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Please find the attached West Big Lake Alluvial Fan Geology Report. This is the drainage on Devil's Mountain above Big Lake's neighborhood consisting of West Big Lake Blvd, Glenn Allen PL, W Lake View Lane, Eagle Point Lane, and the WDFW boat ramp at Big Lake.

The report's author is Dan McShane. Dan is the President and senior geologist at Stratum Group. Dan is a licensed engineering geologist and has over 25 years of geologic and environmental consulting experience. He has expertise in analyzing alluvial fans and their associated watersheds. The report was initiated in 2023 and finished in late fall of 2024.

There has been a lot of speculation about this watershed and the cause of flooding on the alluvial fan. Skagit Land Trust commissioned the study to gain a comprehensive understanding of the watershed. Although the alluvial fan is classified as a geologic hazard on Skagit County and state maps there was no prior detailed analysis of this area.

Skagit Land Trust holds a conservation easement (CE) on 41.5 acres of working forest and wildlife habitat in the studied drainage. We do not own the land. The property owner owns and manages the land while Skagit Land Trust's role is to make sure conservation rules- like "no development"- are followed. However, Skagit Land Trust does not control or manage the land.

In an emergency the landowner or government agencies can take necessary action to protect people and property, even if it impacts the natural resource values. Skagit Land Trust does not decide what actions are taken. After the 2021 flood we informed the landowner and appropriate agencies that they can take emergency actions as needed - either once or on an ongoing basis.

The Conservation Easement (CE) covers most of the beaver pond in the main stem of the drainage. There is a second beaver pond elsewhere in the drainage on a different property (not in the CE). The report identifies a narrow canyon where sediment accumulates which is then deposited on the alluvial fan. This is on a different property (not in the CE).

McShane includes possible mitigation measures based on what has worked to reduce risk on alluvial fans in similar drainages. We hope that having this report will help people understand how this watershed functions, including the role of beavers.

Skagit Land Trust

Stratum Group Report Summary

Dan McShane of Stratum Group, a geologist with expertise in analyzing alluvial fans and their associated watersheds, was hired to study the Devil's Mountain drainage. **His Findings Are:**

- **This alluvial fan is active**. **There will be ongoing sediment movement even without beaver activity in the area.** The alluvial fan where the houses are located is formed by thousands of years of sediment being deposited from the canyon and streams above it. Debris flows and debris floods will continue to occur naturally, with or without beavers.

- **Landslides in the steep canyon above the alluvial fan bring sediment into the stream channel resulting in floods with a lot of debris:** Unlike floods that primarily carry water, debris flows and their associated floods transport large volumes of sediment, rocks, wood and other materials. In the area studied, the debris is picked up in a steep narrow canyon above the alluvial fan. It can quickly fill stream channels, forcing the water to change course and deposit thick layers of sediment across the alluvial fan.

- **Debris flows and their associated floods can be much larger than clear water floods:** Due to the debris being added to the canyon by landslides, much larger and more destructive floods can happen than typical water flow. Even moderate clear water floods can turn into debris-laden floods such as the significant event that occurred in 2021.

- **Beaver dam breaks are not the only factor causing floods:** While the failure of a beaver dam can start a clear water flood, other drivers include intense rainfall, rapid snowmelt or the sudden release of water that has been blocked by natural debris within the canyon. The debris in the canyon is why these floods become large and impactful.

- **In 2021, part of a beaver dam on the main stream broke. The flow of water released by the dam failure passed through a culvert under an old logging road a short distance down stream without damaging the culvert or road. However, due to the narrow, sediment filled canyon downstream, it turned into a debris flow which increased the flood level.** The initial water released did not appear to have caused much impact. However, as the flood moved downhill through the narrow canyon, it picked up sediment, rocks, and large logs, creating a much more powerful and damaging flood than the dam failure alone would have caused.

- **The event that occurred in 2021 was deemed likely a nearly maximal credible event** (largest possible event for this stream).

- **Beaver activity in the watershed goes back many decades**. There are beaver ponds on two different streams in the watershed. Both have been part of flooding events on the alluvial fan. Only the mainstem beaver pond drains into the narrow canyon.

- We hope that having this report will help people understand how this watershed functions, including the role of beavers. This can help inform decisions.

- The author of the report includes possible mitigation measures based on what has worked to reduce risk to landowners on alluvial fans in similar drainages.

STRATUM GROUP
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October 16, 2024

Molly Doran
Skagit Land Trust

Re: Alluvial Fan Geology Assessment
West Big Lake
Skagit County, WA

This geologic assessment was conducted to assess an alluvial fan and watershed on the west side of Big Lake in Skagit County, Washington. Numerous flood events have been reported on this alluvial fan. The most recent flood took place in November 2021. Flood events on the alluvial fan have been reported in 1991, 1995, 2003, 2015, 2016, and possibly in 2018. This geology assessment was conducted to provide an overview of the geology of the alluvial fan and watershed conditions relative to the alluvial fan to evaluate the potential hazards on the alluvial fan area and provide some conclusions and possible options for the alluvial fan area.

Key Findings and Potential Mitigation Measures

Key findings of this assessment and potential mitigation measures are outlined below. More detailed discussion and rationale are presented in the conclusion of the report.

Findings:

- The alluvial fan is an active alluvial fan. Future debris flows and flooding should be expected on the alluvial fan even if beavers are not present in the watershed.

- Sediment derived from numerous landslides in the steep and deep narrow canyon upstream of the alluvial fan have and will continue to result in filling the stream channel on the alluvial fan leading to flooding and redirecting of the stream channel.

- Beaver dam failures at the main stream pond/marsh and the south stream pond/marsh have caused past flood events on the alluvial fan, but they are not the only cause.

- Debris flows in the narrow canyon from blockages can result in floods that are much greater than the expected clear water floods.

- Beaver dams in the watershed above the alluvial fan may increase the frequency of floods. Both the main stream and the south stream that flow onto the alluvial fan have beaver dams.

- The beaver dam on the main stream that forms the large main stream pond/marsh partially failed in 2021. Water exiting the beaver dam break appears to have flowed through a logging road culvert just below the beaver dam without damaging that crossing. However, as the flood descended through the narrow canyon sediment and debris including large logs became entrained in the leading edge of the flood resulting in a much higher flood level than from the beaver dam failure alone.

- The 2021 flood event was very nearly a maximum credible event for this watershed.

Potential Mitigation Measures:

- Excluding beavers is not practical. Beaver dam removal would require endless patrolling and removal efforts. Pond levelers can reduce the size of the flood surge by limiting the pond elevation, but beaver dam failures should still be expected and even the more modest flood surges will mobilize sediment within the narrow canyon leading to channel filling and flooding on the alluvial fan.

- An option to reduce the flood risk would be periodic dredging and removal of sediment by creating sediment capture areas, widening and deepening the stream channel, and construction of berms or levees. This approach will require a not easy level of effort for permitting and will likely require property acquisition and/or easements. It will also require periodic maintenance as sediment will again accumulate within the sediment capture areas.

- Skagit County code does recognize alluvial fans as geologic hazard areas and has identified the area as an alluvial fan; however, Skagit County's code regarding alluvial fan hazards does not have specific assessment or development standards for alluvial fans. Specific assessment and development standards for alluvial fans can reduce alluvial fan risks.

Assessment Method

This assessment included 1) a visual assessment of the alluvial fan, the pond/marsh, beaver dam, and the stream canyon between the pond/marsh and the alluvial fan, 2) review of available geologic mapping, historical aerial photographs, and lidar (light detecting and ranging) imagery of the alluvial fan and watershed, 3) a variety of documents, photographs and videos provided to me by Skagit Land Trust and local residents, or found on line, and 4) past observations at sites with similar geologic conditions including areas in the vicinity of the subject property also aided in my interpretations. This assessment is in part a forensic investigation of the 2021 flood event on the alluvial fan. The field work took place in November and December 2023. The interpretations in this report were also aided by familiarity with geologic literature regarding alluvial fans and debris flows as well as past observations of alluvial fans and debris flows in northwest Washington State.

Summary

This alluvial fan is a composite fan that has developed from deposits of sediment from several streams that flow onto the fan. The majority of the fan deposits are associated with the main stream that flows from the west out of a pond/marsh down through a narrow canyon before the stream reaches the fan area. While the 2021 flood was reported as associated with a partial failure of a beaver dam at the main stream pond/marsh, a significant factor in the flood was the entrainment of large volumes of sediment within the stream between the pond and the alluvial fan. This sediment resulted in the stream channel on the fan as well as drainage ditches on the being filled with sediment further increasing the flooding.

Flooding on the alluvial fan was previously reported 2015, 2016 and possibly in 2018 associated with a section of the stream on the mid section of the fan. This limited capacity area coincided with the stream avulsion location during the 2021 flood where water broke out into multiple stream channels at this location resulting in sheet flooding and associated mud and gravel deposits across a wide area on the alluvial fan.

The 1991 and 1995 floods were reported to have been the result of beaver dam failures. These floods appear to have been the result of dam failures on a pond/marsh located on the different smaller stream located south of the fan. High water flows from these floods resulted in water flowing down across West Big Lake Boulevard and across the Washington State Fish and Wildlife lake access site.

Other reported flood events are of uncertain origin and are not well documented but appear to be associated with limited channel capacity of the stream at a mid point on the fan where the 2021 flood broke out over the lower fan.

Based on my assessment, flooding on this alluvial fan should be expected to continue. Sediment deposition on the alluvial fan and within the stream channel on the fan is a major factor in flooding and will result in future flooding. Sediment transport during high water flows with or without beaver dam breaks will continue to be transported down through the narrow canyon to the alluvial fan. The stream gradient on the fan is too low to transport all of the sediment and the result has been and will continue to be stream agradation (filling of the channel with sediment) on portions of the fan resulting in flooding and stream avulsion or redirection of the stream.

There is a large volume of sediment that will be readily transported during high water events within the narrow canyon reach. Additional sediment will be added to this reach from ongoing shallow landslides and ongoing deep-seated landslides within the narrow canyon reach. There are several locations within the deep narrow canyon reach where there is a potential for landslide dams to be created. These dams will back up water and can potentially fail abruptly leading to a surge of debris flooding downstream.

While the 2021 flood event is associated with a partial failure of the beaver dam at the main stream pond/marsh, this flood was significantly added to by the presence of debris within the narrow canyon between the main stream pond/marsh and the alluvial fan. Some of the debris and sediment was blocked by the bridge that crosses the creek at the apex of the alluvial fan. However, some of the sediment that had accumulated in the narrow canyon was transported onto the fan past the bridge and was deposited within the stream channel downstream resulting in the channel loosing capacity resulting in broad flooding that continued until the stream channel was cleared as well as ditch areas that also filled with sediment.

It is my opinion that flooding should be expected to continue to be a problem on the alluvial fan and may be more frequent as large wood in the canyon reach has been scoured out and sediment in the canyon will be for a time more mobile due to the removal of large wood. A large volume of sediment is currently blocked from the fan by the large wood debris at the bridge but will readily mobilize as that wood dam breaks down.

Beaver dam failures have played a role regarding some of the past flooding on the alluvial fan, but they are not the only cause; flooding should continue to be expected on this alluvial fan due to sediment transport from upstream onto the alluvial fan filling in the stream channel.

The highest flood levels in the 2021 event were likely the result of short term debris dam failures within the narrow canyon reach. Debris and landslides in the canyon likely backed up water that then surged downstream as the blocking debris became mobilized. This flooding mechanism is a common problem in narrow confined stream canyons and can result in peak flood levels many times greater than straight clear water floods. Scour marks and erosion on the canyon sides indicate peak flood flows were much greater than the flows just below the beaver dam.

Mitigation of the flooding problem can be addressed via increasing the stream channel capacity via widening and deepening the channel and construction of berms and levees and possible construction of a sediment trap to capture sediment prior to it being deposited within the channel area. I would note that some of channel work and deflection berms have already been done by individual property owners. However, increasing stream channel depth and width will increase sediment deposition, and hence, ongoing maintenance will be required such as periodic sediment accumulation removal.

Map Review and Geology Units

The watershed is covered by four different quadrangle maps as the corners of four quadrangles meet at approximately the east side of the conservation easement property. The maps are: Preliminary geologic map of the Clear Lake NW quadrangle, Skagit County, Washington (Whetten, Dethier and Carroll, 1980), Preliminary geologic map of the Mount Vernon 7 1/2 minute quadrangle, Skagit County, Washington (Dethier and Whetten, 1981), Geologic map of the McMurray 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington, with a discussion of the evidence for Holocene activity on the Darrington-Devils Mountain fault zone (Dragovich and DeOme, 2006) and Geologic map of the Utsalady and Conway 7.5-minute quadrangles, Skagit, Snohomish, and Island Counties, Washington (Dragovich, Gilbertson, Norman, Anderson, and Petro, 2002).

These maps indicate that the watershed area is underlain by Tertiary volcanic rocks, Chuckanut Formation, Vashon glacial till, peat (or on some maps marsh) and mass wasting deposits. The alluvial fan is not indicated on the geology maps, but the Skagit County Potential Landslide and Erosion Map designates the lower portion of the watershed as an alluvial fan area.

The Chuckanut Formation consists of alluvial sediment that has formed alternating layers of sandstone, conglomerate, silt and mudstone and coal beds. The Sediment was deposited within localized basins during the Eocene approximately 45 million years ago.

The volcanic rocks are Eocene age and in nearby locations intrude and flow over earlier Eocene age Chuckanut sedimentary rocks. The intrusive emplacement of these volcanic rocks appears to be strongly controlled by pre-existing strands of the Darrington-Devil Mountain Fault Zone (DDMFZ) as they are present at multiple locations along the fault zone. Continued faulting along the DDMFZ locally imbricated volcanic rocks with other rock types along the fault zone.

The glacial drift consists of dense and hard silt and clay with coarser grained sand, gravel and cobbles and occasional boulders embedded in the fine grained matrix. Most of the drift appears to have been deposited directly by glacial ice, but there are areas of coarser grained sediment that may be from flowing water deposits under thinning ice or post ice melting. The glacial sediments were deposited between 18,000 and 14,000 years ago.

The DDMFZ is a broad fault zone with multiple fault strands that passes through the area. Seismicity of the DDMFZ is not well understood, but Johnson and others (2001) consider it to be an active fault that has the potential to generate large earthquakes. Personious and others (2014) documented an area where glacial sediments from the last glacial period have been offset by the fault along a fault strand approximately 2.5 miles south of the alluvial fan area that confirms that at least that portion of the fault zone has been active over the past 10,000 years as the ground surface has been ruptured by fault movement and by definition offsets of features less than 10,000 years old indicate an active fault. Personious and others (2014) interpret an alignment of topographic features and offset geologic units in an alignment that includes the main stream pond/marsh as a northern strand of the DDMFZ.

Watershed Geology Unit Observations

My observations are generally consistent with the geologic maps and map descriptions.

Volcanic rocks underlie the very upper slopes above the south side of the main stream marsh/pond area. Below this area the steep slope is underlain by sandstone consistent with the Chuckanut Formation. The Chuckanut Formation underlies most of the watershed but is mostly covered by glacial drift sediments. There are bedrock exposures within the stream canyon and along road cuts and on some of the steeper slopes of the watershed and in the vicinity. The steep slopes just west and south of the alluvial fan are underlain by bedrock. The hardness and erosion resistance of the Chuckanut Formation varies with some units forming very hard resistant ridges and, in the canyon, hard cliffs and waterfalls and some units readily spalling and turning into silt and clay.

The main stream marsh/pond area is underlain by an accumulation of organic material overlying glacial drift sediment. In general, the glacial drift consists of dense and hard silt and clay with coarser grained sand, gravel and cobbles and occasional boulders embedded in the fine grained matrix. The glacial drift is exposed along the creek banks just below the pond/marsh area.

Dragovich and DeOme (2006) mapped areas of mass wasting south of the stream, but that map does not extend to the creek canyon itself. I did observe areas of mass wasting and shallow landslides on the steep slopes of the narrow canyon between the main stream marsh/pond area and the alluvial fan. Some of these slides were recent and others were older and tree covered. The shallow slides ranged in thickness from thin topsoil failures to slides that were on the order of 5 feet thick. There are two relatively large deep-seated translational landslides that have indications of recent movement into and towards the stream canyon. There is an old landslide on the south side of the marsh/pond and another fairly large landslide with sharp features in the upper watershed west of the pond, but these slides are not relevant to any risks on the alluvial fan.

Alluvial fan deposits typically consist of massive to weakly stratified, sand, gravel, and cobbly gravel as well as poorly sorted angular to sub angular debris flow deposits modified by fluvial processes. My observations on the fan found that the upper fan area just where the main creek leaves the steep narrow canyon area is underlain by gravel with some cobbles. There are deposits of woody material at the top of the fan (certainly at the bridge location at the fan apex). Older woody deposits extend down the fan several hundred feet. Below the area of wood deposits the fan is underlain silt deposits with layers of gravel suggesting active channel migration across the fan surface with silts being deposited as overbank deposits and gravel deposited by stream channel deposits. This mix of silt and gravel deposits is apparent in pictures from the 2021 flood event that show broad areas of muddy sediment across the lower fan with multiple gravel channel routs across the muddy areas.

Geomorphology and Geology Processes

The alluvial fan is located on the west side of Big Lake. West Big Lake Boulevard crosses the alluvial fan. Eagle Point Lane, Glenn Allen Place and West Lakeview Lane are located on the alluvial fan as well. Approximately 30 homes are located on the alluvial fan as well as numerous outbuildings/shop buildings, storage buildings and garages. A Washington State Fish and Wildlife boat ramp, dock and parking area is located on the fan. Homes on the lower portion of the fan along the lake shore have boat docks extending into the lake. Most of the land is landscaped yard areas with some wooded area and small grass fields.

Alluvial Fan

The alluvial fan is a composite fan that has been formed by sediment deposition from several streams (Figure 1). The majority of the sediment has been derived from the main creek that flows from the main stream pond/marsh. This main creek flows from west to east and has incised a canyon between the pond/marsh area and the composite alluvial fan.

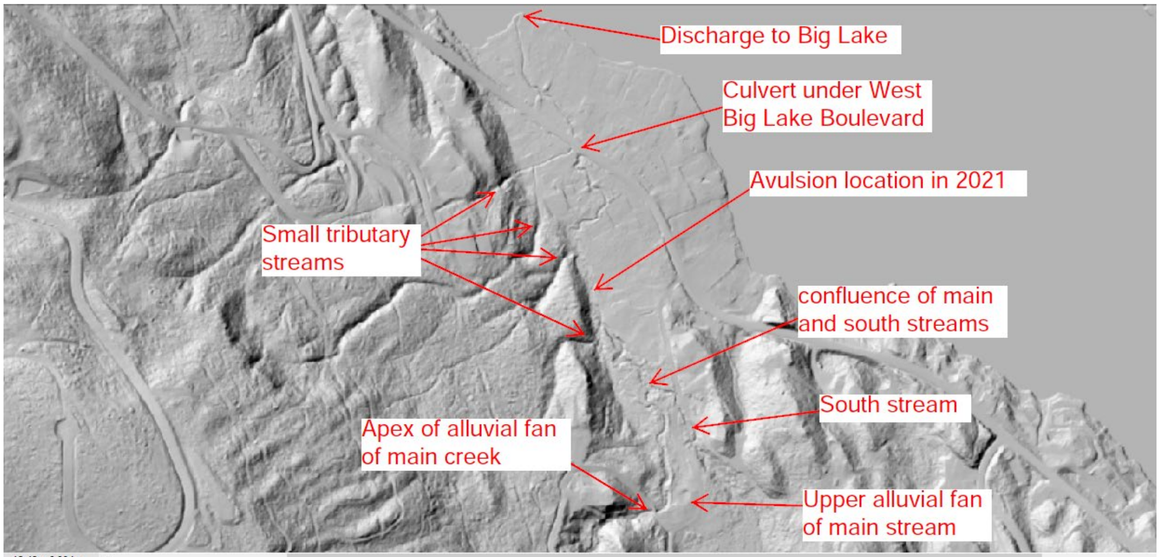

Figure 1. Bare earth image of alluvial fan area

The sediment eroded from the canyon was and is deposited on the alluvial fan area at the mouth of the canyon where the canyon intersects a north-south oriented strike valley. A strike valley is a low area where weaker more easily eroded rock is present with harder resistant rock forming the valley walls on the west and east. The main creek enters the strike valley from the west and has built an alluvial fan across the valley. The main creek turns north and the alluvial fan extends northward as valley fill before transitioning to a more classic broad alluvial fan shapes that extend to the lake shore area to the east and north.

Four small steep drainages are located on the west side of the fan and have all added small volumes of sediment to the fan area. Another stream flows on to the fan area from the south. This steam flows out of a pond/marsh area as well.

The stream from the south flows out of a pond/mash area along the strike valley. This creek flows around the outer east edge of the upper alluvial fan that the main creek has built across the strike valley and then joins the main creek to the north.

The small streams flow from the west down the steep slope above to the alluvial fan. These streams have and do supply relatively small volumes of sediment to the fan and flow from these streams may also result in some incision on the fan surface such as one of the northerly streams that flows across the fan surface for some distance before joining the main creek.

The alluvial fan apex, where the main creek enters the strike valley, has recent debris flow deposits of cobbles and a significant volume of logs from the 2021 debris flood. Much of the large wood is piled up at a bridge crossing the creek right at the apex of the fan (Figure 2), but some large wood did get past this bridge and was deposited on the upper fan area below.

Below the apex area the fan, below the bridge, the main stream is initially deeply incised into the upper fan surface (Figure 3) and then turns northward where it flows through a forested area with a low gradient and is not deeply incised. There appear to be old debris flow deposits within the upper part of this forested reach extending approximately 200 feet downstream from the fan apex based on observed lumpy ground areas, discontinuous debris levees and old partially buried rotting logs.

As noted above, the stream from the south passes around the upper portion of the main stream alluvial fan to the east of the fan. This south stream has cut down into the eastern part of the fan surface. The south stream passes through a 12-inch culvert under West Lakeview Lane and flows through the forested area and into the main stream.

The main stream continues down the relatively moderate slope of the fan surface and trends towards the west side of the fan near the base of the steep slope that rises to the west. The stream flows along the base of the slope within a shallow swale on the west end of several residential lots. There are a few very subtle swales associated with former stream routes or stream overflow routes located east of the existing stream route (Figure 4). It was along this reach that the stream overflowed in 2021 with water flooding out of the channel across the fan surface to the east and northeast.

The stream then trends away from the west slope with a fairly sharp turn towards a more easterly direction. This turn appears to be in part the result of a small alluvial fan associated with one of the larger small creeks that flow onto the fan area deflecting the main creek to the east but may also be the result of past grading during site development. On this reach the creek becomes incised into the fan surface approximately 4 to 5 feet and then turns northward again and flows through a culvert under West Big Lake Boulevard.

Past West Lake Boulevard the creek continues northward to the lake. On this final reach the stream in places appears to follow a channel grading that may have at least been partly graded to its location during development of the residential lots.

There are a number of relevant features on the alluvial fan that will influence flood flow paths. As noted, there are approximately 30 homes and associated buildings on the alluvial fan. Buildings can deflect water flow directions during flood events.

A concrete block wall has been constructed along the south side and at least partially along the west side of one of the upper residential lots since the 2021 flood event (Figure 5). The road side ditch along West Big Lake Boulevard and the road itself has and will redirect high water flows. The stream passes under a bridge to a home on the west side of West Lake Boulevard and passes through a steel culvert under West Lake Boulevard and east of the road is spanned by two small foot bridges and a driveway bridge. A concrete block berm has been built to prevent ditch overflow from very small culvert from flooding a utility box on the lower end of the fan adjacent to the road.

Figure 2. Large wood debris jammed at bridge West Lakeview Lane at the apex of the alluvial fan.

Figure 3. Deep incised stream reach on upper fan just below West Lakeview Lane bridge.

Figure 4. Overflow swale east of main stream which is located behind buildings.

Watershed of the Main Creek

The main creek that flows drains an area of slightly more than 1 square mile above the alluvial fan area. A general overview of the watershed is provided in Figure 5.

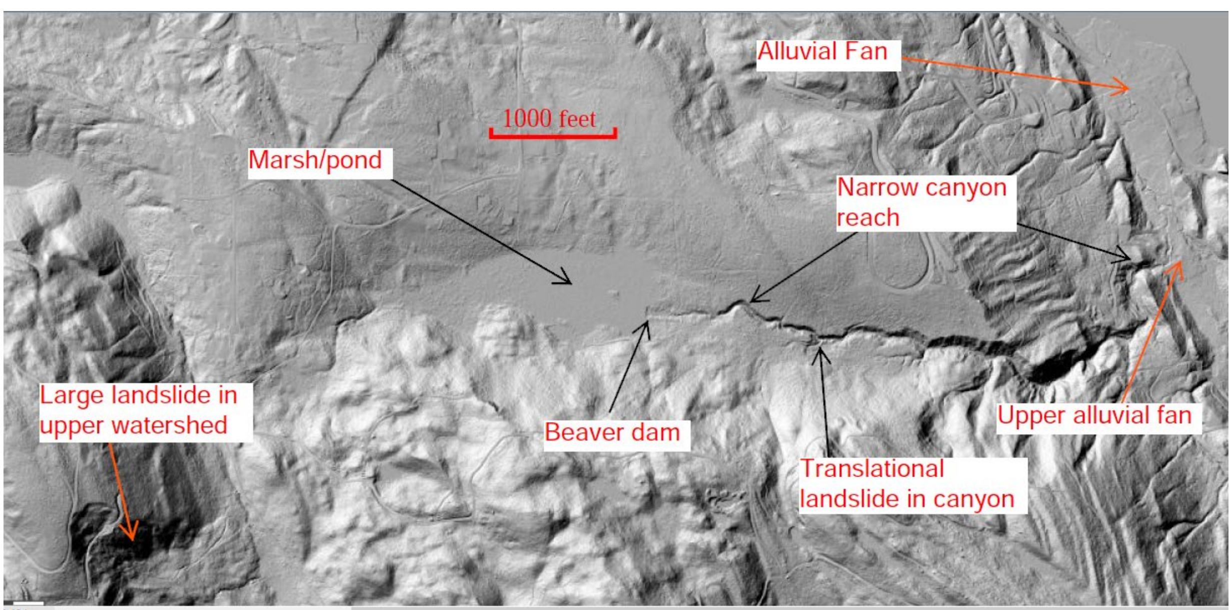

Figure 5. Lidar bare earth imagery of main stream watershed

Above the pond/marsh area there are a few intermittent streams. Water accumulates within the 12.5-acre pond/marsh area from these intermittent streams and groundwater seepage. The main stream exits the pond/mash area at the east end of the pond and begins flowing in a confined channel incised into the glacial drift sediments below the pond through a forest area.

The stream outlet to the pond/marsh has been manipulated by beavers in a manner that raises the water level in the pond/marsh. This activity appears to have been taking place for many decades with water levels varying over time based on historic aerial photographs that date back to 1941 (Figure 6 and 7).

A portion of the beaver dam failed in 2021. Photographs of the dam break area showed scoured soil down to the dense glacial till (Figure 8). The pictures showed that the dam was rebuilt shortly after the failure. At the time of my site visit in November 2023 the scoured area immediately below the dam had become brush covered and vegetation was beginning to become established on portions of the newer dam (Figure 9).

Figure 6. 1941 aerial view.

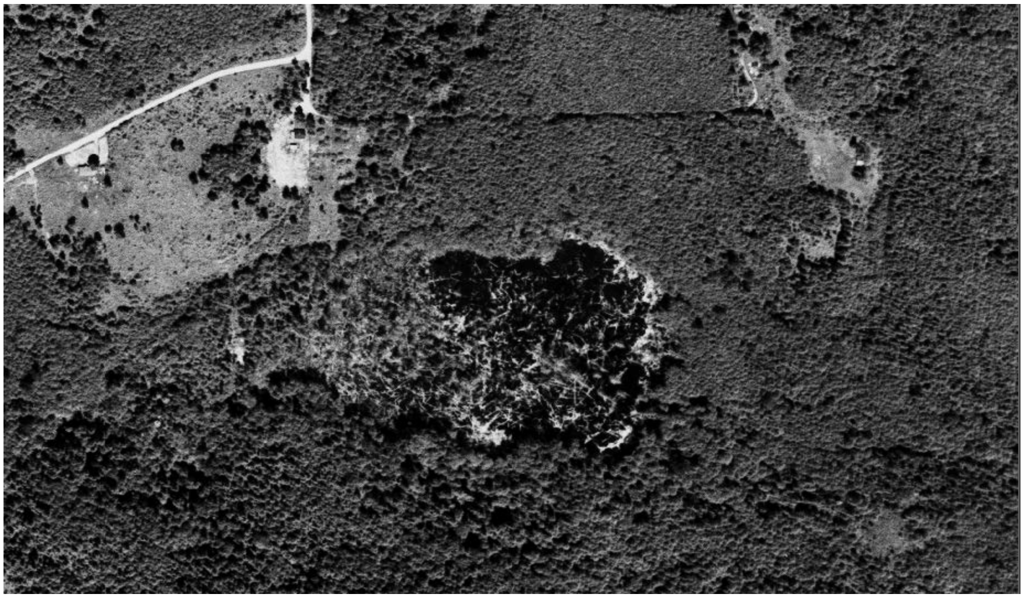
Figure 7. 1954 (USGS) aerial view of pond with larger area inundated


Figure 8. Dam rebuilt at scoured glacial till where dam failed previously.

Figure 9. Vegetation established at newer dam area.

Downstream of the beaver dam there is an old logging road crossing the creek with a steel culvert (Figures 10 and 11). The crossing and culvert did not appear to be damaged. Water may have spilled over the top of the road; however, given that two years had passed since the flood event, the premise that water may have passed over the road is not certain.

Figure 10. Culvert inlet at old logging road

Figure 11. Culvert outlet at old logging road

Scour marks are evident along the creek banks from the pond to the top of the alluvial fan. The level of scour and the apparent height of flood water increased downstream. This increase in peak discharge flow was likely the result of additional blockages of natural debris and soil within the incised narrow canyon resulting in a series of dams and possibly a moving debris front that developed as the water borne debris was pushed down through the canyon. Since the 2021 flood additional debris has accumulated in the stream canyon and a large volume of accumulated wood and cobbles remains within the lower end of the canyon at and just above the bridge across West Lakeview Lane at the apex of the alluvial fan.

This confined narrow channel deepens into a narrow very steep side canyon that continues to the alluvial fan area. The stream bottom area of the canyon is generally cobble covered on its lower reaches, but there are areas where the creek is scoured down to bedrock as well as areas with debris accumulations including logs. Some of the debris appears to be related to recent sloughing as the lower slopes of the canyon have been eroded and undermined the steep slope areas above.

The steep narrow canyon is shown on a lidar bare earth image on Figure 12 with some ground truthed features marked up on the figure. Shallow landslide scars, slope ravel, tree toppling and scouring are evident throughout the canyon (Figures 13-15). As noted in the geology section, there is a deep-seated translational slide area where a large area exhibits slow periodic movement towards the canyon as evidenced by broken ground and recent cracking on the ground surface.

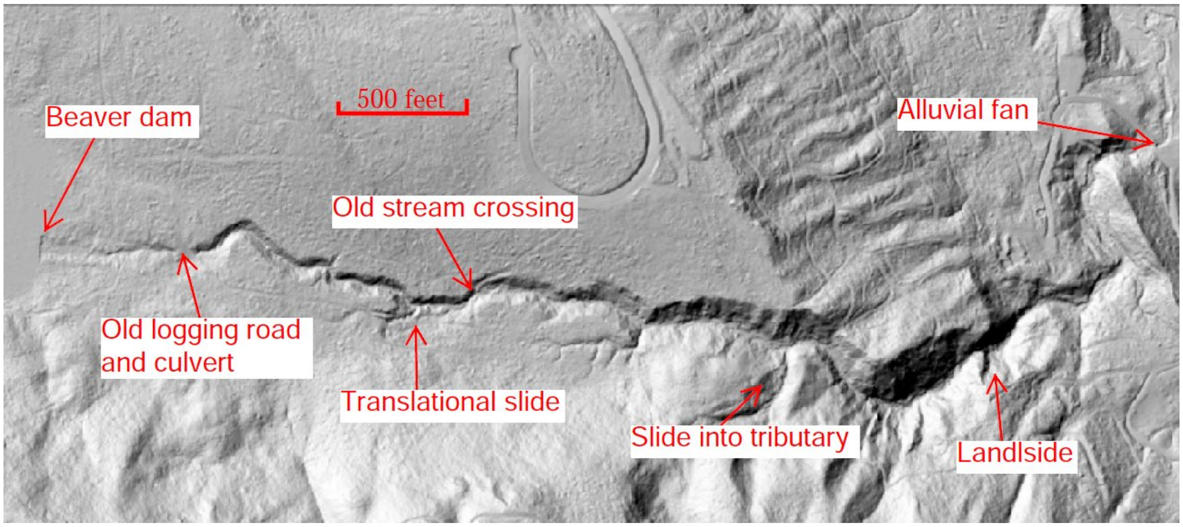

Figure 12. Lidar bare earth imagery of narrow steep canyon with significant features marked.

Figure 13. Toppled trees due to bank erosion in upper canyon.

Figure 14. Shallow bedrock slide in steep narrow bedrock canyon

Figure 15. Broad area of scoured canyon on lower canyon

Watershed of the South Stream

Reports of past flooding in 1991 and 1995 on the alluvial fan indicated flooding was the result of beaver dam failures. Based on where the flooding was reported to have taken place, the source of the flooding was likely from the south stream.

The south stream watershed is located within the strike valley that extends southward above the upper alluvial fan area (Figure 16). There is a pond/mash in the watershed (Figure 16 and 17). The pond/marsh was not accessible, but past reports indicate that there has been and is a beaver dam located at the outlet area of the pond. Variable water levels evident in historic aerial photographs are consistent with beaver activity. The pond is approximately 2.2 acres in size. There appears to be a second marshy area with some beaver use upstream as well.

The size of the watershed and the topography of the watershed are such that flooding from the south stream will be limited to beaver dam failures. As noted above, the beaver dam was not accessible (on private property) so the conditions at the beaver dam could not be fully evaluated.

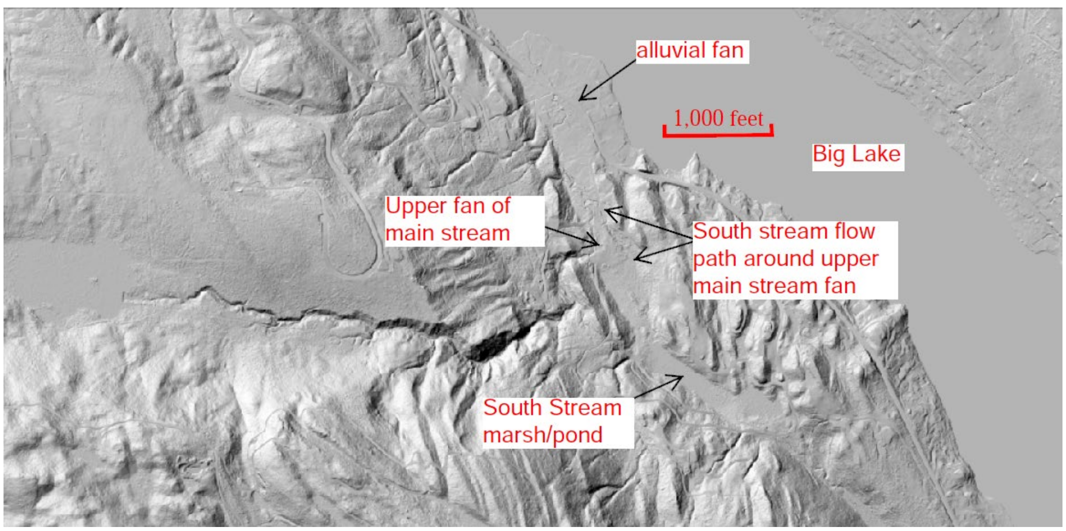

Figure 16. Lidar bare earth image of the south stream watershed and alluvial fan


Figure 17. Aerial view of pond/marsh areas on south stream

GEOLOGIC HAZARD ASSESSMENT

General Discussion of Alluvial Fan Hazards

Four hazards are typically present on alluvial fans: 1) debris flows, 2) debris floods 3) clear water flooding and 4) erosion. These hazards can often be overlapping.

Alluvial fan hazards are the result of specific geomorphic conditions inherent to alluvial fans in which a steep gradient and/or confined stream exits a mountain front onto an unconfined gently sloping area.

High discharge clear water flooding from heavy rainfall and/or rapid snow melt or, in the case of the main stream at this alluvial fan, beaver dam failures also increase the potential for slope failure and erosion processes on steep slopes and inner gorge walls that can lead to debris flows and debris floods. The 2021 beaver dam failure in main stream watershed resulted in debris within the narrow canyon between the beaver dam and the alluvial fan becoming mobilized within the narrow canyon reach of the main stream that extended to the upper alluvial fan.

Debris flows exhibit laminar flow and typically have sediment contents between 45% and 75%. A significant component of that sediment in forested regions may be logs. Due to the high specific gravity of sediment laden debris flows, debris flows are capable of moving large rocks and debris. The bulk of the large sediment and debris is deposited on the upper part of the alluvial fan or within low gradient areas of the drainage. However, even in low gradient stream reaches, debris flows can continue downstream if the low gradient reach is confined within a narrow valley or if the debris flow builds debris levies on either side such that it becomes self-confined and builds a steep gradient leading front to continue further downstream.

Debris floods carry large volumes of sediment; however, the sediment content is typically on the order of 15% to 35%. Debris floods exhibit turbulent flow compared to the laminar flow of debris flows and material moved by the debris flood is more dependent on flow velocity (Hunger and others, 2001).

Debris flood and debris flows have peak discharge rates that can be considerably greater than 100-year flood return periods. Debris flow peak discharges up to 50 times the peak discharge of a 200-year return period flood have been reported by Jakob and Jordan (2001). While heavy rainfall events often trigger landslides in drainage basins leading to debris flows and floods, the debris flows and floods that exceed 100-year return period clear water flood events can occur more frequently than the calculated flood return period. That is, creeks subject to debris flows and debris floods may flood more frequently and at greater intensity than the predicted flood return periods based on standard run off analysis. The return frequency and size of peak discharges associated with debris flows and debris floods is dependent upon stream morphology and stream basin geomorphic processes. Hence, it is essential to have a good understanding of the geomorphic processes and stream morphology to assess the scale of and the frequency of debris events.

A driver of high water flow for the main creek in the 2021 flood was a partial failure of the beaver dam. However, observations along the creek indicate that the peak flood flows were substantially greater than the high flow of water from the dam failure alone. As the flood moved through the narrow canyon entrainment of sediment, landslide debris and large woody debris that had accumulated in the narrow canyon resulted in a debris flow and scour and high water marks on the lower canyon indicated a much higher peak flood discharge than that from the beaver dam failure alone.

In addition to the direct hazard posed by the debris flows and debris floods, these events can lead to large sediment volumes being deposited on the alluvial fan that can alter the existing channel and secondary channels. Channel filling can be a slow incremental process (aggradation) caused by increased sediment loads and/or decreasing stream gradients. If the existing channel is filled in enough, it can cause an avulsion (creating of a new channel) that could be a considerable distance from the original channel depending on the size of the fan. The creation of the new channel can lead to rapid erosion and/or flooding well away from the original channel.

Big Lake Alluvial Fan Hazards

Specific Debris Flow and Debris Flood Hazards

The 2021 flood resulted in a large debris flow within the narrow canyon reach above the alluvial fan. The debris flow began within the narrow canyon. Based on observations within the canyon reach the debris flow initiated at what may have been a very old logging road crossing in the canyon. The flood of water from the partial failure of the beaver dam likely initiated debris entrainment within the narrow canyon reach.

Most of the large wood entrained in the debris flow was 'captured' at the bridge across the alluvial fan apex at West Lakeview Lane. There is evidence that in the past, before the bridge was built, that debris flows extended down the fan towards the north for about 200 feet based on lumpy ground, debris levees, and rotting logs along the stream on the upper fan below the bridge. Upstream of the large pile of logs at the bridge, a thick layer of gravel and cobbles up to 4 feet deep has accumulated.

The very low gradient on the upper fan has and will result in rapid deposition of debris flows and this has been enhanced by the mature trees growing along the stream on the upper fan area as the trees will act as barriers for large logs within the debris flow.

Based on my observations within the narrow canyon, the 2021 flood resulted in a maximal credible event. The term 'maximum credible event' has been utilized for assessing debris flow hazards on alluvial fans in British Columbia and is included in Whatcom County's alluvial fan hazard regulations. The term is utilized due to the difficulty of quantifying a recurrence interval for debris floods. Instead of trying to determine a recurrence interval, an estimate of the largest possible event is made by evaluating the geomorphic conditions within the watershed.

Flood Hazards

<u>Reported Floods</u>

There have been numerous reported flood events on the alluvial fan since 1991. The reported flood events are as follows:

- 1991: This flood took place on July 10, 1991 as a result of a beaver dam failure. The flood damaged a portion of West Big Lake Boulevard, damaged the Washington State Fish and Wildlife fishing access and boat launch and blocked access to the homes. Skagit County performed restoration work on the road and access and an Emergency Declaration was made on July 11, 1991 for that work (Skagit County Resolution 13607). The location of the beaver dam was not described; however, the flooding at the fish access site suggests it was sourced from flooding from the south creek (Skagit County Multiple Jurisdiction Mitigation Plan 2020 Update, page 8-9).

- 1995: This flood took place on May 5, 1995 and the description of the impact is identical to the 1991 flood (Skagit County Multiple Jurisdiction Mitigation Plan 2020 Update, page 8-9).

The specific beaver dam source of the flooding is not described, but as noted above the location of the flooding suggests that the beaver dam failure was associated with the smaller south stream. Letters sent to multiple property owners by Skagit Public Works in 2016 indicate that Public Works was aware of beaver dams in the watershed at both the south stream and the main stream suggesting uncertainty regarding the source. A local residence did indicate that the south stream beaver dam had caused problems in the past, but that the pond now has a leveler that minimizes the risk of blowout dam failure. Due to the limitation of access to the pond I was not able to confirm the presence of a pond leveler.

- 2003: A complaint was filed regarding a private road flooding at 18356 West Big Lake Boulevard.

- 2015: Flooding at 18356 West Big Lake Boulevard in November from water avulsion at the creek impacting the septic and home foundation. The source of the flooding was not identified but notes by Nikki Davis of Skagit Public Works indicated a too small culvert suggesting that the south creek may have been the source. There is a small culvert under West Lakeview Lane that high water flows on the south stream may not be able pass through. There is also a very subtle swale that would direct water escaping from the main creek below the confluence of the main and south creek that would direct water towards the 18356 residence.

- 2016: Flooding was reported along West Big Lake Boulevard. Nikki Davis of Skagit Public Works noted it was a recurring problem and sent letters to property owners where beaver ponds were/are located (Hanson, Wright and Owens).

The property at 18356 appeared to be the most impacted by flooding and began considering fixes such as dredging or a berm (per time line sent to me from a resident). It appears that a berm may have built near the creek in 2018 (aerial image). Post 2021, a concrete block berm was extended along the entire south side of the property.

A 22-foot bridge was built across the creek at 18328 West Big Lake Boulevard. It is not clear if the bridge was installed for flood improvements or simply to provide better access to the new home. The result was a much wider passage for water at this location upstream of the culvert at West Big Lake Boulevard.

- 2018: Property owner at 18273 West Big Lake Boulevard filed a complaint that the stream has no channel capacity left. This site is at the very distill end of the fan east of West Big Lake Boulevard. It appears that the stream channel was widened in 2019 per aerial images.

- 2021: Major flood associated with a partial beaver dam failure at the pond/marsh on the main stream combined with the associated debris flow that developed within the canyon above the alluvial fan.

The 2021 flood appears to have been the largest flood and is the only one that has clear information regarding the extent of flooding and the source of flooding. An extremely good overview is available via drone footage of the alluvial fan area shortly after the flood: https://www.youtube.com/watch?v=13YhRYoHnMw&t=104s.

The 2021 flood impacted most of the alluvial fan (Figure 18). The stream avulsion took place at the back, west end of 18462 West Lakeview Lane (Figure 19). The escaped water flowed across the fan surface in multiple channels and areas of shallow sheet wash flows. The flood of water reached West Big Lake Boulevard at numerous spots and then flowed northward along the roadside drainage ditch (Figure 20). The ditch was not large enough to contain the flow and water spilled across to the east side of the road and across the properties on the east side of the road.

Figure 18. Estimated extent of flooded area from review of drone footage.

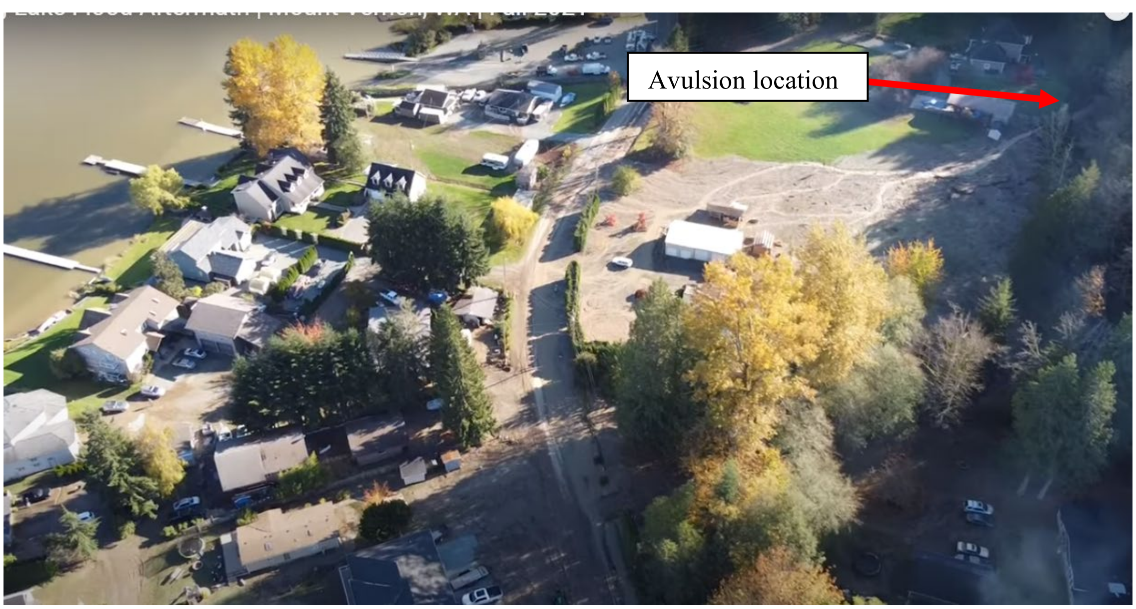

Figure 19. View of flooded area showing the avulsion location and area where flood water spread across the alluvial fan.

Figure 20. View of water flowing in ditch and on road. Note mud from higher water showing areas where water flowed across the road to the properties on the east.

Note that flooding continued on parts of the fan long after the initial flooding took place due to the fact that the main stream channel had been filled with sediment as had the ditch areas and the stream was flowing across multiple routes across the alluvial fan. However, at the time of the drone video all the water from the stream was passing through the culvert under West Big Lake Boulevard (Figure 21). However, a careful review of the drone imagery showed that water was still flooding from the stream channel below the culvert due to sediment accumulation in the channel.

Figure 21. View of water flowing in ditch to stream culvert indicated as blue line across road.

While beaver dam failures have been implicated in the flood events, a substantial portion of the flooding is associated with sediment accumulation within the stream channel on the alluvial fan as well as along over flow pathways such as the roadside ditch. Hence, flooding continues long after the beaver dam drainage took place. Furthermore, the water levels from scour lines just below the beaver dam including at the old logging road culvert that appears to have transmitted most if not all the water from the beaver dam break suggests that sediment deposition on the alluvial fan is the main driver of flooding on the fan.

Lidar imagery and on site observations indicate that for most of its flow path on the alluvial fan the steam channel is shallow and has a low gradient and thus is very susceptible to channel filling and flooding due to low channel flow capacity.

Erosion Hazards

As described in the previous overview of alluvial fan hazards, portions of the alluvial fan may be at risk from erosion. Just below the bridge at West Lakeview Lane significant bank erosion took place as the stream takes a sharp bend and is relatively high gradient on the upper fan.

Below this area the alluvial fan is mostly an area of deposition except where over flow stream paths create concentrated flow. There was some erosion during the flood along the lower part of the ditch section below the stream culvert on West Big Lake Boulevard. This ditch section has since been lined with rocks that will reduce the erosion risk at this location.

CONCLUSIONS

Active alluvial fans that have been developed with numerous homes present a significant challenge for policy and for the property owners. One particularly difficult problem is the perception of the hazard on alluvial fans. It is easy to underestimate the risk a small stream such as the one on this alluvial fan.

Much of the communication and statements regarding flooding on the alluvial fan has implicated beaver dams. However, even if beavers were not present, this alluvial fan will still be susceptible to debris flows and flooding. The beaver dams may result in a greater frequency of flood events on the main creek, but this creek is still subject to floods due to the steep narrow canyon just above the alluvial fan and the upper part of the alluvial fan is at risk from debris flows with large logs being the biggest risk.

The following conclusions and opinions are presented as a means to provide some consideration to this alluvial fan.

Steep canyon above the alluvial fan

The steep narrow canyon on the main stream of the alluvial fan poses the largest risk to the alluvial fan. This canyon has steep unstable slopes subject to shallow landslides, tree toppling, debris accumulation and in one area a fairly large deep-seated translational landslide. The narrowness of the canyon and stream gradient make this canyon susceptible to large debris flows regardless of beaver dam flooding. Landslide dams and debris dams should be expected within the canyon leading to future debris flows and associated flooding on the alluvial fan.

Even without beaver dams in the watershed, the alluvial fan would be at risk from large debris flows and associated floods.

Based on my assessment of the canyon reach and observations of sediment and debris transport and mobilization, the 2021 flood event was very nearly a maximum credible event for this watershed. It is not likely that future debris flows/floods will be much larger.

Beaver Dams

The 2021 partial beaver dam failure on the main stem pond did result in a surge of water that flowed out of the pond/marsh area. The surge of water passed through the culvert on the old logging road down stream of the pond without damaging the stream crossing. However, as the surge of water entered the narrow canyon it mobilized large volumes of sediment and large wood debris and hence became a large flood surge. The combination of higher water flow and large sediment volume resulted in rapid stream channel filling on the alluvial fan and water escaping the partially filled channels leading to wide spread flooding on the alluvial fan.

Beaver dam failures have been blamed for numerous floods at the alluvial fan. However, the specifics of the dam failures and the flooding have been poorly documented with the exception of the last flood event in 2021. It is not clear which dams failed on any given reported flood and some of the flooding reports suggest chronic flooding that was likely not associated with beaver dam failures, but was associated with stream channel filling and/or restrictions. It is also very likely that some flooding events were the result of landslide and/or debris dam failures within the steep narrow canyon.

The presence of the beaver dams and their periodic failures likely increases the recurrence interval of flood events.

The exclusion of beavers or removal of the beaver dams is not a practical proposal. I have seen beaver activity all over the low mountain area west of Big Lake. Excluding beavers is not practical. Beaver dam removal would require endless patrolling and removal efforts.

Pond levelers can reduce the size of the flood surge by limiting the pond elevation, but beaver dam failures should still be expected and even the more modest flood surges will mobilize sediment within the narrow canyon leading to channel filling and flooding on the alluvial fan. The existing narrow canyon still contains significant volumes of sediment.

Stream management on the alluvial fan

Communications with some of the property owners indicated that sediment removal and channel deepening or widening was being considered on an individual basis and appears to have taken place on a limited basis prior to 2021. Sediment excavation also took place post the 2021 flood on an emergency basis on the ditch and must have taken place on the stream as the stream was returned to its pre flood location. Communications regarding the 1991 and 1995 floods indicate that sediment clearing took place then as well.

One option to reduce the flood risk would be periodic dredging and removal of sediment by creating sediment capture areas and widening and deepening the stream channel. This approach will require a not easy level of effort for permitting and will likely require property acquisition and/or easements. It will also require periodic maintenance as sediment will again accumulate within the sediment capture areas.

It is my opinion that this is a viable option for this alluvial fan as the maximum credible event on this alluvial fan is essentially the scale of the event that took place in 2021 and should be manageable with preemptive stream work that can handle the sediment inputs.

Regulations

Skagit County code does recognize alluvial fans as geologic hazard areas and has identified the area as an alluvial fan. It is my experience that Skagit County has required geology hazard assessments on alluvial fans; however, much of the development on the fan may have predated code regulations regarding alluvial fans. I did find several fish and wildlife reports and wetland reports including one that mentioned that the property was on an alluvial fan but that the report did not evaluate the alluvial fan hazard.

Skagit County's code regarding alluvial hazards does not have specific assessment standards for alluvial fans. I would suggest the County consider more specific standards on alluvial fans such as the following used by Whatcom County "*Permanent residential structures and commercial developments shall be allowed in alluvial fan hazard areas only if the fan has undergone a county-approved study to assess potential hazards, determine risks, and identify mitigation measures and is deemed suitable for development. The technical administrator shall make this determination based on a detailed assessment by a qualified professional that identifies the risks associated with a 500-year return period debris flow or the maximum credible event that could impact the alluvial fan"*. (Note that I wrote the Whatcom County Code and Stratum Group uses the same approach as a company policy regardless of the county including for alluvial hazard assessments we have done in Skagit County).

While much of the fan is developed with homes, a more precise standard will allow for individual property improvements to account for the potential hazards such as addressing the broad hazard over much of the alluvial fan of shallow sheet flow flooding. It will also prevent development or building that will increase the hazard to neighboring properties.

Stratum Group appreciates the opportunity to have provided this alluvial fan assessment. Should you have any questions or would like further clarifications on this complex alluvial fan please feel free to contact us at (360) 714-9409 or at (360) 510-5406.

Sincerely yours,

Stratum Group

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