Appendix C

Tidal Study

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PORT OF FRIDAY HARBOR
ALBERT JENSEN AND SONS INC. BOATYARD AND MARINA
FRIDAY HARBOR, WA

MODEL TOXICS CONTROL ACT (MTCA)
AGREED ORDER NO. DE 18071

REMEDIAL INVESTIGATION REPORT – UPLAND AREA
TIDAL STUDY

Prepared for
The Port of Friday Harbor
Friday Harbor, WA

Prepared by
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Seattle, WA

September 2025

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1 INTRODUCTION

The Albert Jensen and Sons Inc. Marina and Boatyard (Project) is located at 1293 Turn Point Road, Friday Harbor, Washington on San Juan Island in the Salish Sea. and the purpose of this tidal study was to determinethe extent of the tidal influence to shallow groundwater at the Project. For tidally influenced groundwater monitoring wells, it is a best practice to collect groundwater samples during a negative low tide, as this represents the time of a lowest tide. Groundwater is sampled during the time of low groundwater elevation in each well in order to collect samples that are most representative of the aquifer groundwater and not the surface water body that is influencing the monitoring well.

The purpose of the tidal study is to:

1. Determine the extent of Project monitoring wells which are tidally influenced.
2. For tidally influenced monitoring wells, estimate tidal lag times to determine when groundwater sampling should be performed relative to low tide.
3. Define net groundwater flow conditions.

2 DATA COLLECTION AND ANALYSIS

2.1 METHODOLOGY

The tidal study was conducted from August 5-16, 2022 during a time period including negative and non-negative low tides, allowing for observation across a full tidal response. A 72-hour subset of this transducer data was used for statistical evaluation. This subset data range was August 12 00:00 through August 14 23:59. A select six (6) monitoring wells and the nearest NOAA-monitored tidal station (ID# 94469880 in Friday Harbor, WA) were used to measure tidal variations. These six monitoring wells were generally the closest to the shoreline and spread across the shoreline west to east.

2.2 WATER LEVEL ELEVATION CONVERSIONS

In-Situ pressure transducers level loggers, Rugged TROLL, were placed in each of the six selected monitoring wells and left undisturbed for the duration of the study. Transducer details are included on Table C-1. Water level measurements were collected by hand in all onsite wells using a water level meter at the time of transducer installation and transducer removal as spot checks of the transducer water level calculations (Table C-2). Raw data collected directly from the transducers (water depths as a function of water head pressure) were corrected against barometric pressure recorded concurrently at the Project using a BaroTROLL. The barometric pressure corrections were performed using Win-Situ 5 software. This tidal study used top of casing reference elevation data for MW-2, MW-3, and MW-5 (Whatcom 2018) and survey data from San Juan Surveying for MW-2, MW-7, MW-8, and MW-9. The reference point for each monitoring well is on the approximate north point of the top of well casing. The barometrically-corrected transducer pressure measurements (water head) were then subtracted from the surveyed well casing depth to calculate water level elevations from the transducer data. The barometrically-corrected transducer data were used in the Serfes analysis. No monitoring wells went dry during the tidal study.

2.4 TIDAL EFFICIENCY

Tidal efficiency is the magnitude of the tidal fluctuation of a groundwater monitoring well, expressed as a percentage of the tidal fluctuation in the adjacent water body. Tidal efficiency is used to understand the hydrologic characteristics of the aquifer. The amplitude of the groundwater fluctuation is generally much less than the tidal range and is usually greatest nearest the shoreline and diminishes further from shoreline, although other factors may affect the groundwater level response observed in wells. The tidal efficiency was calculated by dividing the tidal range for one-quarter of a tidal cycle (lower low tide to the corresponding next higher high tide) by the same tidal range for the tidal station. Calculated tidal efficiencies for each monitoring well during each recorded lower low water to higher high water tidal cycles are summarized on Table C-3 and discussed in Section 3.1.

2.5 LAG TIME

In general, tidally influenced groundwater follows the tidal fluctuations of the adjacent waterway on a delayed cycle. The length of time it takes for water in a well to respond to the tidal cycle is known as the "tidal time lag" (Fetter 1994). The lag time was used to predict groundwater sample timing based on the low tides predicted for the reference station.

Tidal lag time was calculated by averaging the difference in time between the two higher high tides and two lower low tides in each monitoring well relative to the reference tidal station #9449880. Tidal Station 9449880 is at the Port of Friday Harbor on the Salish Sea (Figure C-1). The gauging station is a straight-line distance of less than 1.5-miles from the Project. Calculated tidal lag times for each monitoring well during the tidal study period are summarized on Table C-3.

2.6 NET GROUNDWATER FLOW

Net groundwater elevation and flow direction are used to assess contaminant fate and transport at a site. In a tidally influenced area, groundwater elevations and flow directions may vary through the tidal cycle. As the tides rise and fall, they produce pressure waves in the adjacent aquifers and may cause groundwater levels and hydraulic gradients to fluctuate, resulting in a situation where a single synoptic set of groundwater levels may not adequately characterize the groundwater potentiometric surface. To evaluate net groundwater flow direction, average elevations are typically estimated using the Serfes (1991) method. Data from this tidal study was used to evaluate average elevations using a simple averaging and filtering from the modified method of Serfes (1991). Serfes developed a method based on the earlier work of Godin (1966) to filter out tidal influences. Serfes method uses hourly water-level readings taken over a three-day period (72 hours). The hourly readings from each well are processed using a moving average technique.

The Serfes moving average values for each well within the tidal study window (8/12/2022 00:00 to 8/14/2022 23:59) and final Serfes method averages summarized on Table C-3.

3 TIDAL STUDY RESULTS

3.1 TIDAL RANGE AND TIDAL EFFICIENCY RESULTS

The tidal range on the gauging station during this study period was up to 10.19 feet, ranging in elevation from -2.01 feet mean lower low water (MLLW) to 8.18 feet MLLW. Groundwater levels in the observed monitoring wells fluctuated up to 1.72 feet (MW-7) during a single tidal quarter cycle.

Calculated tidal efficiencies (i.e., magnitude of the tidal fluctuation of groundwater at a monitoring well expressed as a percentage of the tidal fluctuation in the adjacent water body) ranged from 2 percent at well MW-3 (within the SRWA), to 17 percent at MW-7 (near top of bank within the BLWA). While measured tidal efficiencies were relatively low for all wells, the wells near the top of bank within the Boat Lift Work Area (MW-7, -8 and -9) exhibited the most significant tidal influence (efficiencies ranging 8 to 17 percent). These wells also exhibited the greatest specific conductivity showing influence of marine water. See Table C-3 for tidal range and tidal efficiency. See Figure C-2 and Figure C-3 for monitoring well and tidal water level charts.

The northwestern one-third of the Project area comprises the greater Boat Lift Work Area and Former OPALCO Storage Area. This land area has undergone historical grading and fill operations which may affect soil density, porosity, and the permeability. Monitoring wells in this area include MW-7, MW-8, MW-9, and MW-2, with wells MW-4, MW-1, and MW-3 along the likely fill perimeter or outermost extents.

3.2 LAG TIME RESULTS

The averaged tidal lag time for wells at the Project during the 72-hour tidal ranged from 3 hours and 48 minutes (MW-5) to 6 hours and 57 minutes (MW-3). Both monitoring wells are considered nearshore wells and in areas understood to predominantly native soils with little to no fill material present, suggesting that the native, undisturbed soil properties are hydrogeologically different that the site fill soil properties. See Table C-3 for lag times and tidal efficiency. Considering the more immediate proximity of MW-7, MW-8, and MW-9 to the Salish Sea, it would typically be expected that these wells would have the shortest tidal lag times, but MW-3 has this shortest lag time. Due to the relative heterogeneity of the BLWA shoreline soils from the infilling and grading of the BLWA shoreline (sometime between 1941 and 1971), these variable shoreline soils are likely a main factor in tidal lag time variability among these BLWA shoreline wells (MW-7, MW-8, and MW-9) and MW-3. Considering the more immediate proximity of MW-7, MW-8, and MW-9 to the Salish Sea, it would typically be expected that these wells would have the shortest tidal lag times, but MW-3 has this shortest lag time.

3.3 NET GROUNDWATER FLOW

The net groundwater flow direction for the Project was obtained by interpolating elevation contours from the average, filtered groundwater elevations for each well (Figure C-4). The net groundwater flow direction at the Project is to the north towards the Salish Sea. Of the six monitoring wells studied at the Project, the Serfes average groundwater elevations during the tidal study period ranged from 5.8 feet MLLW (MW-7) to 6.2 feet MLLW (MW-3). In general, the hydraulic gradient across the Project is very low. Hydraulic gradient calculations for the water level elevations among the monitoring wells across the site range from 0.00128 to 0.00672 ft/ft.

3.4 GROUNDWATER SAMPLE TIMING

Table C-3 also provides a summary of groundwater sample timing for each well included in the tidal study at the Project based on the logic presented in the introduction to this report (Section 1). Suggested sample collection times based on observed tidal lag times are summarized on Table C-3 and discussed in Section 3.2. Suggested sample collection times vary from 4-hours to approximately 6.5-hours following the lower low tide of a given tidal diurnal tidal cycle. Although data logging was not conducted on MW-1, MW-4, or MW-6, estimated lag times can be inferred for these wells based on proximity and known lithology. MW-1 and MW-4 would likely have a similar of longer lag time than MW-2 and MW-3, so greater than 6-hours. MW-6 would likely have the longest lag time or no appreciable tidal efficiency.

4 REFERENCES

Fetter 1994. Applied Hydrogeology, 376 pp., Prentice-Hall, Englewood Cliffs, N. J., 1994

NOAA Tide Level Observations for Friday Harbor (Station 94498800) retrieved from: https://tidesandcurrents.noaa.gov/noaatidepredictions.html?id=9449880. Accessed October 2022.

Serfes 1991. Determining the Mean Hydraulic Gradient of Ground Water Affected by Tidal Fluctuations. Groundwater Journal, Volume 29, Number 4, July-August 1991.

Whatcom 2018. Draft Remedial Investigation Report, Jensen’s Shipyard and Marina, 1293 Turn Point Road, Friday Harbor, Washington. Prepared by Whatcom Environmental Services, October 15, 2018.

TABLES

Table C-1 Albert Jensen and Sons Boatyard - Level Logger Type and P

Level Logger ID	Level Logger Serial Number	Level Logger Type	Total Well Depth (ft BTOC)
MW-2	675163	In-Situ Rugged TROLL 100	14.74
MW-3	675070	In-Situ Rugged TROLL 100	13.03
MW-5	675049	In-Situ Rugged TROLL 100	14.15
MW-7	675229	In-Situ Rugged TROLL 100	12.85
MW-8	675102	In-Situ Rugged TROLL 100	11.79
MW-9	675029	In-Situ Rugged TROLL 100	11.84
Barometer	643290	In-Situ Rugged BaroTROLL	N/A

NOTES:
BTOC - below top of casing
ft - feet
N/A - not applicable

Table C-2 Albert Jensen and Sons Boatyard - Monitoring Well Gauging, Select Transducer Readings

Well ID	Date	Time	Elevation Top of PVC Casing (ft MLLW)	Gauged DTW (ft BTOC)	Water Level Elevation (ft)	Transducer Level Reading (Head ft)	Difference in Gauged DTW and Transducer Measured Head (ft)
MW-2	8/5/2022	10:15	11.31	5.77	5.54	5.80	-0.03
	8/16/2022	8:28	11.31	5.59	5.72	5.63	-0.04
MW-3	8/5/2022	10:32	10.16	4.27	5.89	4.34	-0.07
	8/16/2022	8:11	10.16	4.15	6.01	4.21	-0.06
MW-5	8/5/2022	10:55	16.36	10.44	5.92	10.45	-0.01
	8/16/2022	8:02	16.36	10.34	6.02	10.39	-0.05
MW-7	8/5/2022	9:47	10.76	6.05	4.71	6.05	0.00
	8/16/2022	8:41	10.76	5.43	5.33	5.66	-0.23
MW-8	8/5/2022	9:36	11.24	5.90	5.34	5.90	0.00
	8/16/2022	8:46	11.24	5.68	5.56	5.75	-0.07
MW-9	8/5/2022	9:30	11.25	5.85	5.40	5.85	0.00
	8/16/2022	8:52	11.25	5.60	5.65	5.77	-0.17

NOTES:

Top of casing data taken from Draft Remedial Investigation Report by Whatcom Environmental dated October 15, 2018 and Star Surveying Inc memorandum dated September 19, 2022.

PVC - polyvinyl chloride

ft - feet

DTW - depth to water

BTOC - below top of casing

MLLW - Mean Lower Low Water

Table C-3 - Albert Jensen and Sons Boatyard - Tidal Lag Time Analysis at Monitoring Wells

Well ID	Elevation	Tidal Range for a Quarter Cycle				Tidal Range for a Quarter Cycle				Tidal Range for a Quarter Cycle				Tidal Timing						Lag Time				Sample Collection Time
	Serfes Method Mean Elevation (72-Hour Period)	First Low Low Elevation	First High High Elevation	Tidal Range	Tidal Efficiency (Quarter Cycle)	Second Low Low Elevation	Second High High Elevation	Tidal Range	Tidal Efficiency (Quarter Cycle)	Third Low Low Elevation	Third High High Elevation	Tidal Range	Tidal Efficiency (Quarter Cycle)	Time of First Low Low Water Level	Time of First High High Water Level	Time of Second Low Low Water Level	Time of Second High High Water Level	Time of Third Low Low Water Level	Time of Third High High Water Level	Lag Time (1st Low Low Tides Only)	Lag Time (2nd Low Low Tides Only)	Lag Time (3rd Low Low Tides Only)	Average Lag Time (3 Low Low tides)	Suggested Sample Collection Time
	MLLW	MLLW	MLLW	ft		MLLW	MLLW	ft		MLLW	MLLW	ft								hr:min	hr:min	hr:min	hr:min	
MW-2	6.09	5.75	6.45	0.70	7%	5.85	6.42	0.57	6%	5.60	6.10	0.50	6%	8/12/2022 18:02	8/12/2022 6:02	8/13/2022 18:32	8/13/2022 7:44	8/14/2022 18:35	8/14/2022 8:32	6:26	6:20	5:47	6:11	6 hours after low low tide
MW-3	6.23	6.07	6.24	0.17	2%	6.22	6.32	0.10	1%	6.01	6.21	0.20	2%	8/12/2022 18:15	8/12/2022 5:51	8/13/2022 19:21	8/13/2022 11:42	8/14/2022 19:51	8/14/2022 8:39	6:39	7:09	7:03	6:57	6.5-7 hours after low low tide
MW-5	6.22	5.83	6.48	0.65	6%	5.98	6.52	0.54	6%	5.85	6.40	0.55	6%	8/12/2022 15:21	8/12/2022 5:03	8/13/2022 16:00	8/13/2022 7:27	8/14/2022 16:39	8/14/2022 8:15	3:45	3:48	3:51	3:48	3.5 hours after low low tide
MW-7	5.80	4.95	6.67	1.72	17%	4.97	6.49	1.52	16%	4.57	6.05	1.48	17%	8/12/2022 15:57	8/12/2022 5:48	8/13/2022 16:12	8/13/2022 6:42	8/14/2022 16:48	8/14/2022 7:42	4:21	4:00	4:00	4:07	4 hours after low low tide
MW-8	5.79	5.70	6.56	0.86	8%	5.75	6.42	0.67	7%	5.39	6.01	0.62	7%	8/12/2022 17:20	8/12/2022 6:14	8/13/2022 18:11	8/13/2022 7:38	8/14/2022 18:44	8/14/2022 8:00	5:44	5:59	5:56	5:53	5.5 hours after low low tide
MW-9	6.16	6.10	6.96	0.86	8%	6.19	6.74	0.55	6%	5.76	6.62	0.86	10%	8/12/2022 16:24	8/12/2022 4:57	8/13/2022 17:48	8/13/2022 5:318:00 AM	8/14/2022 17:30	8/14/2022 7:15	4:48	5:36	4:42	5:02	4.5 hours after low low tide
Tidal Station #9449880	4.45	-2.01	8.18	10.19	NA	-1.64	7.81	9.45	NA	-0.68	7.90	8.58	NA	8/12/2022 11:36	8/12/2022 19:42	8/13/2022 12:12	8/13/2022 20:12	8/14/2022 12:48	8/14/2022 20:36	NA	NA	NA	NA	ND

Notes:

The tidal study window for this analysis and these table values is from 8/12/2022 00:00 (AM) to 8/14/2022 23:59 (PM).

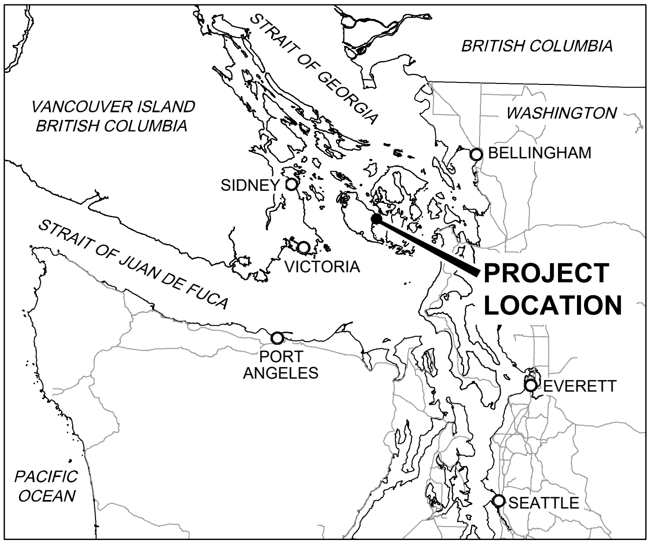
hr:min - Time in hours and minutes

ft - feet

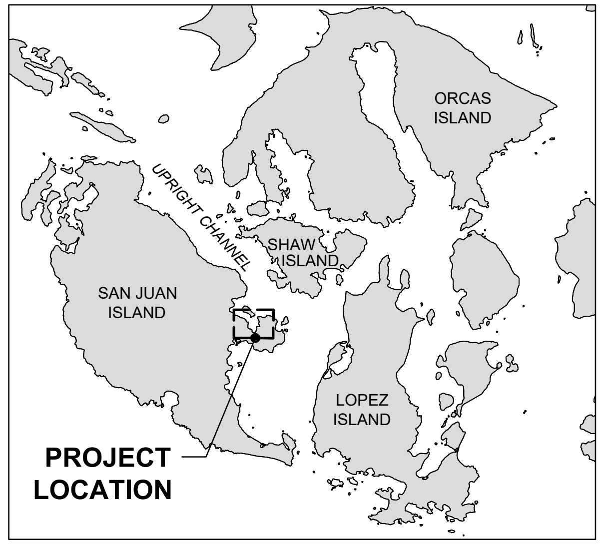
MLLW - mean lower low water

NA - not applicable

FIGURES



VICINITY MAP



VICINITY MAP - SAN JUAN ISLANDS

LOCATION MAP

0 1,250 2,500

SCALE IN FEET

CRETE CONSULTING, INC.

LEON Environmental, LLC

Port of Friday Harbor
Upland Remedial
Investigation Report
September 26, 2025

Figure C-1

Site Location Map

File: PoFH_2025_RI-Cover.dwg Layout: Layout1

Figure C-2
Monitoring Well and Tide Water Levels (Unabridged)

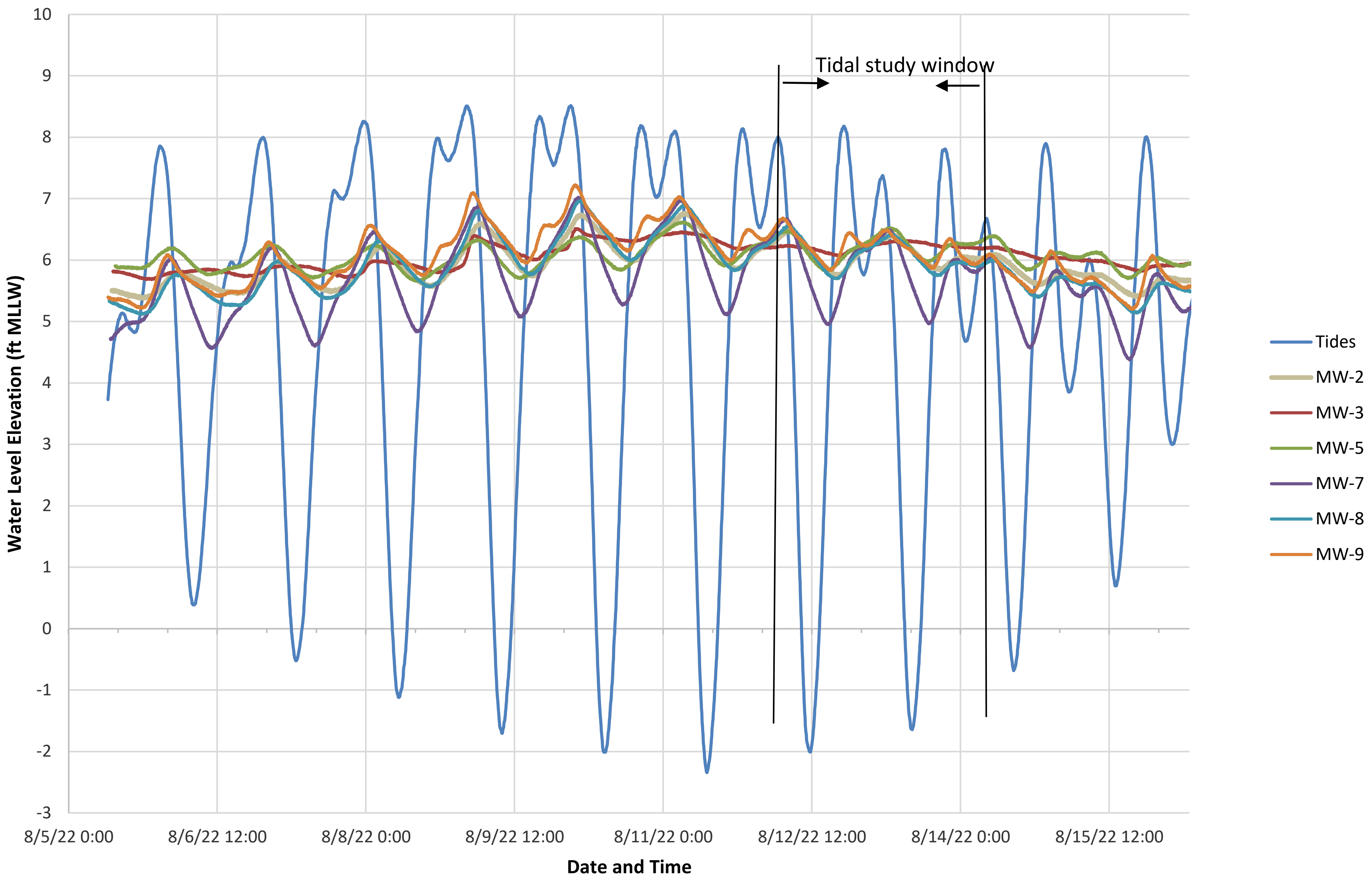
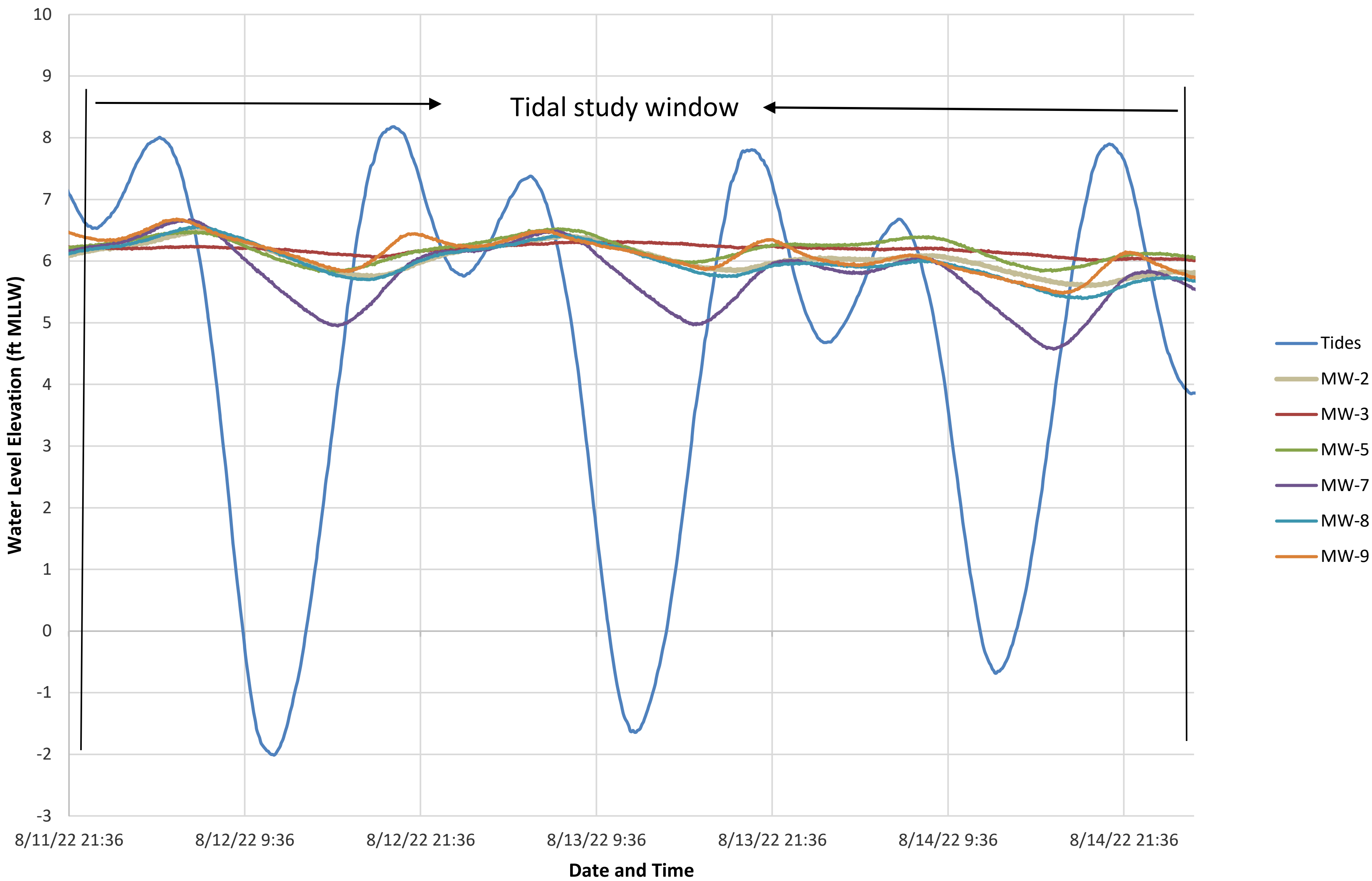
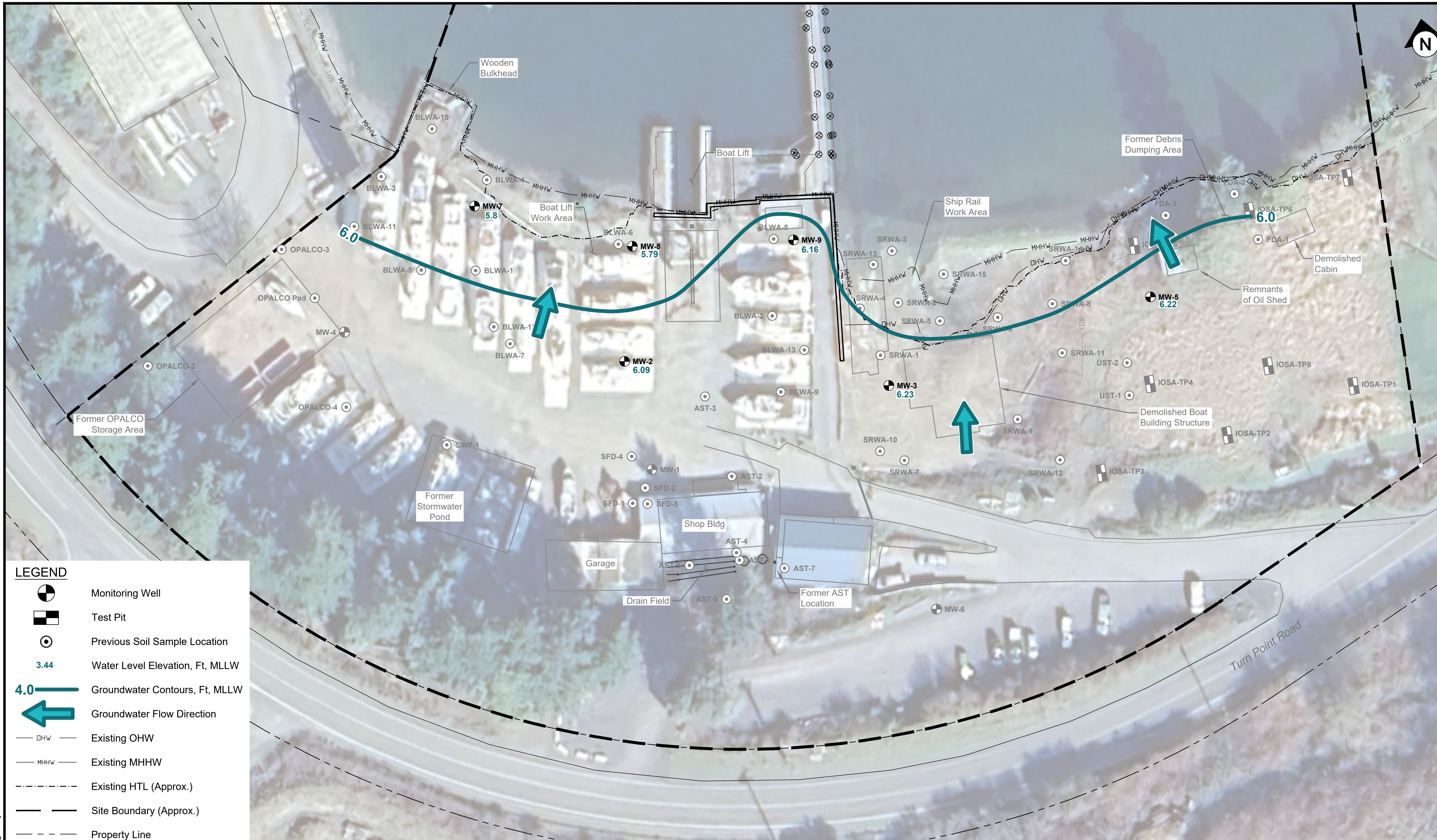


Figure C-3
Monitoring Well and Tide Water Levels (Abridged)





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CRETE CONSULTING, INC.

LEON Environmental, LLC

0 50 100
Scale in Feet

Port of Friday Harbor
Upland Remedial Investigation Report
September 26, 2025

Appendix C-4

Net Groundwater Flow