

HYDROLOGIC STUDIES TO INFORM FUTURE ADAPTIVE RESTORATION FOR THE GIACOMINI WETLANDS



PREPARED FOR:



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INTRODUCTION

Point Reyes National Seashore (Seashore) is conducting a hydrologic study in support of an adaptive wetland restoration project for the Giacomini Wetlands in Tomales Bay, California. The National Park Service (NPS) acquired the former Giacomini Ranch in February 2000 and completed a tidal wetland restoration in collaboration with Point Reyes National Seashore Association (PRNSA) in October 2008 (Point Reyes National Seashore 2021). The Seashore now seeks to enhance natural hydrologic and ecological processes on a creek that flows through the wetlands.

The Giacomini Wetlands are located at the southern end of Tomales Bay at the mouth of Lagunitas Creek, as shown on **Figure 1**. During the 1860s, one-third to one-half of the Study Area was subtidal or intertidal. Excessive sedimentation from logging and poor land use practices during the late 19th and early 20th centuries caused an exponential increase in deltaic expansion of the exiting wetlands, leading to the creation of as much as 650 acres of new salt marsh habitat between 1860 and 1950 (PWA et al. 1993). The higher elevation area at the southern end was used as dairy farm pasture from 1917 (PWA et al. 1993) until 2006. Waldo Giacomini reclaimed the area in 1946 and constructed levees along Lagunitas Creek (Point Reyes National Seashore 2021). The area west of Lagunitas Creek was termed the “West Pasture” and is the focus of this study.

Fish Hatchery Creek (FHC) flows off the Inverness Ridge, through Inverness Park, and then across the 2008 restoration project area before ending into the marshes. Immediately prior to the 2008 restoration, the former ranchers excavated a cross channel between FHC and another smaller slough, the West Pasture Old Slough, as shown on **Figure 2**. FHC started to fill in with sediment, likely due to a reduction in flow volume, velocity, and scour due to the cross-channel diversion. The NPS filled in the cross channel as part of the restoration, but the FHC channel remains disconnected from its formal tidal slough. With the loss of hydraulic capacity in downstream portions of FHC, flood and non-flood flows started to sheetflow across the new marshplain rather than flow through the restored marsh in a defined channel. This change dramatically reduced the quality of habitat for Central California coastal steelhead (*Oncorhynchus mykiss*) in FHC. Initially, steelhead abundance remained similar to pre-restoration numbers, then appeared to increase three to five years after restoration; however, steelhead have not been sighted since 2014 (Point Reyes National Seashore 2021).

Concerns about the adverse impacts to this federally listed salmonid and to natural hydrologic and ecological processes and functions prompted the Seashore to consider an adaptive restoration component to improve performance of the 2008 restoration. Using a small NPS grant to assist with information needs related to this future adaptive restoration project, the Seashore engaged FlowWest to conduct hydrologic studies in support of this future restoration design for a new upper and middle FHC channel alignment that would maximize hydrologic conveyance to improve hydrologic and ecological processes and functions and habitat quality conditions for salmonids while minimizing the potential for flooding of adjacent private property. The information collected for this study built upon previous data collected during the original marsh restoration. The eventual FHC creek design will reflect processes and conditions that have changed since restoration. The original channel course for FHC was constructed by previous landowners to minimize loss of grazing pasture to flood but required continuous management through dredging. This channel management was not sustainable and is incongruous with the goals and management of the area as a marsh restoration site. The results of this hydrologic study were used to inform concept development for future pathways for adaptive

restoration including hydraulic modeling of annual through 100-year (320 cubic feet per second) peak flows and estimated sediment yields to the Study Area (Point Reyes National Seashore 2021).

The hydrologic information collected, presented, and analyzed in this report includes:

1. Analysis of current topographic conditions and changes since restoration, including an updated topographic map for the Study Area produced at +/-1-foot contour intervals and referenced to the NAVD88 datum.
2. Analysis of base flow and peak storm water flow and sediment transport in FHC. Base and peak flows were measured with a flow meter during site visits while continuous water surface elevations were recorded with a stream gage. Sediment load (both bed & suspended loads) were measured during the same four flow measurement events in the period from fall 2021 through spring 2022. Three of these sampling events were conducted during high flow events, although rainfall during that monitoring period was generally below average.
3. Analysis of shallow groundwater contributions to Study Area hydrology from adjacent Inverness Ridge based on data from two shallow monitoring wells at the upland/western Study Area perimeter.
4. Analysis of tidal influence on the Study Area based on continuous water level recorders installed at three channel locations to evaluate current tidal connection to outer FHC and Tomales Bay during the period from fall 2021 through summer 2022. This collected data was then compared to existing tidal data for outer Tomales Bay.

Giacomini Wetlands - Adaptive Restoration to Improve Hydrologic Connectivity and Fish Habitat

Point Reyes National Seashore



National Park Service
Point Reyes National Seashore
Marin County, CA

0 0.8 1.6 Miles

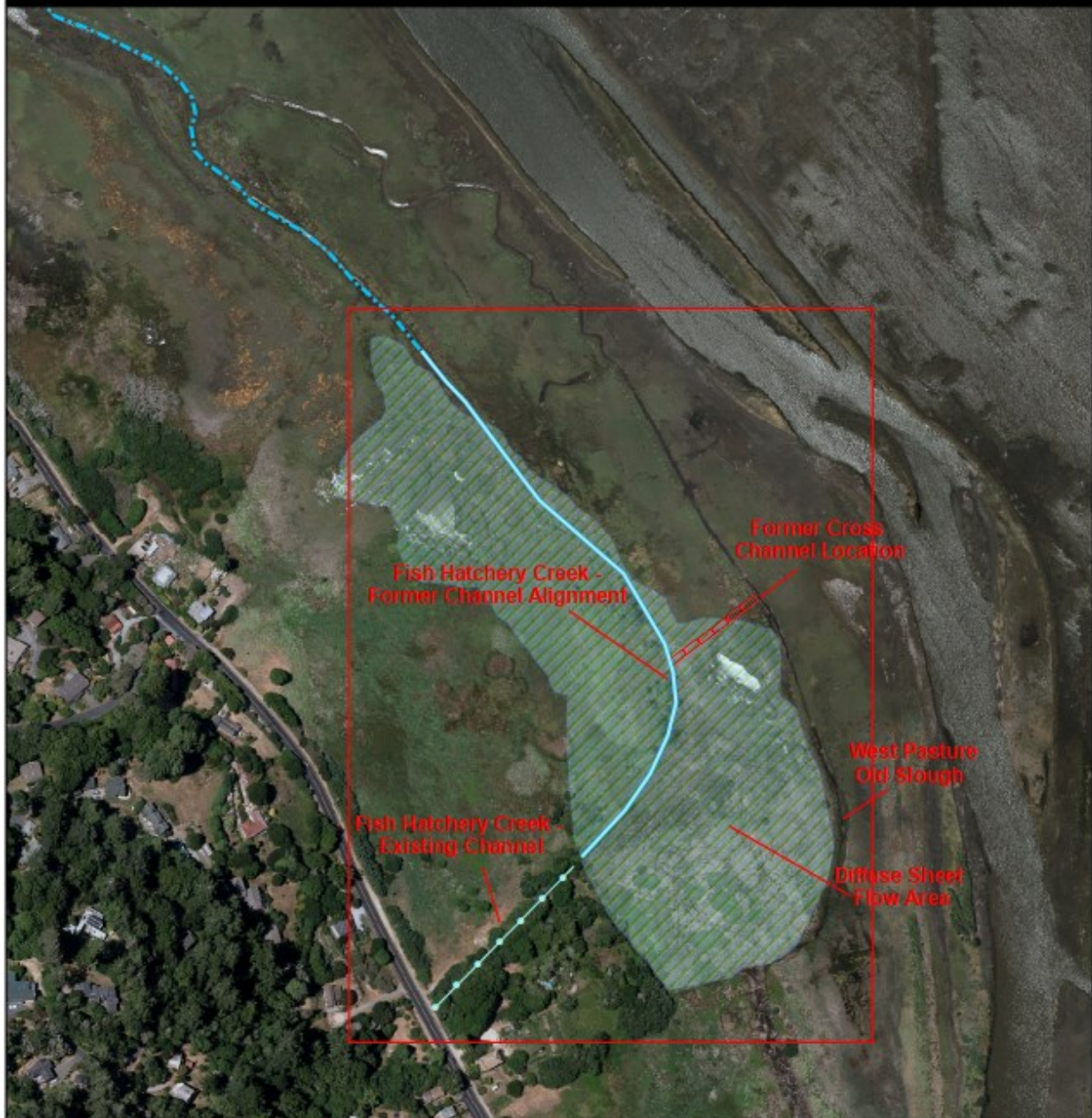


Figure 1. Vicinity map of proposed Fish Hatchery Creek Adaptive Restoration Project Area

FIGURE 1: VICINITY MAP OF PROPOSED FISH HATCHERY CREEK ADAPTIVE RESTORATION STUDY AREA (NPS 2021)

Giacomini Wetlands - Adaptive Restoration to Improve Hydrologic Connectivity and Fish Habitat

Point Reyes National Seashore



National Park Service
Point Reyes National Seashore
Marin County, CA

0 0.075 0.15 Miles



Figure 2. Detailed map of proposed Fish Hatchery Creek Adaptive Restoration Project Area

FIGURE 2: DETAILED MAP OF PROPOSED FISH HATCHERY CREEK ADAPTIVE RESTORATION STUDY AREA.

EXISTING REPORTS PERTAINING TO STUDY AREA

Kamman Hydrology & Engineering (KHE) conducted water surface elevation monitoring throughout Giacomini Wetlands in 2009, 2011, and 2012 and prepared reports for each monitoring year. The purpose of this monitoring was to quantify and describe new tidal dynamics within the restored wetlands and track the development of wetland hydrogeology over time. Monitoring was conducted in each year during summer months throughout Giacomini wetlands. In 2009, data was collected from 07/28/2009 to 10/07/09 at 2 gages in Lagunitas Creek and 6 gages in the East Pasture. In 2011, data was collected from 06/10/11 to 09/13/11 at an upstream and downstream gage in Old Tomasini Slough in the East Pasture of Giacomini Wetlands. In 2012, data was collected from 06/24/12 to 10/19/12 at the same Old Tomasini Slough gages as 2011. The 2009 observations provided a good baseline for post-restoration tidal dynamics, as the system was expected to develop substantially over time.

The 2011 report identified trends between 2009 and 2011 in local tidal maxima and filling/draining tidal water surface elevation slopes due to the geomorphological development of the restored wetlands. The 2011 report also identified a cap on tidal minima created by an ebb shoal at the confluence of Old Tomasini Slough and Lagunitas Creek. KHE predicted that this limit on tidal range would wash out in a large storm event. The 2012 report found that the tidal dynamics had not changed much since 2011, and that the ebb shoal had slightly grown in size.

This monitoring and the accompanying reports have assisted FlowWest by providing initial insights into post-restoration wetland geomorphology and tidal dynamics. Relevant information included:

- A site topographic survey suggested that most of the site was at or above the intertidal elevation.
- The site is underlain by a mixture of creek, delta, and estuary deposits, but has not significantly subsided due to a variety of factors.
- Tide gates on FHC were partially open even before restoration, permitting significant but muted tidal exchange to upstream sections of the creek.
- Shallow groundwater conditions persisted across the site. Groundwater was generally brackish except along the western and eastern margins of the project site where higher inflows from water-bearing valley-margin deposits maintain freshwater conditions at the surface and in the shallow groundwater.
- Model simulation results indicate that a large majority of the Study Area will be subject to tidal action.
- Modeling results indicate increased flood water levels in portions of the West Pasture adjacent to the private properties for the 2- through 500-year floods, but not to levels that threaten structures. Existing homes reside at the highest project elevations on the apex of alluvial fans. Current flooding hazards to these homes arise from sediment and debris-laden flows from Inverness Ridge tributaries that outfall onto the same alluvial fans.
- The ebb shoal identified in 2011 helps explain why tidal ranges in the West Pasture are smaller than those on the Pacific Coast at Point Reyes and removal of any ebb shoals in the West Pasture has the potential to increase tidal ranges and sediment transport capacity.

As described above, this study re-examined the influence that tides, groundwater, and sediment laden-flows from Inverness Ridge (specifically from FHC) have on the Study Area and influenced conceptual restoration designs.

ANALYSIS OF TOPOGRAPHIC CONDITIONS

Giacomini Wetlands Restoration Baseline Digital Elevation Model (DEM)

FlowWest created a Digital Elevation Model (DEM) to represent as best as possible the current topographic conditions in FHC, provided as **Attachment A**. This DEM builds off the 2009 NPS LiDAR DEM for the Giacomini Wetlands and overlays it with a higher resolution data from FlowWest's 2021 topographic survey of FHC. The resulting DEM provides an overall picture of regional elevations and supplements this with a more detailed look at elevations in FHC. A supplemental description of how the DEM was created as well as important information and metadata are provided as part of Attachment A.

The FlowWest 2021 topographic survey spanned FHC from the upstream to downstream limits of NPS dredging management. Thus, topographic comparisons beyond the 2021 survey area are not possible. However, field reconnaissance showed that FHC's channel has apparently remained consistent and intact since 2008, and large piles of dredged material exist on the banks, creating levee-like structures.

HYDROLOGIC INFORMATION FOR FISH HATCHERY CREEK

To understand the hydrologic conditions of FHC and the sediment that the creek contributes to the Study Area, FlowWest collected peak and base flow rates and sediment inflow rates during four visits during the period from fall 2021 to spring 2022, with a fifth visit during the dry season in August 2022 when flows were too low to measure. **Figure 3** shows the location along FHC where FlowWest staff installed a stream gauge, measured flow, and collected sediment samples.



FIGURE 3: LOCATION OF SAMPLING SITE FOR HYDROLOGIC MONITORING.

On 11/11/2021, FlowWest staff installed stream gauging equipment at point CSM-1, along the excavated section of FHC where the NPS boundary ends (i.e., where the previous dredging ends). This included a staff plate and Solinst Levellogger Junior Edge installed within slotted PVC pipe. The Levellogger measures total pressure, which includes the hydrostatic pressure from creek water plus barometric (atmospheric) pressure. To correct this, and determine accurate and continuous creek depth levels, barometric must also be measured, then subtracted from the total pressure. To achieve this barometric pressure compensation, a Solinst Barologger Edge was installed in a PVC pipe strapped to a nearby tree branch.

RANGE OF PEAK AND BASE FLOWS

FlowWest conducted five site visits during the monitoring period, three of them during storm events. Using a Hach FH950 Portable Velocity Meter with topset wading rod, two to three flow measurements were taken per visit in FHC at CSM-1. The third measurement was taken if the standard deviation between the first two was too high. (20% higher or lower). The fifth site visit occurred in August of 2022, during baseflow conditions, when flow was too low to be measured with the Hach FH950. Flow measurements are presented in **Table 1**.

TABLE 1: FLOW MEASUREMENTS TAKEN WITH HACH FH950 PORTABLE VELOCITY METER.

Date	Time	Flow (cfs)	Levellogger Creek Stage (ft)	Staff Plate Creek Stage (ft)
12/13/2021	10:40 AM	4.60	0.830	0.85
	11:30 AM	5.04	0.835	
12/22/2021	8:51 AM	1.72	0.669	0.71
	9:05 AM	1.99	0.672	
3/19/2022	4:25 PM	0.33	0.597	0.61
	4:45 PM	0.34	0.597	
4/14/2022	2:15 PM	1.27	0.795	0.75
	2:32 PM	1.35	0.804	

The highest measured flow in FHC during monitoring was 12/13/2021 between 10:40 and 11:30 am. We measured flows of 4.60 and 5.04 cfs during this time during which the Levellogger a recorded depth of 0.835 ft. The peak depth recorded by the Levellogger at CSM-1 was at 10:15pm on 12/15/2021 during the same period of rain as the flow measurements on 12/13/21.

A second winter storm was monitored on 12/22/21 but its magnitude was smaller than that of 12/13-15. Flows never reached that level for the rest of the season but did increase during the mid- to late-April precipitation events.

According to Marin County Flood Control and Water Conservation District (MCFCWCD) precipitation data from the precipitation gauge at Point Reyes Station—which is ~1.7 miles from the watershed centroid—3.52 inches of rain fell over a two-day period (12/12/2021-12/13/2021). According to NOAA Atlas 14 Precipitation Frequency Estimates (NOAA 2017) for Point Reyes Station, this storm corresponds to the lower end of the one-year recurrence interval for a two-day storm which ranges from 3.33-4.19 inches.

It is notable that the largest storm of the 2021-2022 winter season occurred on October 24th, 2021, before instruments were installed. The MCFCWCD precipitation gauge at Point Reyes Station measured 6.44 inches of rain in a 24-hour period which represents a 25-year return interval, 24-hour precipitation

event (NOAA 2017). Additionally, in the days preceding this downpour, the gauge recorded 4.16 inches of rain from October 17th-23rd meaning that a total of 10.6 inches of rain fell over eight days which represents approximately a 10-year, 7-day precipitation event (NOAA 2017). The most intense rain occurred at the end of this eight-day period when the watershed would have been somewhat saturated. Therefore, the runoff generated in FHC on October 24th would have likely been intense. According to the USGS StreamStats analysis, a 25-year flood on FHC would be ~225 cfs. **Table 2** shows the 2- through 100-year return interval storm flows for FHC determined using the USGS StreamStats [online tool](#) (Gotvald et al. 2012).

TABLE 2: USGS STREAMSTATS PREDICTED STORM FLOWS (GOTVALD ET AL. 2012).

Return Interval	Fish Hatchery Creek Flow (cfs)
2-year	55
5-year	1175
10-year	160
25-year	225
50-year	273
100-year	320

Data were downloaded to a laptop from the Levellogger and Barologger using a Field Reader 5 optical reader and the Solinst Levellogger 4.6.2 software during site visits when possible. Corrected depth was calculated using the Solinst Levellogger 4.6.2 software, which subtracts the barometric pressure from the pressure measured by the Levellogger in the creek. Continuous data were recorded by the loggers for the entire study period.

At some point prior to the date of the final data download on August 1st, 2022, the Barologger malfunctioned, and data during the period from March 19th (not including the monitored event on that day) to August 1 were unable to be downloaded from the instrument. Without barometric pressure data from April 14th flow measurement, creek depth data could not be properly compensated. The Barologger was sent to the manufacturer (Solinst) to attempt to extract the data, but they were only able to extract data through March 25th. To fill in the data gap between March 25 and August 1, barometric data was obtained from the UC Field Station in Olema. We compared data from the UC barometer to overlapping data from the Solinst Barologger and calculated an average difference of ~0.217 psi between the datasets. Accounting for this pressure difference between the two data sets, the UC barometric data was used to manually compensate the Levellogger data from March 19th through August 1st.

Both stage measurement from the visually inspected staff plate and the compensated Levellogger data was used to create a rating curve, presented in **Figure 4**. Due to drought conditions persisting in California, the rating curve represents only flows up to approximately 5 cfs, which limits its usefulness. During future phases of design, we recommend deployment of stream gaging equipment in FHC with the goal of capturing higher flows than were observed in 2021-2022. These flow data can be used to size the conceptual design for the new upper and middle FHC channel and can be used—in conjunction with sediment load data—to create a sediment rating curve for the FHC to better understand sediment transport from the upper watershed to the Study Area.

SEDIMENT INFLOW RATES

In addition to flow measurements, FlowWest collected suspended and bedload sediment samples from FHC. Bed load is material that moves along the bottom of the stream. Suspended load is material that is suspended in the flow and generally includes silt, clay, and fine sand (Stream Restoration Institute 2004). Suspended load samples were collected during the same four visits that flow measurements were taken (there was no flow or sediment transport during the August dry season event). FlowWest attempted to collect bedload samples during the same four site visits, but only the first visit on December 13th, 2021, had high enough flows to produce bedload transport. Two replicate samples were collected on each event.

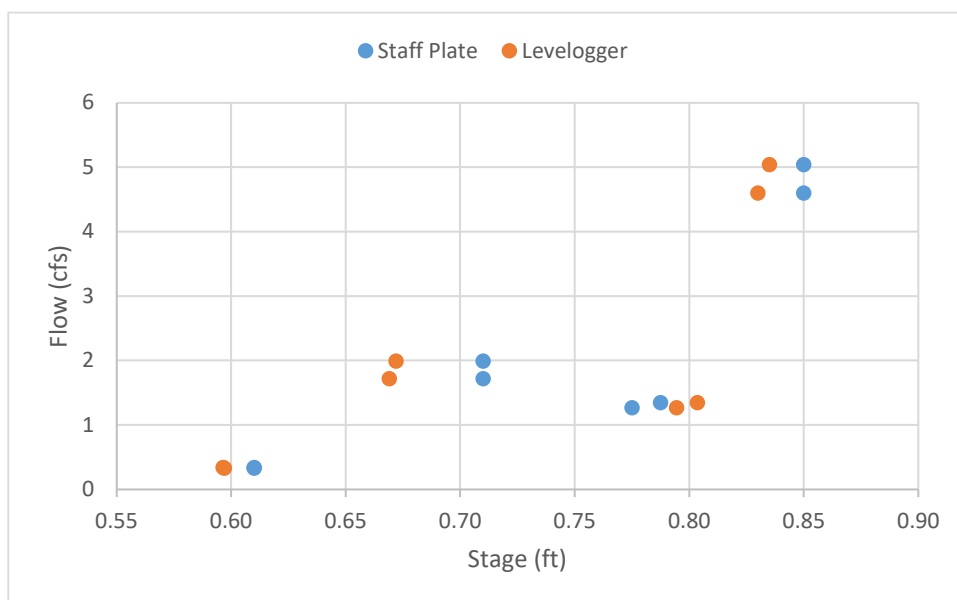


FIGURE 4: RATING CURVE FOR FISH HATCHERY CREEK FROM 12/13/2021 THROUGH 4/14/22.

Suspended load was collected using a US DH-48 Depth-Integrating Suspended-Sediment Sampler. The US DH-48 consists of a streamlined aluminum casing which partially encloses a cylindrical plastic sample container. A nozzle extends horizontally from the nose of the sampler body, which is what captures the flowing water and suspended sediment and directs it to the sample container. A half inch wading rod is threaded to the top of the sampler body (Federal Interagency Sedimentation Project). The samples were collected by lowering the bottle into the creek at such a rate that would fill the sample bottle 2/3 – 3/4 full, in the time it took lower the bottle at a steady rate from the surface to the bottom and back to the surface. This technique ensured that suspended load would be collected evenly through the water column. After collecting enough test samples to determine the proper rate of lowering, two samples were collected for analysis. Sediment sampling in larger creeks usually involves taking multiple vertical samples along a cross section of the creek but because FHC is so narrow, only a single vertical sample was taken. This procedure results in a sample that is used to determine a concentration of suspended sediment in the water in units of mg/L for a variety of sediment particle sizes.

Bedload was collected using a US BLH-84 Sampler (Edwards and Glysson 1998). The US BLH-84 consists of a square-shaped nozzle, a polyester mesh sample bag, and a wading rod assembly. The sample was collected by placing the bedload sampler in the thalweg of the stream for five minutes, with the nozzle facing upstream. This procedure results in a sample that that is used to determine the mass of bedload sediment that was being transported past the monitoring point per unit of time and per linear foot of channel width (units of tons/day/foot). Note that while the time unit for this measurement is in days,

the value reported represents the sediment transport rate at the five-minute moment of collection which generally coincided with peaking flows. Substantially less sediment would have been transported over the course of a day because of the rising and falling of flows throughout the individual rain event. **Figure 5** shows the zones of the water column sampled by both the suspended-sediment and bedload samplers and the unmeasured zone.

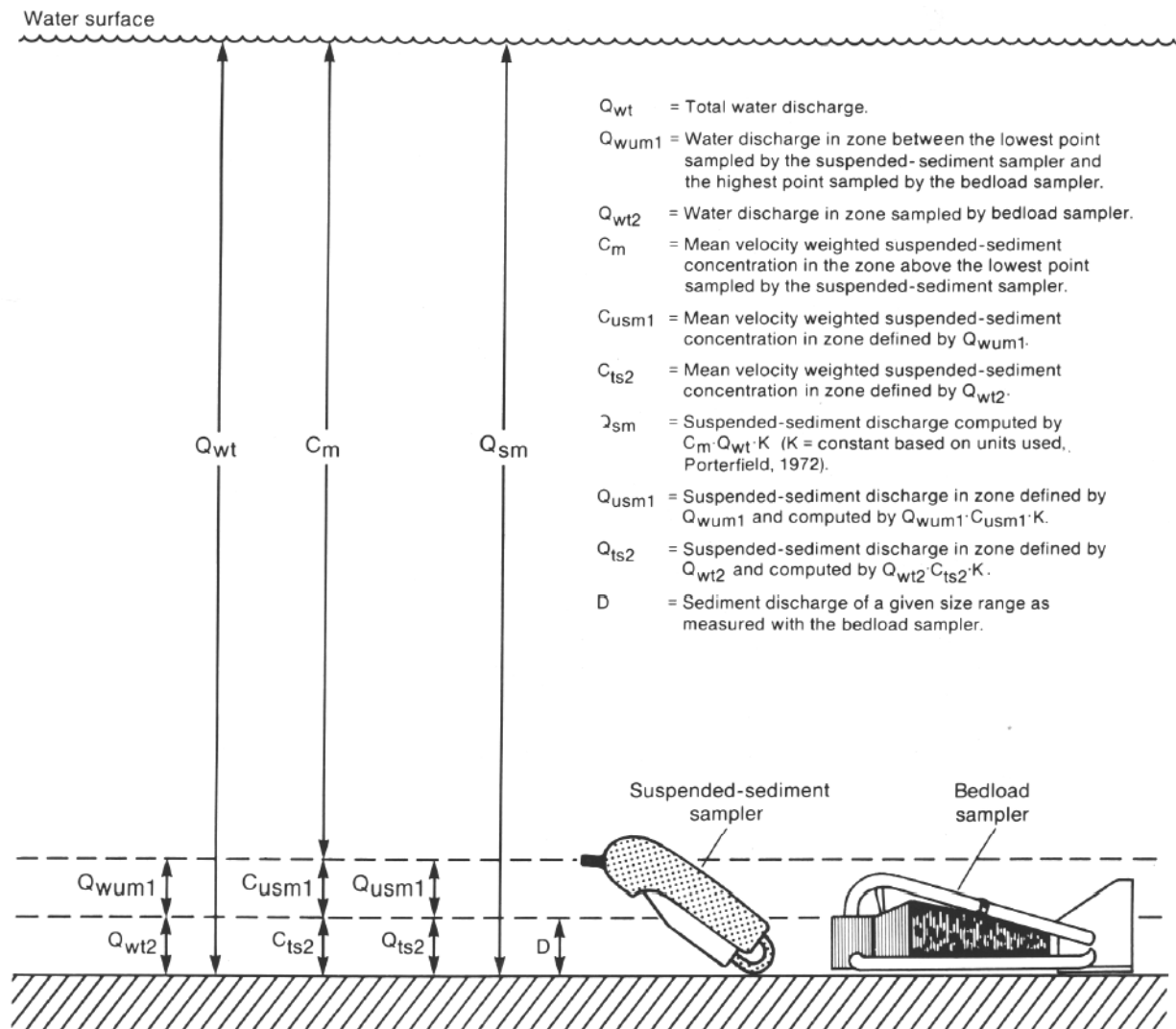


FIGURE 5: SAMPLING ZONES IN WATER COLUMN (EDWARDS AND GLYSSON 1998)

In total, eight bottles of suspended sediment and two bags of bedload sediment were sent to Control Laboratories for analysis.

Suspended Sediment Results

Suspended sediment concentration (SSC) was measured for each sample and broken down into three categories: 1) total particulate solids, 2) total coarse fraction ($>63 \mu m$), and 3) total fine fraction ($<63 \mu m$). Total volume of sample was also reported, along with the "reporting limit" or "RL" which quantify the levels down to which the lab can quantify with reliability. A result that was below the RL

was reported as “ND” for Not Detected, which was the case for the course fraction from 12/22/2021 as well as all SSC for the 3/19/2022 samples. **Table 3** presents the results from the suspended sediment analysis.

TABLE 3: RESULTS FROM SUSPENDED SEDIMENT LAB ANALYSIS.

Date	Sample Name	Collection Time (sec)	Total Sample Vol (mL)	Total SSC* (mg/L)	Course Fraction (> 63 micron) (mg/L)	Fine Fraction (< 63 micron) (mg/L)	Total Sediment Weight (mg)	Flow (cfs)
12/13/2021	FISH 1A	14.47	234	36.6	7.25	29.4	8.5644	4.60
12/13/2021	FISH 1B	14.39	262	34	6.87	27.1	8.908	5.04
12/22/2021	FISH 2A	19	390	5.9	ND*	4.11	2.301	1.72
12/22/2021	FISH 2B	22	399	4.52	ND	2.77	1.80348	1.99
3/19/2022	FISH 3A	30	289	ND	ND	ND	ND	0.33
3/19/2022	FISH 3B	30	101	ND	ND	ND	ND	0.34
4/14/2022	FISH 4A	20	322	56.6	13.7	43	18.2252	1.27
4/14/2022	FISH 4B	20	343	63.4	21.6	41.8	21.7462	1.35

*SSC = Suspended Sediment Concentration

*ND = Not Detected

Figure 6 is a sediment rating curve that associates suspended sediment concentration to creek flow levels.

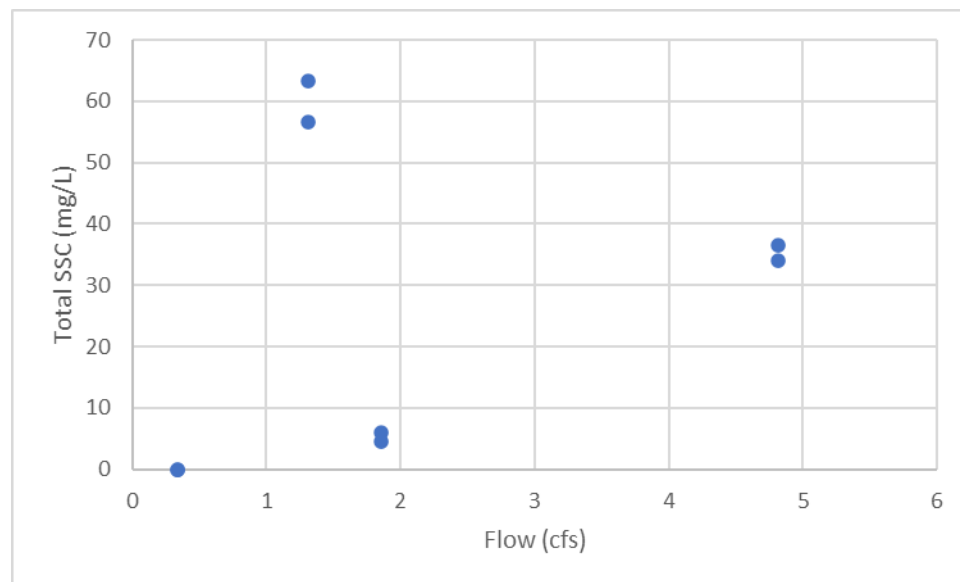


FIGURE 6: SUPSENDED SEDIMENT CONCENTRATION (SSC) VS FHC FLOW

The 4/14/2022 suspended sediment sample had the highest SSC, almost 70% higher than the 12/13/2021 sample, which were during the highest flows. One explanation could be the long period of little to no precipitation between the rainy December period and the April rains, leaving unmoved fine sediment that was picked up during the April storm. This could also explain why the concentration was

so low during the 12/22/2021 sampling, as much of the available fine sediment had probably already been transported downstream during the recent December rains/flows. The 3/19/2022 sampling produced an undetectable amount of suspended sediment, which is expected with the ~0.33 cfs flow.

Bedload Sediment Results

Bedload sediment data were separated into 5 size classes:

1. Sand, silt, and clay: < 2mm
2. Very fine gravel: 2.0 - 4.0 mm
3. Fine gravel: 4.0 – 6.3mm
4. Small gravel: 6.3 – 9.6mm
5. Medium gravel: 9.6 – 16 mm

No large gravel particles (>16mm) were found in the analysis of the bedload sediment samples. Because we observed deposition of sediment of particles of this size in the aftermath of the October 2021 rains, it is likely that the flows that occurred during bedload transport monitoring were simply too low to transport this size of sediment particle. The < 2mm size class was also analyzed by Control Labs, and their findings indicate that over 93% and 96% for the two bedload samples, respectively, were sand.

Table 4 presents the results from the bedload sediment analysis. The Control Labs’ documented results for both suspended and bedload sediment are attached to this report as **Attachment B**.

TABLE 4: RESULTS FROM 12/13/21 BEDLOAD SEDIMENT LAB ANALYSIS.

Sample Name	Collection Time (sec)	Total Sample Dry Weight (g)	Medium Gravel (g) (9.6 - 16mm)	Small Gravel (g) (6.3 - 9.6mm)	Fine Gravel (g) (4.0 - 6.3mm)	Very Fine (g) (2.0 - 4.0mm)	Sand (g) (< 2mm)	Flow (cfs)
FISH 1A	300	1280.1	3.71	32.51	126.09	332.83	784.96	4.60
FISH 1B	300	1295.8	6.74	25.40	76.19	268.75	918.72	5.04

The following equation for the “total cross-section” method from “Field Methods for Measurement of Fluvial Sediment” (Edwards and Glysson 1998) was used to calculate bedload discharge (Q_B):

$$Q_B = K \frac{W_T}{t_T} M_T$$

where,

Q_B = bedload discharge, as measured by bedload sampler, in tons per day;

W_T = total width of stream from which samples were collected, in feet, and is equal to the increment width (W_i) times n (n = total number of vertical samples); *(for our purposes we estimate that total stream width that was transporting bedload was 2 feet, and $n = 1$)*

t_T = total time the sampler was on the bed, in seconds, computed by multiplying the individual sample time by n ; *(in our case $n = 1$)*

M_T = total mass of sample collected from all verticals sampled in the cross section, in grams; and

K = a conversion factor used to convert grams per second per foot into tons per day per foot:

$$K = (86,400 \text{ seconds/day}) \frac{1 \text{ ton}}{(907, 200 \text{ grams})} \frac{1 \text{ foot}}{(N_w)}$$

where,

N_w is the width of the sampler nozzle in feet. (For our 3-inch nozzle, $K = 0.381$.)

For the bedload sample that was taken on 12/13/2021, using the above equation, the computed bedload discharge rate was 3.27 tons/day.

Because the largest flow event was the October 2021 storm, this flow would have transported more sediment than any of the measured events. While no measurements were conducted during this storm, FlowWest staff did visit the site both before and after the storm and visually observed several inches of fresh deposition of gravelly sediment in the dredged reach of FHC.

Better understanding sediment transport in this part of the creek will help inform a creek design that is geomorphically stable (sediment transport equal to sediment deposition), or if necessary, aid in concept development of sediment management. Sediment management, for example, could include building a sedimentation basin along FHC that is periodically dredged to help maintain an open channel downstream.

GROUNDWATER LEVELS NEAR FISH HATCHERY CREEK

Freshwater inflow to the Study Area is comprised not only of creek run-off, but groundwater discharge from the adjacent Inverness Ridge as well. FlowWest installed two shallow (<10') piezometers in the FHC upland boundary in the Study Area. One was installed adjacent to FHC, near the Barologger described above while the second was installed further into the marsh approximately ~425 feet to the north/northwest (**Figure 7**). These piezometers were installed to determine groundwater elevations in relation to the creek and marshplain elevations and whether a defined gradient exists.



FIGURE 7: LOCATION OF GROUNDWATER WELLS.

Groundwater levels in the two wells were measured using a groundwater level sounder six times during the monitoring period including the day of installation (11/11/2021). During initial setup, FlowWest staff surveyed ground elevations at the well (feet NAVD88) and measured from the top of PVC casing (TOC) to ground. The ground surface elevations at the “Near Creek” and “In Marsh” wells were 8.845 and 14.135 ft NAVD88, respectively, a difference of 5.29 feet. Using these data points, and the depth from TOC to groundwater level measured with the sounder, FlowWest calculated groundwater surface elevations, presented in **Table 5** and **Figure 8**.

TABLE 5: GROUNDWATER SURFACE ELEVATIONS IN TWO MONITORING WELLS.

Date	Time	WSE (ft NAVD88)		Difference (ft)
		Near Creek	In Marsh	
11/11/2021	3:00 PM	12.765	5.895	6.87
12/13/2021	1:00 PM	13.845	9.245	4.6
12/22/2021	9:34 AM	13.725	9.445	4.28
3/19/2022	3:30 PM	13.395	9.415	3.98
4/14/2022	2:00 PM	13.655	9.345	4.31
8/1/2022	12:00 PM	13.095	7.79	5.305

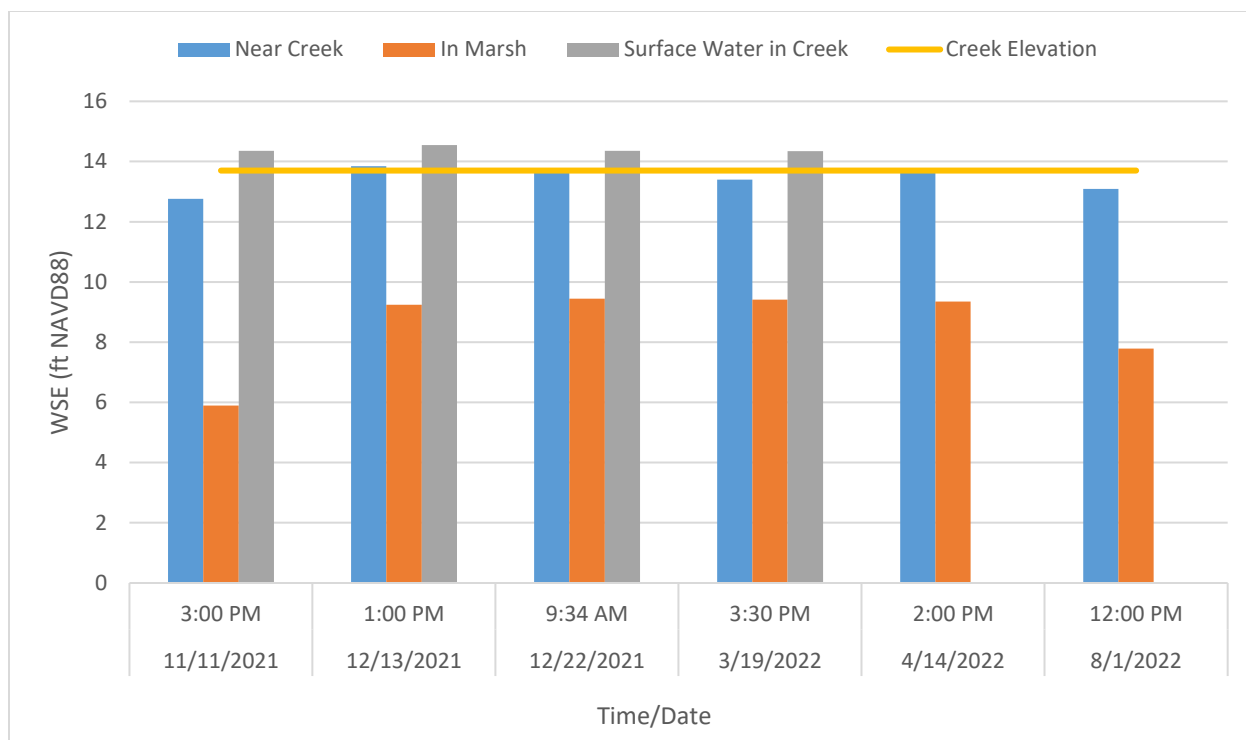


FIGURE 8: GROUNDWATER SURFACE ELEVATIONS IN TWO MONITORING WELLS.

The November reading had the lowest groundwater levels in both locations, and the largest difference between the two. The highest groundwater level near the creek was at 13.845 feet NAVD88 on 12/13/2021 during the largest recorded flow event and the highest groundwater level in the marsh was at 9.445 feet NAVD88 on 12/22/2021. Groundwater elevations between the two locations were closest on 3/19/2022, with only a 3.98-foot difference. Groundwater elevations in the marsh, however, were all very close during the winter and spring measurements. The WSE difference between the two wells ranged from almost seven feet in November 2021 to just under four feet in March 2022 but was always higher near the creek than in the marsh, meaning that groundwater flow direction was always away from the creek, following the topography.

TIDAL HYDROLOGY

In addition to creek runoff/sediment inflow rates and groundwater inflow to the Study Area, tidal hydrology is another potentially important contributing factor to hydrologic conditions in the Study Area. High tides have the potential to back up outflows from FHC -- and if they coincide with storm events -- would limit velocities, sediment transport, and related geomorphic processes. Tidal hydrology may have changed in the intervening 10 years due to post-restoration landscape changes, as well as potentially sea level rise. To understand the potential influence of tidal hydrology, FlowWest installed three tidal water level sensors in the northern to central portions of the Study Area: TM-1 (WPOS1.5) at the existing t-post along the pedestrian bridge along the West Pasture Old Slough; TM-2 (FIS2) at the pedestrian bridge along the main FHC channel (old excavated channel); and, TM-3 along the western shore of Lagunitas Creek (**Figure 9**).



FIGURE 9: LOCATION OF TIDE GAUGES.

The tide stations were setup similarly to the one in FHC at CSM-1, with a Solinst Levellogger Junior Edge installed within slotted PVC pipe, and the ground elevation surveyed in feet NAVD88. FlowWest staff downloaded data during their 12/13/2021, 3/19/2022, and 8/1/2022 site visits. Corrected depth was calculated using the Solinst Levellogger 4.6.2 software, which subtracts the barometric pressure (using data from the same Barologger installed near FHC) from the pressure measured by the Levelloggers. Continuous data were recorded by the loggers for the entire study period; however, during the August 1st site visit, data were unable to be retrieved from both the Barologger (as described above) as well as from the Levellogger at TM-1. The same UC Field Station barometric data, described above, was used to manually compensate the data retrieved from the Levelloggers at TM-2 and TM-3, for the period roughly following March 19 – August 1, 2022. The depth of water was then added to the transducer elevation (surveyed ground elevation, as the transducers were resting on the ground at the bottom of the PVC pipes), to calculate the tide level in feet NAVD88.

Table 6 presents the major tidal statistics calculated from the data at each site, and **Figure 10** shows how the tidal statistics compare to Study Area terrain. Figure 10 also indicates the minimum and maximum ground elevations in the tidal plain and minimum and maximum invert elevations in FHC. Tidal statistics analyzed include mean higher high water (MHHW), mean high water (MHW), mean tide level (MTL), and mean low water (MLW). Mean lower low water was not calculated because gages in the wetland sloughs dried out at the lowest tide periods likely due to an ebb shoal at the downstream end of these sloughs as was observed in Old Tomasini Slough by KHE in 2011.

TABLE 6: TIDE STATISTICS AT TM-1, TM-2, AND TM-3, REPORTED IN NAVD88 FT (11/11/2021 – 3/19/2022)

Statistic	TM-1	TM-2	TM-3
MHHW	5.75	5.60	5.46
MHW	5.05	4.64	4.76
MTL	3.95	4.07	4.05
MLW	2.86	3.34	3.33

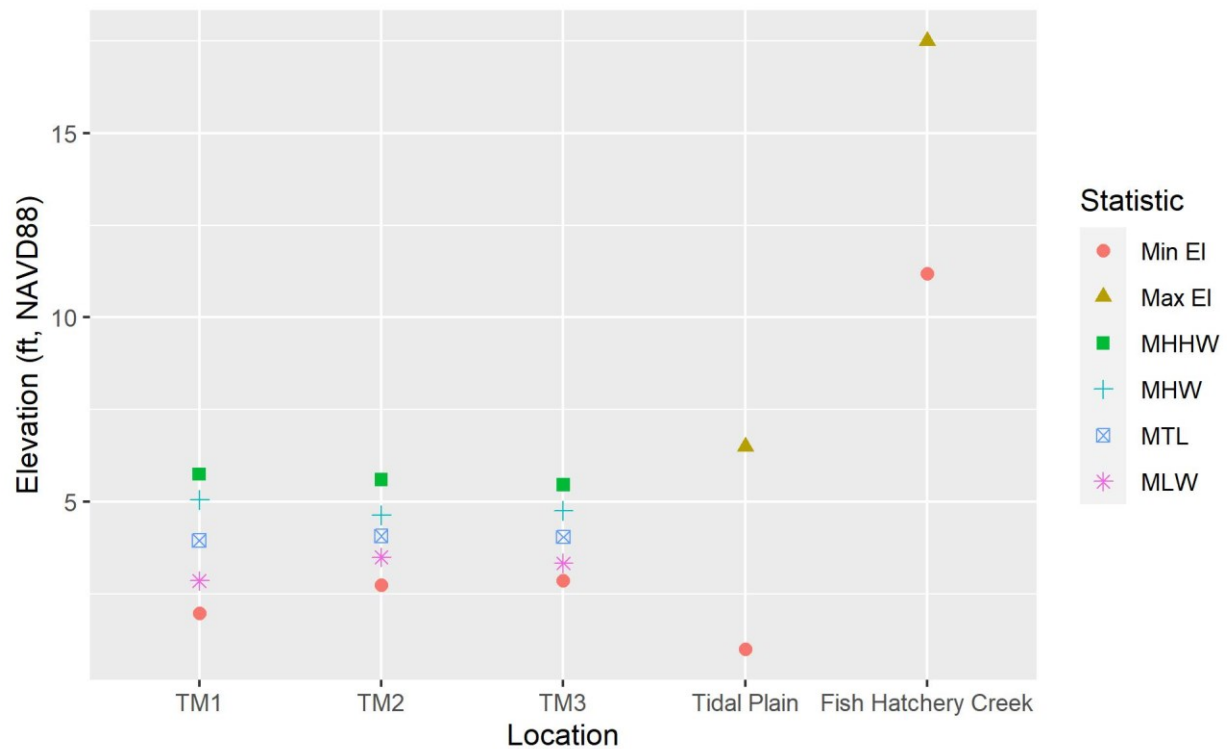


FIGURE 10: TIDAL STATISTICS AT EACH MONITORING LOCATION AND COMPARISON TO STUDY AREA TERRAIN.

Figure 11 compares tidal levels on the West Pasture tidal plains, groundwater WSE ranges, and creek flow WSE ranges with terrain elevations for FHC. **Figure 12** shows the alignment of FHC in relation to the gauges. **Figure 11** indicates FHC may have some groundwater flowing into its low elevation portions and is not tidally influenced.

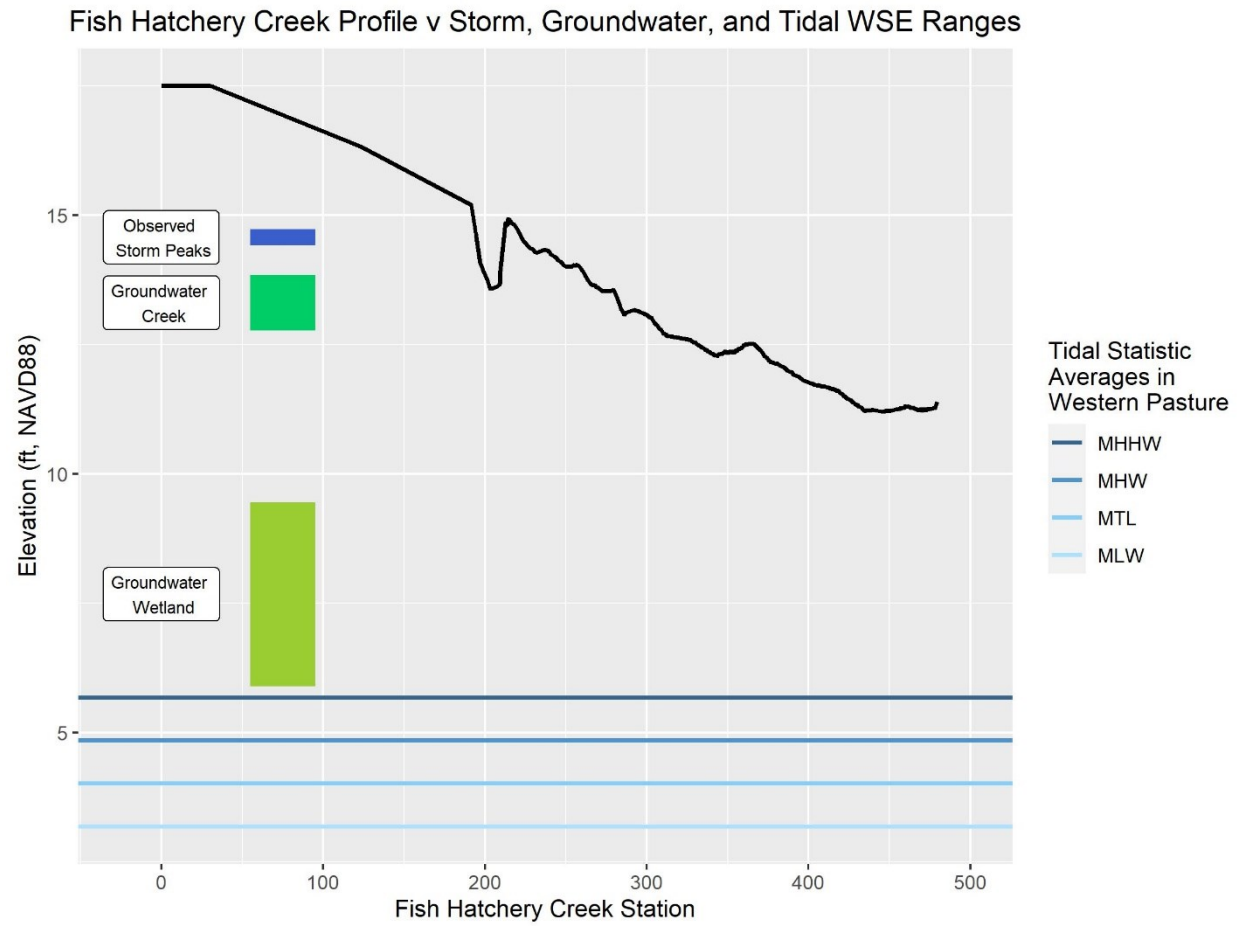
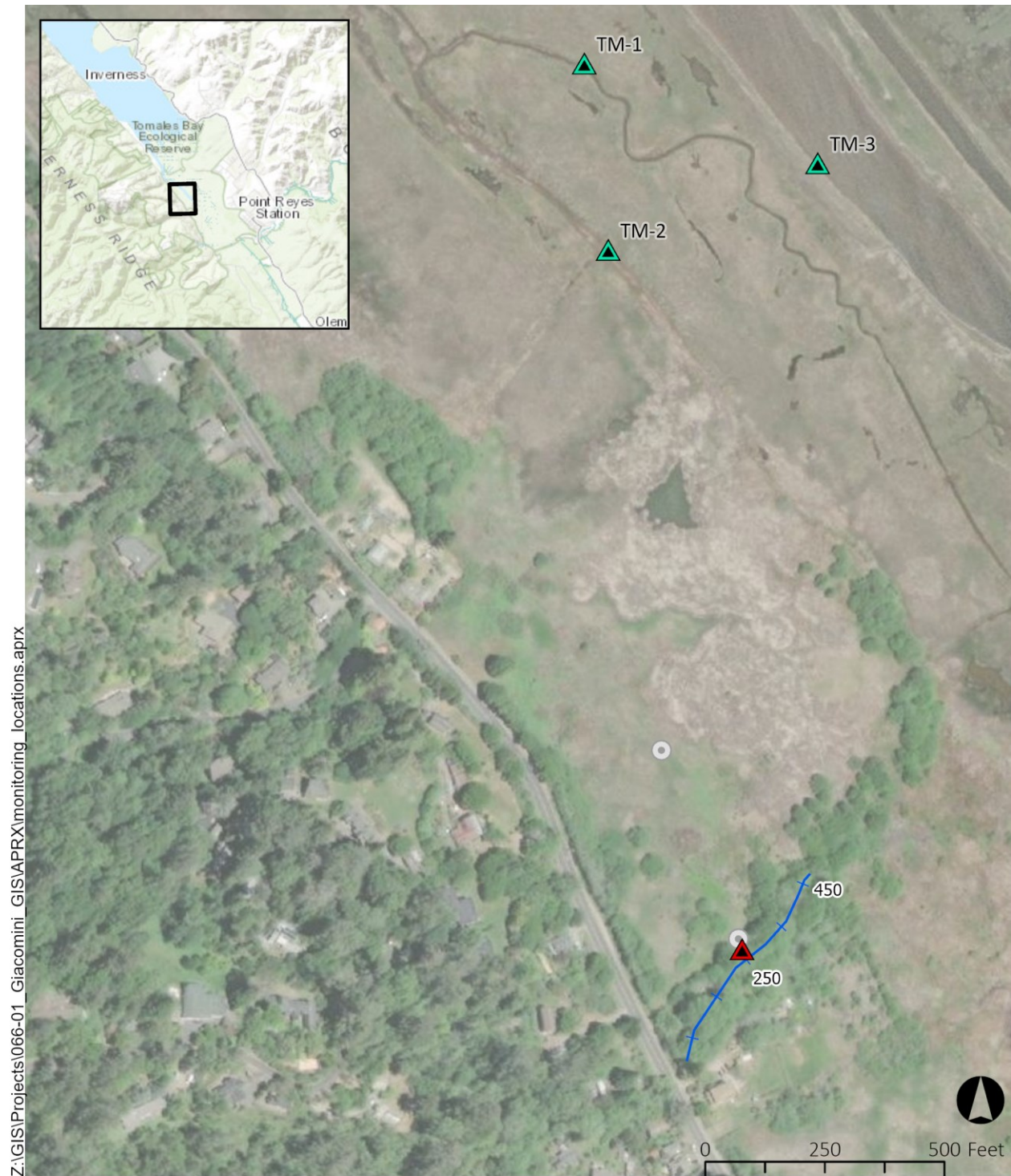


FIGURE 11: FISH HATCHERY CREEK TERRAIN AGAINST WSE'S.



Legend

- + Fish Hatchery Creek Alignment (Existing)
- ▲ Barologger

- ▲ Tide Gauges
- Groundwater Well Locations



FIGURE 12: EXISTING FHC ALIGNMENT AND MONITORING LOCATIONS

A comparison over time between NPS historical tidal data (collected by Kamman Hydrology & Engineering in 2009, 2011, and 2012) and data gathered by FlowWest could not be conducted, as there was no seasonal overlap in the two data sets. NPS data spans mid-July – September while FlowWest data spans November – March. To avoid possible confounding seasonal factors between these two data sets, a comparison was instead conducted on 2009 vs. 2022 data from NOAA’s nearby Pt. Reyes tidal gauge (Station ID 9415020). While this comparison cannot illustrate changes in tidal dynamics unique to Tomales Bay, it will provide insight into whether sea level rise has occurred in the years since restoration and whether such rise is affecting the current hydrology of FHC.

To align with past NPS analyses and avoid seasonal variability, this comparison was done for the months of July and August. Tidal statistics were calculated for July – August 2009 and 2022 and are recorded in **Table 7**. **Figure 13** and **Figure 14** show the 2009 and 2022 tidal records, respectively, and overlays them with lunar phenomena, including new moons, full moons, lunar perigees, and lunar apogees. This enables identification of spring and neap tides and consideration of how lunar distance is intensifying or tempering these tides. Perigean spring tides (spring tides that closely correspond with lunar perigees) were identified in both periods and serve as the basis of graphical comparison. A graphical comparison of these perigean spring tides in both years and the following neap tides is shown in **Figure 15**. The timestamp on data from 2009 was shifted back 7.99 days to align the tidal maxima of both data sets.

TABLE 7: TIDAL STATISTICS COMPARISON OF 2009 VS 2022 NOAA DATA. (FT, NAVD88)

Statistic	2009 Value	2022 Value	Change
MHHW	5.762	5.734	-0.028
MHW	5.226	5.271	+0.045
MTL	3.358	3.410	+0.052
MLW	1.490	1.548	+0.058
MLLW	0.985	0.872	-0.113

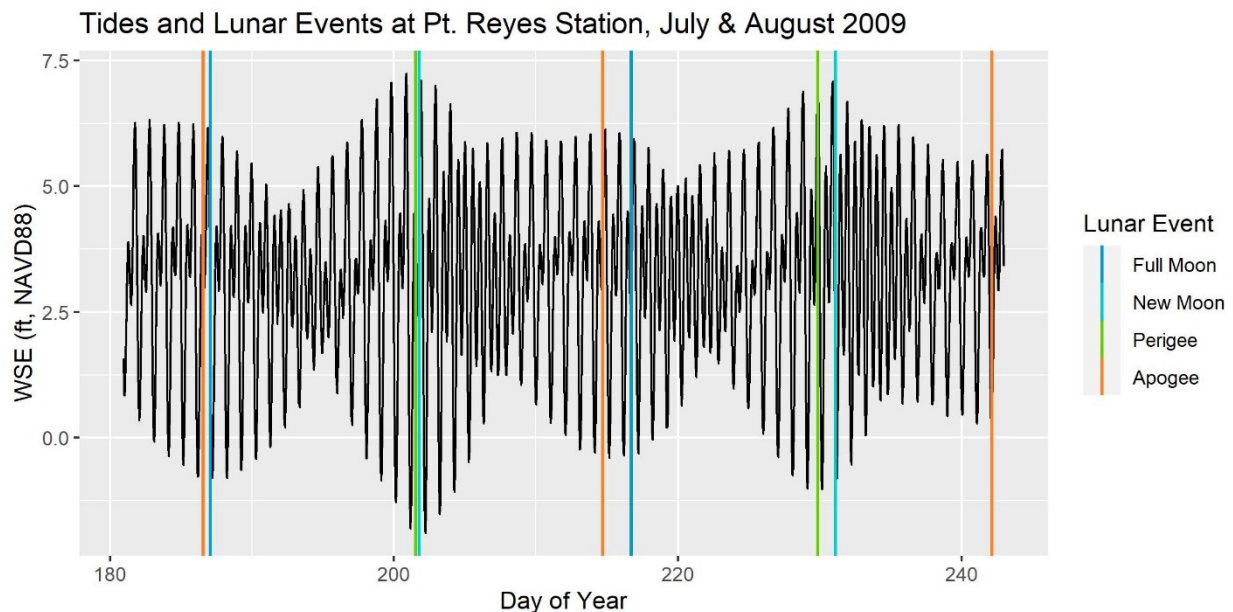


FIGURE 13: 2009 TIDAL RECORDS WITH LUNAR PHENOMENA OVERLAY.

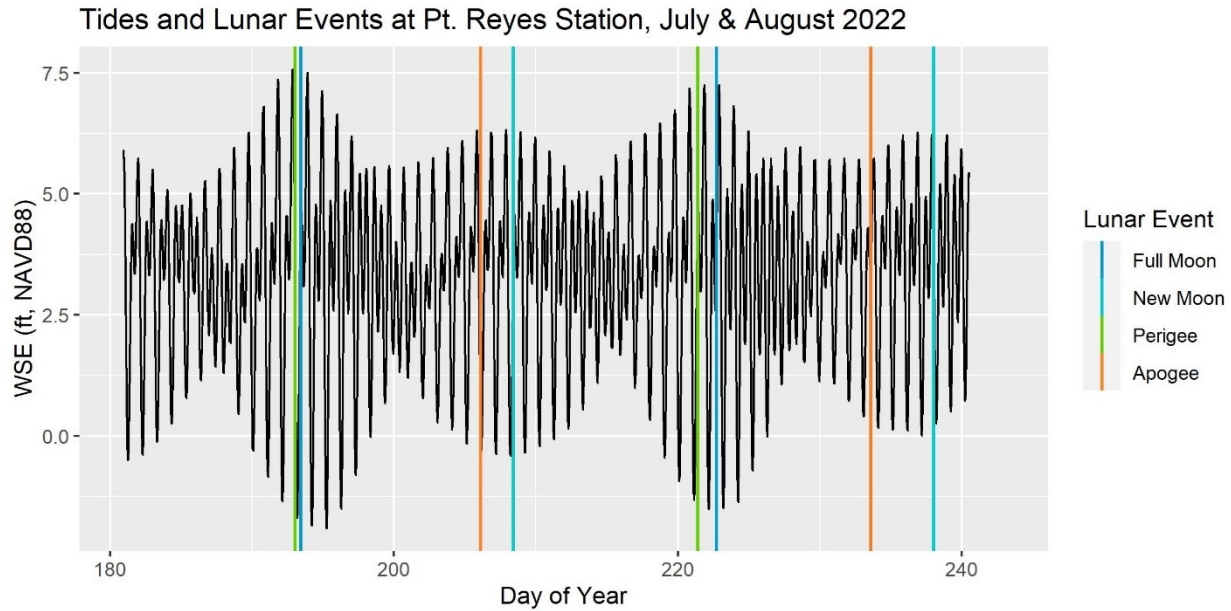


FIGURE 14: 2022 TIDAL RECORDS WITH LUNAR PHENOMENA OVERLAY.

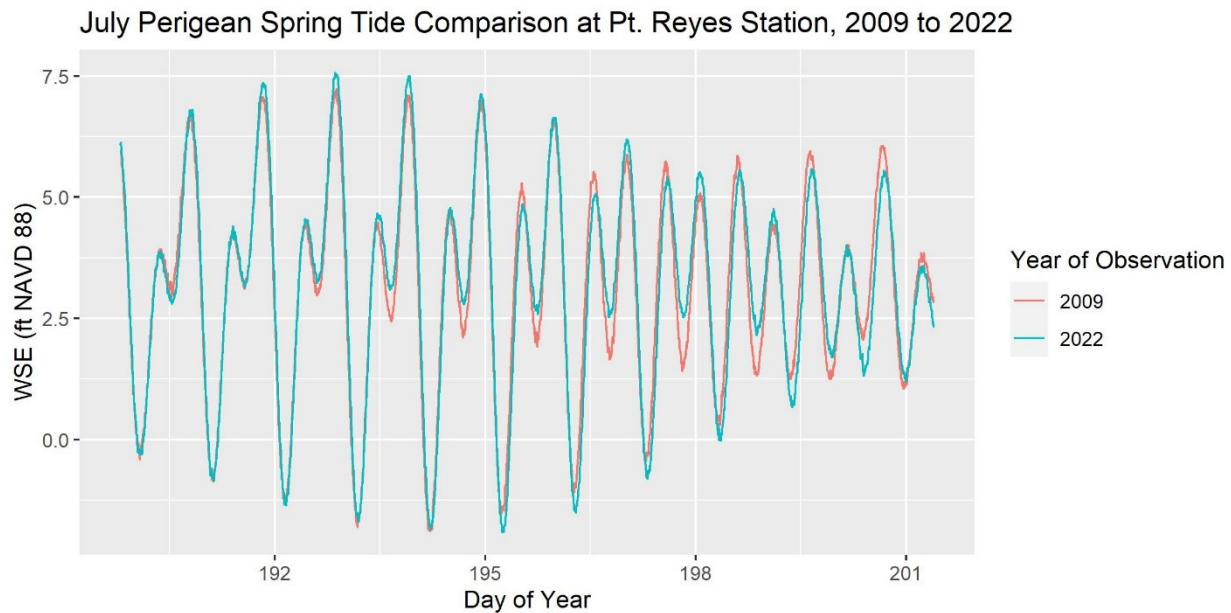


FIGURE 15: COMPARISON OF PERIGEAN SPRING TIDES (AND FOLLOWING NEAP TIDES) IN 2009 & 2022

Comparison of tidal statistics and perigean spring tide time series from 2009 and 2022 does not indicate a significant sea level rise at Pt. Reyes. Only three out of the five tidal statistics increased and did so by amounts that are likely not relevant to design of a new FHC channel. Observed differences are likely due to normal variations in astronomical tidal forcing. However, sea level rise of inches to feet are possible over the longer-term evolution of FHC and should be considered in the design process.

CONCLUSIONS AND NEXT STEPS

We established a suite of surface water, groundwater, and tidal monitoring stations in and around FHC near Tomales Bay between November 2021 and August 2022. During that period, California experienced critical drought conditions with few winter rains resulting in only relatively light stream flows in FHC. During some of our storm flow observations, we were able to collect sediment transport data sets, but these do not present a full picture of sediment transport dynamics in FHC because of the small magnitude of events observed. We supplemented collected data with other publicly available precipitation, tide, and hydrologic data sets. Our efforts resulted in an updated understanding of the local hydrology and its implications for connectivity between FHC and sloughs of Tomales Bay.

FISH HATCHERY CREEK FLOW AND SEDIMENT INFLOW RATES

Water year 2022 (October 1, 2021 – September 30, 2022) was unusual for the Tomales Bay watershed in that an early-season rainfall event in October (prior to deployment of monitoring equipment) produced rainfall amounts consistent with a 25-year, 24-hour return interval precipitation event. While antecedent watershed conditions in October would typically be very dry, and October rain would not produce much runoff, the October 23rd event was preceded by a week of rains totaling approximately 3 to 4 inches, and therefore antecedent conditions were likely to promote significant runoff.

However, for the rest of that water year, only 27.58 inches of precipitation was recorded between October 1st, 2021, and September 30th, 2022 (MCFCWCD). Average annual precipitation for this area is over 36 inches (USGS StreamStats, Marin County 2022), making 2021-2022 a drought year. In the aftermath of the October storm event, we observed sediment deposition in the dredged reach of FHC downstream of Sir Francis Drake Boulevard. This amount was not quantified but estimated as several inches of fresh deposition of mostly pea-gravel sized sediment. The December 13th flow event that was measured also produced measurable suspended and bedload sediment transport. The flow measured at this time was between 4.60-5.05 cfs and had a bedload transport rate of ~1.64 tons/day/foot of channel width and transported largely sands and other fine sediment particles. The next largest flow measured was on December 22nd, which did not produce any measurable bedload, implying that the threshold flows for bedload sediment transport is somewhere between 2 cfs (Dec 22nd) and 4.60 cfs (Dec. 13th). Because the precipitation event that occurred during the 12/13/2021 bedload measurement was equivalent to approximately a one-year storm event, we would expect that a flow event capable of transporting sediment at a rate of 1.64 tons/day/foot will occur every wet season.

Based on our observations and sediment transport data collection, the design of a new channel alignment for FHC should consider episodic pulses of sediment that bring gravels on the order of every two to five years and bring sand and other fine sediment into the creek at least annually. These episodic sediment transport events are likely to be separated by drought years in which little to no sediment is brought into or carried out of the creek upstream of tidally influenced areas.

GROUNDWATER LEVELS NEAR FISH HATCHERY CREEK RIDGE

Groundwater measurements were always significantly higher (~2 feet) than the mean higher high tide levels except for the 11/11/2021 measurement in the well in the marsh. This implies that tides likely do not have a significant impact throughout the year on groundwater around FHC. However, the maximum tide recorded at TM-2 during our study period was 7.35 feet NAVD88 on 12/31/2021, ~1.5 feet higher than the lowest groundwater level measurement, indicating that extensive marsh plain flooding could occur if groundwater levels were high at the same time as a very high tide (King Tide).

Though the 2022 water year was a low precipitation year in Point Reyes Station (26.91 inches), the previous two years were even lower, with only 10.64 inches in water year 2021 and 17.89 inches in water year 2020. This may be part of the reason that the groundwater levels were so low in November 2021, even after the large October precipitation event. This low groundwater measurement may also indicate how slowly groundwater seeps from the Inverness Ridge into the Study Area, because 18 days after the storm had ended, the groundwater was still quite low in the Study Area. The groundwater levels in the well nearest the creek mirrored the flow levels in the creek, with the highest levels corresponding to the highest flows; however, the groundwater levels in the marsh stayed quite consistent through the wet season and were notably lower in the November 2021 and the August 2022 measurements. A longer period of data collection would allow for more analysis of groundwater patterns in this area, for example, comparing marsh groundwater levels in November 2022 to the November 2021 level.

TIDES

Tidal monitoring indicates that the lower portions of the Study Area are heavily tidally influenced while the portions closer to FHC are only influenced by streamflow and groundwater. FHC itself in its current geomorphic state is not tidally influenced, and its hydrology is primarily influenced by surface waters flowing out of the upper watershed. Comparisons of July and August tides in Point Reyes does not indicate any sea level change since restoration work was completed.

CHANNEL DESIGN IMPLICATIONS

If the Seashore intends to implement a restoration project aimed at reconnecting FHC to Tomales Bay via slough(s) that currently exist east and north of the current terminus of the creek, managing sediment will likely be the greatest design challenge. Analysis of topography shows that FHC terminates in a depositional delta that is locally higher than the marshplain surrounding it. Reconnecting FHC along this alignment may prove infeasible due to the quantity and elevation of sediment deposited. We recommend the following considerations during design:

- Consider the shortest alignments possible that maximize channel slope that will in turn maximize velocity, shear stress, and sediment transport in the fluvial reach of FHC.
- Recognize the likely need for ongoing, long-term sediment maintenance which could include creation of a sediment capture basin near Sir Francis Drake Blvd that can be regularly cleaned.
- Optimize channel width and depth for the expected flows so that bedload transport is maximized in two to five-year return interval events. These events have the greatest likelihood for creating maintenance problems due to their relatively high frequency and ability to transport sediment. When the channel overflows its banks, velocities will drop in the channel and promote deposition, and therefore the channel should be sized so as to not overtop at too small a magnitude of flow event.
- Consider tidal sediment transport of fines in the tidally-influence portion of the restored alignment and its effect on geomorphology.
- Conduct additional monitoring in future winters in the hopes of capturing greater magnitude events than were observed in 2021-2022.

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