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INTERIOR DRAINAGE REPORT

Lower Dungeness River Floodplain Restoration and Levee Realignment Project

CLALLAM COUNTY, WASHINGTON

October 29, 2018

Shannon & Wilson No: 21-1-12559-064

SHANNON & WILSON

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Clallam County
Department of Community Development
223 East Fourth Street, Suite 5
Port Angeles, WA 98362

Attn: Cathy Lear

RE: INTERIOR DRAINAGE REPORT, LOWER DUNGENESS RIVER FLOODPLAIN RESTORATION AND LEVEE REALIGNMENT PROJECT, CLALLAM COUNTY, WASHINGTON

Shannon & Wilson participated in this project as a subconsultant to Clallam County. Our scope of services was specified in Agreement Number with 334.16.005 dated June 1, 2016.

10/29/18

David Cline, PE, CFM
Vice President

JBA:DRC/jba

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1 INTRODUCTION

Shannon & Wilson performed an interior drainage analysis to assess the impact of the Lower Dungeness River Floodplain Restoration and Levee Realignment Project (Project) on the hydrologic and hydraulic behavior of Meadowbrook Creek and local drainages landward of the levee setback. This analysis consists of a watershed delineation, estimation of 100-year flood flows, a review of groundwater data and seepage calculations, and a bankfull width survey in support of stream simulation design recommendations for fish-passable culverts.

Ultimately, all of these component analyses were incorporated into a two-dimensional (2D) hydraulic model to characterize local drainage conditions for the proposed Project.

In the subsequent sections of this report, we describe the methods and findings of the individual analyses, with an emphasis on the differences between the existing and proposed conditions.

2 HYDROLOGY

2.1 Watershed Delineation

Watersheds in the Project area were delineated using the GIS-based tool TOPAZ, implemented in Aquaveo's watershed modeling software. Our input for the TOPAZ delineation consisted of a 2016 light detection and ranging (LiDAR) survey from Puget Sound LiDAR Consortium (PSLC) and the United States Geological Survey (USGS) 10-meter National Elevation Dataset in areas that were not covered by the PSLC survey. Given the flat slope and terrain of the floodplain area being delineated, certain streamlines or drainage ditches were not recognized by TOPAZ as continuous, and therefore, the output required some post-processing to ensure that the drainage areas aligned with our field-based understanding of site conditions. We used our knowledge of culvert locations, raised road surfaces, and farm drainage ditch locations and drainage directions to adjust the TOPAZ-derived drainage basin boundaries.

The basin outlet for the delineation exercise was immediately upstream of the Sequim-Dungeness Way Meadowbrook Creek crossing. This location is approximately 200 feet downstream of the confluence of the Mainstem Meadowbrook Creek and a smaller drainage from the west, named the West Tributary to Meadowbrook Creek for the purposes of this

Project. These two forks were treated separately throughout this drainage analysis because they are affected differently by the realignment of the levee. In the proposed condition, roughly 90% of the existing West Tributary drainage area is rerouted to the Dungeness River. The Meadowbrook Creek Mainstem, on the other hand, remains relatively unchanged.

The results of the delineation and the expected changes to the watershed areas are mapped in Figure 1 and summarized in Exhibit 2-1.

Exhibit 2-1: Watershed Areas for Existing and Proposed Levee Alignment

Watershed	Drainage Area (square miles)	
	Existing Conditions	Proposed Conditions
Mainstem Meadowbrook	0.64	0.68
West Tributary Meadowbrook	0.19	0.02
Meadowbrook Creek Total	0.83	0.70

2.2 Flood Frequency Analysis

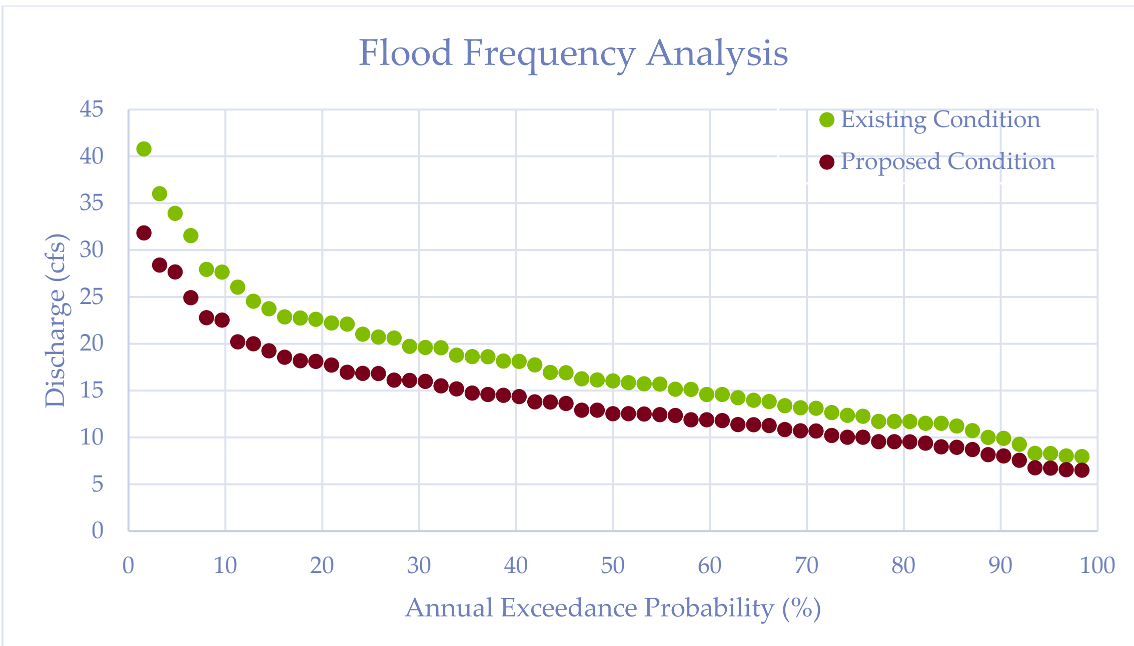
Using the watershed boundaries defined above, we ran a flood frequency analysis with the Western Washington Hydrology Model (WWHM 2012). This model calculates flood frequency curves using a continuous simulation hydrologic model, based on an historic precipitation record and a user-defined distribution of land cover, slope, and soil type in the basin of interest.

The WWHM model parameters and results for the existing and proposed conditions are included in Appendix A. The flood frequency analysis results are summarized in Exhibit 2-2. Flood flows in Meadowbrook Creek decrease as a result of the Project, and this is due to the reduction in total contributing drainage area from 0.83 to 0.70 square miles.

Exhibit 2-2: Western Washington Hydrology Model (WWHM) Flood Frequency Analysis

	Peak Flow (cfs)	
Recurrence Interval	Existing Conditions	Proposed Conditions
1 Year	7.0	6.0
2 Years	16.2	13.1
5 Years	22.3	18.0
10 Years	26.5	21.4
25 Years	31.9	25.7
50 Years	36.0	29.0
100 Years	40.2	32.3

NOTE:
cfs = cubic feet per second



NOTE:
cfs = cubic feet per second

2.3 Groundwater and Seepage

Groundwater and seepage were also considered in estimating streamflow in Meadowbrook Creek. We performed a seepage analysis to estimate how the seepage and groundwater contribution to flow in Meadowbrook Creek would change with implementation of the Project. We performed the seepage analyses using SEEP/W, a component of GeoStudio released by Geo-Slope International in Calgary, Canada (Geo-Slope, 2015). SEEP/W models mass transport of water through soil in two dimensions.

The soil materials used in the seepage model correspond to the geologic units presented in our Geotechnical Data Report (Shannon & Wilson, 2017). The Geotechnical Data Report provides additional information on the geologic units. Figure 2 demonstrates the surface geometry and subsurface stratigraphy used in the model.

For our seepage model, we selected a transect that extends approximately 3,300 feet, beginning 300 feet west of the Dungeness River centerline and ending at Sequim-Dungeness Way to the east. Figure 2 shows the approximate location of the profile with respect to the Project boundary. This transect was selected because it passes through the location of a vibrating wire piezometer (VWP) that has been logging groundwater elevation since 2016, thus providing an opportunity to calibrate the model. The VWP is located in boring B-7-16, as marked on Figure 2.

To calibrate the model, we used the existing conditions ground surface geometry, applied a water surface elevation within the banks of the Dungeness equivalent to a 1.01-year flood flow, and adjusted the thicknesses and orientation of the subsurface layers until the model calculated a groundwater elevation equal to the observed groundwater elevation at the site of the VWP at B-7-16.

Using the calibrated subsurface conditions, we ran the seepage model for a range of flows. In each run, the model was constrained by the water surface elevations in the Dungeness channel and the adjacent floodplain corresponding to the recurrence interval of interest. Figure 2 shows the simulated ground and surface water profiles across the model transect for several flow conditions. Exhibit 2-3 summarizes the model results.

Exhibit 2-3: Groundwater Seepage Rates to Meadowbrook Creek

Flood Recurrence Interval	Flow in Dungeness River (cfs)	Flow into Meadowbrook Creek from Seepage (cfs)	
		Existing Conditions	Proposed Conditions
Summer Low Flow	80	0.0001	0.002
Spring Flow	300	0.0001	0.002
1 Year	574	0.0001	0.002
2 Years	3277	0.0001	0.16
5 Years	5156	0.0001	0.37
10 Years	6317	0.0001	0.48
20 Years	7347	0.042[1]	0.56
50 Years	8562	0.171[1]	0.62
100 Years	9391	0.171[1]	0.64

NOTES:

1 The Dungeness River overtops the existing levee with flow greater than Q20, and there is significant overland flooding (roughly 100 cfs) into Meadowbrook Creek.

cfs = cubic feet per second

Seepage to Meadowbrook Creek increases with implementation of the Project for the full range of flows. This can be explained by the fact that the Project moves the levee, and inundated floodplain areas, approximately 1,500 feet closer to Meadowbrook Creek. Moving the levee closer to the creek means that the floodwater surfaces distributed across the floodplain will be closer to Meadowbrook Creek and have a higher (steeper) groundwater slope, thereby increasing seepage rates through and under the levee per Darcy's Law. The groundwater modeling shows increases in local groundwater elevations immediately landward of the levee, which may support wetland vegetation to the Project property line. To reduce uncertainty of wetland hydrologic conditions landward of the levee, we recommend scraping about 1.5 feet of topsoil in certain areas. These areas are shown in Figure B-1.

3 HYDRAULICS

3.1 Interior Drainage Routing

One component of the hydraulic design of the Project is the routing of interior surface water drainages within the Project boundary. There are several locations where we have elected to grade channels or ditches to route flow so that it maximizes potential for wetland/stream habitat health and/or addresses drainage effects on adjacent farm properties. Figure 3 highlights the existing and proposed channels and ditches and compares the post-Project drainage flow paths to the existing conditions.

In the existing condition, overland flow within the Project boundary is generally routed to the north and northeast. There are existing ditches in the eastern half of the Project site (on the WSDOT property) that concentrate most of the site's surface drainage and direct it toward Meadowbrook Creek. There are also drainage ditches in the southwest corner of the site along the property boundary with the Brown Dairy Farm. These ditches connect to an historical side channel of the Dungeness River that passes via two culverts through the existing levee into the Dungeness River main channel.

In the proposed condition, flow paths within the Project boundary are altered in several ways. First, rather than much of the Project site draining into Meadowbrook Creek, the proposed levee setback retains flood overflow and allows it to accumulate or infiltrate, improving wetland conditions. Second, by removing the levee at the west side of the site, the historical side channel is daylighted from the existing culverts, and connectivity with the Dungeness River is improved. The proposed Project also entails changes to drainage routing landward of the new levee alignment.

The proposed alignment of the levee will disconnect landward areas from the existing drainage ditches leading to Meadowbrook Creek. Therefore, drainage measures are necessary to prevent accumulation of water at the levee base and on the adjacent farm properties. Appendix B contains design drawings of the proposed drainage plan and details of individual drainage measures. We propose to route some of this flow to the east to Meadowbrook Creek and some to the west into the floodplain restoration area. The proposed drainage divide is located near the proposed south parking lot. To direct flow to the east, an excavated ditch that runs parallel to the levee is proposed (referred to as the South Drainage Ditch). This ditch will pass under the new Eberle driveway access through a new 3-foot-diameter culvert (Figure B-3). The location of this ditch was modified to avoid cultural resources.

To direct flow to the west, we propose two options: (1) extend the South Drainage Ditch along the levee alignment to the west and grade it such that it will convey water east to west or (2) install a subsurface drain tile on the PCC property that will intercept flow before it reaches the levee and direct it west (Figure B-2). The drain tile would have an effective width of influence on drainage of roughly 60 to 100 feet (30 to 50 feet on each side of the pipe). Whichever option is selected, the westbound flow will be routed through a new 3-foot-diameter culvert under the Towne Road Levee and be connected to the existing Brown Dairy Farm ditch, which will then carry the flow to the north into the floodplain restoration area. This culvert will have a flapgate on its west end to prevent Dungeness River flooding east of Towne Road.

In addition to the new culvert at the Eberle driveway and Towne Road, the Project will require a culvert at the West Tributary Meadowbrook Creek Towne Road crossing (Figure B-4).

3.2 Culvert Design

The West Tributary Meadowbrook Creek crossing shall be designed to provide fish passage. Washington Department of Fish & Wildlife (WDFW), in their Water Crossing Design Guidelines (WCDG) (2013), uses the stream simulation method, which is based on a stream's bankfull width, to design fish-passable culverts (2013), and we employ this method below. This analysis is supplemental to a previous study for culvert size at this crossing performed by Cardno (2016).

3.2.1 Bankfull Width of Meadowbrook Creek

3.2.1.1 Mainstem

Shannon & Wilson performed a bankfull width survey of the Meadowbrook Creek Mainstem on June 7, 2018. Seven locations upstream from Sequim-Dungeness Way were measured. We performed stream bankfull width measurements along the Mainstem Meadowbrook Creek, as there are no defining banks along the West Tributary, which is a wetland lying in a relict Dungeness River distributary. The primary criterion for selection of the measurement transects was that they be representative of natural alluvial conditions, i.e., they should be outside the zone of influence of culverts, logjams, or other channel effects. Individual transects should also be separated by more than 50 feet along the length of the channel so that naturally occurring variability of the stream profile is captured. We did not have permission to access Meadowbrook Creek downstream of the Sequim-Dungeness Way culverts.

Figure 4 shows the location of the seven measured transects and Exhibit 3-1 summarizes the measurements. The mean bankfull width of Meadowbrook Creek in the surveyed reach was found to be approximately 15 feet.

Exhibit 3-1: Bankfull Width Measurements in Meadowbrook Creek Mainstem

Transect Number[1]	Measured Bankfull Width (feet)
1	12
2	11
3	15
4	15
5	17
6	20
7	17
Mean	15

NOTE:
1 See Figure 4 for transect locations.

3.2.1.2 West Tributary

It was not possible to directly measure the bankfull width of the West Tributary as we did with the Mainstem. The dense vegetation and lack of relief in the drainage basin precludes a measurable channel. The West Tributary Meadowbrook Creek is a post-glacial outwash distributary relic of the Dungeness River. The size and width of the wetland impoundment are a function of glacial outwash conditions, not modern era hydrology. We therefore used our measurements of the Mainstem as a reference for approximating the bankfull width of the West Tributary. We employed two different approaches for this approximation: (1) downscaling of the Mainstem Meadowbrook bankfull width to the West Tributary width using the USGS flood frequency area-based regression equations (2016) and (2) using the watershed area and precipitation-based calculation of bankfull width from WDFW's WCDG for the West Tributary proposed drainage basin.

Approach 1: Downscaling Measured Bankfull Width of Meadowbrook Creek using USGS Gauged to Ungauged Stream Regression Equation

We obtained a scaling factor for converting the measured bankfull width of the Mainstem to the West Tributary by using the regression relationships developed by USGS for flood frequency analysis (2016). While these regression equations are intended for scaling flood flows from gauged to ungauged catchments, they can serve as a rough approximation for our purposes, as both bankfull width and streamflow are dependent on the same set of variables – namely precipitation, watershed characteristics, and flood flow channel forming conditions. Using the basin areas from Section 2.1 and the coefficient (b) for the two-year recurrence interval (as bankfull width is commonly associated with the 1.5- or 2-year flood), our scaling factor becomes:

$$\left(\frac{A_{unmeasured\ basin}}{A_{measured\ basin}}\right)^{b} = \left(\frac{A_{West\ Tributary-Proposed}}{A_{Mainstem-Existing}}\right) = \left(\frac{0.02\ mi^2}{0.64\ mi^2}\right)^{0.899} = 0.044$$

Approach 2: Approximation by Watershed Area and Average Annual Precipitation from WDFW's WCDG

The WCDG provides the following equation for approximating bankfull width in an unmeasurable channel:

Equation	Variable and Definition	
$W_{ch} = 0.95 * WA^{0.45} * AAP^{0.61}$	W_{ch}	Bankfull width
	WA	Watershed area
	AAP	Average annual precipitation

Reference: WDFW Water Crossing Design Guidelines, Appendix C (2013).

The watershed areas were calculated in Section 2.1 and we used 30-year Climate Normals from the PRISM Climate Model (2018) to approximate the average annual precipitation at 16.39 inches. The WCDG also states that there is a standard error of 16% associated with this regression equation, which we account for in our calculation by applying a factor of 1.16.

Summary

Exhibit 3-2 shows the approximated bankfull width for the Mainstem and the West Tributary using both approaches.

Exhibit 3-2: Summary of Measured and Approximated Bankfull Widths

	Bankfull Width (feet)		
Watershed	Measured	Approximation from Approach 1 – USGS Scale Factor	Approximation from Approach 2 – WDFW Equation
Mainstem – Existing	15	N/A	5
West Tributary – Proposed	N/A	0.7	1

The WDFW regression underestimates bankfull width at the Project site. This is unsurprising though, as the WDFW regression was developed using high-gradient (>2%), coarse-bedded streams, where alluvial processes dominate. The streams at the Project site, on the other hand, flow through a relic post-glacial outwash valley that is <2% slope and characterized by wetland conditions.

Since the watershed, streambed, and precipitation characteristics are the same in the Mainstem as they are in the West Tributary, it is fair to assume that the WDFW regression underestimates the bankfull width of the West Tributary by the same factor as it does the Mainstem (i.e., 5 feet approximated vs. 15 feet measured). In other words, a conservative and justifiable approximation for the bankfull width of the West Tributary would be to multiply the WDFW regression approximation by 3. This approach yields a bankfull width of the West Tributary of 3 feet.

3.2.2 Culvert Dimensioning

These bankfull width estimates could then be applied to the WCDG stream simulation method in order to obtain dimensions for fish-passable culverts at the two water crossings involved in the Project. Stream simulation guidelines suggest using the following equation to go from bankfull width to culvert bed width:

$$W_{culvert\ bed} = 1.2 * W_{ch} + 2\ .$$

The results of stream simulation transformation and the final recommended culvert diameters are presented in Exhibit 3-3.

Exhibit 3-3: Culvert Width Recommendations

Crossing	Bankfull Width (feet)	Minimum Culvert Bed Width (feet)	Recommended Design Width (feet)
Existing Anderson Road	15	20	20
New Towne Road	3	5.6	6

4 HYDRAULIC MODELING

A Hydrologic Engineering Centers River Analysis System (HEC-RAS) 2D hydraulic model was developed for Meadowbrook Creek to estimate the impact of the proposed Project on inundation extents and depths. This model brought together the hydrologic analyses described in Section 2 and the hydraulic design considerations described in Section 3 to simulate the conditions at the Project site.

4.1 Model Geometry

The model utilizes a digital elevation model (DEM) and user-defined geometry of hydraulic structures along the flowpath to determine how water flows through the model. The DEMs (both existing and proposed grade) used for this Meadowbrook Creek model are the same as were used in the original HEC-RAS 2D model developed for the Dungeness River by WEST Consultants (2018). There were five stream crossings in the existing condition and six in the proposed condition that were defined in the model according to measurements taken during field survey or, in the case of the two new culverts at Anderson Road and Towne Road, in accordance with the dimensions put forth in Section 3.2.

4.2 Boundary Conditions

We elected to run the model for a 100-year river flood coincident to a 10-year tidal storm surge. The river flood forces the model from the upstream end and the tide levels constrain the downstream.

4.2.1 Upstream – Flow Hydrographs

The hydrographs used as inflow for the HEC-RAS model consist of a surface runoff component (derived from the WWHM analysis from Section 2.2) and a groundwater/ seepage component (adapted from the seepage analysis from Section 2.3).

For the surface runoff component, we extracted an extreme storm event from the historic hydrograph record produced by WWHM. The peak flow for the selected storm event was 36 cfs for existing and 28 cfs for proposed (equivalent to a 50-year storm), which meant that we needed to apply a scaling factor to the flood event to create a 100-year storm. These 100-year storm hydrographs are plotted in Exhibit 4-1.

Our model configuration divided this 100-year storm hydrograph into two separate inflow nodes, one for each fork of Meadowbrook Creek. We divided the hydrograph simply according to the area fraction of the drainage basin, i.e., in the existing condition, 77% of the flow in each timestep was sent through the Mainstem and 23% through the West Tributary, and in the proposed condition, 97% to the Mainstem and 3% to the West Tributary.

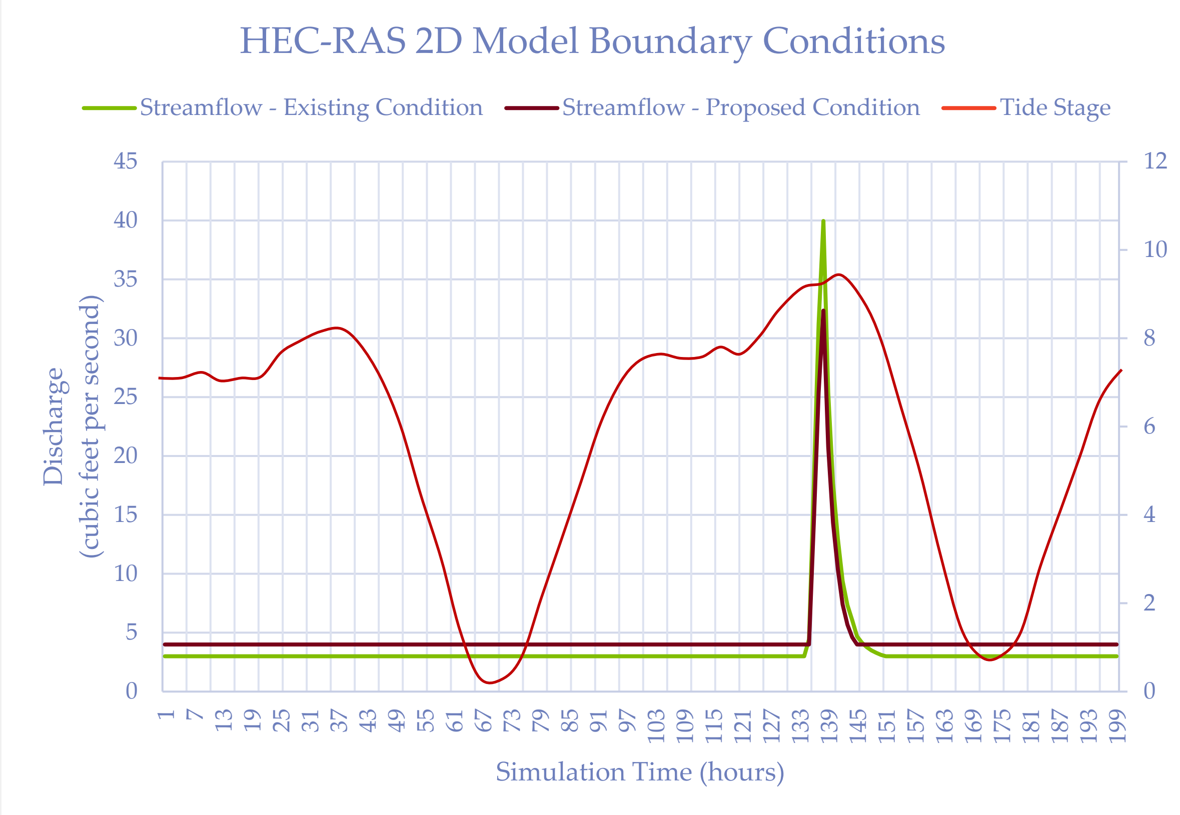
To account for groundwater/seepage in the model, a baseflow was incorporated into the flow hydrographs. We selected a value that produced depths in the channels similar to those observed during field visits for existing conditions. The baseflow for the proposed condition model run was increased by 0.5 cfs over the existing to reflect the findings of the seepage analysis discussed in Section 2.3.

4.2.2 Downstream – Tide Stage Hydrograph

The downstream boundary condition for our model is the fluctuating tide in the Strait of Juan de Fuca. The nearest tide gauge to the Project site is National Oceanic and Atmospheric Administration (NOAA) Station 9444090 at Port Angeles; we used data from the historical record at this gauge as model input. We identified one of the highest storm surges during the last 30 years and extracted hourly water surface elevation data for a two-day period surrounding that event. The peak water level reached during this storm surge was 9.5 feet, occurring on December 10, 2015, which is equivalent to a roughly 10% annual exceedance probability event, as estimated by NOAA (2018). The maximum tide water level peak was aligned with the peak streamflow so that our model simulated their combined effects.

The upstream and downstream boundary conditions are plotted together in Exhibit 4-1. The same tide stage hydrograph was used for both the existing and proposed model runs.

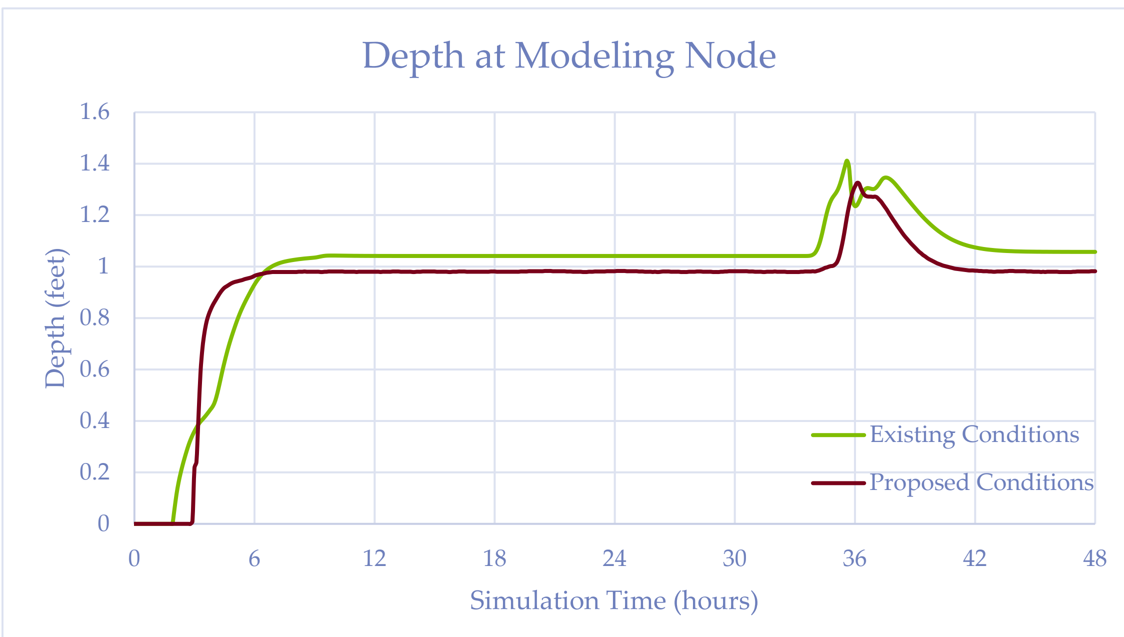
Exhibit 4-1: Tide Stage and Streamflow Hydrographs as HEC-RAS Boundary Conditions



4.3 Model Results

The model suggests that the differences between pre- and post-Project flood behavior are not significant. Figure 5 compares the maximum inundation depths and extents for a 100-year flow with tidal storm surge in the existing and proposed conditions. Given the modest flow rates generated in such a small catchment, flood extents are almost entirely contained within the Meadowbrook Creek near channel areas in both cases. In some locations, flood stages are lower in the post-Project conditions. For example, just upstream of the Sequim-Dungeness Way crossing, average flood depths are reduced by roughly 10% (see Exhibit 4-2). This result indicates that the Project would not adversely affect drainage and flood conditions for properties along Meadowbrook Creek and Sequim-Dungeness Way.

Exhibit 4-2: Depth at Modeling Node Upstream of Sequim-Dungeness Way During Q100 – Existing vs. Proposed



5 CONCLUSIONS

This interior drainage report explored potential changes to the hydrology and hydraulics of the Project area and Meadowbrook Creek that would result from the proposed levee setback and floodplain restoration activities. The findings of this analysis can be summarized as follows:

- The Project reduces the drainage area to Meadowbrook Creek upstream of Sequim-Dungeness Way by approximately 0.13 square miles.
- The reduction in drainage area reduces flood flows in Meadowbrook Creek by roughly 20%; specifically, the 100-year flow is decreased from 40 cfs to 32 cfs.
- By realigning the levee nearer to Meadowbrook Creek, the amount of seepage into Meadowbrook Creek increases during flood conditions. This should have benefits for stream habitat health by supporting baseflow. Also, groundwater levels adjacent to the levee are near the ground surface for the proposed condition and may contribute to wetland hydrology landward of the levee.
- The existing crossing of Meadowbrook Creek at Anderson Road consists of two 4-foot culverts and one 3-foot culvert. A stream survey performed upstream along Meadowbrook Creek on June 7, 2018, found an average bankfull width of 15 feet near this crossing, which suggests that future crossing replacements should be redesigned to a culvert width of 20 feet to meet fish passage requirements.
- The proposed levee realignment includes a new crossing of Meadowbrook Creek's West Tributary at Towne Road, which shall be fish passable. A bankfull width-based, stream simulation design analysis suggests a culvert diameter of 6 feet at this crossing, supporting a previous study by Cardno that used other hydrologic methods for calculating culvert widths.
- A HEC-RAS 2D hydraulic model was developed that incorporates all of the aforementioned pre- to post-Project changes. The model shows that implementation of the Project slightly reduces Meadowbrook Creek flood extents and depths during a 100-year event, including the section of Meadowbrook Creek upstream (south) of Sequim-Dungeness Way, where flood concerns have been expressed by local landowners.
- Certain landward areas along the WSDOT wetland mitigation site will need scraping of topsoil of about 1.5 feet to improve uncertainty in wetland hydroperiod function. These areas are shown in Figure B-1.

6 LIMITATIONS

The judgments, conclusions, and interpretations presented in this report should not be construed as a warranty of existing site conditions or future estimated conditions. It is in no way guaranteed that any regulatory agency will reach the same conclusions as Shannon & Wilson.

Our assessment, conclusions, recommendations, etc., are based on the limitations of our approved scope, schedule, budget, and the data provided to us by others. If a service is not specifically indicated in this report, do not assume that it was performed.

Stream and wetland systems function as a collection of integrated system components. It is not practical or possible to completely know all of the geomorphic, hydrologic, and hydraulic properties of a stream and wetland system. Consequently, uncertainty exists as to actual stream and wetland behavior, performance, and function. Regular inspections of the stream and storm drainage systems should be performed. Risks should be managed as appropriate based on observed conditions, uncertainty, and potential consequences. If conditions different from those described herein are encountered during later phases of work on this Project, we should review our description of the stream and wetland conditions and reconsider our conclusions and recommendations. Potential variation includes, but is not limited to the following:

- The site conditions and areas beyond the study may be different,
- The passage of time or intervening causes (natural and manmade) may result in changes to site and stream conditions,
- Changes in land uses in the watershed beyond the site area, and
- Changes in drainage structure maintenance conditions.

Shannon & Wilson has prepared the enclosed, "Important Information About Your Geotechnical/Environmental Report," to assist you and others in understanding the use and limitations of our report. Please read this document to learn how you can lower your risks for this Project.

7 REFERENCES

Barnard, R. J.; Johnson, J.; Brooks, P.; and others, 2013, Water crossings design guidelines: Olympia, Wash., Washington Department of Fish and Wildlife, 297 p., available: https://wdfw.wa.gov/publications/01501/wdfw01501.pdf.

Cardno, 2016. Lower Dungeness River Floodplain Restoration and Levee Realignment Project, West Fork Meadowbrook Creek Proposed Crossing Sizing, Clallam County, December.

Geo-Slope International, 2015, SEEP/W v 8.15: Calgary, Alberta, Geo-Slope International, August.

National Oceanic and Atmospheric Association, Tides & Currents Data. Retrieved 20 Jun 2018 from: https://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=9444090.

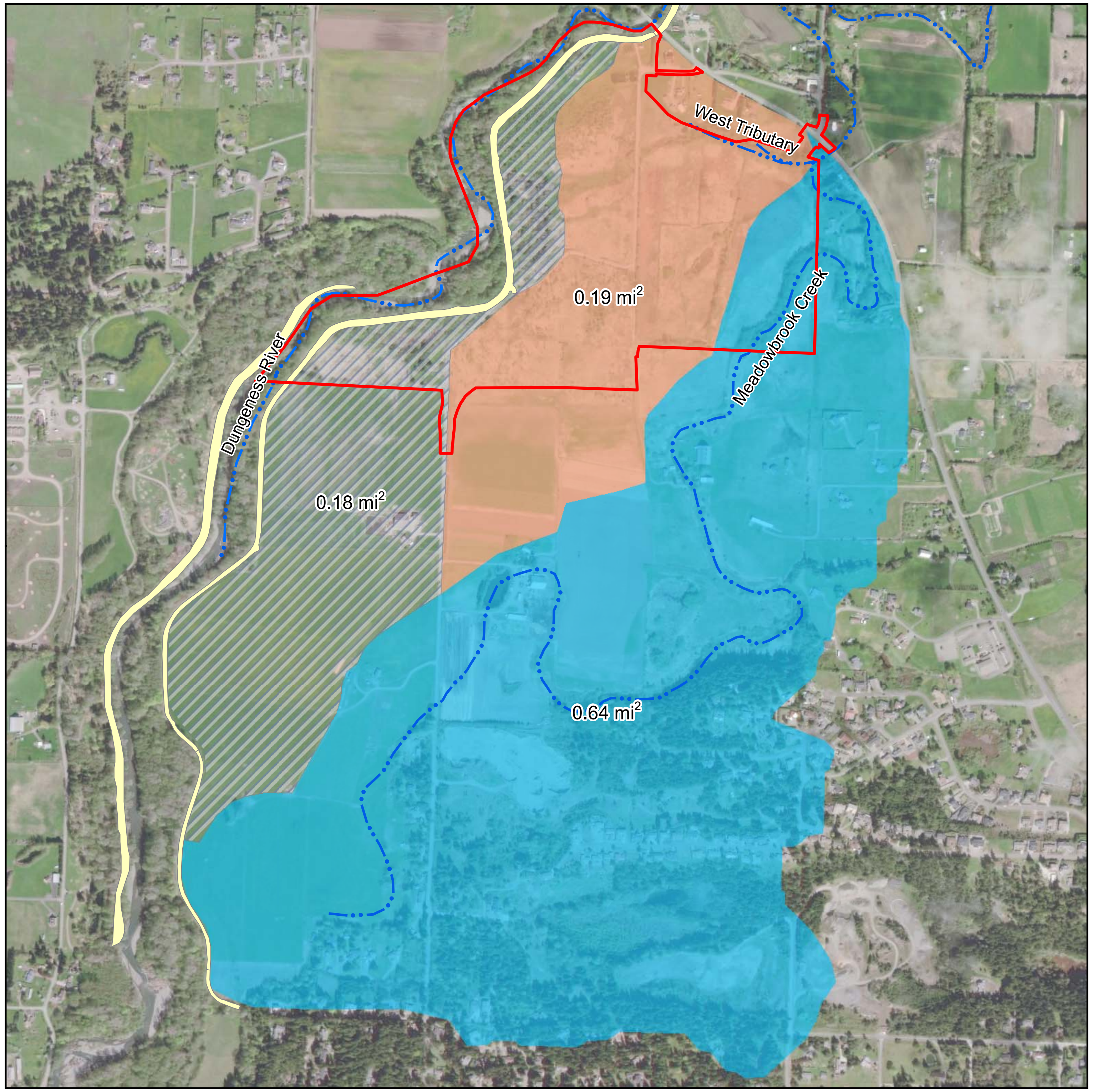
PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 11 Jun 2018.

Shannon & Wilson, Inc., 2017, Geotechnical and Hydrogeologic Data Report, Lower Dungeness River Floodplain Restoration and Levee Realignment Project, Clallam County, WA.

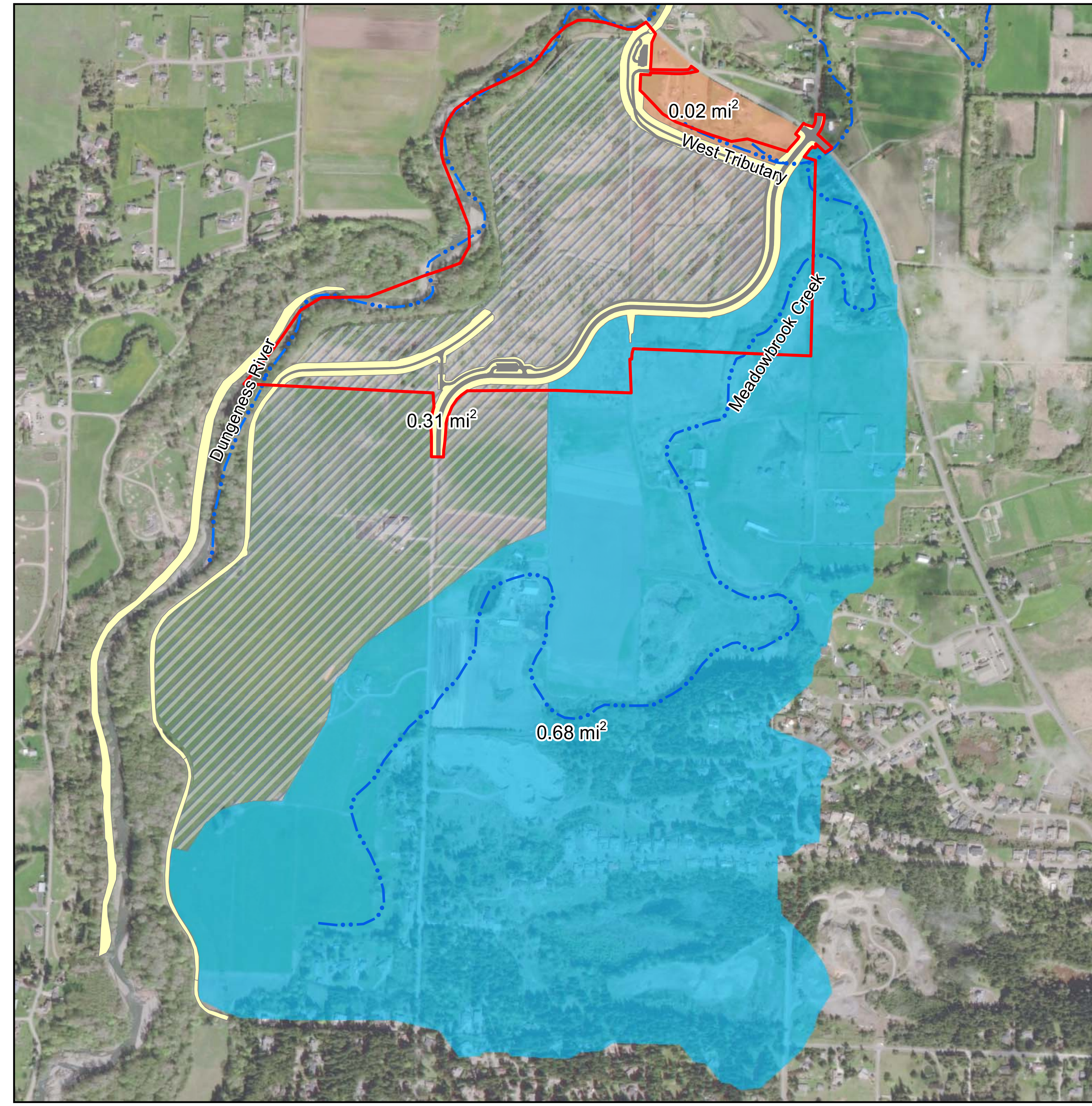
United States Geological Survey, 2016, Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, through Water Year 2014.

WEST Consultants, Inc., 2018, Lower Dungeness River Levee Setback - 65% Hydraulic Analysis.

EXISTING



PROPOSED



Legend

- Project Boundary
- Channel Centerline
- Levee Footprint
- Paved Surface

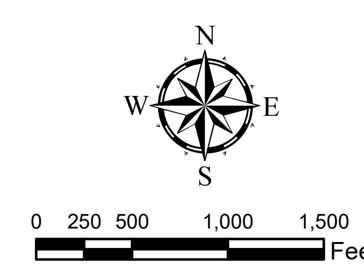
Drainage Basins Areas

- Dungeness River

Meadowbrook Creek

- Mainstem
- West Tributary

SOURCE: Basin areas approximated from TOPAZ basin delineation tool applied to a 2016 LiDAR survey from PSLC and the USGS 10-meter National Elevation Dataset.



Lower Dungeness River Floodplain Restoration and Levee Realignment
Clallam County, Washington

DRAINAGE BASIN AREAS - EXISTING AND PROPOSED

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SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 1

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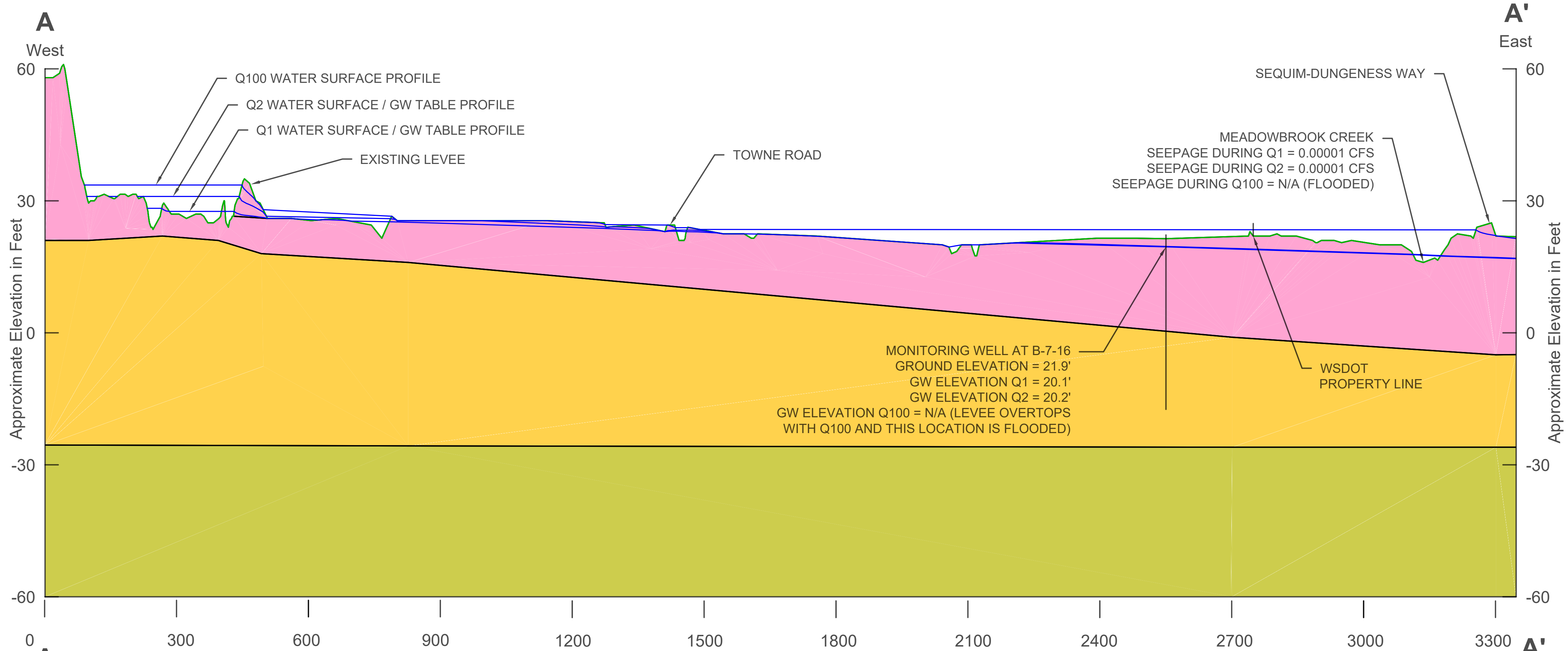
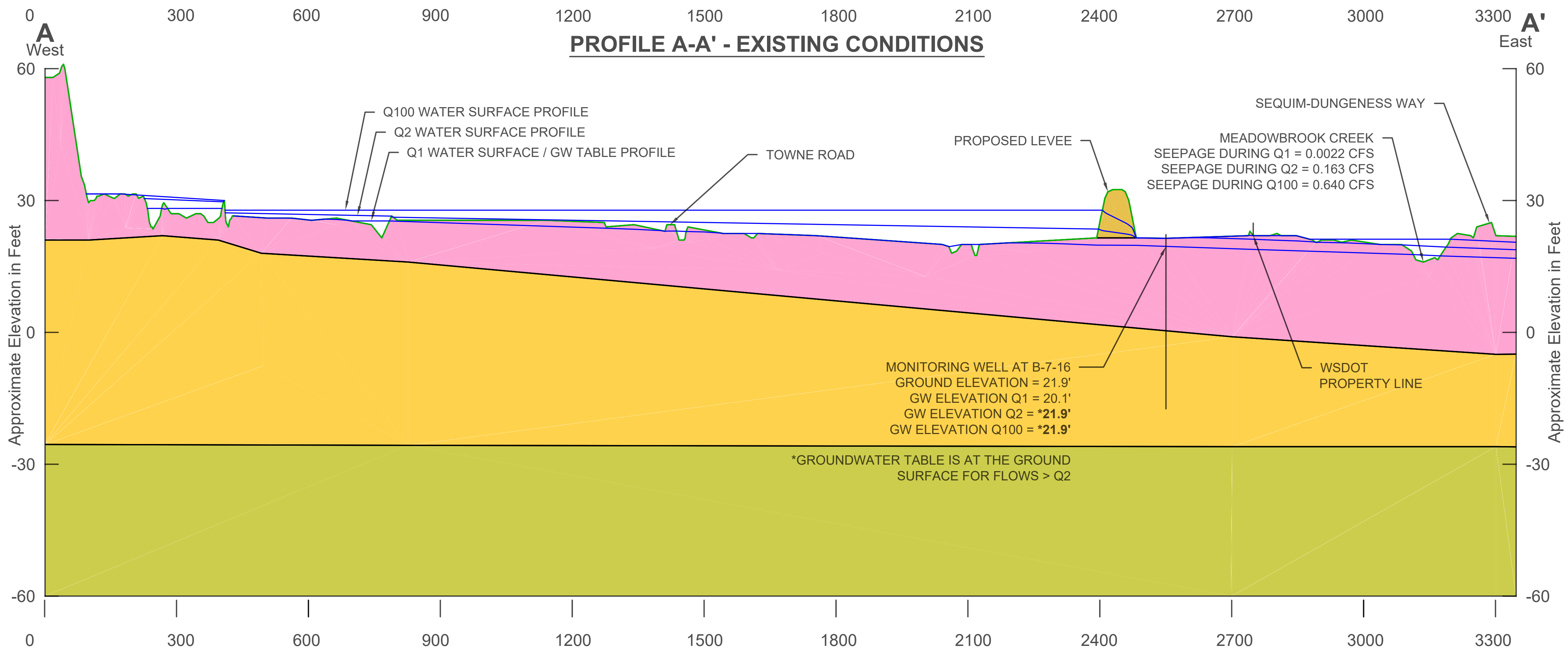
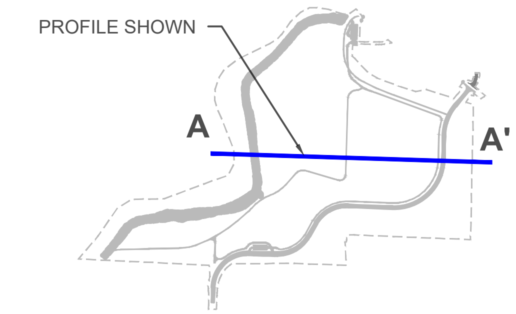


PROFILE A-A' - EXISTING CONDITIONS



PROFILE A-A' - PROPOSED CONDITIONS



GEOLOGIC UNITS

- Alluvium (Ha)
- Drain (Gravel)
- Ha(o) - Drained
- Levee Fill (Granular)
- Qvgm - Drained

NOTES

1. This subsurface profile is generalized from materials observed in soil borings. Variations may exist between profile and actual conditions.

0 30 60
Vertical Scale in Feet

0 300 600
Horizontal Scale in Feet

Vertical Exaggeration = 10x

LOWER DUNGENESS RIVER
LEVEE/ROAD REALIGNMENT AND
FLOODPLAIN HABITAT RESTORATION

CHANGES TO GROUND AND SURFACE WATER PROFILES

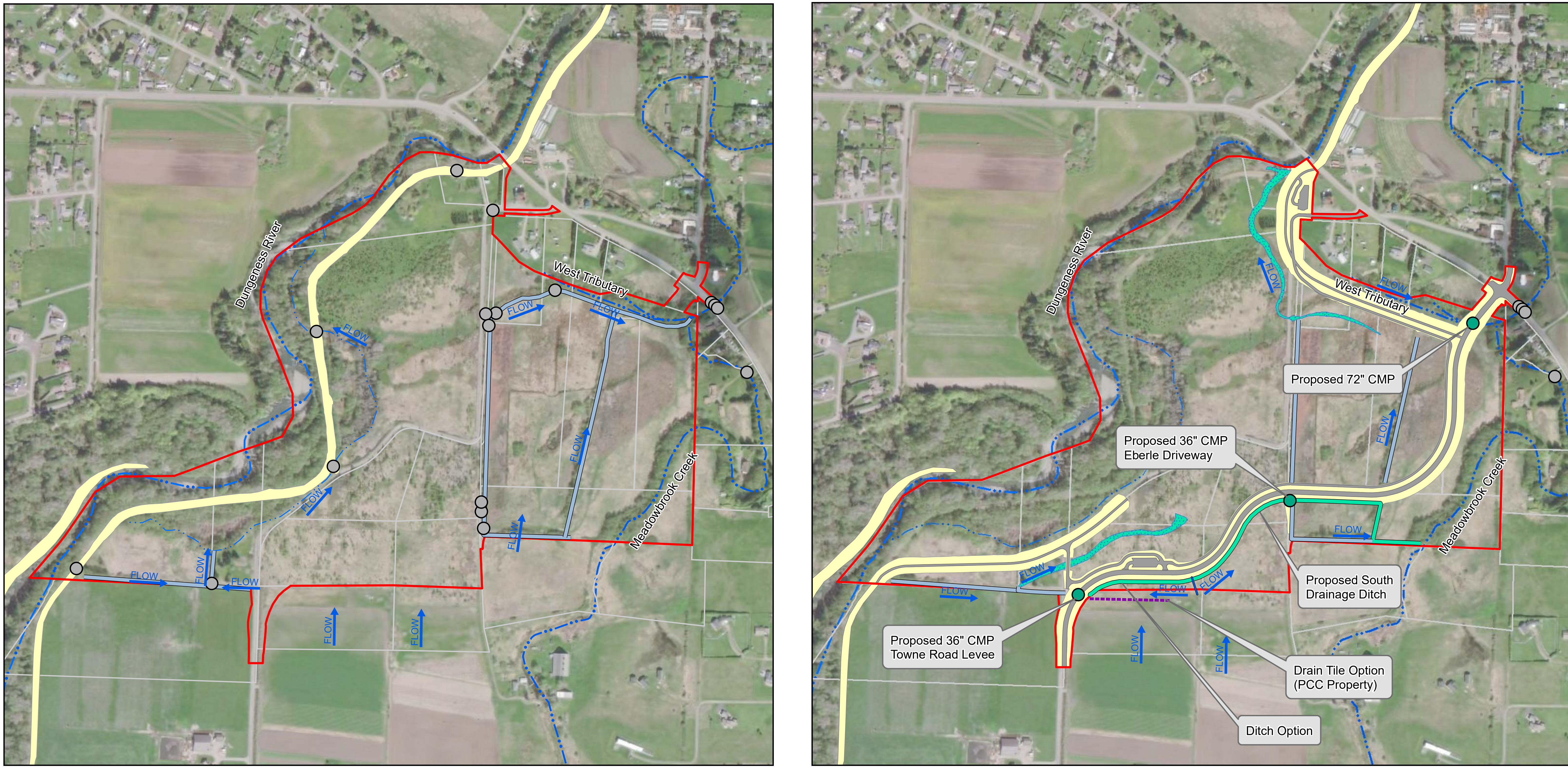
October 2018 21-1-12559-064

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 2

EXISTING

PROPOSED



Legend

- Project Boundary
- Parcel Line
- Levee Footprint
- Paved Surface
- Stream Centerline
- Proposed Channel Excavation
- Existing Drainage Ditch
- Proposed Drainage Ditch
- Proposed Drain Tile
- Existing Culvert
- Proposed Culvert

N W E S

0 300 600 900 Feet

Lower Dungeness River Floodplain Restoration and Levee Realignment
Clallam County, Washington

INTERIOR DRAINAGE ROUTING - EXISTING AND PROPOSED

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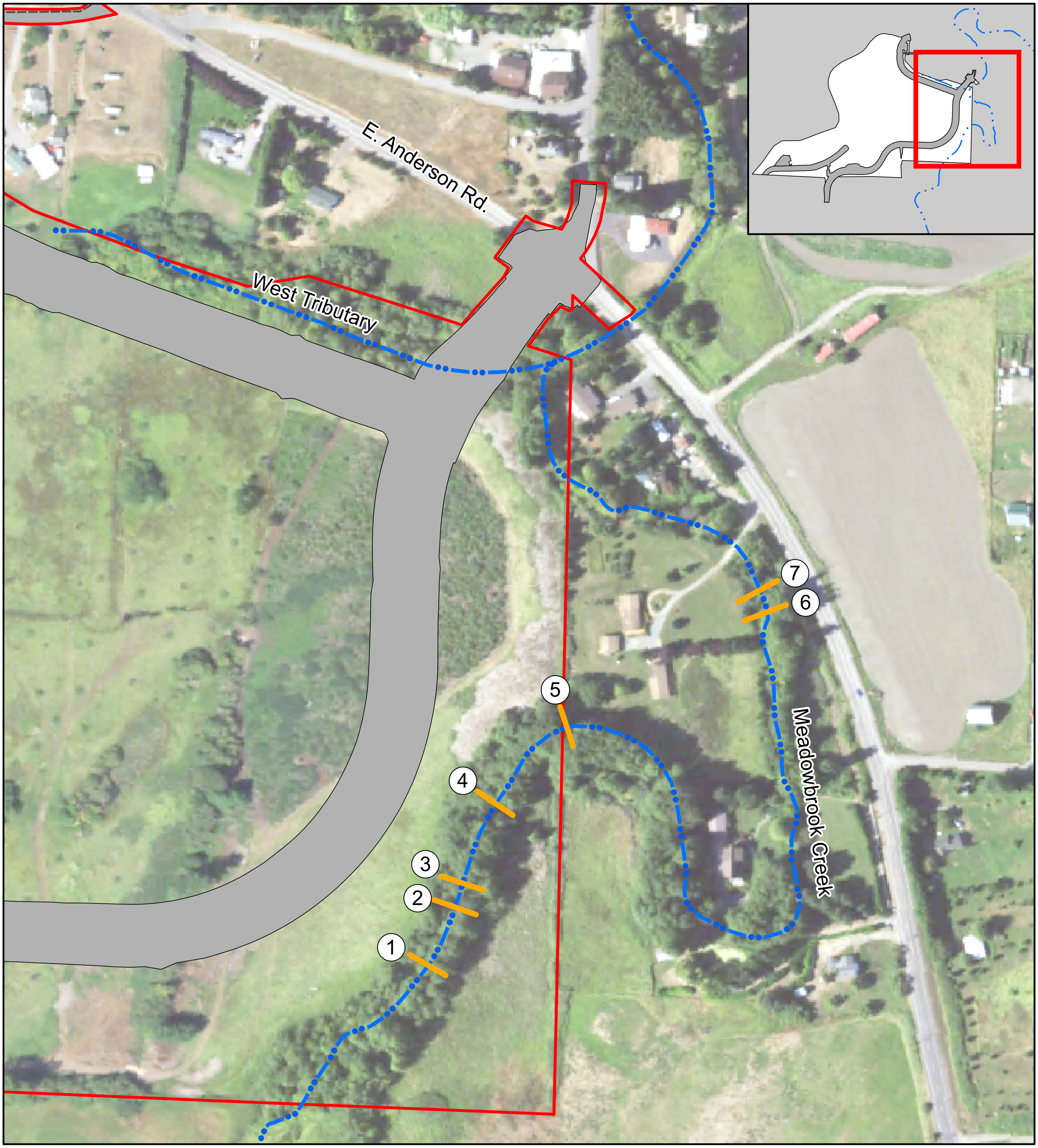
FIG. 3

Filename: I:\EF\21-1 SEA\12500s\12559 DUNGENESS\GIS\INTERIOR_DRAINAGE_EX-PRO_11x17.mxd Date: 10/25/2018 JBA



Legend

Project Boundary

Proposed Levee/Road Footprint

Meadowbrook Creek Centerline

Bankfull Width Measurement Transect

N
W
E
S

0 100 200 400
Feet

Lower Dungeness River Floodplain Restoration and Levee Realignment
Clallam County, Washington

MEADOWBROOK CREEK BANKFULL WIDTH MEASUREMENT LOCATIONS

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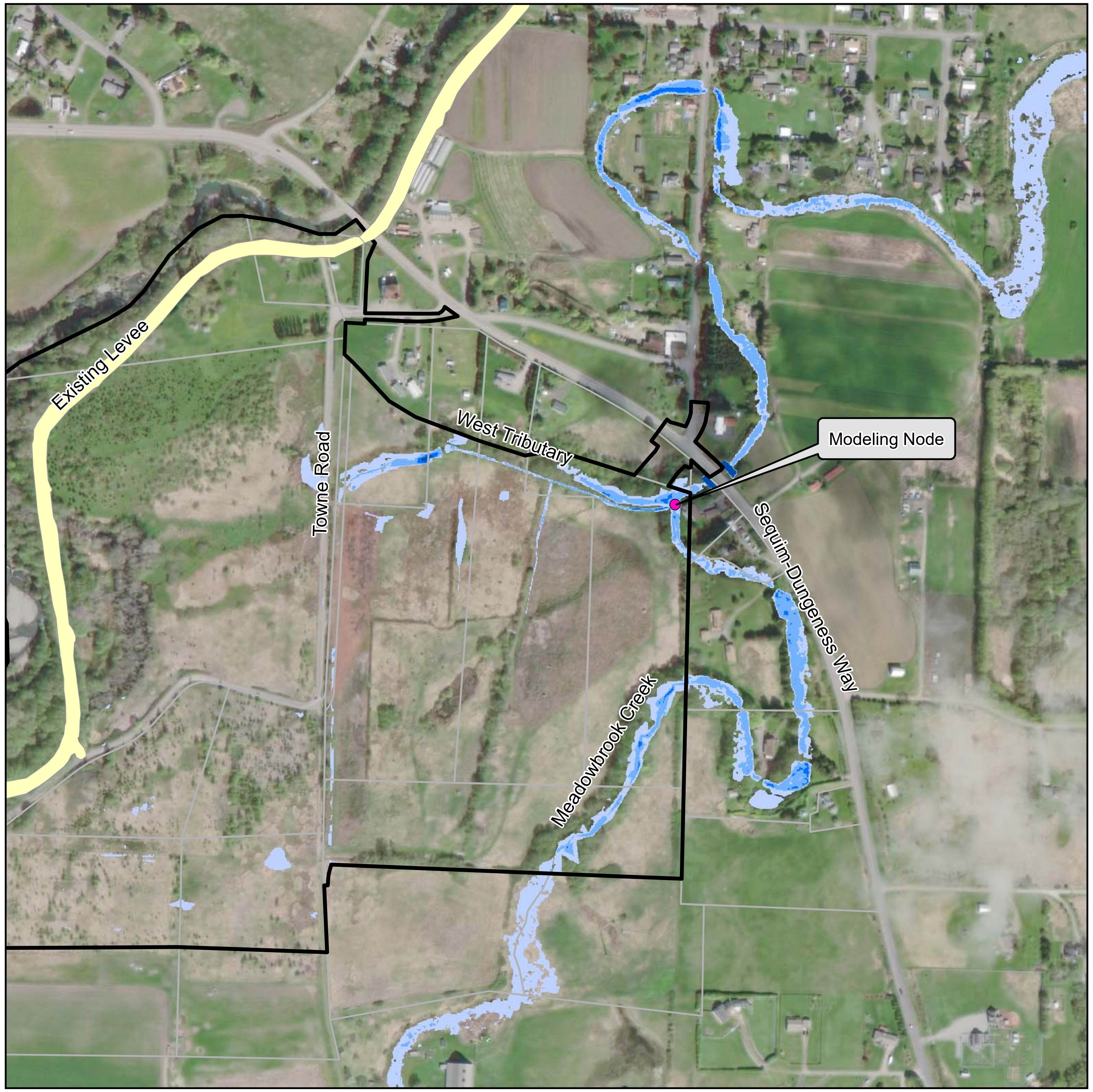
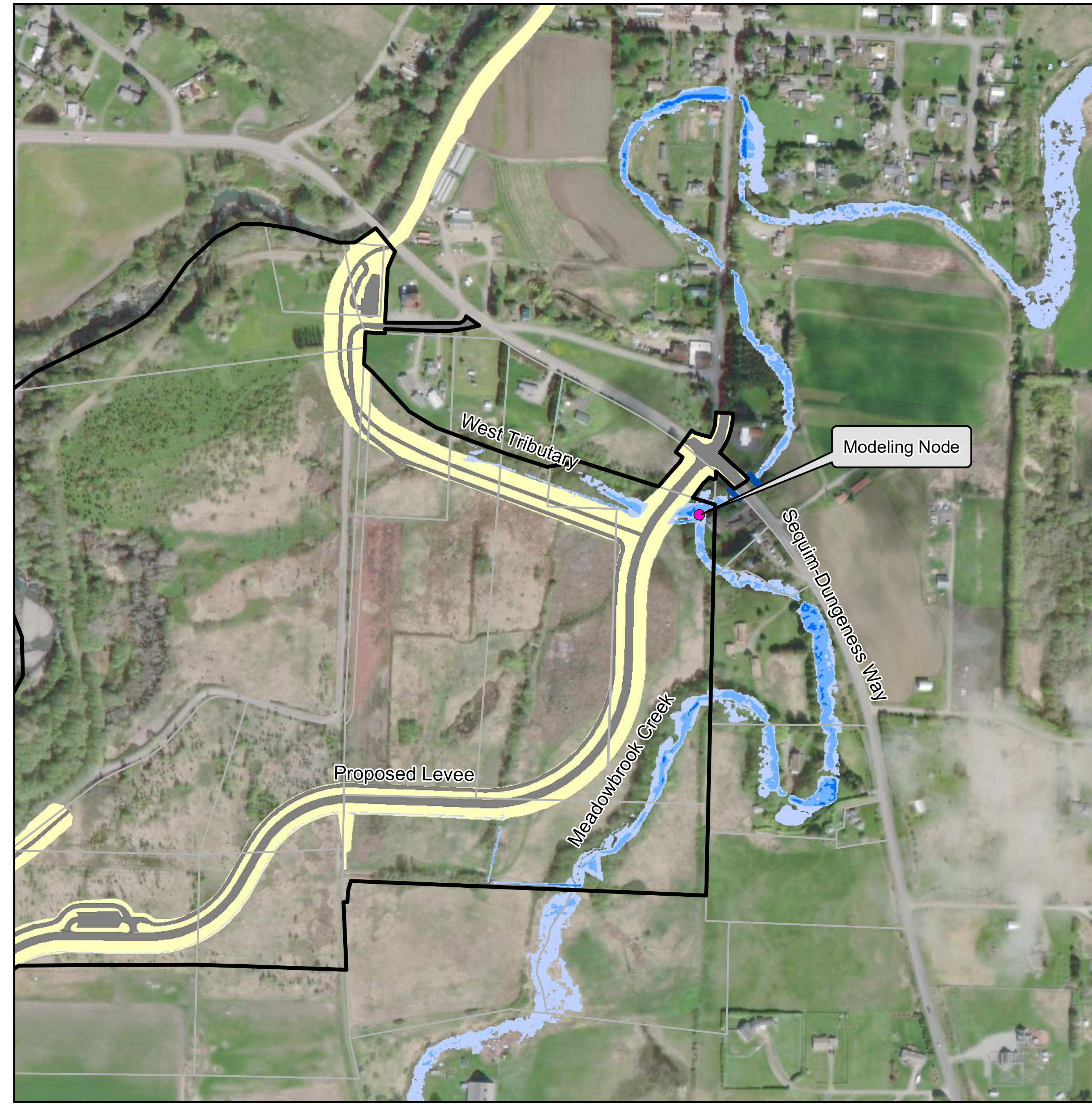
FIG. 4

Filename: I:\EF\21-1 SEA\12500s\12559 DUNGENESS\GIS\MbrookCrk_BFWsurvey\BFWSurvey_LocationMap.mxd Date: 7/2/2018 jba

EXISTING



PROPOSED



Legend

- Project Boundary
- Parcel Line
- Levee Footprint
- Paved Surface

Inundation Depth

- 0-1FT
- 1-2FT
- 2-3FT
- 3-4FT
- >4FT

N E S W

0 250 500 1,000 Feet

Lower Dungeness River Floodplain Restoration and Levee Realignment
Clallam County, Washington

MEADOWBROOK CREEK 100-YEAR FLOOD DEPTHS - EXISTING AND PROPOSED

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FIG. 5

Filename: I:\EF\21-1 SEA\12500s\12559 DUNGENESS\GIS\MBROOK_Q100_EX-PRO_11x17.mxd Date: 10/25/2018 JBA

APPENDIX A: WWHM ANALYSIS

Appendix A

Western Washington Hydrology Model (WWHM) Analysis

General Model Information

Project Name:	MbrookCrk_WWHM_06-2018
Site Name:	Meadowbrook Creek
Site Address:	
City:	Dungeness
Report Date:	9/25/2018
Gage:	Port Angelis
Data Start:	1948/10/01
Data End:	2009/09/30
Timestep:	15 Minute
Precip Scale:	0.800
Version Date:	2018/03/02
Version:	4.2.14

POC Thresholds

Low Flow Threshold for POC1:	50 Percent of the 2 Year
High Flow Threshold for POC1:	50 Year

Landuse Basin Data
Predeveloped Land Use

Mbrook Crk

Bypass:	No
GroundWater:	No
Pervious Land Use	acre
A B, Forest, Flat	4.9
A B, Forest, Steep	37.1
A B, Pasture, Flat	204.1
A B, Lawn, Steep	9.4
C, Forest, Flat	17.3
C, Pasture, Flat	204.1
Pervious Total	476.9
Impervious Land Use	acre
ROADS FLAT	22.9
ROOF TOPS FLAT	27.8
POND	3
Impervious Total	53.7
Basin Total	530.6

Element Flows To:

Surface	Interflow	Groundwater

Mitigated Land Use

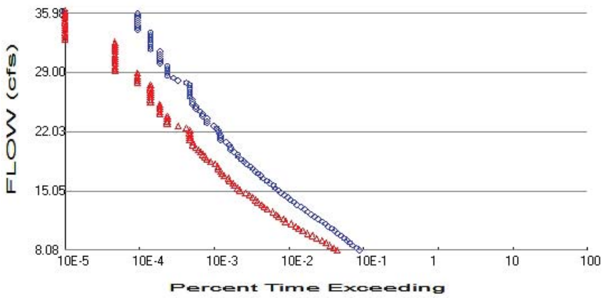
Mbrook Crk

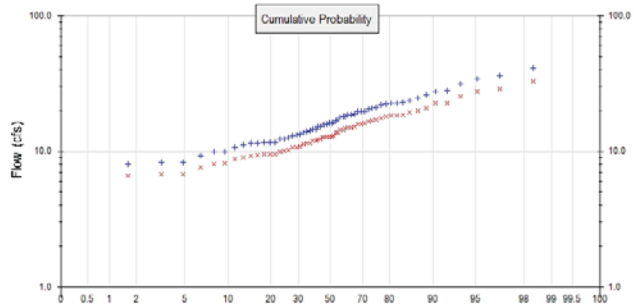
Bypass:	No
GroundWater:	No
Pervious Land Use	acre
A B, Forest, Flat	4.9
A B, Pasture, Flat	187.1
A B, Forest, Steep	37.1
A B, Lawn, Steep	9.4
C, Forest, Flat	17.3
C, Pasture, Flat	149.1
Pervious Total	404.9
Impervious Land Use	acre
ROADS FLAT	12.9
ROOF TOPS FLAT	27.8
POND	3.1
Impervious Total	43.8
Basin Total	448.7

Element Flows To:

Surface	Interflow	Groundwater

Analysis Results
POC 1





+ Predeveloped x Mitigated

Predeveloped Landuse Totals for POC #1
Total Pervious Area: 476.9
Total Impervious Area: 53.7

Mitigated Landuse Totals for POC #1
Total Pervious Area: 404.9
Total Impervious Area: 43.8

Flow Frequency Method: Log Pearson Type III 17B

Flow Frequency Return Periods for Predeveloped. POC #1

Return Period	**Flow(cfs)**
2 year	16.15634
5 year	22.284759
10 year	26.458781
25 year	31.861299
50 year	35.978452
100 year	40.175102

Flow Frequency Return Periods for Mitigated. POC #1

Return Period	**Flow(cfs)**
2 year	13.091224
5 year	18.013631
10 year	21.360224
25 year	25.685989
50 year	28.978825
100 year	32.33234

Annual Peaks

Annual Peaks for Predeveloped and Mitigated. POC #1

Year	**Predeveloped**	**Mitigated**
1949	21.012	17.053
1950	14.220	11.499
1951	27.918	22.771
1952	9.892	8.045
1953	22.739	18.547
1954	26.036	20.783
1955	20.699	16.557
1956	13.815	11.266
1957	13.381	10.874
1958	15.830	12.908

1959	19.711	16.085
1960	17.731	14.414
1961	18.778	14.959
1962	12.358	10.057
1963	15.126	12.338
1964	27.633	22.530
1965	11.198	9.046
1966	11.698	9.539
1967	18.612	14.915
1968	14.563	11.877
1969	13.148	10.718
1970	19.555	15.965
1971	40.790	32.621
1972	22.860	18.250
1973	15.673	12.666
1974	7.952	6.485
1975	20.604	16.804
1976	18.098	14.755
1977	11.675	9.523
1978	11.696	9.540
1979	24.517	19.994
1980	12.635	10.208
1981	23.719	19.298
1982	22.604	18.323
1983	16.923	13.796
1984	11.500	9.380
1985	31.527	25.354
1986	22.077	17.514
1987	33.902	27.650
1988	13.953	11.376
1989	14.565	11.880
1990	16.900	13.777
1991	19.594	15.771
1992	16.020	12.836
1993	9.252	7.546
1994	8.288	6.759
1995	8.020	6.541
1996	11.500	9.220
1997	16.129	12.822
1998	13.105	10.686
1999	18.146	14.290
2000	22.200	18.108
2001	8.264	6.729
2002	16.237	13.052
2003	10.704	8.713
2004	15.711	12.629
2005	18.598	15.167
2006	15.113	12.111
2007	36.003	28.931
2008	12.255	10.006
2009	9.990	8.147

Ranked Annual Peaks

Ranked Annual Peaks for Predeveloped and Mitigated. POC #1

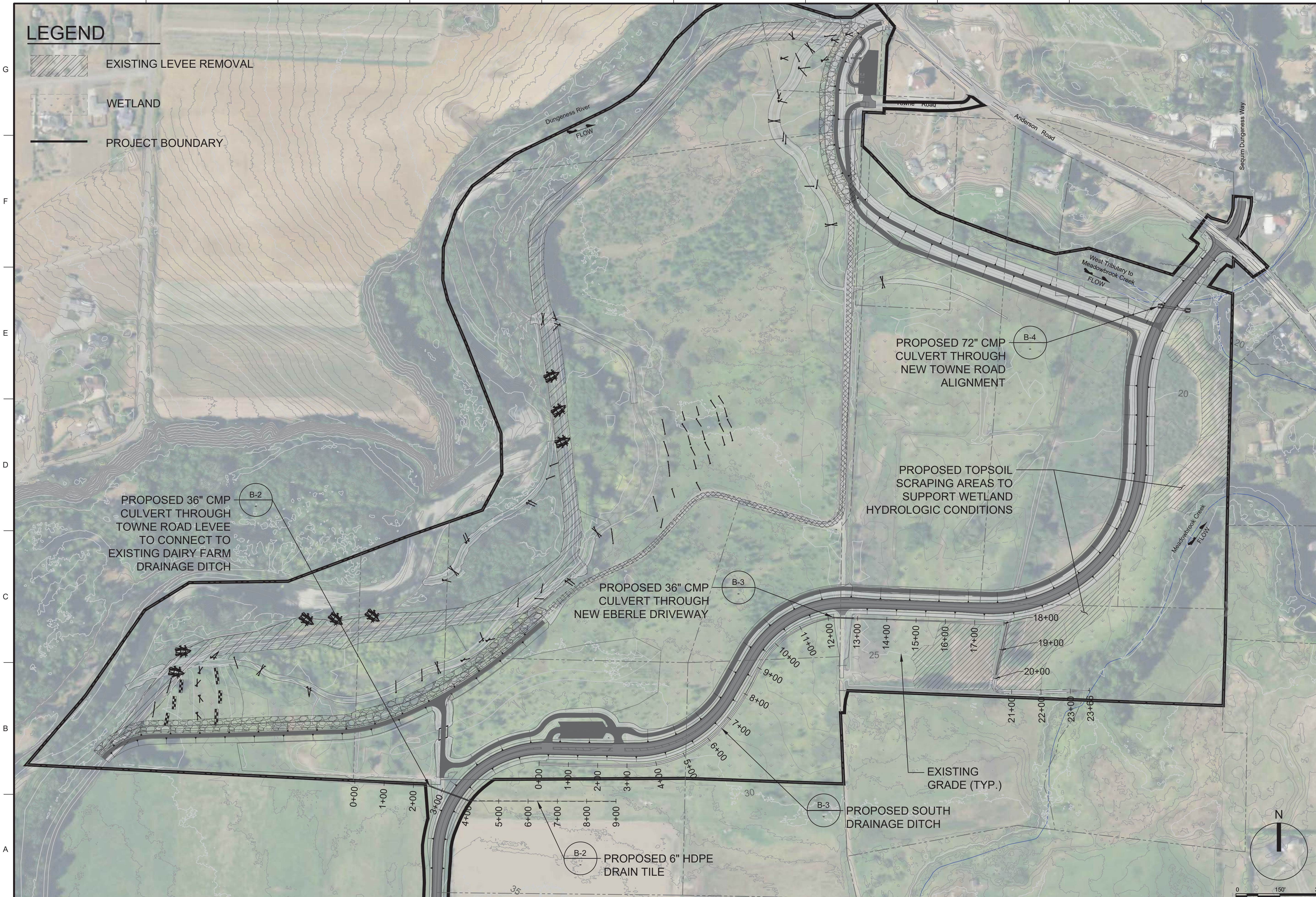
Rank	Predeveloped	Mitigated
1	40.7902	32.6214
2	36.0032	28.9307
3	33.9020	27.6502

4	31.5273	25.3541
5	27.9176	22.7707
6	27.6327	22.5298
7	26.0364	20.7826
8	24.5174	19.9944
9	23.7191	19.2975
10	22.8597	18.5468
11	22.7388	18.3231
12	22.6037	18.2501
13	22.2002	18.1080
14	22.0766	17.5138
15	21.0115	17.0525
16	20.6985	16.8043
17	20.6037	16.5570
18	19.7114	16.0854
19	19.5936	15.9650
20	19.5549	15.7711
21	18.7775	15.1670
22	18.6116	14.9594
23	18.5980	14.9152
24	18.1463	14.7545
25	18.0976	14.4141
26	17.7310	14.2902
27	16.9227	13.7962
28	16.8995	13.7774
29	16.2368	13.0516
30	16.1292	12.9079
31	16.0204	12.8361
32	15.8298	12.8217
33	15.7108	12.6663
34	15.6726	12.6286
35	15.1262	12.3375
36	15.1132	12.1110
37	14.5650	11.8800
38	14.5625	11.8771
39	14.2196	11.4986
40	13.9531	11.3761
41	13.8149	11.2655
42	13.3809	10.8740
43	13.1478	10.7175
44	13.1045	10.6862
45	12.6351	10.2078
46	12.3576	10.0568
47	12.2548	10.0055
48	11.6975	9.5398
49	11.6960	9.5390
50	11.6751	9.5227
51	11.5003	9.3796
52	11.4996	9.2195
53	11.1983	9.0456
54	10.7040	8.7130
55	9.9901	8.1473
56	9.8917	8.0451
57	9.2524	7.5462
58	8.2885	6.7592
59	8.2637	6.7287
60	8.0196	6.5411
61	7.9515	6.4855

Appendix B

Interior Drainage Features – Design Plans

CONTENTS



SEQUIM, WASHINGTON
LOWER DUNGENESS RIVER FLOODPLAIN RESTORATION
21-1-12559-064

INTERIOR DRAINAGE PLAN

CLALLAM COUNTY, WASHINGTON
223 EAST 4TH STREET, SUITE #6
PORT ANGELES, WA 98362

SHANNON & WILSON, INC.
400 NORTH 34TH STREET, SUITE 100
SEATTLE, WA 98103

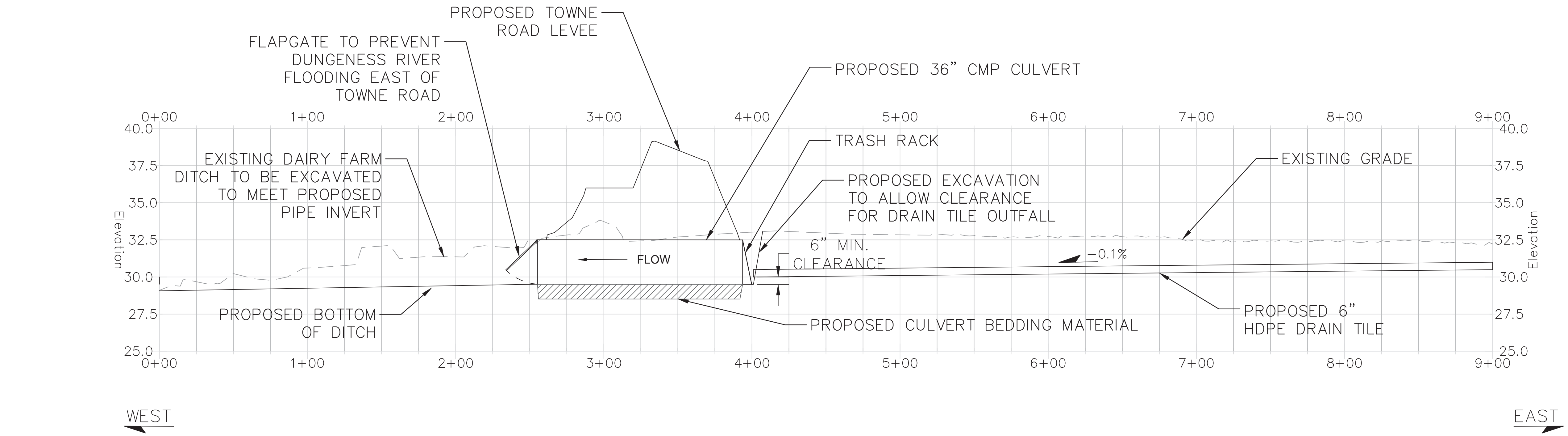
DESIGNED BY: D. CLINE
DRAWN BY: J. ACHENBACH
CHECKED BY: D. CLINE
SUBMITTED BY: D. CLINE
SIZE: ANSI D
ISSUE DATE: OCTOBER 2018
SOLICITATION NO.:
CONTRACT NO.:

REV | DATE | DESCRIPTION

DAVID R. CLINE
STATE OF WASHINGTON
39326
REGISTERED PROFESSIONAL ENGINEER
NOT FOR CONSTRUCTION

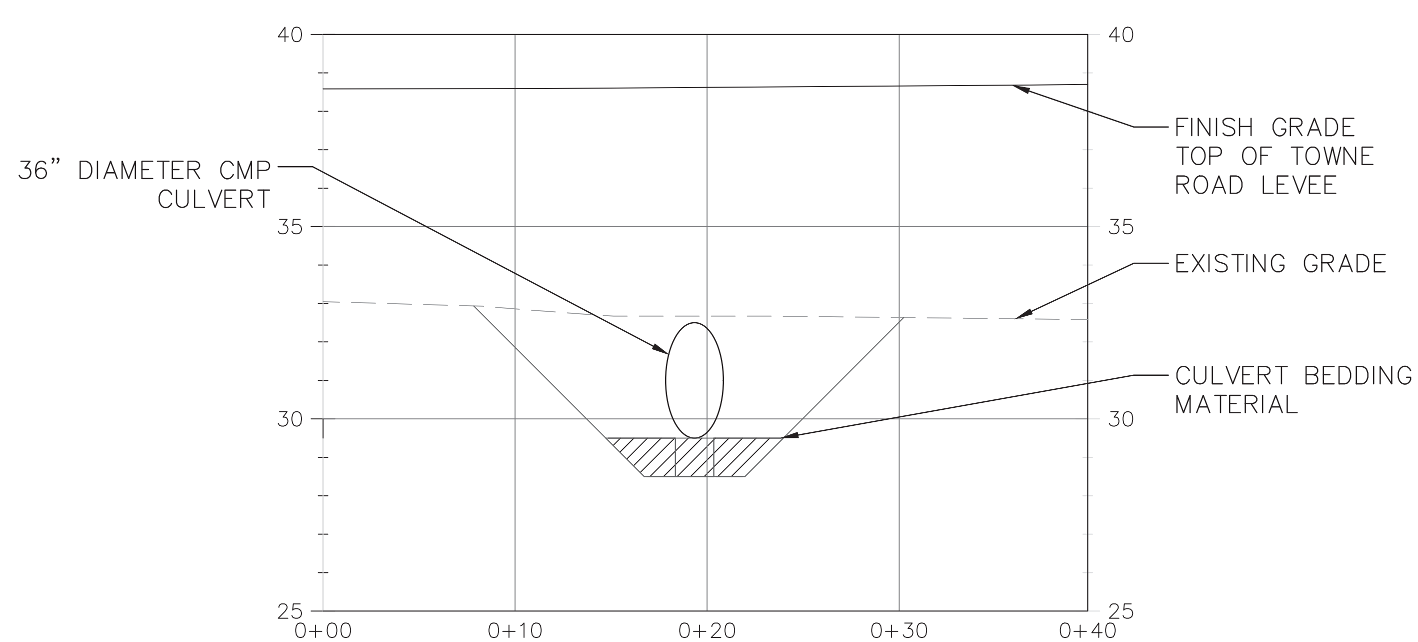
SHEET ID
B-1

Last Saved by: JBA on: Oct 30, 2018 3:25 PM File: I:\EF\21-1 SEA\12500s\12559 DUNGENESS\CAD\HnH\INTERIOR DRAINAGE\INT DRAINAGE_SITE PLAN.dwg



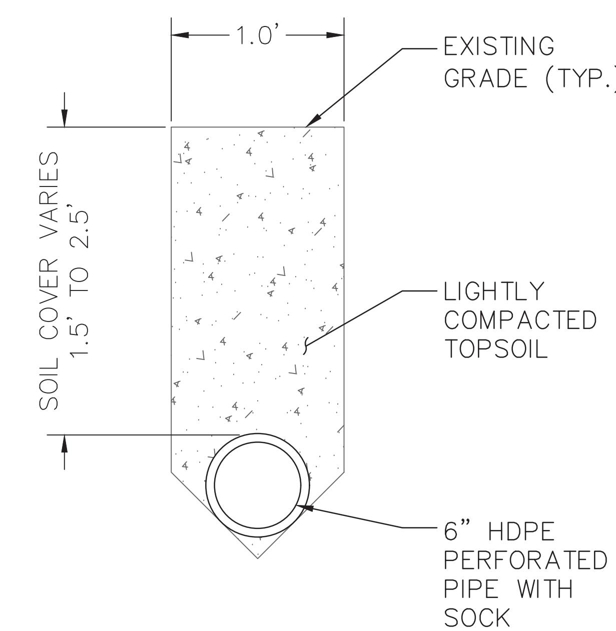
PROFILE: DRAIN TILE AND TOWNE ROAD CULVERT

SCALE: 1"=30' (10V:1H)



TYPICAL SECTION: TOWNE ROAD CULVERT

SCALE: 1"=5' (2V:1H)



TYPICAL SECTION: DRAIN TILE

SCALE: N.T.S.

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ISSUE DATE: OCTOBER 2018
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CONTRACT NO.:

DESIGNED BY: D. CLINE
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SUBMITTED BY: D. CLINE
SIZE: ANSI D

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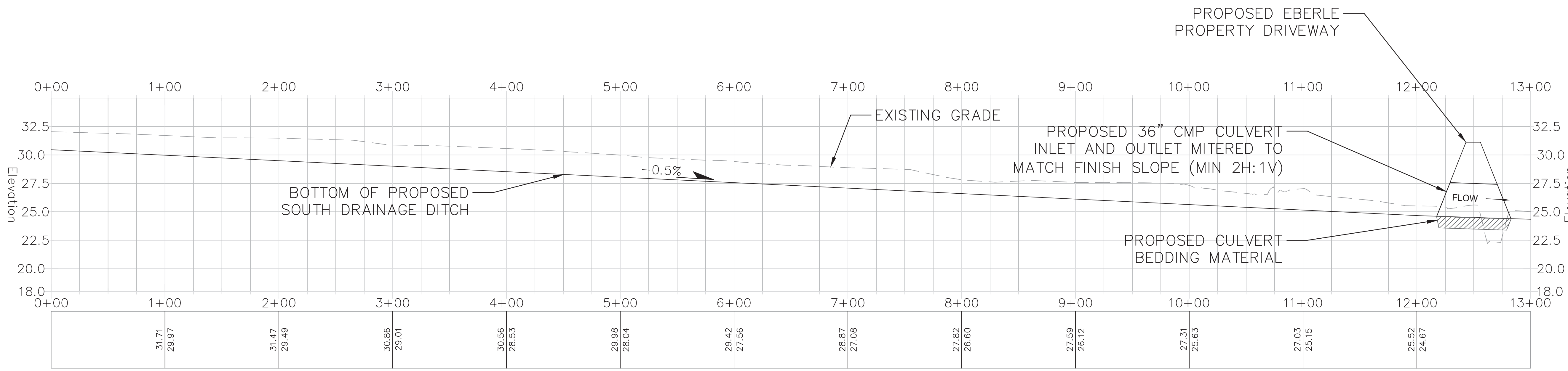
223 EAST 4TH STREET, SUITE #6
PORT ANGELES, WA 98362

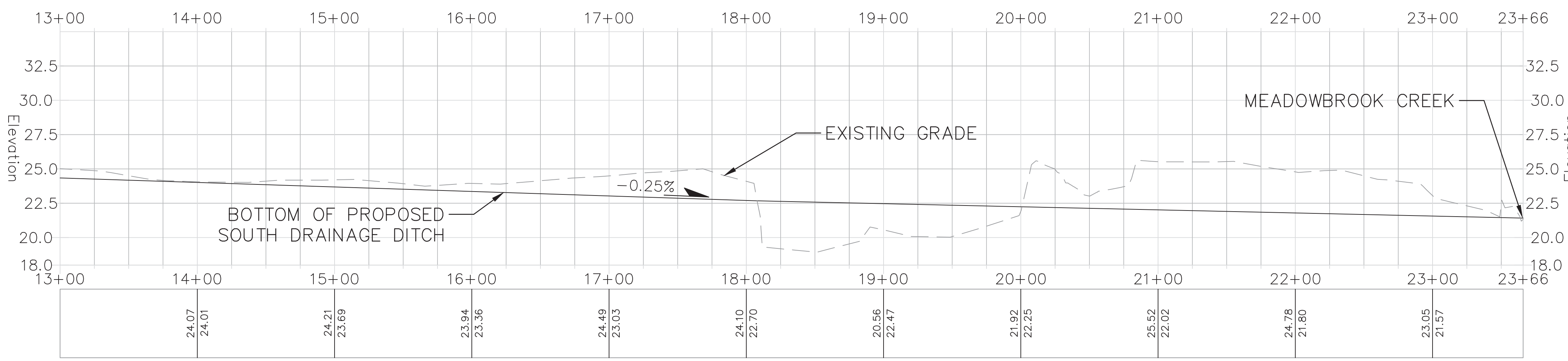
SHANNON & WILSON, INC.
400 NORTH 34TH STREET, SUITE 100
SEATTLE, WA 98103

SEQUIM, WASHINGTON
LOWER DUNGENESS RIVER FLOODPLAIN RESTORATION
21-1-12559

INTERIOR DRAINAGE DETAILS
DRAIN TILE AND TOWNE ROAD CULVERT

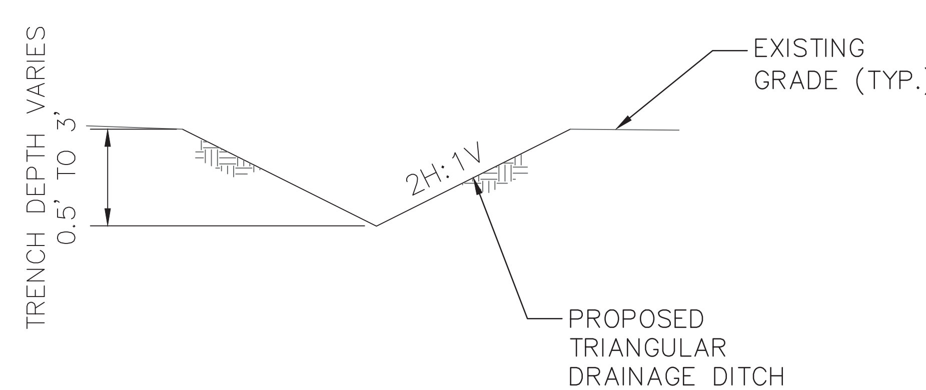
SHEET ID
B-2





PROFILE: PROPOSED SOUTH DRAINAGE DITCH

SCALE: 1"=50' (10V:1H)



TYPICAL SECTION: SOUTH DRAINAGE DITCH

SCALE: N.T.S.

REV | DATE | DESCRIPTION

DAVID R. CLINE, STATE OF WASHINGTON, REGISTERED PROFESSIONAL ENGINEER, 39326

ISSUE DATE: OCTOBER 2018
SOLICITATION NO.:
CONTRACT NO.:

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DRAWN BY: J. ACHENBACH
CHECKED BY: D. CLINE
SUBMITTED BY: D. CLINE
SIZE: ANSI D

CLALLAM COUNTY, WASHINGTON
223 EAST 4TH STREET, SUITE #6
PORT ANGELES, WA 98362

SHANNON & WILSON, INC.
400 NORTH 34TH STREET, SUITE 100
SEATTLE, WA 98103

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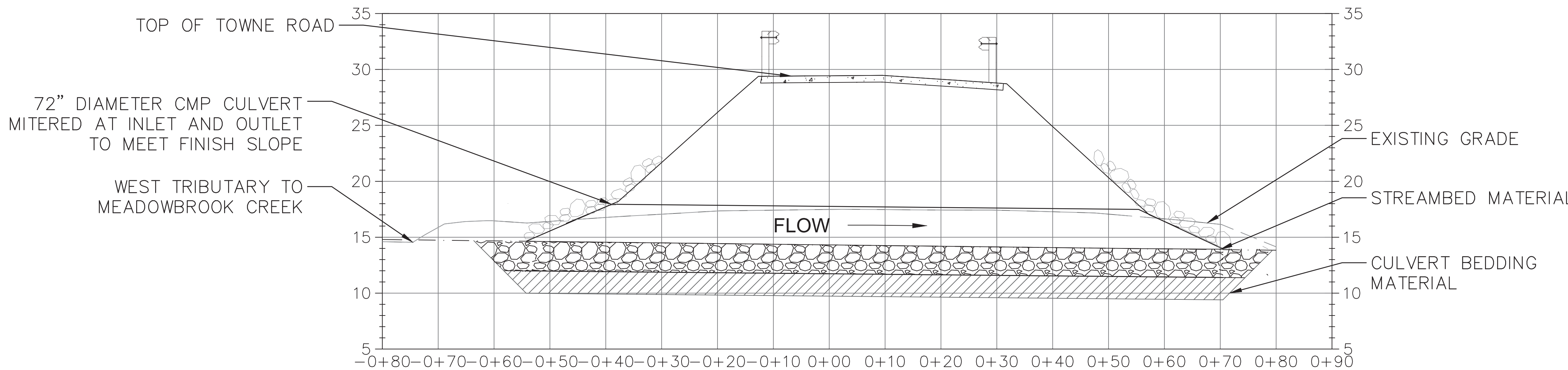
LOWER DUNGENESS RIVER FLOODPLAIN RESTORATION
21-1-12559

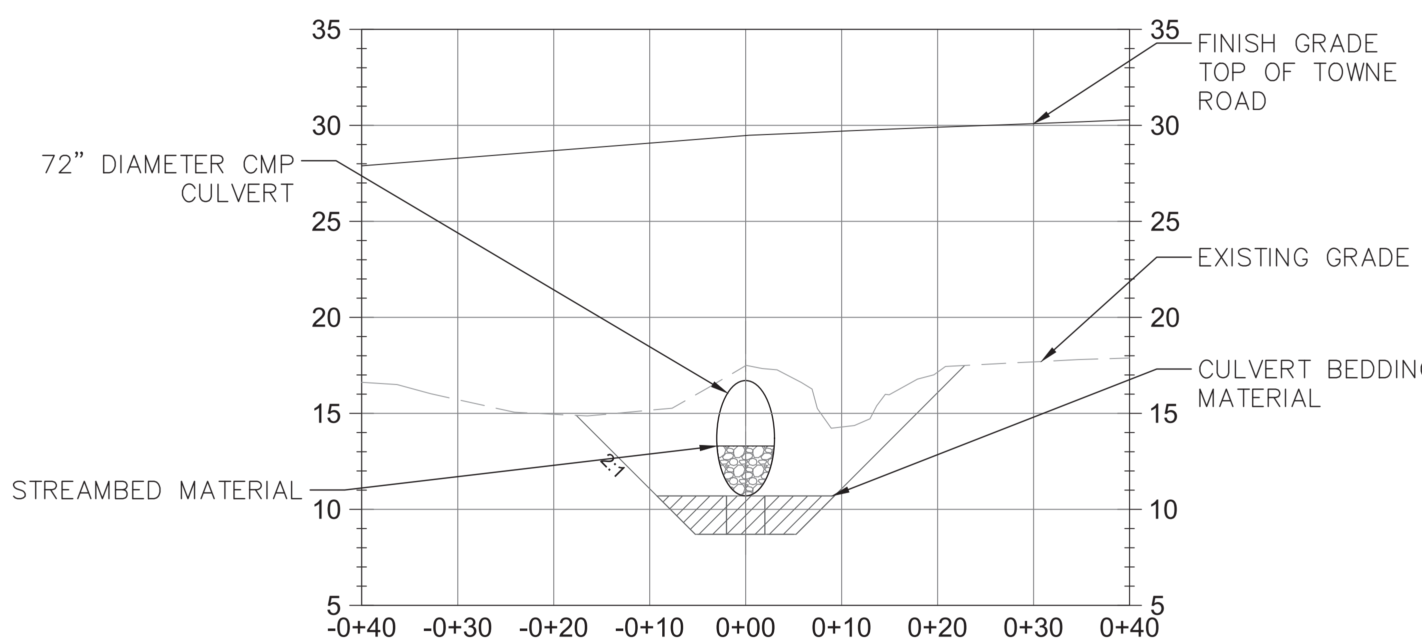
INTERIOR DRAINAGE DETAILS
SOUTH DRAINAGE DITCH

SHEET ID
B-3



PROFILE: WEST TRIBUTARY CULVERT

SCALE: 1"=5' (2V:1H)



TYPICAL SECTION: WEST TRIBUTARY CULVERT

SCALE: 1"=5' (2V:1H)

REV | DATE | DESCRIPTION

ISSUE DATE: OCTOBER 2018
SOLICITATION NO.:
CONTRACT NO.:

DESIGNED BY: D. CLINE
DRAWN BY: J. ACHENBACH
CHECKED BY: D. CLINE
SUBMITTED BY: D. CLINE
SIZE: ANSI D

CLALLAM COUNTY, WASHINGTON
223 EAST 4TH STREET, SUITE #6
PORT ANGELES, WA 98362

SHANNON & WILSON, INC.
400 NORTH 34TH STREET, SUITE 100
SEATTLE, WA 98103

SEQUIM, WASHINGTON
LOWER DUNGENESS RIVER FLOODPLAIN RESTORATION
21-1-12559

INTERIOR DRAINAGE DETAILS
WEST TRIBUTARY TO MEADOWBROOK CREEK CULVERT

SHEET ID

B-4

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IMPORTANT INFORMATION

Important Information

About Your Geotechnical/Environmental Report

IMPORTANT INFORMATION

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors that were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary, because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

IMPORTANT INFORMATION

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports, and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland