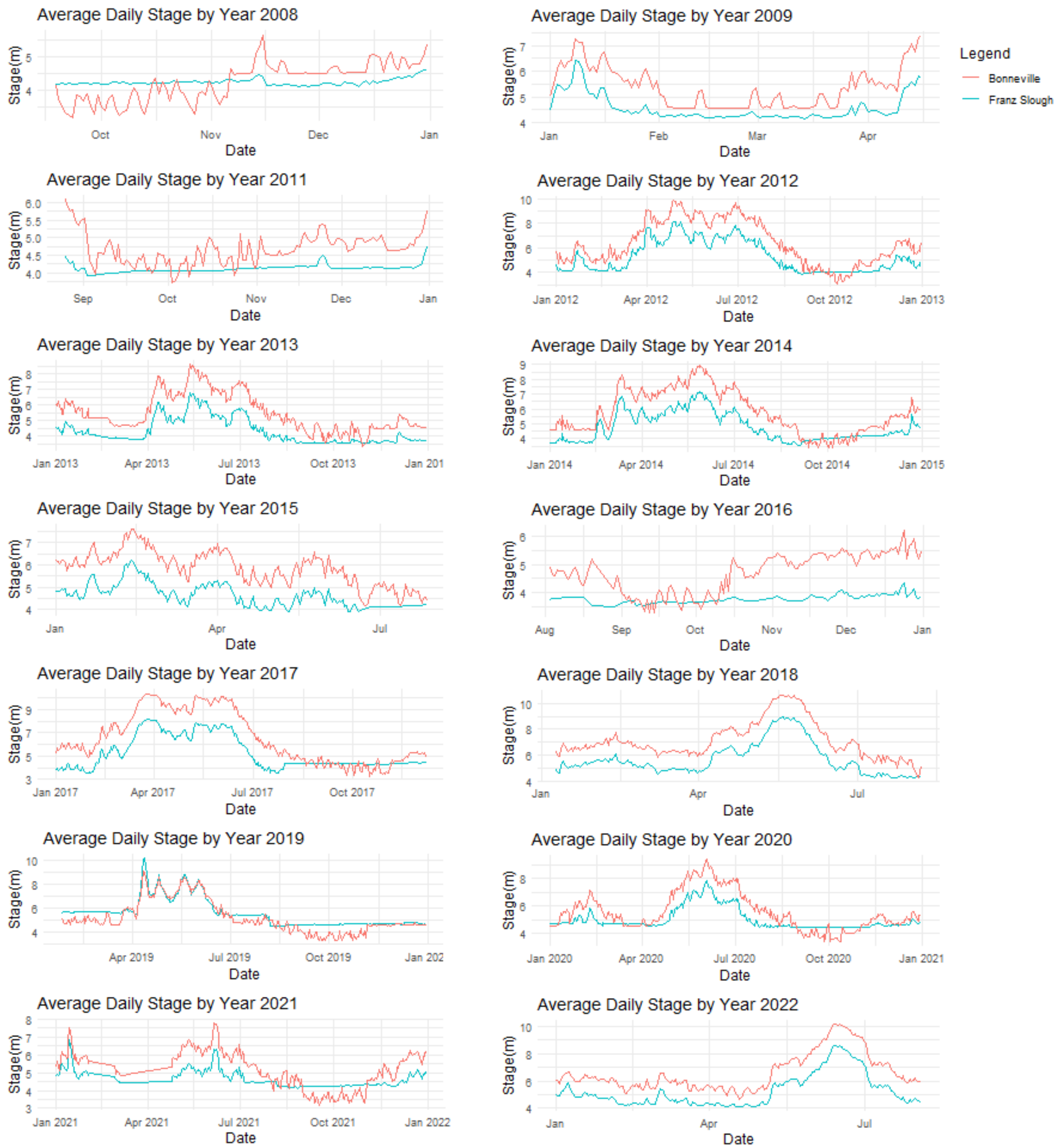


Imagery data source (top to bottom): ACE (grayscale), 1930. ACE (color-infrared), 1995. NAIP, 2022.

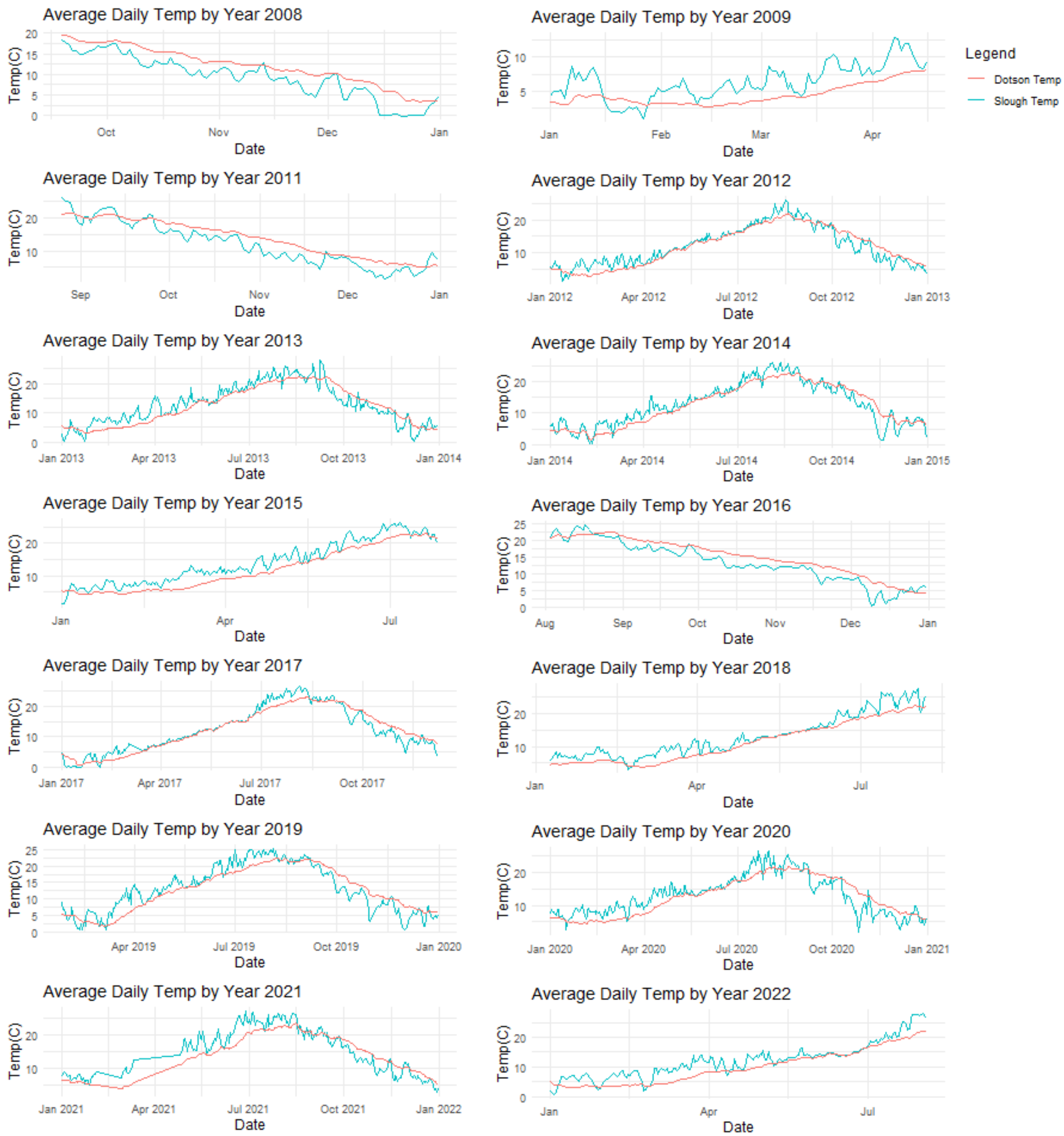
Appendix B: Schematic representation of the biotic and abiotic interactions on *S. latifolia* in Franz Lake



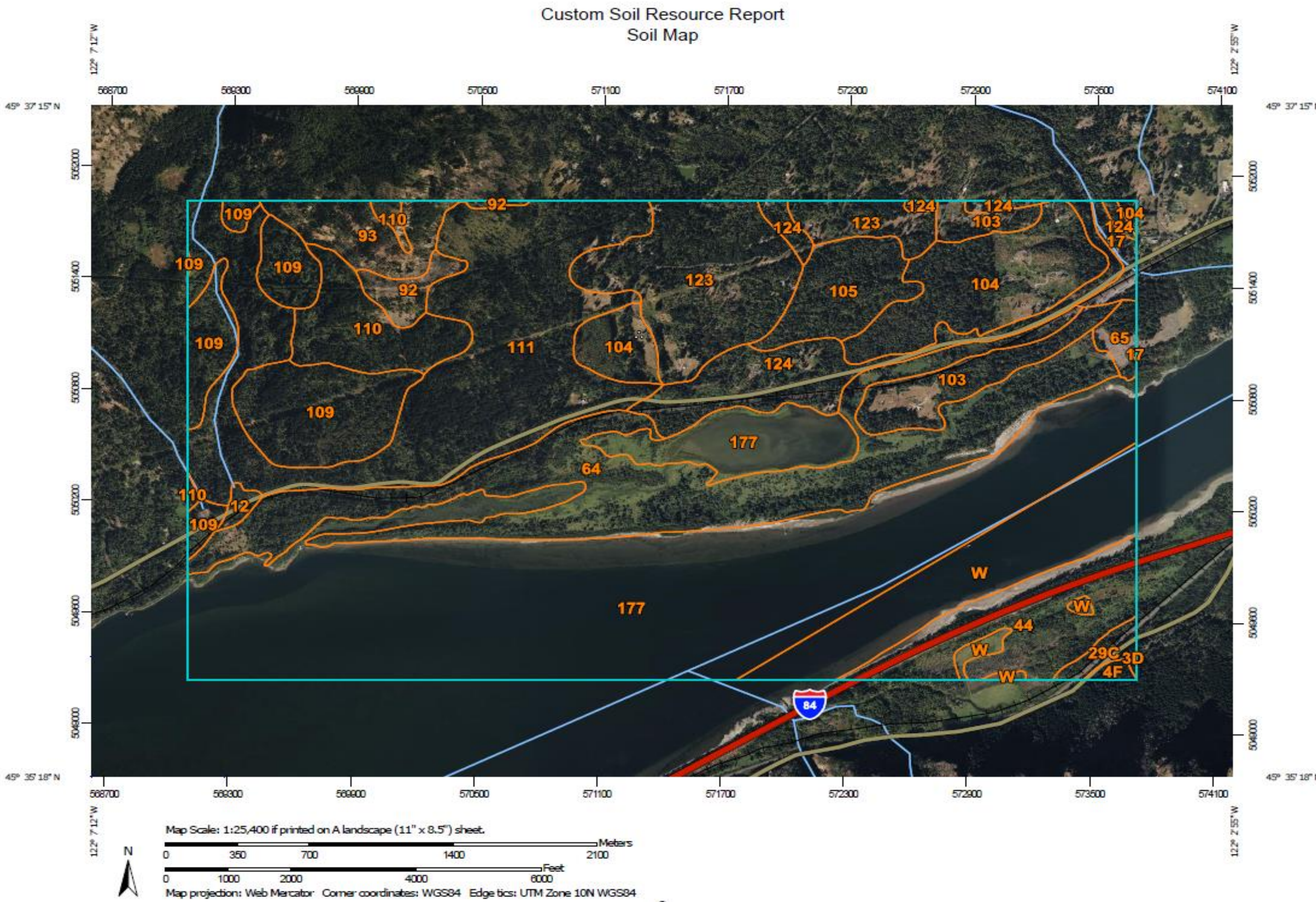
Appendix C: Time series of Franz Slough and Bonneville daily average stage by year from 2008 to 2022



Appendix D: Time series data of Franz Slough and Columbia River at Dotson Creek daily average water temperature by year from 2008 to 2022



Appendix E: USDA NRCS Soil Survey Report for Franz Lake Refuge



9

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at scales ranging from 1:20,000 to 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Multnomah County Area, Oregon
Survey Area Data: Version 22, Sep 7, 2023

Soil Survey Area: Skamania County Area, Washington
Survey Area Data: Version 19, Aug 29, 2023

Your area of interest (AOI) includes more than one soil survey area. These survey areas may have been mapped at different scales, with a different land use in mind, at different times, or at different levels of detail. This may result in map unit symbols, soil properties, and interpretations that do not completely agree across soil survey area boundaries.

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Sep 16, 2022—Oct 11, 2022

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background

MAP LEGEND

MAP INFORMATION

imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
3D	Aschoff cobbly loam, 5 to 30 percent slopes	0.7	0.0%
4F	Aschoff-Rock outcrop-Wahkeena association, very steep	4.6	0.2%
29C	Multnomah silt loam, 8 to 15 percent slopes	13.6	0.5%
44	Sauvie silt loam	124.5	4.2%
W	Water	165.1	5.6%
Subtotals for Soil Survey Area		**308.5**	**10.4%**
Totals for Area of Interest		**2,952.4**	**100.0%**

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
12	Bannel cindery sandy loam, 5 to 30 percent slopes	6.4	0.2%
17	Bonneville stony sandy loam	16.0	0.5%
64	McBee silt loam	368.1	12.5%
65	McDoug silt loam	14.8	0.5%
92	Rock outcrop-Rubbleland complex	24.2	0.8%
93	Rock outcrop-Xerorthents complex, 50 to 90 percent slopes	58.1	2.0%
103	Skamania very fine sandy loam, 0 to 8 percent slopes	76.6	2.6%
104	Skamania very fine sandy loam, 8 to 15 percent slopes	161.9	5.5%
105	Skamania very fine sandy loam, 15 to 30 percent slopes	68.5	2.3%
109	Skoly stony loam, 2 to 15 percent slopes	173.1	5.9%
110	Skoly stony loam, 15 to 30 percent slopes	83.6	2.8%
111	Skoly stony loam, 30 to 65 percent slopes	414.8	14.0%
123	Steever stony clay loam, 2 to 30 percent slopes	197.6	6.7%
124	Steever stony clay loam, 30 to 65 percent slopes	122.5	4.1%
177	Water	857.5	29.0%
Subtotals for Soil Survey Area		**2,643.5**	**89.5%**
Totals for Area of Interest		**2,952.4**	**100.0%**