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GEOTECHNICAL REPORT

Debris Flow Hazard and Risk Analysis - Gavan Hill Public Facilities

SITKA, ALASKA

November 4, 2020

Shannon & Wilson No: 100900-001

Submitted To: City and Borough of Sitka, Alaska
100 Lincoln Street
Sitka, AK 99835
Attn: Mr. Michael Harmon

Subject: GEOTECHNICAL REPORT, DEBRIS FLOW HAZARD AND RISK ANALYSIS - GAVAN HILL PUBLIC FACILITIES, SITKA, ALASKA

Shannon & Wilson prepared this report and participated in this project as a consultant to the City and Borough of Sitka, Alaska (City). Our scope of services was specified in the Agreement (CBS Project No. 90859) with the Municipal Administrator, dated June 12, 2018. This report presents our final Geotechnical Report on Debris Flow Hazard and Risk Analysis for Gavan Hill Public Facilities. It includes revisions based on comments you provided to the Draft Report we submitted on April 15, 2019. We made further revisions to address comments provided to the City by Ronald Daanen, Geohydrologist, Division of Geological and Geophysical Surveys, Alaska Department of Natural Resources, dated April 17, 2019.

We appreciate the opportunity to be of service to you on this project. If you have questions concerning this report, or we may be of further service, please contact us.

Sincerely,

SHANNON & WILSON

STATE OF ALASKA
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REGISTERED PROFESSIONAL ENGINEER

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ACRONYMS

ADNR	Alaska Department of Natural Resources
City	City and Borough of Sitka
yd3	cubic yards
dbh	diameter at breast height
DEMs	digital elevation models
elementary school	Keet Gooshi Heen Elementary School
GIS	geographic information system
GPIP	Gary Paxton Industrial Park
high school	Sitka High School
lidar	light detection and ranging
mph	miles per hour
RAMMS	RApid Mass Movements Simulation
recreation fields	City recreation fields
UBC	University of British Columbia

1 INTRODUCTION

The City and Borough of Sitka (City) contracted Shannon & Wilson to perform debris flow hazard and risk analyses and develop conceptual designs of protective works for public facilities adjacent to Gavan Hill in Sitka, Alaska. The limits of the study area are from the City water tank east of Georgeson Loop southward to Sitka High School (high school). This area includes the slope northeast of Keet Gooshi Heen Elementary School (elementary school) (formerly Verstovia Elementary School) and the City recreation fields (recreation fields) (Figure 1).

Following the geotechnical services that we performed on the South Kramer Avenue debris flow (Shannon & Wilson, 2016a), the City requested that Shannon & Wilson perform a desktop evaluation of the potential for a debris flow to impact the elementary school. The desktop assessment relied on two geotechnical studies from the 1980s for the elementary school, the adjacent landfill closure (now the recreation fields), and existing light detection and ranging (lidar) images of the area. We concluded that the elementary school was potentially at risk for damage by a debris flow from a channel on Gavan Hill. Our current services focus on evaluating debris flow risk to selected public facilities along the toe of Gavan Hill. These services were authorized in a contract signed by the City Administrator, on June 12, 2018.

For this study, we evaluated public facilities along the toe of Gavan Hill: the water tank, the elementary school, the recreation fields, and the high school. The purposes of our services were to identify debris flow hazards on the Gavan Hill slopes, evaluate the risk to the facilities, and provide concepts for protecting facilities, if necessary.

Our recommendations rely upon numerical debris flow runout modeling results. Our numerical modeling approach and inputs use our field and remote-sensing observations of the study area and our understanding of local and regional geologic conditions. Our evaluation of modeling results and our risk assessment are ultimately based in professional judgment.

2 DEBRIS FLOW CHARACTERISTICS

A debris flow is a moving mass of soil, rock, organics, and water that travels down a slope under the influence of gravity. Channelized debris flows occur when the moving mass is confined in a stream, river, valley, or other channel. Channelized debris flows can be triggered by shallow landslides that travel into channels where they encounter more significant water flows. With more water, debris flows may become more mobile, especially on slopes of about 25 to 50% or greater.

Debris flows typically erode soil and sometimes bedrock along the channel bed and banks. Therefore, a debris flow tends to incorporate, or entrain, more debris, gaining more erosive power as it increases in volume and velocity. A boulder front may form, contributing to the erosive force, and can shear, topple, and entrain mature trees. Mature tree trunks and other large woody debris are common in debris flow deposits that form in steep timbered terrain. For example, we estimate that large woody debris-mantled soil and rock debris across less than a third of the debris flow deposit surface at South Kramer Avenue. The large woody debris formed dams that affected the debris flow path.

Debris flows tend to slow down and deposit as they approach flatter slopes and with less channelization. As a debris front becomes less confined upon exiting the channel and loses turbulence from decreasing slopes and decreasing velocity, it tends to dewater and spread laterally. Subsequent debris flow surges in the same event, or future debris flows and floods, will tend to rework the debris flow deposit, changing its surface appearance and complicating its interpretation during field reconnaissance.

3 STUDY AREA DESCRIPTION

The study area (Figure 2) includes the southwest slopes of Gavan Hill and the gentle terrain below. The summit of Gavan Hill is at about elevation 2,100 feet. The southwest slopes of Gavan Hill are forested, with soil-mantled hillslopes and mountainous creeks. Above about elevation 800 feet, rock intermittently outcrops. Slope inclinations average about 85% above elevation 800 feet and become progressively flatter at lower elevations.

We studied four facilities:

- The elementary school located at 307 Kashevaroff Street (Exhibit 3-1),
- The City recreation fields immediately northeast of the elementary school (Exhibit 3-1),
- The high school, including the Center for Performing Arts located at 1000 Lake Street (Exhibits 3-2 and 3-3), and
- The City water tank located near 1209 Georgeson Loop (Exhibit 3-4).

Exhibit 3-1: View to North of Watersheds Behind the Elementary School and the Recreation Fields

Exhibit 3-2: View South of the North-Facing Wall of the High School and Vegetated Terrain that is Upslope of Topographic Depression (Photo Left) and the Center for Performing Arts (Photo Right). Note the Distance Across the Parking Lot to the Wall of the High School Building that is Exposed to Potential Debris Flow Runout from Gavan Hill.

Exhibit 3-3: View Southeast of Driveway to North of Center for Performing Arts at the High School

Exhibit 3-4: View to Northwest of Water Tank and Cut Slope

The elementary school is located on flat and gently sloping terrain southwest of Gavan Hill. A low-lying area is present north of and about 10 to 15 feet below the school and its paved parking lot. The low-lying area is vegetated with numerous deciduous trees and a few conifers with trunks that are typically 6 to 12 inches diameter (diameter at breast height [dbh]), and occasional larger trees (14 to 24 inches dbh). The understory vegetation is typical of wet areas, including skunk cabbage and salmon berry. This low-lying depression (Exhibit 3-5) forms a natural "barrier" for potential debris flow events.

Exhibit 3-5: Low-Lying Stream Area in a Topographic Depression to North of the Elementary School

A short distance to the northeast of the school are the recreation fields, consisting of ball fields, a parking area upslope, and a materials staging area. The recreation fields are constructed on a covered landfill and formed into a relatively flat surface, which are generally free of vegetation except grasses. The parking area, materials staging area, and the gently inclined road leading from the elementary school to the recreation parking area have gravel surfaces. A minor drainage ravine that is about 2 to 3 feet deep is present between Gavan Hill and the fields. The ravine is at about elevation 80 to 95 feet, and approximates the limit of the forested, hillside terrain.

The water tank is an approximately 70-foot-diameter ground-level water storage tank located northwest of the elementary school and adjacent to the Sitka Cross Trail. This tank was constructed on a bench cut into a hillside, forming a platform at about elevation

180 feet. A channel that is about 7 feet wide with banks of about 3 feet high occurs at the Sitka Cross Trail, which is about 30 feet uphill and flows downslope west of the tank. A broad, unconfined linear depression occurs to the east. The sloping terrain above the water tank is planar to slightly concave along contours, but lacks the extent and depth of incision and channelization as the stream channels above the other facilities. The terrain upslope of the tank is densely forested, and the ground is irregular and covered with stumps and thick muskeg.

The high school is located to the southeast of the other facilities; the elevation of the building footprint is approximately elevation 80 feet. Paved asphalt surfaces surround the buildings, and vegetated, forested terrain occurs outside the footprint of the buildings, driveways, and parking areas. A low-gradient stream northeast of the school forms a topographic depression between Gavan Hill and the high school. This depression forms a natural "barrier" for potential debris flow events.

4 APPROACH TO DESKTOP STUDY AND FIELD RECONNAISSANCE

Prior to our field reconnaissance, we performed a preliminary desktop study, which included reviewing published information and making preliminary interpretations using remote sensing data. We identified specific features for field verification. We then performed four days of field reconnaissance in June 2018 that included surficial geologic mapping.

Our field reconnaissance focused on verifying desktop observations made from published maps and reports, satellite images, lidar hillshades, and aerial photographs. Our field mapping included evaluating the distribution of soil deposits, interpreting landforms and processes, and estimating dimensions and geometries of the debris flow channels. We mapped a transect of a mountainous stream channel from the elementary school to the summit of Gavan Hill. Then we mapped portions of the other channels and hillsides above the four selected facilities. In addition to field reconnaissance of the study area, we visited five other locations (discussed in Section 6.2.3) where recent debris flows and floods occurred.

Upon returning from the field, we reviewed the regional and watershed-scale topography, geology, and geomorphology of Harbor Mountain and Gavan Hill. We compared them for similar conditions with the intention of making geological analogies between the terrain surrounding the South Kramer Avenue debris flow and the study area. Our review included desktop interpretation of published geologic maps, published soils maps

(Figure 3), lidar hillshade images (Figure 2), field photographs, and aerial photographs/ satellite imagery.

From our field reconnaissance and review, we developed an understanding of the geologic and geomorphologic conditions to characterize geologic process, landform, and material associations regarding landslide triggering, debris flow runout and erosion behavior, and debris flow deposits.

5 GEOLOGIC AND GEOMORPHOLOGIC CONDITIONS

An understanding of the geology and geomorphology of the study area, historic debris flows, and the greater geographic region is of fundamental importance in debris flow hazard analyses. We compared the physical landscape conditions between the study area at Gavan Hill and the southwestern flanks of Harbor Mountain (Figure 2), which include the South Kramer Avenue debris flow. We made our comparisons using our desktop studies, field mapping, and reconnaissance. Our understanding of the physical landscape relationships between these areas helped us to:

- Develop base case, more conservative, and upper-bound conservative triggering landslide volumes;
- Calibrate the numerical modeling software;
- Refine our erosion modeling parameters; and
- Evaluate the debris flow runout modeling results.

5.1 Geologic Materials

Sitka is geologically diverse, with meta-sedimentary bedrock draped with glacial, volcanic, and mass-wasting soil types. The bedrock in the study area consists of Sitka greywacke, which is a slightly metamorphosed sandstone. Sitka greywacke on Gavan Hill is moderately hard, light brown to light gray, and fine- to medium-grained (Karl and others, 2015). Sitka greywacke also underlies the North and South Kramer Avenue debris flow areas.

Soil deposits that overlie the Sitka greywacke include the following:

Colluvium is soil deposited by landslides, debris flows, soil creep, and other mass-wasting processes. It typically is a mixture of weathered bedrock, glacial till, volcanic ash, and organics. The texture of colluvium is typically varied, not sorted, and occasionally stratified. Colluvium in the study area is loose to dense, gray to light gray-brown, silty sand with trace clay, and few to some gravels and cobbles. Large woody debris, fibrous organics, and trace boulders also occur in colluvial deposits. Stony debris flow deposits are classified as colluvium and occur as stratified and non-stratified sequences, estimated 1 to 30 feet thick on the hillsides in the study area, and likely thicker in some locations.

Volcanic Ash typically underlies the colluvium. The volcanic ash is a product of up to two eruptions of Mount Edgecumbe (Rhiele, 1996). Colluvium older than these eruptions is also present in the landscape, i.e., colluvium may be present above and below the volcanic ash. Golder Associates (1986 and 2008) describe the weathered volcanic ash as loose to dense, brown, gray, red, and yellow, silty sand with a trace clay. The volcanic ash typically is 1 to 10 feet thick near Harbor Mountain and Gavan Hill.

Glacial Till is present beneath colluvium and volcanic ash. Till is typically a compact to dense, gray, poorly graded gravel with silt, sand, and cobbles (Yehle, 1974; Golder Associates, 1986).

Talus and Scree deposits occur locally, commonly below intermittent outcrops of greywacke that are present above about 800 feet in elevation. These deposits consist of clast-supported, angular to subangular gravel to boulders that may be locally infilled with silty sand and some organics. In some locations, talus and scree are intermittently overlain by 0.5- to 3-foot-thick muskeg and duff (Exhibit 5-1).

Exhibit 5-1: Intermittent Greywacke Outcrops in the Upper Terrain Above the Elementary School; Forest Duff Obscures Talus Deposits

5.2 Typical Triggering Landslide Characteristics

Debris flows in the Sitka area typically begin with a shallow landslide. Shallow landslides may begin to transition to debris flow almost instantaneously after triggering and translation downslope. Our observations indicate that landslides trigger in colluvium, volcanic ash, and glacial till, and commonly fail along the contact of two types of deposits. These deposits occur pervasively in this landscape, but their individual occurrence is non-uniform across the land surface and at depth. Weathered bedrock surfaces occur intermittently in landslide source areas above debris flow channels, indicating shallow landslides can erode to bedrock.

Groundwater is a key factor in landslide triggering. During our field reconnaissance, we commonly observed evidence of perched groundwater, including seepage in and below landslide scarps. Seepage in channel banks tends to increase the erodibility of soil in the channels and the mobility of debris flows. Seepage increases during and after rainfall and can be exacerbated by prolonged periods of antecedent rainfall. The qualitative relationship between rainfall and groundwater seepage became more apparent after the Sitka area incurred above-normal precipitation in the 2½ months leading up to the August 18, 2015, debris flows that were triggered during and shortly after a heavy rain event (Shannon & Wilson, 2016a; Jacobs and others, 2015).

The recent landslides that triggered debris flows in the Sitka area typically occurred on slopes greater than 80%. They tend to form near the headwaters of existing channels.

5.3 Runout/Erosion Characteristics

In the terrain near the Sitka Cross Trail and behind the elementary school (Exhibit 5-2) and east to the high school, the channels are typically trapezoidal in shape and range in width from about 20 to 90 feet. Channel gradients are typically 15 to 30% slopes, with channel banks inclined 35 to 80% slope and 5 to 10 feet in height below an elevation of about 230 feet.

Exhibit 5-2: Low-Gradient Channel Mouth Exiting toward Sitka Cross Trail

At about 850 feet upslope from Sitka Cross Trail above the elementary school (about elevation 330 feet), the channels are confined with incised banks and a V-shaped cross-sectional geometry. Channel gradients are typically 50 to 80% slopes with channel banks inclined typically 80% slope and locally steeper than 100% slope. Bank height is variable ranging from 2 to more than 15 feet. Variability in channel bank height and plan view geometry/curvature of the channels is due, in part, to episodic debris flows that caused natural dams and avulsions of the stream. In our opinion, the natural dams and evidence of avulsions in the study area indicate that debris flows here tend to occur in multiple surges.

The study area upslope of the elementary and high schools, and the recreation fields, have similar channel sizes and geometries. The channel conditions above the water tank are different, with smaller, less well-confined channels that are trapezoidal to broad in shape. The area of the watershed is less than half those above the schools and recreation fields and is more planar than concave along topographic contour.

Debris flow levees (Exhibit 5-3) form during bank overtopping as debris flows begin to deposit but flow out of the channel banks. We observed debris flow levees in recent and historic deposits that tend to come to rest where channels lose confinement across a break in slope of the overall topographic profile. On Gavan Hill we observed debris flow levees around elevation 400 to 500 feet. We also observed boulder front deposits and large woody debris dams, which indicate debris flow runout and deposition.

Exhibit 5-3: Convex, Elongate Landform with Boulder-Strewn Surface Indicative of Debris Flow Levee Morphology Above Left Bank of Stream Channel. Logged Old Growth Pines up to 5 Feet in Diameter (dbh) Were Observed on Levee Deposits, Providing Some Constraints on Age and Activity State of Deposits.

5.4 Deposition Characteristics

Stream channel incision tapers out and channels widen or "flatten-out" near or closely below the Sitka Cross Trail. Some of the natural channels in this area were modified for drainage control, fill borrows, or development purposes. We observed evidence of debris flow deposits in these areas and up to 150 feet south of the Sitka Cross Trail. Based on this geologic evidence, we concluded that debris flows with total volumes up to 20,000 cubic yards (yd^3) tend to deposit hundreds of feet upslope of the schools. We further concluded that the terrain position of the recreation fields and water tank were relatively closer than the schools to where debris flows tend to deposit.

6 RUNOUT ANALYSIS

We evaluated future debris flow risk to the selected facilities below Gavan Hill with numerical runout modeling using the computer program, RApid Mass Movement Simulation (RAMMS). This software was developed to simulate debris flow motion in three-dimensional terrain (Christen and others, 2012). Following accepted practices for debris flow runout modelling, we developed an approach to model and evaluate potential debris flow runout, and then calibrated the model to a historic debris flow event in Sitka.

6.1 Model Selection, Purpose, Application, and Compatibility

We are not aware of published guidelines for performing debris flow hazard and risk studies in Alaska. Further, our research did not find previous relevant studies of debris flow hazard studies in Sitka. Therefore, we performed our studies using our understanding of the current practice for debris flow runout modeling. Prior to commencing our studies, we contacted a debris flow runout modeling expert in coastal British Columbia, which has similar climate and geomorphology to the Sitka area. McDougall (2018) informed us that the program commonly used in coastal British Columbia, DAN3D, is currently unavailable, and recommended three other available modelling programs, including RAMMS.

We judge that the RAMMS model is appropriate for this study given its similarity with DAN3D (Schraml and others, 2015; Hungr and McDougall, 2009). The RAMMS and DAN3D codes have been verified for alpine, coastal and mountainous terrain for numerous historical debris flow events in North America and Europe. Few empirical, semi-empirical, statistical, and numerical runout models that are appropriate for debris flows are available for practical application by consulting engineers and geologists. While research is ongoing into a variety of approaches to runout modeling and analyses (Ho and others, 2018), those approaches are not yet widely available for application in professional practice.

The numerical modeling methods used by Shannon & Wilson at Gavan Hill (this study) and the empirical analysis methods used by Shannon & Wilson at South Kramer Avenue (Shannon & Wilson, 2016a) are based in decades of specialized scientific research on debris flow physics, debris flow hazards, and other disciplines. Our selection of RAMMS for this study and UCBD-flow (University of British Columbia [UBC] Civil Engineering Department, 2014) for our previous study (Shannon & Wilson, 2016a), reflects the development of the research and practice.

We considered other commercial and open-source programs for our analyses, including LAHARz (Schilling, 2014). LAHARz is the empirical, "model-based" analysis program that Alaska Department of Natural Resources (ADNR) used for their regional hazard mapping (see discussion below). Our literature review found few debris flow research or case studies published using LAHARz since 2014, which is when the computer program was last substantially updated. The U.S. Geological Survey developed LAHARz for analyzing large volcanic flows (e.g., lahars). It was not developed for site-specific engineering analyses. Our experience and research show that numerical methods typically outperform LAHARz for modeling post-wildfire debris flows (Youberg and McGuire, 2019) and for inundation due to debris flows (Reid and others, 2016).

For the South Kramer and Gavan Hill studies, our study areas and sites were selected in consultation with the City. Neither the Gavan Hill nor South Kramer Avenue studies were intended to provide *regional* hazard and risk mapping assessments, rather, they are *site-specific* studies. While similar modeling and analytical approaches might be used, regional and site-specific studies are performed at different scales and for different purposes. The different approaches for these sites we used reflect scale and purpose of each study:

2015 South Kramer Avenue Debris Flows: We performed runout analyses using UCBD-flow to estimate potential future runout. These analyses were intended to supplement hazard and risk mapping. We performed the hazard and risk mapping using terrain analysis, geomorphic interpretation of lidar, evaluation of runout analysis results, and expert judgment to develop an areas-based hazard and risk map. We did not use UCBD-flow model results to design of mitigation measures, nor was it specifically applied to delineate the risk to specific parcels or structures.

Gavan Hill: This study is intended to evaluate site-specific risks to four City facilities: recreation fields, two school buildings, and a water storage tank. Our scope of services included developing conceptual mitigation measure designs, if needed. We evaluated the stability and structural integrity of the water tank for potential debris flow impacts.

We understand ADNR is performing regional, "community-scale" mapping and "model-based analysis" of debris flow hazards in the Sitka region (Masterman, 2020). We understand the draft regional hazard maps undergoing revision by the ADNR. Preliminary findings from these efforts were not available at the time we performed of our site-specific studies.

Regional-scale debris flow hazards maps are intended to identify areas that may be subject to debris flow hazards. However, regional-scale maps should not be used to evaluate potential debris flow impacts to specific areas or individual structures. Site-specific engineering studies require site-specific mapping, modeling, and analyses. The draft, regional hazard maps undergoing revision by the ADNR (Masterman, 2020) are hazard maps, not risk maps, because their approach does not analyze potential consequences from or vulnerability to debris flow impacts to specific parcels or structures.

6.2 Modeling Approach and Model Input Parameters

Our approach to debris flow runout modeling uses the following basic steps:

1. Develop model input parameters;
2. Calibrate model input parameters using sensitivity analyses and back-analyses of historical debris flow events;
3. Evaluate calibrated debris flow modeling results using graphical analyses, spatial analyses in geographic information system (GIS), and professional judgment;
4. Perform predictive debris flow modeling; and
5. Evaluate predictive debris flow modeling results using graphical analyses, spatial analyses in GIS, and professional judgment.

The key RAMMS input parameters include topography, friction and turbulence, initial source volume, and rate of erosion.

6.2.1 Topography

Topography is fundamental to evaluating debris flow runout. RAMMS simulates topography in three dimensions using digital elevation models (DEMs). We used DEMs from ground-filtered aerial lidar data available from the Alaska Division of Geological & Geophysical Surveys (available: https://elevation.alaska.gov/). Two lidar surveys are available, which were made in 2014 and 2016.

6.2.2 Friction and Turbulence

The RAMMS model simulates debris as a viscous fluid (Christen and others, 2012). Friction and turbulence control the mobility of the viscous fluid. Friction tends to slow and stop the debris and control lateral spread. Turbulence tends to mobilize the debris and maintain motion of the moving mass. The calibration of these two parameters controls the mapped extent of the runout and debris deposit in the model results.

Our calibrated value for the friction coefficient, *mu*, is 0.23 and for the turbulence term, *xi,* is 200. These values agree closely with published values for debris flows in coastal British Columbia (Hungr and others, 1984).

6.2.3 Initial Source Volume

To evaluate the initial source volume, i.e., volume of a triggering landslide, we reviewed published descriptions of Sitka area landslides and made field observations at several historic debris flow sites, including:

- North Kramer Avenue debris flow (field observations; Exhibit 6-1; Landwehr and others, 2015),
- South Kramer Avenue debris flow (field observations; Exhibit 6-1; Shannon & Wilson, 2016a; Gould and others, 2015; Landwehr and others, 2015),
- Starrigavan Valley landslide (Dunbar, 2015),
- Sitka Cross Trail debris flow deposit (Exhibit 6-2), which is approximately 3,600 feet due north of the Sawmill Creek Road and Indian River Road intersection (this study),
- Gary Paxton Industrial Park (GPIP) debris flow (Shannon & Wilson, 2016b), and
- West Fork Sawmill Creek debris flows on the southeast slopes of Mt. Verstovia (Shannon & Wilson, 2016b).

Exhibit 6-1: Left: North Kramer Avenue Debris Flow; Right: South Kramer Avenue Debris Flow. Both have Steep Initiation and Erosion Zones, Evidence of Multiple Surges and Levees, Extensive Woody Debris and Organics in Colluvial Debris Deposits.

Exhibit 6-2: Left: View South of Stone Debris Flow Deposit Across Sitka Cross Trail to the East of the Study Area (Arrow Indicates Person for Scale). Right: View to East of Same Deposit.

Most of the documented debris flows that occurred in 2015 had triggering landslide volumes between 200 and 4,000 yd^3. These include the North and South Kramer Avenue debris flows and GPIP. Our best estimate of the initial volume of soil in the landslide that triggered the 2015 South Kramer Avenue debris flow is about 2,500 yd^3. This landslide source volume is based on observations by engineers and scientists from the Sitka GeoTask Force (Gould and others, 2015; Landwehr and others, 2015) and our field photographs, field reconnaissance, aerial imagery interpretation, and measurements from lidar. We conclude triggering future landslides on Gavan Hill likely will have similar volumes. As described in Section 5, we use the South Kramer Avenue triggering landslide as the base case for our runout analyses.

In our opinion, larger, less frequent triggering landslides could occur on Gavan Hill. We base our opinion largely on our geomorphic interpretation of the lidar and field observations we made during our reconnaissance on Gavan Hill. A larger landslide occurred in 2014 in the Starrigavan Valley (our observations from Dunbar, 2015; Becker, 2014; Harris, 2014; and satellite imagery interpretation). Based on the reports and aerial photographs, we estimate the triggering volume of the Starrigavan Valley landslide was about 50,000 yd^3. Unlike the landslides and consequent debris flows on Harbor Mountain and Gavan Hill, the Starrigavan Valley landslide was not confined to existing channels but spread across the slopes below. Most of the runout apparently occurred on slopes greater than 75%. If a landslide with similar size occurred on Gavan Hill, we estimate its width would be about 450 feet, which would result in debris entering multiple channels. Therefore, such a large landslide could trigger more than one debris flow.

6.2.4 Erosion Rates

Debris flows typically erode their channels following triggering. Erosion commonly increases the total debris flow volume up to more than four orders of magnitude of the triggering landslide volume. The RAMMS model calculates the depth of erosion in the channel bed and includes that in the volume in the debris flow as it progresses downslope. Erosion can be "turned on or off" in the model, but we keep it on for our calibration and predictive analyses because it would be unusual for a natural debris flow to result in zero erosion and entrainment. The erosion rate is a responsive parameter to calibration.

6.3 Model Calibration

The model should be calibrated to a historic event that has similar expected runout distance and debris volume. The calibrated case should share similar physical landscape conditions as the study area, otherwise the calibration may represent landforms, materials, and processes that do not occur in the study area. In our opinion, the August 18, 2015, South Kramer Avenue debris flow (described in Shannon & Wilson, 2016a) meets these criteria; therefore, we used it as the basis of our calibration of the RAMMS debris flow software.

According to a publicly available soils map and GIS database (Natural Resources Conservation Service, accessed 2018), the soil complexes and parent materials on the southwestern flanks of Harbor Mountain and Gavan Hill are similar in physical landscape conditions and occur as the same map unit (map unit 3248E in Figure 3). These areas of mountainous, natural terrain are shallowly incised mountain backslopes of 75 to 120% slopes; the soils are well-drained, slightly to moderately decomposed plant material and sandy silt with some clay, gravels, and cobbles from parent materials of organics, lithic bedrock, and volcanic ash. In our opinion, the regional and watershed scale topography, geology, geomorphology, and vegetation of Harbor Mountain and Gavan Hill are similar, which satisfies basic criteria for selection of a historic case for calibration.

We used the 2014 and 2016 lidar DEMs for calibration; the 2016 DEM has complete coverage of Sitka, while the 2014 DEM only has partial coverage of Harbor Mountain and Gavan Hill. Although the surveys have differences in the resolution and coverage, we mosaicked the 2014 and 2016 DEMs to approximate the pre-landslide topography for back-analysis of the South Kramer Avenue debris flow. We verified model parameters and inputs using field observations, photographs taken in the days following the 2015 debris flows, a photogrammetry-derived DEM and orthophotograph from August 22, 2015, and lidar topographic change analysis from 2014 and 2016 survey data.

We performed calibration sensitivity analyses including more than 60 iterations of the model to back-analyze the runout of the South Kramer Avenue debris flow runout. This back-analysis uses calibration targets that rely upon field observations and post-event photography.

Our calibration target values included:

- Estimated debris deposition heights,
- Estimated channel erosion depths,
- Mapped distribution of debris deposits, and
- Total event volume.

Our calibration of the South Kramer Avenue debris flow resulted in a set of primary parameters that were held constant across all predictive models, including:

- Friction coefficient, *mu*;
- Turbulence term, *xi*; and
- Erosion rate.

The calibration results are best fit for our purposes. We developed the calibration for the purposes of site-specific hazard and risk analyses, so the results may not be appropriate for uses outside of the scope of our services.

6.4 RAMMS Modeling Assumptions and Limitations

RAMMS cannot model direct inputs for large woody debris dynamics, although we concluded that the numerous mature tree trunks incorporated into the historic debris flows affected their runout behavior. Runout models using numerical and semi-empirical modeling approaches tend to simulate excess lateral spread of the debris deposit that we considered during evaluation of the modeling results. The natural effects of large woody debris on debris flow dynamics and controlling the modeling effects of lateral spread are areas of ongoing academic research (McDougall, 2017).

We evaluated debris flow mobility and runout, but not landslide susceptibility, landslide initiation, landslide frequency, storm frequency, or frequency-magnitude relationships. Therefore, our conclusions do not include constraints on the timing or frequency of debris flow events.

6.5 Predictive Debris Flow Runout Modeling

After calibrating the RAMMS software using the South Kramer Avenue debris flow, we ran more than 50 iterations of predictive scenarios using the calibrated parameters and a range of source volume and erosion/entrainment scenarios. We further focused our predictive debris flow simulation scenarios, especially for debris volumes, using observations from other landslides and debris flows in the area. These observations provide "real-world" context to numerical runout modeling and help better inform our regional understanding of debris flow processes.

Our triggering landslide volumetric scenarios for debris flow runout are:

Scenario No.	Source Volume Class (yd^3)	Minimum Total Flow Volume (yd^3)	Maximum Total Flow Volume (yd^3)
Scenario A (refer to Figure 4)	2,500	2,500	15,000
Scenario B (refer to Figure 5)	15,000	15,000	50,000
Scenario C (refer to Figure 6)	50,000	50,000	90,000

Scenarios A, B, and C (results presented in Figures 4 through 6) use the parameters and inputs developed during the calibration sensitivity analysis of the South Kramer Avenue debris flow event. Scenario A (Figure 4) represents the triggering landslide source volume of the South Kramer Avenue landslide. Scenarios B (Figure 5) and C (Figure 6) represent landslide volumes that were not observed in the August 2015 landslides at Gavan Hill or Harbor Mountain. We justify their use based on the larger Starrigavan Valley landslide. Because the geology and hillslope morphology differ, we consider the Starrigavan Valley landslide scenario unlikely at Gavan Hill. Therefore, we use it as an upper-bound conservative scenario.

We only modeled Scenario A in the relatively planar terrain upslope of the water tank because, in our opinion, the landforms could not form more than about 2,500 yd^3 source volume. We judged Scenarios B and C, modeled upslope of the elementary school, as inappropriate for risk analysis at the water tank.

Scenario C is the upper-bound source volume, which we based on the largest regional event reviewed, the 2014 Starrigavan Valley landslide source area. Additional erosion, entrainment, and bulking of the debris during simulated runout results indicate an upper-boundary total flow volume for Scenario C of about 90,000 yd^3.

Scenario B forms a relatively more severe volumetric scenario than Scenario A and less severe than Scenario C. The basis for a 50,000 yd^3 upper-boundary total flow volume in Scenario B is that this value is the lower-boundary total flow volume for Scenario C.

6.6 Modeling Results

A complete reporting of our modeling results comprises more than 15 gigabytes of digital information, including model set-up files, 100s of GIS maps, and more than 1,000 printed pages of input/output log files. Therefore, including the modeling results in this report is impractical. The files are available in our records, if needed. We analyzed the model results using graphical, GIS, and statistical techniques.

The City requested that ADNR review an earlier draft of this report. This report includes clarifications that consider ADNR's comments (Daanen, 2019).

Figures 4 through 6 present some of our modeling results for Scenarios A, B, and C, respectively. These representative figures show likely debris flow runout paths and hazards. The Maximum Simulated Debris Height shown in the figures represents the maximum depth of debris during all time-steps of the model run at each DEM grid-cell location. We exclude presentation of model results where Maximum Simulated Debris Heights are less than 3 feet to compensate for lateral spread effects of the model. We present Maximum Simulated Debris Heights instead of final deposit height because the final deposit height (height at final model time-step) may be less than the maximum debris height during a debris flow.

RAAMS calculates debris velocity, volume, and pressure. The maximum modeled debris velocity typically occurs in the steep areas just downslope of the simulated source area. For Scenario A, the modeled maximum velocity is about 14 miles per hour (mph). Although these higher velocities indicate significant *hazards*, the greater relative *risks* from debris flows occur closer to Sitka Cross Trail and downslope, where people are more likely to be present and structures exist; maximum debris velocities at and downslope of Sitka Cross trail are less than 6 mph.

In general, our modeling indicates debris flow runout would not reach either school and most of the playing fields for all scenarios. Further, we anticipate our modeling may be conservative because the runout slopes are forested for their entire length, which differs from South Kramer. On lower-gradient slopes where deposition occurs, the presence of forest should attenuate energy and cause more rapid deposition. By contrast, the lower-gradient slope deposition areas at South Kramer had been cleared for development.

At the elementary school, our modeling indicates runout from the upper-bound triggering landslide volume (Scenario C) would end about more than 200 feet upslope from the school buildings and parking lot. Further protection for the school is present because the area toward Gavan Hill is lower than the school parking lot and buildings.

At the recreation fields, our modeling indicates debris flow runout for the base and more conservative cases (Scenarios A and B) would not reach the fields. For the upper-bound conservative case (Scenario C), our modeling indicates debris flow runout could extend about 130 feet into the northeastern corner of the parking and material staging area. Debris could cover up to about 35,000 square feet, to a maximum depth of about 5 feet. Our modeling indicates the maximum velocity of a debris flow near the northeastern corner of the parking area would slow to about 2 mph. The modeled debris flow velocity is slow because (a) the area is at the distal portion of the debris flow, (b) the ground is essentially flat, and (c) the debris flow is not confined, but would spread out over a larger area.

At the water tank, our modeling for the base case (Scenario A) indicates less than 3 feet of debris could reach the water tank. Its maximum velocity at the water tank likely would be about 5.5 mph. For this velocity, we estimate the maximum impact pressure could be about 260 pounds per square foot. Scenario B does not substantially differ from Scenario A. However, the upper-bound conservative Scenario C modeling results indicate the maximum debris depth could be up to 8 feet, the maximum velocity about 10 mph, and the maximum impact pressure about 750 pounds per square foot.

At the high school, our modeling indicates runout from the upper-bound triggering landslide volume (Scenario C) would end about more than 600 feet upslope from the school buildings and parking lot. Further protection for the school is present because the area toward Gavan Hill is lower than the school parking lot and buildings.

Modeling debris flow runout onto private property and public areas other than the two schools, playing fields, and water tank was not included in our scope of services. However, our modeling does show potential debris flow runout onto private properties near the elementary school and over portions of the Sitka Cross Trail.

7 STRUCTURAL STABILITY OF WATER TANK

We engaged Coffman Engineers, Inc. to analyze the effects of debris flow impact loading to the water tank. In our opinion, Scenario C is unlikely to occur in the design life of the tank; therefore, we developed impact load parameters using modeling results from Scenario B (Figure 5). Coffman Engineers analyzed two impact loading cases based on an assumption of two debris flow surges of the same velocity impacting the tank in succession. The parameters for their analyses included information regarding the water tank structure provided by the City and debris impact loading provided by Shannon & Wilson.

The water tank stability analyses included failure modes for sliding, overturning, buckling, and buoyancy of the steel structure in response to debris flow impact loading. Based upon our debris flow runout analyses and Coffman Engineers structural stability assessment, we believe the water tank will remain stable under the impacts of a two successive debris flows modeled in Scenarios A and B.

The water tank structural stability assessment is detailed in Coffman Engineers letter report (Coffman Engineers, 2019) included in Appendix A.

8 CONCLUSIONS

In our opinion, debris flows originating from Gavan Hill pose a negligible risk to the elementary school and the high school. In this discussion, negligible risk means that for the scenarios we evaluated, the debris flow runout should not reach or affect the facilities. Therefore, we do not recommend mitigation measures. Negligible risk is not zero risk because landslide scenarios that do not have relevant, historical examples in the Sitka area and that we did not consider could have longer runout.

As described in the previous section, our modeling indicated debris flow runout could deposit up to 3 feet of debris at the water tank for Scenarios A and B, and up to 8 feet for Scenario C. We believe that the presence of timber through the runout and deposition areas make these scenarios less likely. Further, we consider the upper-bound conservative debris flow Scenario C unlikely; therefore, we do not recommend mitigation measures based on Scenario C. We do not recommend mitigation measures based on Scenarios A or B because the structural stability assessment (Coffman Engineers, 2019; Appendix A) indicates the water tank should withstand the impacts from two successive debris flow surges. We note that Hungr and others (1984) and VanDine (1996) indicate debris flow depths that pose risks typically have flow depths of more than about 3 to 6 feet deep in the deposition area.

Our modeling shows the upper-bound conservative case (Scenario C) could deposit debris over a portion of the parking area for the recreation fields close to the Sitka Cross Trail. We anticipate the risk to the public would be limited to during inclement conditions conducive to debris flow initiation. Potential mitigation measures for this upper-bound conservative case could include closing the areas where Figure 6 shows potential impacts or building a berm along the parking area margins.

As described in the previous section, our modeling does indicate debris flow runout could affect other facilities that were not included in our scope of services. Those property owners may wish to evaluate debris flow risks. We recommend they retain an appropriately experienced and licensed geotechnical engineer and/or geologist to assess the risks indicated by our modeling results.

9 CLOSURE

The conclusions and recommendations in this report are based on a review of published and unpublished data and literature, discussions with other professionals familiar with the landslide, and a visual examination of the surface conditions as they existed during the time of our field reconnaissance. No subsurface explorations were performed for this study. We performed these services using practices consistent with geologic and geotechnical industry standards in the region for slope stability and international practice for debris flow risk assessment; however, prediction of slope movement with absolute certainty is not possible with currently available scientific knowledge or computing technology. As with any steep slope, there are always risks of instability that present and future owners must accept. Such risks include extreme or unusual storm events and forest fire, among others. If conditions described in this report change, we should be advised immediately so that we can review those conditions and reconsider our conclusions and recommendations.

Considering uncertainties encountered in and the level of information available for the debris flow hazard and risk analysis, without landform age, extensive subsurface information, or extensive geomorphological mapping, debris flow runout modeling is particularly useful. However, the runout modeling analysis cannot be relied upon singularly; we use a computer model to simulate a debris flow scenario, and by definition, a model is a simplification of a real-world, physical situation. Other runout models besides RAMMS exist and differences between modeled runout distances and actual distances may occur due to uncertainties and limitations in the modeling environment or differences in software code or design. Computer modeling is a supplement for geologic judgment and experience.

This report was prepared for the exclusive use of the City to evaluate debris flow hazards to the facilities described herein. This report is not suitable for evaluating debris flow hazards to other properties.

Within the limitations of scope, schedule, and budget, the analyses, conclusions, and recommendations presented in this report were prepared in accordance with generally accepted professional geotechnical engineering principles and practice in this area at the time this report was prepared. We make no other warranty, either express or implied. These conclusions and recommendations were based on our understanding of the project as described in this report and the site conditions as observed at the time of our reconnaissance.

Shannon & Wilson has included the enclosed, “Important Information About Your Geotechnical/Environmental Report,” to assist you and others in understanding the use and limitations of our reports.

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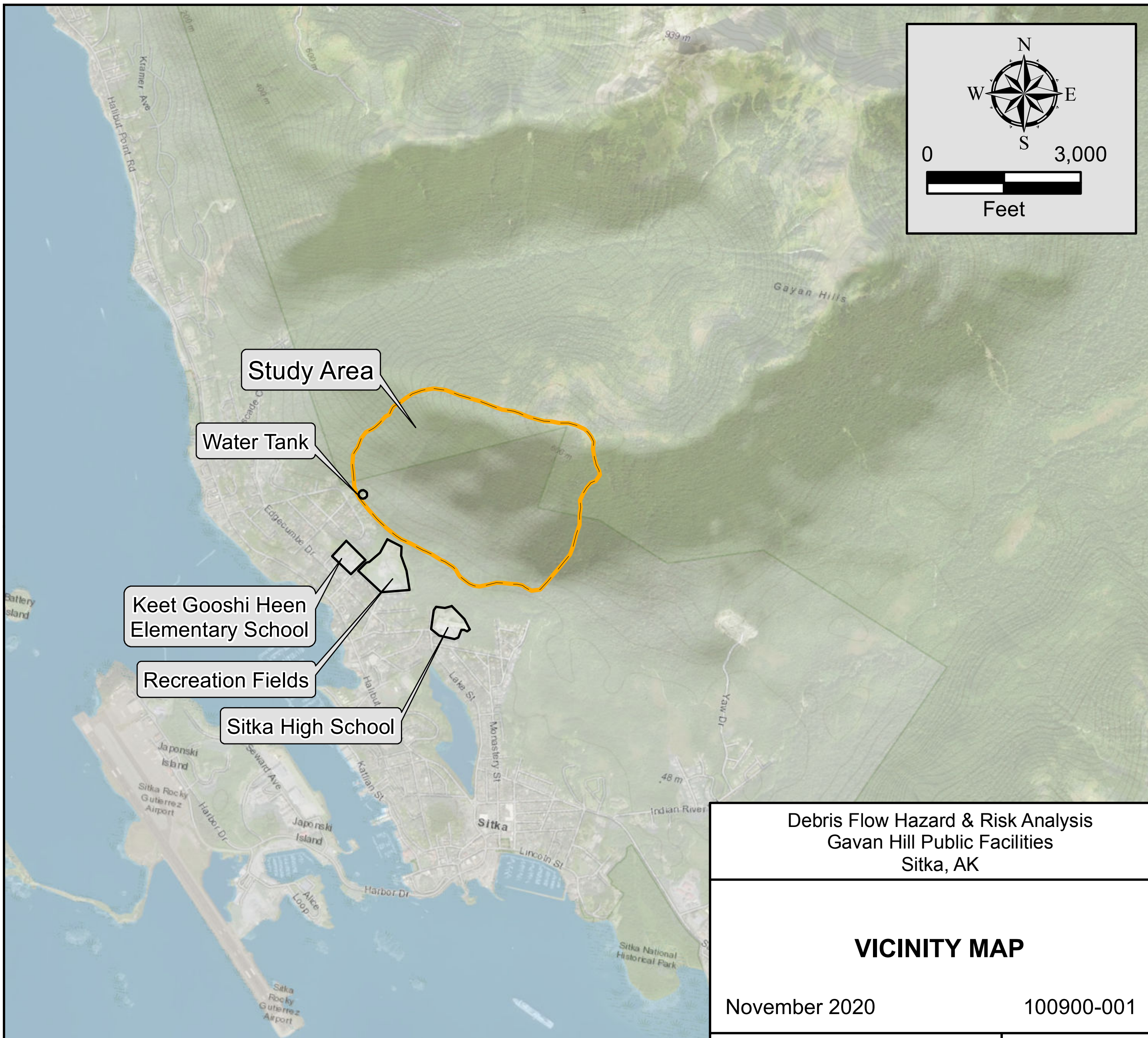

Debris Flow Hazard & Risk Analysis
Gavan Hill Public Facilities
Sitka, AK

VICINITY MAP

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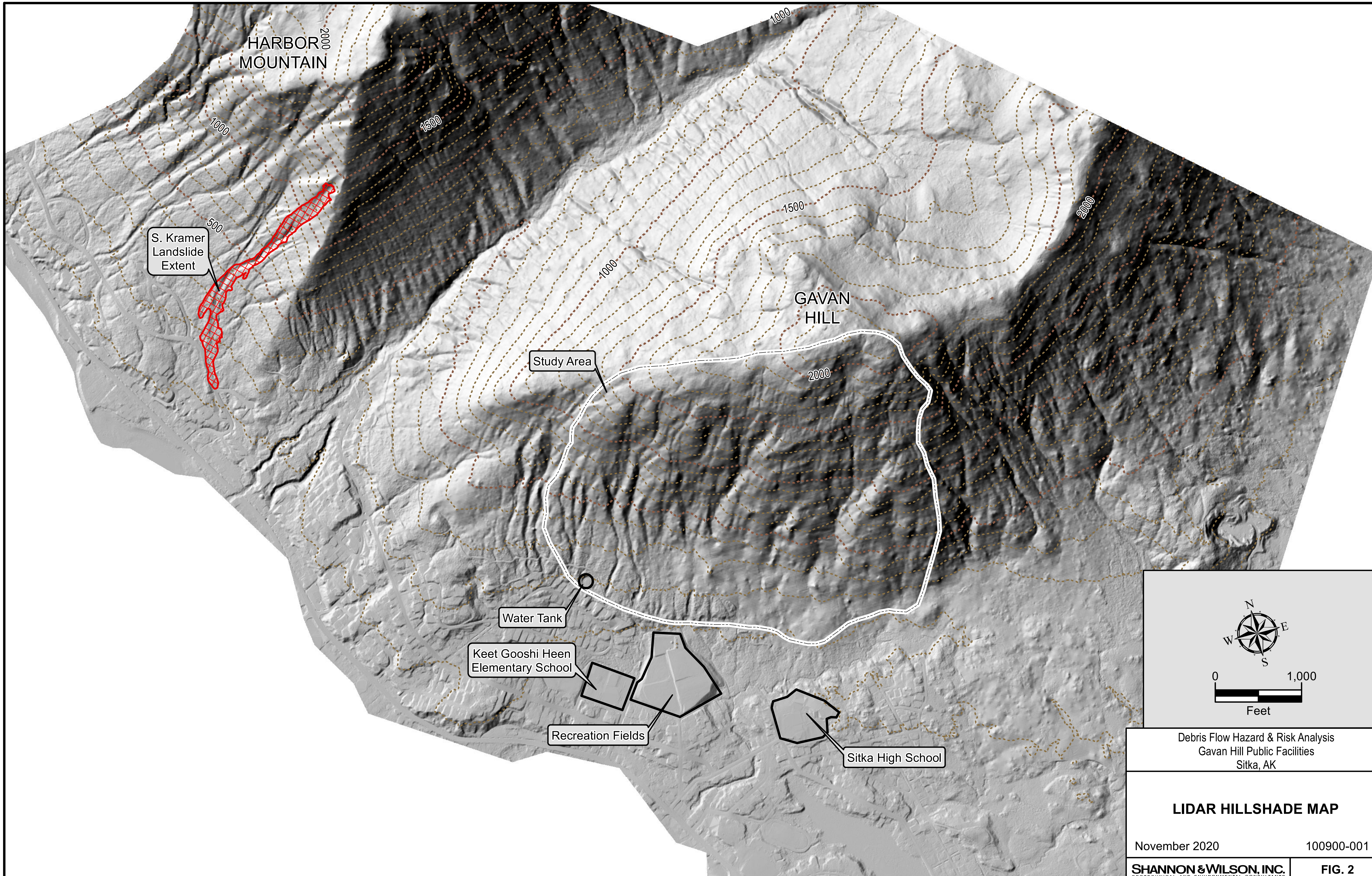
FIG. 1



Debris Flow Hazard & Risk Analysis
Gavan Hill Public Facilities
Sitka, AK

LIDAR HILLSHADE MAP

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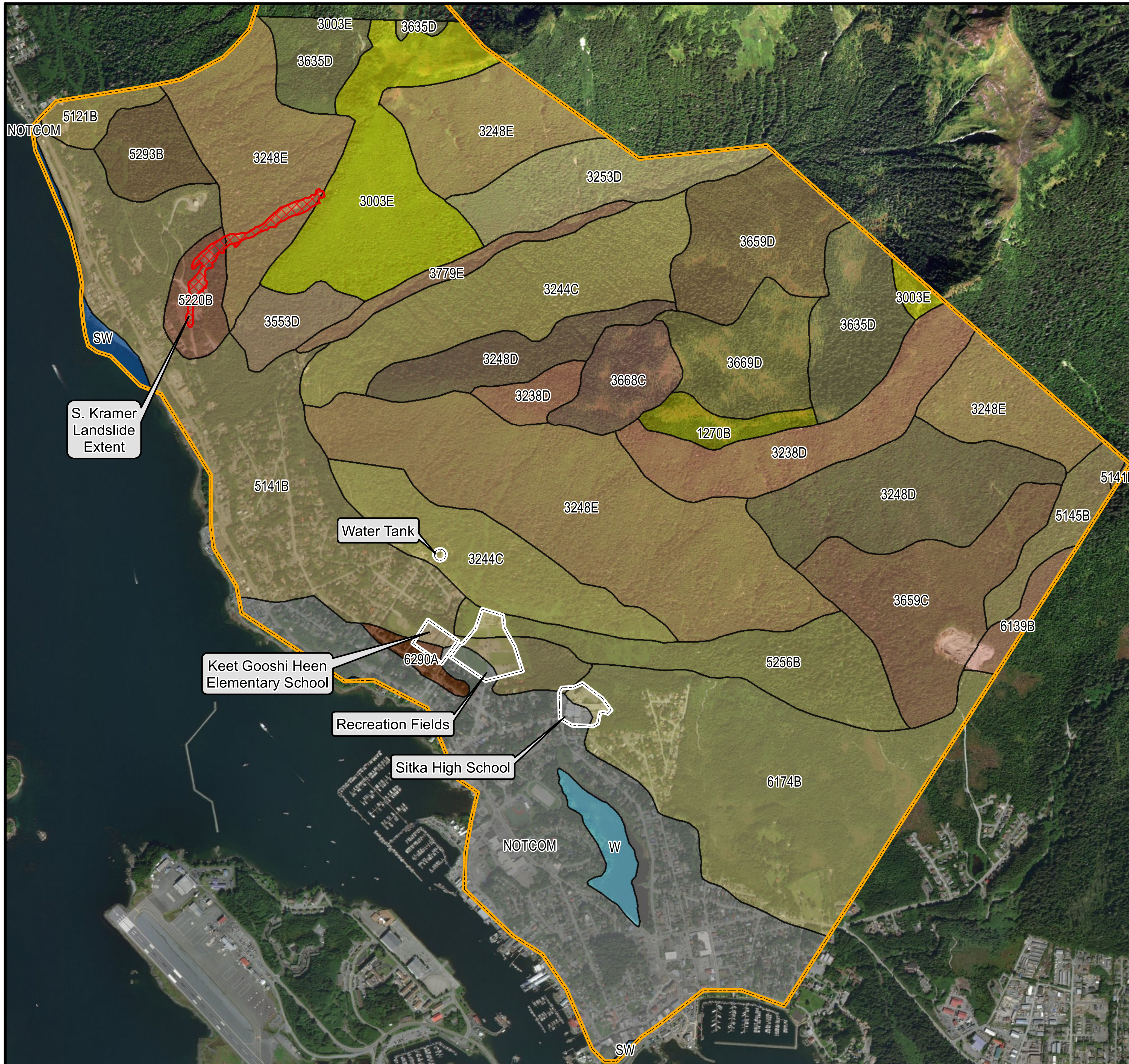
FIG. 2



LEGEND

Soil Unit
National Resource Conservation Service
(NRCS) Soil Survey

- 1270B - Tolstoi and Kaikli soils, subalpine, 6 to 35 percent slopes
- 3003E - TTolstoi and Kaikli soils, alpine, 76 to 120 percent slopes
- 3238D - Tolstoi, Kupreanof, and Peril soils, subalpine, shallowly incised 56 to 75 percent slopes
- 3244C - Partofshikof silt loam, shallowly incised, 36 to 55 percent slopes
- 3248D - Verstovia-McGilvery complex, shallowly incised, 56 to 75 percent slopes
- 3248E - Verstovia-McGilvery complex, shallowly incised, 76 to 120 percent slopes
- 3253D - Sitka-Partofshikof complex, shallowly incised, 56 to 75 percent slopes
- 3553D - Sitka-Partofshikof complex, smooth, 56 to 75 percent slopes
- 3635D - Sitka and Partofshikof soils, subalpine, 56 to 75 percent slopes
- 3659C - Partofshikof-Sukoi complex, 36 to 55 percent slopes
- 3659D - Partofshikof-Sukoi complex, broken, 56 to 75 percent slopes
- 3668C - Sukoi, Kaikli, and Verstovia soils, subalpine, 36 to 55 percent slopes
- 3669D - Verstovia and Sitka soils, subalpine, 56 to 75 percent slopes
- 3779E - Entic Cryumbrepts, McGilvery, and Rock outcrop soils, ravines, 76 to 140 percent slopes
- 5121B - Kupreanof gravelly silt loam, 6 to 35 percent slopes
- 5141B - Kasiana-Kushneahin complex, footslopes, 6 to 35 percent slopes
- 5145B - Mitkof loam, footslopes, 6 to 35 percent slopes
- 5220B - Kupreanof-Tuxekan complex, 6 to 35 percent slopes
- 5256B - Kupreanof-Tuxekan-Mitkof complex, 6 to 35 percent slopes
- 5293B - Baranof-Mitkof complex, 6 to 35 percent slopes
- 6139B -Sukoi silt loam, sloping lowlands, 6 to 35 percent slopes
- 6174B - Kina-Kasiana association, sloping lowlands, 6 to 35 percent slopes
- 6290A - Kina peat, 0 to 5 percent slopes
- NOTCOM -No Digital Data Available
- SW -Water, Saline
- W - Water

N
W E
S

0 1,500 3,000
Feet

Debris Flow Hazard & Risk Analysis
Gavan Hill Public Facilities
Sitka, AK

NRCS SOIL SURVEY UNITS

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FIG. 3

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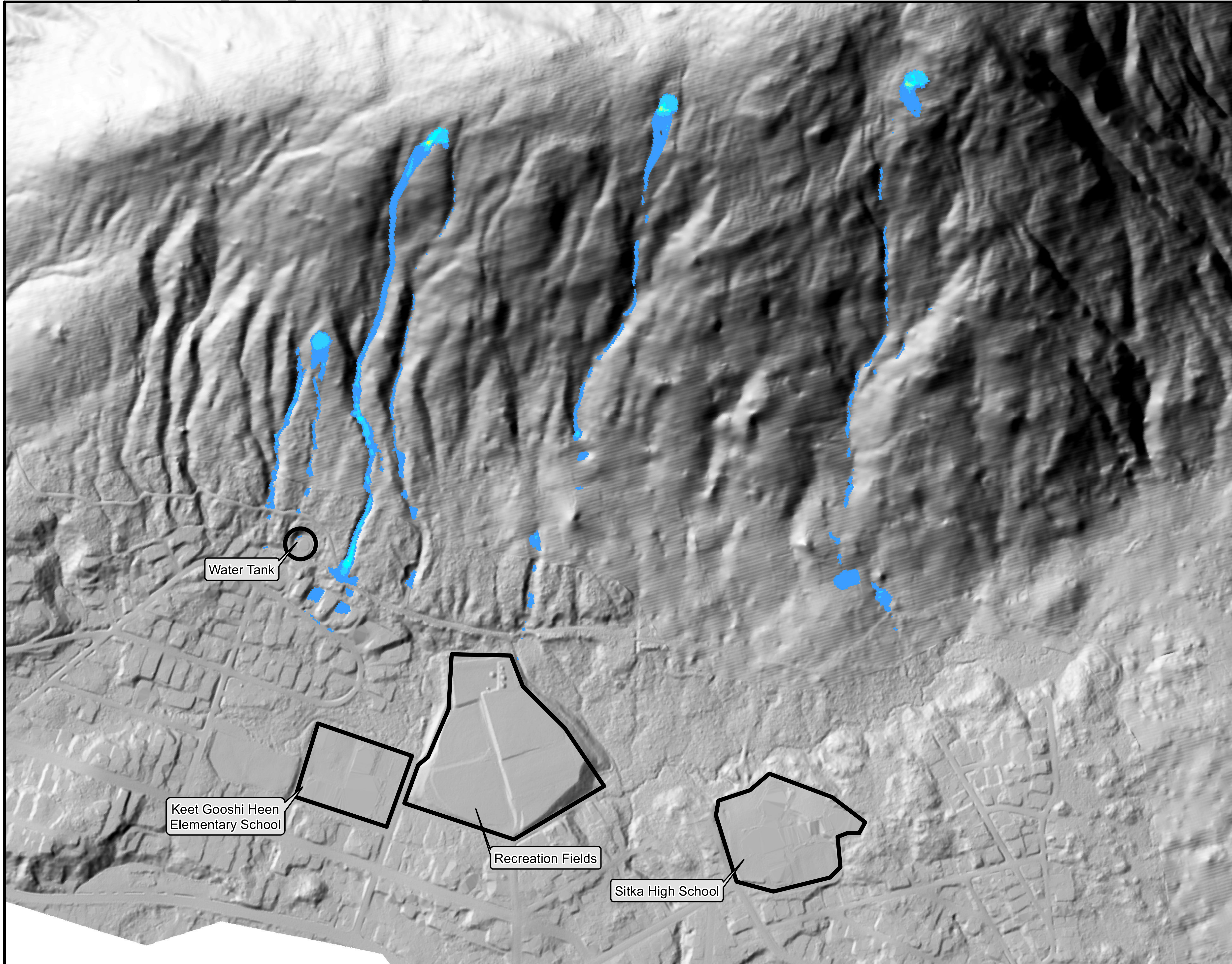

LEGEND

Maximum Simulated Debris Height (ft)

- 3.0 - 6.5
- 6.5 - 10
- 10 - 13.5
- 13.5 - 17.0
- 17.0 - 20.5
- 20.5 - 24.0
- 24.0 - 27.5
- 27.5 - 31.0
- 31.0 - 34.5
- 34.5 - 38.0
- 38.0 - 41.5
- 41.5 - 45.0
- 45 - 48.5

NOTES
1. Scenario A: Volumetric Class 2,500 to 15,000 yd^3
2. Parameters for rheology and erosion from calibration for South Kramer Avenue Debris Flow

N E S W

0 500

Feet

Debris Flow Hazard & Risk Analysis
Gavan Hill Public Facilities
Sitka, AK

DEBRIS FLOW RUNOUT RISK ZONATION MAP SCENARIO A

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FIG. 4

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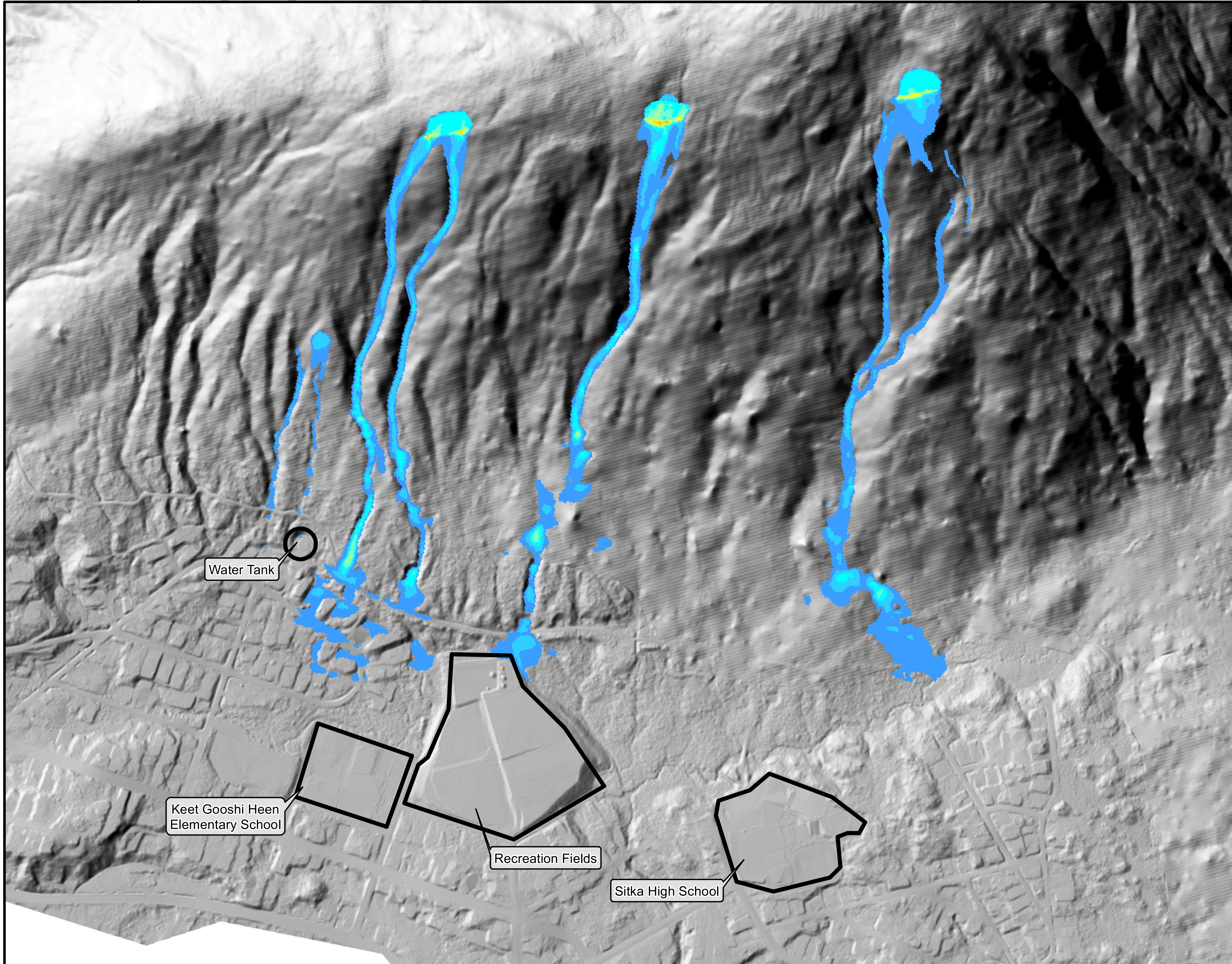

NOTES
1. Scenario B: Volumetric Class 15,001 to 50,000 yd^3
2. Parameters for rheology and erosion from calibration for South Kramer Avenue Debris Flow

Debris Flow Hazard & Risk Analysis
Gavan Hill Public Facilities
Sitka, AK

DEBRIS FLOW RUNOUT RISK ZONATION MAP SCENARIO B

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FIG. 5

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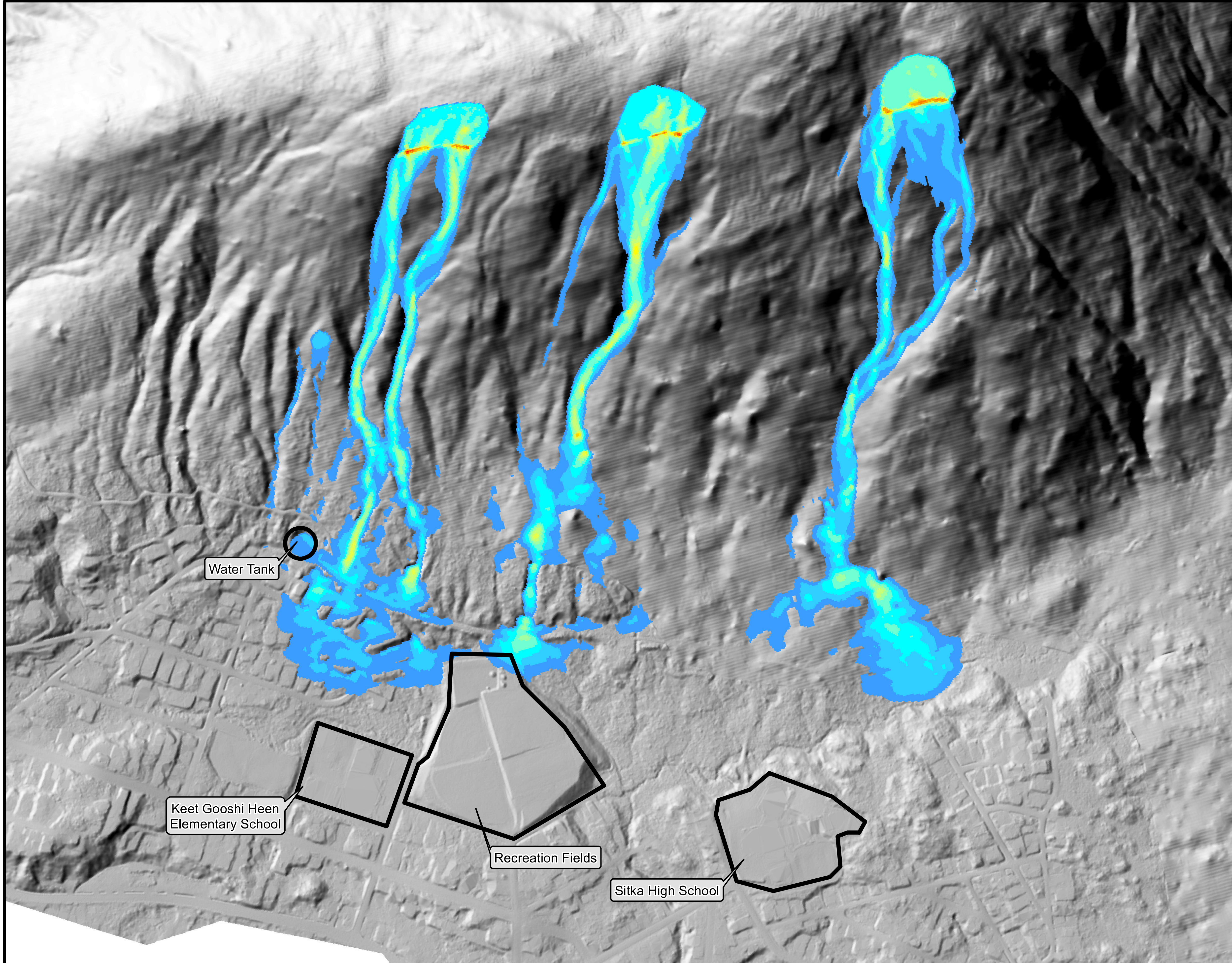

LEGEND

Maximum Simulated Debris Height (ft)

- 3.0 - 6.5
- 6.5 - 10
- 10 - 13.5
- 13.5 - 17.0
- 17.0 - 20.5
- 20.5 - 24.0
- 24.0 - 27.5
- 27.5 - 31.0
- 31.0 - 34.5
- 34.5 - 38.0
- 38.0 - 41.5
- 41.5 - 45.0
- 45 - 48.5

NOTES
1. Scenario B: Volumetric Class 50,000 to 90,000 yd^3
2. Parameters for rheology and erosion from calibration for South Kramer Avenue Debris Flow

N E S W

0 500
Feet

Debris Flow Hazard & Risk Analysis
Gavan Hill Public Facilities
Sitka, AK

DEBRIS FLOW RUNOUT RISK ZONATION MAP SCENARIO C

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FIG. 6

APPENDIX A: STRUCTURAL STABILITY ASSESSMENT OF WATER TANK

Appendix A

Structural Stability Assessment of Water Tank

COFFMAN ENGINEERS

April 13, 2019

Bob Sas, L.G., Senior Geologist
Shannon & Wilson, Inc.
400 N 34th Street, Suite 100
Seattle, WA 98103

Project: Sitka Water Tank Structural Assessment for Debris Flow (Rev 1)

Dear Mr. Sas:

Coffman Engineers has accomplished a structural evaluation of the existing water storage tank under loading from a debris flow. Checks include stability for sliding, overturning, shell stability, local shell buckling, and buoyancy.

The tank is evaluated based on the assumption the water depth in the tank will be maintained at 32 feet. The evaluation results indicate the existing tank is stable under the predicted external loading from the debris flow.

An evaluation for minimum allowable water depth to maintain stability in a debris flow event was also performed. That evaluation results in a recommended minimum allowable water depth in the tank of 20 feet to maintain stability.

The greater the water depth in the tank the more stable the tank is for resisting the external loading. If the tank were empty at the time of the event it would likely be displaced laterally.

Existing Tank Data

The existing water storage tank is a welded steel vertical cone roof tank with a flat bottom. The tank is 70 feet diameter with a shell height of 42 feet. The tank is founded on gravel fill. Original drawings for the tank do not indicate shell, floor, or roof plate thickness or material specifications. The Owner provided a summary of field measured shell thicknesses[1]. The roof and floor thicknesses were assumed based on similar tank designs. Material was assumed to have a yield strength of 30,000 psi. The thicknesses of the roof, shell, and floor used in the evaluation are summarized in Table 1.

Component	Location	Thickness	Height	Source
Roof	All	0.3125”		Assumed
Shell	Course 1 (top)	0.30”	6’	Owner measured
	Course 2	0.31”	6’	Owner measured
	Course 3	0.36”	6’	Owner measured
	Course 4	0.50”	8’	Owner measured
	Course 5	0.55”	8’	Owner measured
	Course 6 (bottom)	0.67”	8’	Owner measured
Floor	All	0.3125”		Assumed

Table 1 – Tank Thicknesses

Tank External Loading Data
The evaluation accomplished is for estimated horizontal pressure loads occurring from a debris flow impinging on the shell on one side of the tank. The loading profile and load magnitudes were provided by Shannon & Wilson (S&W)[2]. Two loading cases are evaluated.

For the first case, the tank loading is in the form of equivalent static pressure from two surges of debris flow acting horizontally on the shell. S&W's evaluation indicated the pressure load would be 320 psf at the bottom of the shell (tank floor), linearly declining to 120 psf at 5 feet above the tank floor, and a constant 260 psf from 5 feet to 8 feet above the tank floor.

For the second case, the tank loading is in the form of a hydrodynamic load based on the density and speed of the debris flow, with an added hydrostatic load based on the depth of the debris flow, converted to an equivalent static pressure acting horizontally on the shell. The pressure load would be 812 psf at the bottom of the shell, linearly declining to 168 psf at 5.2 feet above the tank floor.

For both loading cases, when evaluating overall stability of the tank for sliding and overturning, the pressure loads provided are applied as a load on the projected area of the tank, uniformly applied across the 70 feet width (diameter). This is consistent with the way external horizontal loads are applied to tanks in codes and industry standards. The evaluation did not modify the loading based on the angle of application, which declines toward the edges of the tank due to curvature of the shell.

The debris flow load is considered a unique load case, and not combined with any other lateral load cases (wind or seismic).

Evaluation Details
The evaluation considers sliding stability, overturning stability, local shell stability, shell buckling, and buoyancy stability from the debris runout loading.

Sliding Stability
The tank was evaluated for resistance to lateral displacement (sliding) from the horizontal loading. Since the tank is not anchored to the foundation, sliding resistance is provided by static friction between the tank floor and the soil foundation. Coefficients of static friction for determining sliding stability vary based on tank design standards, with AWWA D100[3] recommending 0.58 maximum (tan30) and API 650[4] recommending 0.40 maximum.

With the water level at 32 feet, the coefficient of friction needed to prevent sliding was found to be 0.023, which is less than 0.40, so the tank is considered to be stable for sliding.

Overturning Stability
The tank was evaluated for overturning stability to determine if the pressure on the shell would lift the leading edge of the floor off the foundation. The lateral load from the debris flow is applied to the shell above the floor, which results is an overturning moment occurs on the tank. The overturning moment is resisted by the gravity loading on the shell and a portion of the floor adjacent to the shell. The tank is considered stable[5] if the overturning ratio is less than 0.785.

With the water level at 32 feet, the overturning ratio was found to be 0.03, which is less than 0.785, so the tank is considered to be stable for overturning.

Shell Stability
The water inside the tank results in a triangular outward radial load on the shell, starting at 0 psf at the water surface and reaching 1,996 psf at the floor to shell joint with a 32 feet water depth. At 8 feet above the floor the radial load is 1,497 psf; at 5 feet above the floor the radial load is 1,684 psf.

Considering the maximum external load on the tank shell is 812 psf, which is less than the corresponding 1,996 psf internal horizontal load, the shell will not be subject to any stress reversal. The tank shell remains in a state of positive hoop stress, which results in stability.

Local Shell Buckling
Procedures for evaluating shell buckling due to external loads are provided in API 650[6]. The procedures assume an empty tank, without the effect of the contents pushing outward on the shell to offset the inward loading. Based on the assumed minimum 32 feet water depth in the tank, the external load is not large enough to overcome the internal load, so buckling is not expected to be a plausible failure mode.

The tank shell was evaluated for buckling ignoring the internal contents. The evaluation indicates the shell thickness of the bottom course is thick enough to prevent local buckling.

A comparison of shear and moment in a vertical strip of shell was also accomplished to compare the calculated maximum external pressure for the entire shell with the localized loading (lower 8 feet of shell) from the debris flow load. The evaluation shows the shear to be slightly larger for the debris flow load case, but well within the allowable shear capacity for the shell and shell to floor weld. The moment was found to be smaller for the debris flow load.

Buoyancy
The effect of buoyancy on the tank is neglected in the sliding resistance evaluation as the initial shell loading will be prior to the debris flow surrounding the tank. After the flow occurs, the tank would have a buoyancy load (uplift) assuming the flow has free water. However, the tank will have 32 feet of internal hydrostatic head and up to 8 feet of external hydrostatic head, for a net of 24 feet of internal, so it will not float.

Minimum Allowable Water Depth
An additional evaluation is accomplished for determining a minimum allowable water depth. The evaluation indicates the minimum water depth is controlled by shell stability. The depth of water that would result in a neutral shell stress (internal pressure equals external pressure) is 13 feet. Due to variables in the determination and application of the external pressure, we recommend a water depth that has a high likelihood of maintaining a greater internal pressure than external pressure, or a positive hoop stress in the shell. We recommend applying a 1.5 factor to the equilibrium water depth of 13 feet, for a minimum allowable water depth of 20 feet.

The 20 minimum depth also provides for stability for sliding, overturning, and buoyancy.

Assumptions

- The evaluation does not predict resistance to puncture loads or concentrated loads within the debris flow such as logs or boulders. The thickness of the lower course of shell is 0.67 inches, so would have significant resistance against small concentrated loads.
- The evaluation is based on the debris flow load not occurring simultaneously with other lateral load events. Although the debris flow load is a type of earth load, and ASCE 7 indicates that earth loads should be combined with other loads[7], the ASCE 7 earth load type is for a constant load (eg for a retaining wall). The debris flow load is considered to be an abnormal loading event, so combining with wind or seismic is not appropriate.

Please contact us if there are questions or if additional information is needed.

Sincerely,

COFFMAN ENGINEERS, INC.

Will Veelman, P.E., S.E.
Principal, Structural Engineering

STATE OF ALASKA 49TH WILL VEELMAN No.SE14016 REGISTERED PROFESSIONAL ENGINEER

References:

1. Longtin, David; "RE: Draft Geotechnical Report- Water Tank Hazard and Risk Analysis - information request"; Message to Bob Sas; February 7, 2019; email
2. Bob Sas; "RE: Draft Geotechnical Report- Water Tank Hazard and Risk Analysis - information request"; Message to Brian Dow; February 13, 2019; email
3. American Water Works Association (AWWA) D100-11, Welded Carbon Steel Tanks for Water Storage, 2011, paragraph 13.5.4.6
4. American Petroleum Institute (API) 650, Welded Tanks for Oil Storage, Twelfth Edition Addendum 1, paragraph 5.11.4
5. American Water Works Association (AWWA) D100-11, Welded Carbon Steel Tanks for Water Storage, 2011, paragraph 13.5.4.1
6. American Petroleum Institute (API) 650, Welded Tanks for Oil Storage, Twelfth Edition Addendum 1, Annex V
7. American Society of Civil Engineers (ASCE) 7-10, Minimum Design Loads for Buildings and Other Structures, Chapter 2

IMPORTANT INFORMATION

Important Information

About Your Geotechnical/Environmental Report

IMPORTANT INFORMATION

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

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

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

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

SUBSURFACE CONDITIONS CAN CHANGE.

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

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

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

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

IMPORTANT INFORMATION

your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

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

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

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

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

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

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

READ RESPONSIBILITY CLAUSES CLOSELY.

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

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