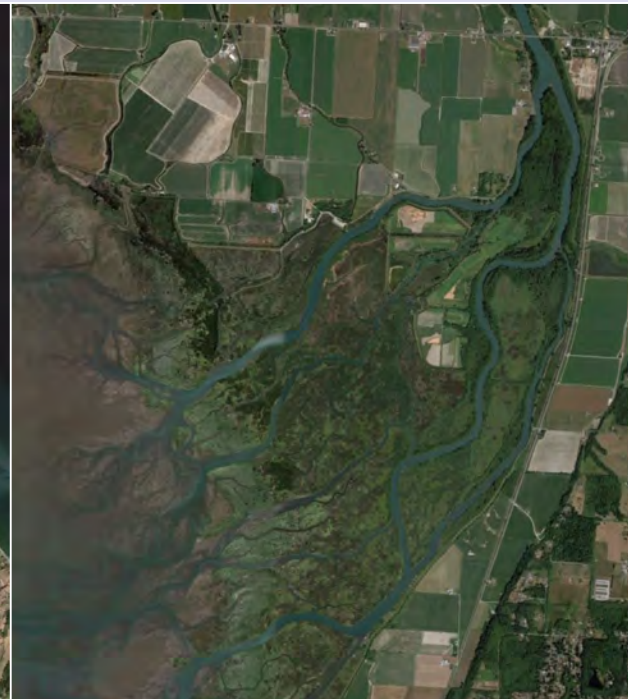
Climate Change and Sea Level Rise

Tips and Tools for Evaluating Future Conditions with Hydraulic Models

By Dave Cline, PE, CFM

Shannon & Wilson Inc.



Habitat Restoration and Shoreline Resilience

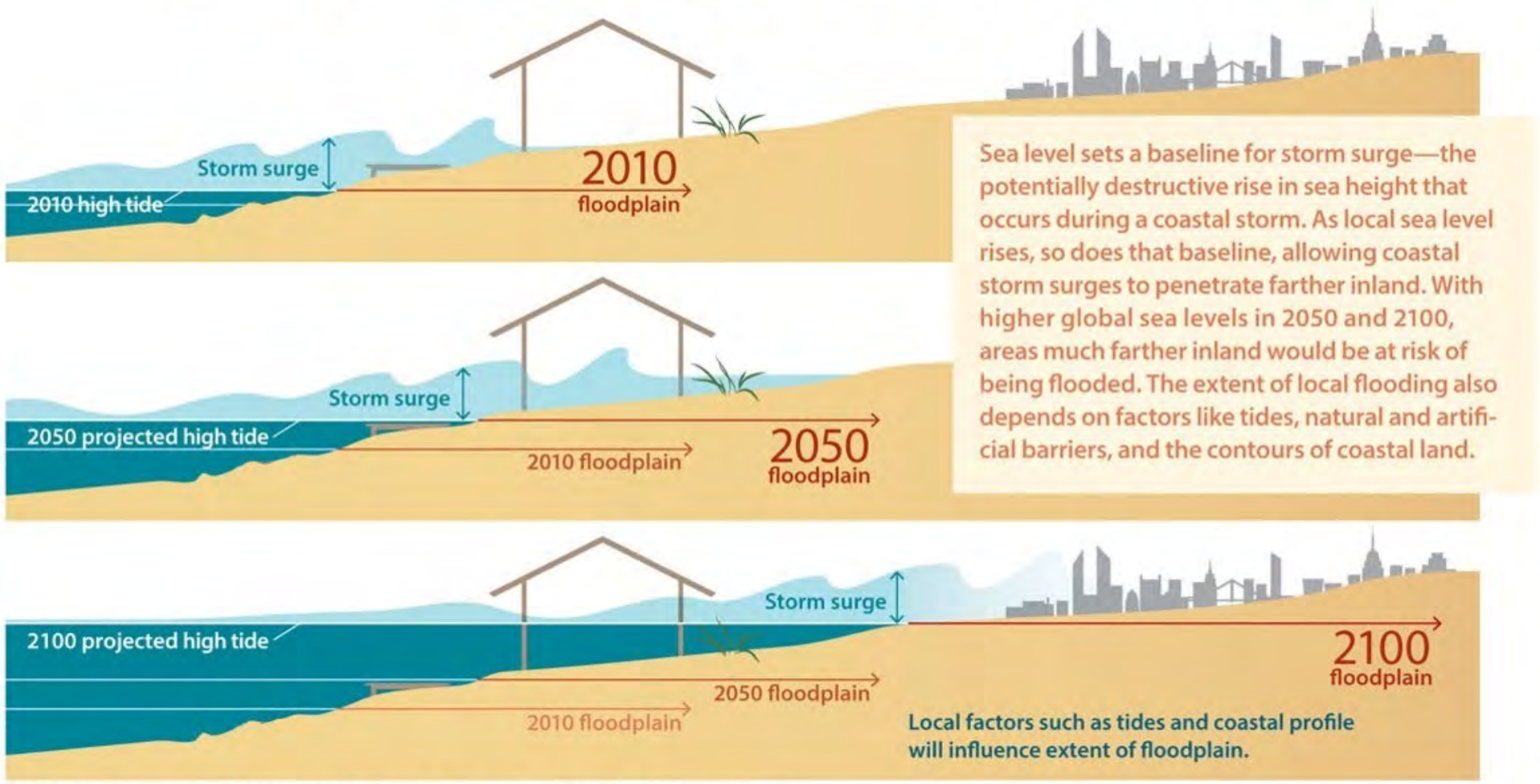
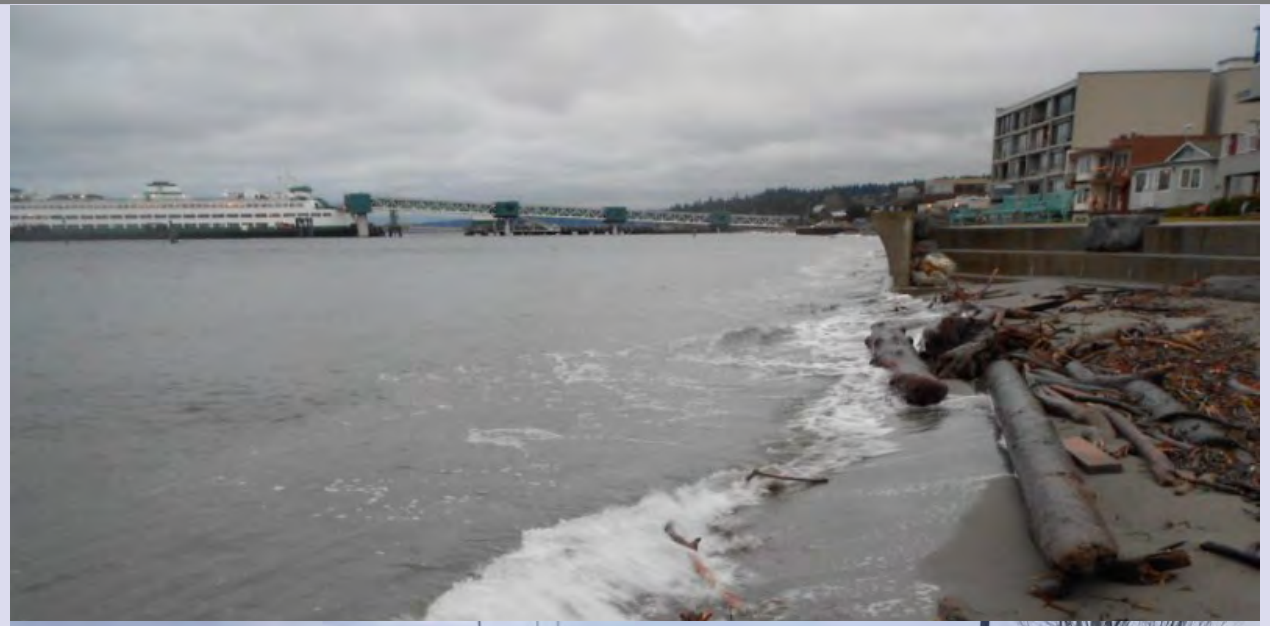
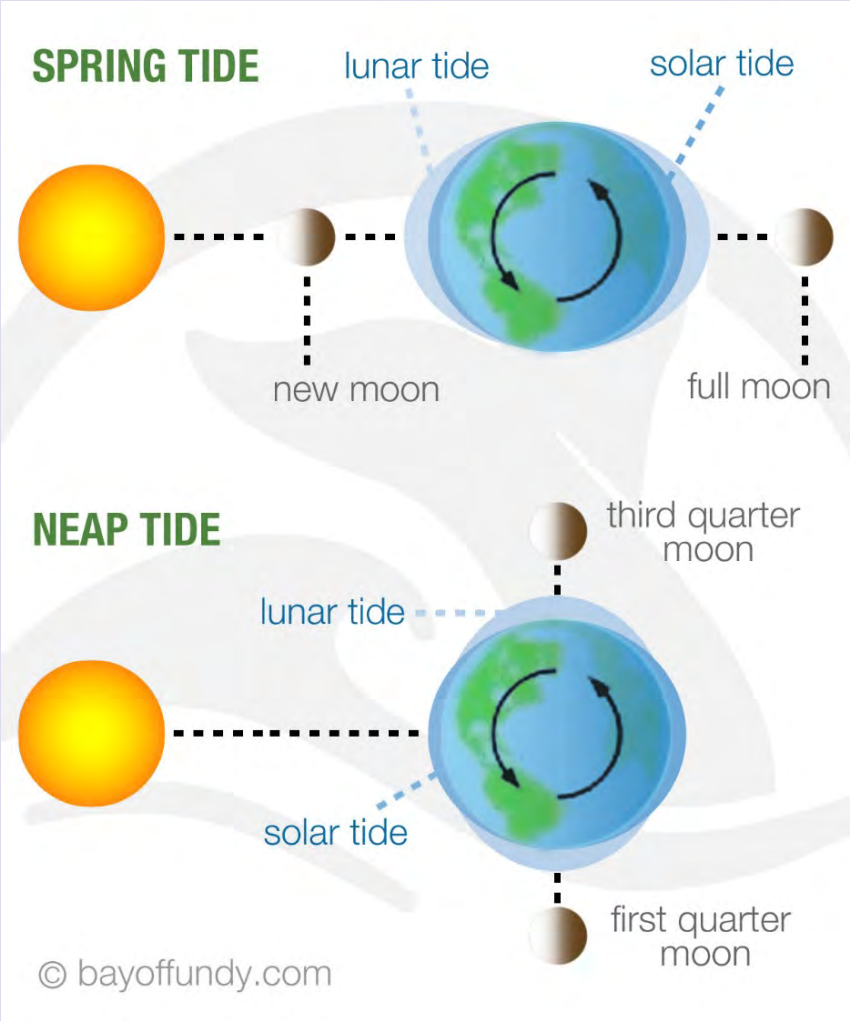


Image adapted from Union of Concerned Scientists 2013; www.ucsusa.org/sealevelrisescience

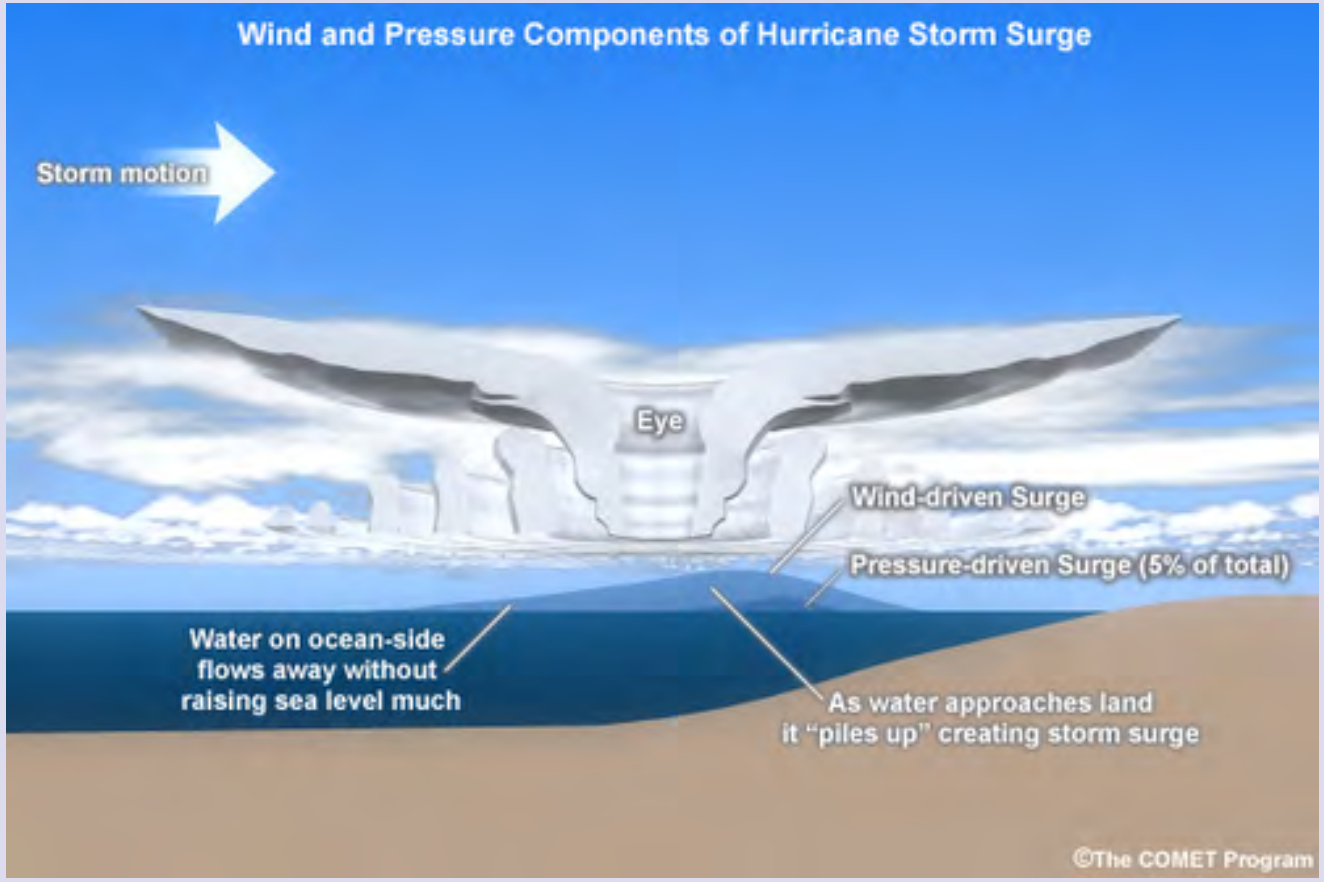
High Astronomical “King” Tides





Stillwater Extreme Tides

Storm Surge



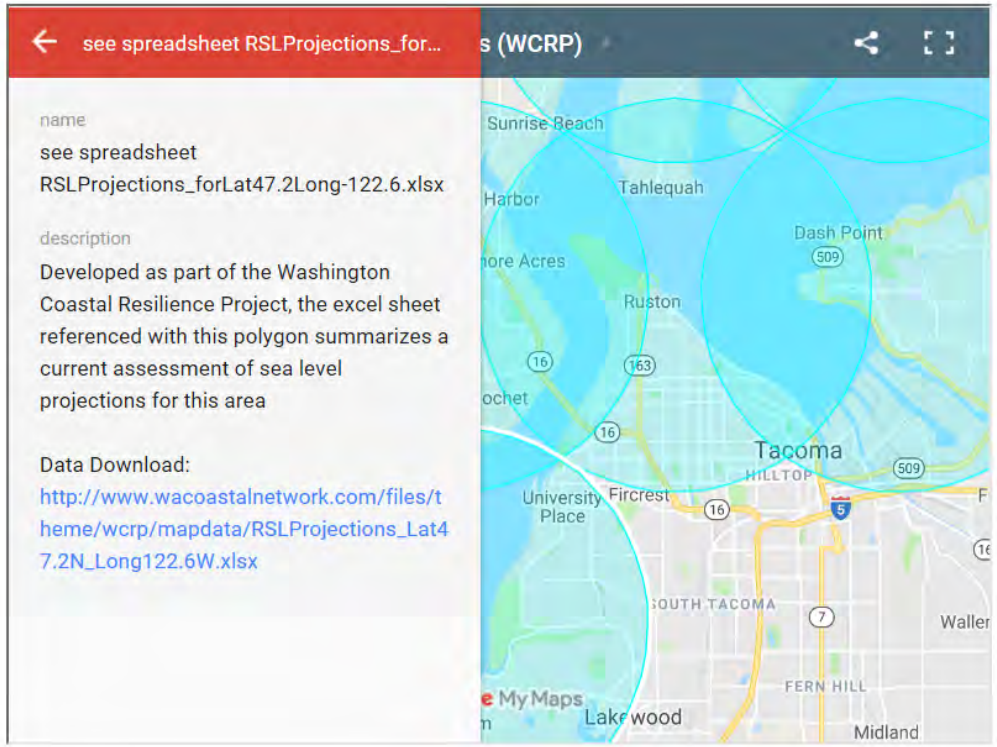
Storm Surge

Low Pressure / Wind Surge / Wind Waves

Sea Level Rise Planning Tools

Washington Coastal Hazards Resilience Network
Sea Level Rise Calculator

http://www.wacoastalnetwork.com/files/theme/wcrp/SLR-Report-Miller-et-al-2018.pdf



RELATIVE SEA LEVEL PROJECTIONS FOR **RCP 4.5** FOR THE COASTAL AREA NEAR: 47.2N, 122.6W

For more information about these projections go to www.coastalnetwork.com/wcrp-documents.html

Table 1: Projected average sea level magnitudes, in feet, for different assessed likelihoods and time periods

19 year period	Assessed Probability of Exceedance:									
	99	95	**90**	83	**50**	17	**10**	5	**1**	0.1
2010	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.3
2020	0	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5
2030	0	0.1	0.2	0.2	0.4	0.5	0.5	0.6	0.7	0.8
2040	0.1	0.2	0.3	0.3	0.5	0.7	0.8	0.9	1	1.3
2050	0.1	0.3	0.4	0.5	0.7	1	1.1	1.2	1.4	2
2060	0.2	0.4	0.5	0.6	0.9	1.2	1.3	1.5	1.8	2.7
2070	0.2	0.5	0.6	0.8	1.1	1.5	1.7	1.9	2.4	3.7
2080	0.3	0.6	0.7	0.9	1.3	1.8	2	2.2	2.9	4.9
2090	0.3	0.6	0.8	1	1.5	2.1	2.3	2.6	3.6	6.1
2100	**0.3**	**0.7**	**0.9**	**1.2**	**1.8**	**2.5**	**2.7**	**3.1**	**4.3**	**7.5**
2110	0.3	0.8	1	1.3	2	2.8	3.1	3.6	5.1	9.1
2120	0.3	0.8	1.1	1.4	2.2	3.1	3.5	4	5.9	10.9
2130	0.3	0.9	1.2	1.5	2.4	3.4	3.9	4.5	6.8	12.4
2140	0.2	0.9	1.2	1.5	2.6	3.8	4.3	5.1	7.8	14.5
2150	0.2	0.9	1.3	1.6	2.8	4.2	4.7	5.6	8.8	16.6

Sea Level Rise Planning Tools

Washington Coastal Hazards Resilience Network
Sea Level Rise Calculator

http://www.wacoastalnetwork.com/files/theme/wcrp/SLR-Report-Miller-et-al-2018.pdf

Representative Concentration Pathway (RCP 4.5)

RELATIVE SEA LEVEL PROJECTIONS FOR **RCP 4.5** FOR THE COASTAL AREA NEAR: 47.2N, 122.6W

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2010	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.3
2020	0	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5
2030	0	0.1	0.2	0.2	0.4	0.5	0.5	0.6	0.7	0.8
2040	0.1	0.2	0.3	0.3	0.5	0.7	0.8	0.9	1	1.3
2050	0.1	0.3	0.4	0.5	0.7	1	1.1	1.2	1.4	2
2060	0.2	0.4	0.5	0.6	0.9	1.2	1.3	1.5	1.8	2.7
2070	0.2	0.5	0.6	0.8	1.1	1.5	1.7	1.9	2.4	3.7
2080	0.3	0.6	0.7	0.9	1.3	1.8	2	2.2	2.9	4.9
2090	0.3	0.6	0.8	1	1.5	2.1	2.3	2.6	3.6	6.1
2100	**0.3**	**0.7**	**0.9**	**1.2**	**1.8**	**2.5**	**2.7**	**3.1**	**4.3**	**7.5**
2110	0.3	0.8	1	1.3	2	2.8	3.1	3.6	5.1	9.1
2120	0.3	0.8	1.1	1.4	2.2	3.1	3.5	4	5.9	10.9
2130	0.3	0.9	1.2	1.5	2.4	3.4	3.9	4.5	6.8	12.4
2140	0.2	0.9	1.2	1.5	2.6	3.8	4.3	5.1	7.8	14.5
2150	0.2	0.9	1.3	1.6	2.8	4.2	4.7	5.6	8.8	16.6

Representative Concentration Pathway (RCP 8.5)

RELATIVE SEA LEVEL PROJECTIONS FOR **RCP 8.5** FOR THE COASTAL AREA NEAR: 47.2N, 122.6W

For more information about these projections go to www.coastalnetwork.com/wcrp-documents.html

Table 1: Projected average sea level magnitudes, in feet, for different assessed likelihoods and time periods

19 year	Assessed Probability of Exceedance:									
period	99	95	**90**	83	**50**	17	**10**	5	**1**	0.1
2010	0	0	0	0	0.1	0.2	0.2	0.2	0.2	0.3
2020	0	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.5
2030	0.1	0.2	0.2	0.2	0.4	0.5	0.5	0.6	0.7	0.8
2040	0.1	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1	1.3
2050	0.2	0.3	0.4	0.5	0.8	1	1.1	1.2	1.5	2.1
2060	0.3	0.5	0.6	0.7	1	1.3	1.4	1.6	2	3
2070	0.4	0.6	0.8	0.9	1.3	1.7	1.8	2	2.6	4.2
2080	0.5	0.8	1	1.1	1.6	2.1	2.3	2.5	3.3	5.5
2090	0.6	0.9	1.1	1.3	1.9	2.5	2.8	3.1	4.1	6.8
2100	0.6	1.1	**1.3**	1.5	**2.2**	3	**3.3**	3.7	**5.1**	8.4
2110	0.8	1.2	1.5	1.7	2.4	3.2	3.6	4.1	5.7	9.9
2120	0.9	1.4	1.7	1.9	2.7	3.7	4.1	4.7	6.8	11.9
2130	1	1.5	1.8	2.1	3	4.2	4.7	5.4	7.8	14.1
2140	1.1	1.7	2	2.3	3.4	4.7	5.3	6.1	9	16
2150	1.1	1.8	2.1	2.5	3.7	5.3	5.9	6.9	10.3	18.8

Sea Level Rise Planning Tools

USACE Sea Level Change Calculator

http://corpsmapu.usace.army.mil/rccinfo/slc/ccaceslcurves(superseded).html

EC 1165-2-212, Equation 2: $E(t) = 0.0017t + bt^2$

This on-line Sea Level Change Calculator produces the amount of predicted sea level change from 1992 forward.

USACE SLC Coeffcients:	0.0000000 | 0.0000271 | 0.0001130
Base Year (Mid Point of NTDE):	1992
Enter Project Start Year:	2020
Rate of Eustatic Sea Level Rise per year in mm:	1.7
Rate of Subsidence per year in mm:	0.540
Select the closest NOAA gauge station to the right:	WA, Seattle: 109 yrs
Enter FEMA Base Flood Elevation (ft):	0 (NA
Enter Project End Year:	2100
Enter Interval:	5
Include NOAA Curves: NOAA Technical Report OAR CPO-1	☑
Output Units:	◉ Feet ○ Meters
Chart Size:	Height: 500
Compute Curves Based on:	◉ EC 1165-2-212

Calculate Curves | Reset Fields

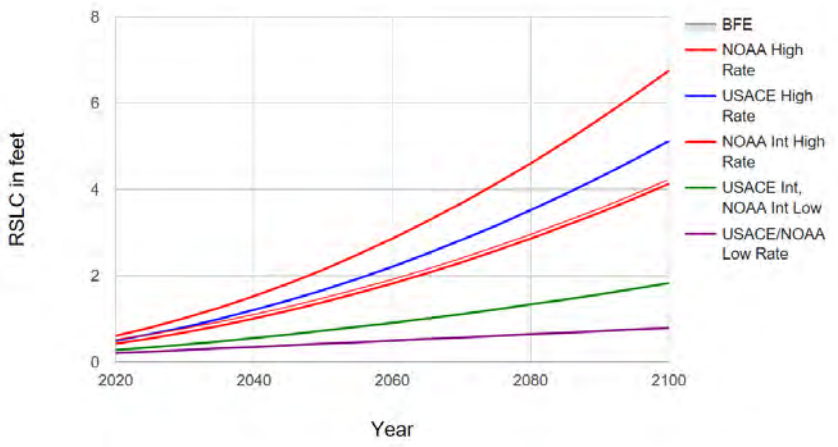
USACE Curves computed using criteria in USACE EC 1165-2-212

NOAA Curves computed using criteria in NOAA SLR Report 06-Dec-2012

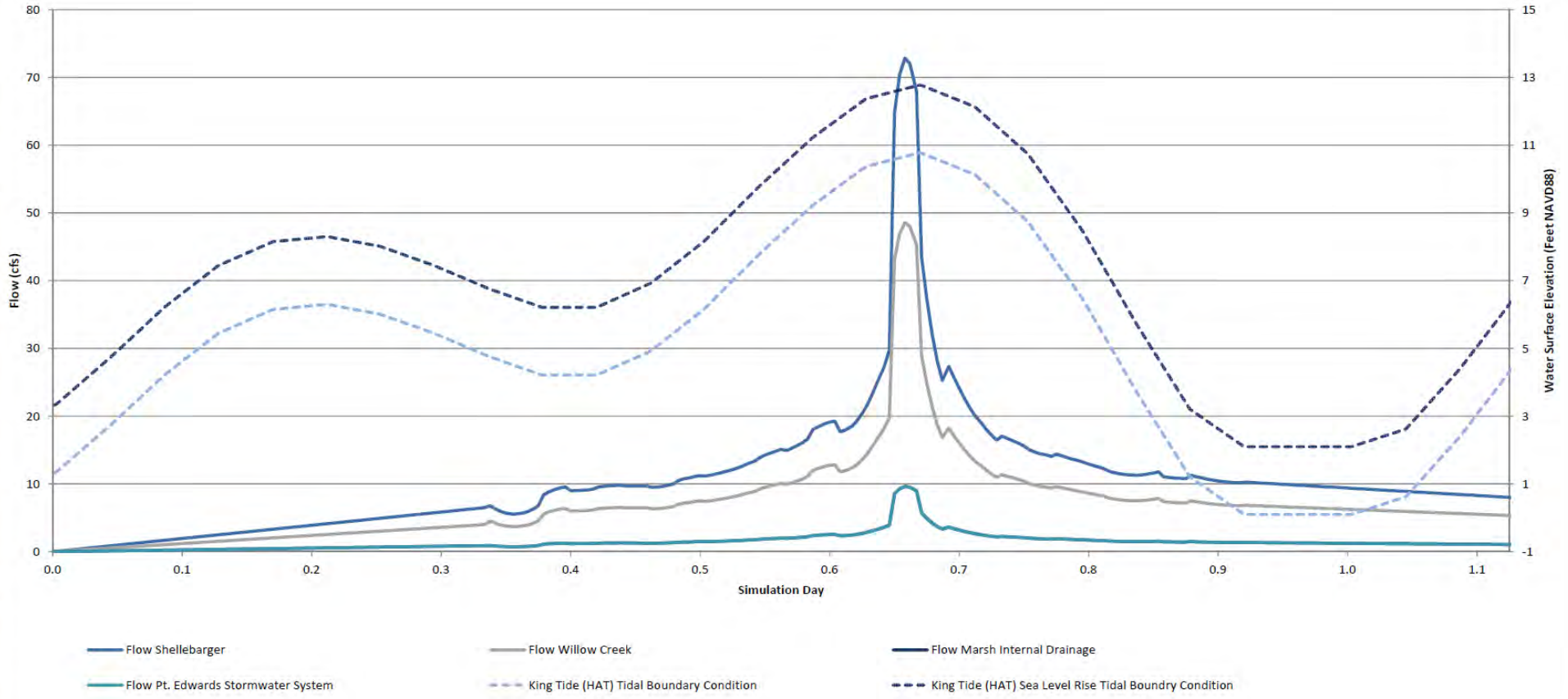
Gauge: 9447130, WA, Seattle: 109 yrs
All values are in feet

Year	NOAA Low	USACE Low	NOAA Int Low	USACE Int	NOAA Int High	USACE High	NOAA High
2020	0.21	0.21	0.28	0.28	0.43	0.50	0.61
2025	0.24	0.24	0.34	0.34	0.55	0.65	0.80
2030	0.28	0.28	0.41	0.41	0.69	0.81	1.02
2035	0.32	0.32	0.48	0.48	0.84	1.00	1.26
2040	0.35	0.35	0.56	0.56	1.01	1.21	1.53
2045	0.39	0.39	0.64	0.64	1.19	1.43	1.82
2050	0.43	0.43	0.73	0.73	1.39	1.67	2.14
2055	0.46	0.46	0.82	0.82	1.60	1.93	2.49
2060	0.50	0.50	0.91	0.91	1.82	2.21	2.86
2065	0.54	0.54	1.01	1.01	2.06	2.51	3.26
2070	0.57	0.57	1.11	1.11	2.31	2.83	3.68
2075	0.61	0.61	1.22	1.22	2.58	3.16	4.13
2080	0.65	0.65	1.34	1.34	2.86	3.52	4.60
2085	0.68	0.68	1.45	1.45	3.16	3.89	5.10
2090	0.72	0.72	1.57	1.57	3.46	4.28	5.63
2095	0.76	0.76	1.70	1.70	3.79	4.69	6.18
2100	0.79	0.79	1.83	1.83	4.13	5.12	6.75

USACE and NOAA SLC Curves - Gauge: 9447130, WA, Seattle: 109 yrs
USACE Curves computed using criteria in EC 1165-2-212



Storm Surge & SLR-2100 Tidal Hydrology Adjusted



WILLOW CREEK DAYLIGHT PROJECT
EXPANDED MARSH CONCEPT DESIGN AND
HYDRAULIC MODELING EDMONDS, WA

1% (100-YR) AEP SAIC STREAM FLOOD HYDROGRAPHS AND KING TIDE/KING TIDE WITH SEA LEVEL RISE TIDAL BOUNDARY CONDITIONS

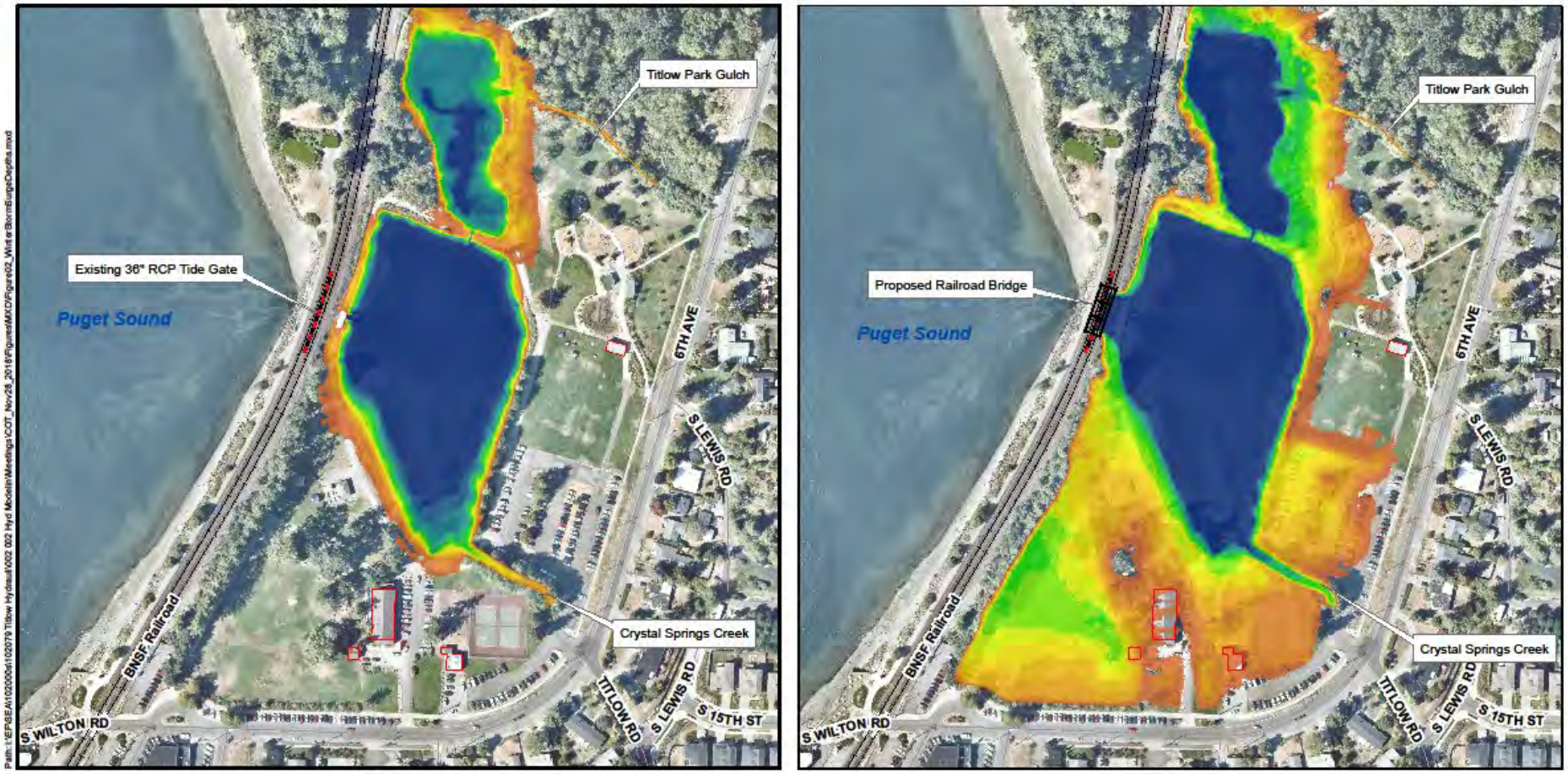
March 2019 21-1-12588-050

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 11A

Printed: 3-10-19 17:38 File: I:\EF\21-1 SEA\12500s\12588 Willow Creek Daylight H& and Soils Study\050 H&H FINAL ALTS - FLOODGATE\Report\Tables\[Figures.xlsx]Fig12A_Hydrographs-

Hydraulic Modeling of Storm Surge (2019)



EXISTING

PROPOSED

Inundation Depths

0 - 0.5 FT	3.5 - 4 FT
0.5 - 1 FT	4 - 4.5 FT
1 - 1.5 FT	4.5 - 5 FT
1.5 - 2 FT	5 - 5.5 FT
2 - 2.5 FT	5.5 - 6 FT
2.5 - 3 FT	6 - 6.5 FT
3 - 3.5 FT	6.5+ FT

Legend

Limit of Study

Buidling Footprints

Tidal Boundary: Storm Surge
Stormwater Inflow: Western Slopes 04 - 1% (100-yr) AEP

DRAFT

N W E S

0 180 360
Feet

South Puget Sound Salmon Enhancement Group

Titlow Shoreline Restoration
Pierce County, Washington

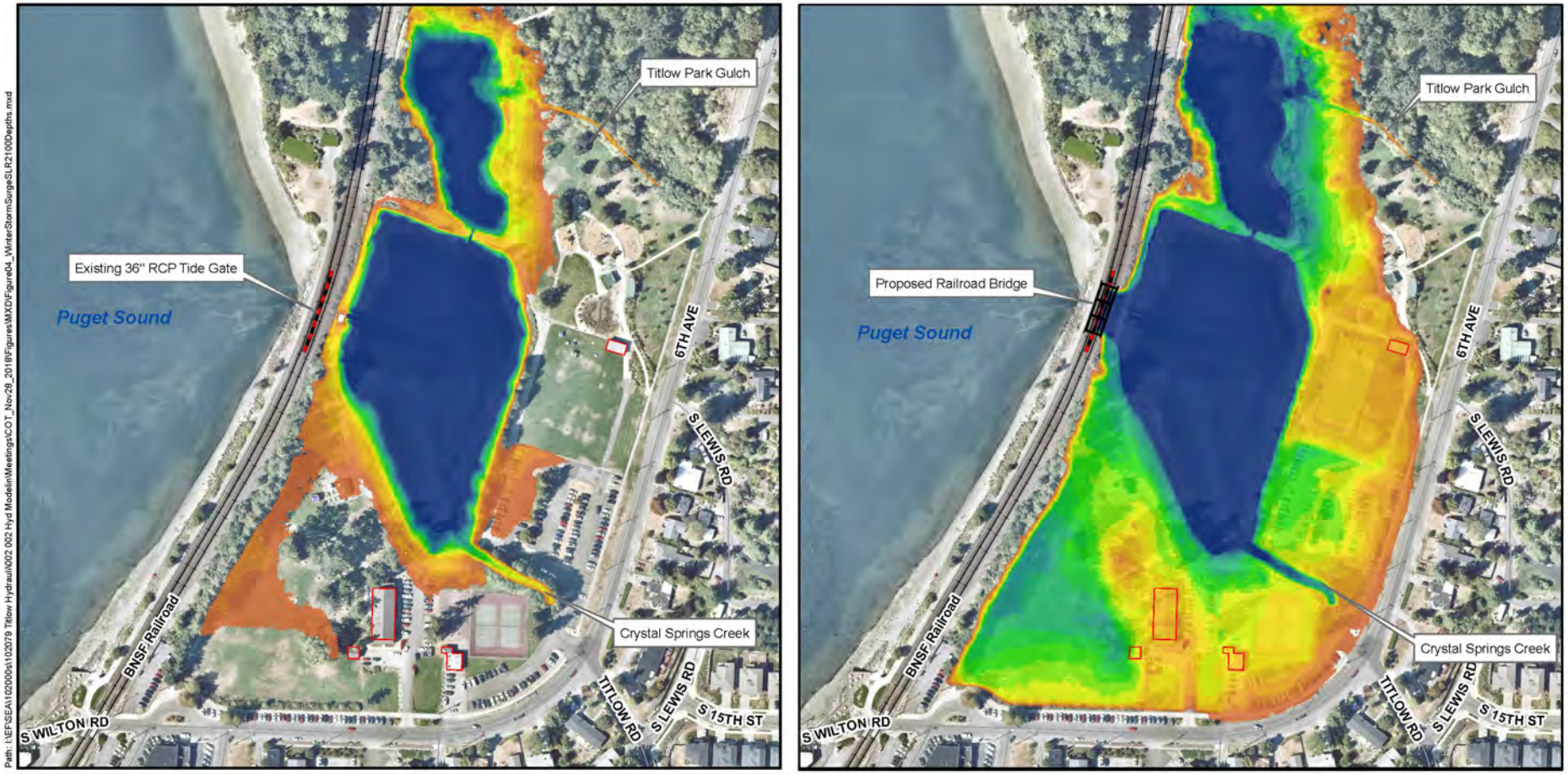
WINTER - STORM SURGE
INUNDATION DEPTHS

November 2018 102079-002

Shannon & Wilson, Inc.

FIG. 2

Hydraulic Modeling of Storm Surge (Future SLR-2100)



EXISTING

PROPOSED

Inundation Depths

0 - 0.5 FT	3.5 - 4 FT
0.5 - 1 FT	4 - 4.5 FT
1 - 1.5 FT	4.5 - 5 FT
1.5 - 2 FT	5 - 5.5 FT
2 - 2.5 FT	5.5 - 6 FT
2.5 - 3 FT	6 - 6.5 FT
3 - 3.5 FT	6.5+ FT

Legend

Limit of Study

Buidling Footprints

Tidal Boundary: Spring/Early Summer + SLR-2100
Sea Level Rise (SLR): +1.6 ft
Stormwater Inflow: Western Slopes 04 - Baseflow

DRAFT

N W E S

0 180 360
Feet

SOUTH PUGET SOUND Salmon ENHANCEMENT GROUP

Titlow Shoreline Restoration
Pierce County, Washington

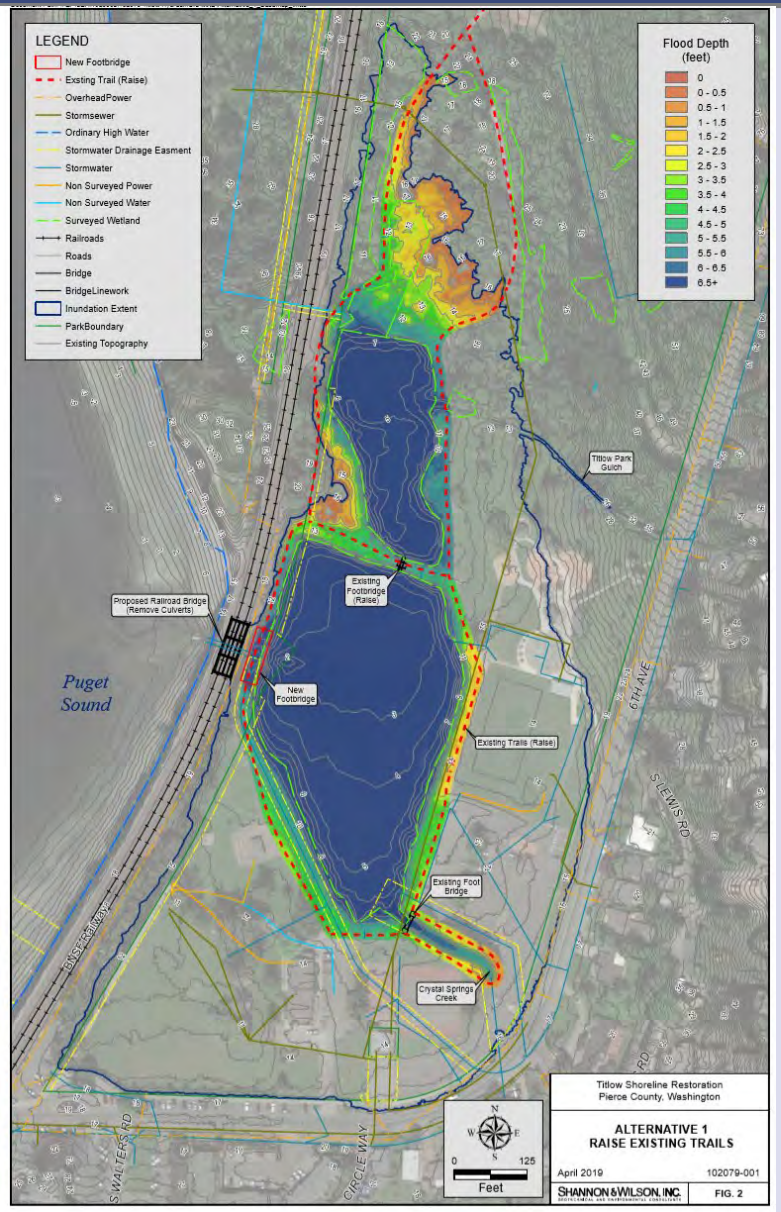
WINTER STORM SURGE + SLR-2100 INUNDATION DEPTHS

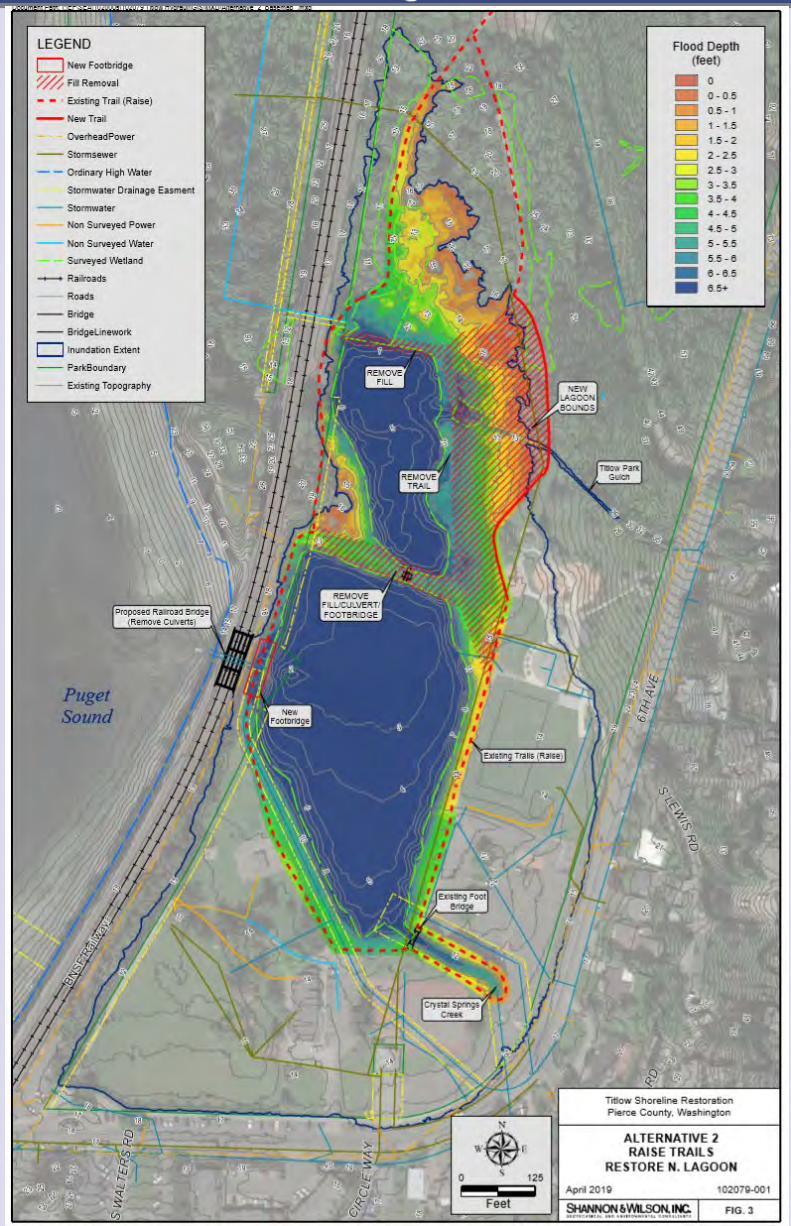
November 2018 102079-002

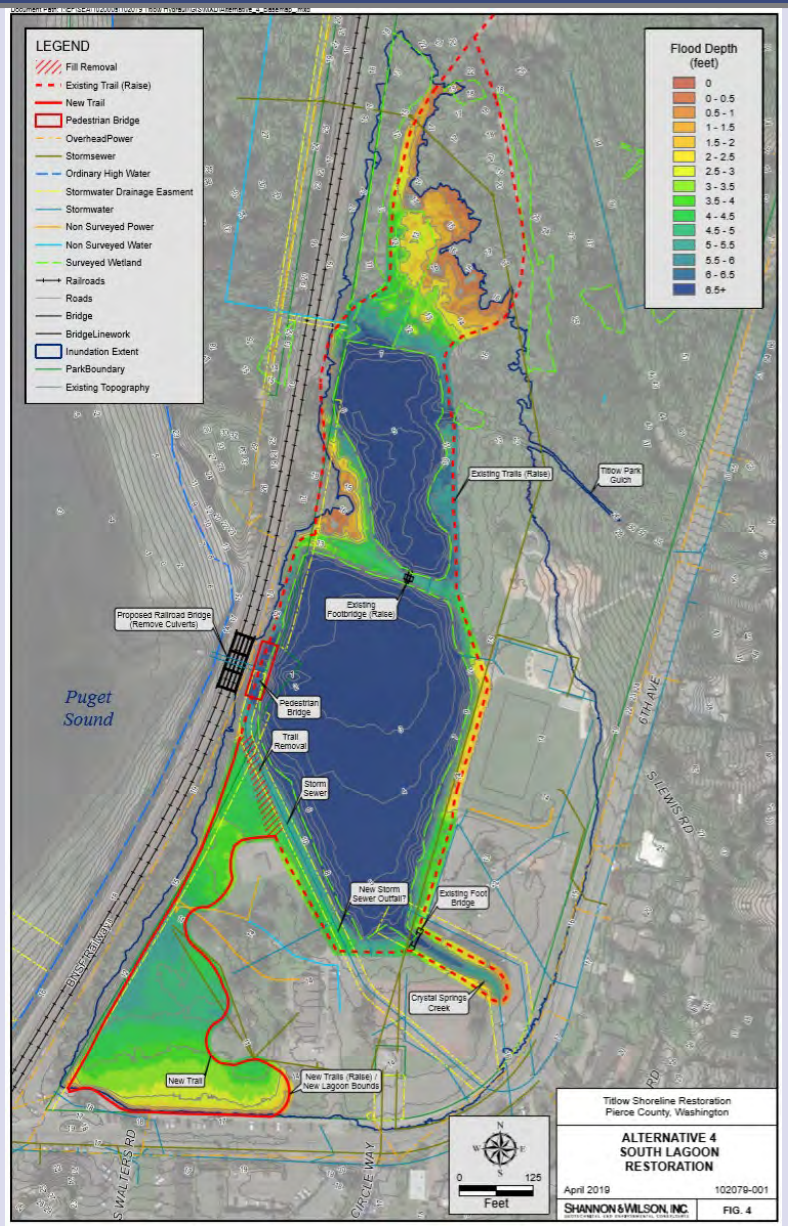
SHANNON & WILSON, INC. GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 4

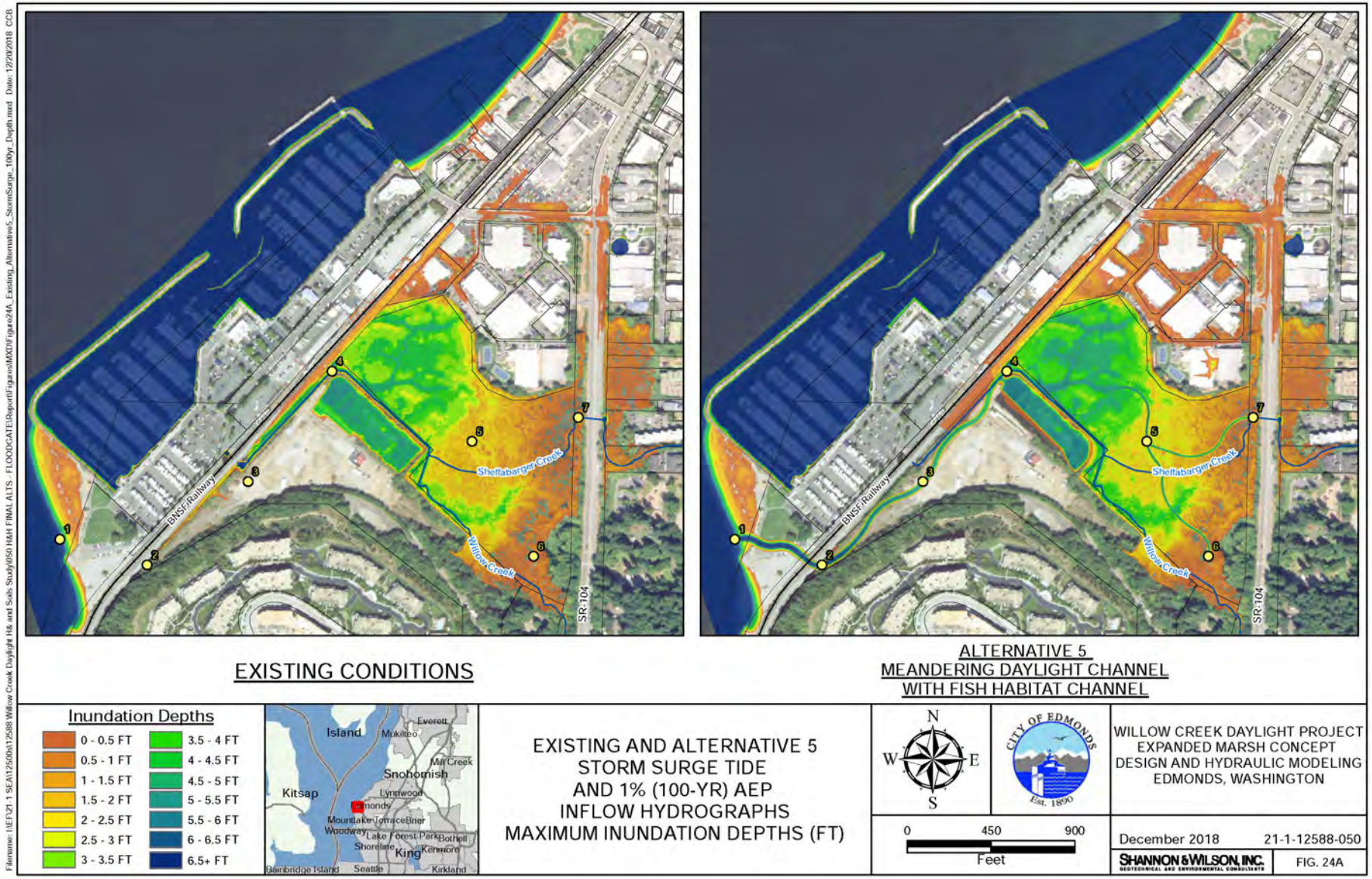
Hydraulic Modeling of Storm Surge (Future SLR-2100) w/ Adaptation



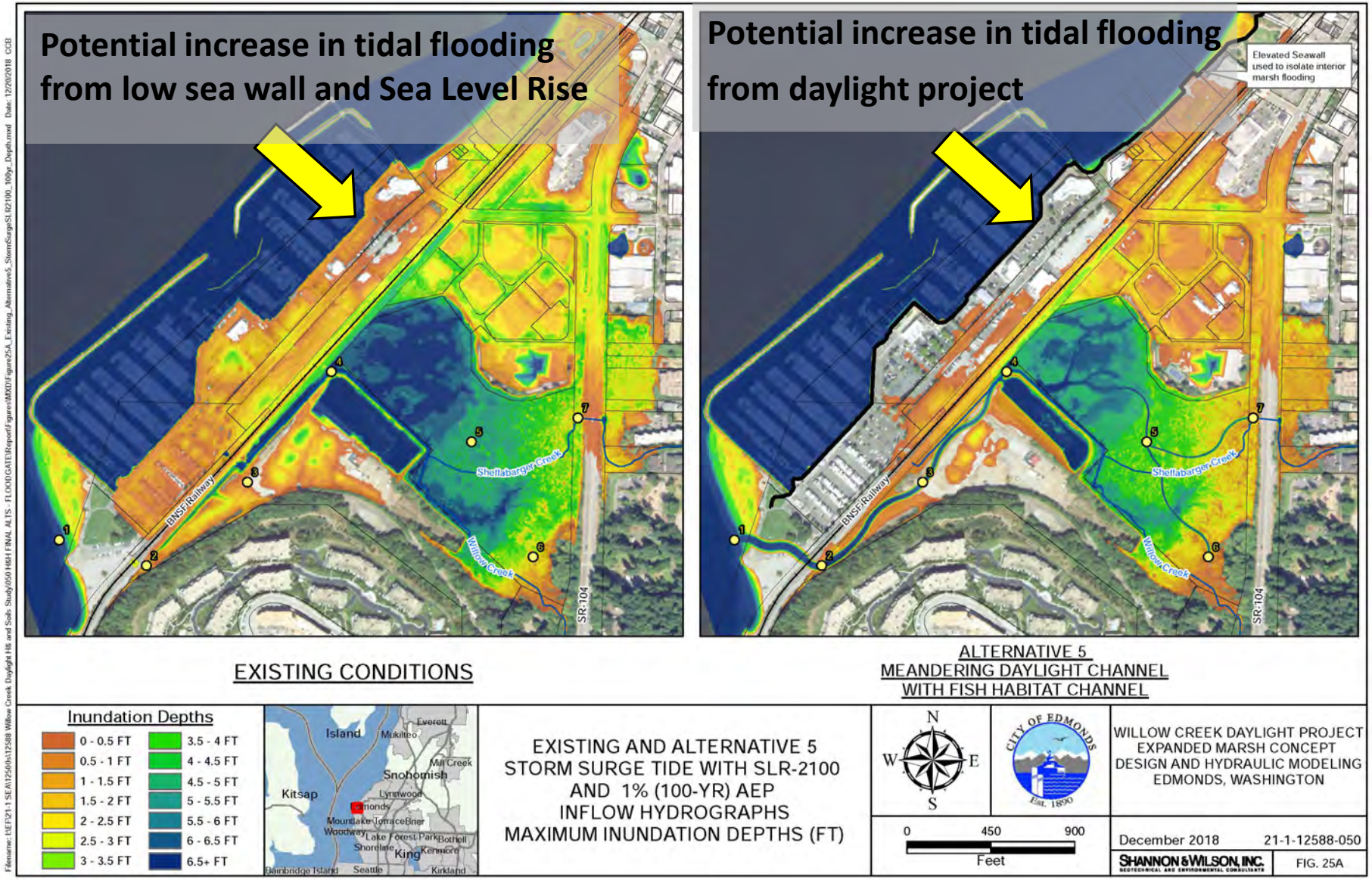




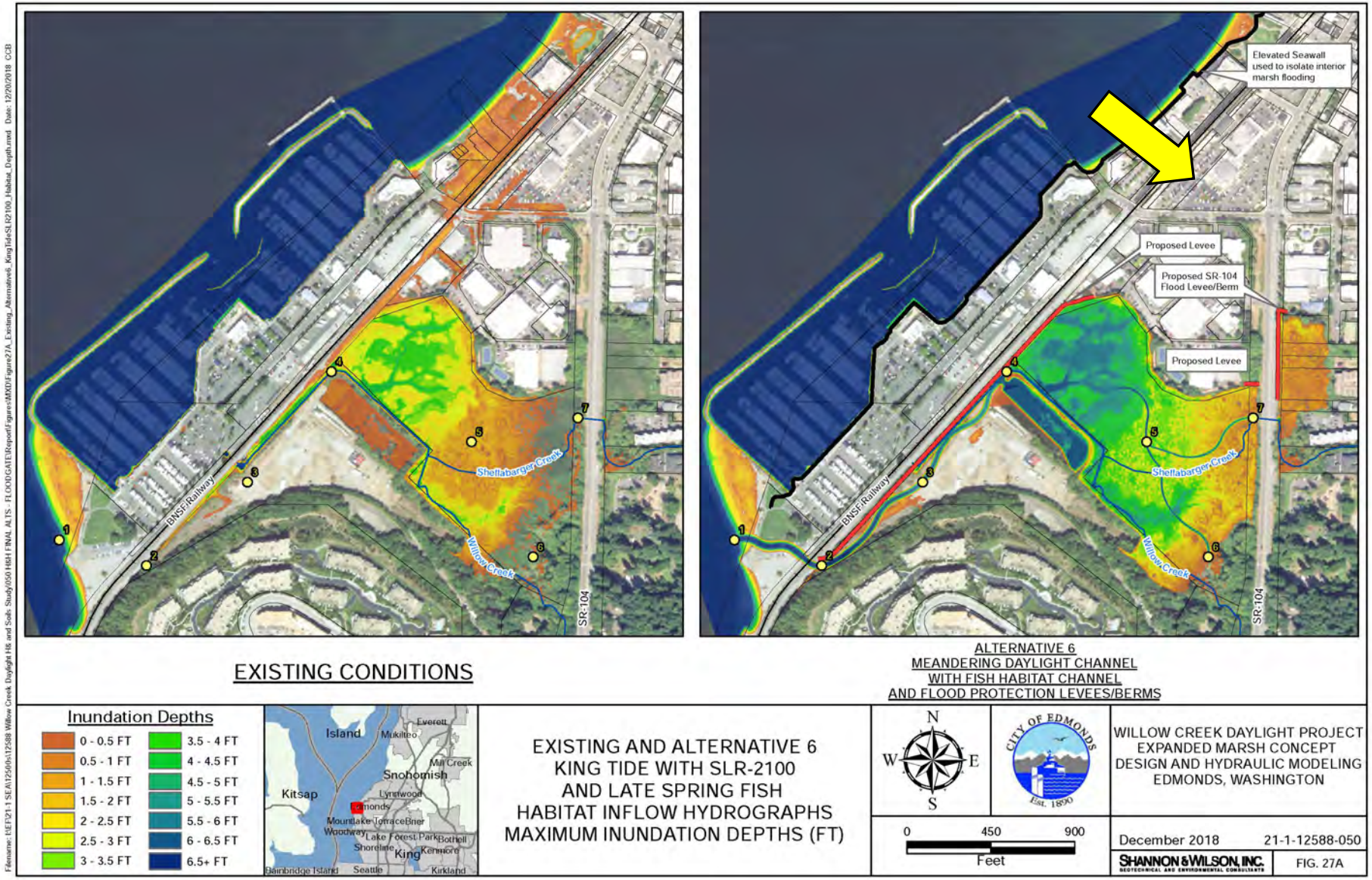
Hydraulic Modeling of Storm Surge (2019)



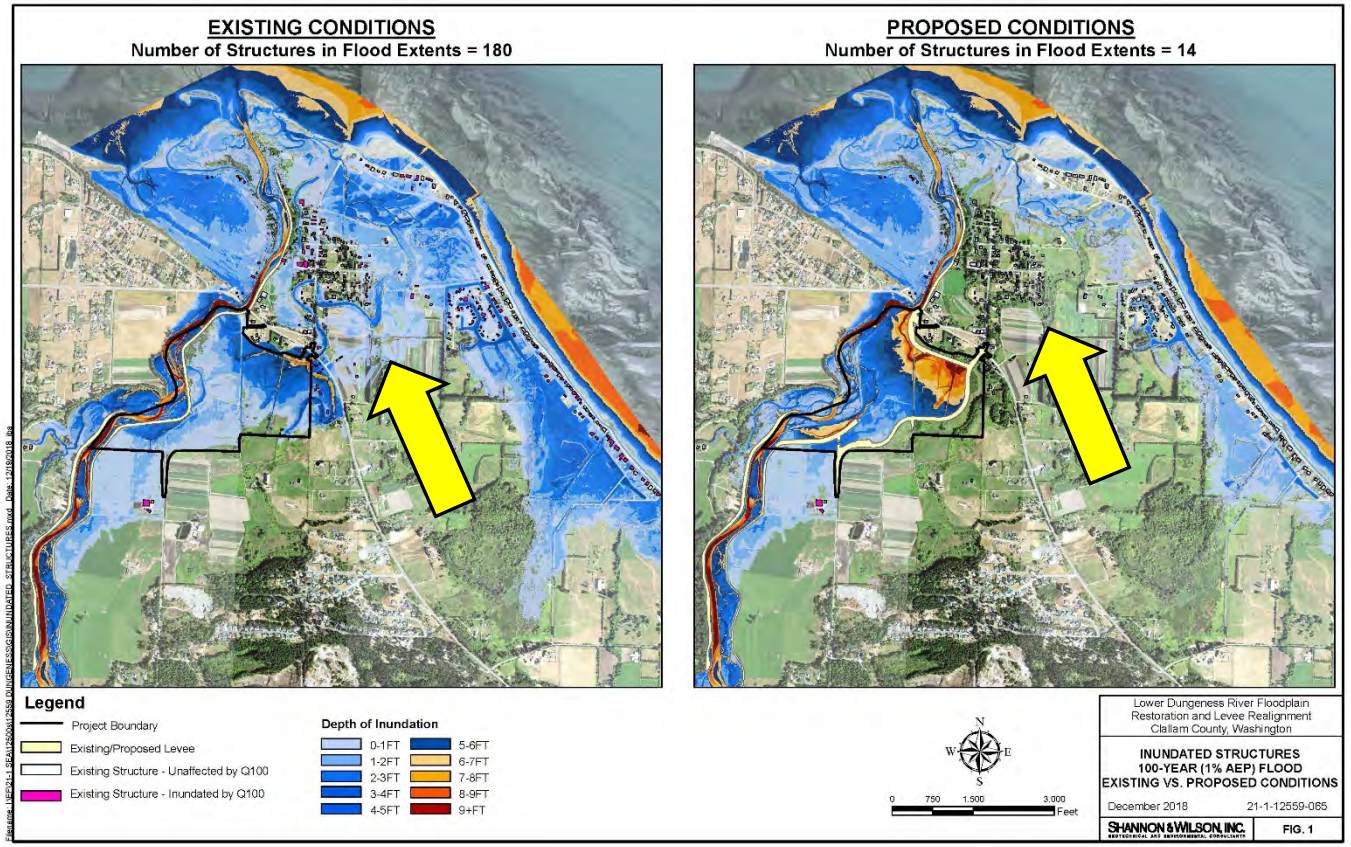
Hydraulic Modeling of Storm Surge (Future SLR-2100)



Hydraulic Modeling of Storm Surge (Future SLR-2100) w/ Adaptation



River Deltas – Combined River & Tidal Effects



Water Surface Elevation (ft. NAVD88)	22,000	22,026	26,903	32,860	40,135	49,021	59,874	73,130	89,322	109,098	133,252	162,755	198,789	242,802	296,559	362,217	442,413
13.2	0	0	0	0	0	0	0	0.000025	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0.000025	0	0.000025	0	0	0.000025	0	0	0	0	0	0
12.8	0	0	0	0	0.00005	0.00005	0.000125	0.00005	0.000025	0.00005	0.000025	0	0	0	0	0	0
12.6	0	0	0	0.00005	0.000025	0.00015	0.000025	0.0001	0.0001	0.000025	0	0.00005	0	0	0	0	0
12.4	0	0	0.00005	0.000175	0.000175	0.0005	0.0006	0.0005	0.000425	0.0002	0.000075	0.00005	0	0	0	0	0
12.2	0	0	0.00005	0.00035	0.001	0.001925	0.001975	0.0016	0.0015	0.000625	0.0002	0.000075	0.000125	0	0	0	0
12	0	0	0.00035	0.001275	0.0034	0.00385	0.0048	0.004475	0.0032	0.001425	0.0012	0.000275	0.00015	0.00005	0	0	0
11.8	0	0.000075	0.00055	0.002475	0.006375	0.010325	0.01135	0.0091	0.006025	0.00285	0.001675	0.0007	0.000025	0.000025	0.000025	0	0
11.6	0	0.0001	0.000975	0.004425	0.011525	0.0169	0.018825	0.016875	0.010475	0.005875	0.002875	0.001	0.0004	0.000075	0.000025	0	0
11.4	0	0.000125	0.00135	0.00655	0.01675	0.025075	0.02935	0.024675	0.017375	0.0084	0.00375	0.0013	0.0004	0.000175	0.00005	0.000025	0
11.2	0	0.0002	0.001675	0.0076	0.01985	0.0328	0.0372	0.029975	0.02125	0.01045	0.00425	0.0024	0.000525	0.00025	0	0.00005	0
11	0	0.00015	0.002075	0.0081	0.0222	0.033525	0.035275	0.031225	0.01905	0.01075	0.004425	0.002175	0.000575	0.000075	0.000025	0.000025	0
10.8	0	0.00005	0.0015	0.006325	0.018375	0.028375	0.030425	0.02635	0.017675	0.0087	0.0045	0.0017	0.00055	0.0003	0.00005	0	0
10.6	0.000025	0.0001	0.001175	0.004875	0.010475	0.01915	0.022575	0.0193	0.01235	0.0062	0.0028	0.0012	0.00045	0.00005	0	0	0
10.4	0	0.00005	0.000625	0.00315	0.008525	0.01165	0.012325	0.01155	0.007425	0.004325	0.001875	0.0007	0.000175	0.000025	0	0	0
10.2	0	0.00005	0.000375	0.001225	0.003425	0.0056	0.005175	0.004625	0.00295	0.001625	0.00075	0.000375	0.0001	0	0	0	0
10	0	0	0.0001	0.000825	0.00155	0.00315	0.00315	0.00275	0.001675	0.000775	0.000475	0.000125	0.0001	0	0	0	0

Discharge (cubic feet per second)

Residual flood risks

Hydrodynamic models - wind surge and waves

Joint probability - Monte Carlo simulations

Thank You