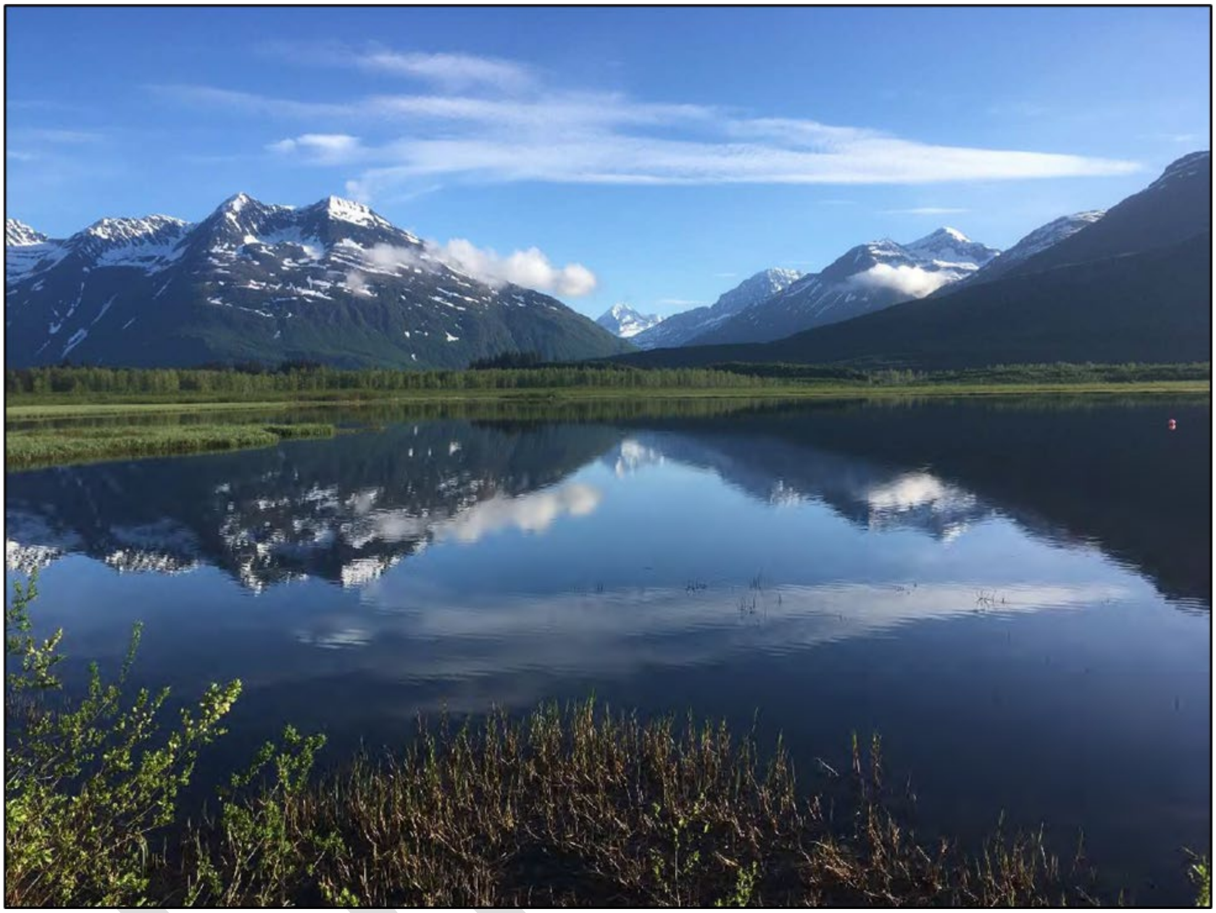
Robe Lake Ecosystem Restoration
Appendix A: Hydraulics and Hydrology | DRAFT
Feasibility Study
Valdez, AK



U.S. Army Corps
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Alaska District

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1.0 INTRODUCTION

This Hydraulics and Hydrology Appendix describes the technical aspects of proposed alternatives for the Robe Lake Ecosystem Restoration feasibility study authorized under the Continuing Authorities Program (CAP) Section 206 of the Water Resources Development Act (WRDA) of 1996 (33 U.S.C. §2330), as amended. It provides the engineering background information for determining the Federal interest in the major construction features, including diverting Corbin Creek to its relic channels. Existing data was gathered and analyzed to determine the site characteristics. Numerical modeling was performed to determine the physical impacts of the flood flows for the design of the proposed ecosystem restoration measures.

2.0 PROJECT SUMMARY

Robe Lake is located within the northern portion of Prince William Sound in southcentral Alaska and lies within the city limits of Valdez. Robe Lake is the largest freshwater lake in the Valdez area, with three tributary streams: Brownie Creek, Deep Creek, and the relic channel Old Corbin Creek. In the 1950s a gravel berm was constructed on Corbin Creek, which begins at the terminus of Corbin Glacier, to divert flow and prevent flooding and washout of the Richardson Highway. Prior to this diversion, the main channel of Corbin Creek originally flowed into Robe Lake. Currently, Corbin Creek is a tributary of Valdez Glacier Stream and does not flow into Robe Lake. Corbin Creek's historic channel is now known as Old Corbin Creek, a relic channel with minimal flow.

At Robe Lake, historical human induced hydrologic impacts resulting from a diversion of Corbin Creek have resulted in broad scale effects. The loss of cold, turbid, glacial flow from the Corbin Creek tributary has led to an excessive overgrowth of macrophytes. The macrophytes have impacted salmonid habitat by reducing available rearing and spawning habitat. Current mitigation requires mechanical harvesting of excess macrophytes. Mechanical harvesting of excess macrophytes has a high operational cost and is time-consuming.

A Continuing Authorities Program (CAP) feasibility study was initiated with the City of Valdez and the Native Village of Tatitlek on 10 June 2022 with the execution of the Feasibility Cost Share Agreement (FCSA). The U.S. Army Corps of Engineers (USACE) worked with the City of Valdez, the Native Village of Tatitlek, and the Valdez Fisheries Development Association (VFDA) to find a solution to reduce excess overgrowth of macrophytes and improve the salmon rearing and spawning habitat in Robe Lake. Authority is provided by Section 206 of the Water Resources Development Act (WRDA) of 1996 (33 U.S.C. §2330), as amended.

3.0 VALDEZ HYDROLOGY

3.1 Location and Vicinity

Robe Lake is located within the city limits of Valdez, which is at the northern end of Prince William Sound in southcentral Alaska roughly 300 miles due east of Anchorage. The outlet of Robe Lake discharges into the Robe River which flows west under the Richardson Highway through two 12.75-foot diameter culverts that are located roughly 6.5 miles southeast from downtown Valdez (Figure 1). The Robe River discharges into Lowe River approximately 1.5 river miles downstream of the Richardson Highway crossing. The Lowe River then discharges into the upper end of Port of Valdez.

Robe Lake has a surface area of 682 acres, a volume of 6,980 acre-feet, and a mean depth of 10.23 feet (Koenings et al., 1987) (Figure 2). There are three tributary streams within the Robe Lake watershed consisting of Brownie Creek, Deep Creek, and the relic Old Corbin Creek. Corbin Creek, and subsequent flows from Valdez Glacier Stream, used to flow through the relic channel of Old Corbin Creek and into Robe Lake (Figure 3). In 1956, a gravel berm was constructed to divert any flows from Valdez Glacier Stream and Corbin Creek from Robe Lake due to concern with washing out the Richardson Highway (Figure 2; Koenings et al., 1987). Figure 4 shows aerial imagery of present-day conditions.

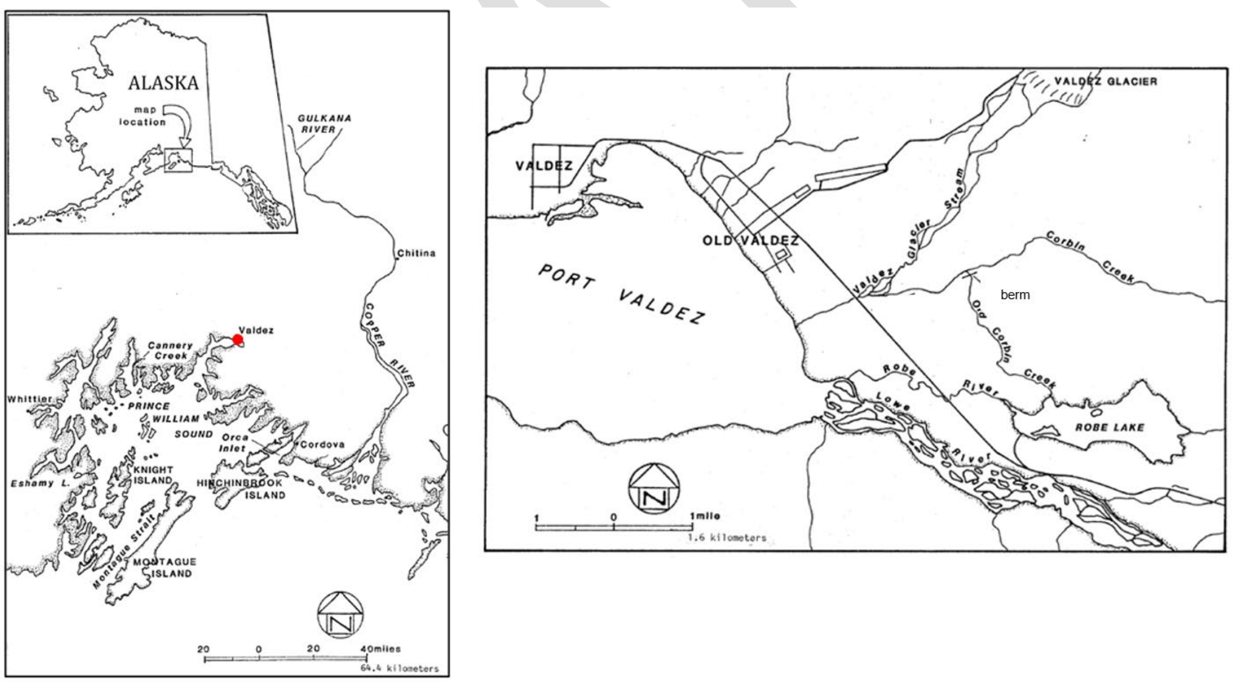

Figure 1. Geographical location of Valdez (left) and vicinity map of Valdez, Alaska showing gravel berm and Robe River and tributary locations (right) (Koenings et al., 1987).

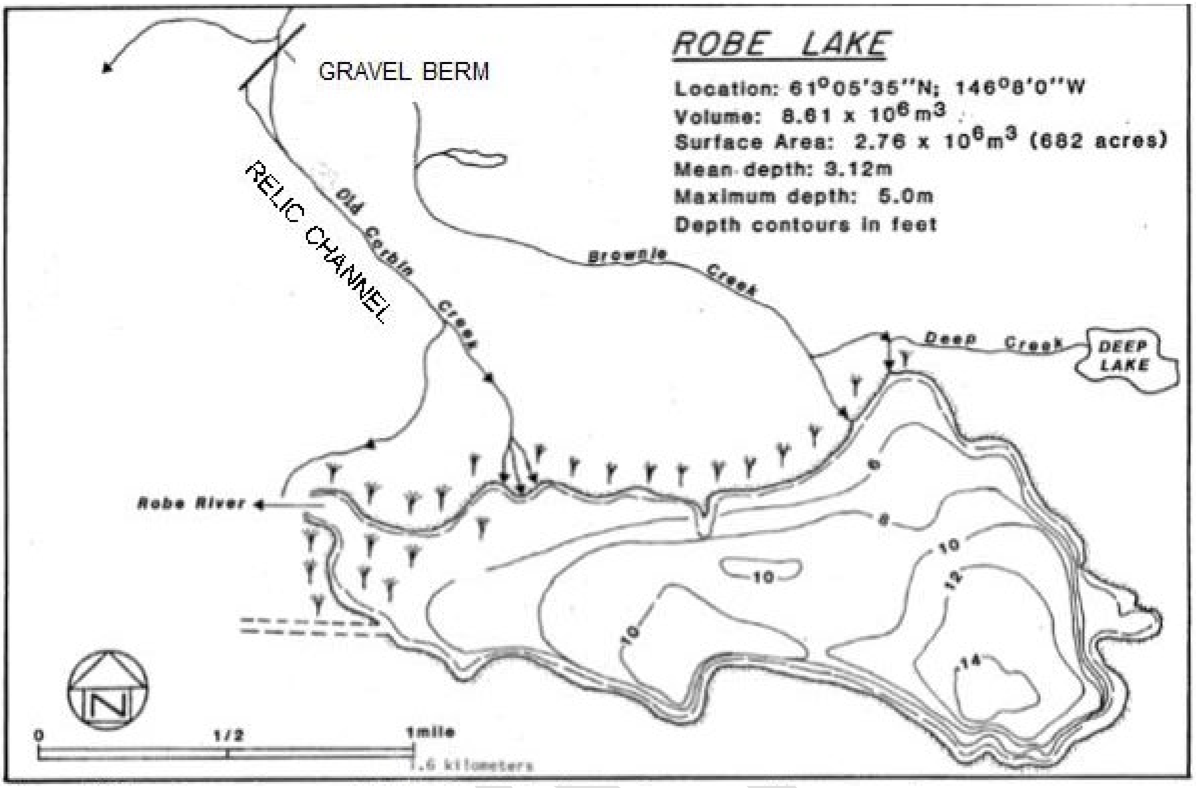

Figure 2. Morphometric map of Robe Lake relative to surrounding tributaries (Koenings et al., 1987).

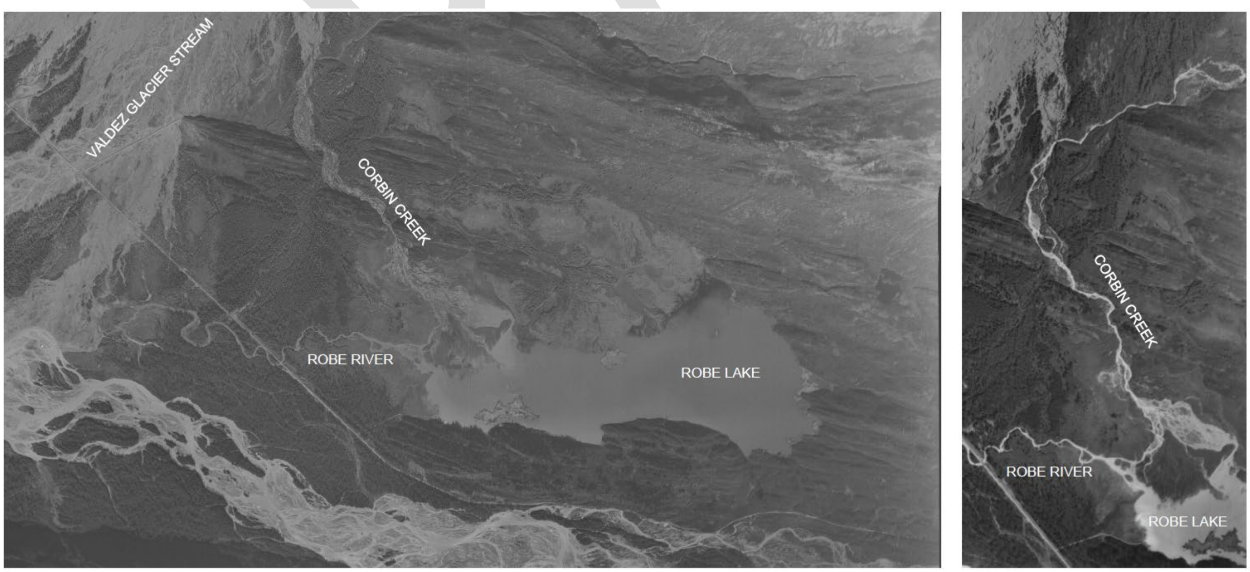

Figure 3. Historical aerial imagery of Robe Lake watershed from 1950 (left) and 1957 (right) (USGS Imagery).

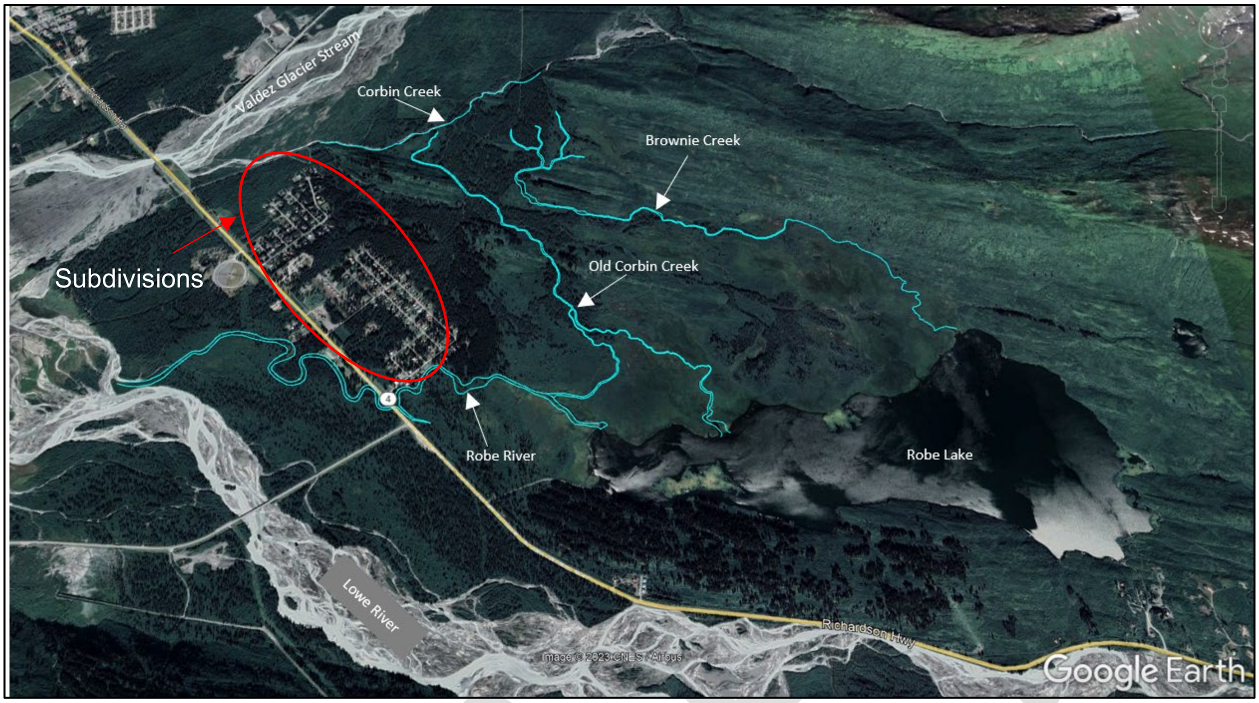

Figure 4. Present day aerial imagery (Google Earth; accessed 2023).

Since the diversion, subdivisions have been built near Robe River and along the Richardson Highway (Figure 4). Any alternative that is selected cannot induce flood damages to this area above the baseline condition. Otherwise, mitigation measures, either structural or nonstructural; need to be implemented.

3.2 Climatology

Valdez is in a gulf coast maritime climate zone which is characterized by a rainy atmosphere, long, cold winters, and mild summers (DCRA, 2021). Due to the amount of heavy precipitation and low temperatures leads to numerous mountain glaciers within the surrounding coastal mountains. The Alaska Climate Research Center has climate normals from 1991-2020, provided by the National Climatic Data Center, for mean annual temperature and total precipitation for the City of Valdez, and 1981-2010 climate normals for total snowfall (Table 1).

Table 1. Climate data for the City of Valdez.

Month	Mean Temperature (°F)	Total Precipitation (Inches)	Snowfall (Inches)
January	20.7	9	67.8
February	23.7	6.98	61.3
March	26.3	5.18	48.4
April	36.2	4.55	21
May	44.7	3.38	1.9
June	52.3	4.47	0
July	55.1	3.44	0
August	53.8	7.29	0
September	46.0	11.15	0.5
October	36.4	9.25	10.7
November	26.2	9.28	42.8
December	20.5	8.13	71.9
Annual Average	**36.8**	**82.1**	**326.3**

3.3 Downstream Conditions

The Robe River discharges into the Lowe River approximately 1.3 river miles from where the Lowe River discharges into the Port of Valdez. The Robe River inlet elevation at the lake is 25.06 feet NAVD 88, and the outlet elevation at the Lowe River is 12.6 feet NAVD 88. Due to these elevation differences, potential backwater along the Lowe River would not impact the Robe River.

3.3.1 Tide Table

Tide datums at Port Valdez (NOAA Station ID 9454240) (Figure 5), referenced to mean lower low water (MLLW) and mean higher high water (MHHW), are provided in Table 2. The tidal datums shown below are based on the 1983-2001 tidal epoch.

Figure 5. Location of Port Valdez NOAA Tide Station

Table 2. Tidal datums, Valdez, Alaska.

Tide	Elevation (ft. MLLW NAVD 88)	Elevation (ft. MHHW NAVD 88)
Highest Observed Water Level	17.1	4.91
Mean Higher High Water	12.2	0.0
Mean High Water	11.2	-0.93
Mean Tide	6.5	-5.79
Mean Low Water	1.5	-10.64
Mean Lower Low Water	0.0	-12.15
Lowest Observed Water Level	-5.4	-17.59

3.3.2 Storm Surge

Since Port Valdez is a deep fjord, it does not experience significant storm surges due to wind stresses. Storm surge can be shown to be inversely dependent on water depth.

That is, for a given wind speed, storm surge is less in deep water than in shallow water. There may be a surge elevation between +2.1 feet and -1.2 feet on occasion due to atmospheric pressure differentials. However, there is also a 12.5-foot difference in elevation between the inlet and the outlet of the Robe River, with the inlet also being almost 8 feet above the highest observed water level. Therefore, storm surge and coastal water levels were determined to not have an impact on the water surface elevation in the Robe River where induced flooding to nearby residential areas are of concern.

3.3.3 Sea Level Change

USACE sea level change (SLC) projections for the City of Valdez, Alaska can be seen in Figure 6. All sea level change projections, excluding the high SLC, show a downward trend. A decrease in sea level over time should not impact the Robe Lake watershed. The high SLC curve shows a slight upward trend, with a maximum increase of -0.3 feet change to MSL. All trends may cause some impact to the model's boundary condition due to backwater effects on the Lowe River, but these would be minor. The Lowe River was also determined to not influence the stage on the Robe River in the area of concern near the residential development.

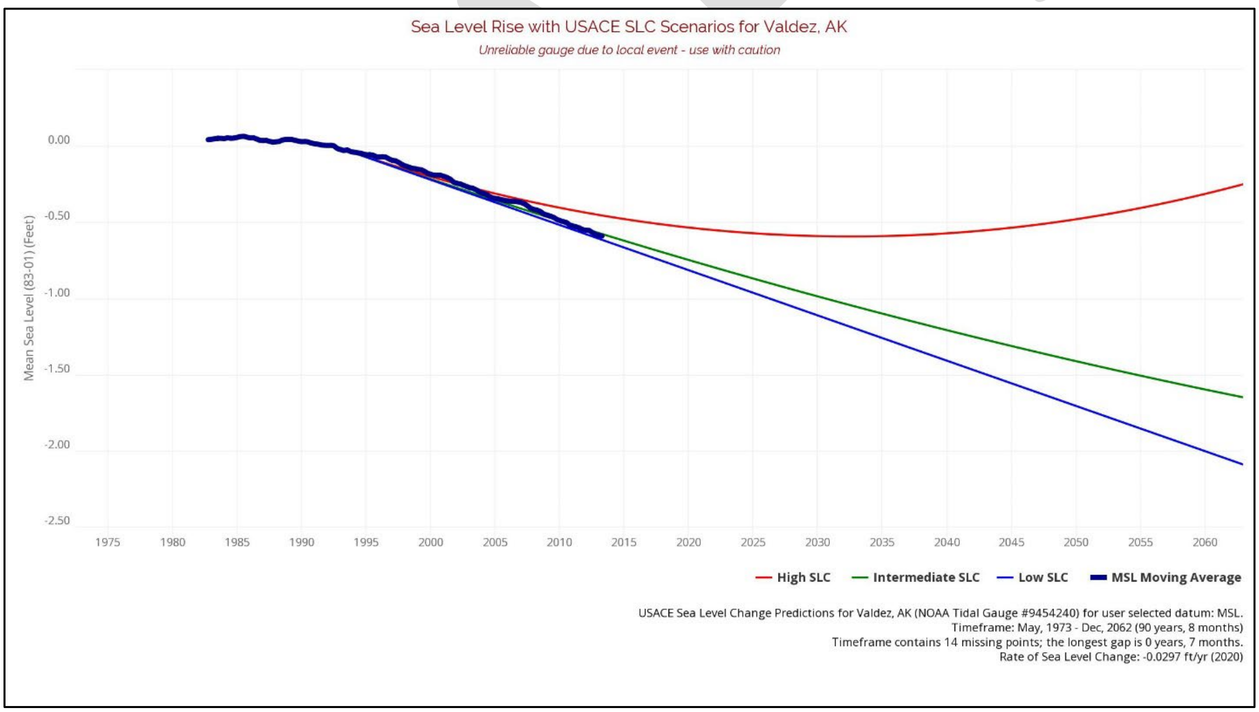

Figure 6. Sea level change projections for Valdez, Alaska.

3.4 USGS Regression Equations

The 2016 U.S. Geological Survey (USGS) Scientific Investigations Report 2016-5024, *Estimated Flood Magnitude and Frequency at Gaged and Ungaged Sites on Streams in Alaska and Conterminous Basins in Canada, Based on Data through Water Year 2012* reports regional regression equations for estimating annual exceedance-probability discharges for unregulated streams in Alaska and conterminous basins in Canada (Figure 7).

[**Regional regression equation:** DRNAREA, drainage area, in square miles; PRECPRIS00, basin average mean annual precipitation, in inches, for 1971 to 2000 from the PRISM climate dataset. **AVP:** Average variance of prediction. **SEP:** Average standard error of prediction. R^2_{pseudo}**:** pseudo coefficient of determination]

Percent annual exceedance probability	Regional regression equation for estimating annual exceedance probability discharge, in cubic feet per second[1,2]	AVP (log units)	SEP (percent)	R^2_{pseudo} (percent)
50	$0.944\,(DRNAREA)^{0.836}(PRECPRIS00)^{1.023}$	0.077	70.8	91.1
20	$2.47\,(DRNAREA)^{0.795}(PRECPRIS00)^{0.916}$	0.074	69.1	90.6
10	$4.01\,(DRNAREA)^{0.775}(PRECPRIS00)^{0.865}$	0.074	69.2	90.0
4	$6.53\,(DRNAREA)^{0.755}(PRECPRIS00)^{0.816}$	0.077	71.2	89.0
2	$8.79\,(DRNAREA)^{0.743}(PRECPRIS00)^{0.787}$	0.080	72.8	88.2
1	$11.4\,(DRNAREA)^{0.732}\,(PRECPRIS00)^{0.764}$	0.083	74.6	87.4
0.5	$14.3\,(DRNAREA)^{0.723}(PRECPRIS00)^{0.744}$	0.089	77.4	86.3
0.2	$18.7\,(DRNAREA)^{0.712}(PRECPRIS00)^{0.721}$	0.097	81.9	84.7

[1]Equations are valid for DRNAREA between 0.4 and 1,000 mi^2 with PRECPRIS00 between 8 and 280 in. and for DRNAREA greater than 1,000 and less than 31,100 mi^2 with PRECPRIS00 between 10 and 111 in.

[2]Equations are not suitable for use in the Aleutian Islands and other islands outside the study area.

Figure 7. Regional regression equations for estimating annual exceedance probability discharges on unregulated streams in Alaska.

The drainage area was taken from the USGS National Water Information System. The precipitation for each drainage area was determined using the PRISM dataset for the basin average annual precipitation for Alaska from 1971-2000. The Corbin Creek watershed (HUC 190202010804) has a drainage area of 19.9 square miles and the average annual precipitation based on the PRISM dataset is 64.8 inches. The discharges in cubic feet per second (CFS) are calculated for each annual exceedance probability (AEP) using the regression equations is given in Table 3.

Table 3. Discharges from 2016 USGS regional regression equations.

		Discharge (CFS)
AEP	**Return Period (Years)**	**Corbin Creek**
0.2	2	820
0.5	5	1210
0.1	10	1500
0.04	25	1880
0.02	50	2160
0.01	100	2470
0.005	200	2770
0.002	500	3180

3.5 FEMA FIS

The Federal Emergency Management Agency (FEMA) performed a flood insurance study in 2011, that was later revised in 2019, for the City of Valdez. Table 4 shows the peak discharges calculated by FEMA. Old Corbin Creek, Deep Creek, and Brownie Creek were not part of the analysis. FEMA used a 1D model and only modeled extents south of the outlet of Robe Lake on the Robe River (Figure 8). Since inflows were not considered from any of the tributary creeks into Robe Lake, the FEMA flood map extents were used as a rough form of model calibration. Extents and magnitude of flooding were anticipated to be greater due to inclusion of the inflows from Old Corbin Creek and Brownie Creek. No other flood information (such as high-water marks (HWMs) are available to use for model calibration purposes.

Figure 8. FEMA National Flood Hazard Map layer for Robe River.

Table 4. Peak discharges calculated by FEMA.

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Mineral Creek	Approximately 3.5 miles upstream of confluence with Port Valdez	41	4,338	5,314	6,066	6,826	8,695
Mineral Creek	Approximately 5.0 Miles upstream of confluence with Port Valdez	32	4,195	5,041	5,691	6,334	7,920
Robe River	Just upstream of the confluence with Port Valdez	10	511	620	707	795	1021
Robe River	Approximately 0.6 miles upstream of the confluence with Port Valdez	8	430	523	596	670	861
Valdez Glacier Stream	Just upstream of confluence with Port Valdez	152	14,064	16,788	18,901	20,973	26,160
Valdez Glacier Stream	Approximately 0.8 miles upstream of the confluence with Port Valdez	152	14,029	16,746	18,854	20,920	26,095
Valdez Glacier Stream	Approximately 1.3 miles upstream of the confluence with Port Valdez	130	12,601	15,011	16,877	18,705	23,274

3.6 Hydrograph for Unsteady Flow Analysis

There are no gages on any of the creeks that flow into Robe Lake. The closest gage with instantaneous flow measurements in the area that would most closely resemble the hydrograph for Corbin Creek is the gage located on the Solomon Gulch Bypass (USGS gage 15225998; Figure 9). Solomon Gulch Bypass is of similar size and slope to Corbin Creek and is also glacially fed. The 30-minute instantaneous flow data is available from 1991-1994. The hydrographs were similar over the four-year period, so the event from 21-29 August 1992, was chosen for the unsteady analysis within HEC-RAS (Figure 10). Since no other gage information was available, this hydrograph was used and scaled to the flows determined for Corbin Creek from the USGS regression equations listed in Table 3.

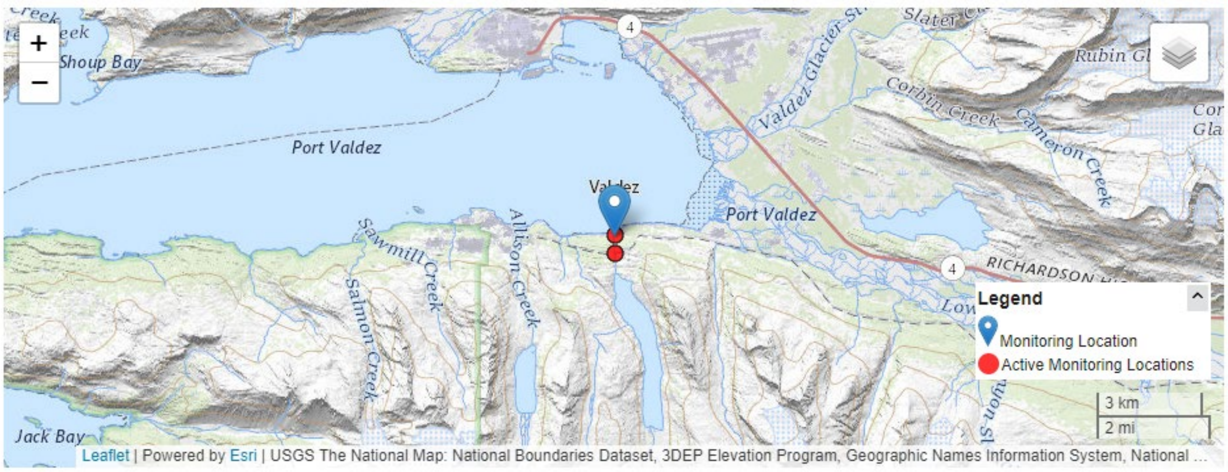

Figure 9. Solomon Gulch Bypass gage location (USGS).

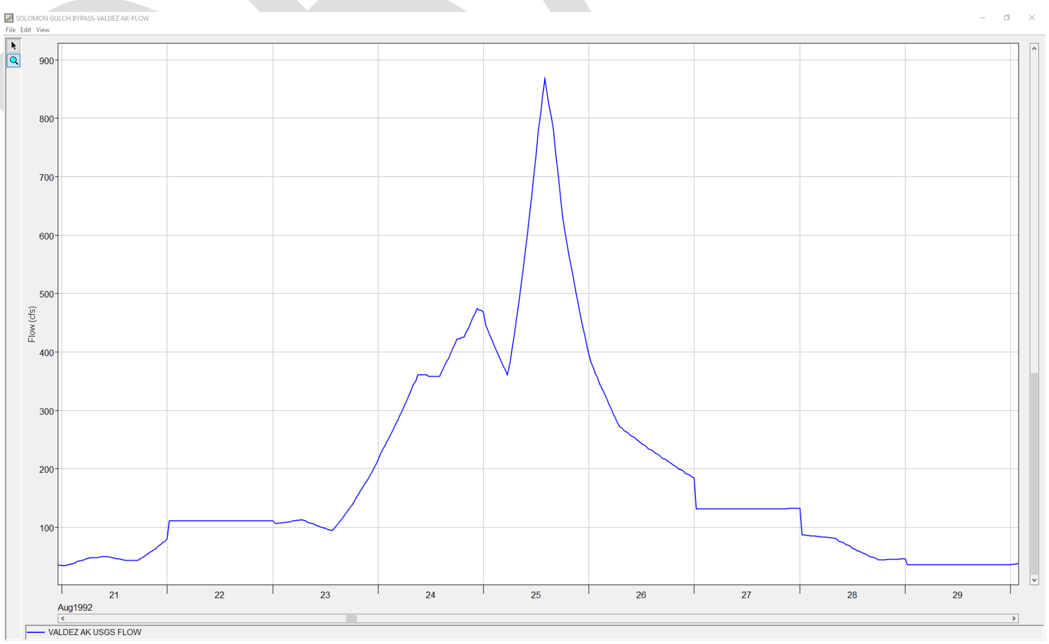

Figure 10. USGS flow hydrograph for Solomon Gulch Bypass in Valdez, Alaska.

3.7 Climate Change

3.7.1 Climate Change Impacts to Valdez

The analysis of climate change was conducted in accordance with Engineering and Construction Bulletin (ECB) 2018-14, *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects*. The publication *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Water Resources Region 19, Alaska, 2015*, was used in this analysis. The Climate Hydrology Assessment Tool and the Vulnerability Assessment tool described in the ECB was not used because the HUC-4 units that cover Alaska are not included in the tool's database.

Climate in the project area is projected to change over this century. Temperatures are expected to increase for the Alaska Region. Higher winter temperatures could bring more precipitation as snowfall is converted to rain. Qualitatively, this would lead to a reduction in snowpack and a longer rainfall driven season with flashier events due to rainfall and more rain on snow events. These effects are projected to be more prevalent in the latter part of the century as opposed to the early part.

According to the Fourth National Climate Assessment (USGRCP, 2018) annual average temperatures were variable from 1925 to the late 1970s, with no clear pattern of change. A trend of increasing temperatures starting in the late 1970s has been identified, at an average rate of 0.7°F per decade and is projected to continue throughout the state of Alaska. The largest temperature increases have been found in winter months with average minimum temperature increases of around 2°F statewide.

In the Region 19 Report, a consensus among the peer-reviewed literature emerged that indicates a warming trend for the Alaska Region, especially in the winter and spring seasons. The Region is experiencing warmer average winter temperatures, warmer average annual temperatures and earlier spring onset/longer growing seasons. Extreme cold temperatures have become less frequent while extreme warm temperatures have become more frequent.

The primary potential climate change impacts to the hydrology of Valdez would be changes to precipitation volumes. An increase in 24-hour precipitation would generally increase the frequency flow values for the basin.

Precipitation is expected to increase over the remainder of this century. In the Region 19 Report, there is general agreement of increases in projected annual precipitation, increased occurrence of large rain events, and a corresponding increase of dry days in the Alaska Region. This will result in a projected increase of runoff.

Annual maximum 1-day precipitation is projected to increase by 5%–10% in southeastern Alaska and by more than 15% in the rest of the state, although the longest dry and wet spells are not expected to change over most of the state.

Temperature increases are being observed and are projected to continue increasing in the future. This will result in a shift in the timing of snowmelt runoff to earlier in the year. Shifts in the hydrological regime due to glacier melting will alter stream water volume, water temperature, runoff timing, and aquatic ecosystems (USGRCP, 2018). Heavy precipitation events are also projected to increase, and if they were to occur concurrently with a high snowmelt event, it could increase the severity of floods seen in Valdez from increased runoff and larger volumes of water.

3.7.2 Nonstationarity Analysis

According to the Fourth National Climate Assessment (USGRCP, 2018), evidence for changes in maximum gauged streamflow's is mixed, with a majority of locations having no significant trend. There is the significance for seasonal changes in the timing of peak flows in Alaska, though increases in the absolute magnitude are not evident in existing data.

To investigate whether a trend of changing peak annual flow is occurring in Valdez, the Solomon Gulch Tailrace near Valdez gage record (USGS 15225996) was tested using the Nonstationary Detection Tool in accordance with Engineering Technical Letter 1110-2-3 (Figure 11). The tool notes four abrupt nonstationarities in the data set.

The gage record for the Solomon Gulch Tailrace near Valdez gage includes peak annual stream flow from 1987 to 2016, which is a 29-year period of record. The gage captures a drainage area of 19.2 square miles and is located roughly 3 miles due east from the confluence of the Robe River and Lowe River. Monotonic trend analysis of this period detected a significant trend using the Mann- Kendall Test at a 0.05 level of significance (exact p-value of 0.0000085831), the Spearman Rank Order Test at the 0.05 level of significance (p-value of 0.000004384) and using the t-Test at a 0.05 level of significance (p-value of 0.000002688). A positive trend was detected using traditional slope methods and the Sen's Slope method (Figure 12). With volumes of discharge expected to increase over time, it is not known what relationship this will have on peak flow magnitudes.

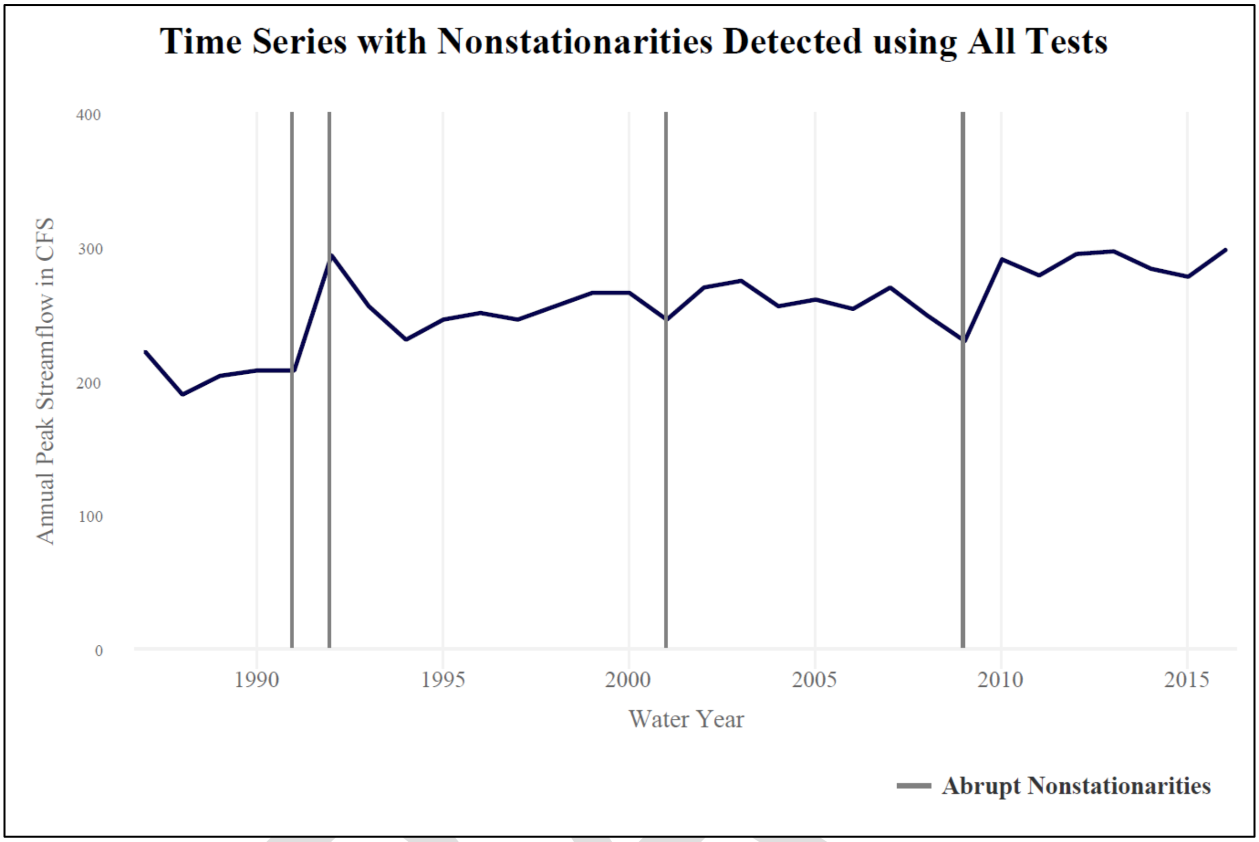

Figure 11: Nonstationarity detection tool results for the Solomon Gulch Tailrace near Valdez gage.

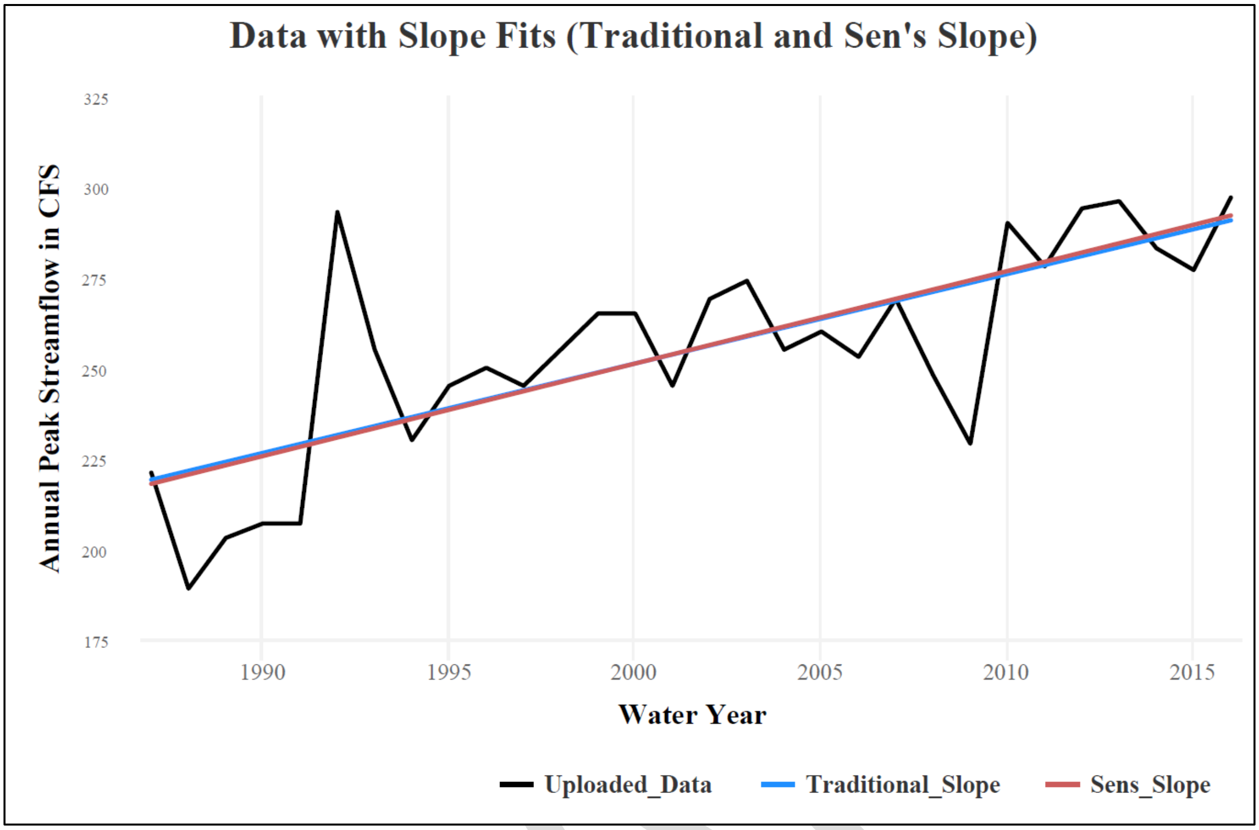

Figure 12. Annual peak stream flow (CFS) with traditional and Sen's Slope fit.

3.7.3 Climate Risks

ECB 2018-14 requires the evaluation of the risk climate change poses to the project features. Table 5 illustrates the features under consideration in this project and how they may be affected by climate change.

Table 5: Climate change risk for each alternative.

<table>
<tr><th>Feature</th><th>Trigger</th><th>Hazard</th><th>Harm</th><th>Qualitative Likelihood</th></tr>
<tr><td>Alternative A</td><td rowspan="4">Increases in the frequency and magnitude of precipitation (storms larger and more intense)</td><td rowspan="4">Increases in flood discharge and stage frequency</td><td>Increased possibility of overtopping, seepage issues, erosion, and flood extents</td><td rowspan="4">Low</td></tr>
<tr><td>Alternative B</td><td>Increased possibility of overtopping, seepage issues, erosion, and flood extents</td></tr>
<tr><td>Alternative C</td><td>Increased possibility of weir failure</td></tr>
<tr><td>Alternative D</td><td>Increased possibility of overtopping, seepage issues and erosion</td></tr>
</table>

4.0 ALTERNATIVE PLANS

Different alternatives were developed to restore and improve the habitat within Robe Lake to a less degraded state while ensuring flood levels do not increase from the future without project condition levels. Four main alternatives were modeled using the hydrologic engineering centers river analysis system (HEC-RAS) (see Section 5), with some of the alternatives having sub-alternatives with slight variations. Figure 14-Figure 15Figure 16 show the layout of the alternatives. Prior to the gravel berm being constructed in the 1950's (Figure 13) that diverted Corbin Creek into Valdez Glacier Stream, macrophytes were not an issue, and this was hypothesized to be due to the cold, turbid, glacial water that was entering the lake. Thus, the focus of these alternatives was to divert a portion or all the flow from Corbin Creek back into Robe Lake through either Old Corbin Creek or Brownie Creek. To divert all the flow, a dike would be implemented; and to divert a portion of the flow, a weir would be used. To ensure flooding was not induced, different scenarios were modeled for the culverts under the Richardson Highway (Figure 16).

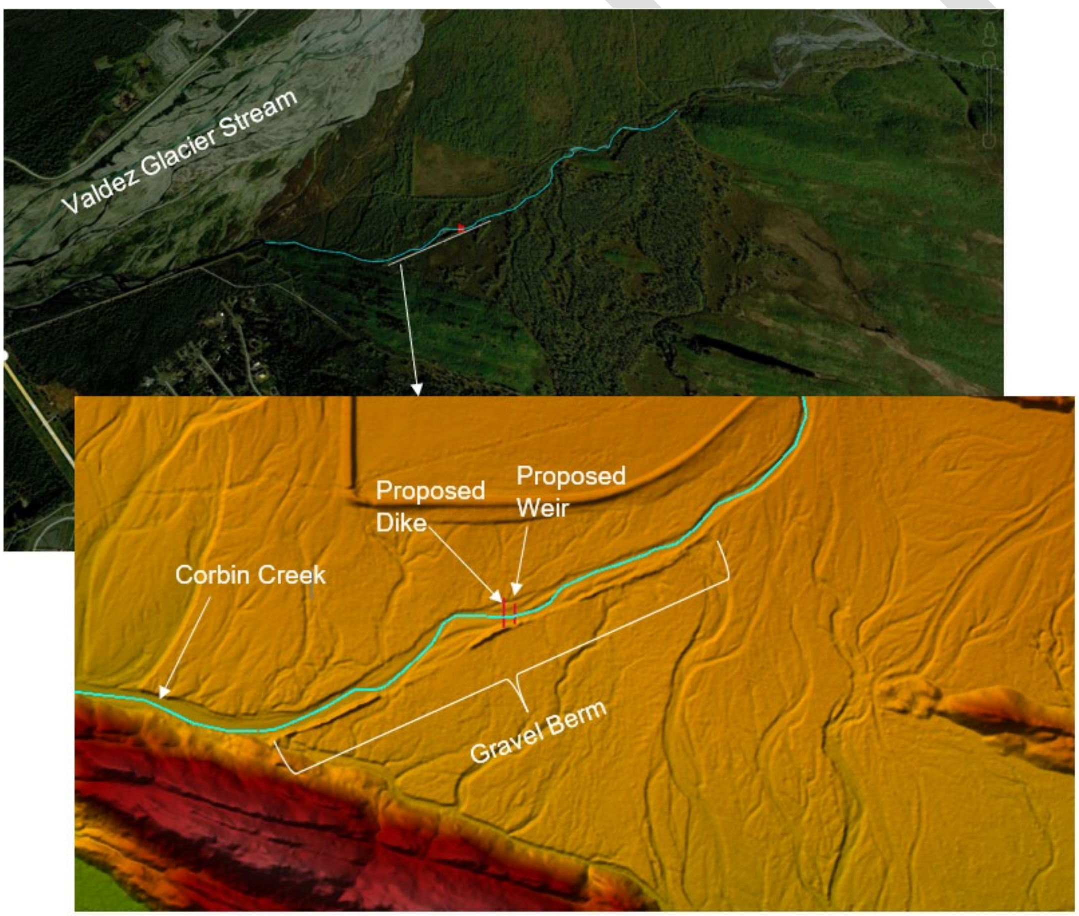

Figure 13.Gravel Berm Location

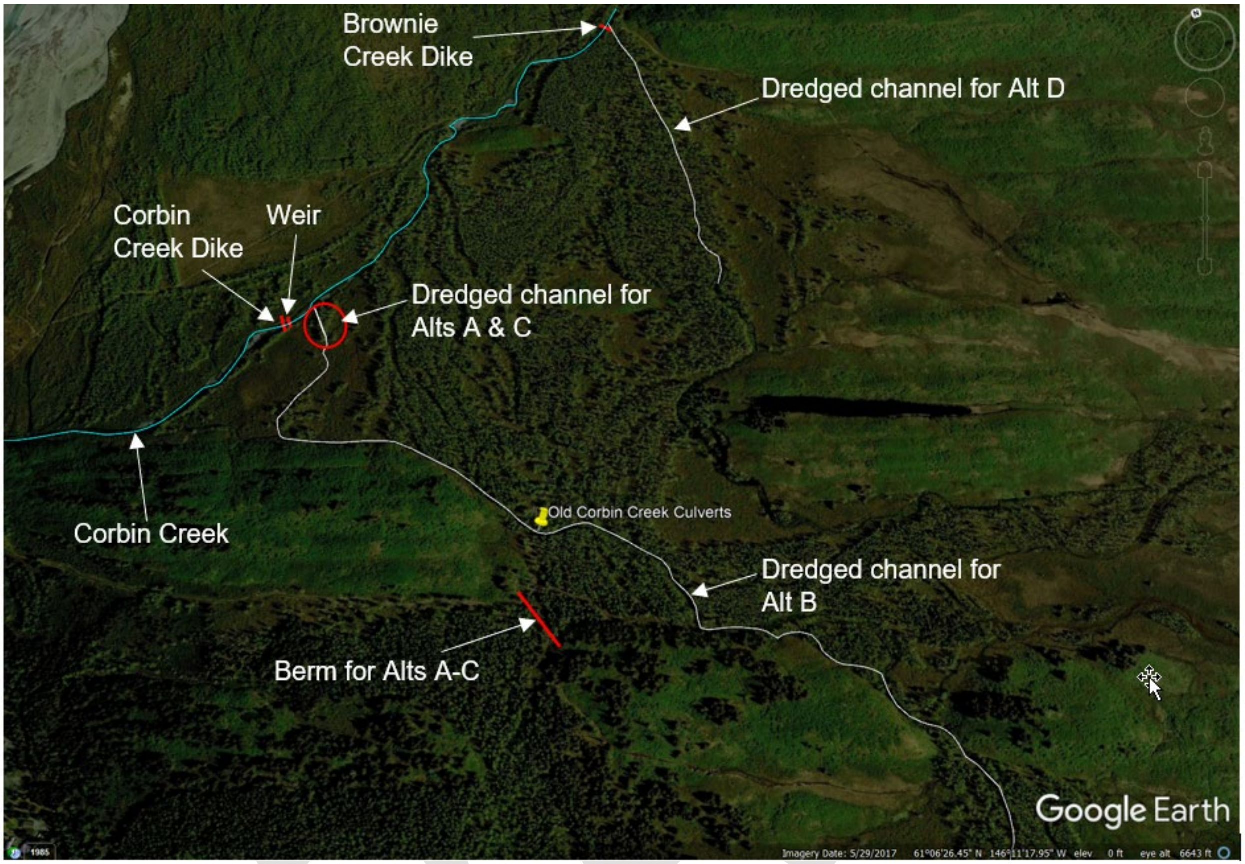

Figure 14. Layout of the array of alternatives considered.

Figure 15. Full extent view of the 1.5-mile-long dredged channel on Old Corbin Creek for Alternative B.

Figure 16. Location of culverts at the Robe River crossing under the Richardson Highway.

4.1 Alternative A

A training dike (Figure 17) will be constructed across Corbin Creek to divert all the flow into Old Corbin Creek. The dike will be 7 feet high and 250 feet long with 3H:1V side slopes with an armored toe and 10-foot crest width. The armor rock (A rock) will have median rock size of 1,200 pounds, B rock has a median rock size of 120 pounds, and the C rock (core rock) will have rock less than 120 lbs. A 275-foot-long channel will need to be excavated to connect the relic channel of Old Corbin Creek to Corbin Creek. The channel will be 30 feet wide, 3 feet deep, and have 3H:1V side slopes. The culverts under ALPETCO trail on Old Corbin Creek will be replaced with a trail bridge. A 450-foot-long berm (Figure 18) will be placed in the low-lying area between the two bluffs near the Old Corbin Creek culverts to prevent overland flow from entering old relic channels that flow towards the Valdez subdivision. See Figure 14 for locations.

Three different options for the culverts at the Robe River crossing under the Richardson Highway (Figure 16) were proposed and modeled. The first was keeping the culverts and not making any changes to this area (Alternative A-1). The second was replacing the two culverts for new culverts of the same size and adding an additional 12.75-foot diameter CMP culvert next to them to convey more flow (Alternative A-2). The third was replacing the culverts with three new 14-foot diameter CMP culverts (Alternative A-3).

4.2 Alternative B

A training dike (Figure 17) will be constructed across Corbin Creek to divert all the flow into Old Corbin Creek. The dike will be 7 feet high (84' NAVD88) and 250 feet long with 3H:1V side slopes with an armored toe and 10-foot crest width. The armor rock (A rock) will have median rock size of 1,200 pounds, B rock has a median rock size of 120 pounds, and the C rock (core rock) will have rock less than 120 lbs. A 275-foot-long channel will need to be excavated to connect the relic channel of Old Corbin Creek to Corbin Creek. The channel will be 30 feet wide, 3 feet deep, and have 3H:1V side slopes. Additionally, roughly 1.5 miles (8,237 feet) of the relic channel of Old Corbin Creek will be excavated to a depth of 3 feet and be 12 feet wide with 2H:1V side slopes. The culverts under ALPETCO trail on Old Corbin Creek will be replaced with a trail bridge. A 450-foot-long berm (Figure 18) will be placed in the low-lying area between the two bluffs near the Old Corbin Creek culverts to prevent overland flow from entering old relic channels that flow towards the Valdez subdivision. See Figure 14 and Figure 15 for locations.

Three different options for the culverts at the Robe River crossing under the Richardson Highway (Figure 16) were proposed and modeled. The first was replacing the two culverts under the Richardson Highway with a 50-foot span DOT designed bridge (Alternative B-1). The second was replacing the two culverts for new culverts of the same size and adding an additional 12.75-foot diameter CMP culvert next to them to convey more flow (Alternative B-2). The third was replacing the culverts with three new 14-foot diameter CMP culverts (Alternative B-3).

4.3 Alternative C

Flow will be diverted into Old Corbin Creek using a weir. The broad crested weir will be constructed on Corbin Creek out of sheet pile, with rock placed on either side for scour protection, and will need to be 2.7 feet high (78.9 feet NAVD88), 65 feet long and 1-foot thick. Flow will spill over into Corbin Creek at the roughly 25-year flow event. A 275-foot-long channel will need to be dredged to connect the relic channel of Old Corbin Creek to Corbin Creek. The channel will be 30 feet wide, 3 feet deep, and have 3H:1V side slopes. The culverts under ALPETCO trail on Old Corbin Creek will be replaced with a trail bridge. A 450-foot-long berm (Figure 18) will be placed in the low-lying area between the two bluffs near the Old Corbin Creek culverts to prevent overland flow from entering old relic channels that flow towards the Valdez subdivision. See Figure 14 for locations.

4.4 Alternative D

A training dike (Figure 17) will be constructed across Corbin Creek to divert all the flow into Brownie Creek. The dike will be 10 feet high (112 feet NAVD88) and 300 feet long with 3H:1V side slopes, an armored toe, and a 10-foot crest width. The armor rock (A rock) will have median rock size of 1,200 pounds, B rock has a median rock size of 120 pounds, and the C rock (core rock) will have rock less than 120 lbs. A 3,115-foot-long channel will need to be excavated to connect the relic Brownie Creek to Corbin Creek. The channel will be 30 feet wide, 3 feet deep, and have 3H:1V side slopes. See Figure 14 for locations.

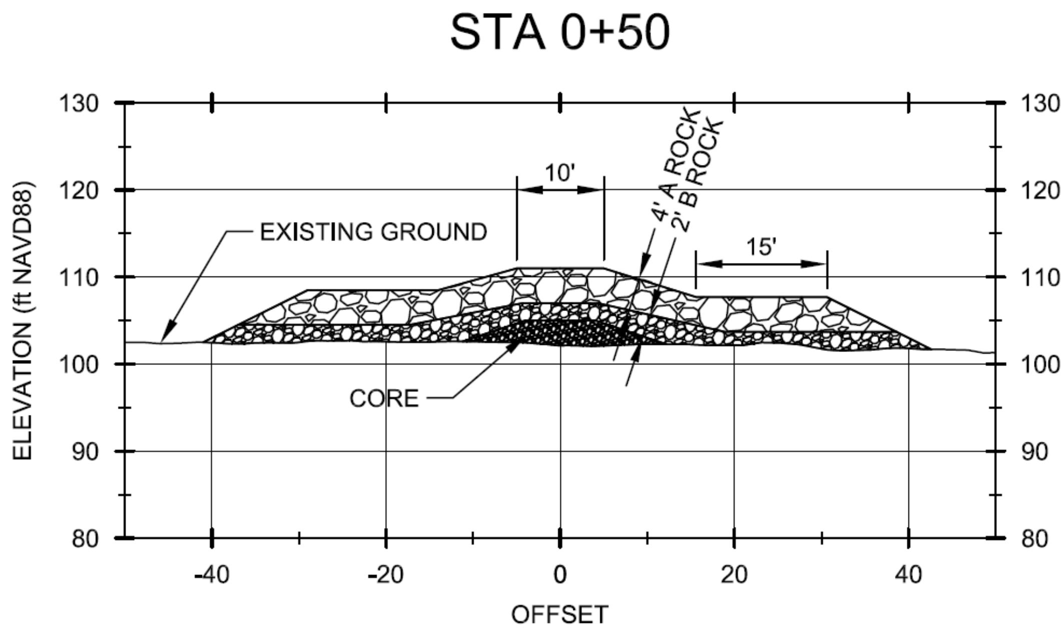

Figure 17. Old Corbin Creek and Brownie Creek diversion training dike cross section.

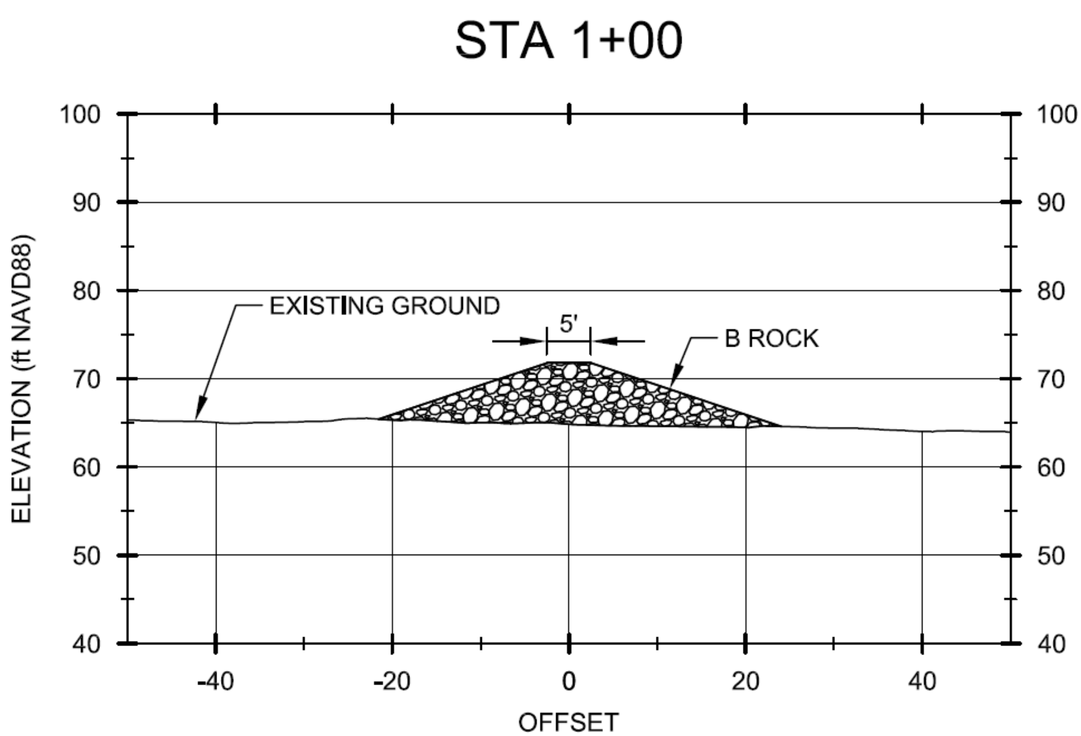

Figure 18. 450-foot-long berm cross section.

5.0 NUMERICAL MODEL STUDIES

The Hydrologic Engineering Centers Riverine Analysis System software (HEC-RAS) version 6.3.1 was used to model the effectiveness of alternatives for Robe Lake and to determine flood extents associated with each flood event.

5.1 Elevation Data

Elevation data for the model grid was from two different Light Detection and Ranging (LiDAR) surveys of Valdez collected in 2012 and 2019. The horizontal datum for the surveys were Alaska State Plane Zone 3, US survey feet, and the vertical datum was NAVD88, US survey feet. The 2019 LiDAR had 1.5 feet grid cell sizes but did not cover the entire extent of the project. Whereas the 2012 LiDAR had 3.28 feet grid cell sizes but covered the entire extent of the project. For more accurate results, the two terrains were merged using HEC-RAS, making sure the finer cell size from the 2019 LiDAR was kept for the areas where the two overlapped (Figure 19).

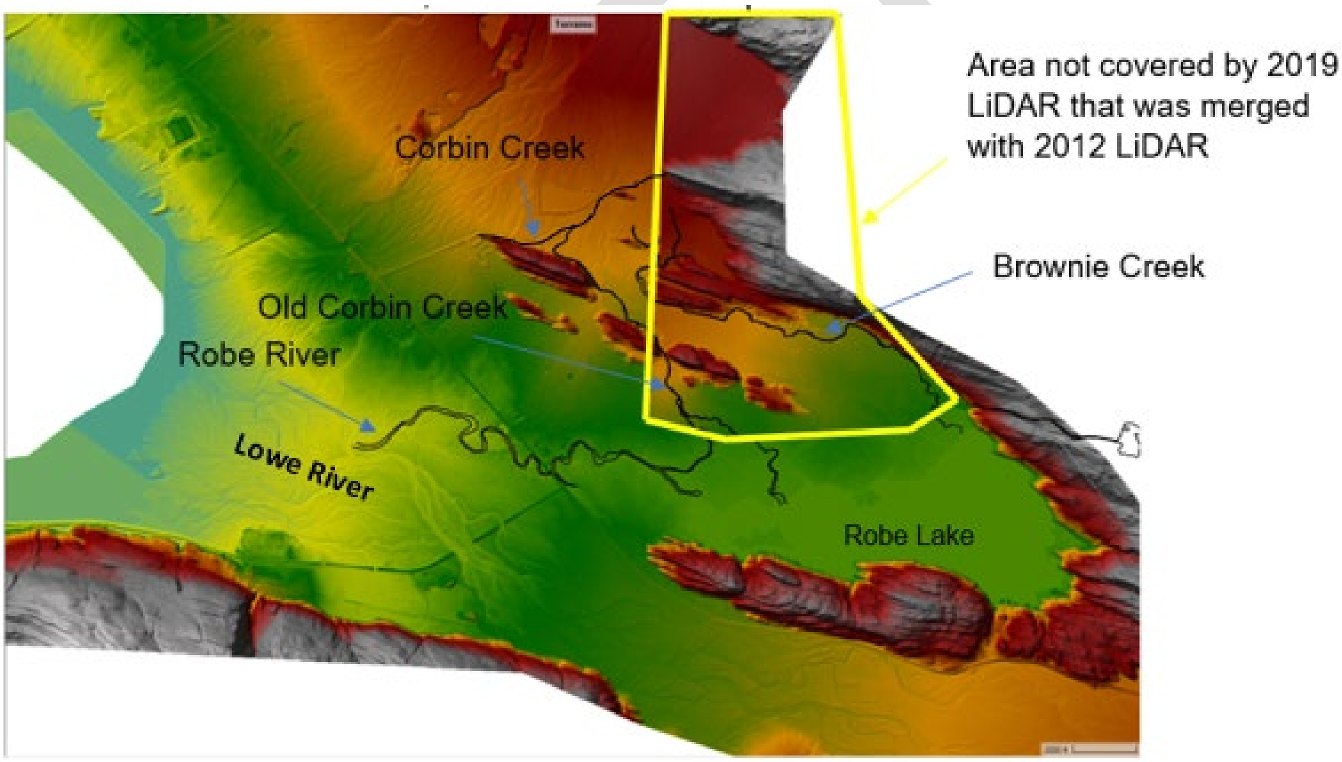

Figure 19. LiDAR merged area.

5.2 Model Domain and Boundary Conditions

The model domain covers the extents of the low-lying areas of the Robe Lake watershed and included the Robe River (Figure 20). The upstream boundary of the model was located on Corbin Creek roughly 2 miles upstream from the Richardson Highway. The downstream boundaries of the model were located approximately three quarters of a mile upstream from the Richardson Highway on Corbin Creek and 1.8 miles downstream of the Richardson Highway where the Robe River reaches the confluence with the Lowe River, respectively.

The upstream boundary condition for Corbin Creek is an inflow hydrograph using the scaled hydrograph discussed in section 3.0 VALDEZ HYDROLOGY. Unsteady flow conditions were used, and the inflow hydrographs were scaled based on the flows in Table 3. The downstream boundary condition for both Corbin Creek and the Robe River were based on normal depth, with friction slopes of 0.0046 and 0.0016 ft/ft, respectively.

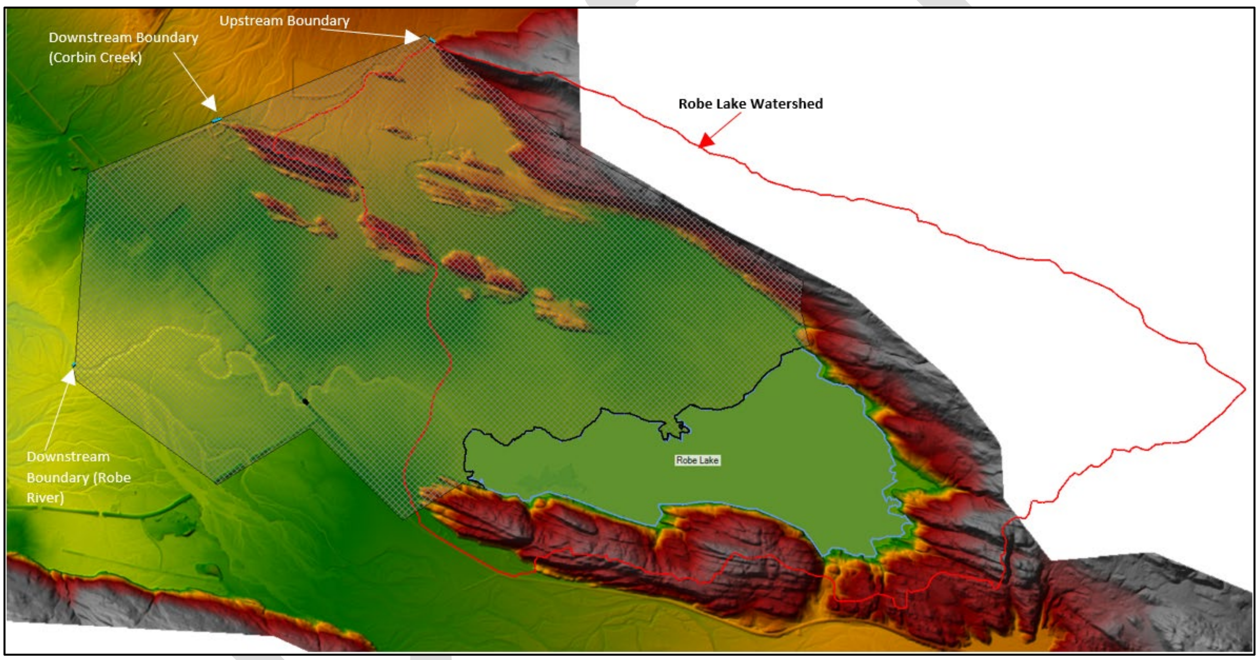

Figure 20. Robe Lake HEC-RAS model domain extents.

5.3 Channel Bathymetry and Culverts

Channel bathymetries for Corbin Creek, Robe River, Old Corbin Creek, and Brownie Creek were based on data gathered from gages that were deployed on each creek/river on June 4, 2020, to collect a years' worth of flow and channel measurements. This was done by Inter-Fluve out of Hood Oregon for the *Robe Lake Habitat Analysis Report* that was completed in October 2021. The Robe River gage was installed upstream of the two 12.75 foot-diameter corrugated metal pipe (CMP) culverts beneath the Richardson Highway (Figure 22). The Old Corbin Creek gage was installed in a pool upstream of the ALPETCO trail near the two 24 inch-diameter CMP culverts that go beneath the trail (Figure 23). The Brownie Creek gage was installed near a beaver complex on the 0.3-mile reach closest to the ALPETCO trail. The Corbin Creek gage was installed where bedrock outcrops form a pool with a sheltered embayment. The Brownie Creek, Old Corbin Creek, and Corbin Creek gages can be seen in Figure 21. The culverts under the Richardson Highway and on Old Corbin Creek under the ALPETCO trail were included in the model, except for alternatives where they were to be taken out.

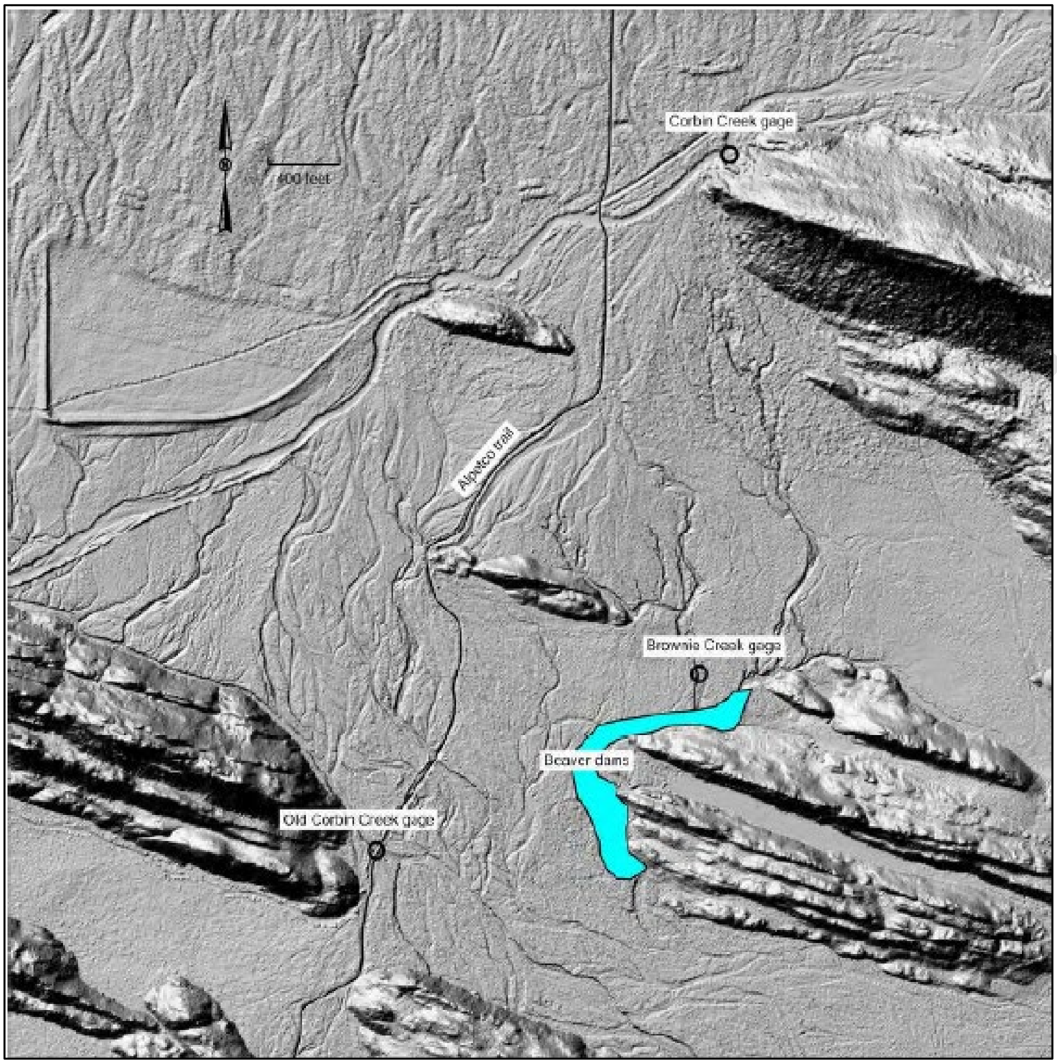

Figure 21. Upper basin stream gage locations.

Figure 22. Robe River culverts under the Richardson Highway.

Figure 23. Old Corbin Creek culverts under the ALPETCO trail.

Channel depth and width were measured as part of the gage readings. The width along with the mean depth from each gage was used as the channel bathymetry that was burned into the LiDAR. Since no other bathymetry information was available for these bodies of water, these values were kept consistent over the entire length of each creek/river for the future without project conditions (Table 6).

Table 6. Channel bathymetry.

Gage	Width (ft)	Mean Depth (ft)
Old Corbin Creek	12.1	0.54
Brownie Creek	12.35	0.73
Corbin Creek	38.0	1.06
Robe River	48.3	0.96

5.4 Terrain and Roughness

The 2D area was based on a 50-ft square grid using the bare earth terrain model. Manning's n values varied depending on the land use type. The National Land Cover Database (NLCD) 2016 layer was imported into RAS. The Manning's n value associated with each land use layer were chosen based on typical value ranges reported in the Technical Manual for Dams (MMC, 2020) (Table 7).

Table 7. Manning's n values used in HEC-RAS model.

NLCD Land Use Classification	Manning's n Value
Open Water	0.03
Developed, Low Intensity	0.05
Developed, Medium Intensity	0.055
Developed, High Intensity	0.07
Barren Land Rock/Sand/Clay	0.03
Deciduous Forest	0.17
Evergreen Forest	0.16
Mixed Forest	0.19
Shrub/Scrub	0.1
Sedge-Herbaceous	0.07
Dwarf Scrub	0.07
Woody Wetlands	0.08
Emergent Herbaceous Wetlands	0.07

Manning's n values for Corbin Creek, Old Corbin Creek, Brownie Creek, and the Robe River were inputted using calibration regions within the 2D editor of HEC-RAS. The values for these can be found in Table 8 and were determined based on Chow, 1959.

Table 8. Manning's n values used for creeks and rivers

Creek/River	Manning's n Value
Corbin Creek	0.05
Brownie Creek	0.07
Old Corbin Creek	0.07
Robe River	0.05
Dredged Portion of Brownie Creek (Alternative D)	0.05
Dredged Portions of Old Corbin Creek (Alternatives A, B, C)	0.05

5.5 Storage Area

Robe Lake was modeled as a storage area within HEC-RAS. The lake has an area of 618 acres and the volume-elevation curve that is based off the terrain can be seen in Figure 24. The 2D perimeter mesh is connected to Robe Lake via 2D/SA connectors, with elevations based off the terrain. These connectors run along the entire north section of the lake that is low lying. Anything to the east of the Robe River mouth was modeled as inflows to the lake, whereas the Robe River mouth and to the west of the mouth were modeled as outflows (Figure 25).

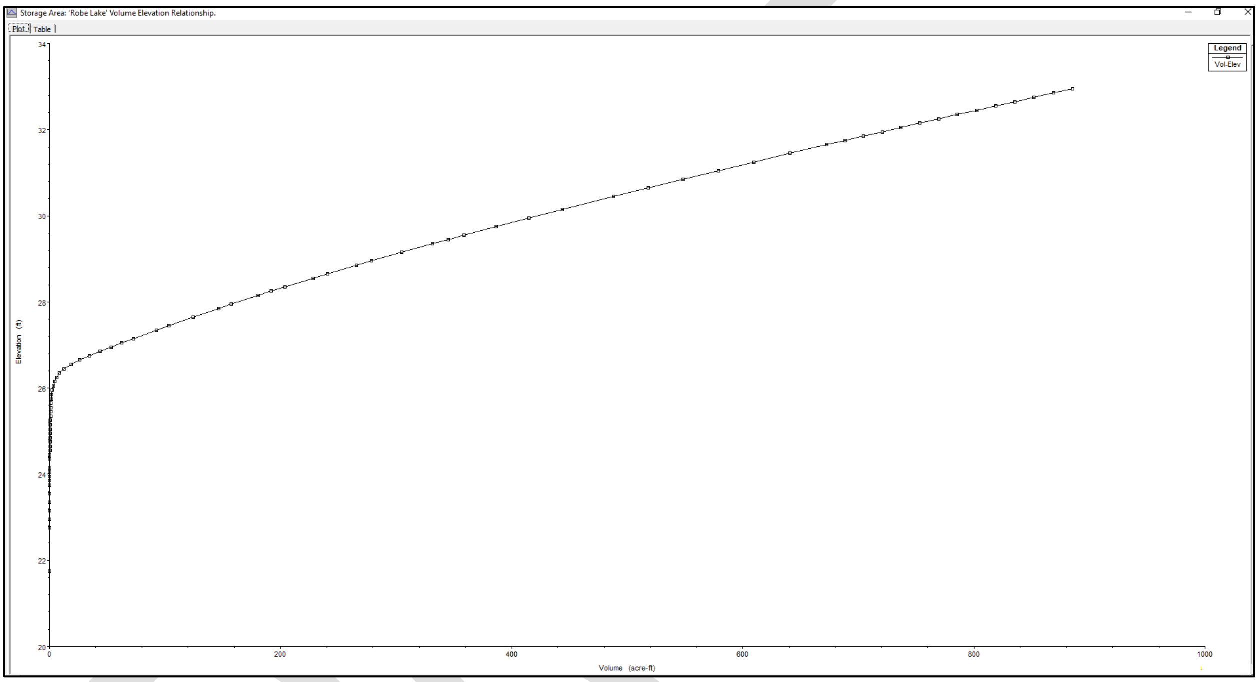

Figure 24. Volume-elevation curve for Robe Lake.

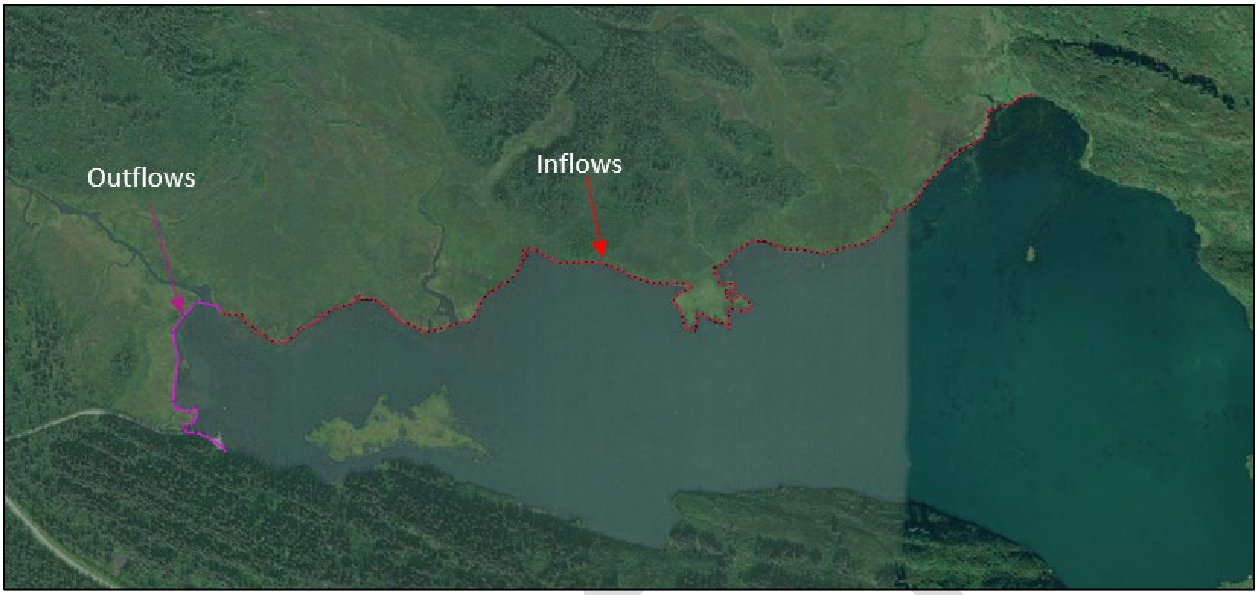

Figure 25. SA/2D connections to Robe Lake.

5.6 Model Output

Model simulation runs were performed for all eight annual exceedance probabilities (50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2); or the 2, 5, 10, 25, 50, 100, 200, and 500-year return periods, respectively, for the existing future without project (FWOP) conditions and the depth grid maps can be found at the end of this report in Appendix A. HDF grids were produced for economic analysis in HEC-FDA to compare the existing FWOP conditions against the different alternatives. The purpose of this comparison was to make sure that there were no areas with induced flooding from any of the proposed alternatives (Table 9). A node was chosen that was representative of the flooding in the area (Figure 26) and the depths and water surface elevations (WSEs) can be seen in Table 10.

Table 9. Number of Induced Structures

NUMBER OF INDUCED STRUCTURES

	1% Annual Exceedance Probability Flood		0.2% Annual Exceedance Probability Flood		Induced Flooding	Carried Through to CE/ICA?
	0.01-0.50 ft	> 0.50 ft	0.01-0.50 ft	> 0.50 ft		
Alternative A-1	1	2	2	5	Yes	No
Alternative A-2	0	0	2	0	Yes	No
Alternative A-3	0	0	0	0	No	Yes
Alternative B-1	0	0	0	0	No	Yes
Alternative B-2	0	0	2	0	Yes	No
Alternative B-3	0	0	0	0	No	Yes
Alternative C	1	2	3	4	Yes	No
Alternative D	1	2	2	3	Yes	No
Alternative F	0	0	0	0	No	Yes

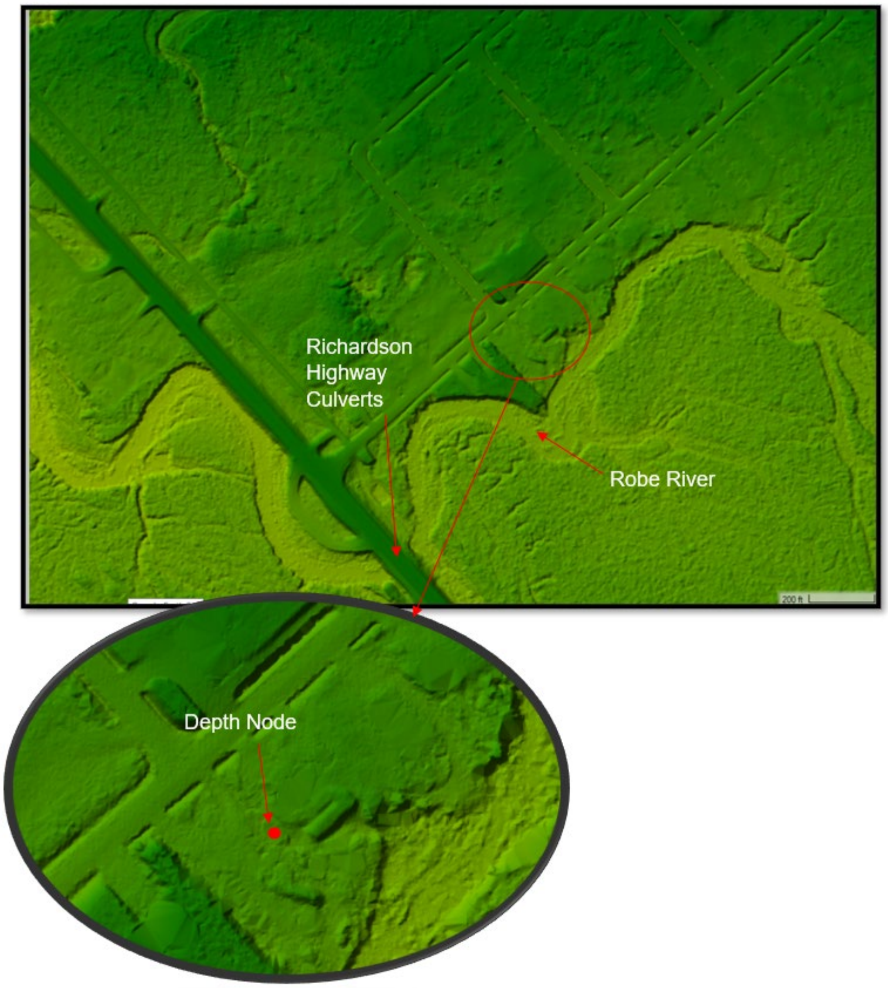

Figure 26. Depth Node Location

Table 10. Depth and WSE at Depth Node Location

	FWOP		Alternative A-1		Alternative A-2		Alternative A-3		Alternative B-1	
AEP (%)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)
50	0	0	0	0	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0	0
20	0	0	0	0	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0	0
10	0	0	0.71	28.59	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0	0
4	0.02	28.86	1.29	29.19	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0.07	27.96
2	0.45	28.37	1.71	29.59	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0.33	28.24
1	0.93	28.85	2.1	29.98	1.46	29.35	1.37	29.25	0.58	28.51
0.5	1.42	29.29	2.51	30.39	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0.86	28.76
0.2	1.96	29.85	3	30.89	2.31	30.19	2.19	30.07	1.17	29.07

	Alternative B-2		Alternative B-3		Alternative C		Alternative D			
AEP (%)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)	Depth (ft)	WSE (ft NAVD88)		
50	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0	0	0	0		
20	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0	0	0	0		
10	Not Modeled	Not Modeled	Not Modeled	Not Modeled	0.64	28.54	0.57	28.45		
4	Not Modeled	Not Modeled	Not Modeled	Not Modeled	1.21	29.11	1.06	28.94		
2	Not Modeled	Not Modeled	Not Modeled	Not Modeled	1.61	29.49	1.38	29.27		
1	1.45	29.34	1.35	29.24	2.00	29.88	1.71	29.61		
0.5	Not Modeled	Not Modeled	Not Modeled	Not Modeled	2.39	30.27	2.05	29.94		
0.2	1.97	30.16	2.16	30.05	2.88	30.76	2.47	30.37		

5.6.1 Future Without Project Conditions

The existing FWOP conditions HEC-RAS 1% and 0.2% annual exceedance probabilities for Robe Lake in Valdez are presented in Figure 27 and Figure 28. The full HEC-RAS profiles for all modeled FWOP conditions recurrence intervals in the Robe Lake study area are in the *HEC-RAS Output Attachment* at the end of this report in Appendix A.

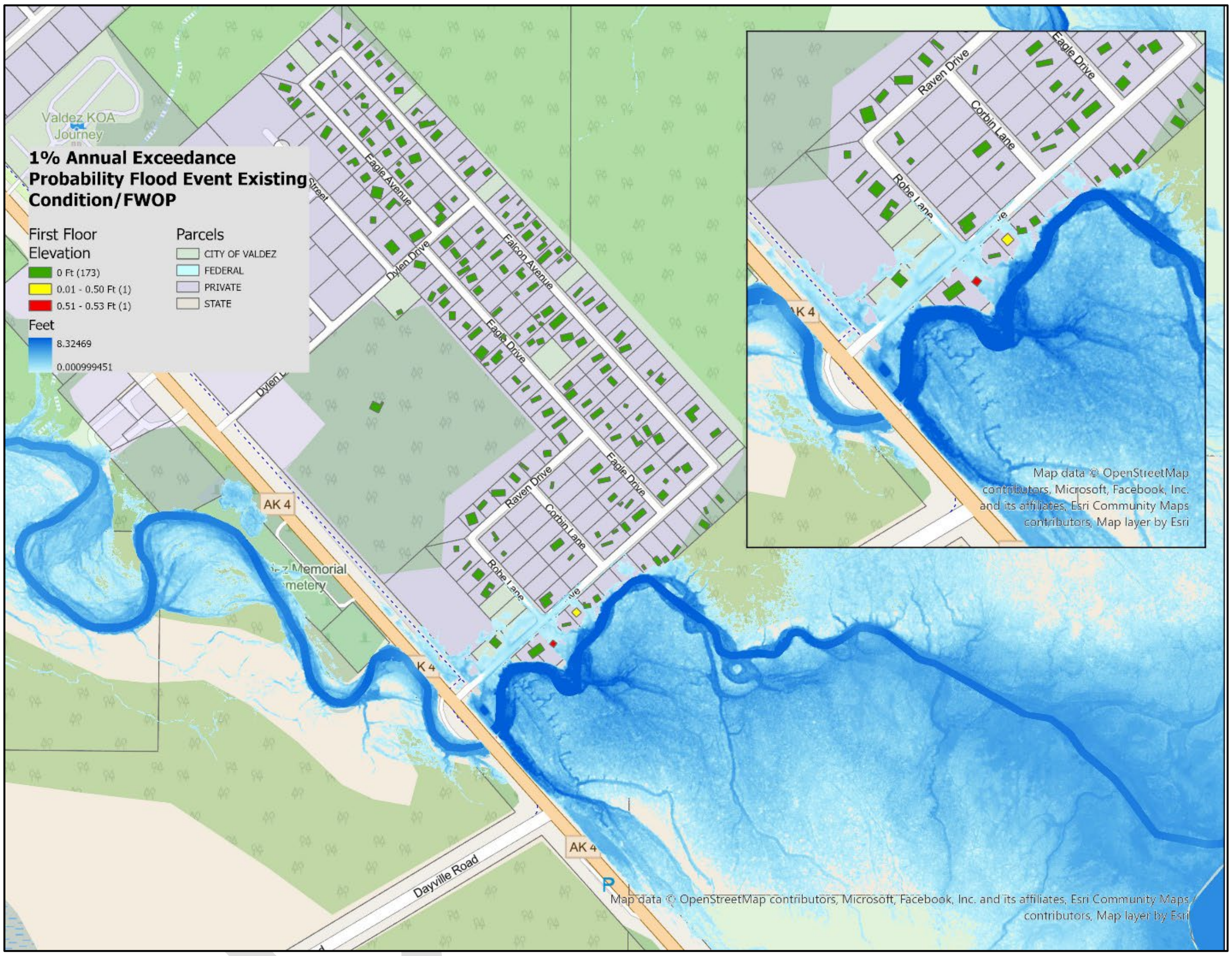

Figure 27. 1% annual exceedance probability for FWOP conditions.

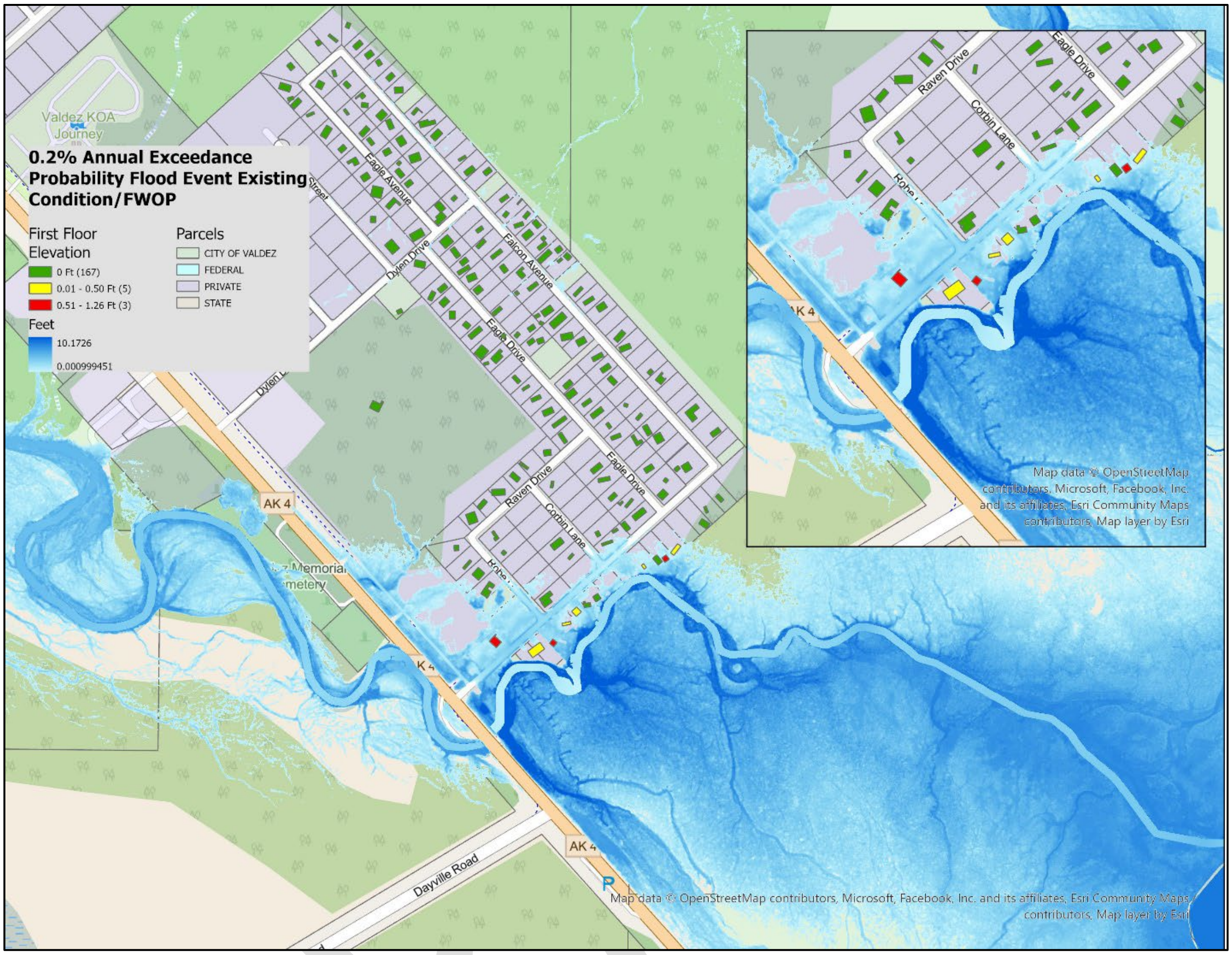

Figure 28. 0.2% annual exceedance probability for FWOP conditions.

5.6.2 Future With Project Conditions

The future with project conditions HEC-RAS 1% and 0.2% annual exceedance probability depth grids for Robe Lake are presented in Figures 29-44. The full HEC-RAS profiles for all modeled with-project conditions recurrence intervals in the Robe Lake study area are in the *HEC-RAS Output Attachment* at the end of this report in Appendix A.

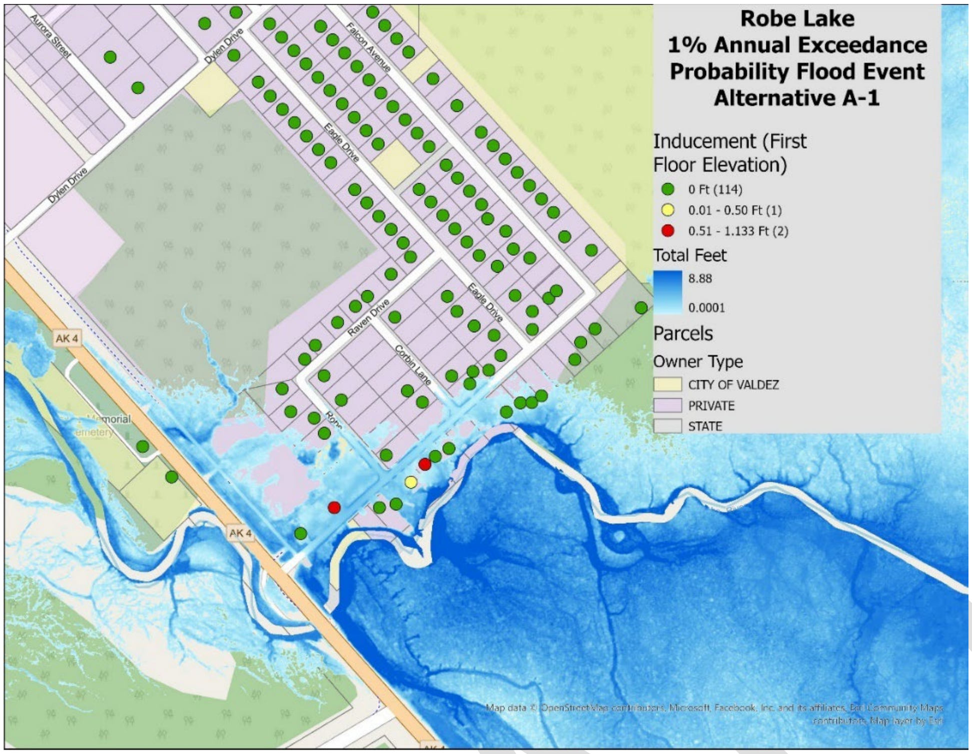

Figure 29. 1% annual exceedance probability for Alternative A-1.

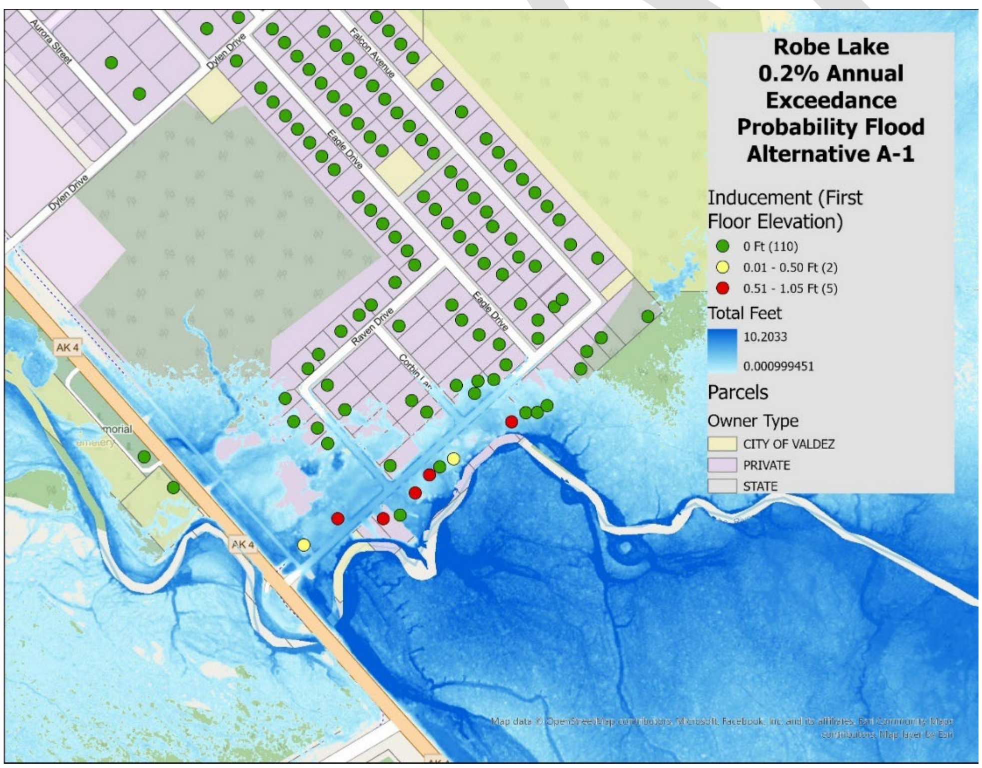

Figure 30. 0.2% annual exceedance probability for Alternative A-1.

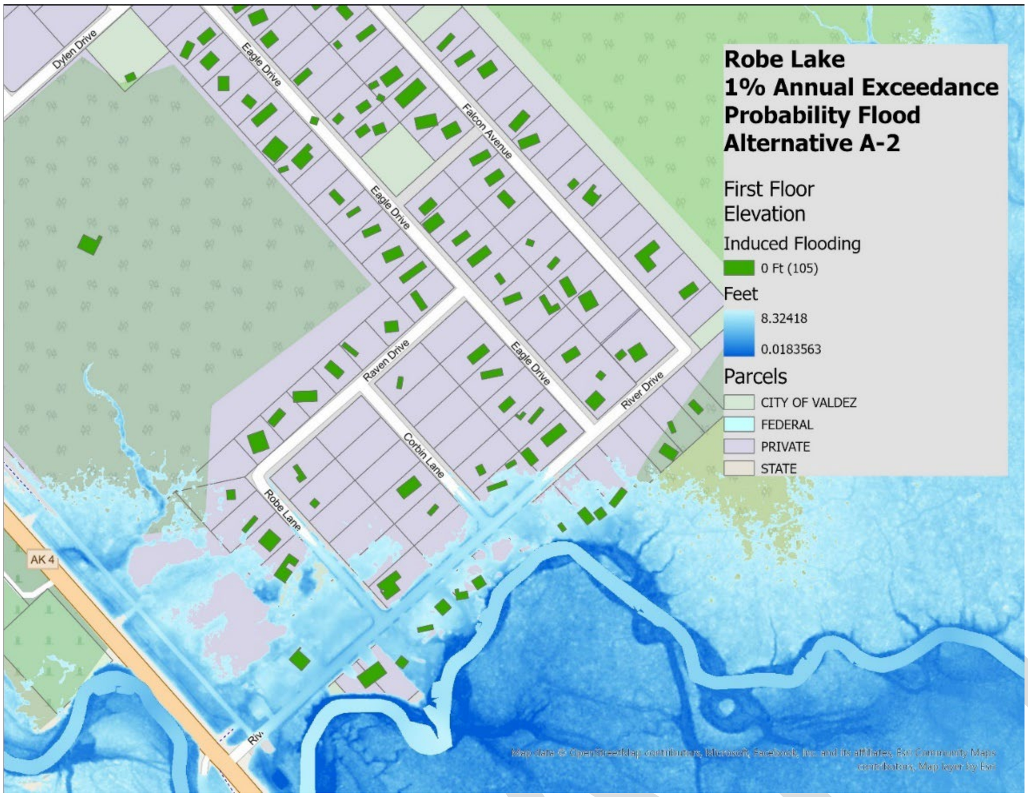

Figure 31. 1% annual exceedance probability for Alternative A–2.

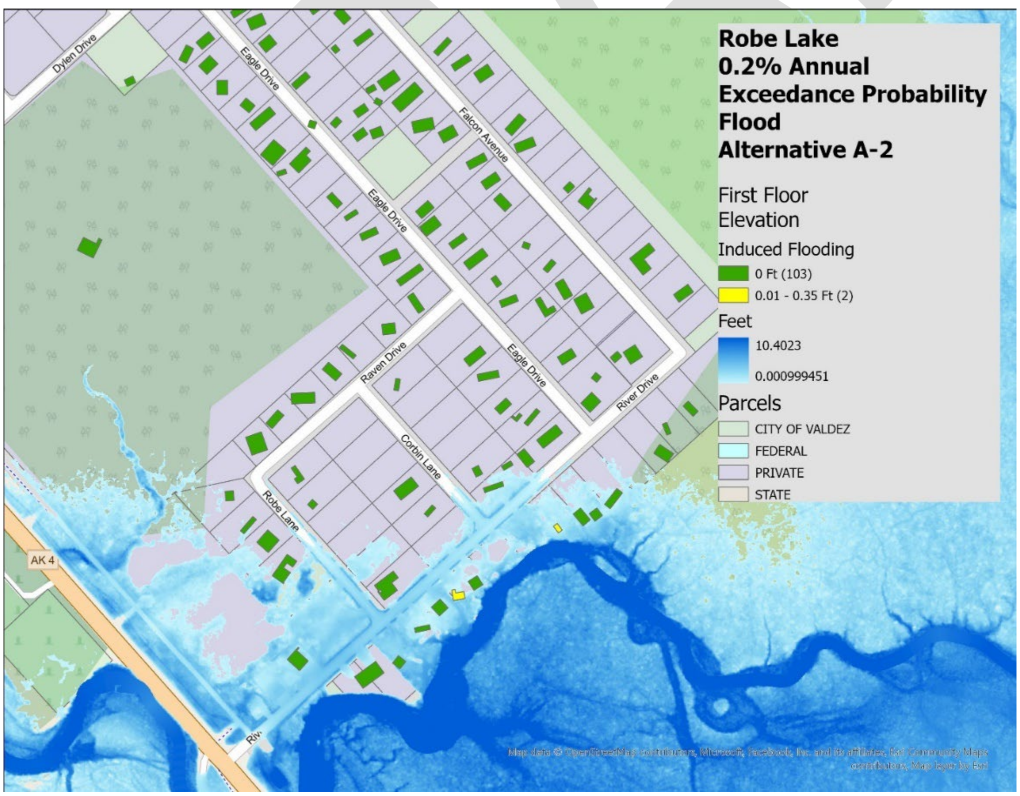

Figure 32. 0.2% annual exceedance probability for Alternative A–2.

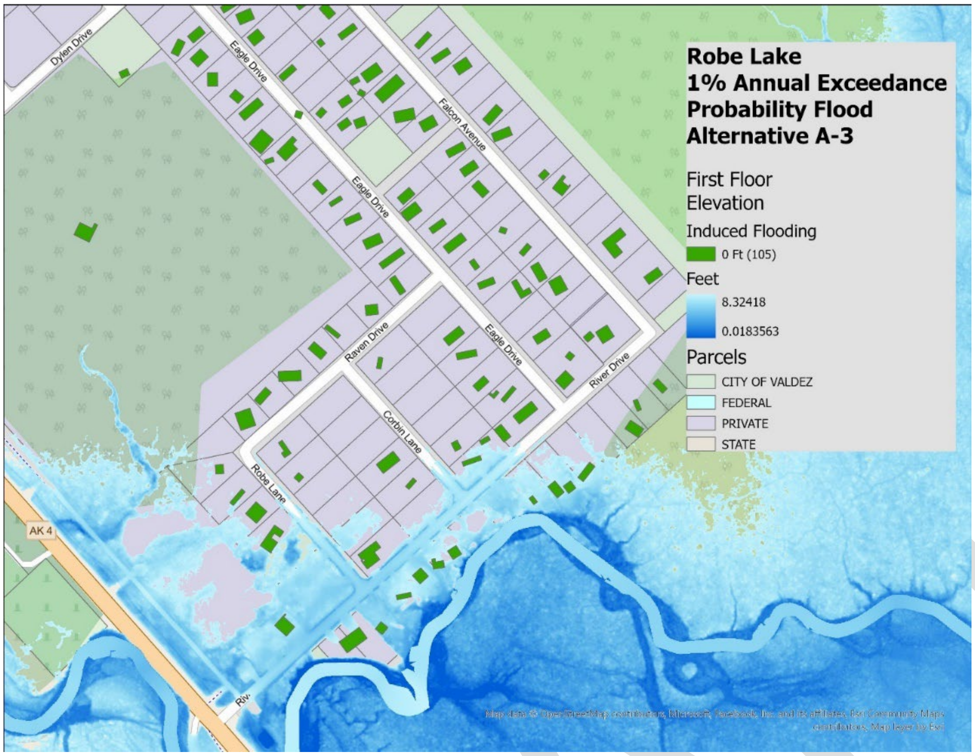

Figure 33. 1% annual exceedance probability for Alternative A-3.

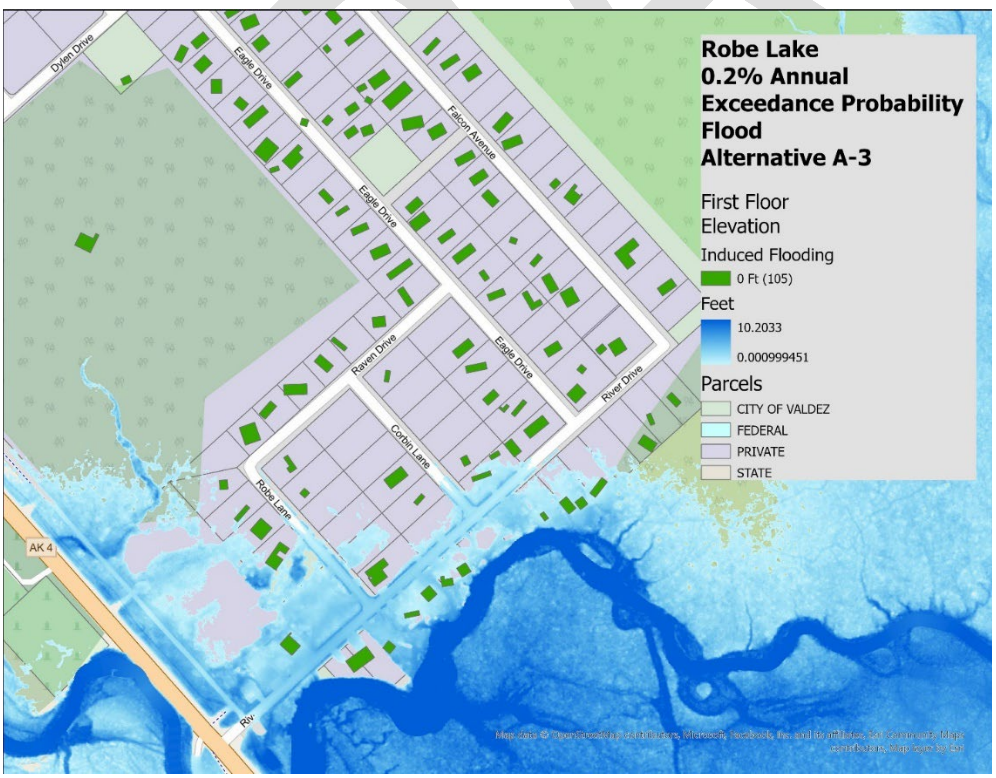

Figure 34. 0.2% annual exceedance probability for Alternative A-3.

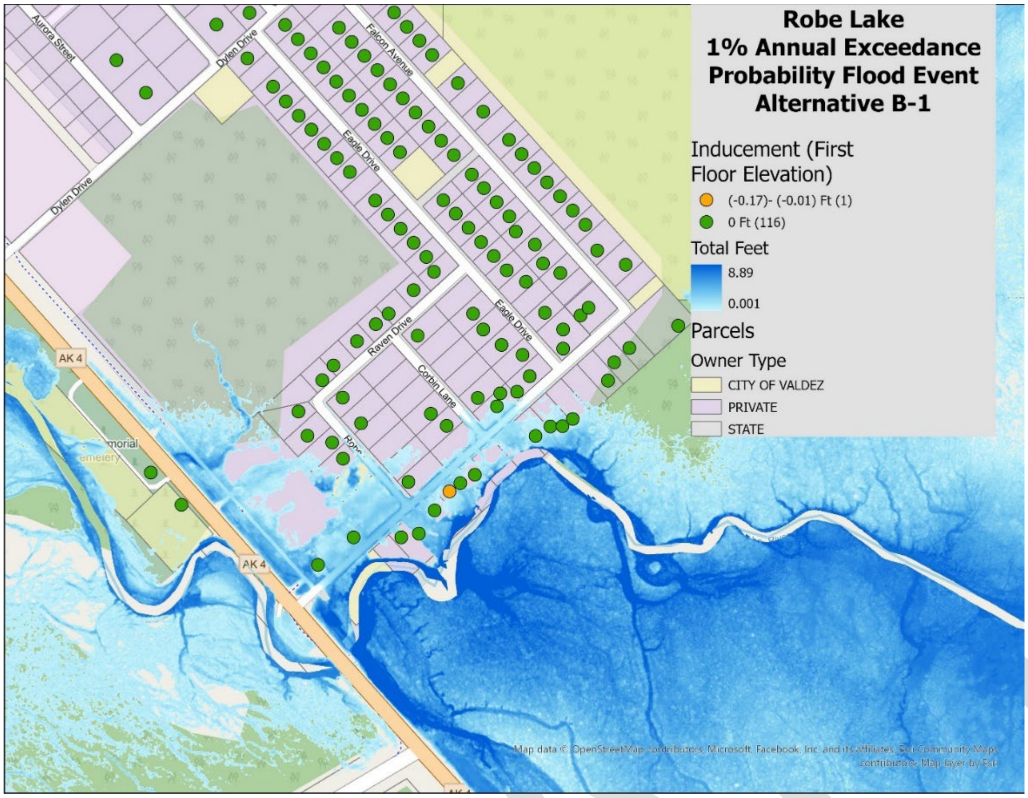

Figure 35. 1% annual exceedance probability for Alternative B-1.

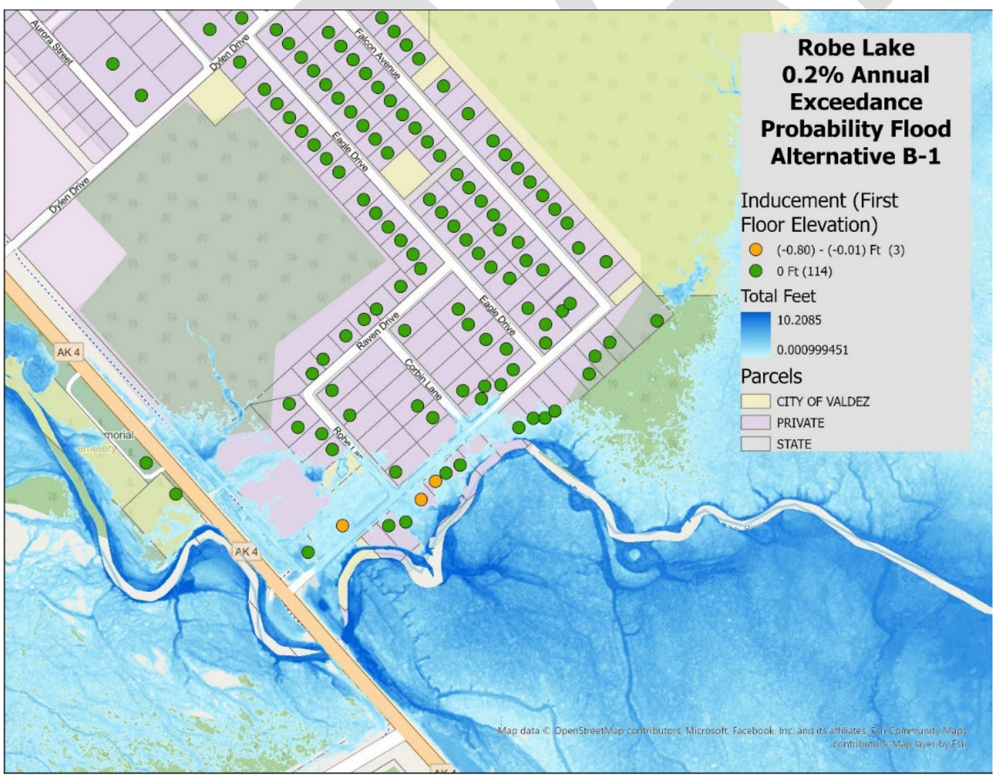

Figure 36. 0.2% annual exceedance probability for Alternative B-1.

Figure 37. 1% annual exceedance probability for Alternative B-2.

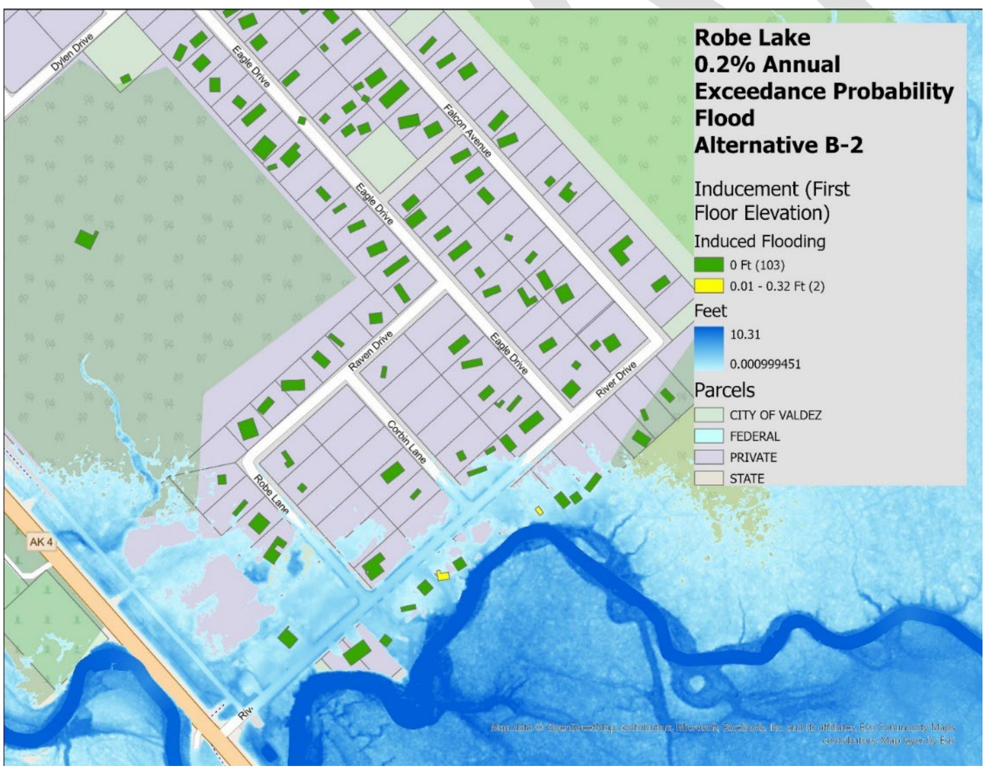

Figure 38. 0.2% annual exceedance probability for B-2.

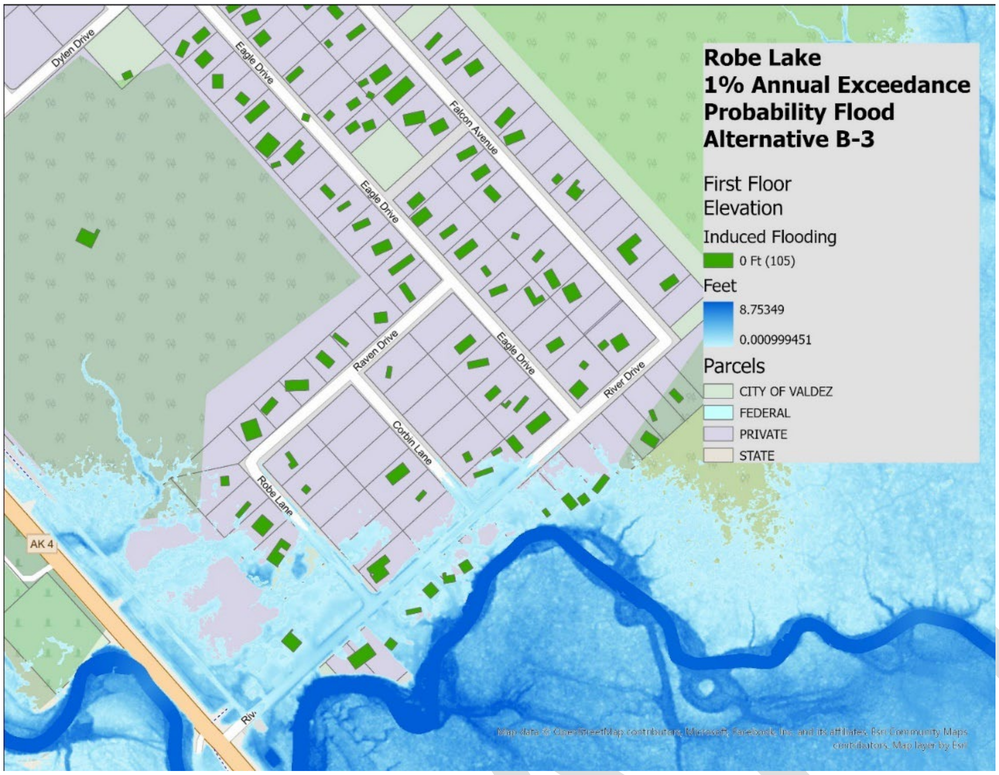

Figure 39. 1% annual exceedance probability for Alternative B-3.

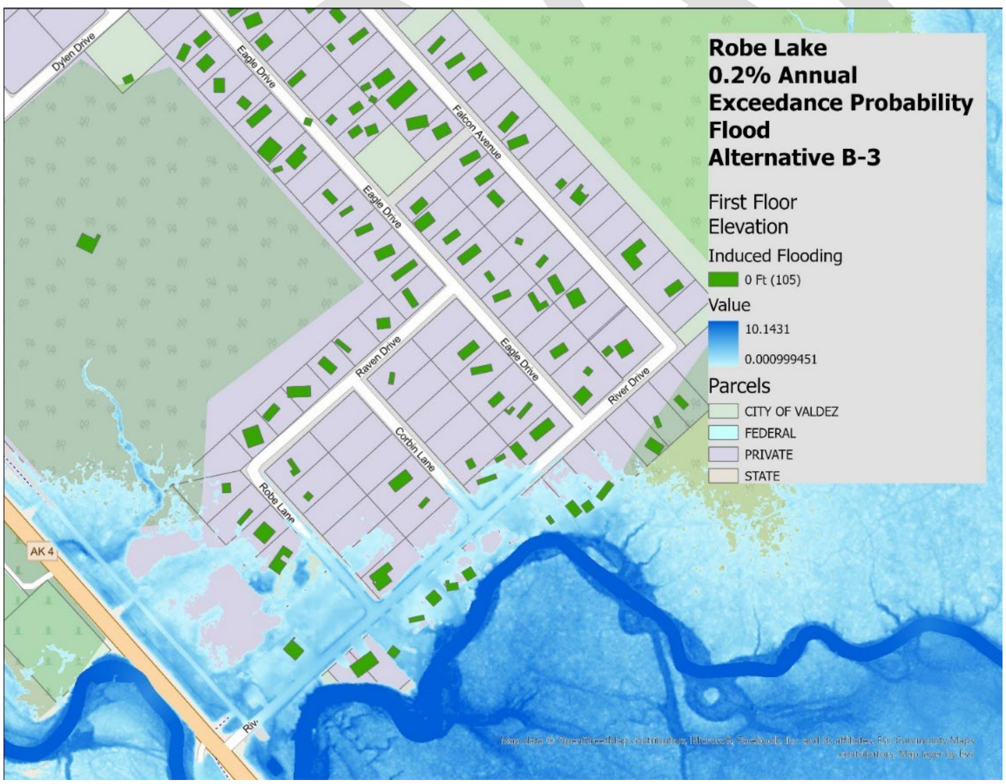

Figure 40. 0.2% annual exceedance probability for Alternative B-3.

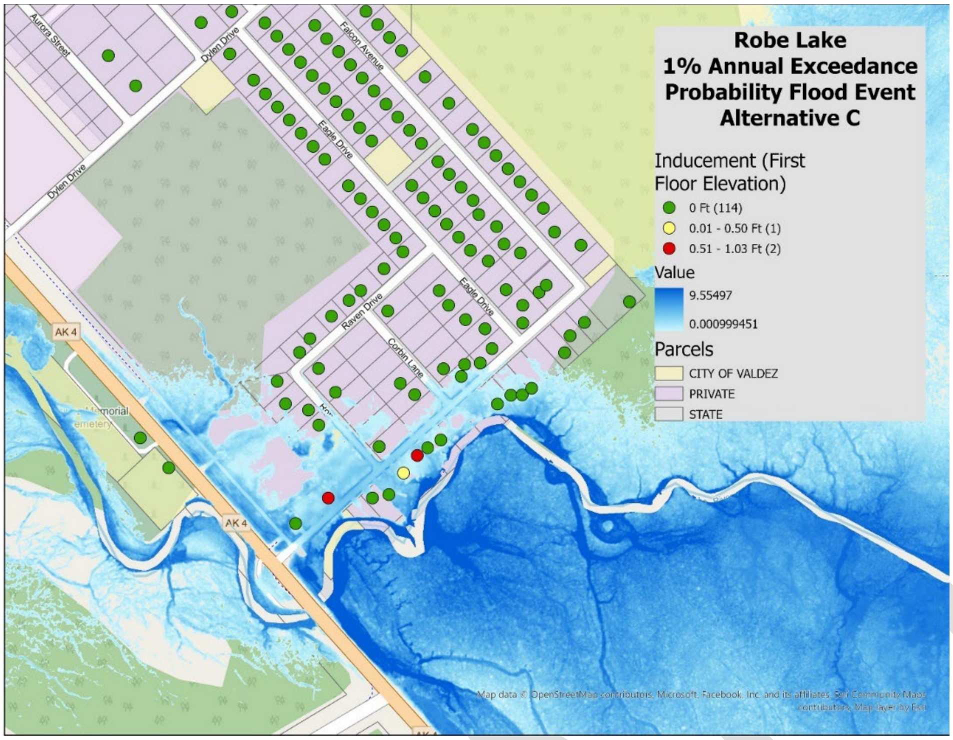

Figure 41. 1% annual exceedance probability for Alternative C.

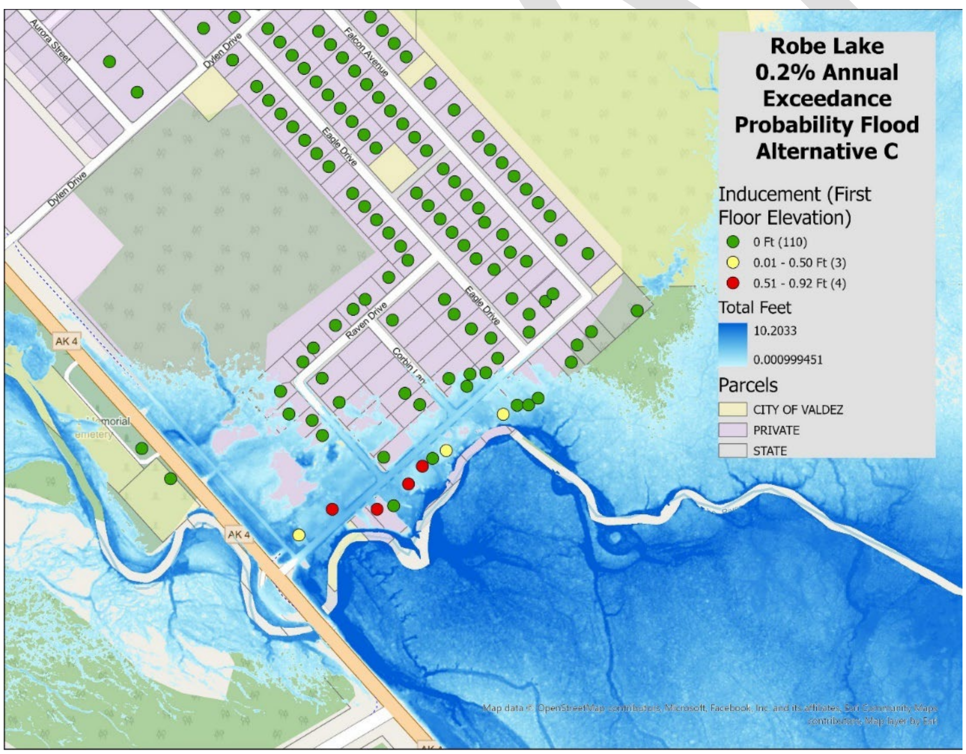

Figure 42. 0.2% annual exceedance probability for Alternative C.

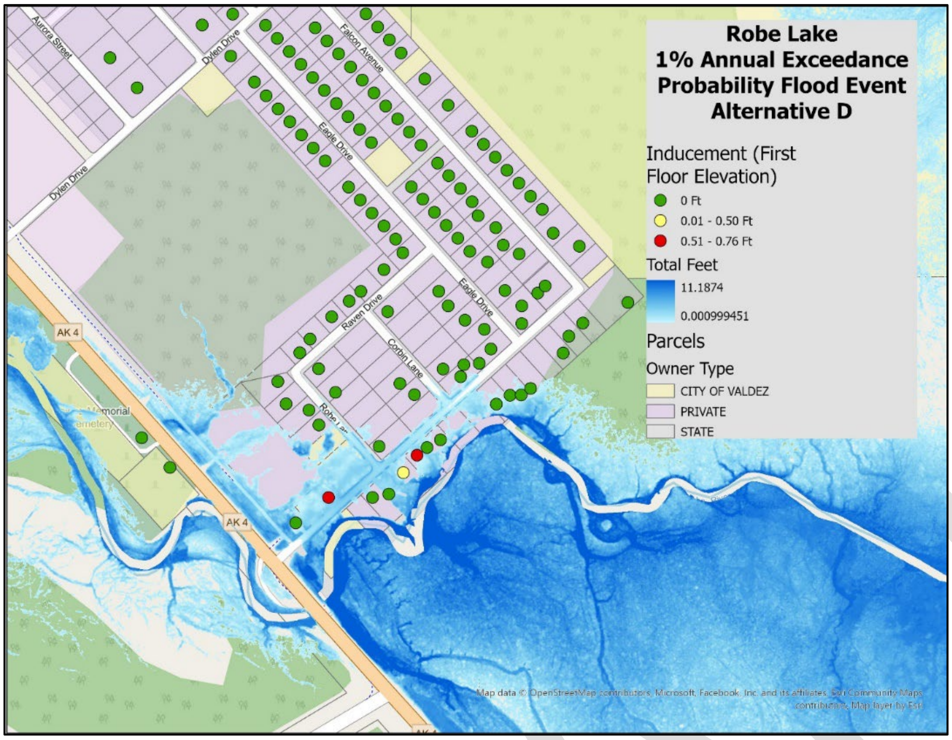

Figure 43. 1% annual exceedance probability for Alternative D.

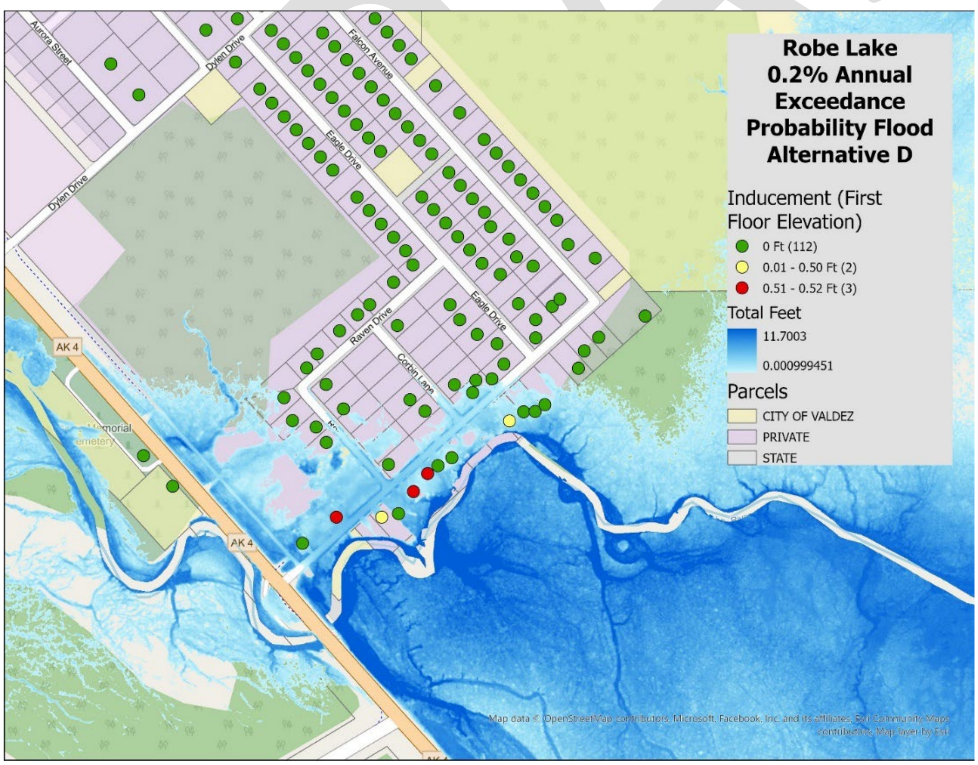

Figure 44. 0.2% annual exceedance probability for Alternative D.

6.0 CONCLUSIONS

Both non-structural and structural alternatives were considered for evaluating possible ecosystem restoration techniques for Robe Lake in Valdez, Alaska. Since the diversion of Corbin Creek in the 1950's, subdivisions and other infrastructure were built along the Richardson Highway. Proposed structural alternatives include different techniques to divert Corbin Creek back into its relic channel. To ensure inundation from flooding does not increase from the current future without project conditions, a HEC-RAS hydraulic model was developed for the Robe Lake watershed. The outputs of the hydraulic model were used for economic evaluation.

Should any of the alternatives considered in this study be selected for design and implementation, the following data collection and analyses will be required:

- Perform a bathymetric survey of each creek leading into Robe Lake (i.e., Corbin Creek, Old Corbin Creek, Brownie Creek) and the Robe River and adjust the HEC-RAS model if necessary.
- Survey the culverts over the Richardson Highway and adjust the HEC-RAS model if necessary.
- If a large flood event were to occur, obtain HWM data and perform a sensitivity analysis within the HEC-RAS model using this new data.

It should be reiterated that no HWM information was available for this watershed or instantaneous flow information, and thus the model could not be calibrated to different flood events. The extents of flooding from published FEMA flood maps for the area for the 1% and 0.2% annual exceedance probabilities were the only forms of calibration performed.

7.0 REFERENCES

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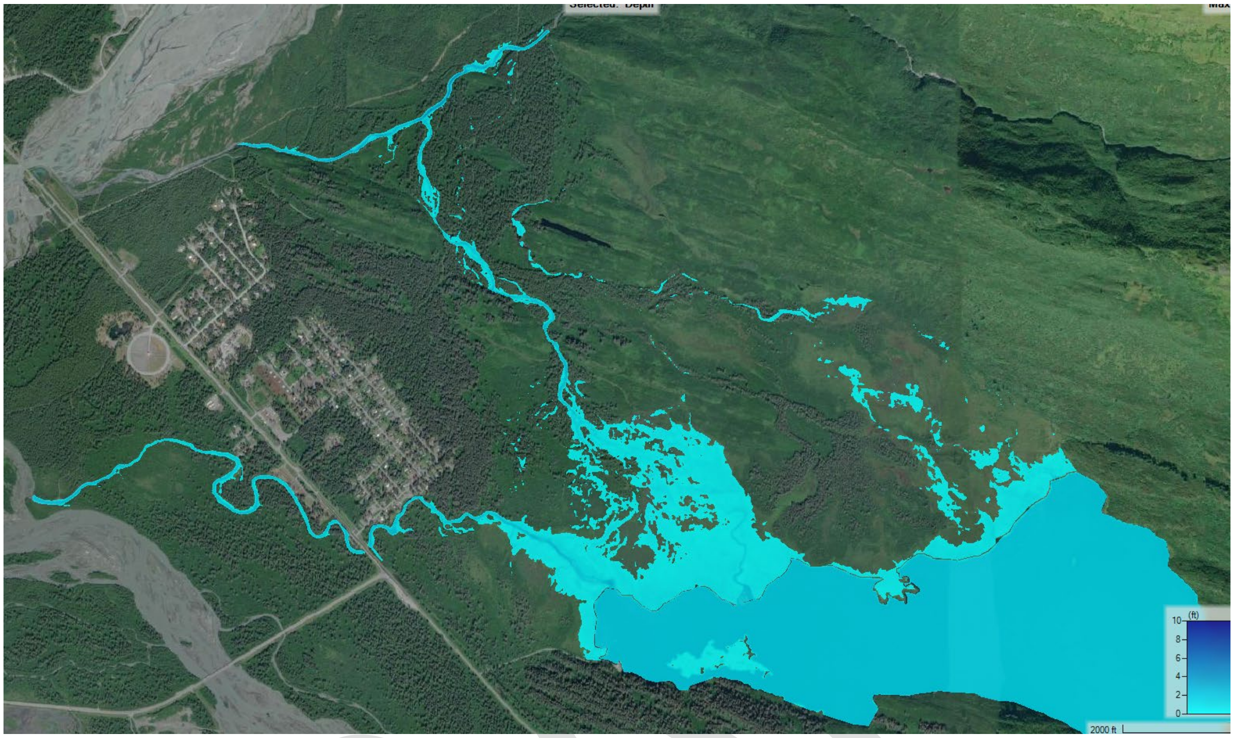
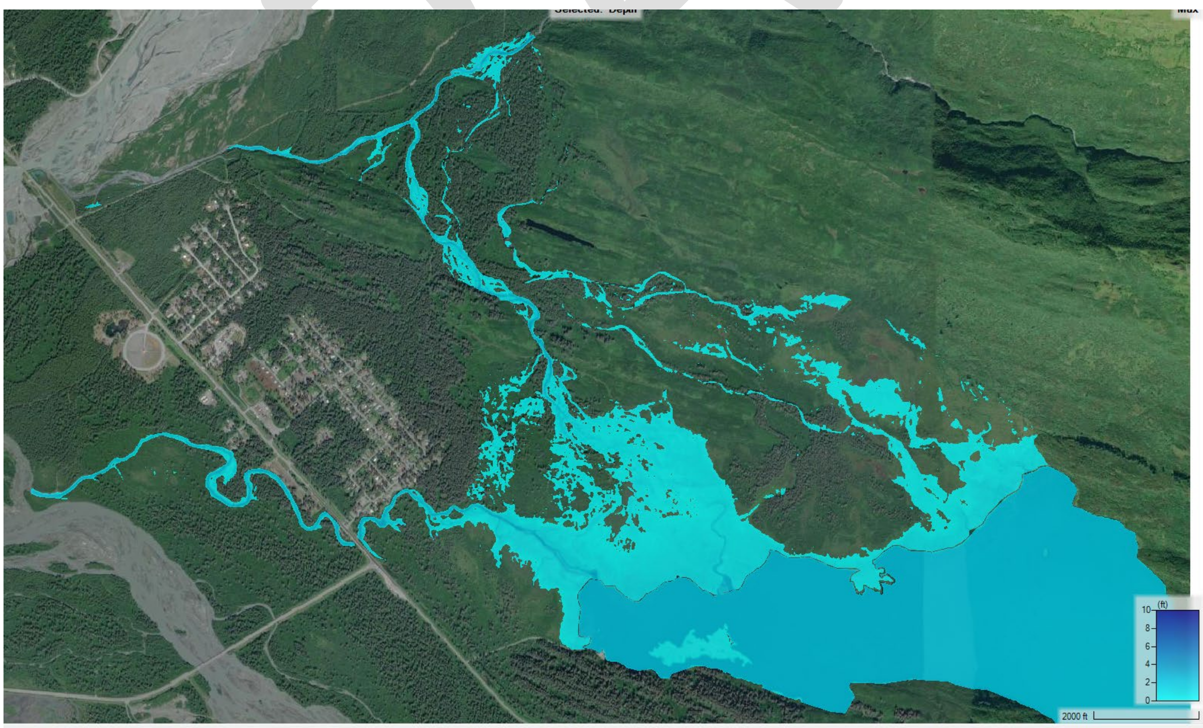
Appendix A: HEC-RAS Depth Grid Maps

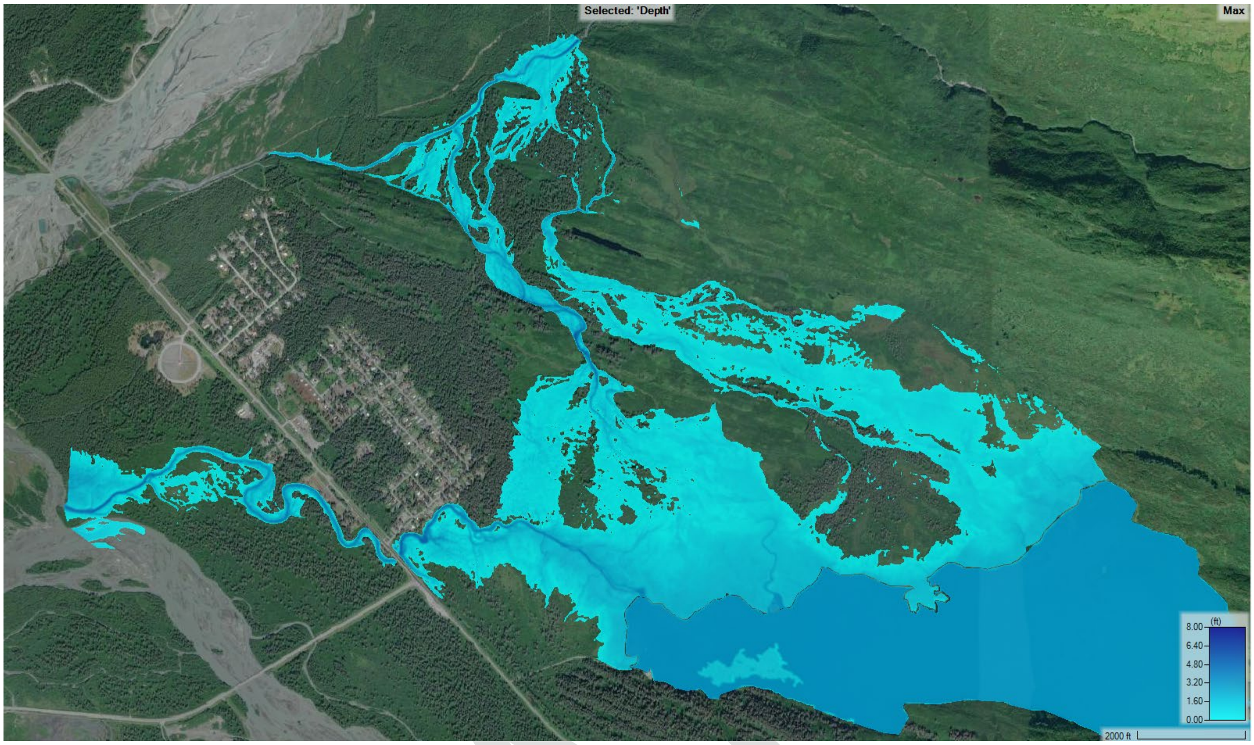
Future Without Project Runs



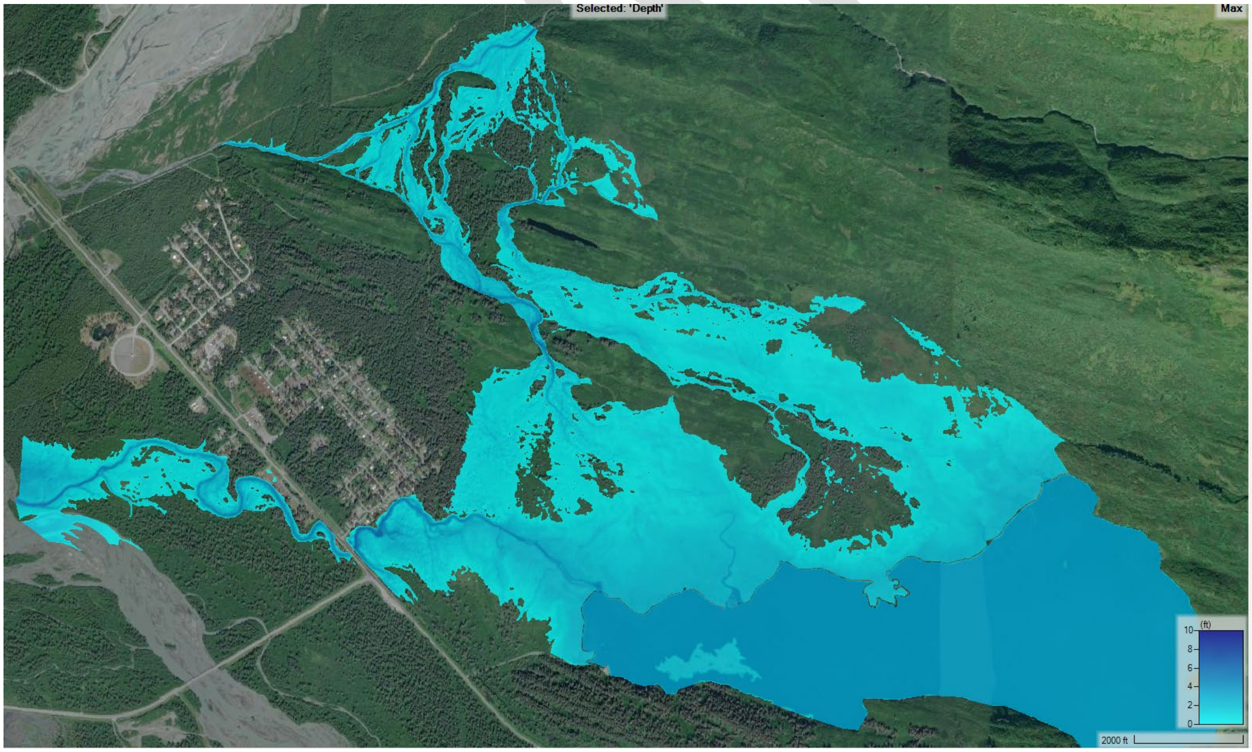
50% Annual Exceedance Probability



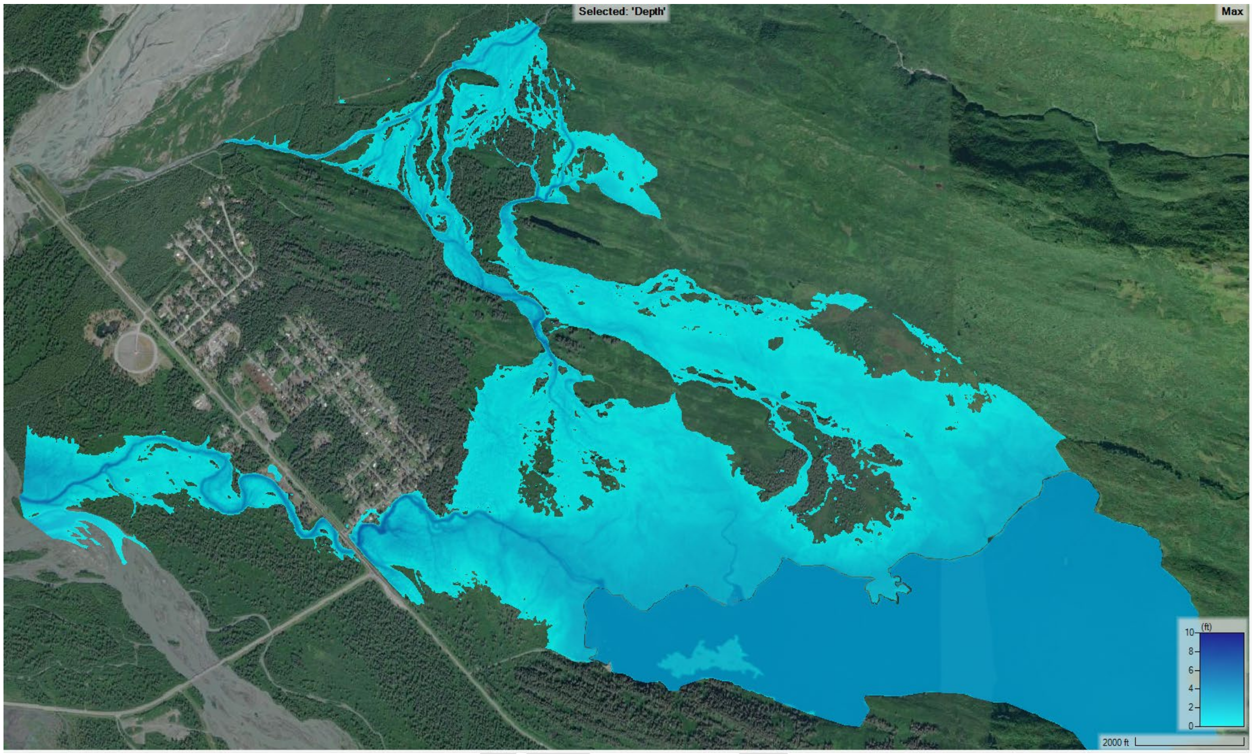
20% Annual Exceedance Probability



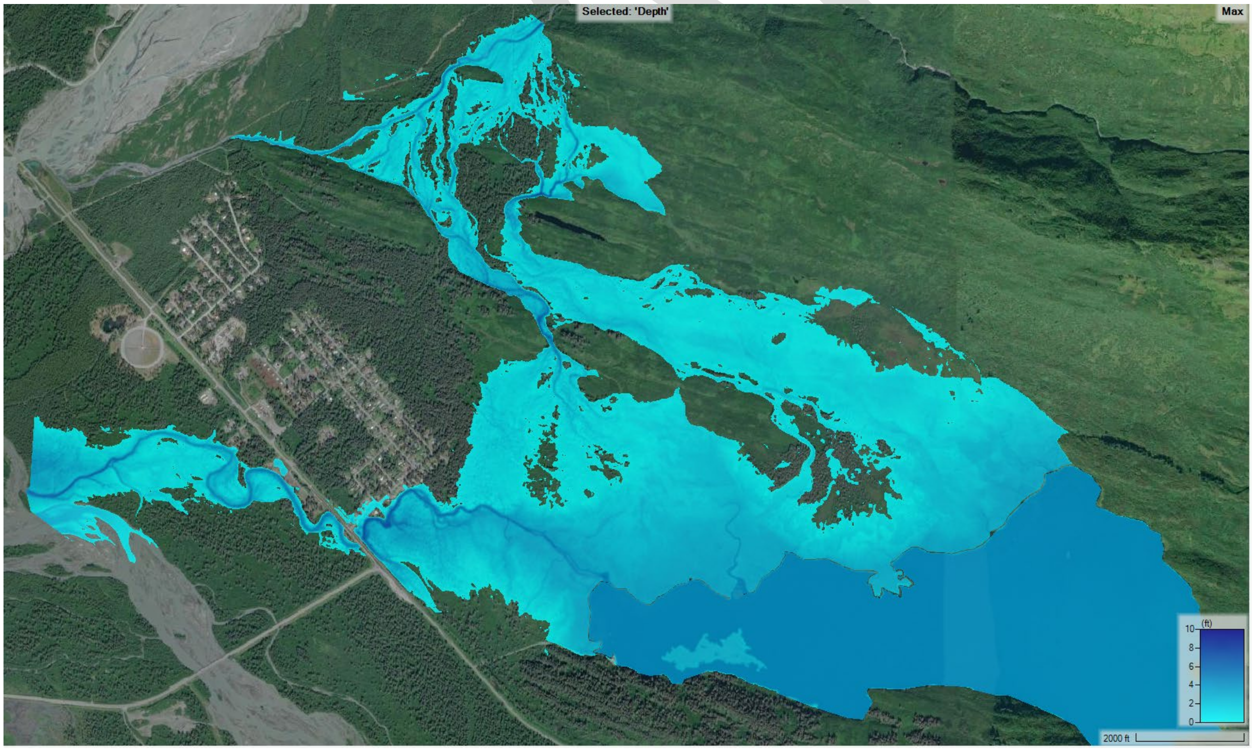
10% Annual Exceedance Probability



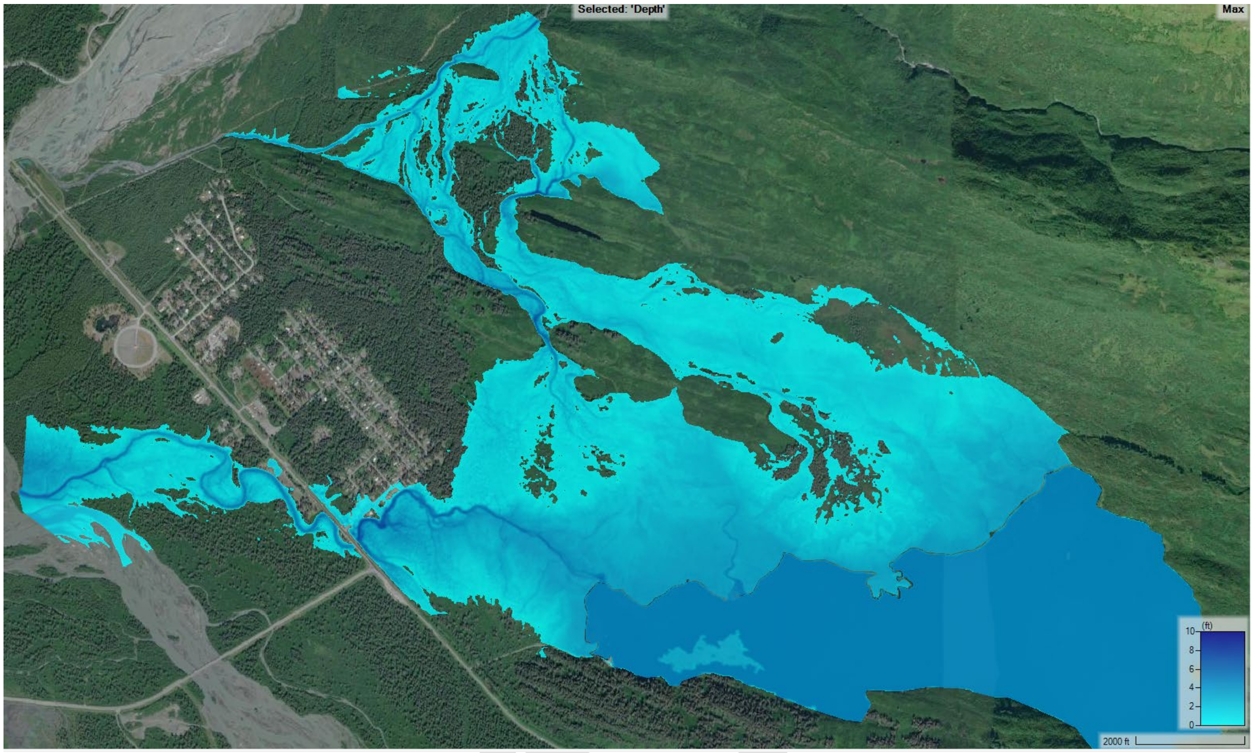
4% Annual Exceedance Probability



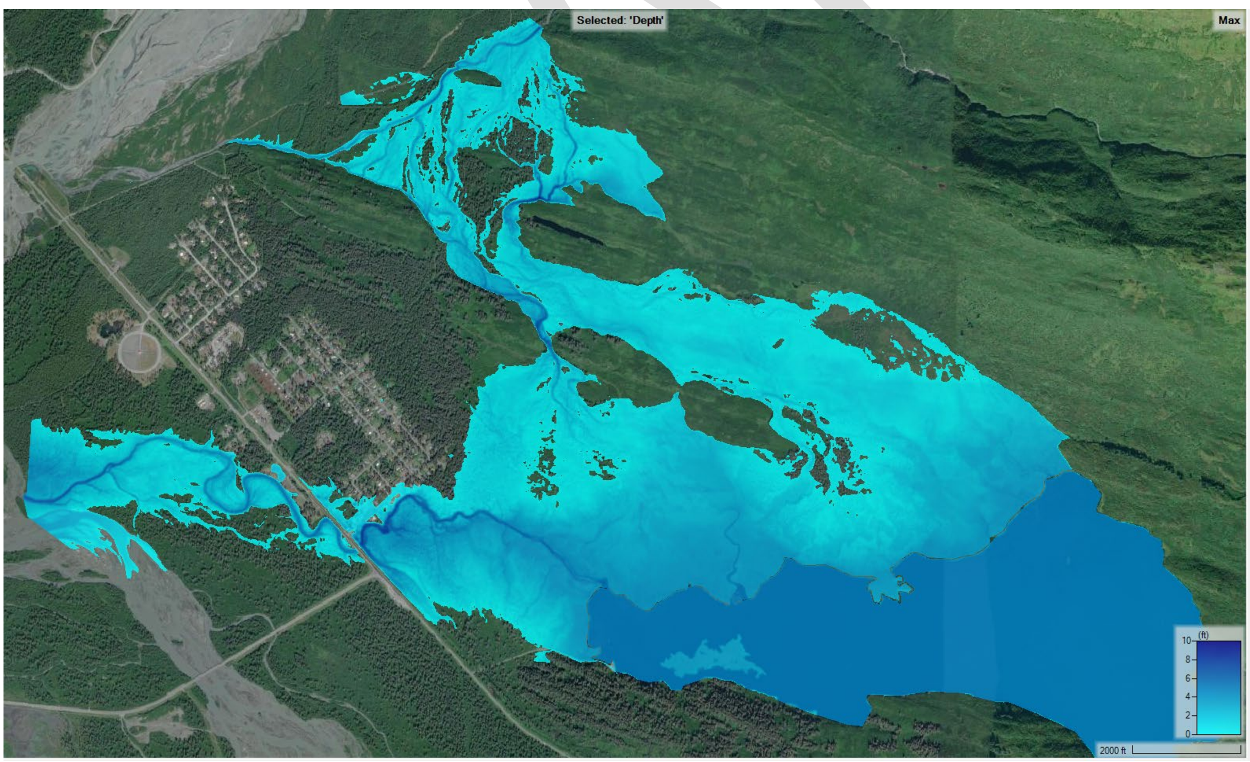
2% Annual Exceedance Probability



1% Annual Exceedance Probability

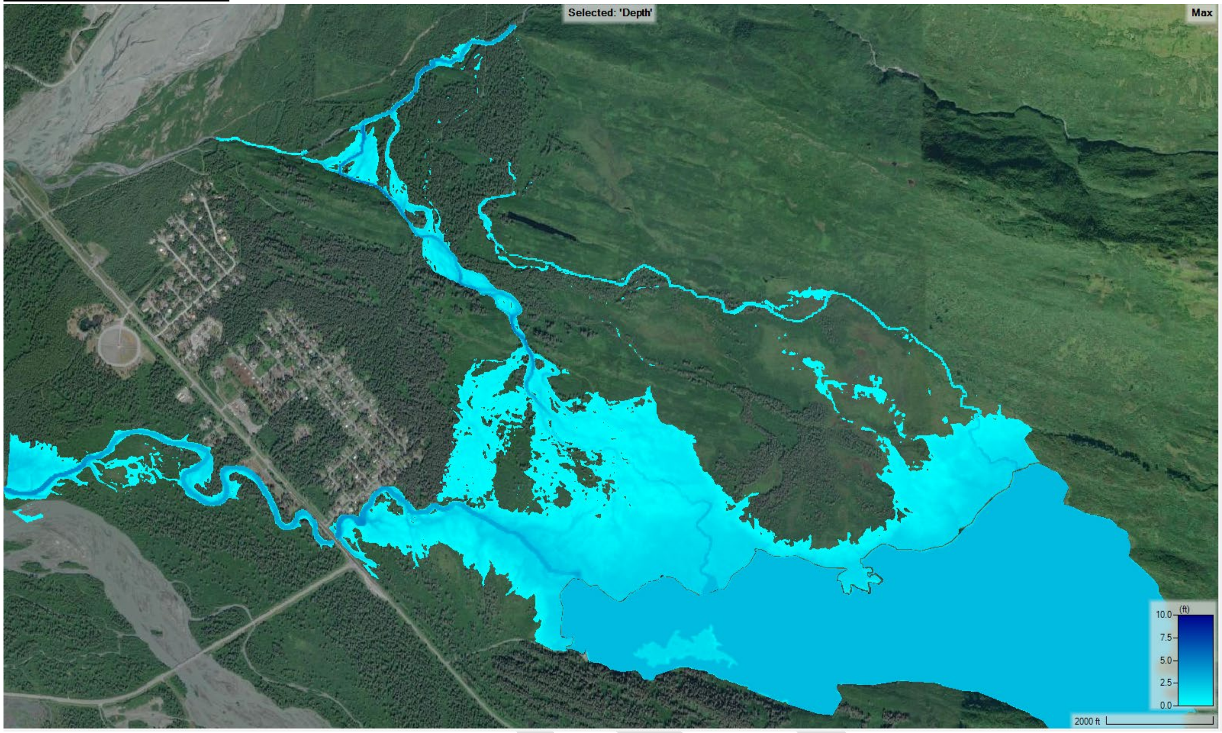


0.5% Annual Exceedance Probability

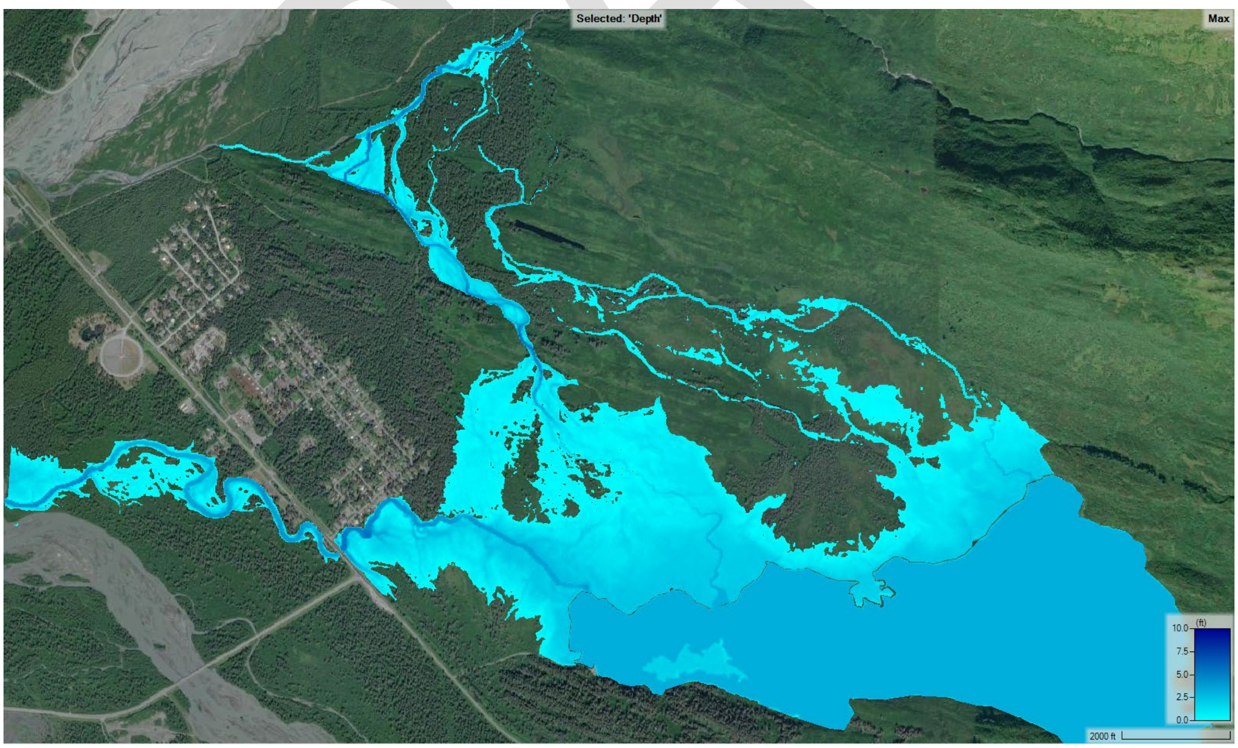


0.2% Annual Exceedance Probability

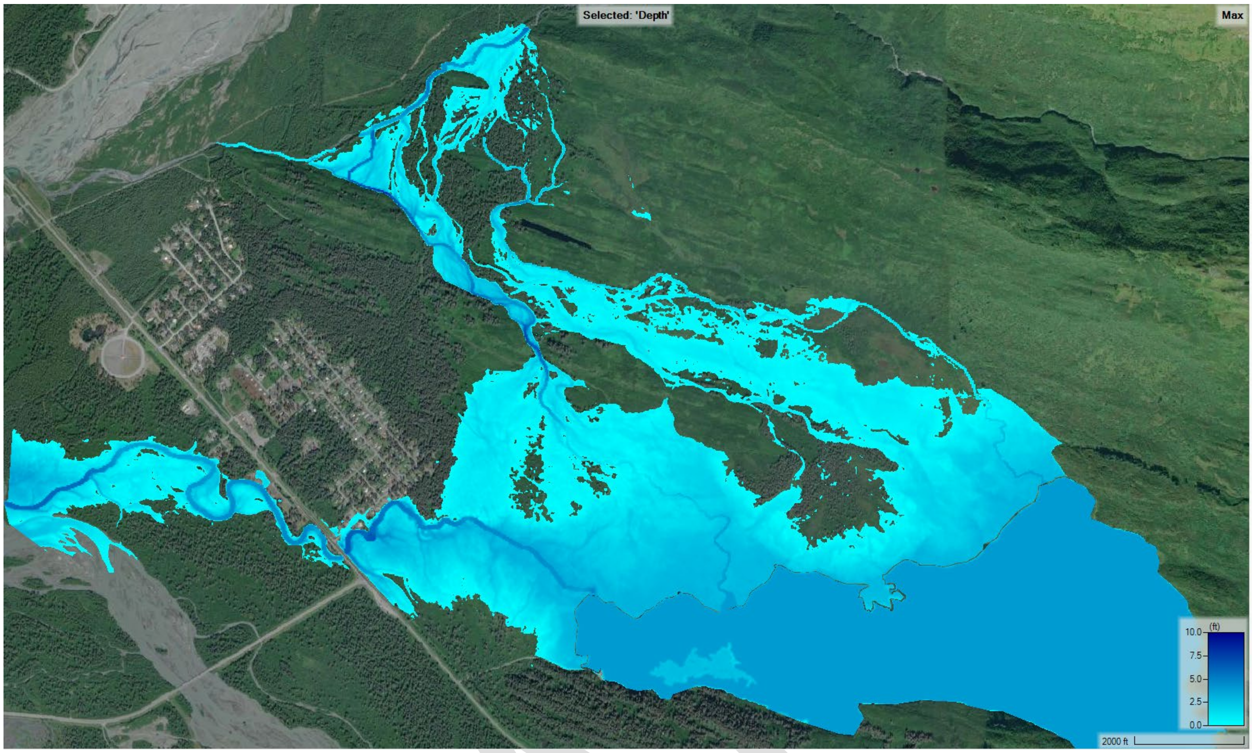
Future With Project
Alternative A-1



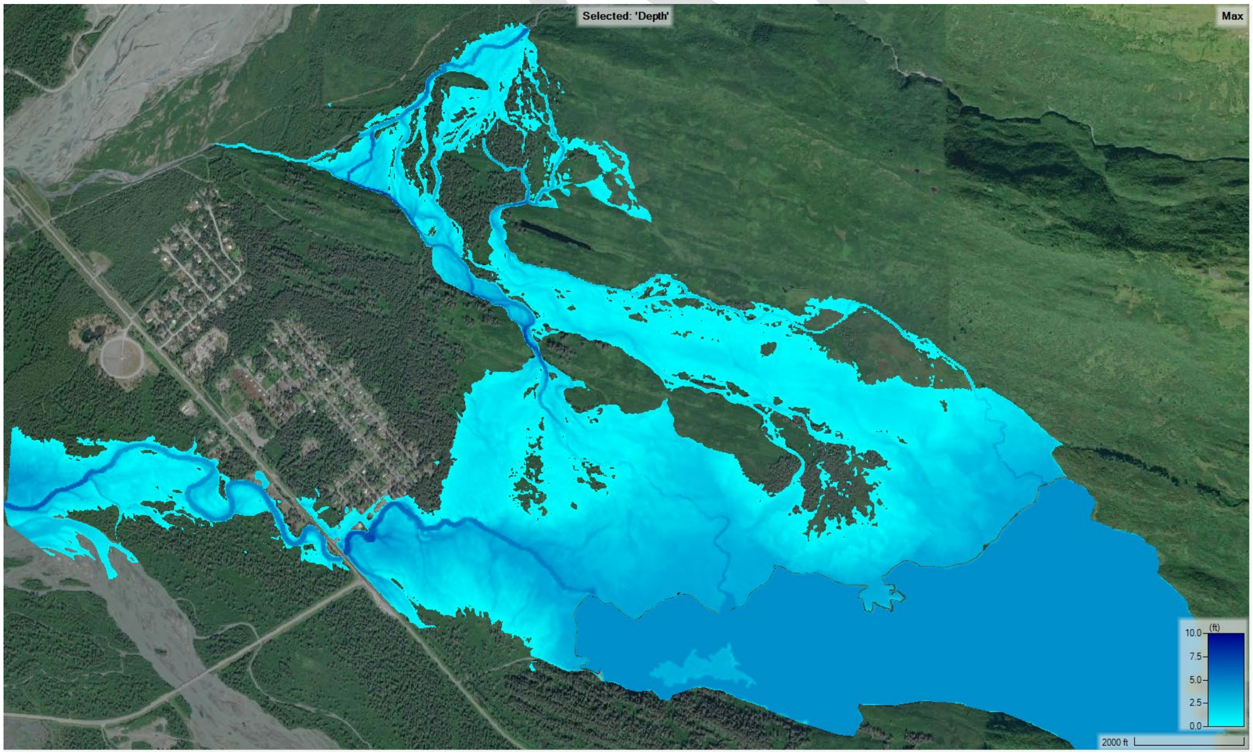
50% Annual Exceedance Probability



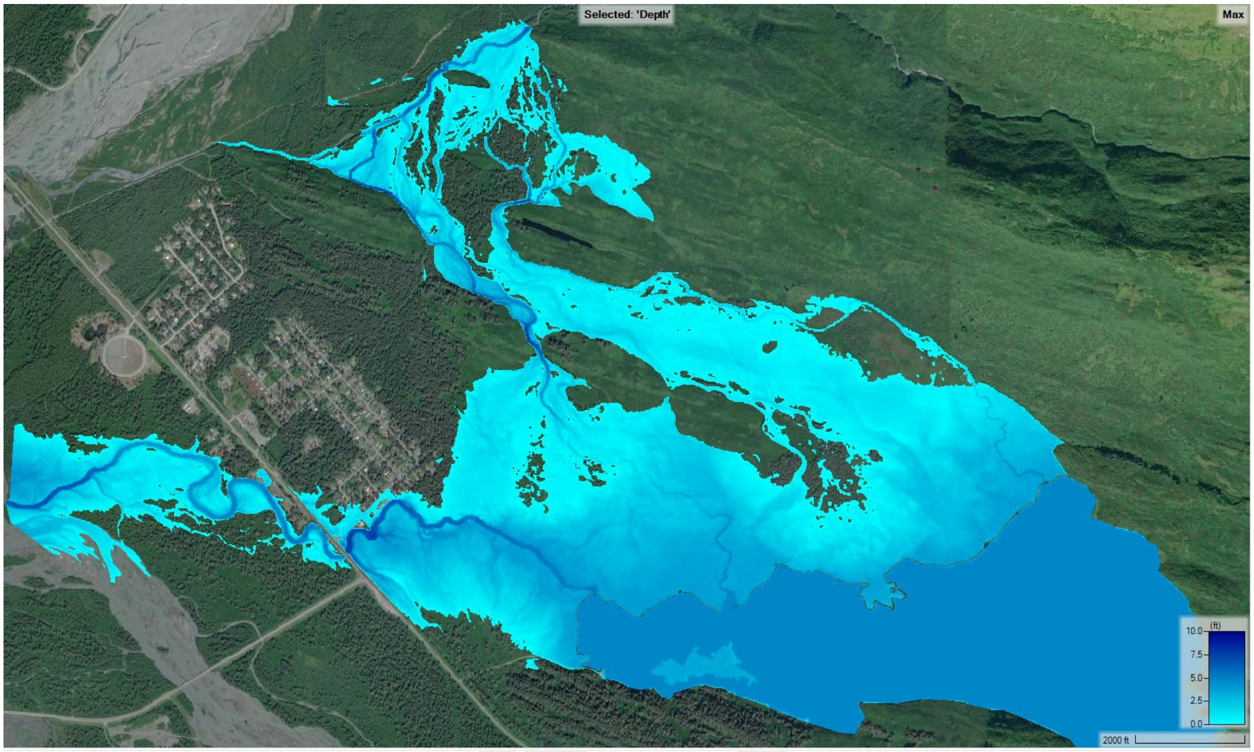
20% Annual Exceedance Probability



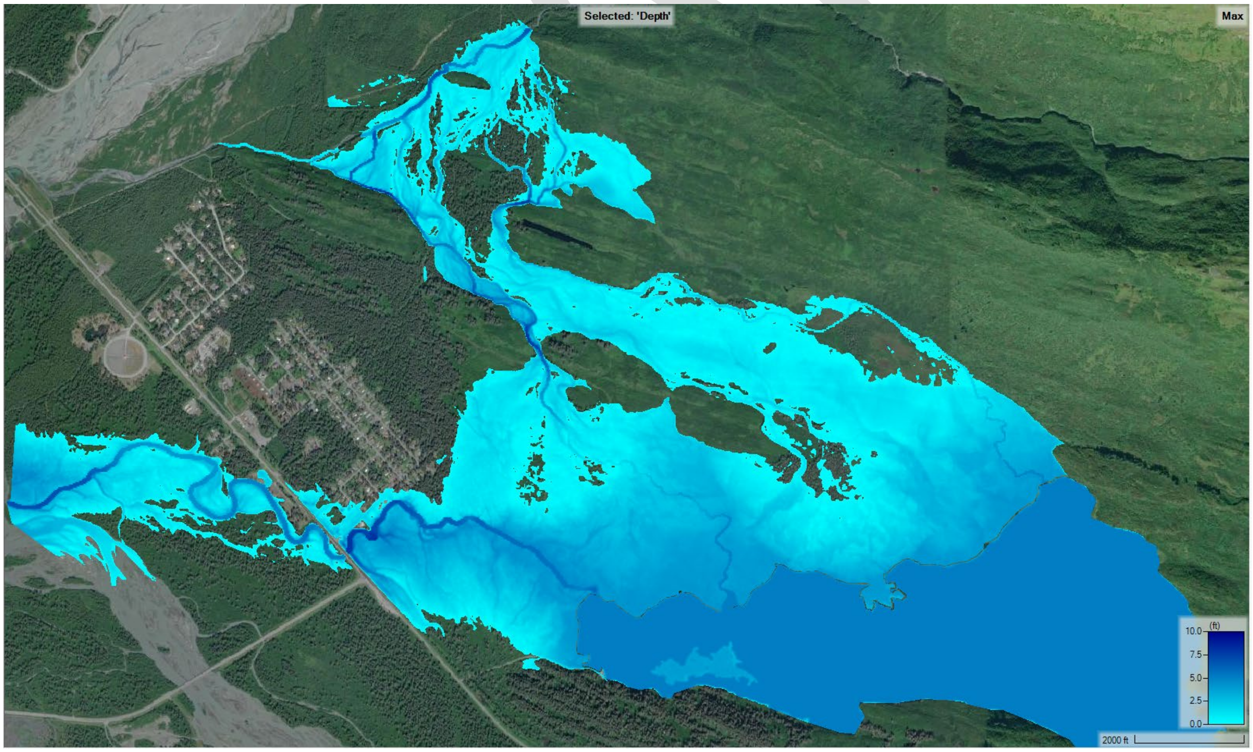
10% Annual Exceedance Probability



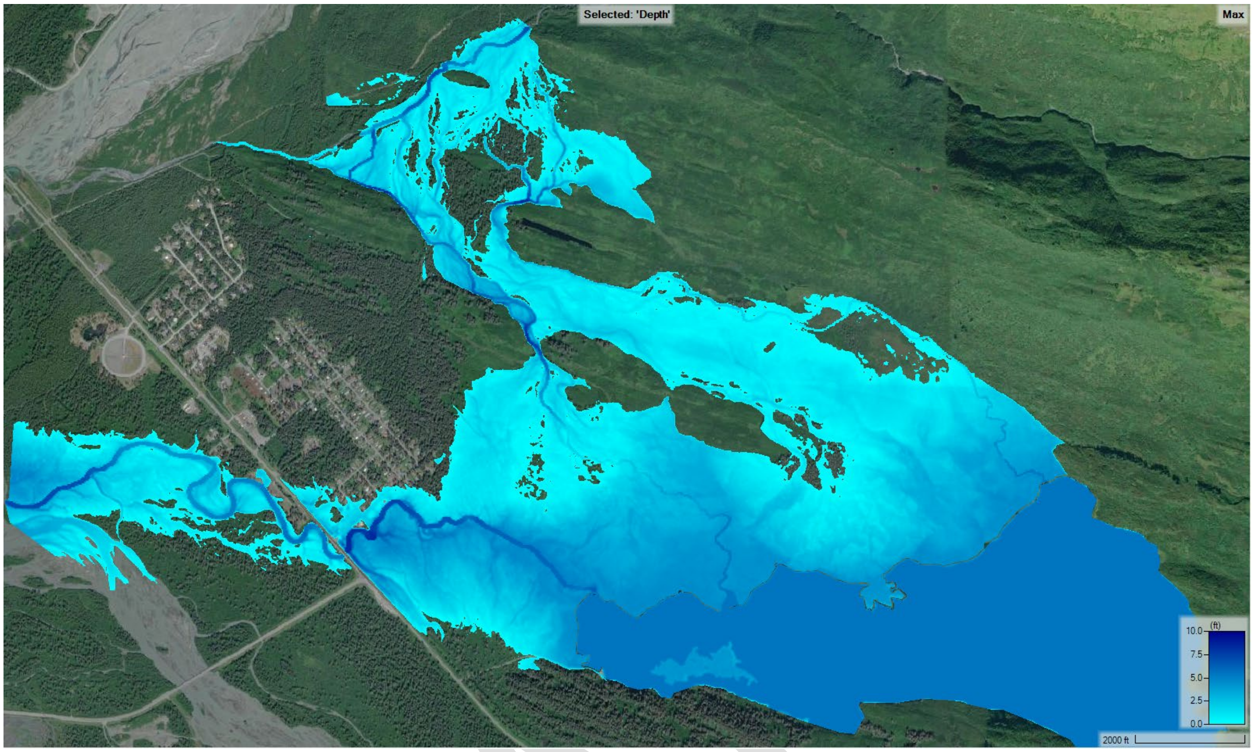
4% Annual Exceedance Probability



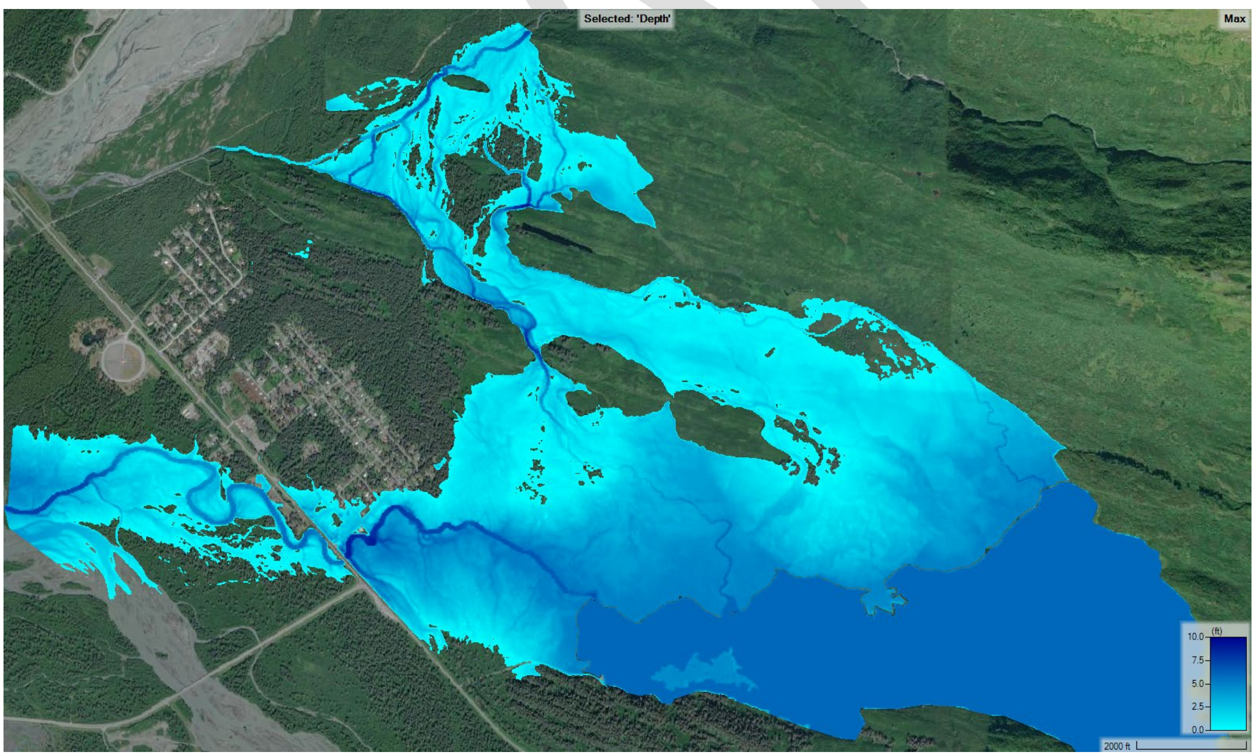
2% Annual Exceedance Probability



1% Annual Exceedance Probability

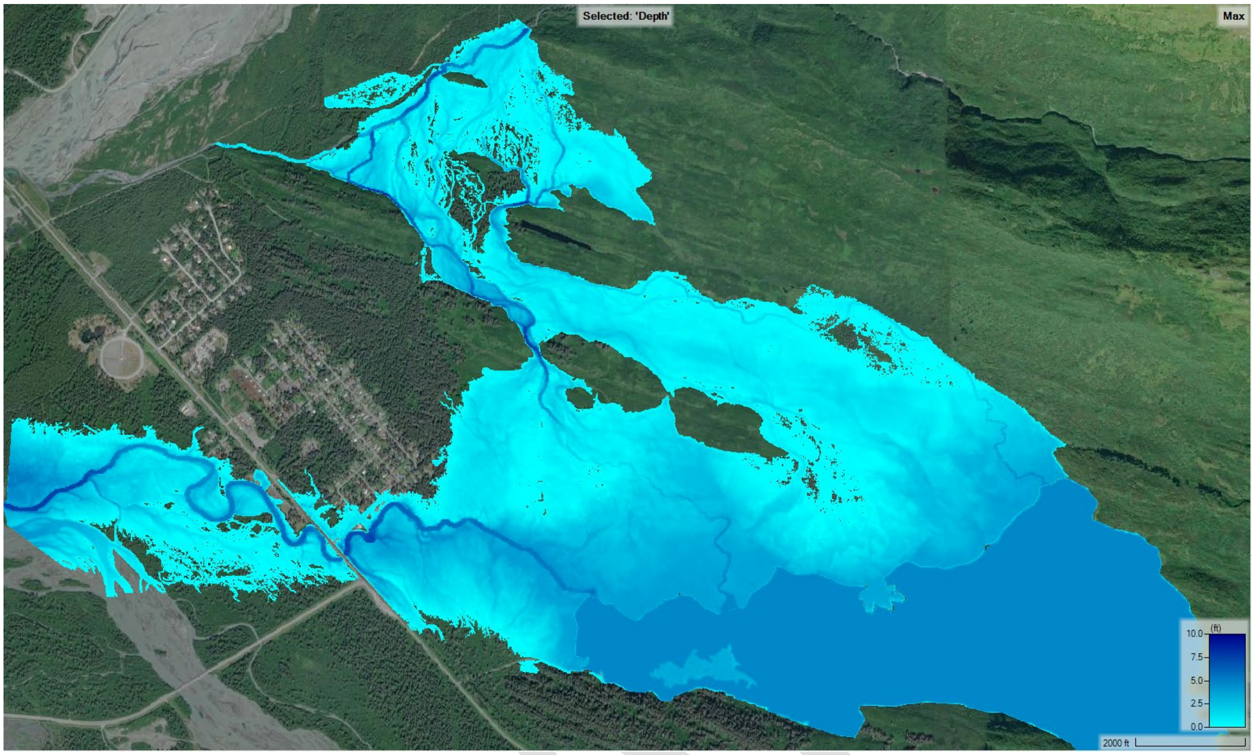


0.5% Annual Exceedance Probability

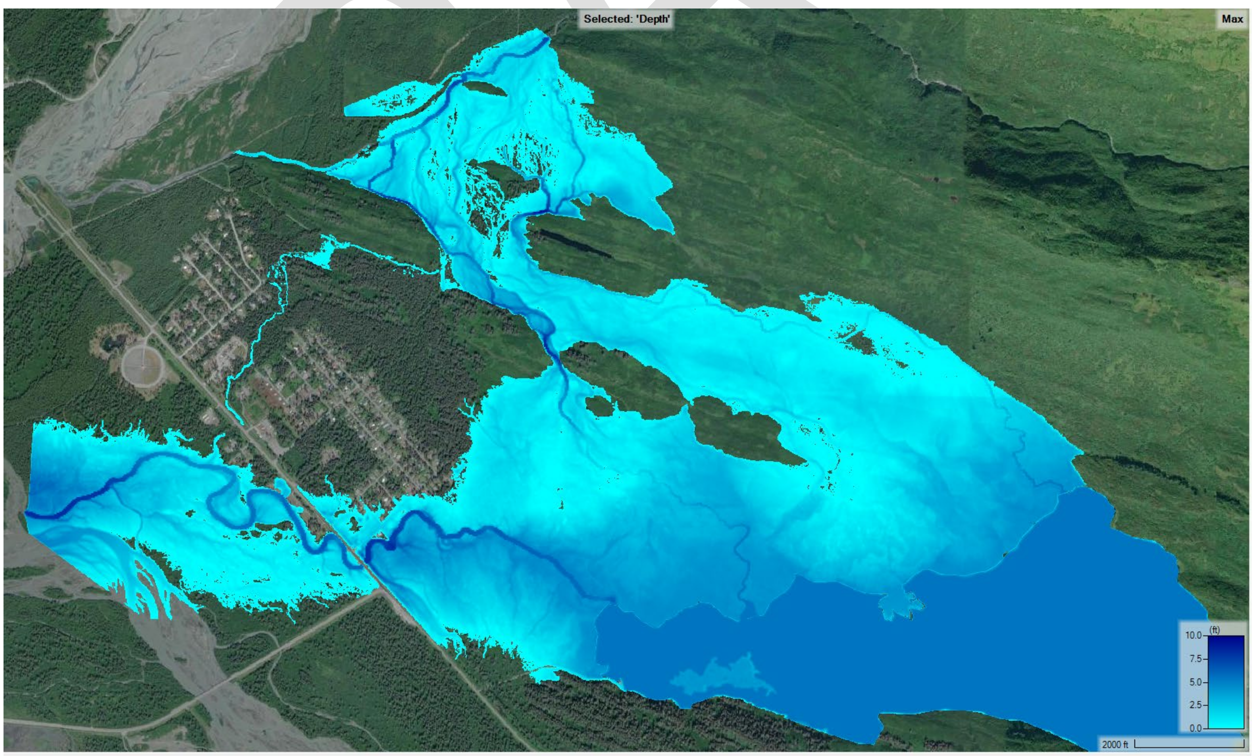


0.2% Annual Exceedance Probability

Alternative A-2

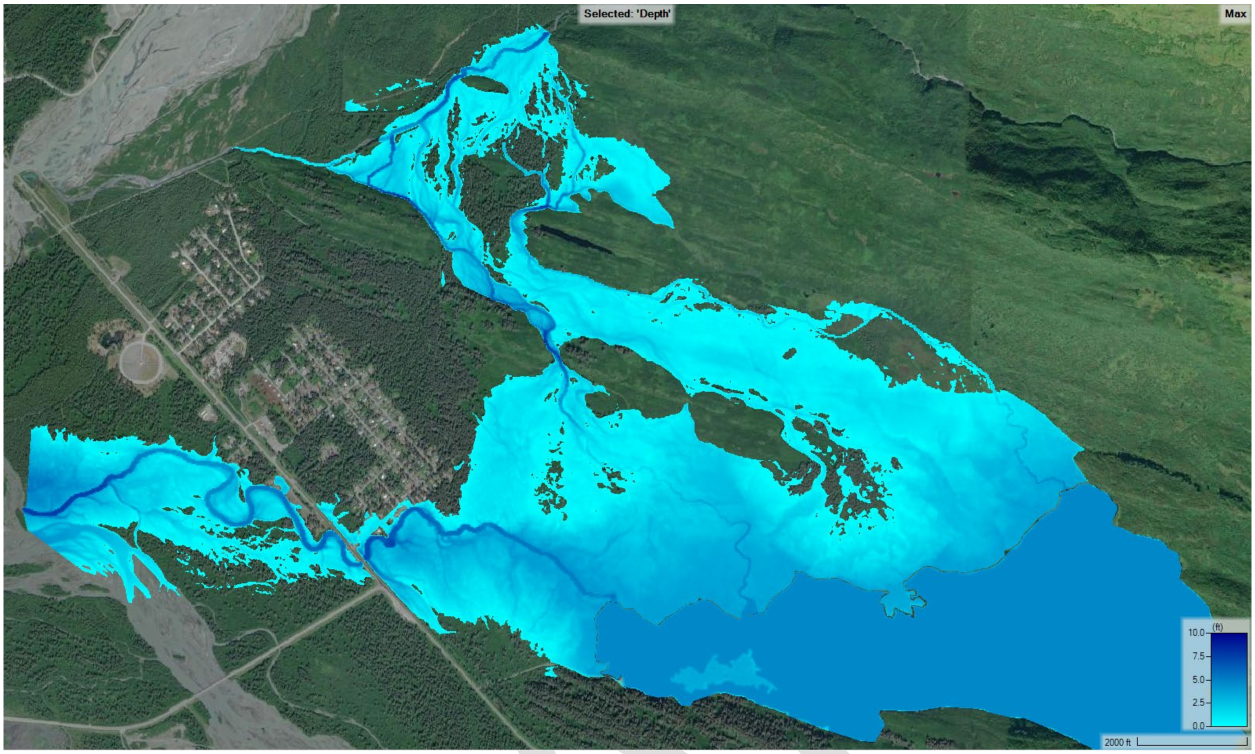


1% Annual Exceedance Probability

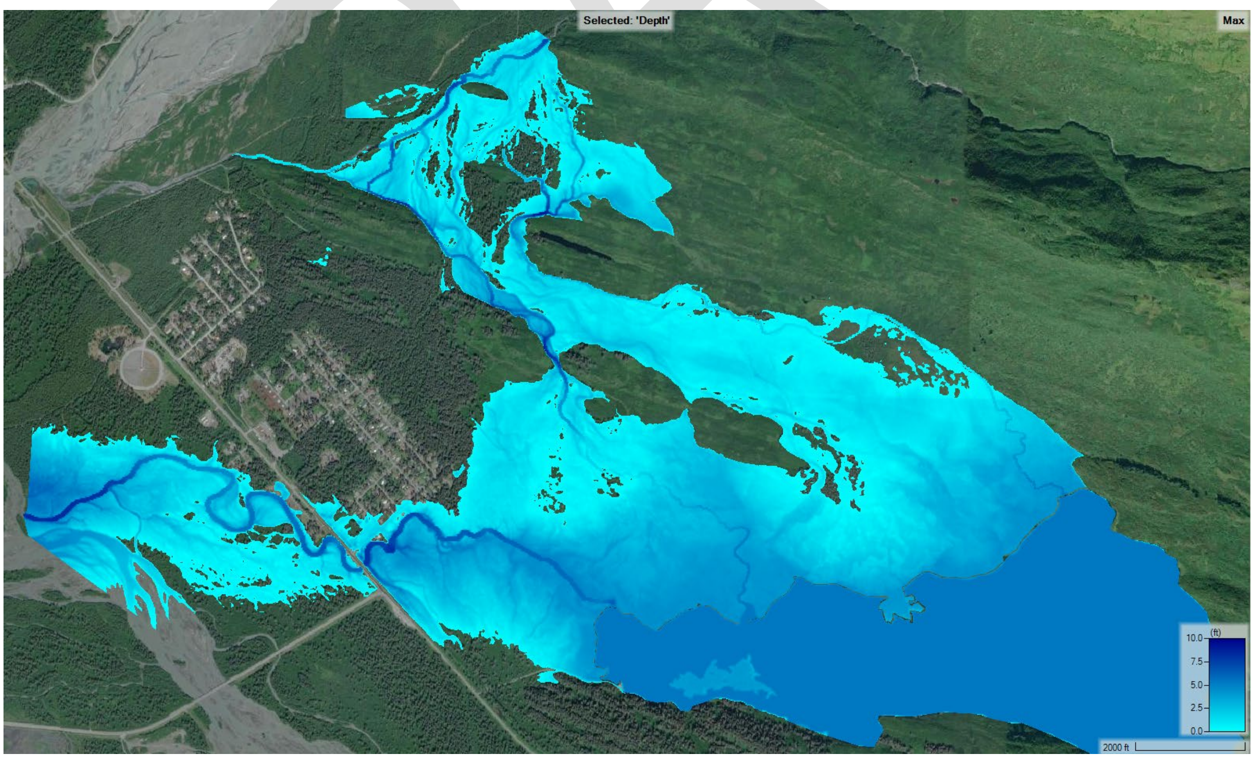


0.2% Annual Exceedance Probability

Alternative A-3

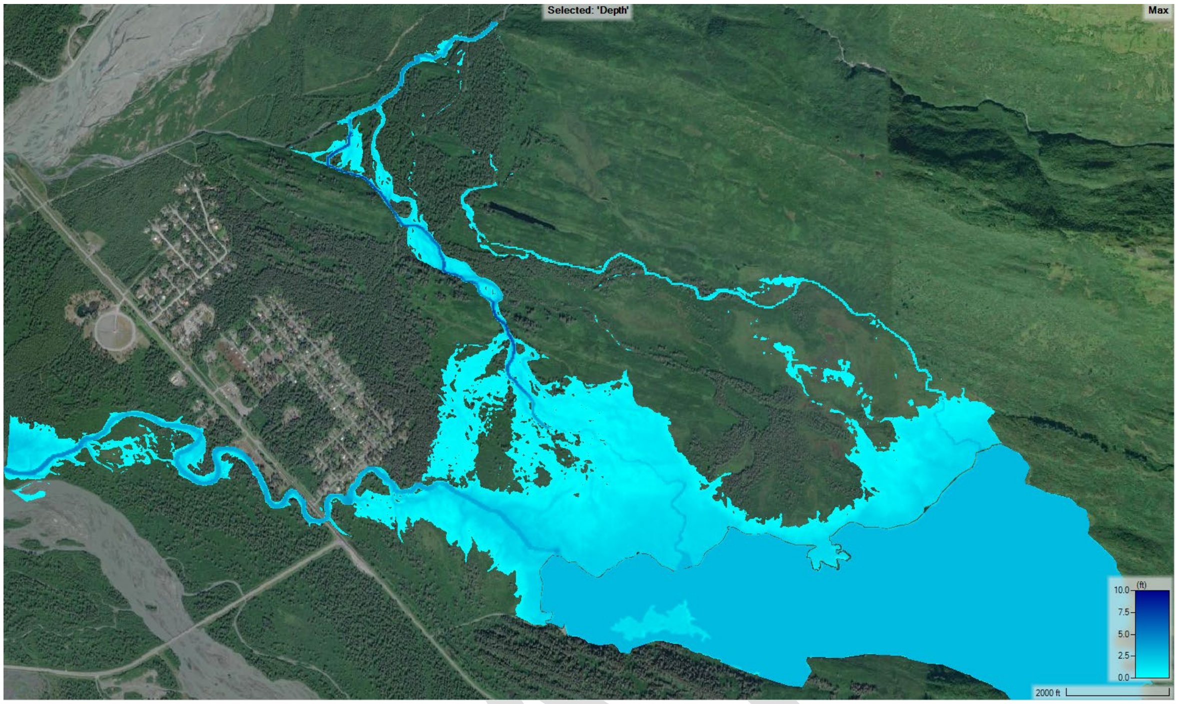


1% Annual Exceedance Probability

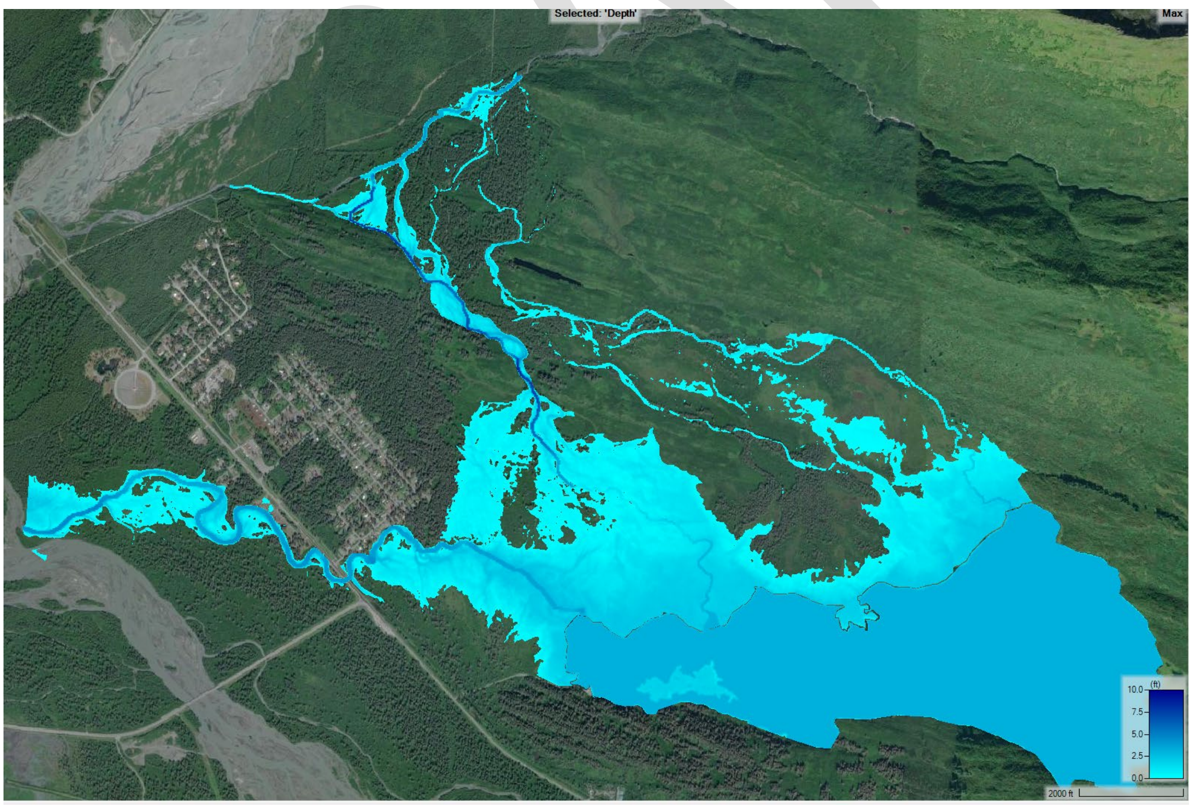


0.2% Annual Exceedance Probability

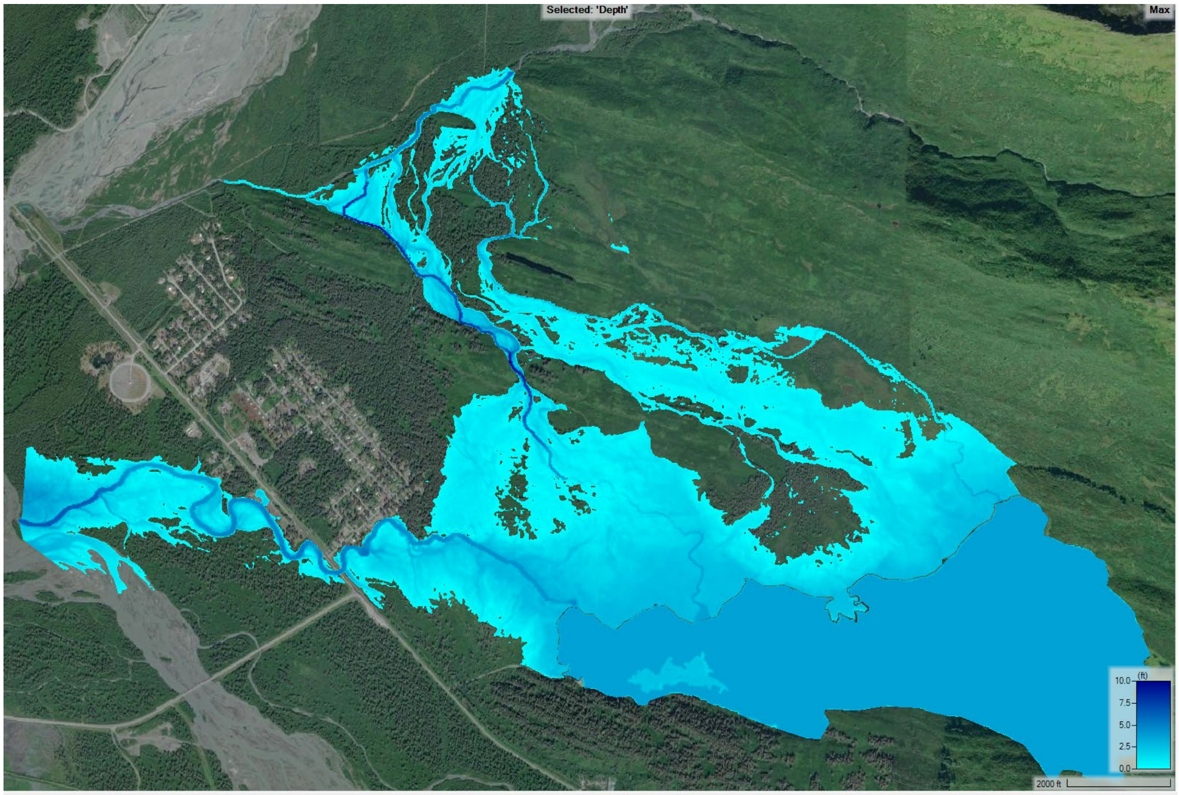
Alternative B-1



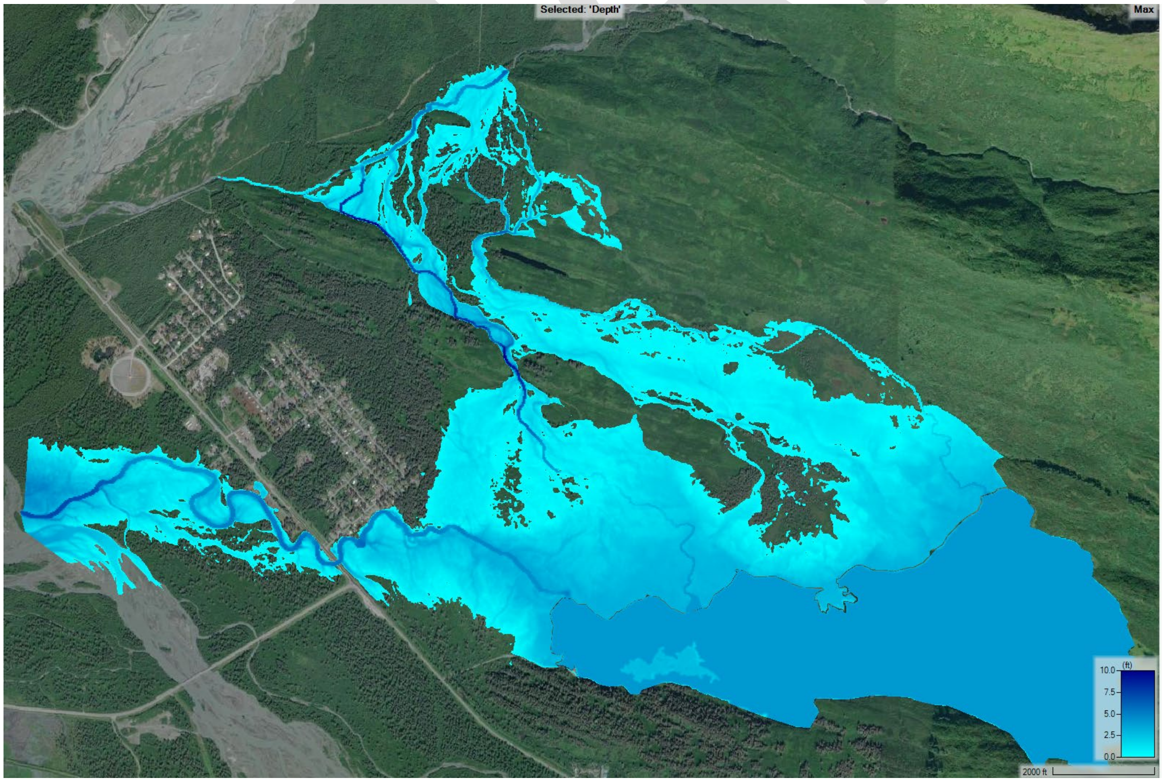
50% Annual Exceedance Probability



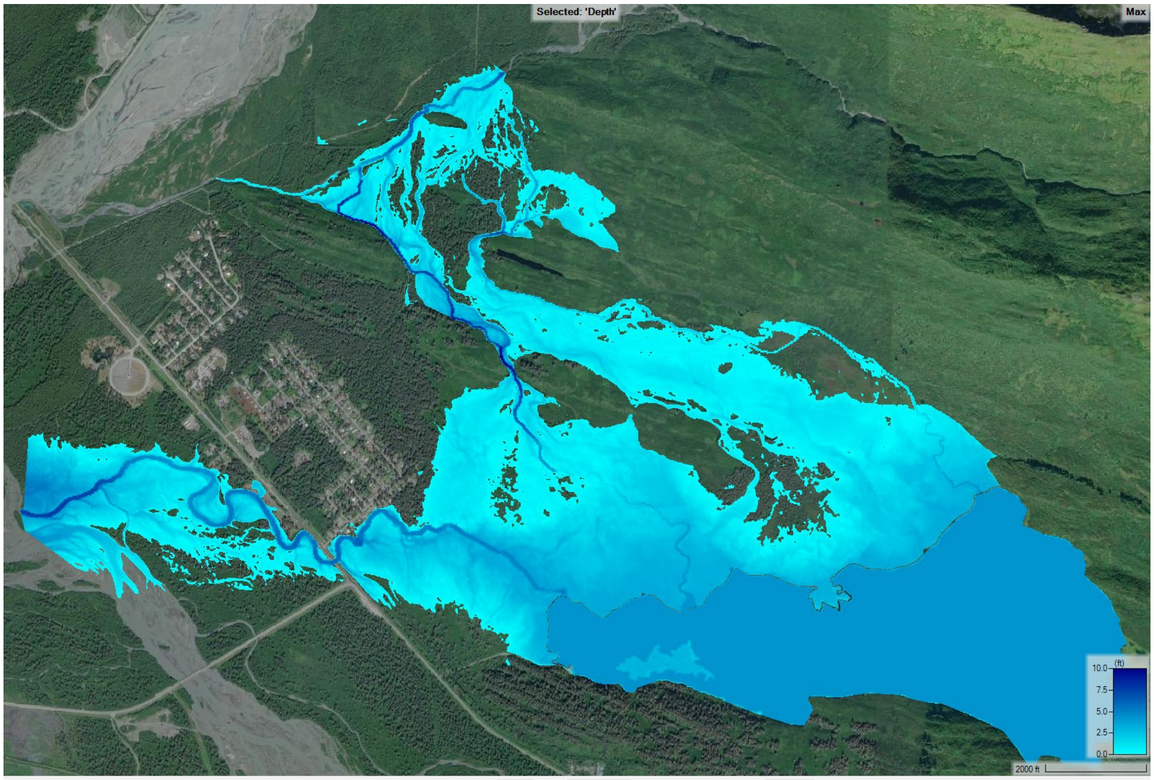
20% Annual Exceedance Probability



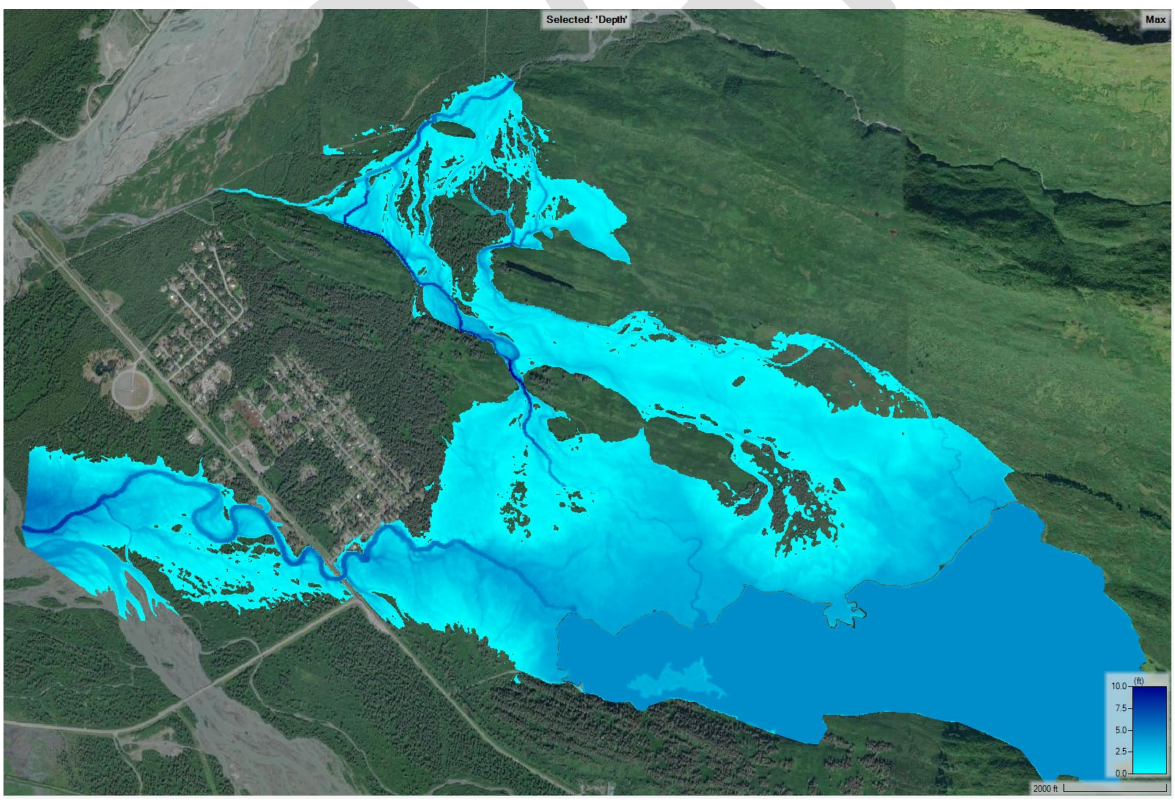
10% Annual Exceedance Probability



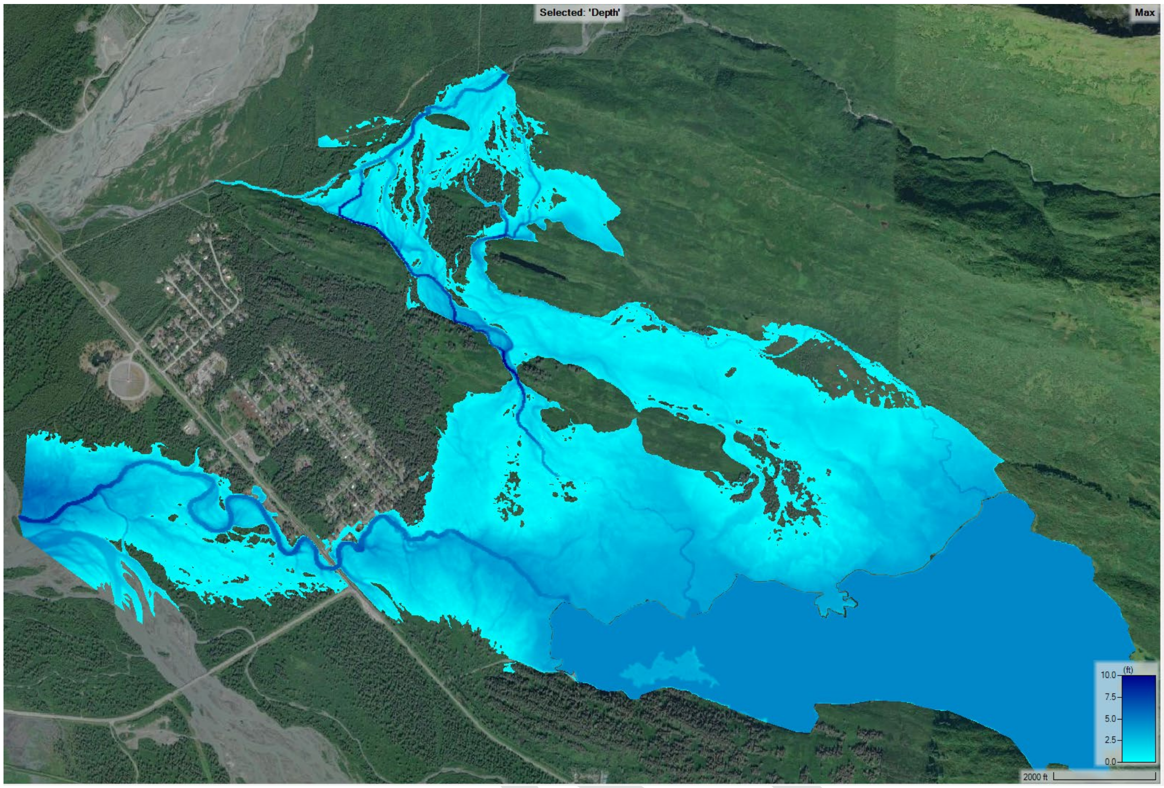
4% Annual Exceedance Probability



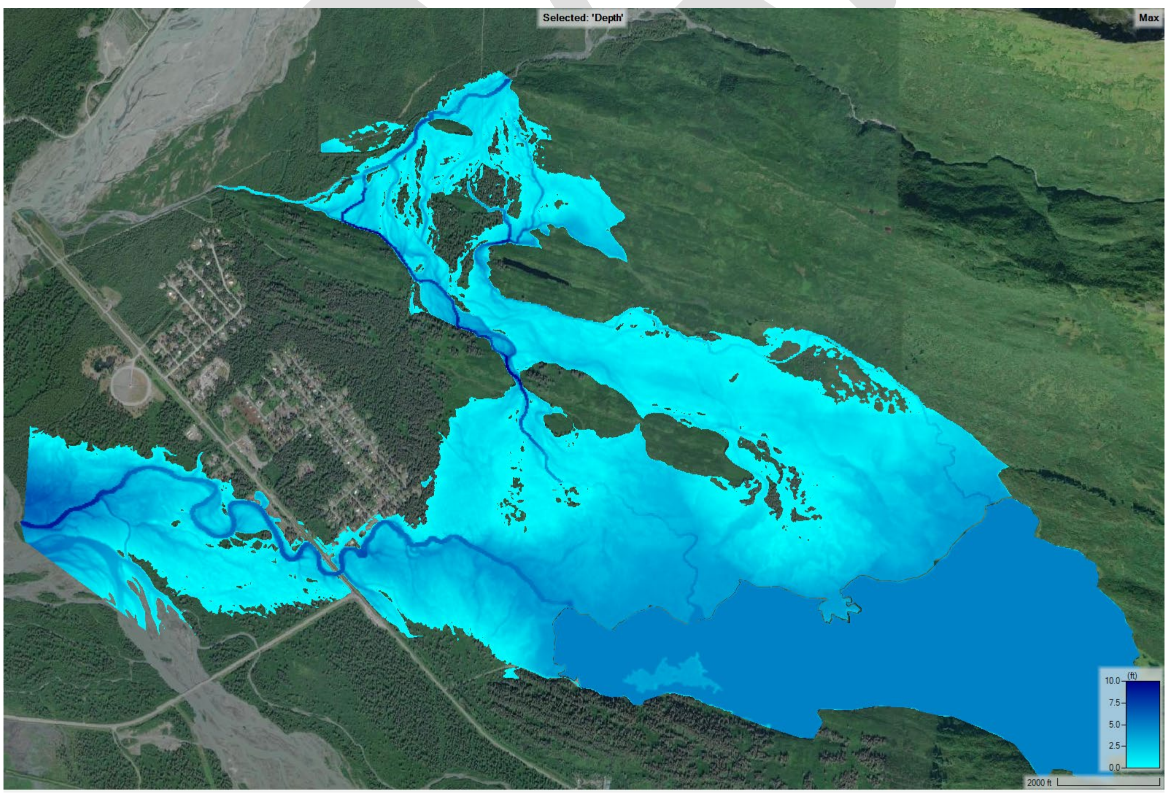
2% Annual Exceedance Probability



1% Annual Exceedance Probability

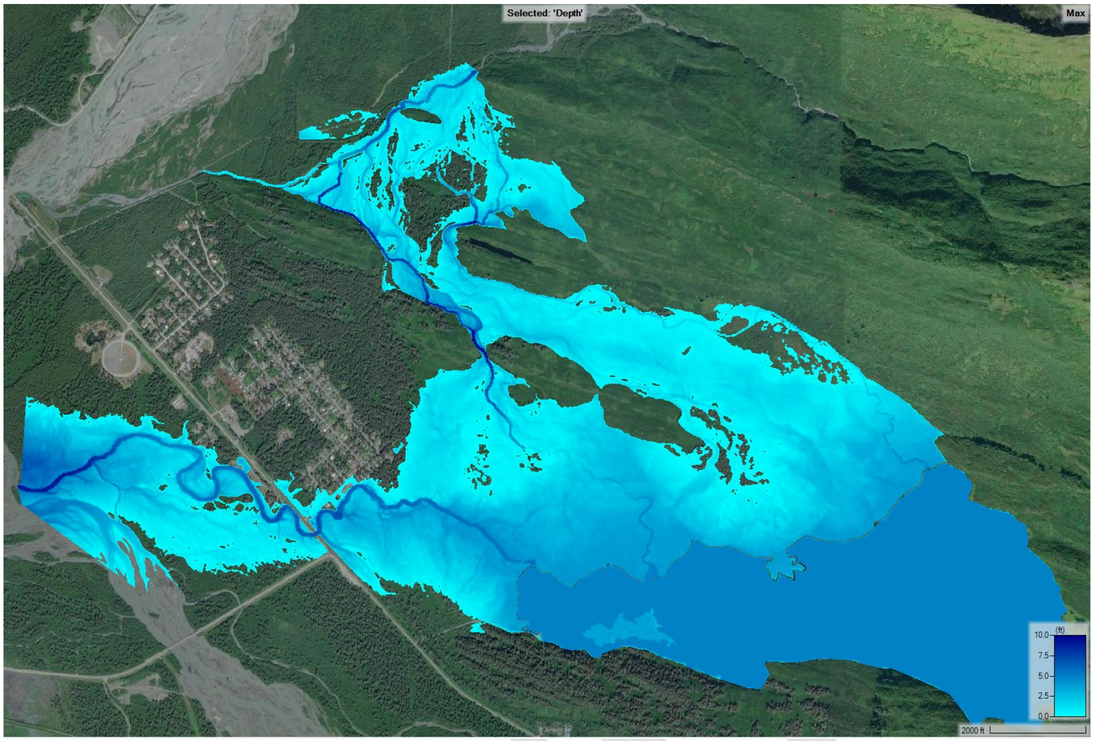


0.5% Annual Exceedance Probability

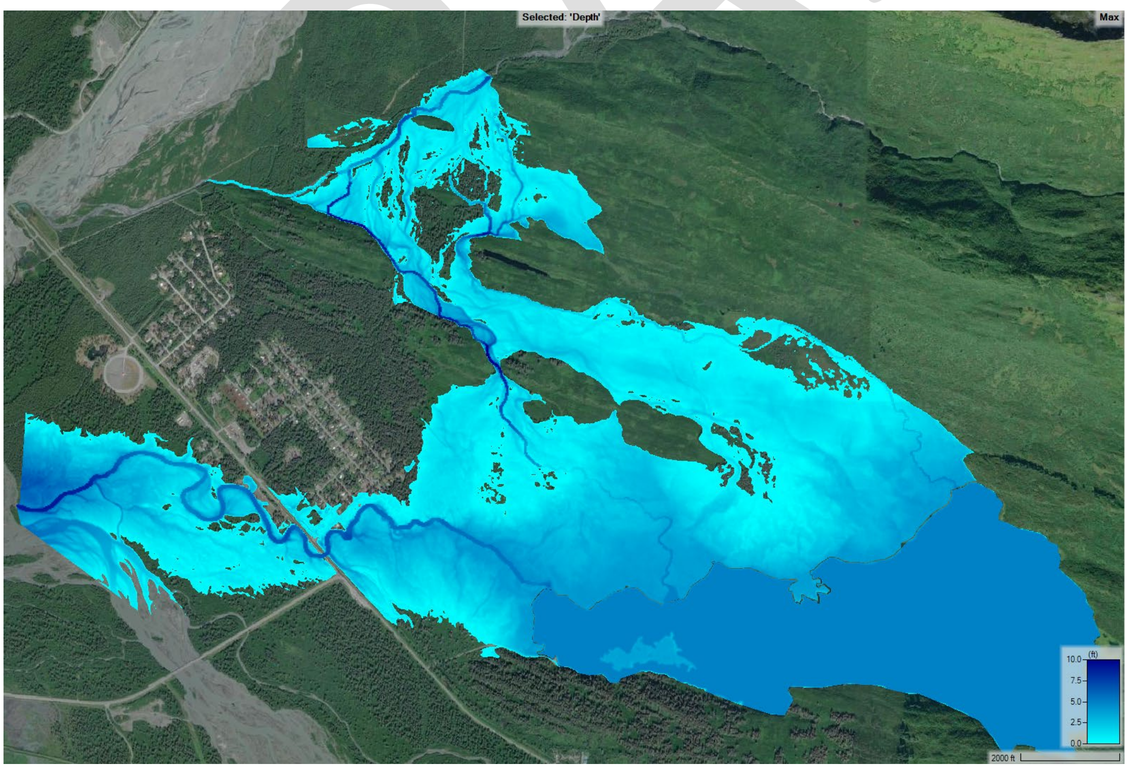


0.2% Annual Exceedance Probability

Alternative B-2

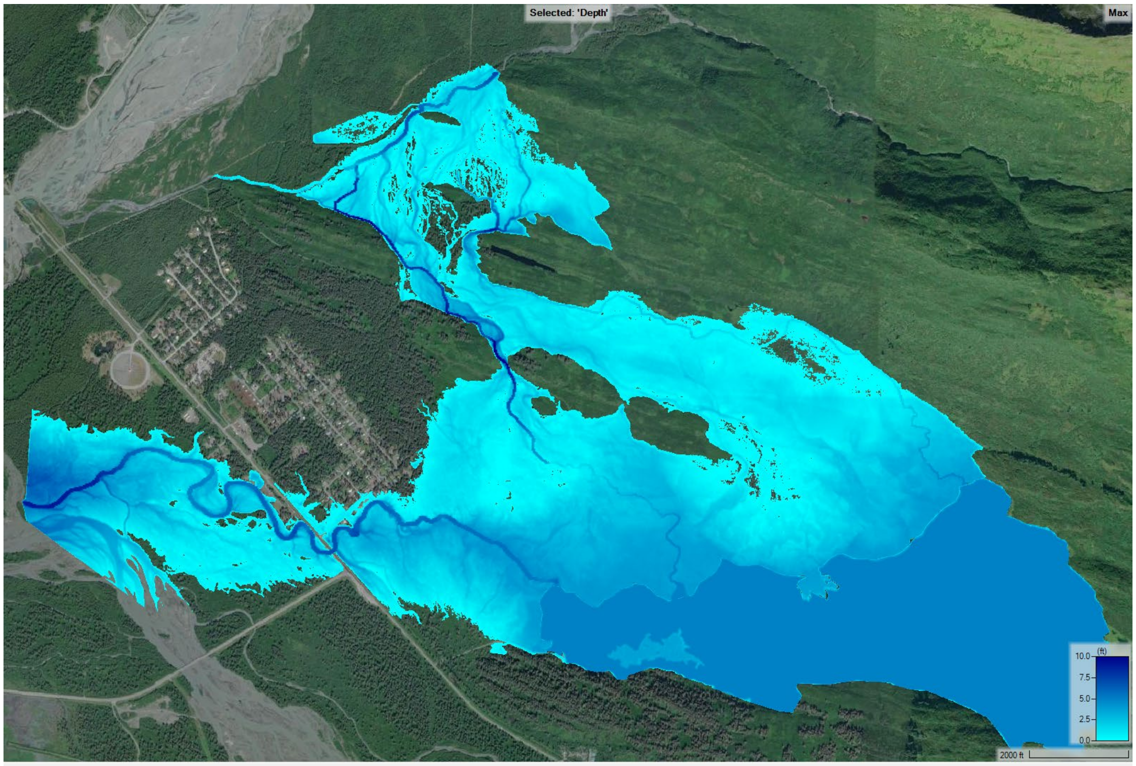


1% Annual Exceedance Probability

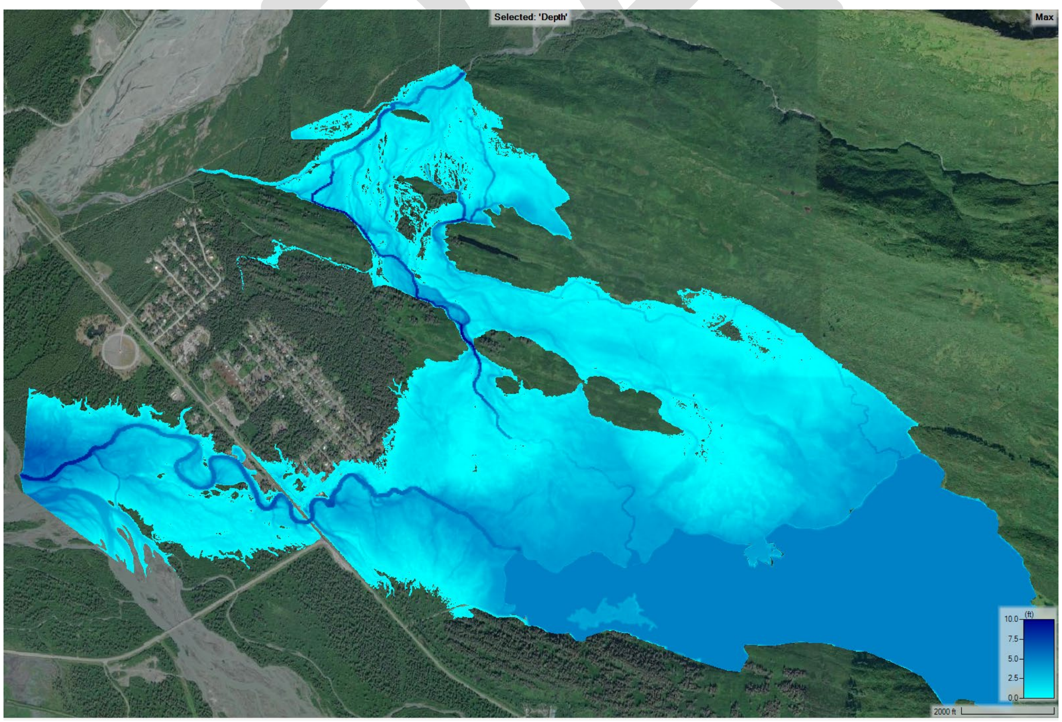


0.2% Annual Exceedance Probability

Alternative B-3

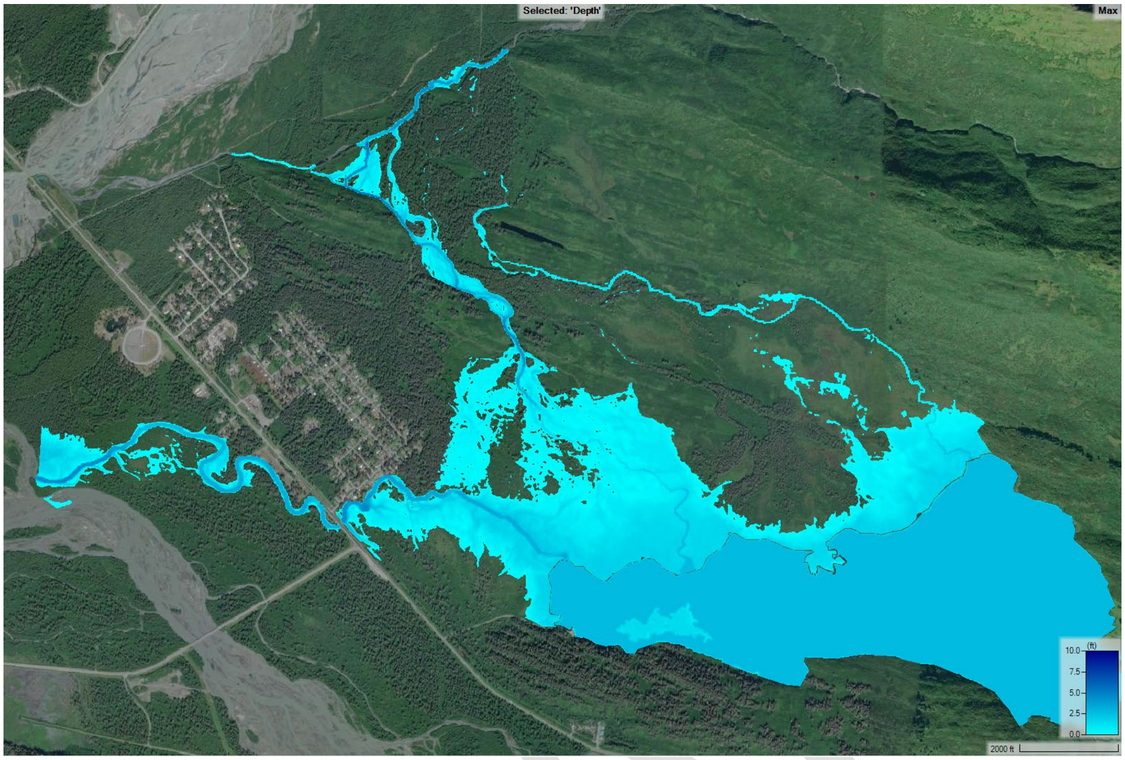


1% Annual Exceedance Probability

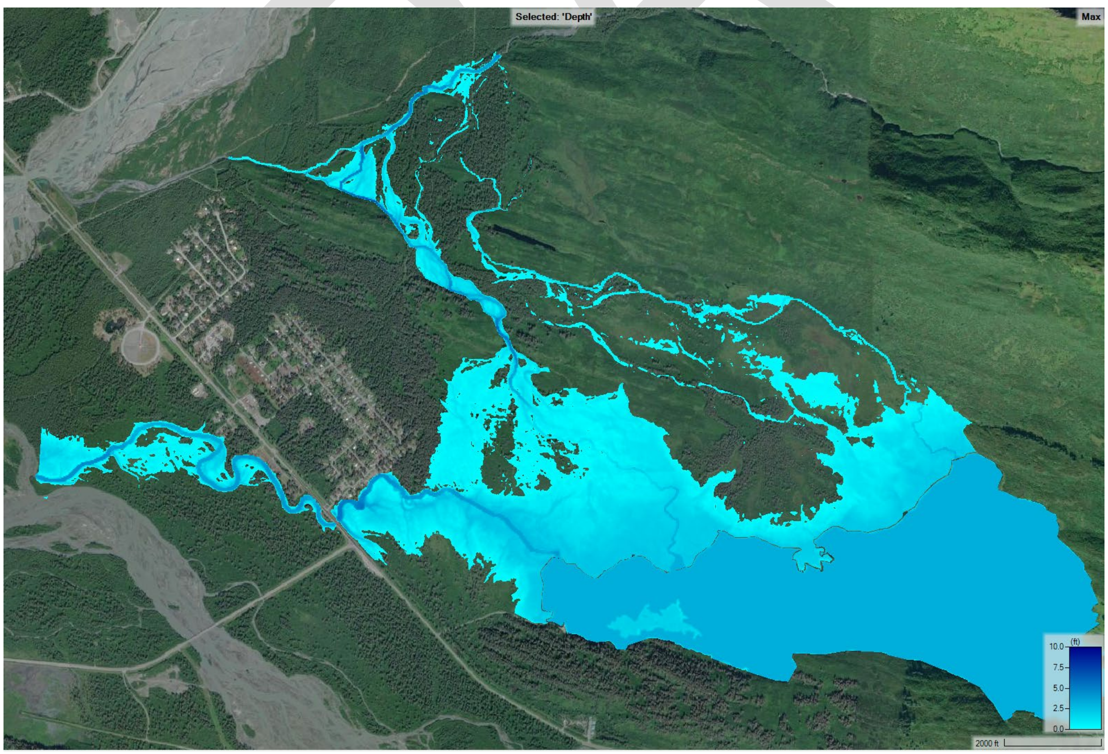


0.2% Annual Exceedance Probability

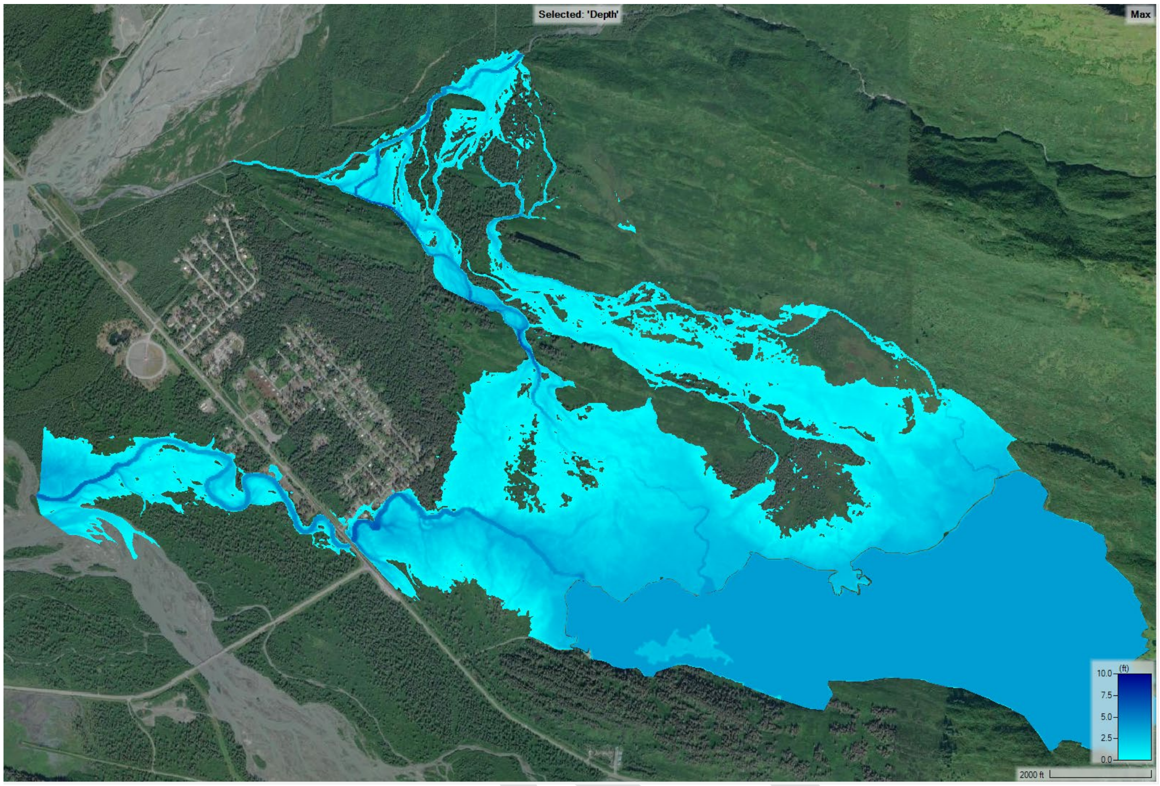
Alternative C



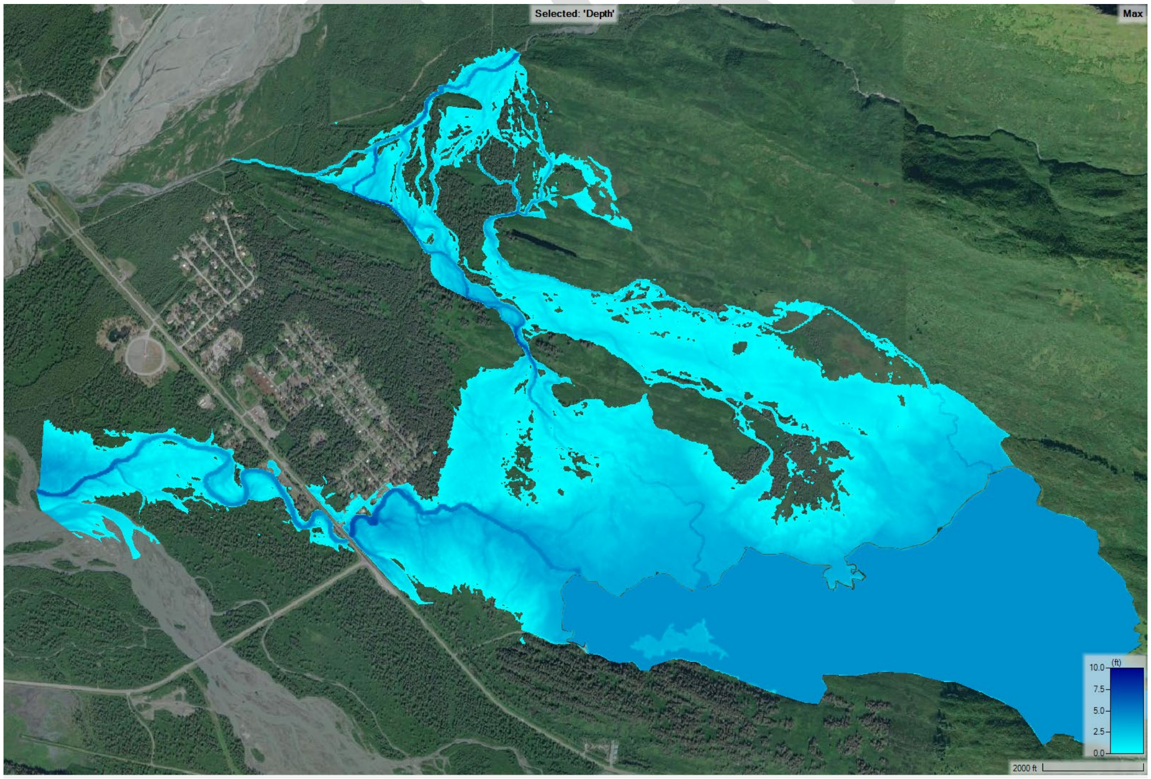
50% Annual Exceedance Probability



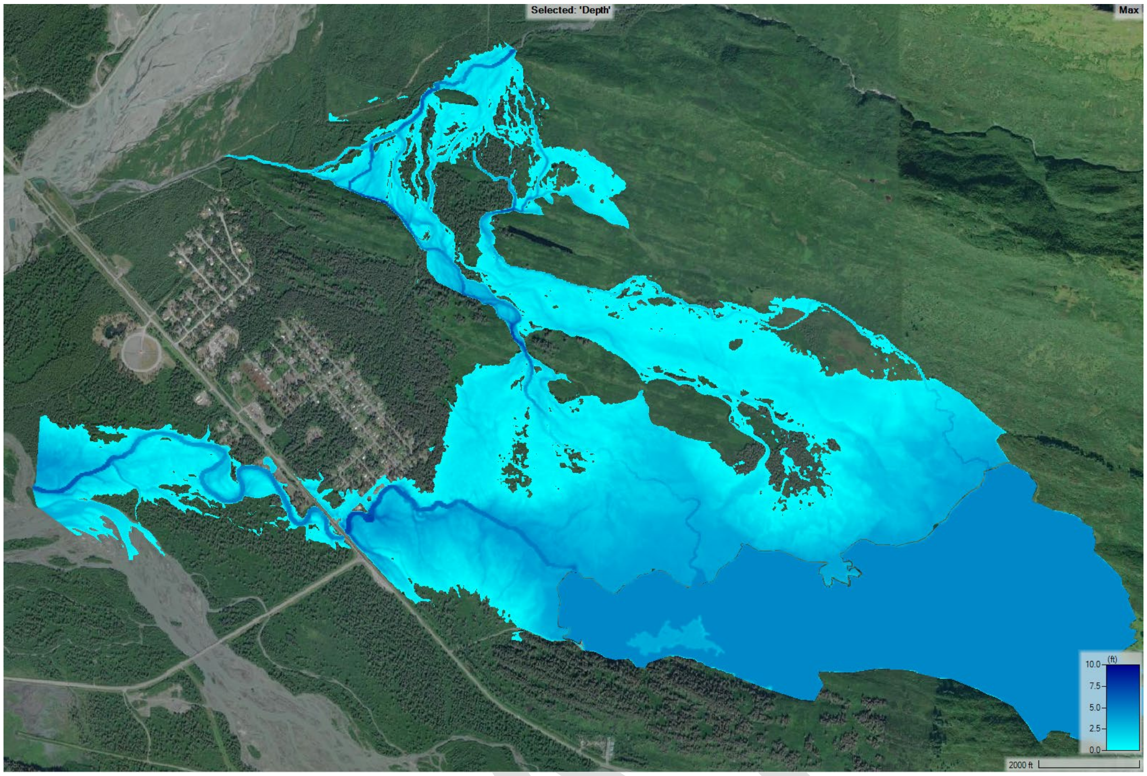
20% Annual Exceedance Probability



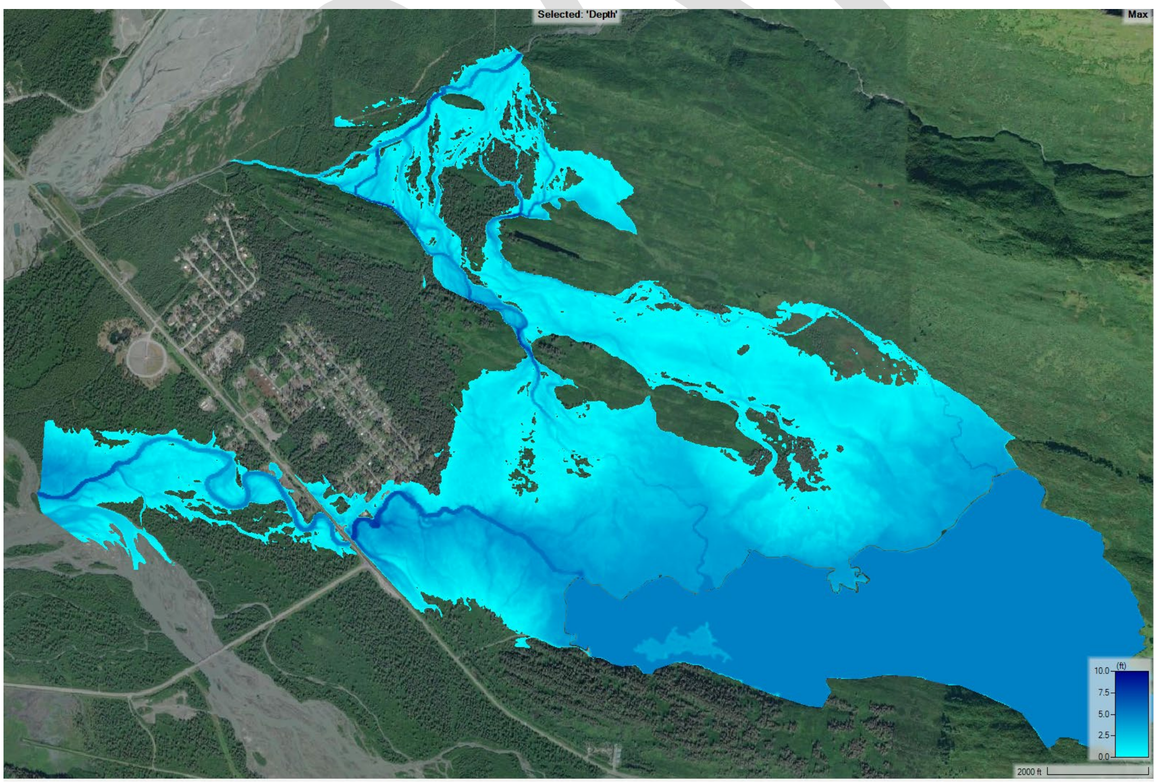
10% Annual Exceedance Probability



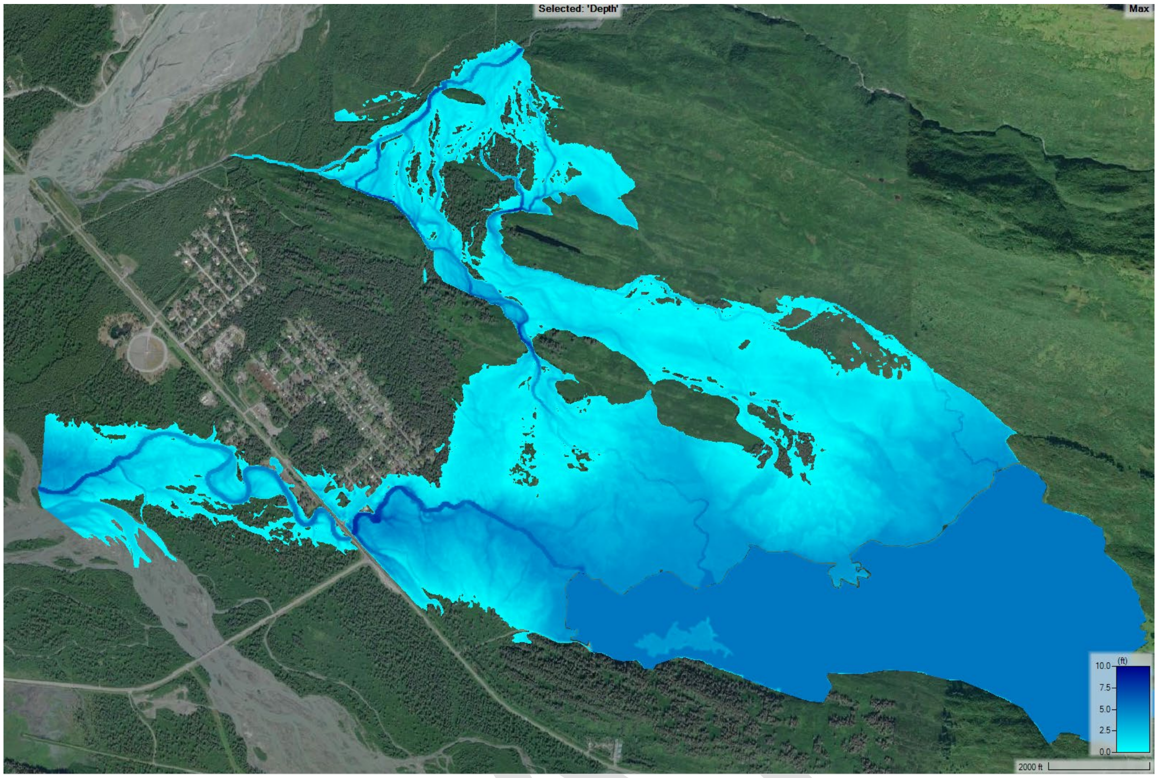
4% Annual Exceedance Probability



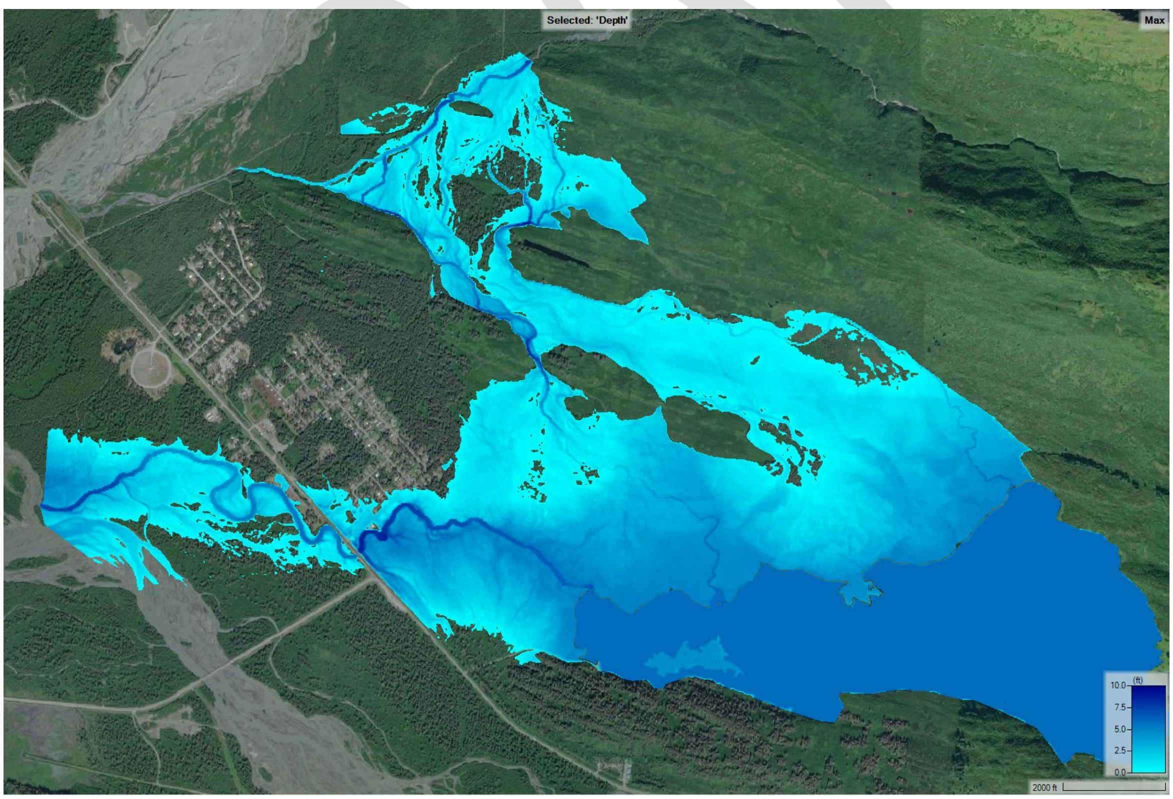
2% Annual Exceedance Probability



1% Annual Exceedance Probability

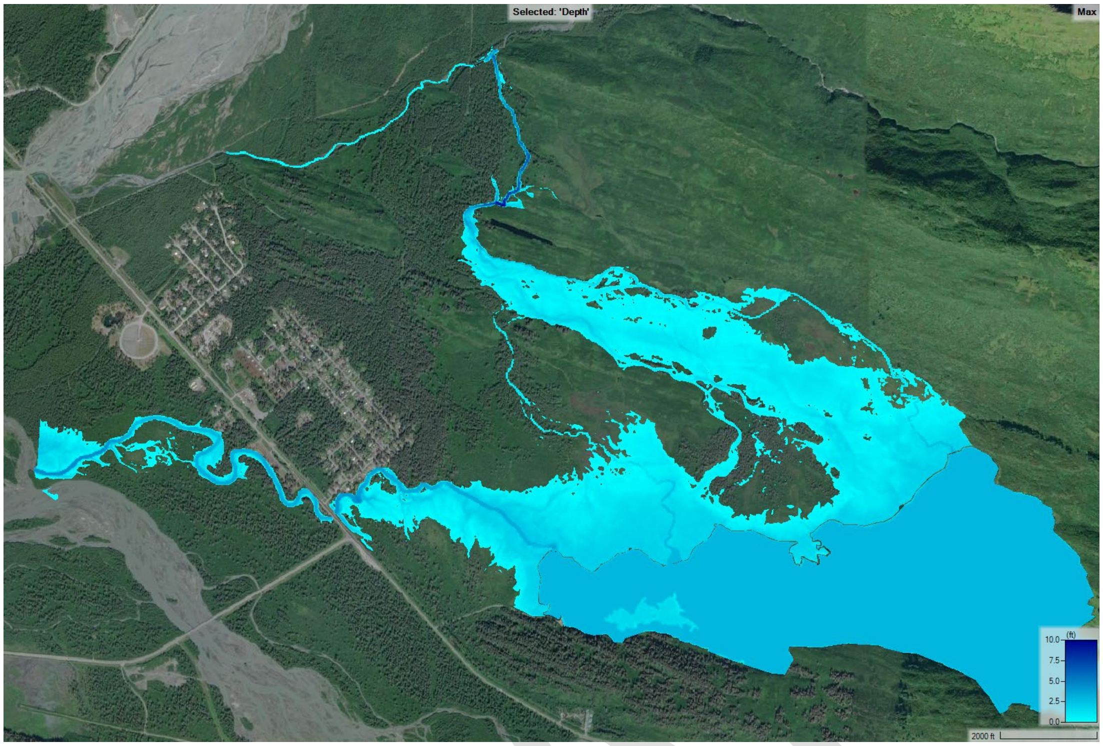


0.5% Annual Exceedance Probability

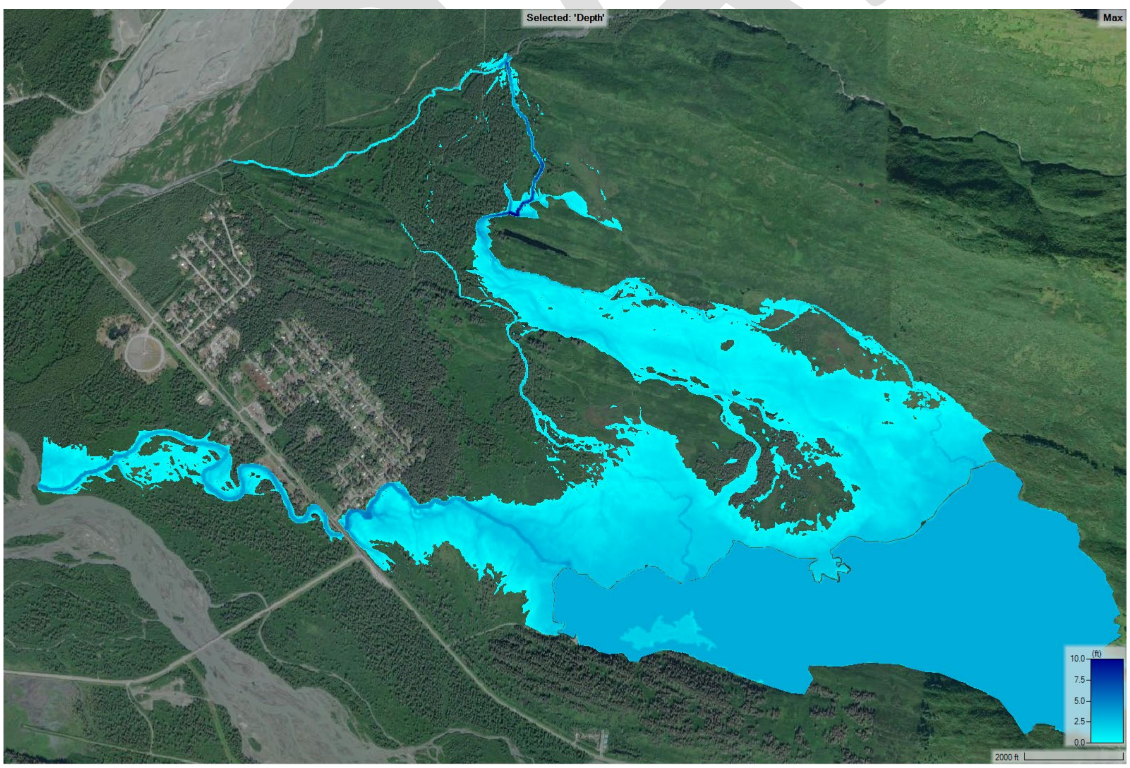


0.2% Annual Exceedance Probability

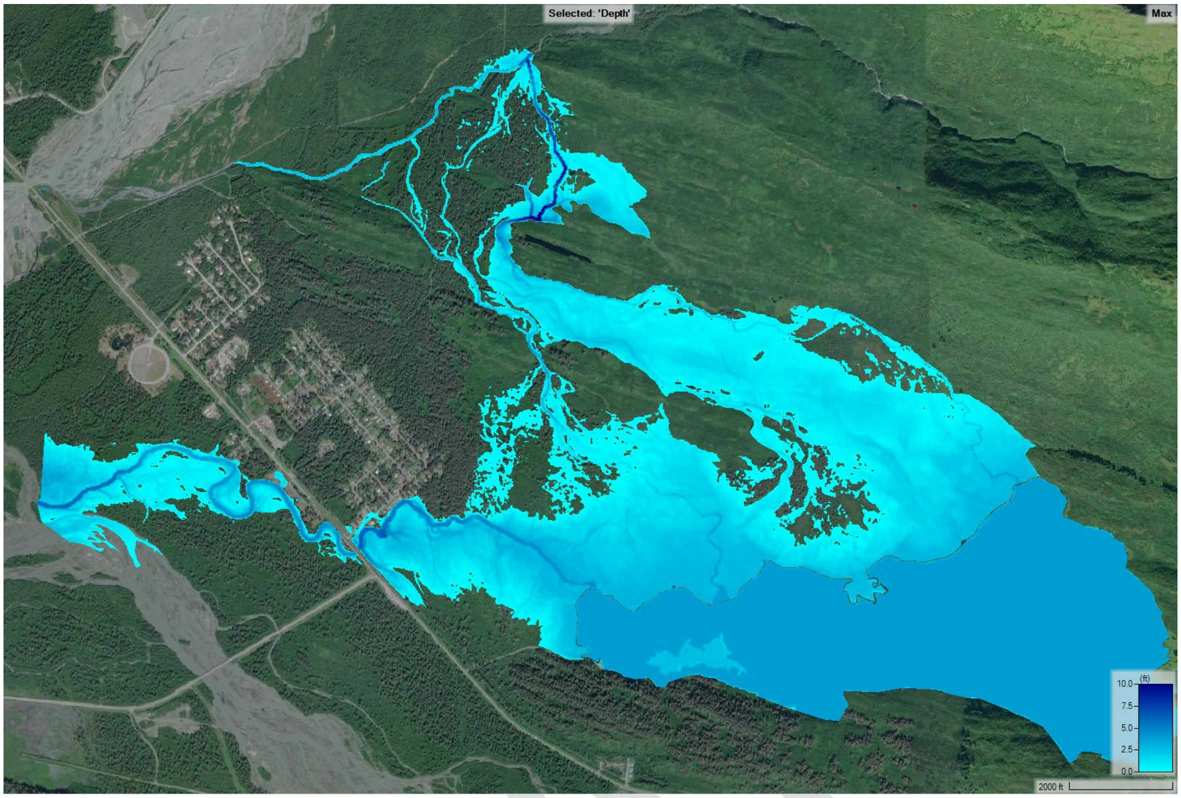
Alternative D



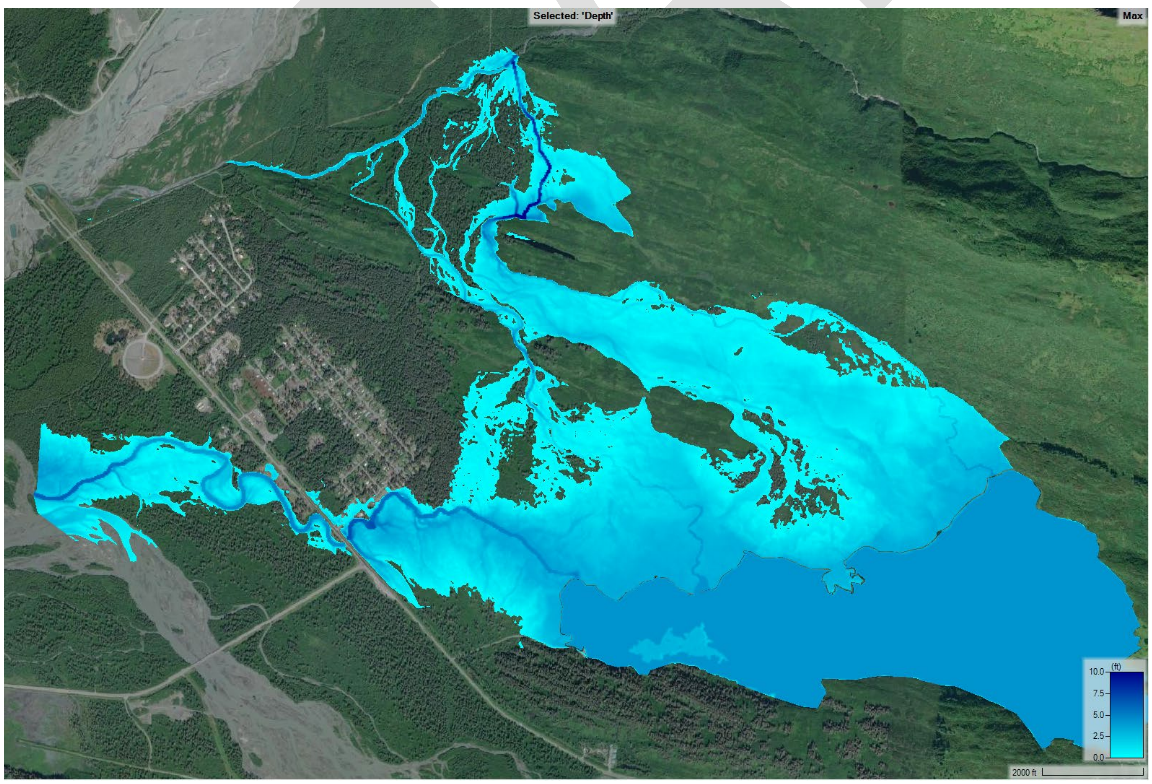
50% Annual Exceedance Probability



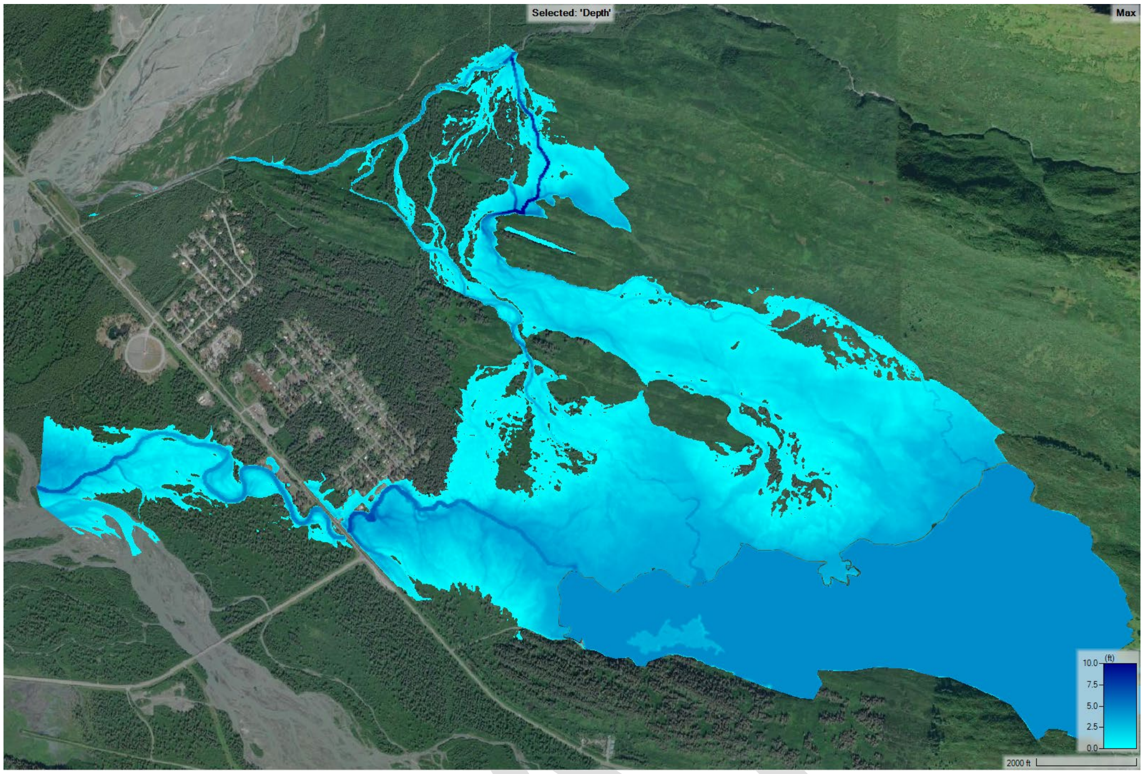
20% Annual Exceedance Probability



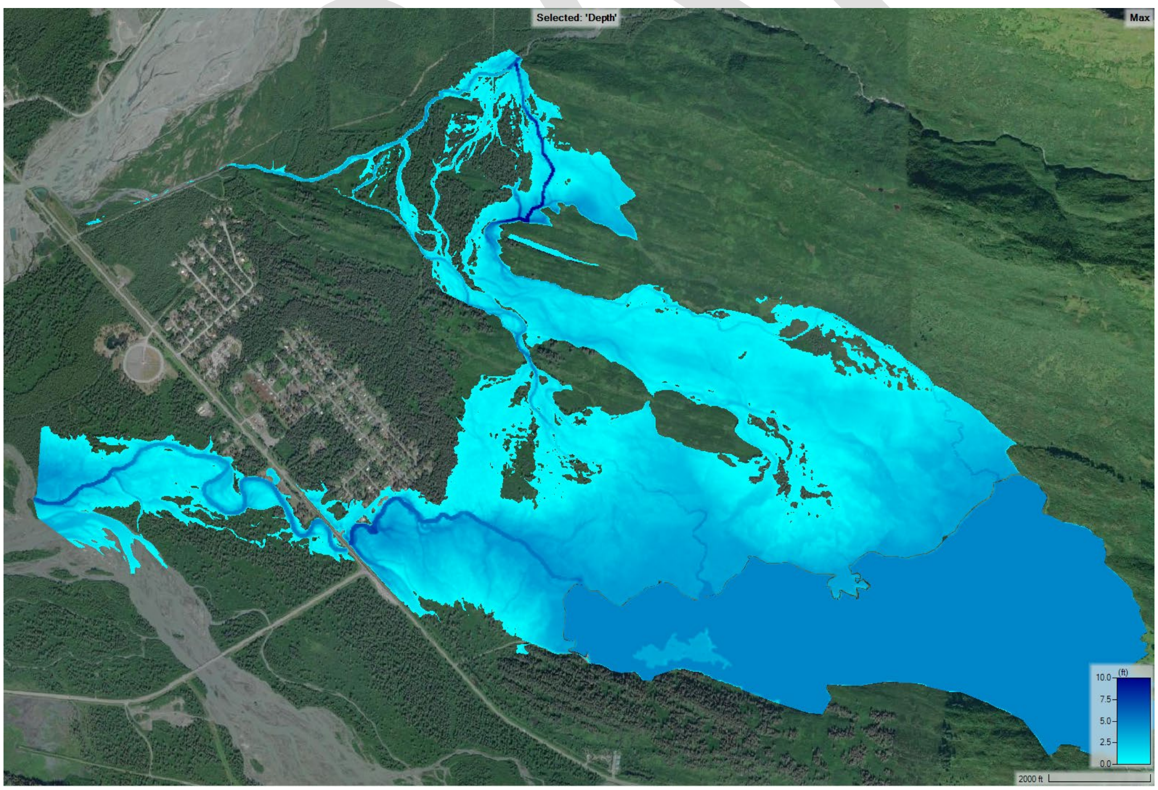
10% Annual Exceedance Probability



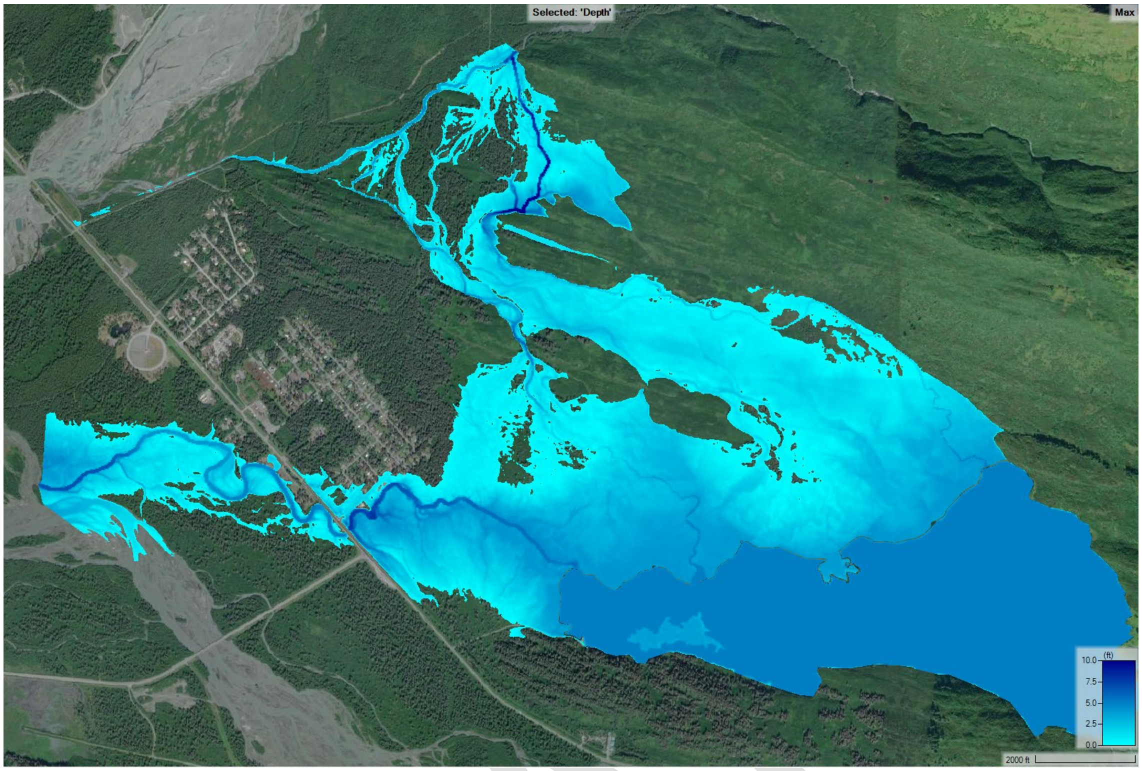
4% Annual Exceedance Probability



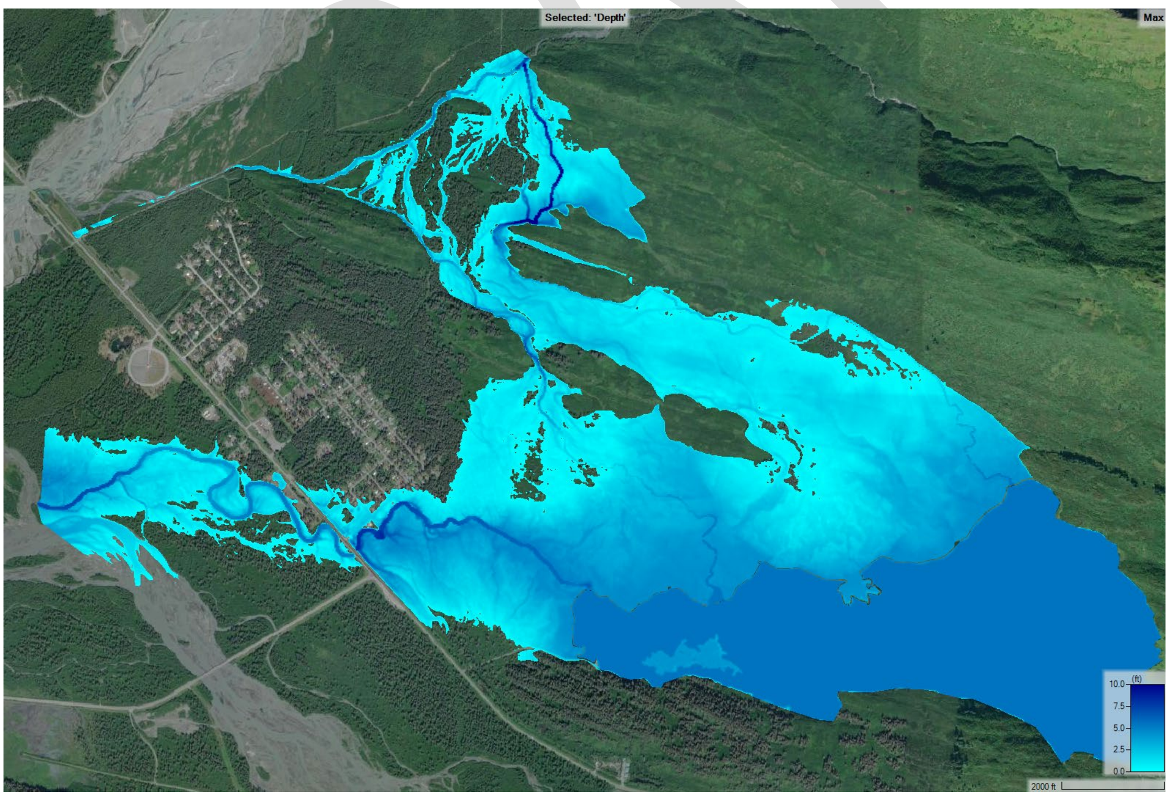
2% Annual Exceedance Probability



1% Annual Exceedance Probability



0.5% Annual Exceedance Probability



0.2% Annual Exceedance Probability