US Army Corps of Engineers®

Planning Assistance to States Technical Report

Valdez Glacier Stream and Mineral Creek Technical Assistance Valdez, Alaska

Draft

October 2020

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Valdez, Alaska

Prepared By:

U.S. Army Corps of Engineers
Alaska District

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1.0 INTRODUCTION

1.1 Study Authority

Section 22 of the Water Resources Development Act of 1974, as amended (42 U.S.C. 1962d-16)

1.2 Study Purpose

The Planning Assistance to States (PAS) technical assistance program aims to provide flood mitigation information, including risk assessment, hydraulic, economic, and environmental information that would assist in the long-term water resources management. This study will focus on Valdez Glacier Stream and Mineral Creek, the structures in place on these watersheds, and their areas. This study will support the Valdez Hazard Mitigation Plan and the State of Alaska Hazard Mitigation Plan.

Valdez Glacier Stream and Mineral Creek are braided watersheds with glacial sources. Due to the glacial processes and steep mountain terrain, both watersheds are prone to high sediment transport rates and glacial outwash processes. These processes and sediment loads can result in rapid and continually changing localized erosional and depositional environments. In addition, Valdez Glacier Stream experiences glacial outburst flood events. The purpose of this Technical Assistance Study is to provide hydraulic modeling and risk analysis of the flood hazards to Valdez along with risk reduction measures that can be implemented.

1.3 Stakeholder and Project Location

The City of Valdez (City), population 4,353 (United States Census Bureau 2008), is located approximately 120 air miles east of Anchorage (Figure 1). The City marks the start of the Richardson Highway (State Highway No. 4), the only road that leads in and out of town. Surrounded by the steep mountains of the eastern Chugach Range, the City is situated between two glacier-fed streams, Valdez Glacier Stream and Mineral Creek (Figure 1). These streams are prone to flash flooding caused by glacial lake outbursts, especially from the valley above Valdez Glacier Lake. Valdez Glacier Stream flows under the Valdez Glacier Stream Bridge #556 east of the City.

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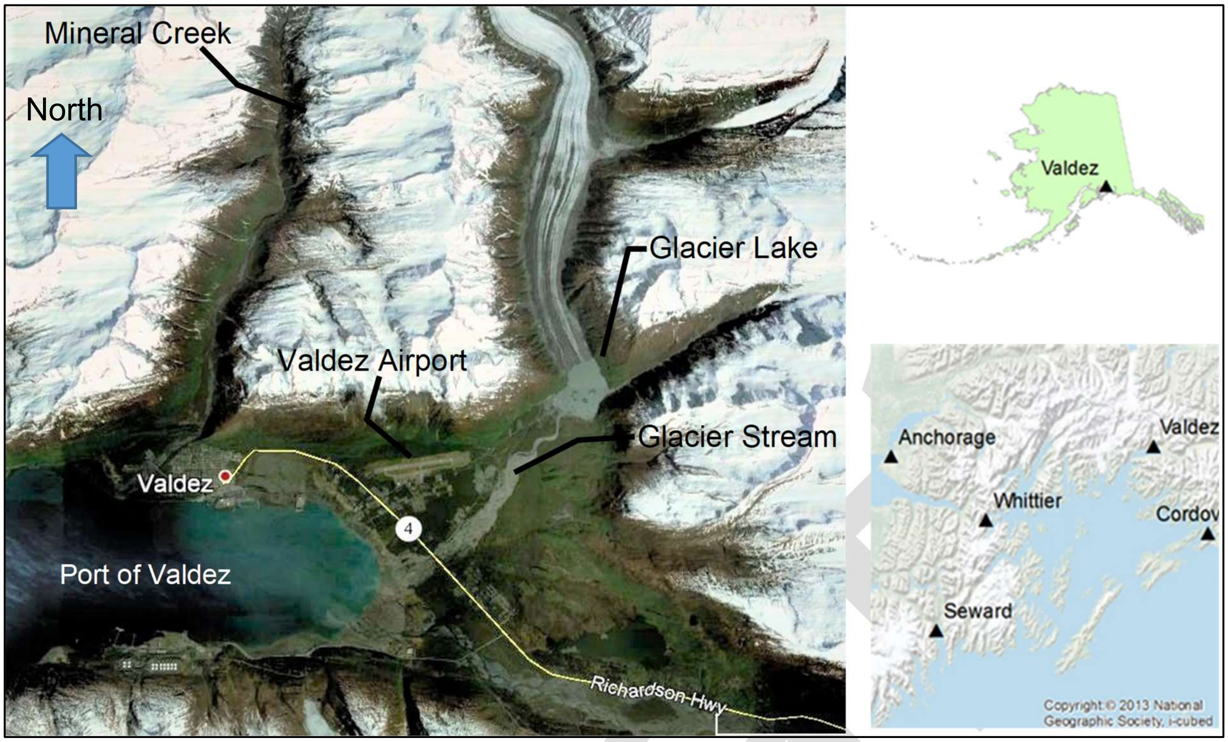

Figure 1. Location Map

Located in the northeast corner of Prince William Sound, Port Valdez is a glacial carved fjord with an ice-free deep-draft port with all-weather air and road access to the major population and supply centers of Southcentral and Interior Alaska. The Trans-Alaska Pipeline terminates at the Alyeska Oil Terminal on the south shore of Port Valdez, where oil is transferred to ships for market. Valdez Airport (see Figure 1), also known as Pioneer Field, is a state-owned public-use airport located three nautical miles east of Valdez's central business district. It has one asphalt paved runway measuring 6,500 by 150 feet.

The area's climate is maritime and relatively mild, except it experiences a high average annual snowfall of approximately 300 inches and rainfall of approximately 60 inches. The City's economy is based on oil, tourism, commercial fishing, shipping/transportation, and city/state government. Valdez's original town site was completely destroyed on Good Friday in 1964 by the strongest recorded earthquake ever to strike the North American continent. The earthquake was registered as 9.2 on the Richter scale. The tsunamis generated by the earthquake-ravaged the original townsite town. As a result, the townsite was condemned unsafe, and the City was relocated 4 miles to the west.

1.4 Related Reports and Studies

The following documents were consulted in the preparation, but not necessarily referenced or cited in this report. They are listed chronologically, beginning with the earlier dated documents.

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Baker, V.R., R.C. Kochel, and P.C. Patton. 1998. Flood Geomorphology.

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FEMA, November 2012, Best Practices for Incorporating Building Science Guidance into Community Risk MAP Implementation.

Wolken, G.J., Arendt, A.A., and Rich, J.L., 2015, Bathymetry of Valdez Glacier lake: Raw Data File RDF 2015-1, Alaska Division of Geological & Geophysical Surveys, Fairbanks, Alaska, United States.

Wolken, G.J., and Wikstrom Jones, Katreen, 2017, Valdez Glacier ice-dammed lake: June 2017 glacial lake outburst flood: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2017-4.

City of Valdez, Alaska, Natural Hazard Mitigation Plan Update, May 30, 2018.

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Wolken, G.J., and Wikstrom Jones, Katreen, 2019, Valdez Glacier ice-dammed lake: June 2018 glacial lake outburst flood: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2019-4.

FEMA Map, Revised January 3, 2019, Flood Insurance Study, City of Valdez Unorganized Borough, County Number 020094.

2.0 IDENTIFIED PROBLEMS

Local development has occurred on alluvial fans located between the mountains and Port of Valdez because of the steep, rugged terrain surrounding Valdez. As the stream flows exit steep, confined valleys onto these alluvial fans, they are prone to spread out in a braided channel network down and across the fan. Particularly at high flows, these flow paths are uncertain and prone to rapid, significant changes in stream paths (channel avulsions) with the potential for inundation (flooding) of low-lying areas. These braided stream systems are characterized by lateral erosion, rapid sediment deposition, and constant channel migration due to increased flows and flow velocity. These conditions pose threats to the development upon and adjacent to the alluvial fans primarily if flood events are sudden and result in out-of-channel flow, causing flooding, as discussed in the following paragraphs.

The Valdez Glacier Stream valley has historically experienced annual to bi-annual flooding events to varying degrees caused by a sudden release of water from the Valdez Glacier Ice-dammed Lake (VGIDL). The most significant events have an out-of-channel flow that impacts Valdez Glacier Stream drainage's lower areas. Potential impact zones are upstream of the Valdez Glacier Stream Bridge #556. The bridge is part of the Richardson Highway, the only access road to and from the City that is connected to the Alaska Road system.

The VGIDL area is located at an elevation of approximately 722 feet above mean sea level, 4.5 miles up from the Valdez Glacier terminus (Figure 2). The basin where the VGIDL temporarily forms is recharged by runoff from snow melt and rain in the drainage and glacial runoff from a receded tributary glacier (Camicia Glacier). The Valdez Glacier temporarily blocks these waters with the accumulating water forming the VGIDL (Figure 4). This water is released periodically in outburst events that occur annually to bi-annually, typically in June, in association with the spring runoff and September–October due to significant rain from fall storms (Jones and Wolken, June 2017 and April 2019).

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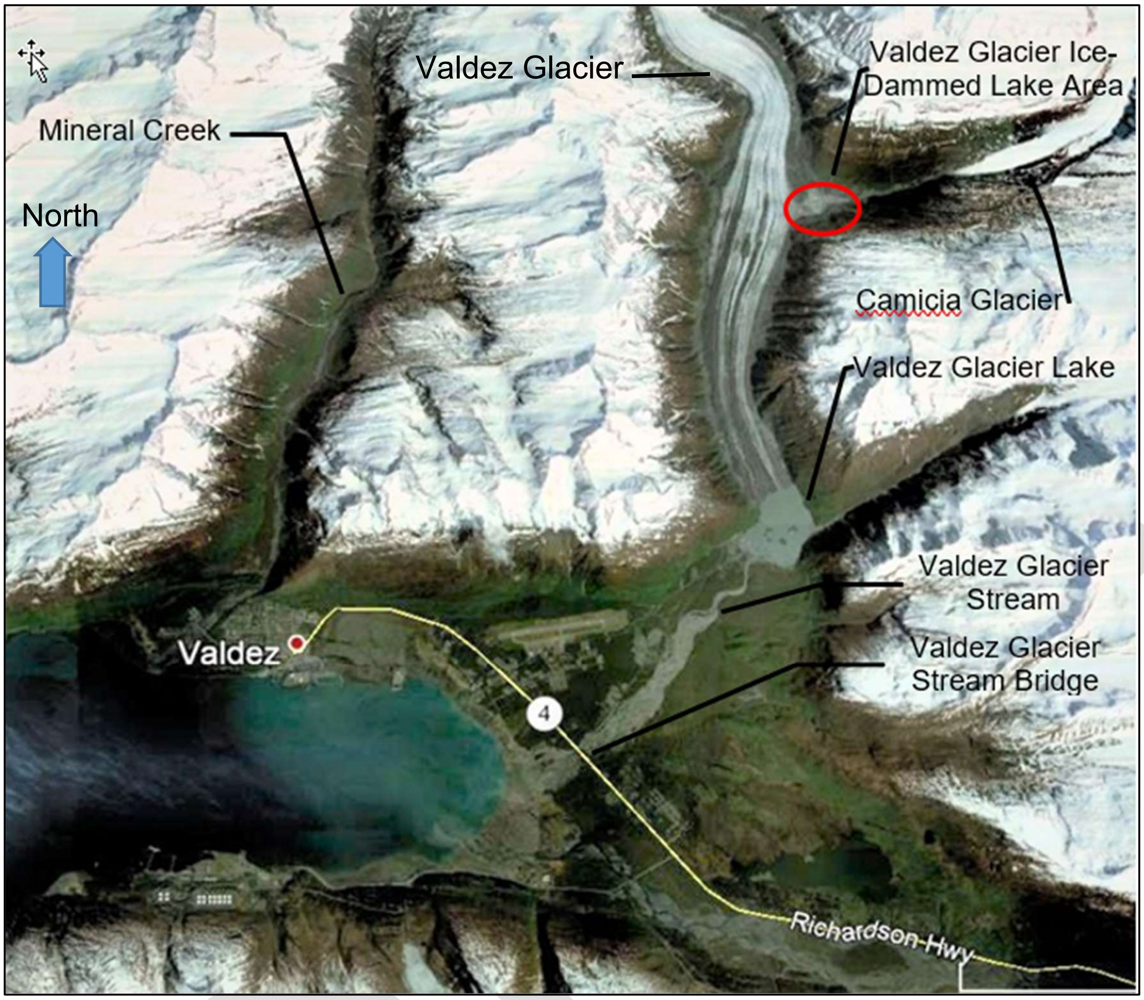

Figure 2. The location where the Valdez Glacier Ice –Dammed Lake forms.

According to Jones and Wolken (June 2017 and April 2019), the exact dynamics of the drainage and outburst events are currently unknown. Still, the triggering mechanism is likely to increase hydraulic pressure as the lake volume and height increase. Interaction with the englacial and subglacial process that creates drainage conduits near the lake margin allows efficient water flow to Valdez Glacier Lake (Figure 3Figure 4) at the terminus of Valdez Glacier.


Figure 3. Valdez Glacier Lake

The drainage of the VGIDL has been relatively fast, taking a few hours to several days, as demonstrated by the comparison of photographs taken on 18 June 2018 when the VGIDL water level was high and one day later(Figure 4) when the lake was empty. The estimated volume of water released was estimated at 19,700,000 cubic meters (25,800,000 cubic yards or 5,204,189,431 gallons) by Wikstrom and Wolken, 2019.

This rapid release of water from the VGDIL causes an abrupt, rapid rise in the Valdez Glacier Lake and Stream water level. The flow from Valdez Glacier Lake appears to stay relatively confined within the upper third of the stream reach above the Valdez Glacier Stream Bridge #556 (see Figure 2). Below this relatively narrow reach, the steam channel widens and becomes braided with more channel migration.

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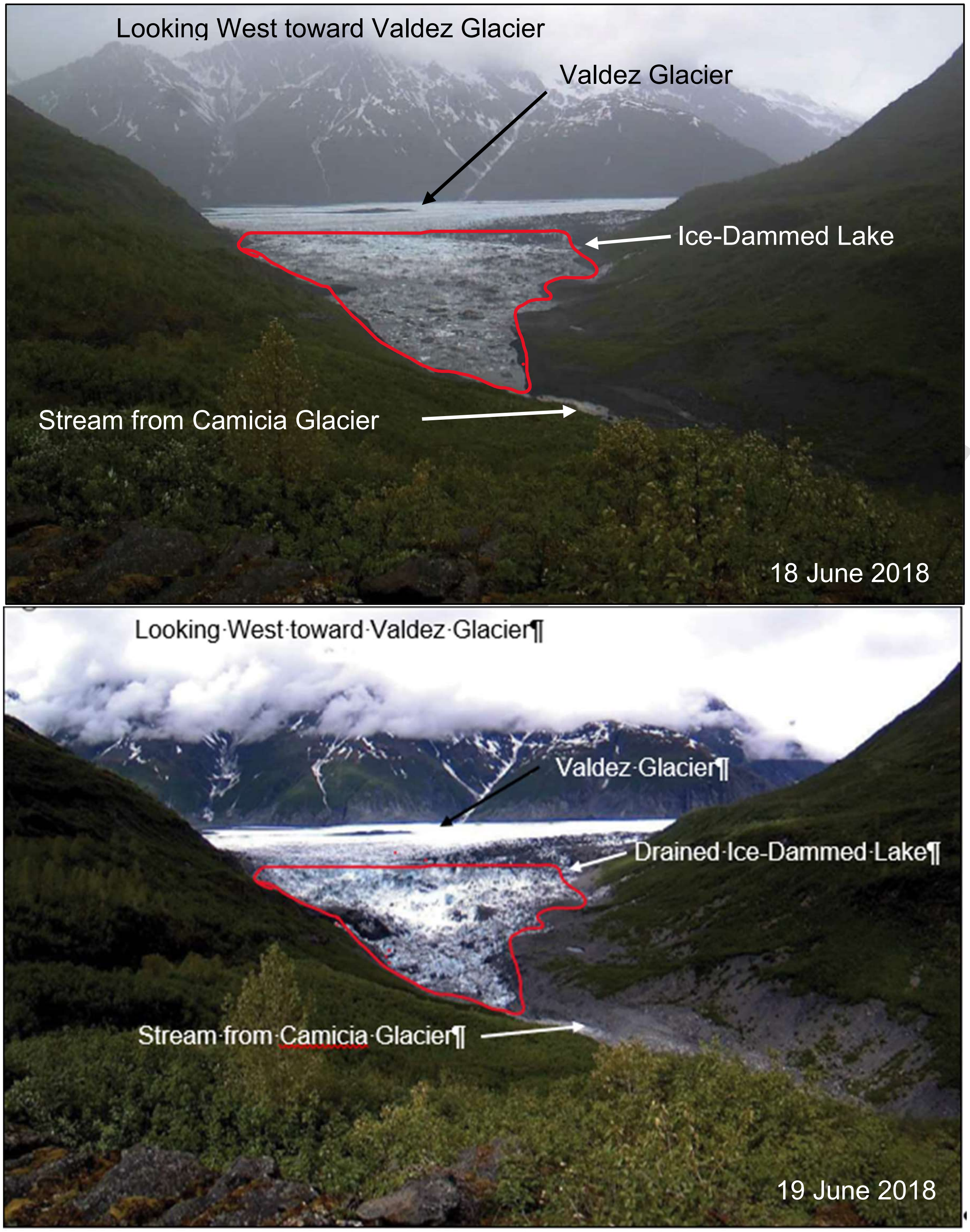

Figure 4. Water Level of Valdez Ice-Dammed Lake before and after outburst, observed on 18 and 19 June 2018. (photographs from Wikstrom and Wolken, Preliminary Interpretive Report 2019-4, State of Alaska Department of natural resources, Division of Geological and Geophysical Survey, dated April 2019)

The City is concerned that historic inactive river channels in the mostly wooded area west of Valdez Glacier stream could become active during a high flow event. The concern is that gravel mining operations near the stream may act as a conduit to these historic channels. If this happens, floodwaters may reach areas not typically impacted by floods, including the Valdez Airport. These historic channels are difficult to notice in typical aerial photography but are visible in lidar imagery (Figure 5).

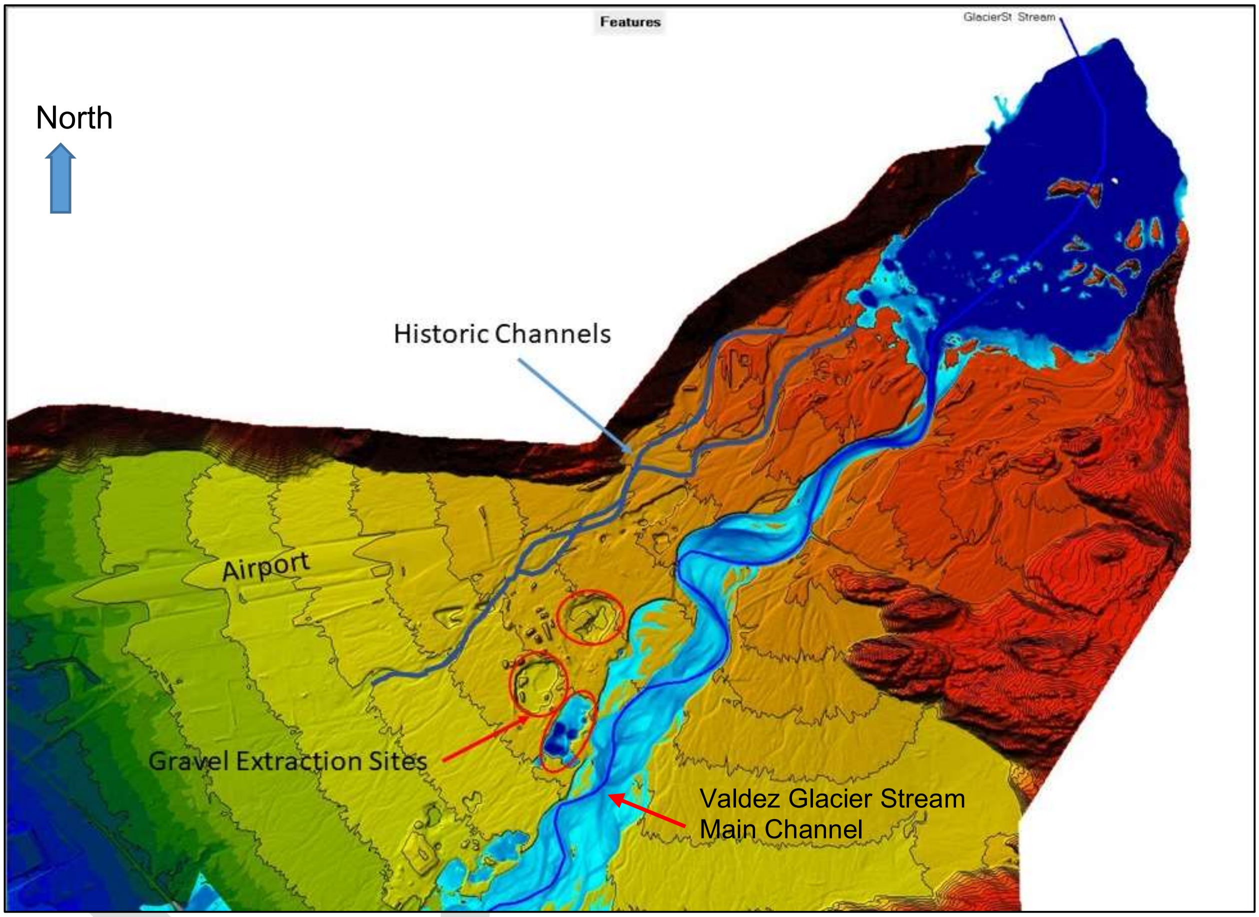

Figure 5. Historic Stream Channels west of Valdez Glacier Stream

3.0 EXISTING STREAM BANK STRUCTURAL MEASURES

3.1 Valdez Glacier Stream

Various structural measures have been constructed above and below the Valdez Glacier Stream Bridge #556 (Figure 6) for the purposes of flood control, bank erosion protection, and/or to stabilize the stream channel location. A levee approximately 3,100 ft long protects a community north of the Richardson Highway and southeast of the Valdez Glacier Stream (Figure 7). This levee was constructed prior to 2007 and extended north from the Richardson highway to a bedrock outcrop.

Training dikes revetted with armor stone are located on the left and right banks upstream of the bridge. The purposes of these training dikes are to protect the stream banks and bridge abutments from erosion and to stabilize the stream channel. The right-bank training dike constructed in 2018 extends from the bridge to the Haul Road, which is also revetted for similar purposes from approximately 2013 to 2016. The Haul Road extends to Valdez Glacier Lake and were susceptible to stream erosion; it is also armored with riprap on the streamside (Figure 8 and Figure 9). The road core is probably sand and gravel fill or natural alluvial deposits shown in Figure 9 and Figure 10.

Figure 6. Valdez Glacier Stream Bridge #556 (looking downstream)

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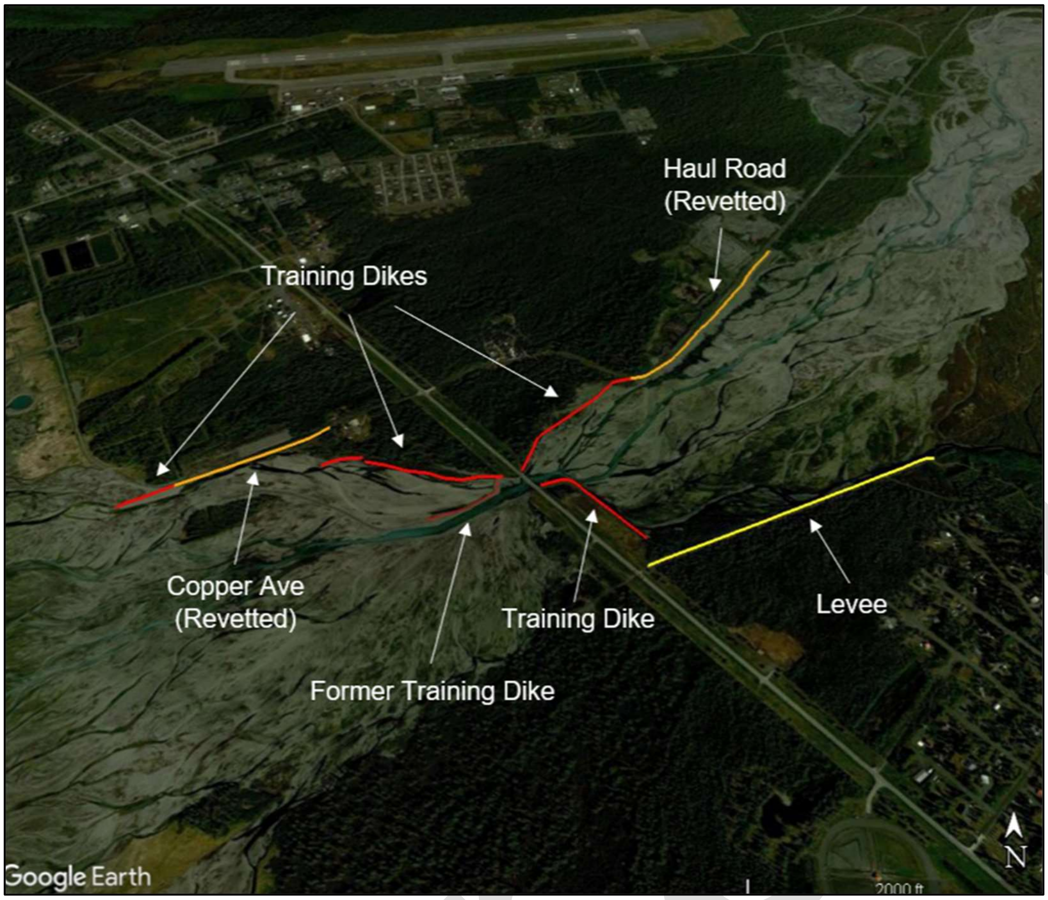

Figure 7. Structural Measures Constructed on Valdez Glacier Stream

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Figure 8. Right bank Training Dike upstream of Valdez Glacier Stream Bridge #556 (Looking downstream toward the bridge).

Figure 9. Haul Road armored section near the landfill (Looking north and upstream)

Figure 10. The northern end of west side armored road (Note that it is assumed the alluvial deposits underlie the haul road.)

Training dikes and a revetted road have also been constructed downstream of the Valdez Glacier Stream Bridge #563 at the approximate locations shown in Figure 7 above. The revetted road on the right bank downstream of the bridge was constructed in approximately 2018 to 2019 (Figure 11 and Figure 12). An earlier constructed revetment immediately downstream washed away (Figure 13) between 2017 and 2019. The Copper Avenue revetment and training dike were built in 2018, and the right bank training dikes were mostly built in 2019.

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Figure 11. Armored road downstream on the right bank downstream of the Valdez Glacier Stream Bridge #563

Figure 12. The south end of right bank downstream of Valdez Glacier Stream Bridge #556 (Looking South)

Figure 13. West bank of Valdez Glacier Stream directly below the bridge looking west (3 Oct 19). What remains of the washed-out control structure is covered in woody debris.

3.2 Mineral Creek

Mineral Creek is a glacially-fed stream that flows along the west side of the townsite. Egan Bridge, a small bridge providing access to a residential neighborhood, crosses the creek approximately one mile upstream of the creek's delta.

Each side of the creek has an earthen levee structure, often unarmored, running from the bridge upstream to the hillsides north of town (Figure 14). The right bank levee is protected from erosion by four armored groins or bend-way weirs (Figure 14) and small revetment at the northernmost section tying into the hillside. Additionally, on the right bank just upstream of the bridge, a revetment was constructed in 2019.

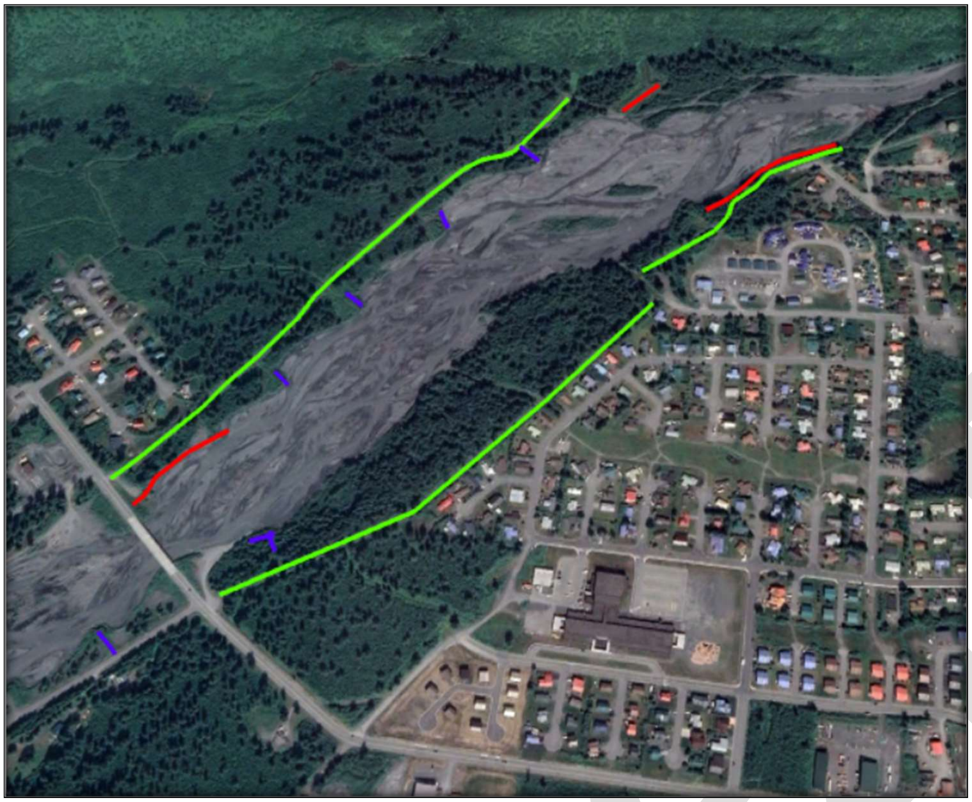

Figure 14: Approximate location of flood structures on Mineral Creek. Levees in Green, Armored sections and revetments in red, and Armored groins in blue.

Figure 15: Bendway weir or Groin on the right bank.

On the left bank, the earthen levee has an armored section on the far upstream section (Figure 16) that was upgraded and extended in 2019. In addition, there is a groin just upstream and downstream of the bridge to protect against erosion (see Figure 15).

Figure 16: Newly rebuilt and the armored section of the left levee, looking downstream.

4.0 INUNDATION MODELING - VALDEZ GLACIER STREAM

4.1 Methodology

Little is known for certain about the ice-dammed lake IDL outburst process. Outburst event data does not record the method of ice dam failure or the type of flow conduit that transports the flood flows (Figure 17). It is assumed that failure occurs when the foundation materials beneath the Valdez Glacier are eroded, creating a flow path, or utilizing thermal erosion of the glacier ice creating a flow path within the Valdez Glacier, or a combination of the two methods.

Figure 17. Potential flow conduit through caved glacier ice (photo from nps.gov\aknatureandscience)

IDL outburst scenarios flows were developed to represent the maximum flow conditions that could reasonably be expected from three IDL conditions at the terminal end of Camicia Glacier. The IDL water surface elevations that were used were 950 feet, 1000 feet, and 1050 feet. The IDL overflow elevation of Valdez Glacier at the time of the 2013 Interferometric Synthetic Aperture Radar (IFSAR) survey was roughly 1050 feet. The outburst flow rates were estimated based on a quickly developing ice dam breach and rapid drawdown of the IDL level to maximize the downstream flow rates.

4.2 Hydrodynamic Model Description

The hydraulic analysis was performed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. Detailed information concerning this software is available on the USACE Hydrologic Engineering Center website https://www.hec.usace.army.mil/software/hec-ras/. The HEC-RAS software is designed to perform one and two-dimensional hydraulic calculations for a full network of natural and constructed channels. It allows the user to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, water temperature/water quality modeling.

The HEC-RAS system contains several river analysis components for (1) steady flow-water surface profile computations; (2) one- and two-dimensional unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to these river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed. The system can handle a full network of channels, a dendritic system, or a single river reach.

The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). Graphics include X-Y plots of the river system schematic, cross-sections, profiles, rating curves, hydrographs, and inundation mapping. Inundation mapping is accomplished in the HEC-RAS Mapper portion of the software. Inundation maps can also be animated and contain multiple background layers (terrain, aerial photography, etc.). Using the HEC-RAS geometry and computed water surface profiles, inundation depth, and floodplain boundary datasets are created through the RAS Mapper.

4.3 Model Input

The HEC-RAS model input consists mainly of three types: terrain data, roughness factors, and boundary conditions.

Terrain data used in the HEC-RAS model is the 2012 Valdez FEMA lidar data set provided by the City and 2013 15-minute IFSAR data. The high-resolution data of the 2012 FEMA lidar makes up nearly all of the model terrain. Features not covered by the lidar data like the west levee and Richardson highway bridge data were input by hand using as-built data provided by the Alaska Dept of Transportation and Public Facilities.

Roughness factors for the various channel and over bank areas of the model were estimated using Manning's roughness guide contained within the HEC-RAS user's

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manual. Channel Manning's n values were based on clean and winding main channels with some pools and shoals. Manning's n values for overbank areas were based on heavy stands of trees with little undergrowth and dense willows.

Boundary conditions for the model were prescribed using flow data at the upstream boundary at the north end of Valdez Glacier Stream lake and high tide elevation conditions at the downstream boundary at Port Valdez. The upstream boundary condition was defined by the three scenarios of combined 50-year (yr) FEMA rainfall flood flow and maximum IDL outburst events, and the 50-yr FEMA rainfall flood flow alone (Figure 18). The peak flows of the three combined flow scenarios all exceeded the FEMA 500-yr rainfall event peak flow.

The 50-yr, 100-yr, and 500-yr flow hydrographs presented in Figure 18 within this are hydrographs based on a 2018 flood event scaled to the FEMA peak flow data for the various return periods. The 100-yr and 500-yr scaled flood hydrographs are shown for comparison purposes with the IDL outburst event scenarios. The FEMA 100-yr and 500-yr floods were not modeled as part of this report.

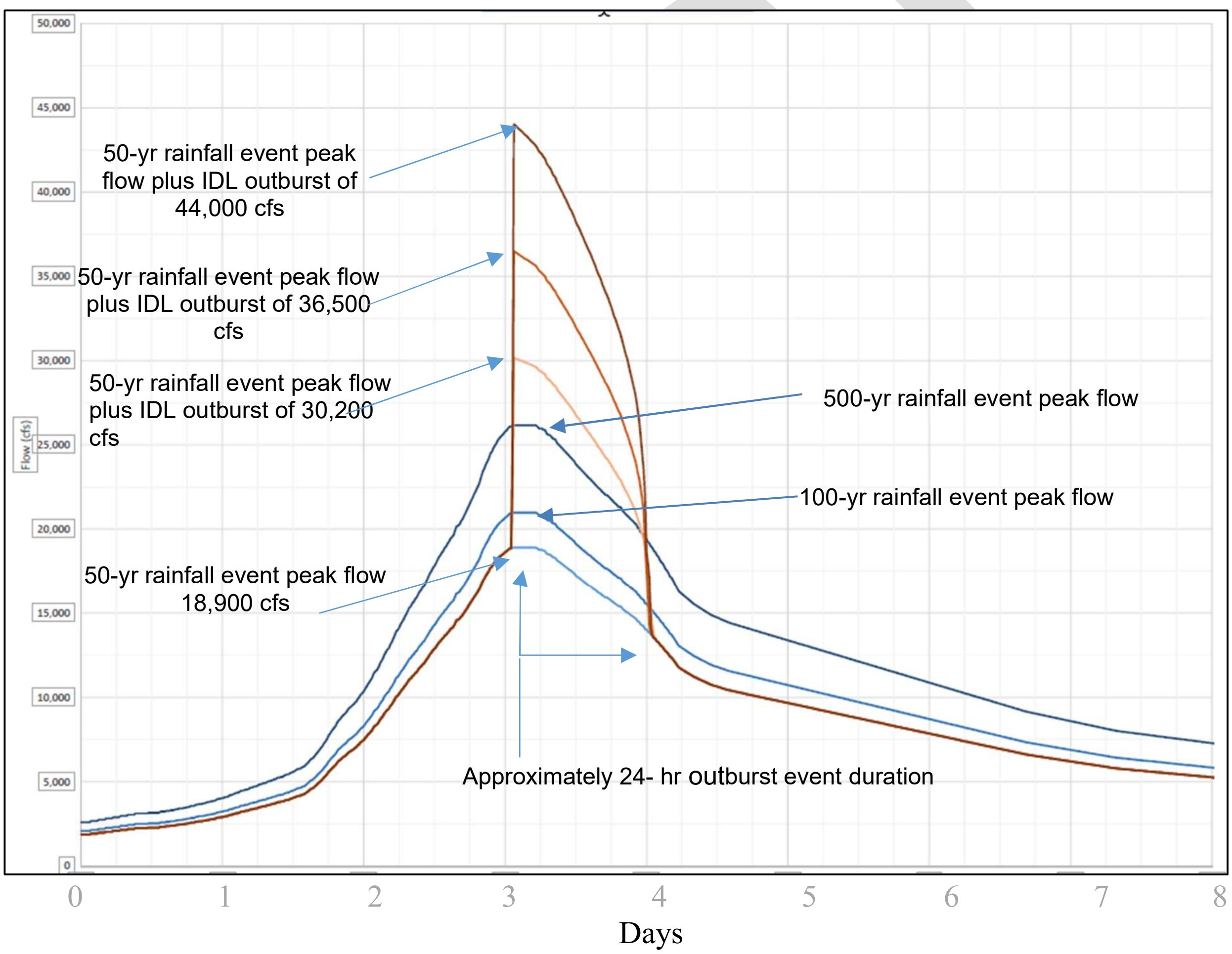

Figure 18. Hydrograph presenting 50-yr rainfall event with three Ice-dammed lake outburst flow rates

The three combined rainfall flood and IDL outbursts are based on rapid breach development and IDL drawdown to generate maximum downstream flows. All three combined scenarios include full breach development within 30 minutes and full IDL drawdown in 24 hours. Ice dam-breach development rates and IDL drawdown durations significantly impact peak downstream flow rates and flood stages.

IDL outburst events are highly variable. IDL breach development and glacier flow conduit capability can be more important than IDL volume. The estimated IDL volume of the 2017 and 2018 outburst events were 14,500 acre-feet and 16,000 acre-feet, respectively. The IDL drawdown duration for the 2017 outburst event was nearly four days, and the duration of 2018 was estimated to be 6-12 hours. The difference in breach development and IDL drawdown duration resulted in the shorter 2018 peak flood flow being more than double that of the 2017 event even though the IDL volumes were similar.

4.4 Results

4.4.1 50-yr FEMA rainfall flood scenario

Valdez Glacier Lake level changes of up to 7 feet can be expected during the 50-yr FEMA rainfall flood scenario (Figure 19). Inundation areas for scenario 50-yr FEMA rainfall event is shown in Figure 20. The park and approximately 1/3 of the rock quarry adjacent to the Valdez Glacier lake are expected to flood. Flood flow should be contained in the main stream channel below the Valdez Glacier lake, with some historic channels and gravel pits flooded. The stream stage is expected to be 2.5 feet below the lowest elevation of the left bank levee above the Richardson Highway bridge. Levee overtopping is not expected. Gravel pits adjacent to the stream my see elevated ground water inundation during longer duration flood events.

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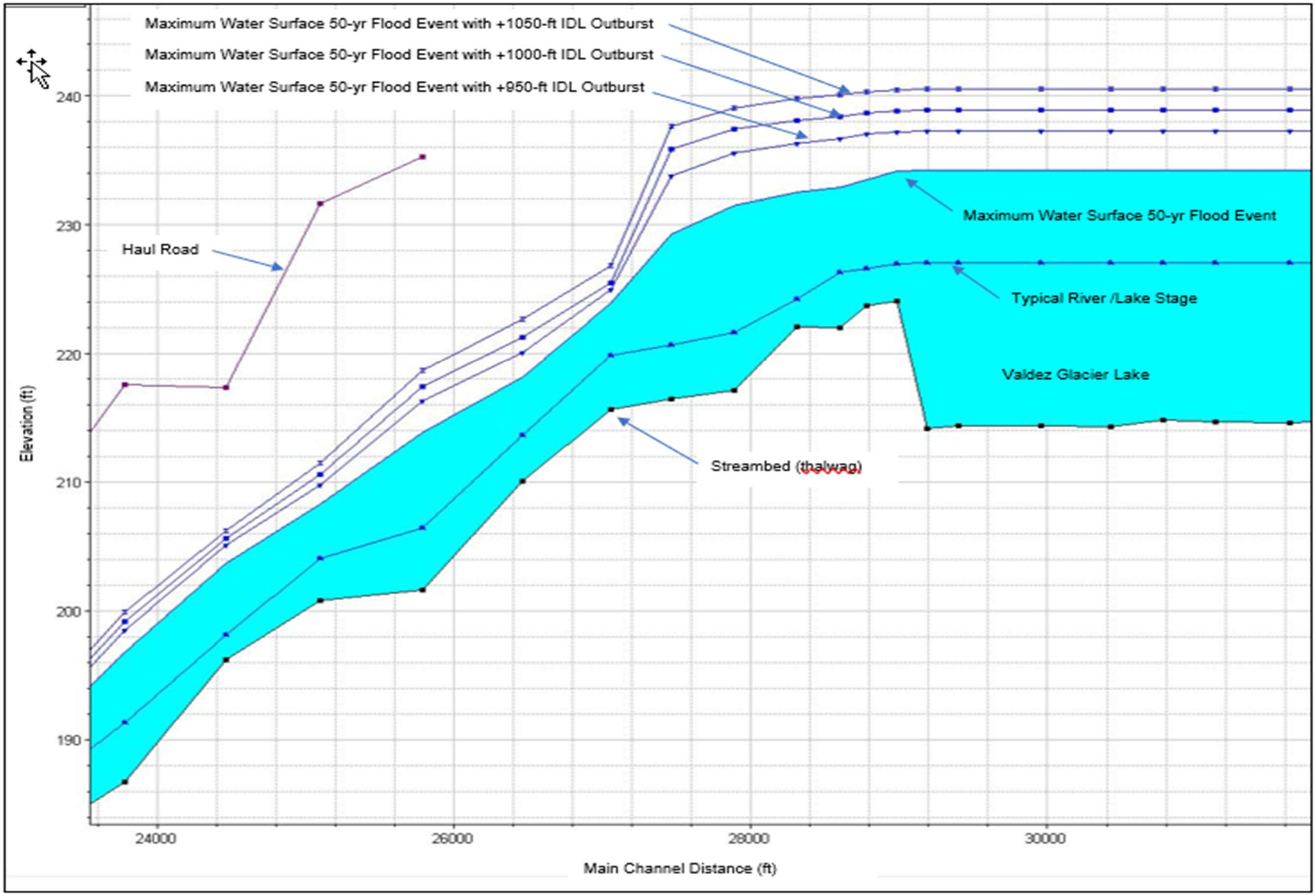

Figure 19. Maximum water surface profiles for the Valdez Glacier Lake outlet vicinity

Peak flow velocities exceed 6 feet per second (fps) in most areas of the stream channel (Figure 21). Channel migration and bank erosion should be expected. Bridge channel velocities of up to 16 fps were modeled. Severe bridge scour during the event can be expected. Erosion of material from beneath the bridge could potentially reduce peak velocity.

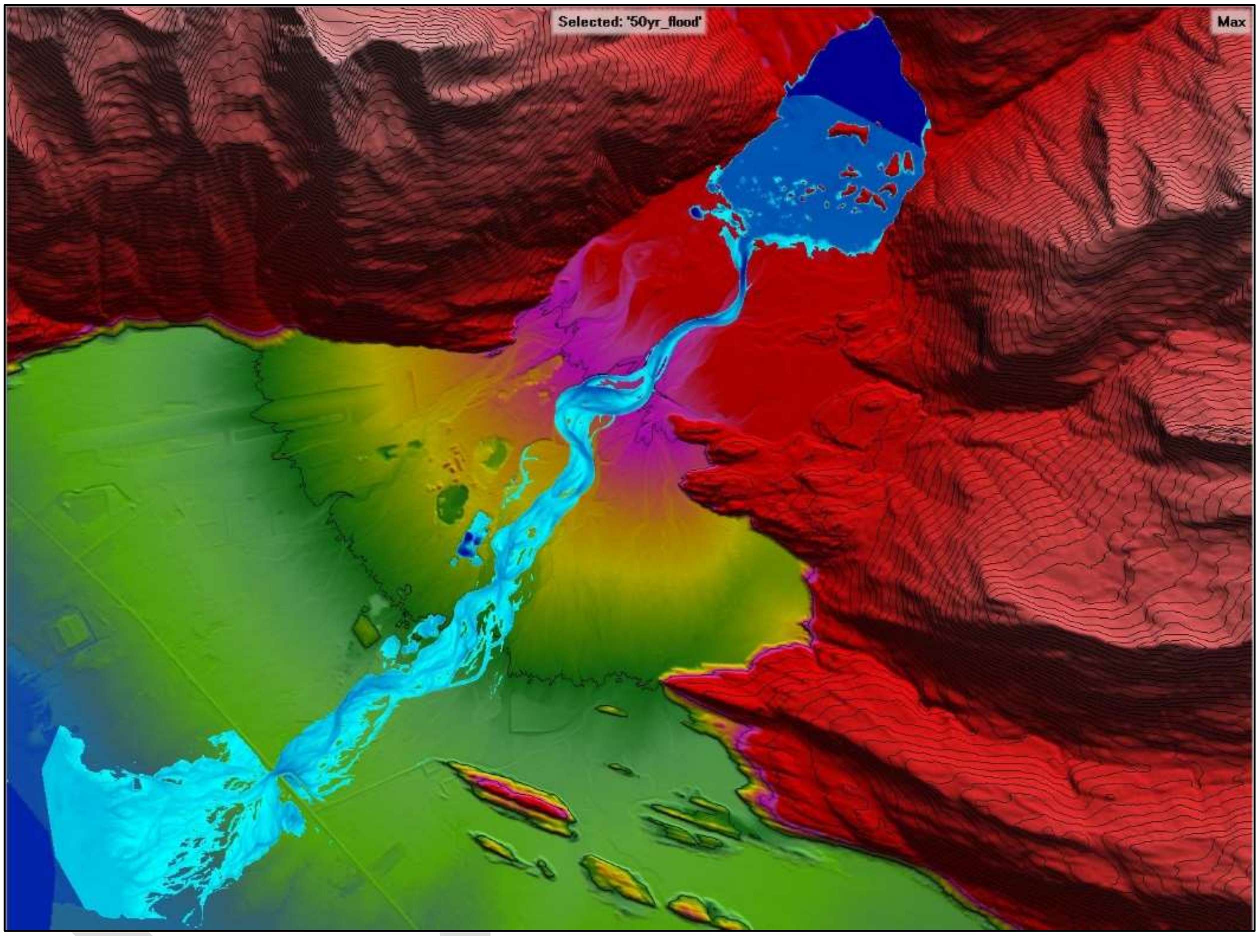

Figure 20. Inundation areas for scenario 50-yr FEMA rainfall event

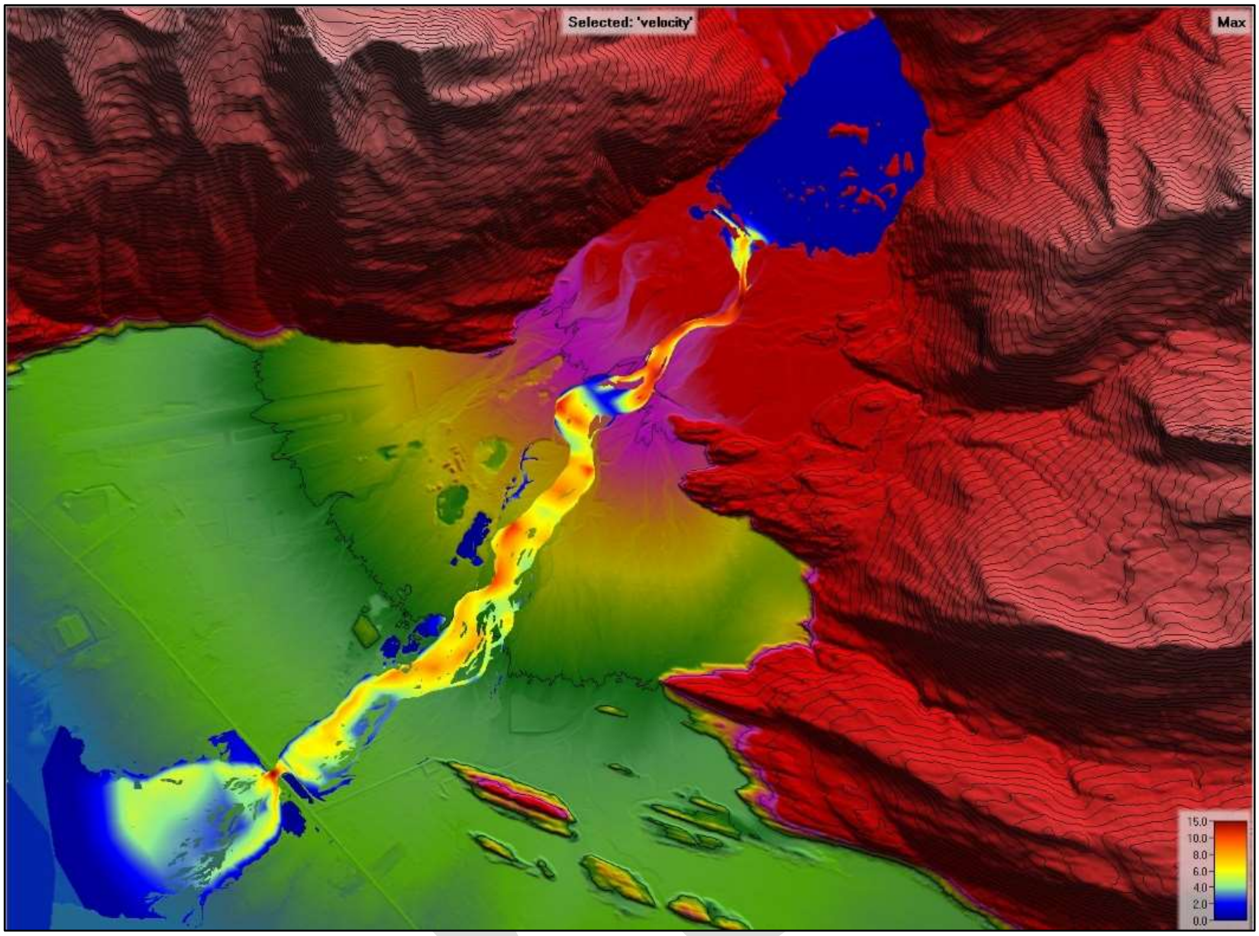

Figure 21. Peak flow velocity estimate for scenario 50-yr FEMA rainfall event

4.4.2 Combined 50-yr FEMA rainfall flood and 950-foot IDL outburst scenario

Valdez Glacier lake level changes of up to 10 feet can be expected during the 50-yr FEMA rainfall event with a 950-foot IDL outburst scenario (see Figure 19). Inundation areas for scenario 50-yr FEMA rainfall event with a 950-foot IDL outburst are shown in Figure 22. The park and approximately half of the rock quarry adjacent to Valdez Glacier lake are expected to flood. Below Valdez Glacier lake, the flood flows are generally contained within the stream channel. Historic channels adjacent to the main channel may begin to fill. Gravel pits adjacent to the stream my see elevated ground water inundation during longer duration flood events. The lowest portion of the western levee is expected to be overtopped by 0.4 feet. Due to the nature of the 1D model, the inundation mapping does not accurately depict the extents of the flooding in the area upstream of the Richardson Highway bridge. The inundation area is expected to be greater than that shown in Figure 22.

Peak flow velocities exceed 6 fps in most areas of the stream channel (Figure 23). Channel migration and bank erosion should be expected. Bridge channel velocities of up to 18 fps were modeled. Severe bridge scour during the event can be expected. Erosion of material from beneath the bridge could potentially reduce peak velocity.

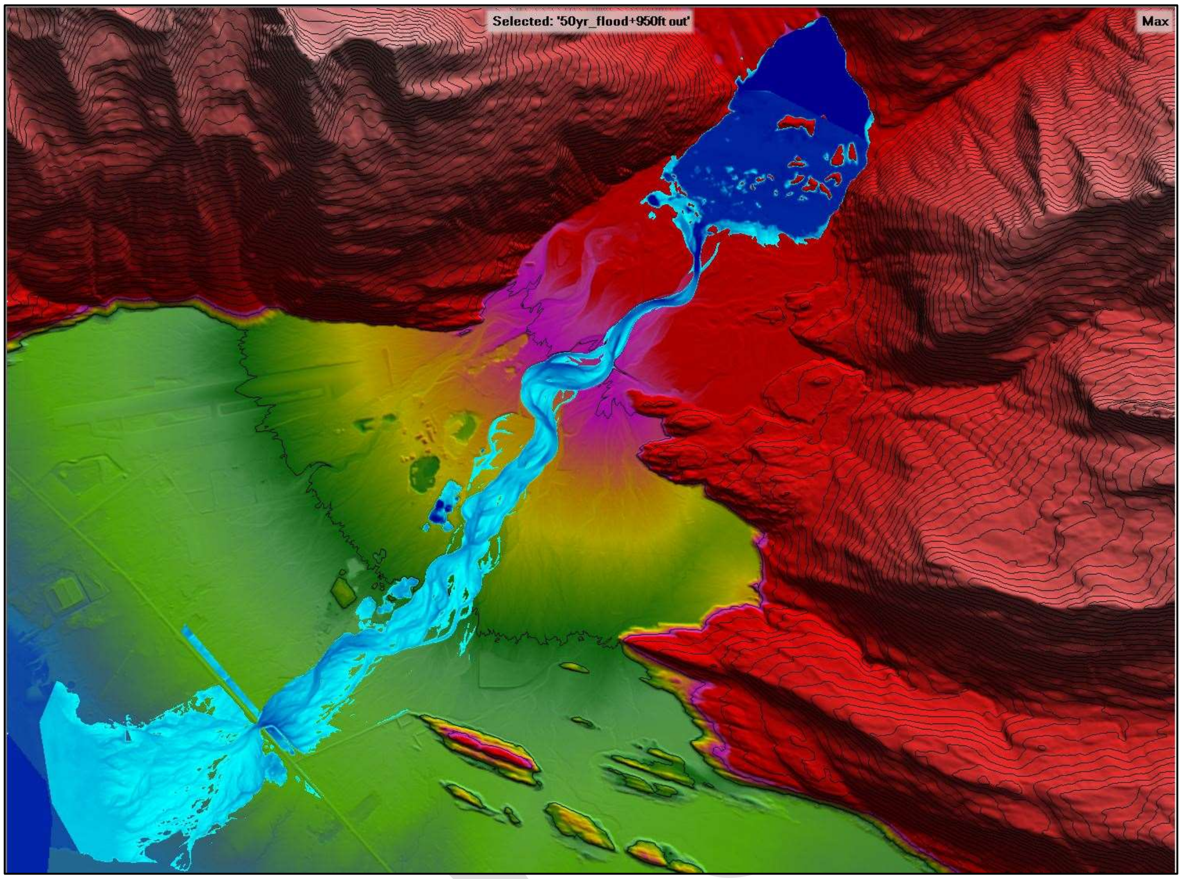

Figure 22. Inundation areas for scenario 50-yr FEMA rainfall flood and 950-foot IDL outburst event

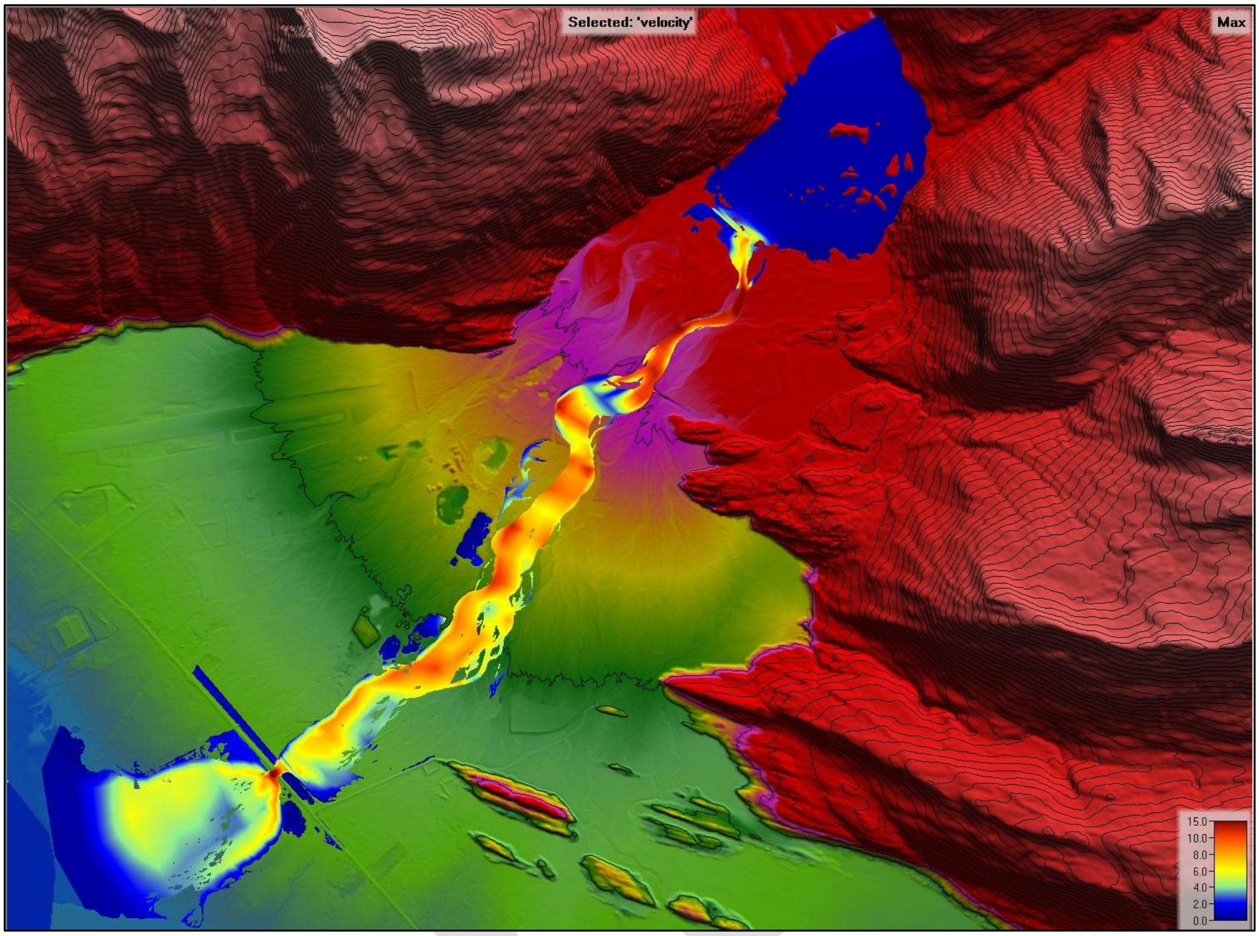

Figure 23. Peak flow velocity estimate for scenario 50-yr FEMA rainfall flood and 950-foot IDL outburst event

4.4.3 Combined 50-yr FEMA rainfall flood and 1000-foot IDL outburst scenario

Inundation areas for scenario 50-yr FEMA rainfall event and 1000-foot IDL are shown in Figure 24. Valdez Glacier lake level changes of up to 12 feet can be expected during the event (see Figure 19). The park and more than half of the rock quarry adjacent to Valdez Glacier lake are expected to flood. Flood flows are generally contained within the stream channel. Historic channels adjacent to the main channel may begin to fill. Gravel pits adjacent to the stream my see elevated ground water inundation during longer duration flood events. The lowest portion of the western levee is expected to be overtopped by 0.9 feet. Due to the nature of the 1D model, the inundation mapping does not accurately depict the extents of the flooding in the area upstream and downstream of the Richardson Highway bridge. The inundation areas are expected to be greater than that shown in Figure 24.

Peak flow velocities exceed 6 fps in most areas of the stream channel (Figure 25). Channel migration and bank erosion should be expected. Bridge channel velocities of up to 19 fps were modeled. Severe bridge scour during the event can be expected. Erosion of material from beneath the bridge could potentially reduce peak velocity.

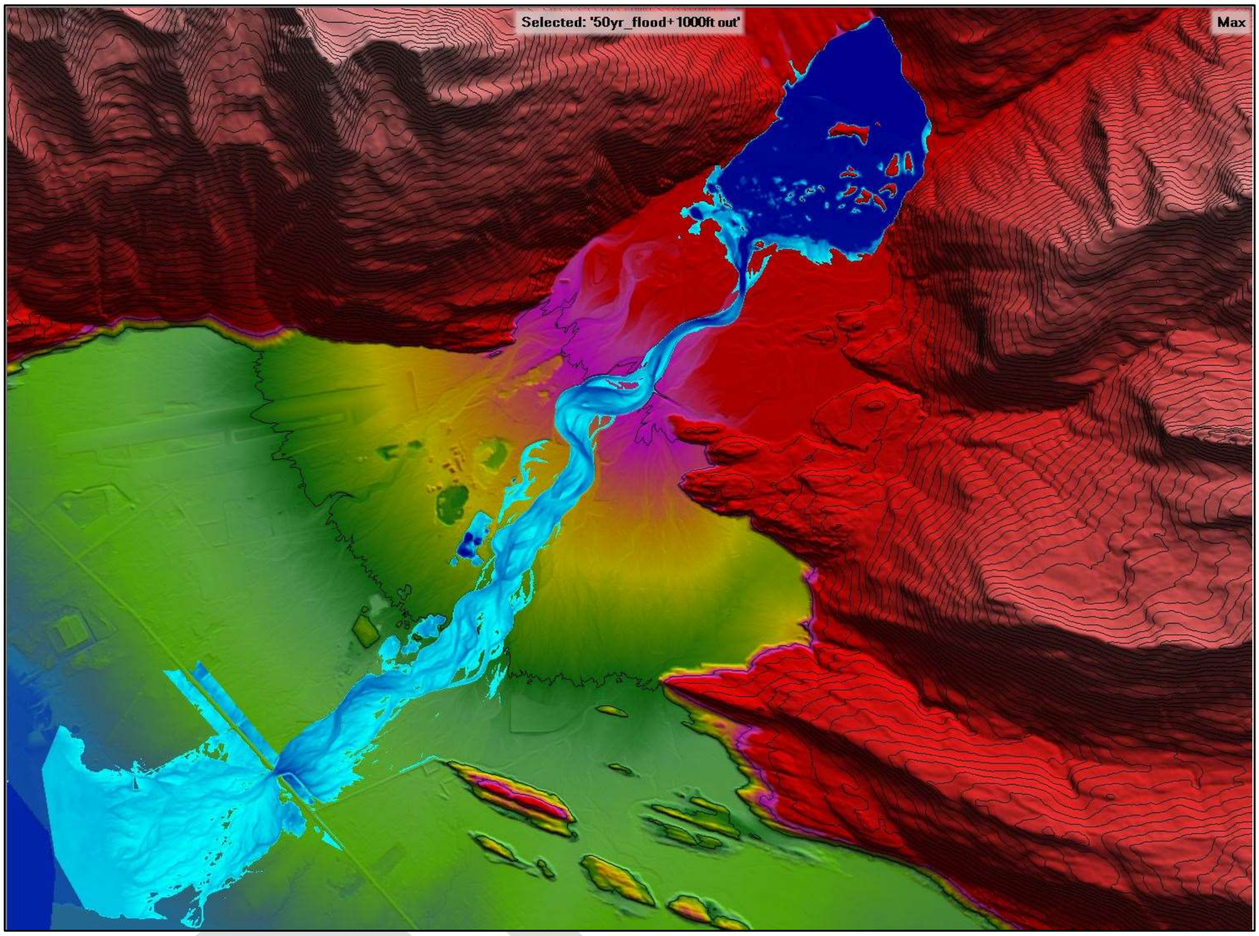

Figure 24. Inundation areas for scenario combined 50-yr FEMA rainfall flood and 1000-foot IDL outburst event

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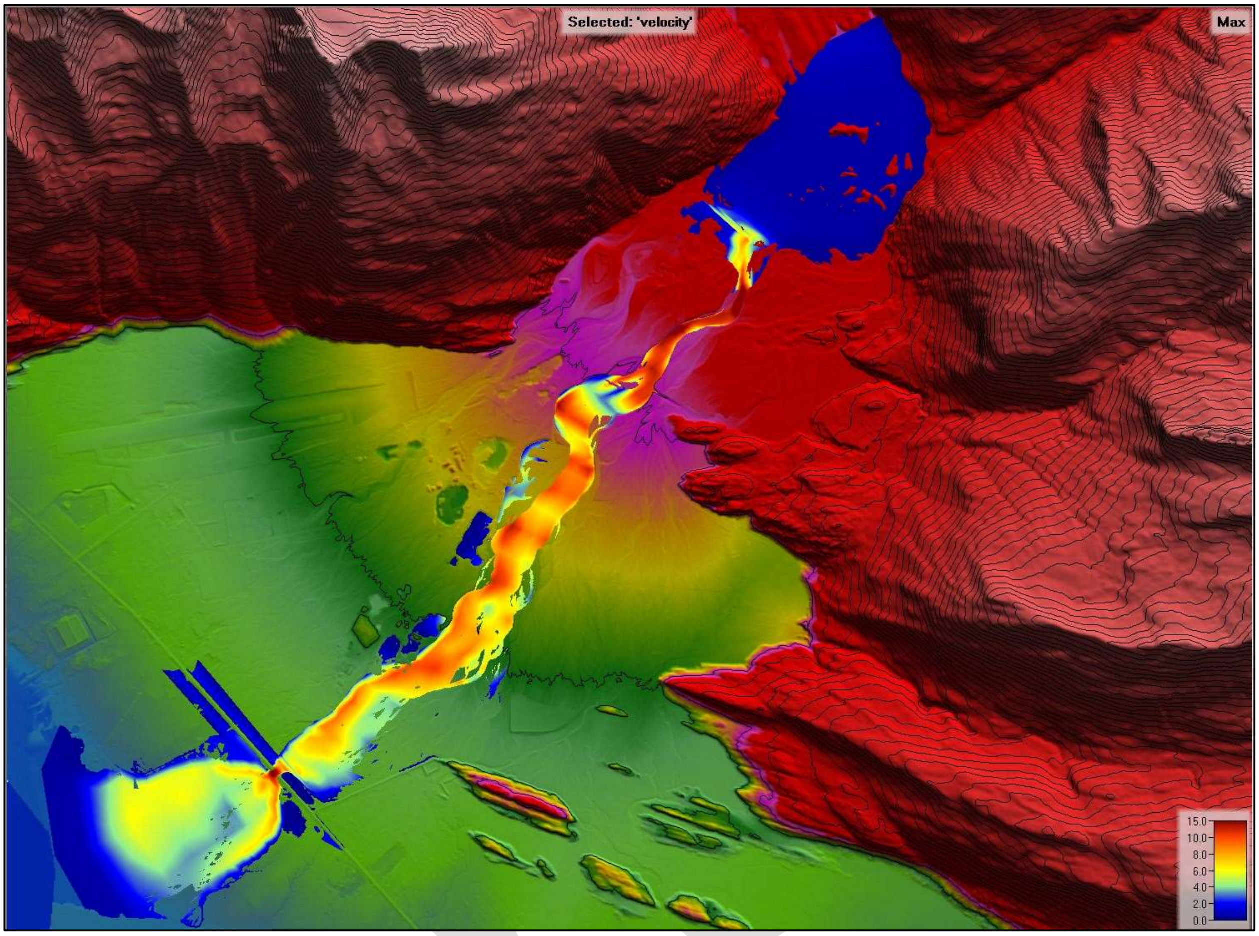

Figure 25. Peak flow velocity estimate for scenario 50-yr FEMA rainfall flood and 1000-foot IDL outburst event

4.4.4 Combined 50-yr FEMA rainfall flood and 1050-foot IDL outburst scenario

Valdez Glacier lake level changes of up to 14 feet can be expected during the 50-yr FEMA rainfall flood scenario (see Figure 19). Inundation areas for scenario 50-yr FEMA rainfall events are shown in Figure 26. Valdez Glacier lake level changes of up to 14 feet can be expected during the event. The park and approximately 2/3 of the rock quarry adjacent to Valdez Glacier lake are expected to flood. Flood flows are generally contained within the stream channel. Historic channels adjacent to the main channel may begin to fill. Gravel pits adjacent to the stream may see elevated ground water inundation during longer duration flood events. The lowest portion of the western levee is expected to be overtopped by 2.1 feet. Due to the nature of the 1D model, the inundation mapping does not accurately depict the full extent of the flooding in the areas upstream and downstream of the Richardson Highway bridge. The inundation areas are expected to be greater than that shown in Figure 26.

Peak flow velocities exceed 8 fps in most areas of the stream channel (Figure 27). Significant channel migration and bank erosion should be expected. Bridge channel velocities of up to 19 fps can be expected. Severe bridge scour during the event can be expected. Erosion of material from beneath the bridge could potentially reduce peak velocity.

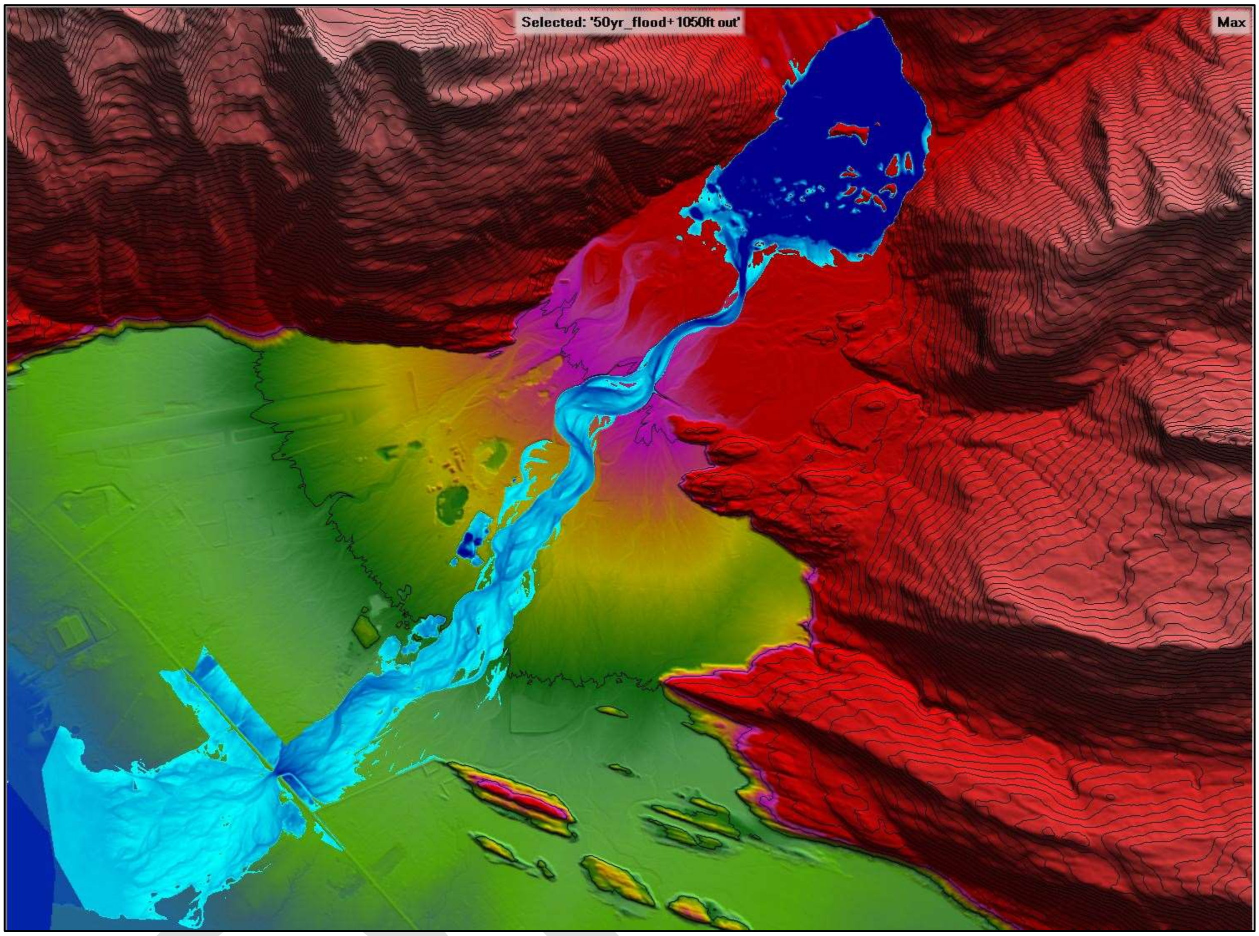

Figure 26. Inundation areas for scenario combined 50-yr FEMA rainfall flood and 1050-foot IDL outburst event

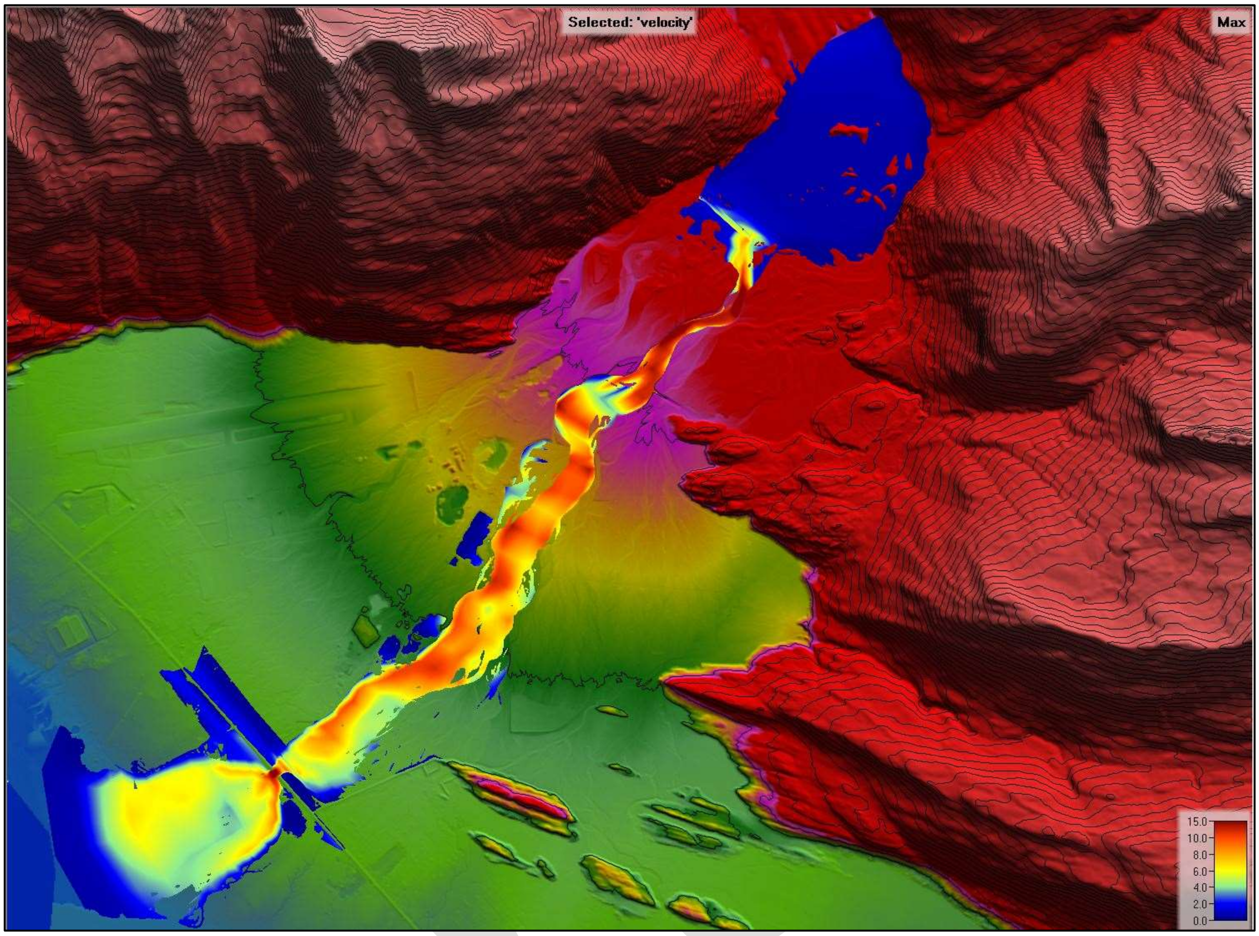

Figure 27. Peak flow velocity estimate for scenario 50-yr FEMA rainfall flood and 1050-foot IDL outburst event

4.4.5 Bridge Area Inundation

The eastern over-bank area upstream of the Richardson Highway bridge will not be inundated during any of the three outburst scenarios presented in this report. The levee is nearly two feet higher than the highest scenario presented (Figure 28 and Figure 29).

The western over-bank area upstream of the Richardson Highway bridge will be inundated during each of the three outburst scenarios presented in this report. Each outburst scenarios overtopping the right bank training-dike by between 0.4 feet to 2.1 feet is shown in Figure 28. Based on the three combined rainfall and outburst scenarios, the west levee upstream of the Richardson Highway bridge will begin to be overtopped at roughly 27,000 cubic feet per second (cfs).

Mapping of the inundation area of the overtopped training dike is complex with highway access points, down sloping terrain, and culverts running through the right over-bank area. Inundation mapping in complex areas is a difficult task for a one-dimensional model. Model limitations dictate that there can be only one water surface for each cross-section. The cross-section water surface applies to the main channel and both over-bank areas without making modifications for slopes, fill areas, or culverts. Accurately identifying the right over-bank inundation area would require more information concerning the culverts in the area. The inundation area would have to be modeled separately in 1D or 2D, and the modeling area would have to be extended to capture the extents on inundation fully.

The HEC-RAS model uses a fixed terrain or fixed bed to compute scenario flows. Fixed bed models are used to simplify significantly modeling computations required to estimate flow velocity and stage. The bed models are an important model attribute because the model terrain remains fixed without considering the scour and depositional potentials of the flows calculated within the model runs. Normally, this attribute does not impact the model output's accuracy because modeled flows generally kept below erosion velocity thresholds to prevent significant channel migration. However, Valdez Glacier Stream and the IDL outburst flows are significantly above the erosion velocity threshold for the gravel and cobble bed materials found within the Valdez Glacier Stream bed. Extensive channel migration and erosion can be expected from the flows calculated for the IDL outburst scenarios. The expected erosion and channel migration can be investigated, and modifications to the computational terrain can be made to simulate those changes. The exact changes to the terrain are impossible to calculate. Still, the ranges of channel migration could be made to capture the range of variation in the scenario flows.

The currently modeled scenarios also make simplifying assumptions concerning the possible debris capturing capacity of the bridge. Bridge piers normally collect woody debris during floods. See Figure 6 for an example of the woody debris capturing capacity of the Richardson highway bridge piers. Note that the two bridge piers depicted in the conveyance area of the upstream bridge cross-section shown in Figure 29. The build-up of debris on the bridge piers can limit the flow area under the bridge and cause the bridge's water level to increase due to reduced downstream flow. The modeled scenarios can be modified, or additional scenarios can be generated to account for defined debris build-up levels on the bridge piers.

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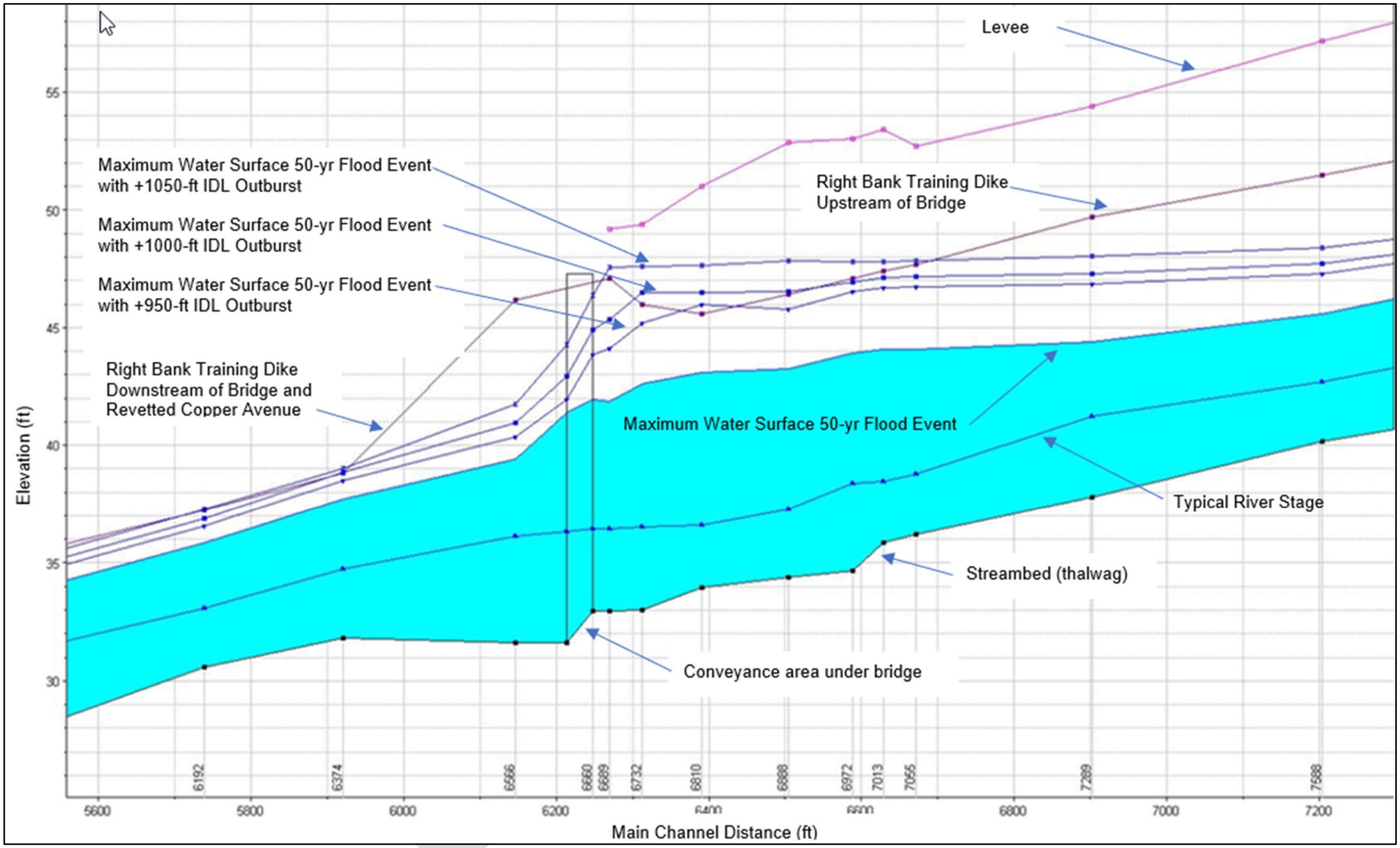

Figure 28. Maximum water surface profiles for highway bridge vicinity

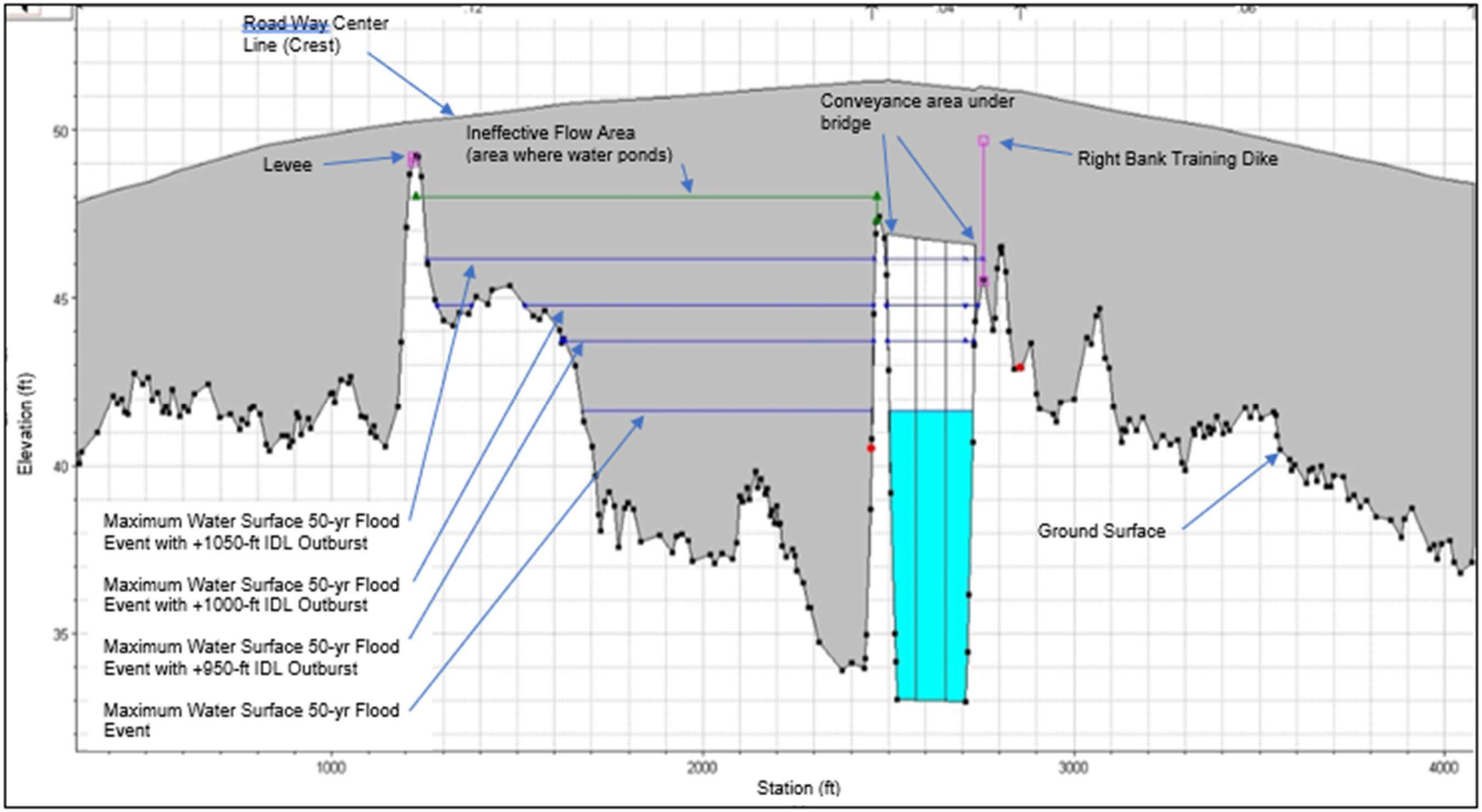

Figure 29. Maximum water surfaces at cross-section of Valdez Glacier Stream Bridge

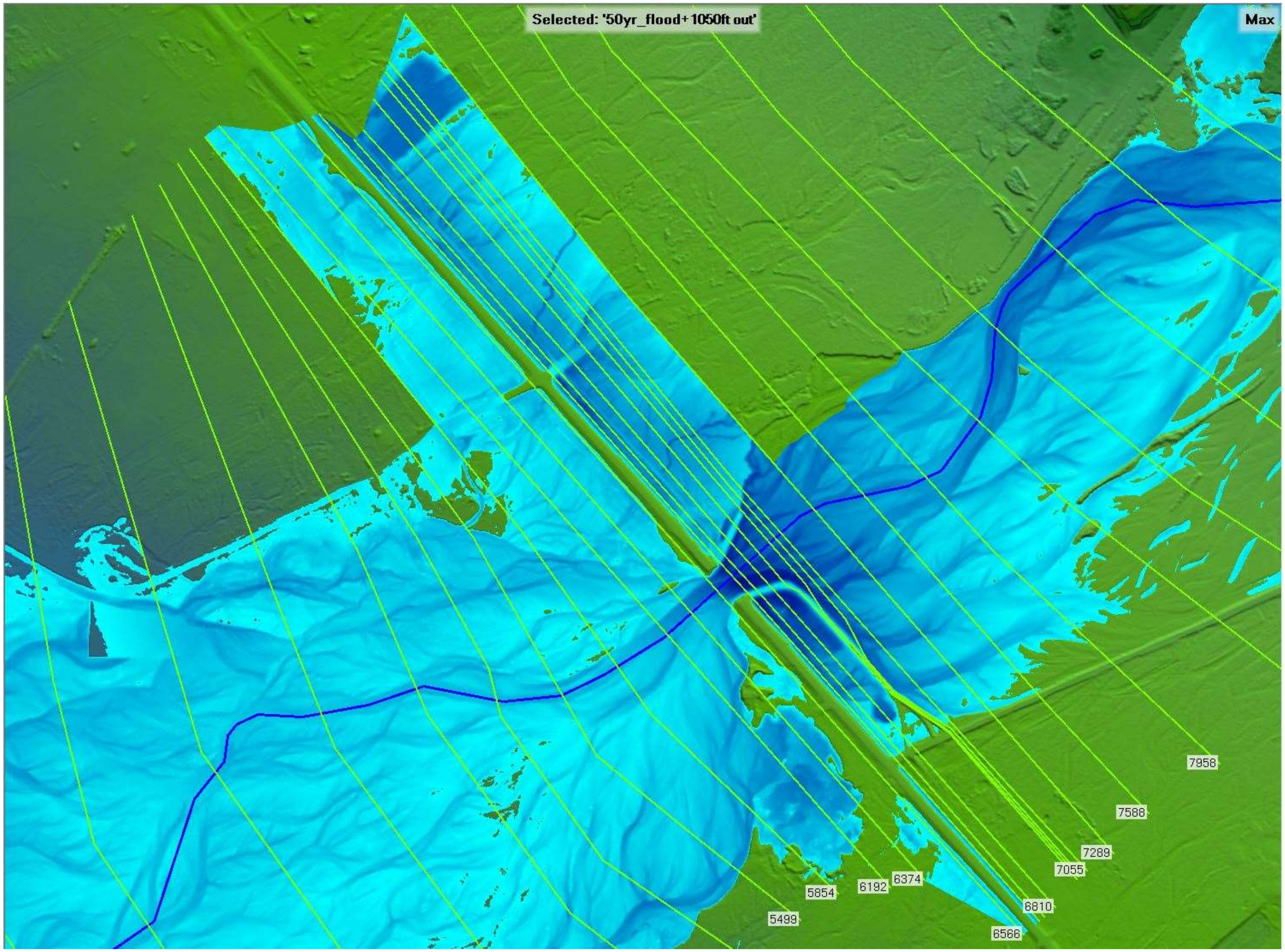

Figure 30. Maximum inundation from 50-year flood plus 1050-foot IDL scenario near the Richardson highway bridge

4.5 Suggestions for future model improvement and additional modeling

Modeling results will vary with changes in the stream channel. A review of aerial photography of the Valdez Glacier Stream channel indicates that stream channel geometry changes frequently. Changes in channel geometry can significantly impact flow velocity and stream stage, especially in areas of constriction and expansion like that of the Richardson highway bridge. Periodic re-evaluation of channel geometry would likely be needed to maintain a current understanding of flooding potential for Valdez Glacier Stream.

Additional refinement of the 1D RAS model and/or 2D modeling of the likely inundation areas could be undertaken to define inundation extents better.

Additional breach development and IDL drawdown duration scenarios can be modeled to develop the range of flood inundation impacts for susceptible areas.

5.0 POTENTIAL FLOOD RISK REDUCTION MEASURES

Flood risk is a combination of two components: the chance (or probability) of a particular flood event and the impact (or consequence) that the flood would cause if it occurred. Flood damage reduction or mitigation measures can either reduce the chance of flooding or the impact of flooding. Non-structural measures alter the impact or consequences of flooding and have little to no impact on the flood's characteristics. Structural measures such as dams, levees, and floodwalls alter the flood characteristics and reduce the probability of flooding in the location of interest. Common non-structural and structural flood mitigation measures are listed below:

Non-structural Measures:
- Elevation Enhancement
- Relocation
- Buyout/ Acquisition
- Flood Proofing
  - Dry Flood Proofing
  - Wet Flood Proofing
- Floodplain Management/Regulation
  - Flood Warning System
  - Education
  - Levee Certification
- Maintenance and Emergency Action Plan

Structural Measures:
- Debris Basin
- Local Levees and Floodwalls
- Levees
- Channel Modification/Dredging/Gravel Mining

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- Non-Engineered Levees
- Bridge and Culvert Size Optimization
- Raising and Armoring Roads

Please note that the measures presented above and discussed below are not necessarily applicable, recommended, or a complete list of potential flood mitigation measures. A detailed evaluation of the effectiveness of these and potentially other measures that could be developed would be considered in a more detailed study. The development of designs and feasibility analysis of individual measures is beyond the scope of the PAS program.

5.1 Non-Structural Measures

Elevation Enhancement. Elevation enhancement involves raising the buildings in place so that the structure sees a reduction in frequency and/or depth of flooding during high-water events. Elevation can be done on fill, foundation walls, piers, piles, posts, or columns. The selection of a proper elevation method depends on flood characteristics such as flood depth or velocity and debris presence.

The primary environmental effects of increasing the lowest elevation of structures susceptible to flooding and debris flows within these watersheds would reduce the pollution caused when non-elevated structures are flooded or destroyed.

Because this flood reduction measure can improve the survivability of structures within many floodplain locations substantially, making a structural occupation of floodplains more economically attractive, it can also be expected to extend the longevity of existing human effects within floodplains and potentially attract additional similar development.

Relocation. Relocation involves moving the structure to another location away from flood hazards. Relocation is the most dependable protection method and provides the benefit of using the evacuated floodplain for recreation or wildlife viewing.

Presuming adequate cleanup of formerly occupied properties and relocation is to habitats that are less sensitive than originally occupied, relocation should positively affect riparian and riverine habitats affected primarily by floodplain occupation.

Buyout/Acquisition. Buyout/acquisition involves purchasing and eliminating damageable flood structures, allowing inhabitants to relocate to areas away from flood hazards. Land purchased is to remain undeveloped, often under the care of a land trust organization, to provide floodplain functions. Similarly, currently, undeveloped land in the floodplain may be permanently preserved to provide floodplain functions as opposed to future development.

Flood Proofing. Flood proofing involves dry and wet flood proofing to mitigate flooding of structures.

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Dry Flood Proofing. Dry flood proofing involves sealing building walls with waterproofing compounds, impermeable sheeting, or other materials to prevent floodwaters' entry into damageable structures. Dry flood proofing is applicable in areas of shallow, low-velocity flooding. The environmental effects of dry flood proofing are largely similar to elevation in that it would likely result in extending the longevity of floodplain occupation.

Wet Flood Proofing. Wet flood proofing allows floodwater to enter the structure, but vulnerable items such as utilities, appliances, and furnaces are relocated to higher locations or waterproofed. By allowing floodwater to enter the structure, hydrostatic forces on the inside and outside of the structure can be equalized, reducing the risk of structural damage. The environmental effects of wet flood proofing are largely similar to elevation in that it would likely result in extending the longevity of floodplain occupation.

Floodplain Management/Regulation. The development and implementation of a comprehensive floodplain management plan are best handled at the local government level through planning, zoning, and building permit processes (FEMA 1989).

Through these processes, future development can be planned, and its effects on flood hazards adequately addressed. The management and regulation of future development are best coordinated at the local level among local government officials, planners, engineers, residents, and the development community through establishing and effective enforcement of planning, zoning, and building laws.

Enforcement is currently a challenge. At the borough level, a floodplain inspector or inspectors are responsible for enforcement within a large area. Likewise, enforcement resources may be limited.

The effects of additional regulations generated to minimize flood damages can be either positive or negative for the related environments. Regulations may act to expand floodplain protection or facilitate floodplain development.

Flood Warning System. Flood warning systems-alert inhabitants in flood-prone areas of impending high water. Depending on the type of warning system and advance time, inhabitants have the opportunity to evacuate the damageable property and themselves from the flood-prone area.

Education**.** The goal of education and outreach efforts should be to build a consensus to support the implementation of a comprehensive flood management plan that maximizes benefits to the region.

Levee Certification**.** Levee certification is a technical finding for floodplain mapping purposes as part of the National Flood Insurance Program (NFIP). It concludes there is reasonable certainty that the levee protecting the area will contain the base (1% annual chance exceedance, sometimes referred to as the 100-yr) regulatory flood. The certification finding must be accomplished by either a registered professional engineer

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or a Federal agency with levee design and construction qualifications such as USACE. Areas protected by a certified levee system are eligible to receive a moderate flood risk hazard from FEMA and be eligible to lower NFIP flood insurance rates.

FEMA issued the basic policy governing levee certification for NFIP in 1986 as 44 CFR 65.10. This policy requires complete engineering analysis of hydrology, hydraulics, structural and geotechnical, and operations and maintenance of the levee undergoing certification determination study. Protective structures constructed of river derived material typically do not meet FEMA design requirements and hence are not eligible to be certified as a levee.

Maintenance and Emergency Action Plan. Any of the described measures, or others not discussed, may be used in a flood emergency. Regular maintenance of flood control structures is paramount to their effectiveness during a flood event. Formally designed maintenance plans should be developed for the engineered levees and the non-engineered levees.

An Emergency Action Plan (EAP) is a formal document that identifies potential emergency conditions and specifies preplanned actions to be followed to minimize property damage and loss of life. The EAP specifies actions that should take place to moderate or alleviate the flood problems. It contains procedures and information to assist the stakeholders in issuing an early warning and notification messages to responsible downstream emergency management authorities. It also contains inundation maps to show the emergency management authorities the critical areas in case of an emergency.

5.2 Structural Measures

Debris Basins. Debris basins are specially engineered and constructed basins for storing large amounts of sediment moving in an ephemeral stream channel and are placed to protect and prevent downstream damage. Debris basins can be extremely expensive to construct and require a commitment to annual maintenance.

The construction and maintenance of debris basins designed to retain 50 to 80 percent of stream load could have minor to substantial effects on salmon rearing, resting, and foraging habitats within the basins' footprints because of temporary loss or modification of habitat. The same types of habitats downstream could see minor to moderate effects from modification of the quantity, type, and rate of sediment and organic input that comprise and refresh in-stream benthic habitat. This presumes that the debris basins regularly trap large percentages of silts, sands, and gravels and that maintenance removes these materials from the system.

Local Levees and/or Floodwalls. Local levees and/or floodwalls are freestanding structures located away from the building that prevents floodwaters' encroachment. The environmental impacts of local levees and floodwalls would be similar to those described below but on a smaller scale.

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Levees. Levees are embankments of a natural or artificial slope to regulate water levels and are usually earthen and parallel to the course of a river. These structures are engineered using the hydraulic properties of the stream. Levees are constructed to a specific flood risk protection level and are designed to withstand extreme flows. Regular maintenance governed by an operations and maintenance manual is required for levees to perform as designed.

Construction and maintenance of levees have moderate to substantial effects on in-stream and riparian habitats, typically due to direct habitat loss. Habitats landward of levees typically become wetter or drier due to changes in local hydrologic flow regimes. Adjacent and downstream in-stream habitats are modified because of changes in in-stream flow rate, duration, velocity, deposition rates, large and small woody debris input, and nutrient input.

Floodwalls. Floodwalls are primarily vertical artificial barriers designed to contain floodwaters during seasonal or extreme weather events temporarily. Floodwalls are used mainly in locations where space is limited or where levees would interfere with existing structures or future development. These structures usually contain flood gates that would allow passage of flows when opened. Floodwalls can be expensive to construct and maintain.

The construction and maintenance of floodwalls can have very similar effects on levees, but there can be some marked differences. While the levee toes' construction tends to result in substantial footprints in and along waterways, floodwall construction typically affects a substantially narrower footprint. However, while the slope and covering (vegetation, rock, etc., but not concrete) of levees can still provide some minimal habitat benefits depending on flows, floodwalls typically are virtually devoid of habitat value. More importantly, floodwalls completely lock-up sediment, input can substantially restrict organic input, and cut-off hydrologic flows through their footprints. For these reasons, interrupt biological, chemical, and physical processes that generate, refresh, or damage adjacent and downstream aquatic and terrestrial habitats.

Channel Modification/Dredging/Gravel Mining. River channels are frequently deepened, widened, or straightened to increase their capacity to convey streamflow. Such alterations require the design of a stable river channel.

The potential effects of dredging, mining, and maintenance within the work's footprints would be largely similar to debris basin construction and maintenance; assuming, a similar interval of excavation and removal of the system's substrates. Suppose the rate of excavation (particularly related to an on-going mining operation) substantially exceeds a single annual excavation and maintenance event. In that case, there is a larger probability that in-stream habitats within the footprint and downstream could be negatively affected. As with debris basins, this presumes that a moderate to substantial quantity of silts, sands, and gravels are removed from the system. The positive or negative effects of channel modification can vary widely depending on where in the system they occur, the type of modification, the stability of the affected reach(s), and the intent of the modifications. The majority of the positive and negative in-stream and riparian effects discussed throughout this section may occur due to channel modifications.

Non-engineered Levees. Embankments constructed with river-run material to protect homes and facilities during large flow events are not permanent structures. These embankments cause changes in the natural sediment transport and deposition of the stream. During normal flows, a wider channel is less efficient at transporting bedload material, and the channel slowly fills up. During high flow events, the channel's flows, aided by the embankments, may become deep enough to remobilize a large amount of deposited sediment and transport to a new location downstream. This "unnatural" deposition may cause changes in other downstream locations. Despite these drawbacks, construction and maintenance of such embankments may prove to be warranted on a short-term basis, while funding and designs for longer-term solutions are sought. Timely and effective maintenance of river-run material embankments in areas where they are deemed the most efficient form of flood protection is essential in alleviating damages from flood waters.

Non-engineered levee construction and maintenance environmental effects are very similar to levee effects described above.

Bridge and Culvert Size Optimization. A river system's ability to pass high flows can be compromised by undersized bridge and culvert openings. These "choke points" along a flow path can cause backwater flows into a smaller capacity stream, change the stream's depositional properties, and cause flood waters to inundate areas that may have been previously dry.

Bridge or culvert size optimization primarily affects in-stream habitat. Long, steep culverts can impair fish passage because of high-velocity currents and lack of resting areas for migrating fish. While having minimal negative effects on in-stream habitat via excavation, these actions can have a moderate to substantially greater positive effect via restoration of a portion of the natural hydrologic flow regime resulting in a more natural rate, volume, and deposition pattern of stream load.

Raising and Armoring Roads. Flooding in Seward can be severe, and road access in and out of the City has historically been completely cut off. Raising and armoring select roads in the area would assist in evacuations and emergency flood fighting services.

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6.0 GENERALIZED CONCLUSIONS

Many of the threats and problems identified are unique to steep terrains and the resultant alluvial fan topographies. Also, the Valdez watersheds are impacted by hydrologic conditions driven by glaciers. In particular, ice dammed lake dam-bursts events that can significantly raise the flood risk of a watershed, as demonstrated by the outburst event modeling for Valdez Glacier Stream. Hence, many conventional floodplain management techniques are not as effective on alluvial fans. A combination of adaption of standard flood mitigation measures and identification of flood mitigation measures specific to alluvial fan topographies will be required to best minimize future flood damages in the Mineral Creek and Valdez Glacier Stream water sheds.

6.1 Valdez Glacier Stream

Valdez Glacier stream experiences typical seasonal high flow events that have caused some flooding of adjacent lands. Some measures are currently in place to manage channel migration and erosion that could impact existing infrastructures, including the Haul Road and Valdez Glacier Stream Bridge #556, to name two. A levee protects a community east of the stream. The flows from these seasonal events from snow melt and rainfall can be increased significantly by periodic sudden releases of water from a ice dammed lake in the watershed over a very short period.

Inundation modeling was performed to evaluate what areas are at risk of flooding during three different magnitudes of burst events assuming these events occurred at the peak of a 50-yr flow event. The results indicate the following:

- It is unlikely that the gravel mining operations, as currently developed, would act as conduits for flood waters to the historic stream channels between Valdez Glacier Stream and the Valdez Airport.
- The Valdez Glacier Stream Bridge #556 is a limiting factor for stream flow, which results in an increase in water levels upstream of the bridge during high flow events.
- Inundation occurs upstream of this bridge during all three outburst event levels evaluated, and this out of channel flooding extends on both sides of the stream.
- The community east of the levee could be at risk in all three outburst event scenarios, although the model shows no overtopping of the levee.
- The areas impacted on the west side of the stream are primarily a result of the damming induced by the narrow bridge opening. Water is anticipated to be impounded in this area until the road is over toped.
- In addition to flooding, stream flow velocities will increase that could cause stream bank erosion, stream channel migration, and potentially threaten inadequately protected infrastructure such as roads and bridges.

6.2 Mineral Creek

Mineral Creek is a glacially fed creek; however, glacially dammed lakes in the watershed have not formed in the past. Additionally, the glaciers that feed the

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watershed are far upstream, reducing the glacial impacts to the watershed. The recently revised FEMA Flood Maps and analysis that became effective in the 2019 model flood events based on rain fall events. The FEMA models and risk analysis captures the likely flood events on Mineral Creek.

Portions of the existing flood structures (levees, groins, and armored embankments) on Mineral Creek were repaired and rebuilt during 2019. Due to the recent rehabilitation and construction, these structures appear to be in good working order. These structures should continue to be monitored and assessed for effeteness during any future flood events. If additional structures are deemed necessary, an analysis of feasibility and cost effectiveness should be conducted.

7.0 NEXT STEPS

7.1 Valdez Glacier Stream

Additional Models. Rivers are a dynamic environment; any hydrodynamic model of a river system requires simplification of the system to create meaningful results. For this analysis of Valdez Glacier Stream, a one-dimensional model was used. The creation of a two-dimensional model would improve the results of the model and subsequent analysis.

The dynamics of rivers systems also result in expiration or shelf-life for any given model result. As the system migrates and changes over time, the inputs used in a modeled system change over time. These inputs will no longer reflect the existing conditions on the ground. Improving and updating models is recommended to maintain the most accurate analysis.

Continued Study. The analysis presented in this report looks at the potential for an outburst flood superimposed or combined with a rainfall flood. The results of this analysis indicate flooding and risks beyond those presented in the FEMA flood analysis. While potential measures to reduce the flood risk are discussed in this report, an additional study would be required to determine the feasibility, effectiveness, and cost to benefit analysis associated with each measure. Should the City choose to pursue the measures discussed in this report, it would be advisable to conduct an additional study.

Early warning system. The results and analysis of flooding presented in this report require a sequence of events to occur for a large-scale flood event to happen. The Valdez Glacier IDL must be full while a large storm or rainfall event occurs for the large-scale flooding presented to occur. Both events are predictable and easily monitored.

A simple and easily implementable measure would be to monitor the conditions that result in large outburst floods. If the Valdez Glacier IDL is full, and a large weather system moves into the area, alerting the community of the flood risk would be advisable. The Valdez Glacier IDL could be monitored with the existing Division of Geological & Geophysical Surveys (DGGS) webcam or the installation of a water gage. While

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weather systems are easily monitored using the National Oceanic and Atmosphere Administration (NOAA) weather forecasts.

Incorporation of early warning. While the design and implantation of an early warning system are beyond this report's scope, several issues should be evaluated before implementation. Community involvement and education are critical to success. Plans for what to do and possible evacuation should be thought out well in advance. Drills and tests of the system should be conducted regularly to determine if there are flaws in the system and ways the system can be improved. The Operation and Maintenance (O&M) Manuel provides some guidance on planning for a flood and items to consider for improving community resilience. It is advisable to incorporate flooding plans and stockpiled material into the early warning system.

7.2 Mineral Creek

The Mineral Creek watershed should be included in the City's flood response plans. As the watershed flows along the City's populated portions, conducting flood drills and planning a flood response would be a simple and effective way to build community resilience. Plans could include; preplanned evacuation, stockpiles of flood-fighting equipment, and supplies (i.e., sandbags, light plants, readied earthmoving equipment). An early warning system could also be incorporated into the community's mitigation planning.

7.3 Potential Future Corps Assistance

Planning Assistance to States. Additional technical studies can be implemented using the Planning Assistance to States program just as this study was implemented. The cost sharing for such efforts would be 50 percent Federal and 50 percent local.

Section 205 Small Flood Control projects. This program would allow for the planning, design, and construction of a flood control project with a Federal cost not to exceed $10 million. This program's cost sharing is 50 percent Federal and 50 percent local for the study and 65 percent Federal and 35 percent local for construction. At present, nationwide funding for this program is quite limited.

Specifically Authorized Study. Because of the magnitude of the problem in the Valdez area, a specifically authorized study and project would likely be needed to develop a comprehensive solution. Similar to the Section 205 program, cost sharing for this program is 50 percent Federal and 50 percent local for the study and 65 percent Federal and 35 percent local for construction. A specifically authorized study would require a congressional study resolution and a new study start in the Corps' annual appropriation bill.

Watershed study. A watershed study is similar to a specifically authorized study in how it is initiated; however, the cost sharing and end product are somewhat different. The purpose of a watershed study would be to develop a watershed plan that would help

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local entities address flooding and any other water resource issue. This is a study only authority, with the cost sharing being 75 percent Federal and 25 percent local. Any Corps implementation of action items in the watershed plan would be done utilizing the other Corps construction authorities.

All of these suggested methodologies are dependent upon adequate funding and approvals to proceed.

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