Statewide Threat Assessment: Identification of Threats from Erosion, Flooding, and Thawing Permafrost in Remote Alaska Communities

Report Prepared for the Denali Commission

By

University of Alaska Fairbanks Institute of Northern Engineering

U.S. Army Corps of Engineers Alaska District

U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory

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Executive Overview

The goals of this study were to 1) assess individual threats to public infrastructure associated with erosion, flooding, and thawing permafrost in Alaska communities; 2) evaluate the combined threat imposed by interactions between erosion, flooding, and thawing permafrost in Alaska communities; and 3) provide guidance to decision makers regarding the technical information required to develop mitigation or adaptation strategies related to those threats.

The study was carried out by three entities working closely with the Denali Commission. The US Army Corps of Engineers Alaska District (USACE) was responsible for evaluating threats from flooding and erosion. The new work carried out by USACE focused primarily upon flooding, because erosion was considered extensively in the Baseline Erosion Assessment (USACE 2009) for 134 communities that were also evaluated for this study. The University of Alaska Fairbanks (UAF) Institute of Northern Engineering and the USACE Engineer Research and Development Center Cold Regions Research and Engineering Laboratory (CRREL) were responsible for evaluating the risk from thawing permafrost, as well as integrating the combined threats from erosion, flooding, and thawing permafrost into an overall score.

Data collection focused entirely on publicly available data and data volunteered by agencies or the private sector. No communities were visited, nor was any effort made to validate the data beyond a review by the study team for consistency and reasonableness. It is recognized that the amount and reliability of the data varies among the communities.

Chapters 1, 2, and 3 of this report provide information related to the scope, previous efforts, and general characteristics of the individual and combined threats, respectively. Chapter 4 describes the methodology developed and employed by the study team to attribute numerical scores to erosion, flooding, and permafrost threats across 187 rural Alaska communities. Tabulated results are provided in Appendix A.

Chapter 5 provides the summarized results of the study. The numerical results of the individual threat evaluations are grouped according to relative threat (1 = high, 2=medium, 3= low) and presented in distribution plots and maps. The groupings were developed based upon the distribution of normalized data. As described in the results, 29 communities were placed in Group 1 for erosion, 38 communities were placed in the Group 1 for flooding, and 35 communities were placed in the Group 1 for thawing permafrost. The estimated level of uncertainty for the individual threats are also presented in the results section, emphasizing that the rankings should be interpreted as a guideline rather than an inflexible list of relative threat levels. In addition, Chapter 5 presents the combined threat ranking in a distribution plot and map. As the interrelated processes between flooding, erosion, and thawing permafrost are not only themselves uncertain, but also site-specific, the study team opted against placing communities into groups of relative threat based on the combined ranking. The rankings for individual threats in each community studied are presented in Appendix A.

Chapter 6 presents the study conclusions and recommendations. In most instances, development of specific mitigation and adaptation strategies for public infrastructure in individual communities requires the collection of additional data. In Chapter 6, a generalized list of data recommendations and requirements is presented according to threat in order to guide site-specific studies.

The rankings and groupings developed under this study are intended to be used to identify those communities requiring additional investigation. However, the threat levels alone are insufficient to determine an appropriate course of action in any given community. It is intended that decision makers will utilize the estimated threat levels presented in Chapter 5, the data requirements in Chapter 6, and a substantial amount of professional judgment to allocate resources necessary to conduct more in-depth investigations and/or mitigation projects in individual communities.

Data used to develop this report as well as analytical spreadsheets have been provided to the Denali Commission. A web page has been established on the Institute of Northern Engineering website providing the public with maps and other pertinent information related to this study (http://ine.uaf.edu/projects/statewide-threat-assessment/). The website is designed such that users can access, download, and view summarized project results using widely available free software.

A more detailed database of geospatial information collected during this study will be made available for download from the UAF Scenarios Network for Alaska + Arctic Planning (SNAP) database Arctic Data Collaborative. The database was created to catalog information used to assess erosion, flood, and permafrost hazards and to present the results of the process. Final rankings for each community for the three individual hazards, a time factor, and a combined score are included. This database summarizes the information used to derive scores for each hazard, as well as provides an appropriate spatial framework for more detailed analysis by others in the future.

The information provided in this report represents a snapshot in time. The report represents an effort to provide guidance to planners and decision makers regarding the relative threat to Alaska rural infrastructure based upon readily available information collected primarily during or before February 2018. However, the evaluation techniques, as well as the data collected, are intended to be incorporated into ongoing and future efforts to understand and mitigate threats to Alaska’s rural infrastructure and communities. It is recommended that stakeholder agencies build upon the information presented in this report, and collaborate to develop advanced data hosting, design, and decision support tools intended to foster a unified approach to mitigating Alaska’s infrastructure challenges.

Chapter 1.0 Introduction and Scope

Communities throughout Alaska are facing threats to infrastructure imposed by erosion, flooding, and thawing permafrost. In many instances, the impacts of erosion, flooding, and thawing permafrost amplify one another to form a combined threat known as usteq. The Alaska Statewide Hazard Mitigation Plan utilized the Yupik word "usteq" to describe the compounding effects of such threats (ADHS&EM, 2018). Usteq roughly translates as "surface caves in," and is defined in the Statewide Hazard Mitigation Plan as "a catastrophic form of permafrost thaw collapse that occurs when frozen ground disintegrates under the compounding influences of thawing permafrost, flooding, and erosion." Thus, the term usteq is intended to characterize complex interactions that occur when erosion and flooding are combined with thawing permafrost.

A lack of long-term spatially or temporally discrete monitoring throughout Alaska challenges the ability of engineers, scientists, and planners to study and address the level of threat from erosion, flooding, thawing permafrost, and usteq. For many Alaska communities, the only information available to determine potential damage from these threats is found in historic records and disaster declarations or determined from anecdotal information or physical evidence. The purpose of this study is to help identify communities that may be facing such threats based upon existing data, and to recommend further data collection efforts intended to provide information necessary for assessing threats and responding to them.

The State of Alaska Immediate Action Workgroup, in 2009, recommended that a methodology be developed for prioritizing need based on risk to infrastructure from environmental threats including erosion, flooding and thawing permafrost. (Immediate Action Work Group, 2009) In response to this recommendation as well as ongoing concerns statewide, the Denali Commission organized a 2016 charrette drawing in experts from government, academia and the private sector. The charrette participants confirmed that data gaps did exist, and that a methodology for prioritizing and evaluating data needs was indeed required.

Following the charrette, the Denali Commission contracted with the US Army Corps of Engineers Alaska District (USACE), the University of Alaska Fairbanks (UAF) Institute of Northern Engineering, and the USACE Research Engineering and Development Center Cold Regions Research and Engineering Laboratory (CRREL) to collaborate in a study designed to provide guidance to Alaska decision makers regarding threats to public infrastructure. USACE was selected due to their historic and ongoing work addressing erosion and flooding hazards throughout the state, including the development of a 2009 Alaska Baseline Erosion Assessment (U.S. Army Corps of Engineers, 2009). UAF and CRREL were selected based upon their expertise in permafrost impacts to infrastructure. Critical public infrastructure was taken to include, but not limited to, schools, clinics, government buildings, sanitary sewer systems (i.e., sewage lagoons), freshwater sources, airstrips, fuel tanks, and primary roads. While the study was focused on public infrastructure, it was also recognized that the impacts of these threats on housing, the environment, and culturally significant locations are also of concern to communities.

The original list of communities under study included 211 rural Alaska communities provided to the study team by the Denali Commission. The Denali Commission list did not include Alaska's larger, more urban communities because the study was designed to address data gaps in remote locations with fewer data available and limited resources for data collection. Based on preliminary evaluations of the communities, the study team determined that 24 of the communities in the original list were either uninhabited or were subsistence camps that did not have a permanent population and no public infrastructure. Thus, the study evaluated 187 of Alaska's communities. In some cases, a single place included in this study represents multiple tribal entities residing in a common townsite. For example, the community of Kotlik consists of 3 village councils: Kotlik Tribal Council, Bill Moore's Slough, and Hamilton Tribal Council.

The study team began its work by evaluating previous efforts to determine the level of risk to communities due to erosion and flooding. In 2003, the U.S. Government Accountability Office (GAO) reported that 86% of Alaska Native communities are in some way threatened by erosion and flooding (U.S. Government Accountability Office, 2003). Nine communities were evaluated in the 2003 study and four—Kivalina, Koyukuk, Newtok, and Shishmaref— were deemed in imminent danger. In 2009, an updated GAO report evaluated 31 communities facing imminent threat from erosion and flooding, of which 12 are exploring relocation options (U.S. Government Accountability Office, 2009). In the 2009 Alaska Baseline Erosion Assessment (BEA), the U.S. Army Corps of Engineers identified 178 communities that have reported erosion problems (U.S. Army Corps of Engineers, 2009). Of these 178 communities, 26 were declared "Priority Action Communities," indicating that they should be considered for immediate action by either initiating an evaluation of potential solutions or continuing with ongoing efforts to manage erosion.

In addition to their review of previous flood and erosion publications, the study team also evaluated existing reports regarding the relative threats to Alaska infrastructure imposed by thawing permafrost. Two particularly relevant studies included *Thaw Settlement Hazard of Permafrost Related to Climate in Alaska* (Hong, Perkins, & Trainor, 2014) and *Climate Change Damages to Alaska Public infrastructure and the Economics of Proactive Adaptation* (Melvin, et al., 2016), both of which sought to describe the impacts to infrastructure imposed by thawing permafrost using a thawing settlement index which is a function of climate and ice content of the permafrost statewide. However, since the threat of thawing permafrost is highly dependent upon the characteristics and spatial distribution of permafrost immediately adjacent to the infrastructure in question, the prior statewide analyses did not have sufficient spatial resolution to provide direct measures of permafrost threat on a community-by-community basis. We know of no other previous efforts in Alaska to qualitatively or quantitatively determine the threat to individual community infrastructure statewide posed by thawing permafrost.

Following evaluation of existing data (further described in Chapter 2), the study team collaborated with Denali Commission to develop evaluation methodologies, collect existing data, evaluate the individual and combined threats, and assemble this resulting report. The threats of erosion, flooding, and thawing permafrost were assessed in the 187 communities using only readily available data. Community site inspections were not included in the study's scope of work, and no data sets were sought except those in the public domain or those that were volunteered. The data considered in this report focused upon events or information available as of February 2018. Uncertainty of community ratings vary based on available data.

This study does not provide specific recommendations for risk reduction strategies or identify funding for communities facing erosion, flooding, or thawing permafrost threats. Rather, the focus was to identify the most vulnerable communities so community members, policy makers, and government agencies can make better-informed decisions. Anticipated actions based upon this report include collection of site-specific data pertinent to the threat(s), as recommended in Chapter 6.

To facilitate future work, all data collected in this study have been provided to the Denali Commission. A project overview including summarized results and downloadable KMZmap files is available on the UAF Institute of Northern Engineering website (http://ine.uaf.edu/projects/statewide-threat-assessment/). In addition, a database of project geospatial information will be available at the Arctic Data Collaborative, hosted by the UAF Scenarios Network for Alaska + Arctic Planning. The database was originally developed as the Alaska Hydrologic Hazard Database and included georeferenced data on riverine (rainfall, break-up/ice-jam, glacial outburst) and coastal flooding (storm surge and wave) events for communities in the State of Alaska. A relational database structure linking data sources to communities was used to facilitate intuitive data discovery, allowing users to query data using community locations as the main parameter. The structure also tied event-based flood data developed by the National Weather Service to specific communities. The project added additional data on permafrost including community-specific information on massive ice, thaw susceptibility and permafrost occurrence and temperature. Intermediate results for each hazard were added for flooding, erosion, and permafrost that relate categories including commercial infrastructure and housing distribution. Final rankings for each community for the three individual hazards, a time factor, and a combined score are included. This database summarizes the information used to derive scores for each hazard, as well as provides an appropriate spatial framework for more detailed analysis by others in the future.

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Chapter 2.0 Background

Eight sources provided a wealth of information concerning prior efforts to identify Alaska communities threatened by erosion, flooding, and thawing permafrost.

2.1 Alaska Native Villages Report – 2003

In its 2003 report, "Alaska Native Villages: Most Are Affected by Flooding and Erosion, But Few Qualify for Federal Assistance," the GAO noted that erosion and flooding, in some way, affect 86% of 213 Alaska Native communities, as evidenced by the 190 disaster emergencies recorded between 1977 and 2003. The GAO added that, while the problems are long-standing, they have not been addressed because these communities do not qualify for assistance under programs administered by USACE and the Natural Resources Conservation Service. Largely, the communities do not qualify because the projects cannot be justified based on an economic cost benefit analysis. Even if communities do meet this economic cost benefit requirement, they can find it challenging to meet the cost-share requirements.

The GAO was directed to review nine communities, of which four—Kivalina, Koyukuk, Newtok, and Shishmaref—were in imminent danger from erosion and flooding. At that time, these four communities were planning to relocate even as agencies were investing in infrastructure at their present locations.

The GAO recommended three alternatives that, separately or in combination, would have a significant impact on communities threatened by erosion or flooding:

- Expand the role of the Denali Commission to include responsibility for managing an erosion and flooding assistance program, which the commission currently does not have.
- Direct USACE and the Natural Resources Conservation Service to consider social and environmental factors in their cost benefit analyses for projects requested by Alaska Native villages.
- Waive the federal cost-sharing requirement for erosion and flooding programs for Alaska Native villages.

In addition, the GAO suggested bundling funds from agencies to address erosion and flooding in Alaska Native villages.

Update: Since the 2003 GAO publication, the USACE has been directed by Congress to begin considering non-monetary benefits (Section 116 of the Energy and Water Development and Related Agencies Appropriations Act of 2010, Public Law 111-85) for Alaska communities when determining federal interest in a potential project.

2.2 Alaska Climate Impact Assessment Commission

The focus of the Alaska Climate Impact Assessment Commission was to gain an understanding of climate change in Alaska.

The Alaska Climate Impact Assessment Commission was established in 2006 by Legislative Resolve 49 (Alaska Climate Impact Assessment Commission, 2008). While the focus of the Commission was climate change, the Commission made several recommendations that are applicable to this study:

- Update technical maps to address soils, erosion, floodplain features, surface water, stream and river course changes, and permafrost conditions.
- Develop appropriate Memorandums of Agreement between the State of Alaska and the Denali Commission, USACE, and the U.S. Departments of Interior and Transportation to establish a point of leadership on behalf of village relocation projects in the state.
- Develop best practices for engineering projects submitted to the state that address cold region conditions.
- Identify at-risk communities in need of relocation due to erosion or other potential damage and identify communities that require mitigation/protection.
- Update precipitation frequency estimates. (Note that this was completed in 2012 by the UAF Water and Environmental Research Center with funding from the Alaska University Transportation Center, Alaska Department of Transportation and Public Facilities, U.S. Department of Transportation, and National Weather Service. (Kane & Stuefer, 2013).)
- Identify funds to assess public infrastructure needs to protect against loss due to erosion and loss due to thawing permafrost.

2.3 Alaska Climate Change Subcabinet

In 2007, Alaska's Governor established the Alaska Climate Change Subcabinet under Administrative Order 238. Four groups were established under the administrative order:

- Adaptation Advisory Group
- Mitigation Advisory Group
- Immediate Action Work Group
- Research Needs Work Group

The Immediate Action Work Group (IAWG), which addressed known community threats related to coastal erosion, thawing permafrost, flooding, and fires (Immediate Action Work Group, 2009), suggested three actions:

- Identify the communities at risk, the timeframe, and actual needs to address climate change impacts.
- Develop a methodology for prioritization of needs based on the risks to health, infrastructure, homes, businesses, subsistence harvests, significant cultural attributes, and quality of life.
- Determine the needs of coastal communities subjected to climate change impacts.

While the IAWG worked within the climate change agenda established by the executive order, its focus was on near-term needs, resulting in the identification of six communities that required action within 18–24 months.

2.4 Alaska Baseline Erosion Assessment

In 2009, USACE published the Alaska Baseline Erosion Assessment (U.S. Army Corps of Engineers, 2009), which identified 178 communities in Alaska as having erosion problems ranging from minor to severe. The BEA categorized the study communities into three groups: "Priority Action Communities" (26), "Monitor Conditions Communities" (69), and "Minimal Erosion Communities" (83). The BEA summarized the community survey as follows:

- Sixty-eight of the 127 respondents indicated riparian or coastal erosion or both in their communities.
- Twenty-five percent of respondents indicated that erosion is ongoing gradual threat.
- Nineteen percent of respondents indicated erosion was due to discrete events.
- Seventeen percent of respondents indicated they were experiencing both types of erosion.
- Thirty-nine percent of respondents were unable to answer the question.

The survey indicated that the success of corrective measures was variable. While 44 communities reported that protective measures had been effective, 14 of these communities noted that there had been some partial failure over time. Another 23 communities reported that measures undertaken had failed.

Corrective measures typically include some type of fill material—concrete blocks, gabion baskets, 55-gallon drums, dikes, and tree branches—which is not surprising since many communities lack rock that can be used for riprap and lack the funding needed for more permanent measures (U.S. Government Accountability Office, 2009).

The 2009 BEA developed a list of 26 communities considered Priority Action Communities that warrant "immediate and substantial" intervention. The process used to select these communities will be discussed in detail later in this report.

2.5 Alaska Native Villages Report – 2009

In its 2009 report, "Alaska Native Villages: Limited Progress Has Been Made on Relocating Villages Threatened by Flooding and Erosion," the GAO noted the lack of progress on relocating Alaska Native villages threatened by erosion and flooding and pointed out that the 2009 BEA only included communities threatened by erosion (U.S. Government Accountability Office, 2009). The GAO chose to address 31 communities identified by federal, state, and village officials, which included 5 communities threatened by flooding, along with the 26 Priority Action Communities identified in the BEA. The GAO recommended that Congress consider these actions:

- Directing USACE to conduct a flooding assessment to augment its recently completed erosion assessment.
- Amending the Housing and Community Development Act of 1974 to allow 64 additional villages to be eligible grant recipients.
- Designating, or creating, a lead federal entity that could work in conjunction with the lead state agency to coordinate and oversee village relocation efforts.

2.6 Other Related Literature

2.6.1 Imperiled Community Water Resources Analysis

At the request of the Immediate Action Work Group (IAWG), Tetra Tech prepared an evaluation report of risk to water infrastructure due to climate change in 214 communities (Tetra Tech, 2010). The Imperiled Community Water Resource Analysis (ICWRA) provides insight into potential threats to public water/wastewater systems. Communities were prioritized using a process similar to that used by the BEA in 2009. Tetra Tech used four criteria developed by the IAWG for selecting and ranking communities regarding their water infrastructure:

- Life/safety risk during storm/flood events.
- Loss of critical infrastructure.
- Public health threats (as defined by the Centers for Disease Control and Prevention) or by Alaska's Regional Health Corporations.
- Loss of 10% or more residential dwellings.

Using available data, including that from the BEA, the ICWRA found that 23 communities currently face some threat to water infrastructure, and 44 communities may face threat to water infrastructure at some point. The latter group either faced lesser threats or did not supply enough information to confidently assess those threats. The report contained six recommendations:

- Supplement this analysis with a more detailed analysis.
- Collect additional hydrologic data.
- Increase permafrost monitoring.
- Adopt prevention and adaptation strategies for managing water and wastewater assets.
- Mitigate landfill and tank farm risk.
- Implement relevant recommendations from the Governor's Climate Change Subcabinet Adaptation Advisory Group.

The ICWRA report contains community profiles of priority communities and includes potential impacts from erosion, flooding, and thawing permafrost, information that is useful to this study's threat analysis.

2.6.2 Thaw Settlement Hazard Index

Hong et al. (2014) developed a Permafrost Settlement Hazard Index (PSHI) that uses six ecosystem characteristics—topography, surface water, groundwater, soil properties, vegetative cover, and snow cover—to estimate thaw settlement in permafrost. Using the analytic hierarchy process developed by Saaty (Saaty, 2008), the authors developed a PSHI, combining the relative importance of ground temperature, ground ice, soil texture, snow depth, and organic soil content. Referring to permafrost maps developed by Jorgenson et al. (Jorgenson et al., 2010), to vegetation maps developed by Fleming (Fleming, 1997), and to temperature maps developed by SNAP (Scenarios Network for Alaska & Arctic Planning, 2010), Hong et al. used the GIS (Geographic Information System) to develop PSHI maps for Alaska. The research group then added communities for which the risk of thaw subsidence could be estimated. The maps used to develop the PSHI resulted in a generalized map of permafrost settlement threat at the community level. That said, in-depth analysis of community infrastructure requires consideration of not only the ground conditions, but also consideration of the type, design, and distribution of infrastructure within each community. Thus, the PSHI maps developed by Hong et al. provide a starting point, but not an endpoint, for an in-depth analysis of each community.

2.6.3 Cost of Infrastructure under Greenhouse Gas Scenarios

Another pertinent study is by Melvin et al. (2016), in the *Proceedings of the National Academy of Sciences of the United States of America.* This study evaluated projected costs of infrastructure damage under various greenhouse gas scenarios. The study predicted that the largest drivers would be flood damage to transportation infrastructure in Interior and Southcentral Alaska due to changes in hydrology, as well as damage to buildings based on thaw of near-surface permafrost. This analysis was primarily a cost analysis, ultimately expressing damages in units of repair dollars. A drawback of this assessment is that the infrastructure components were assigned to relatively large grid cells, which were then assessed according to predicted climatic impacts. However, erosion, flood, and especially permafrost impacts tend to be highly dependent upon the specific location of the infrastructure within the grid cells. Permafrost damage, for instance, is highly dependent upon the specific soil and ground ice conditions underlying the infrastructure and the engineering controls put into place during or after construction. Thus, from an engineering perspective, a large-scale evaluation such as this one would not be enough to provide predictive capability for specific units of infrastructure. However, the study was useful in describing the parameters of the thawing permafrost challenge.

2.7 Summary

Several of the reports described above identified specific communities that were most threatened by some combination of threats pertinent to this study. Thus, it is informative to consider which communities were among those considered most threatened by multiple reports. Table 2-1 is a summary of the communities that the highlighted reports designate as "threatened." While there is overlap among these reports, consensus should not be expected since the focus of each report is on different threats and different infrastructure, and the reports were prepared by different teams over a period of years (2003-2016). The reports noted in Table 2-1 laid the foundation for this study, providing invaluable background information and data, as well as insight into the driving forces behind the project.

Table 2-1. Summary of at-risk communities identified by highlighted reports.

Community	GAO, 2003	BEA, 2009	IAWG, 2009	GAO, 2009	ICWRA, 2010
Akiak		*		*	
Alakanuk		*		*	
Aniak					*
Atmautlauk					*
Allakaket				*	
Utqiaġvik (Barrow)		*		*	
Brevig Mission					*
Chalkyitsik					*
Chefornak		*		*	
Chevak		*		*	*
Chignik Lagoon					*
Clark's Point		*		*	
Cordova/Eyak		*		*	
Deering		*		*	*
Dillingham		*		*	
Diomede					*
Emmonak		*		*	*
Golovin		*		*	
Hughes				*	*
Huslia		*		*	*
Kivalina	*	*	*	*	
Kotlik		*		*	
Koyukuk	*		*	*	
Kwigillingok		*		*	
Lime Village		*		*	
McGrath		*		*	*
Napakiak		*		*	
Nelson Lagoon					*
New Stuyahok					*
Newtok	*	*	*	*	
Noatak					*
Nulato				*	
Nunapitchuk		*		*	
Port Heiden		*		*	
Quinhagak					*
Saint Michael		*		*	*
Selawik		*		*	*
Shaktoolik		*	*	*	
Shishmaref	*	*	*	*	
Stebbin					*
Talkeetna					*
Teller				*	*
Unalakleet		*	*	*	
Venetia					*
Wales					*

Chapter 3.0 Erosion, Flooding, Thawing Permafrost, and Combined Threat

The vulnerability of 187 communities to three infrastructure threats—erosion, flooding, and thawing permafrost—were evaluated individually in this report. These threats generally operate at different timescales and impact infrastructure through different processes. Any of these threats can be catastrophic to a community. When combined, the impacts can be exacerbated, resulting in usteq.

Of the threats described above, erosion is the most readily observed and identified. The erosion process is continuously observable at the point of impact, although the rates may vary according to conditions. Prediction of erosion usually involves observations of current rates and consideration of potential changes to those rates. Flooding, on the other hand, is readily observed during a flood event, but is a discontinuous process. Prediction of future floods is based upon the frequency of past floods, sometimes in conjunction with predictions of potential changes in climatic conditions. The threat of damage via thawing permafrost is highly dependent upon subsurface conditions, which are themselves often poorly characterized. Moreover, thawing permafrost damage is also dependent upon a host of other factors including engineering design and climatic conditions. Thus, thawing permafrost is not only difficult to observe until after the infrastructure has been damaged, but is also relatively difficult to predict in areas where damage has not yet occurred. Usteq is the most difficult to predict because it incorporates the uncertainties associated with each individual threat. Usteq is a subset of the combined threats but was not separated for the purpose of this study. The occurrence of usteq does not conflict with the combined scores. When the threat of permafrost thaw is high in a location also subject to erosion and flooding, the occurrence of usteq may be high.

The purpose of this chapter is to provide additional background information regarding the individual and combined threats, in order to provide context for the interpretation of study results.

3.1 Erosion Threat

For the purposes of this study, erosion is defined as the removal of soil, either thawed or frozen, due to the movement of water. Erosion places communities at risk when the erosion process causes a net migration of the top of the shoreline or riverbank toward fixed infrastructure. When the shoreline or bank line reaches community infrastructure it undermines foundation material, causing structural failure of buildings, utilities, and transportation facilities. The processes for erosion can be subdivided into two broad categories: coastal erosion and riparian erosion.

Coastal erosion is primarily due to ocean current, wave action, and/or storm surge. Wave action is the most common cause. Coastal erosion is usually described in terms of sediment transport, which is identified by the volume and direction of material moved along a coastline, longshore or cross-shore. The rate of sediment transport is dependent upon wave energy and direction along a section of coastline, as well as the material composition of a shoreline. Most dynamic shorelines are composed of coarse to fine sand, which is more easily transported by wave action. In some high energy environments, beaches are formed of gravel, cobbles, and boulders, which are only transported by larger wave action.

Longshore sediment transport occurs when waves approaching the coastline at an angle move beach material down the shoreline in the same direction as the waves, an action also known as the direction of sediment drift. This process is dependent on the availability of sediment from updrift locations and on the wave-energy affecting a site. When considering a section of coastline, if the volume of material being transported into an area is the same as the volume transported out, the beach is in equilibrium, and no erosion or accretion occurs. If more material enters the section of coastline than leaves it, accretion occurs, with the beach width and elevation increasing and dune formations, if present, increasing in size. If more sediment leaves the area than enters it, a sediment deficit occurs, and the shoreline retreats inland.

Cross-shore sediment transport occurs when material along the beach profile is moved either onshore to higher elevations, or offshore to lower elevations, depending on the wave conditions. During mild wave conditions, typically during summer months in Alaska, material is deposited on the upper slopes of the beach, which builds up the shoreline. During fall and early winter, storm events produce more energetic wave conditions, which tend to erode material from the shore and deposit it in an offshore bar. When net transport over time is offshore, the shoreline retreats inland (Figure 3-1).

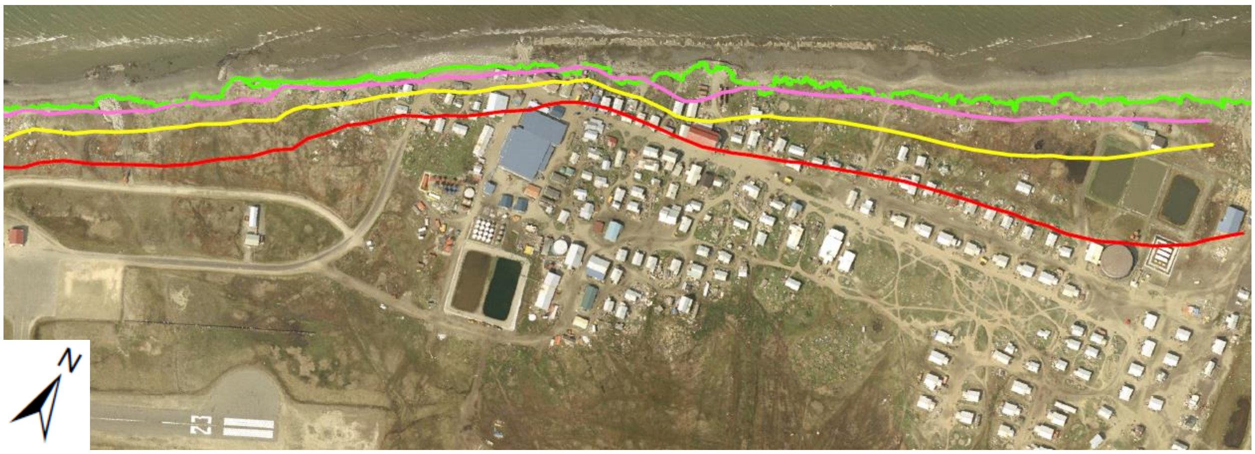

Figure 3-1. Shishmaref, Alaska, erosion prediction assuming no coastal protection.

In Figure 3-1 above, this site is subject to coastal sediment transport processes. The colored lines represent shorelines, as reported in the 2009 BEA: green is the 2004 shoreline, pink is the 2013 predicted shoreline, yellow is the 2028 predicted shoreline, red is the 2053 predicted shoreline.

Shorefast ice that forms in the fall protects the shoreline from damaging energetic fall storms. Between 1976 and 2007, the extent of shorefast ice in the Arctic has decreased by approximately 0.7% per year (Yu Y. , Stern, Fowler, Fetterer, & Maslanik, 2013). In 2006, NOAA began publishing an annual peer-reviewed Arctic Report Card. In the 2018 Report Card, researchers reported that "pan-Arctic observations suggest a long-term decline in coastal landfast (herein referred to as *shorefast*) sea ice since measurements began in the 1970s, affecting this important platform for hunting, traveling, and coastal protection for local communities (Osborne, Richter-Menge, & Jeffries, 2018)." With decreasing shorefast ice extent, coastal communities could be exposed to ocean currents, wave action, and storm surge for a longer period, putting infrastructure at greater risk of being undermined by erosion.

Riparian erosion is primarily due to river currents. Rivers and streams are dynamic systems that respond to changes in flow and sediment. Usually, these changes alter the course of a stream or the shape of its banks. The current of a river typically flows fastest over the deepest portion of the channel, called the thalweg. Most streams in Alaska are meandering streams that follow sinuous paths. At river bends, the thalweg is located along the outside bend, often called the cut bank. At the cut bank, higher velocity currents flow adjacent to the bank and result in erosion. Along the inside bank, or point bar, the current is slowest (Figure 3-2). These slower currents tend to cause deposition. By these two processes, rivers tend to meander toward the outside banks of their bends. Over time, the channel of the river will shift laterally. Many communities in Alaska build infrastructure on the cut bank of a channel to take advantage of the greater water depth along the thalweg. Deeper water enables the use of barges to deliver goods and materials to a community; however, it also makes ground near the barge landing susceptible to erosion that can undermine infrastructure. Boat wakes also contribute to this process, though wakes can cause erosion on both banks of a channel. In areas of high boat traffic, channels generally become wider over time as waterline erosion causes steepening and calving of the riverbanks.

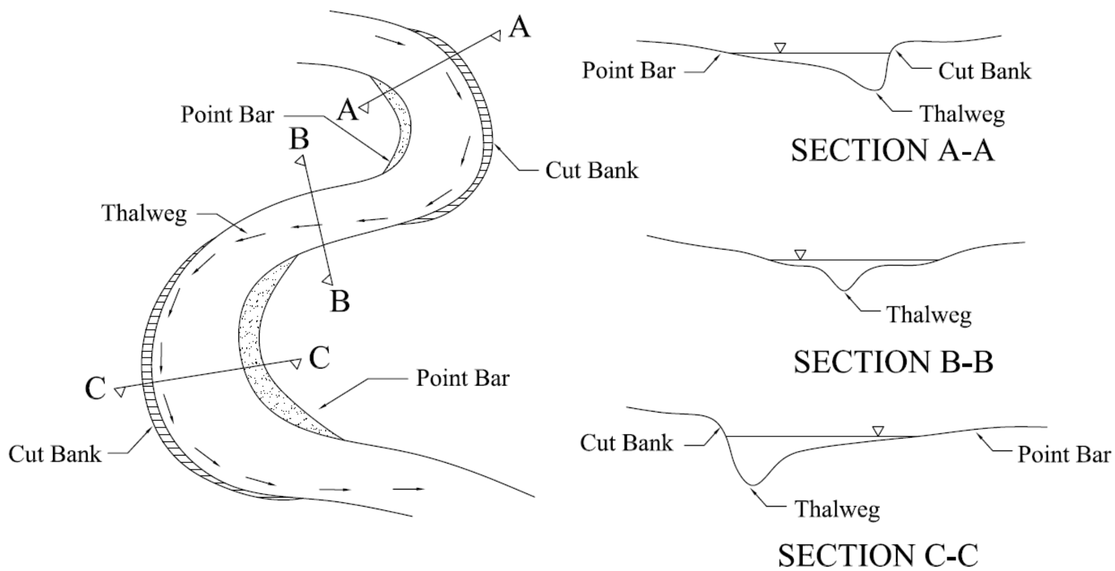

Figure 3-2. Morphology of a meandering stream (from 2009 BEA).

Flow conditions on rivers constantly change. Seasonal changes due to precipitation and freezing can cause dramatic changes in channel flow, moving from virtually no flow (freezing) to flood stage (large rainstorm or thawing events). While erosion can be a continuous process in streams, it is usually most significant during high-flow events. Flow velocity is greatest when a reach is at stream-forming flow, when the water level is at the top of the bank but not in the floodplain. This stage causes the greatest rates of erosion. Beyond seasonal changes, long-term climatic trends can either increase or decrease the amount of water a river carries. Rivers react to changes in flow by altering channel geometry to best accommodate the water. A channel experiencing increasing flow may become wider and straighter to allow it to carry the water to its terminus more quickly. Where flows are reduced, the channel may become braided as velocities decrease, causing suspended material to settle out more quickly.

In braided river systems, such as the Tanana and Matanuska rivers in Alaska, the amount of sediment available to the system far exceeds the water's ability to transport it downstream. The channel extents are defined by a braid plain that developed where the channel has historically run. The main flow of these rivers is unpredictable, and channel avulsion can rapidly change the river course within the braid plains. When the channel runs against the edge of the braid plain, erosion will occur, potentially very rapidly, depending on the material at the braid plain boundary.

3.2 Flood Threat

For the purpose of this study, flooding is the inundation of infrastructure or the impassibility of airstrips and roads due to elevated water levels along a coast (Figure 3-3) or river (Figure 3-4). Flooding becomes a risk to the viability of a community when it threatens use of and access to critical infrastructure. Flooding also poses risk to life when inhabited areas become inundated with moving water, which can carry residents downstream or offshore.

Figure 3-3: Coastal flooding in Golovin, Alaska, September 2005 (photo courtesy of the National Weather Service).

Figure 3-4. Flooding in Galena, Alaska (photo courtesy of the National Weather Service).

Coastal flooding can be caused by elevated water levels due to highest astronomical tides, wave setup, or storm surge. In addition to elevated water caused by these processes, waves can wash up over a beach and into developed areas, causing inundation. These events may carry debris (logs, etc.) into communities posing a potential threat to critical infrastructure, housing, and human health.

Storm surge is the most common cause of flooding in coastal Alaska. The National Weather Service defines storm surge as the abnormal rise of water generated by a storm, over and above the normal highest astronomical tide; a surge is expressed in terms of height above predicted or expected tide levels. Storm surge severity depends on strength and duration of the driving storm event as well as coastline geometry and bathymetric profile. Topography beyond the beachline also determines how much land is susceptible to such surges. While storm surge is an issue throughout western Alaska, Norton Sound communities experience some of the most severe events.

As relative sea level change is realized, the depth of storm surge flooding may increase in areas that experience rising relative mean sea level. The changes in shore-fast ice extent also affect the period of time that the shoreline is exposed to storm surge. If local shore-fast ice decreases, the community's infrastructure, which historically has been shielded by shore-fast ice, may be at risk due to storm events.

River flooding can be caused by elevated water levels due to ice jams, large rain events, frequent, consecutive small rain events, quick melting of snowpack, or a breaking earthen or ice dam. In all these cases, the conveyance capacity of the channel is exceeded, and excess water is impounded in the overbank areas where infrastructure is located. Flood severity is typically classified by the peak elevation of water within a community. This usually corresponds to the highest flow in the river; however, ice jams add impoundment to the problem and cause elevations higher than the flow of the river alone would produce.

Flood frequency is typically measured statistically using a record of peak elevations at a fixed location and is based upon a probability that the water surface elevation will exceed a defined level in any given year. This is expressed as an annual exceedance probability. Historically, the return periods for these probabilities were expressed in years; for instance, a water elevation that has a 1% chance of occurring every year was estimated to occur on average once every 100 years; hence the term "100-year flood." This terminology leads to the misconception that once a severe flood has happened, it will be less likely for a similar event to occur for a long period of time (100 years, in popular thought). In truth, a 100-year flood has an equal probability of occurring in any given time, regardless of the amount of time elapsed since the last 100-year flood.

Climate change may be altering the historic patterns of rainfall, snowmelt, and thermal ice breakup. The 2018 Arctic Report Card addresses changes in discharge patterns across the pan-Arctic between the reference period 1980–1989, and 2018 (Holmes et al., 2018). The combined daily discharge of the Yukon River and Mackenzie River, located predominantly in the Yukon Territory, Canada, peaked four days earlier in 2018 than the average day during the reference period and had a total discharge between July 15 and September 30 that was 4% greater than the average during the reference period (Holmes et al., 2018). Bennett et al. (2015) studied the historic trends and extremes of river flow for basins ranging from the Chena and Salcha basins near Fairbanks, Alaska, to the Susitna basin in southcentral Alaska, east to the Yukon at Eagle, and west to the Nuyakuk near Dillingham. The researchers found that the period of time of change is dependent on a system's physical response to climate change. For snowmelt-dominated systems, the maximum spring streamflow is increasing. For glacial systems, streamflow is declining in spring, in summer, and annually. Across many river systems in Alaska, the winter baseflow was observed to be increasing. Thus, while the probability of future flood events (and hence the level of threat to infrastructure) are commonly predicted based upon the frequency of past flood events, dynamic climatic trends can impart uncertainty into those predictions.

3.3 Thawing Permafrost Threat

Thawing permafrost has long been recognized as a threat to infrastructure built upon it. Indeed, Major Wilds P. Richardson, an early 20th Century Alaskan highway commissioner, observed that "A serious detriment to the making of a road in Alaska is the thawing of the ground beneath the moss. It has been the universal experience that whenever the moss is cut into, thawing immediately commences…" (Naske, 1983). Thus, Major Richardson's observation brings to light an important consideration with respect to the threat of thawing permafrost. Permafrost thaws when the thermal balance of a frozen soil is altered. The thermal balance can certainly be altered by climatic effects but can also be altered by the construction of infrastructure itself, or by the heat transferred through existing infrastructure to the underlying soils.

Permafrost is defined as any soil or rock that remains at or below 0°C for two or more consecutive years and may or may not contain ground ice (van Everdingen, 1998). The potential for damage due to thawing permafrost is related to the ice content of the soil, surface cover, and the surface energy balance. The greater the ground-ice content, the greater the potential for damage due to loss of structural integrity of the soil. While in some cases surface features provide clues as to occurrence of massive ice bodies (Figure 3-5), there is no guarantee that the ground-surface features will indicate the subsurface ice content. The only means to accurately determine the amount of ground ice is to perform a thorough geotechnical investigation. Even with an investigation, it may be difficult to predict the ice content outside the investigation area due to spatial variations in soil structure. Geotechnical investigations are usually performed for design or construction of a specific building, roadway, or other infrastructure. It is rare that investigations are sufficiently comprehensive to describe the permafrost characteristics underlying an entire community.

Damage to infrastructure due to thawing permafrost is rarely well documented. It is difficult to identify the number of structures damaged by naturally thawing permafrost, compared with structures that have failed due to poor engineering, construction, and/or maintenance (Figure 3-6). However, it is well known that the thermal imbalance caused by the infrastructure typically leads to thawing of permafrost either directly or indirectly. Heat from the building itself is widely recognized as a factor that contributes to thermal imbalance; however, snowdrifts, reflected sunlight, shading, destroyed vegetation, and changes in drainage patterns can all contribute to thermal imbalance. In addition, increases in surface temperatures and changes in precipitation due to climate change also play a role in thawing of permafrost.

Thaw-related impacts associated with engineering design or surface modification generally begin shortly after construction of infrastructure, and the damage may be dramatic. Impacts due to climate change generally occur over a longer period of time and are often masked by the impacts resulting from the construction of the infrastructure. Since warmer permafrost such as that produced by climate change is more susceptible to damage from infrastructure-related surface modifications, it is often difficult to attribute specific causation to any given event.

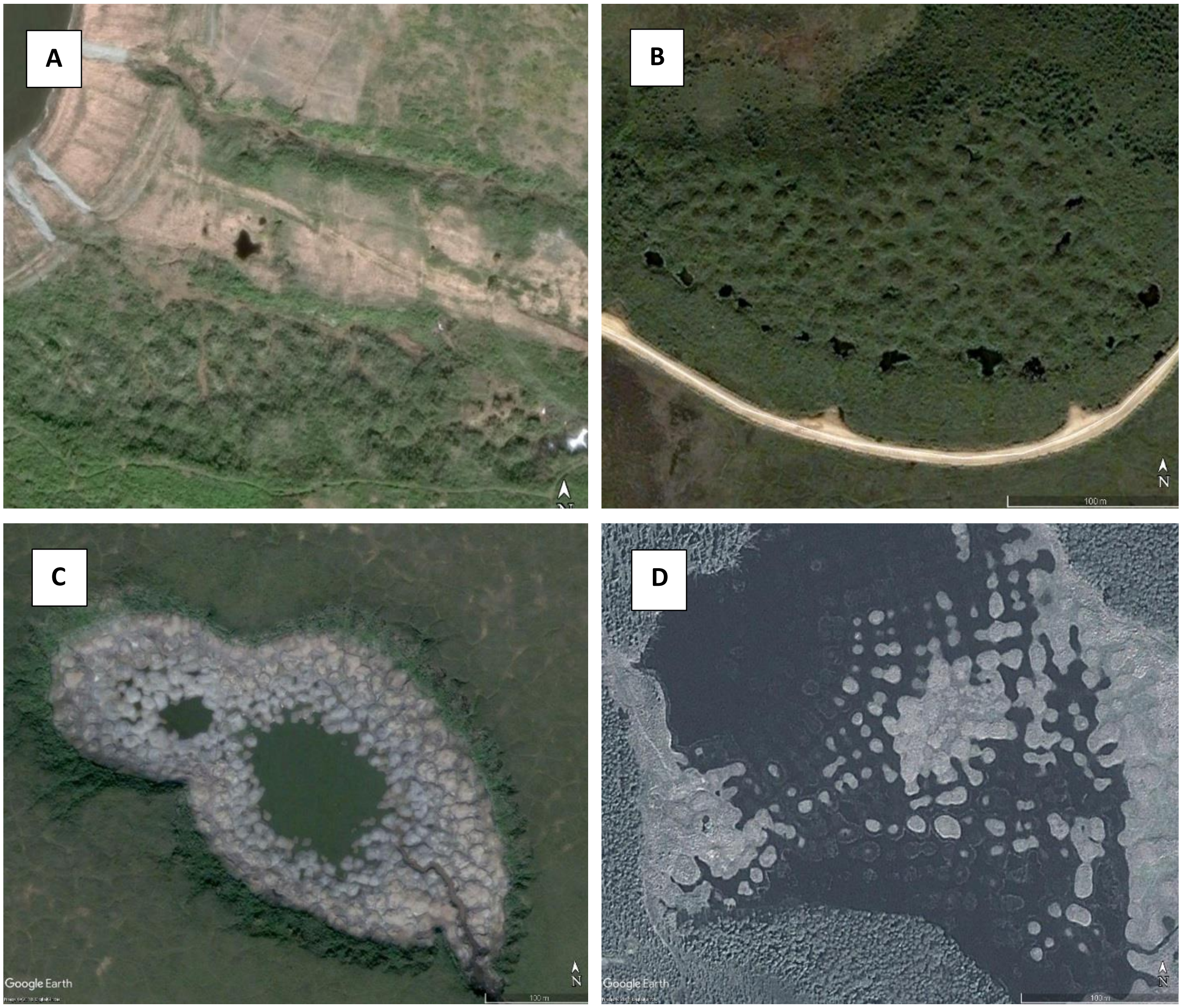

Figure 3-5. Baydzherakhs (conical thermokarst mounds that form as a result of thawing of the upper permafrost with large ice wedges): A – near Kotzebue airport; B – near Buckland; C – at the bottom of partially drained thaw-lake basin, Seward Peninsula; D – at the bottom of partially drained thaw-lake basin, Horseshoe Lake, Interior Alaska.

Figure 3-6. Crushed carrier line in Pt. Lay, Alaska, due to thawing permafrost (photo courtesy of UMIAQ Environmental, LLC).

3.4 Combined Threat

Though threats from erosion, flooding, and thawing permafrost were evaluated separately in this report, there can be a feedback loop between the threats.

The eroding riverbank at Newtok, Alaska provides an excellent example of usteq. Usteq is a subset of the combined threats, and represents the impacts flooding and erosion can have upon sites also subject to permafrost thaw. In Newtok, ice rich permafrost along the bank would likely thaw relatively slowly in the absence of other processes. However, waves and storm surges caused by autumn storms now batter the bank due to loss of sea ice. If the soils were composed of sands and gravels the erosion rate would likely be slower than observed. However, the loss of land in Newtok is very rapid, in excess of 80 feet per year (Personal conversation with Gavin Dixon, ANTHC). This is because the ice-rich frozen silts newly exposed to the elements by waves and storm surge tend to thaw quickly, thus decreasing structural stability. As a result, the historic town site of Newtok is not expected to be viable within a few years.

Figure 3-7. Crumbling blocks of permafrost along the Beaufort Sea coast (photo courtesy of the USGS).

While the processes at Newtok provide one example of usteq, usteq should not be considered a process limited to coastal or riverine sites. Water conducts heat much more readily than air, for example. Thus, any contact of water with ice rich permafrost in coastal, riverine, or terrestrial environments may cause rapid thaw and resultant infrastructure damage.

The interactions between erosion, flooding and thawing permafrost often become clear after the onset of usteq, but their combined impacts are rarely considered beforehand. This is due to a lack of knowledge regarding how best to predict the interaction between the threats. Predictions of erosion, flood, and thawing permafrost damage are themselves fraught with uncertainty and highly dependent upon the location and design of the infrastructure within each community. When attempting to predict the interactions between these threats, this uncertainty is compounded. As a result, this report does not attempt to parse the combined scores in individual communities into semi-quantitative groups such as “high” or “low” threat. Instead, the combined scores are represented as an aggregate of the individual threats.

Chapter 4.0 Risk Evaluation, Criteria, and Methods

4.1 Overview

A team of scientists and engineers from UAF, USACE, and CRREL evaluated erosion, flooding, and thawing permafrost threats for 187 communities across Alaska. The evaluation was conducted through a series of in-person team meetings during early 2018, as well as close collaboration between the team and the Denali Commission thereafter. The analytical approach was modeled after the approach employed for the BEA, using similar criteria for the ratings (U.S. Army Corps of Engineers, 2009). In the current study, USACE developed flood and erosion ratings, while UAF and CRREL developed thawing permafrost ratings. The team then collaborated on the development of an algorithm to compile the individual ratings into a combined (or aggregate) threat rating. This chapter describes the analytical process employed to develop the ratings for the individual threats of erosion, flood, and thawing permafrost, and to introduce the rationale behind the combined ratings.

4.2 General Process of Developing Ratings

Techniques for attributing ratings to individual communities were developed by an expert panel of scientists and engineers from UAF, USACE, and CRREL. The panel determined which criteria to evaluate, and how best to interpret the criteria in the context of erosion, flood, and thawing permafrost threats. In addition, the panel established the most effective methodology to scale, weigh, and assign values to the criteria. A schematic describing the overall analytical process employed in this study is presented in Figure 4-1 at the end of this chapter.

The expert panel sought to apply and score evaluation criteria consistently for each individual threat across all 187 communities. For a given community, the following steps were followed during the rating process. This process was repeated for each evaluation of erosion, flooding, and thawing permafrost:

1. Gather all available data pertaining to the threat in question for the community (see Sections 4.3, 4.4, and 4.5).
2. Determine the best fit **Impact Rating** from 0 (no impact) to 3 (high impact) for each of nine evaluation criteria using the information available (Section 4.6). Combine the individual evaluation factors into an **Aggregate Impact Rating** by applying the relative weights to each factor and then summing the factors.
3. Estimate the most likely **Time to Damage** using the information available (Section 4.7).
4. Calculate the **Risk Rating** based upon the **Aggregate Impact Rating** and **Time to Damage** (Section **Error! Reference source not found.**).
5. Rate the overall level of **Uncertainty** associated with the evaluation (see Section 5.4).

For erosion and flooding, the 187 community ratings were performed by three USACE engineers. Several ratings were performed as a group to help develop consistency. Afterwards, the remaining communities were divided, and evaluations were performed individually. When evaluations were complete, the panel reviewed the ratings together for consistency and errors and made changes as appropriate.

Whereas statewide erosion and flood data are generally available via public data sources, thawing permafrost data is scarce, and not often measured directly. Thus, the permafrost team, composed of eight engineers and scientists from UAF and CRREL, conducted a preliminary evaluation intended to produce data suitable for implementation in Steps 1-5 as described above. In the preliminary analysis, predominant permafrost occurrence, temperature, thaw susceptibility, massive ice, and known problems were assessed and assigned a preliminary score (see Table 4-1 for preliminary criteria). These values were then summed to determine a preliminary permafrost risk level for each community based primarily upon soil characteristics. Once the preliminary permafrost risk was determined, the expert panel utilized that value plus additional community information (e.g., location and distribution of infrastructure, etc.) for application in steps 1-5 as described above.

Detailed information regarding the preliminary assessment of permafrost risk can be found in (Kanevskiy, et al., 2019). In that report, the risk levels for each of the 187 communities evaluated are provided so that each community may use the information for community planning purposes. A planning tool developed to present the permafrost data from the preliminary report is available online at the following url: https://www.snap.uaf.edu/tools/permafrost. Note: The data presented in that preliminary report are insufficient for design and construction of individual buildings or other infrastructure. Rather, the data are intended to be used as a starting point to plan geotechnical investigations.

Table 4-1. Preliminary evaluation matrix for permafrost-related threats based on soils criteria.

PF occurrence	**PF temperature**	**Thaw susceptibility**	**Massive ice**	**Existing problems**	**Risk level (ranking score)**
0. No permafrost	**0.** No permafrost	**0.** No permafrost	**0.** No permafrost	**0.** No permafrost	**No risk (0)**
1. Mostly unfrozen soils with isolated patches of PF	**1.** Mean annual ground temperature (MAGT) < -5°C	**1.** Almost no excess ice, thaw settlement is less than 0.1 m;	**1.** No massive ice	**1.** No PF-related problems (or minor problems)	**Low risk (5-8)**
2. Discontinuous permafrost (intermittent distribution of PF and unfrozen soils, numerous open and/or closed taliks)	**2.** MAGT = -5 – -2°C	**2.** Thaw settlement is 0.1 to 1.0 m	**2.** Sparse small to medium ice wedges (inactive or slightly active), rare occurrence of buried ice	**2.** Moderate problems	**Medium risk (9-11)**
3. Continuous permafrost (rare taliks exist only under large and deep waterbodies)	**3.** MAGT = -2 – >0°C	**3.** Thaw settlement is more than 1 m	**3.** Abundant large ice wedges close to the surface (yedoma and/or active modern wedges)	**3.** Severe problems	**High risk (12-15)**

4.3 Erosion Data Sources

Since the BEA criteria were used as a model for the criteria in this report, the BEA itself served as a primary source of erosion data (U.S. Army Corps of Engineers, 2009). Indeed, BEA data were available as source data for 132 communities evaluated in this report. The list of additional data sources for erosion is provided below. Note that for erosion as well as for the other threats, the amount of readily available information varied widely between communities:

- USACE Baseline Erosion Assessment.
- Maps detailing local topography, hydrography, and infrastructure.
- Alaska Department of Commerce, Community, and Economic Development (DCCED) online
- resources including the Community Index and the Community Plans Library. These include:
  - Community population
  - Number of occupied and vacant residencies
  - Hazard mitigation plans
  - Community development plans
  - FEMA National Flood Insurance Program (NFIP) information
- Additional online news sources.

4.4 Flood Data Sources

For flooding, the team predominantly relied on historic information regarding the frequency and magnitude of flooding. Most of the sources were available in the National Weather Service Flood Database and Hazard Mitigation Plans. The data sources used to determine the threat ratings for flooding are as follows:

- Maps detailing local topography, hydrography, and infrastructure.
- Alaska Department of Commerce, Community, and Economic Development (DCCED) online resources including the Community Index and the Community Plans Library.
- National Weather Service Alaska–Pacific River Forecast Center Draft Alaska Flood Database including:
  - Number of floods
  - Cause and severity of flood
  - Disaster Declarations
  - Costs of damage, specific infrastructure affected
  - Evacuations
- USACE Alaska District's Floodplain Data electronic files including:
  - Flood data sheets
  - Trip reports
  - Studies
  - Community surveys
  - Maps and photos
- Internet—an online search to find news articles reporting on flooding in the communities.

4.5 Thawing Permafrost Data Sources

As described in Section 4.2, much of the permafrost data was subjected to a preliminary analysis prior to evaluation under the BEA-derived criteria. Thus, the preliminary analysis itself served as a primary data source for further consideration (Kanevskiy, et al., 2019). Data sources for the preliminary analysis and/or the primary evaluation described in this report include:

- Alaska Department of Commerce, Community, and Economic Development (DCCED) online resources including the Community Index and the Community Plans Library.
- Alaska Department of Transportation & Public Facilities geotechnical reports.
- Engineering community geotechnical reports.
- Scientific literature describing permafrost distribution and related information.
- Satellite and air photos.
- Terrain maps.
- Surficial geology maps.

4.6 Initial Erosion, Flooding, and Thawing Permafrost Evaluation Factors Workshop

The study group (UAF, USACE, and CRREL) met on the UAF campus in February 2018 for a three-day workshop to develop the evaluation factors used for community assessment. The goal of the workshop was to identify a rating system to determine the relative impact of erosion, flooding, and thawing permafrost threats across communities. The 2009 BEA was used as a template for developing the evaluation factors.

After initial brainstorming and screening in order to include thawing permafrost threats, the group generated a list of evaluation factors with associated impact ratings. The study group added a “zero impact” rating to the rating system to capture circumstances that produced no impacts, or for communities not experiencing a threat. The evaluation factors were initially applied to each community, without consideration of the frequency of the threat impacts (short-term to long-term). The intent of the initial score was to evaluate each community equally, based solely on the type of threat and its impact. The nine evaluation factors are listed below, and their relative impact ratings (in parentheses) are described in Table 4-2.

Critical Infrastructure. Critical infrastructure included facilities in the community that, if destroyed, would affect the community’s viability if not replaced quickly. Critical infrastructure include clinics, water supply, roads and airports, water/wastewater systems, water storage, schools, and the Post Office.

Human Health and Safety. Human health and safety focused on a community’s ability to seek emergency services due to a threat. For example, if a road that connects a community to emergency services would be threatened, or if airport facilities would be jeopardized, the community impact was rated high. Damage to critical infrastructure affects human health and safety only when the damage directly impacts the delivery of health services. For example, damage to a clinic would impact health and safety only if the damage is severe enough to impede health services. As such, the impacts to infrastructure may affect the rating of both critical infrastructure and human health and safety.

Subsistence and Shoreline Use. Subsistence and shoreline use examined whether the community's ability to gather natural resources would be threatened. For example, if a community lost the ability to launch boats or if the only land available for processing catch was compromised, the community impact was rated high.

Land Use/Geographic Location. Land use/geographic location focused on whether a community has room to retreat from a threat, whether the land is highly susceptible to that threat, and the community's relative impact on surrounding communities. For example, a community situated on a spit of land affected by a threat with no area to retreat was rated high. If the community was situated on a bluff with adequate safe ground, the impact was rated low. An impacted community serving as a hub, providing goods and services to other communities, received a higher impact rating.

Regional communities such as Galena, Nome, Bethel, Kotzebue or Barrow are transportation hubs, and health centers. As a consequence, loss of services in these communities directly impact surrounding communities.

Percentage of Population Affected. Population affected was rated low if less than 10% of the population would likely be impacted by a threat and rated high if more than 25% of the population would likely be impacted.

Housing Distribution. Housing distribution evaluated the manner by which a community's housing layout could exacerbate damages from a threat. The impact to a spread-out community with a small percentage of housing at risk was rated lower, whereas the impact to a community with a condensed utility corridor at risk was rated higher.

Environmental Threat. Environmental threat addressed the potential or capacity for erosion, flooding, or thawing permafrost to degrade the water quality, and/or increase human exposure to waste. If a community was considered to be in danger of losing a fuel tank or landfill, or of having a wastewater lagoon breached, the threat received a high impact rating.

Cultural Importance. Cultural importance measured threat-related impacts to historically and culturally significant sites such as cemeteries and artifacts. A situation where documented cultural and historic resources are likely to be damaged or lost due to threat received a higher impact rating.

Commercial Infrastructure. Commercial infrastructure involved measuring the impact of a threat on commercial services in the community such as stores, fuel supply, barge landings, and other cash-generating businesses. If a community was in danger of losing its only store, or if the store might close for an extended period of time, that area received a higher impact rating.

Table 4-2. Impact evaluation criteria and their relative impact ratings.

Evaluation Factor	Impact Rating	Justification
Critical Infrastructure (school, utilities, airport, water or fuel storage facilities)	No Impact (0)	• No evidence or likelihood of impact to critical infrastructure due to threat
	Low Impact (1)	• One item of critical infrastructure at risk from threat • Loss of infrastructure would not result in loss of community sustainability • Damage could be repaired, or alternative service restored in less than 1 month
	Medium Impact (2)	• More than one item of critical infrastructure at risk from threat • Loss of infrastructure would not result in loss of community sustainability • Damage could be repaired, or alternative service restored between 1 and 6 months
	High Impact (3)	• More than one item of critical infrastructure at risk from threat • Loss would impact community sustainability • Repairs or establishing alternative service would take more than 6 months
Health and Human Safety (hospital/clinic and emergency services)	No Impact (0)	• No evidence or low likelihood of life safety concerns due to threat
	Low Impact (1)	• Threat unlikely to cause life safety concerns or negatively affect ability to provide emergency services • Community has ability to mitigate or avoid life safety concerns
	Medium Impact (2)	• Only rare threat events would cause life safety concerns or negatively affect ability to provide emergency services • Quick and easy access to emergency services is available
	High Impact (3)	• Threat is likely to result in life safety or affect ability to provide emergency services • Portions or all of the population cut off from emergency services
Subsistence and Shoreline Use (hunting, gathering, processing, and storage)	No Impact (0)	• No evidence or low likelihood of threat affecting subsistence and shoreline use
	Low Impact (1)	• Minor and temporary interruptions of subsistence activities or access to shoreline that are a nuisance but are restored or mitigated in the same year • Damage due to threat could be repaired locally (i.e., repairing boat launch access each spring)
	Medium Impact (2)	• Frequent loss or disruption of subsistence activities or access to shoreline • Critical habitat and/or use areas mild to moderately threatened; traditional practices inconvenienced but not disrupted
	High Impact (3)	• Interruptions of subsistence activities or access to shoreline severe enough to cause impact on continual basis • Critical habitat and/or use areas severely threatened; traditional practices limited to focus on survival

Evaluation Factor	Impact Rating	Justification
Land Use/Geographic Location	No Impact (0)	• Land is readily available in threat-free zones for new development or relocations • Community is located outside of known threat zones
	Low Impact (1)	• Land is available in threat-free zones for new development or relocations • Land use controls in place and/or safe area between existing development and threat zone • Soils and hydrology/hydraulic conditions not conducive to threat • Aggregate resources available locally if mitigation measures needed (for instance, revetment)
	Medium Impact (2)	• Open lands in threat-free zones are limited and future development will likely be in threat zone or significantly alter community footprint • Existing development close to threat zone with some local resources available to assist with mitigation • Soils and hydrology/hydraulic condition conducive to threat
	High Impact (3)	• Open lands are only available in threat zones • Significant damage from threat • Poor soils conducive to erosion and permafrost degradation
Percentage of Population Affected	No Impact (0)	• Threat does not impact the population or housing areas
	Low Impact (1)	• Less than 10% of population affected; alternative housing available
	Medium Impact (2)	• 10 to 25% of population affected; alternative housing available, but limited
	High Impact (3)	• Over 25% of population affected; limited to no alternative housing available
Housing Distribution	No Impact (0)	• Housing distribution does not exacerbate threat
	Low Impact (1)	• Only a few structures and limited associated infrastructure at risk (one-time loss) • Utilities not impacted
	Medium Impact (2)	• Structures in clusters and associated infrastructure at risk with some expected future recurrence of damages • Some impacts to utilities
	High Impact (3)	• Structures in clusters and associated infrastructure at risk with frequent expected future recurrence of damages • Major impacts to utilities
Environmental Threat	No Impact (0)	• Threat does not result in damages to drinking water supply, bulk fuel storage, waste water system, and/or solid waste disposal
	Low Impact (1)	• Minor damages that can be addressed locally through normal operating procedures
	Medium Impact (2)	• Moderate damages that will require limited intervention by an external agency for a limited period

Evaluation Factor	Impact Rating	Justification
	High Impact (3)	• Significant damage that will require extensive intervention by one or more external agencies for an extended period • Damage or loss will impact a percentage of the population's ability to maintain residence • Threat will cause damage that may impact other communities or region, either directly (i.e., upstream contamination) or indirectly (i.e., displaced community members)
Cultural Importance (tanning, carving, dance, art, sports, etc.)	No Impact (0)	• No significant cultural/traditional activities and/or sites impacted by threat
	Low Impact (1)	• Minor or temporary disruption to cultural/traditional activities with no lingering negative impacts • Documented cultural and historic resources may have little to no damage due to threat
	Medium Impact (2)	• Resources required for community to continue with cultural/traditional activities and use of traditional sites • Documented cultural and historic resources may be damaged or lost due to threat • Damages caused by threat exposes previous unknown cultural and historic sites that may be subject to future damages
	High Impact (3)	• Traditional practices abandoned to focus solely on life-safety and survival • Documented cultural and historic resources have been damaged or lost due to threat • Damages caused by threat exposes previous unknown significant cultural and historic sites that are under immediate threat
Commercial Infrastructure (i.e., private enterprise, barge landings, quarries, ports)	No Impact (0)	• Threat does not affect commercial infrastructure • Community is not a hub
	Low Impact (1)	• Temporary impact to operability of commercial infrastructure
	Medium Impact (2)	• Threat has moderate impact on commercial infrastructure associated with overall community cash flow • Impact on commercial infrastructure operability may require external assistance • Loss of commercial infrastructure operability can be temporarily replaced
	High Impact (3)	• Threat has severe effect on commercial infrastructure associated with overall community cash flow • Commercial infrastructure operability is lost, cannot be replaced, and is no longer viable • Community is hub of good/services supporting other communities in region

During the analysis, each of the nine evaluation factors was given relative weighting consistent with the BEA to allow evaluation factors that put a community's viability at greater risk to have a larger influence on the aggregate rating. The highest relative weighting of 3 was applied to Critical Infrastructure, Health and Human Safety, and Environmental Threat. All weightings are shown in Table 4-3.

Table 4-3. Evaluation factors and relative weights.

Evaluation Factor	Relative Weight
Critical Infrastructure	3
Health & Human Safety	3
Subsistence & Shoreline Use	2
Land Use/Geographic Location	1
% Population Affected	2
Housing Distribution	2
Environmental Threat	3
Cultural Importance	1
Commercial Infrastructure	2

Following attribution of an impact rating for each of the nine criteria, those ratings were multiplied by the appropriate relative weight, then summed to form an Aggregate Impact Rating for each individual threat (erosion, flood, thawing permafrost) in each community. Those aggregate impact ratings were then multiplied by a time to damage rating to establish a relative community risk rating for each threat.

4.7 Time to Damage

While evaluating each community for the potential impacts of a threat from erosion, flooding, and thawing permafrost, the expert panel also considered the time to damage. Anticipated damage in the near term indicated a higher urgency than damage that may occur over the long term. For example, rapid erosion that may occur in the next 5 years would likely generate immediate action compared to erosion that occurs slowly over 20 years. In this evaluation, a value of 3 was ascribed to the most urgent threats with short term time to damage, a value of 2 was ascribed to mid-term processes, and a value of 1 was attributed to processes that are expected to impart impacts after a longer period of time.

Factors that informed the time to damage weighting include documented historic losses due to erosion, flooding, or thawing permafrost, such as state or federal disaster declarations. Other documentation used included self-reported damages such as information in the Community Development Plan or Hazard Mitigation Plan. For communities that had ratings pulled from the BEA for erosion risk, first iteration time to damage factors for erosion were also pulled from the BEA.

Mitigation features in the community, such as erosion revetments and levees, were also used to inform time to damage. Communities that have relocated due to devastating damage at an old town site were evaluated based on the time to damage at the current town site. If mitigation features were either temporary or ineffective, the time to damage factors were modified accordingly. Evaluating the time to damage for erosion and flooding was dependent on previously reported issues within the community and through research of available data.

Factors considered in the time to damage for erosion included the BEA, which informed the time to damage assessment for each community evaluated in that study. If new project data indicated that time to damage occurs quicker than the BEA predicted, the rating was adjusted accordingly. For those communities not included in the BEA, the time-to-damage assessment was conducted concurrently with the flooding time to damage using Hazard Mitigation Plans, Community Development Plans, and news articles.

General guidelines used in the time to damage consideration for flooding included:

- Disaster declarations for a community or region:
  - Three or more disaster declarations set the initial rating to 3 to represent a time-to-damage factor of the community being affected in the short term.
  - One or two disaster declarations set the initial rating to 2 to represent a time-to-damage factor of the community being affected in the mid-term.
  - No disaster declarations set the initial rating to 1 to represent a time-to-damage factor of the community being affected in the long term.
- National Weather Service river notes were reviewed to identify recorded flood events not considered a disaster:
  - If there was evidence that the community had a significant number of smaller floods, the time-to-damage factor was elevated by one rating (e.g., from 1 to 2), not to exceed the short-term rating (3).

The time to damage for thawing permafrost threats was universally attributed with the lowest rating (1) since thawing permafrost is a comparatively slow process, and engineers often have time to take corrective action before catastrophic damage occurs. Both construction of the infrastructure and climate change impact the rate of thawing in permafrost. Impacts due to the construction of infrastructure generally occur much more rapidly than damage resulting as the result of climate change. We note, however, that when thawing permafrost is influenced by erosion and/or flood, the resulting usteq threat could have a much shorter time to damage.

4.8 Calculating Risk and Normalized Scores

This study utilized a risk analysis approach (examination of individual risks from erosion, flooding, and thawing permafrost) across 187 communities throughout the state of Alaska. In the risk analysis, the **Aggregate Impact** ratings estimate the relative nature and magnitude of threat risk in each community, while the **Time to Damage** ratings estimate the likelihood/timing of the expected event. Together, these two factors provide the basis for the community Relative **Risk Rating**. The following relationship was employed to develop the risk rating:

Relative Risk Rating = Aggregate Impact * Time to Damage

The risk ratings above were calculated for the individual threats associated with erosion, flooding, and thawing permafrost. As described previously, however, another goal of this report was to develop an approach for calculating a composite risk rating. This was accomplished by summing the erosion, flooding, and thawing permafrost threats. Since the time to damage rating of the thawing permafrost threat was universally assumed to be 1, however, the highest possible risk rating for permafrost was lower than the highest possible risk ratings for erosion and flood. Thus, without further modification, the permafrost component of the combined rating would exert a comparatively smaller influence on the rating than would erosion or flood. For this reason, the ratings for erosion, flooding, and thawing permafrost were first normalized using the following equation so that the scale would be consistent between each of the risk factors:

Normalized Score = 100*(Risk Rating/Maximum Possible Rating)

The normalized scores within each threat category are plotted and presented in Figure 5-1 through Figure 5-7. Those normalized scores were also used to order and rank the communities from highest to lowest risk rating. In each category, communities with a rank of 1 were associated with the highest threat level. Note that in some instances, multiple communities had identical normalized scores, and thus were ascribed with identical ranks.

In order to better visualize the distribution of the data, the normalized scores were plotted against the score percentile in Figures 5-1 through 5-4. The percentile was calculated using the following equation:

Score Percentile = (Community Rank Value/Total Number of Discrete Rank Values) * 100

Consideration of the data via the techniques described above provided the means with which to categorize communities into groups associated with high, medium, or low risk to the individual threats of erosion, flooding, or thawing permafrost. It also allowed the study team to characterize the combined threat as the aggregation of the individual threats. Detailed results are presented in Chapter 5.

4.9 Analytical Process Schematic

This chapter described the process by which raw data were evaluated and employed to determine the relative threats imposed by erosion, flood, and thawing permafrost for 187 rural Alaska communities. The process is summarized in Figure 4-1. The figure is intended to represent the generic process applied to each of the three individual threats independently. We note that the combined risk rating, while represented in the process diagram, requires input information from all three threats. As there are numerous steps in the process, this report does not present the intermediate steps on a community level basis. However, that information was provided to the Denali Commission in the form of spreadsheets. In Chapter 5, the normalized community risk rating scores as well as the uncertainty estimates are presented in aggregate in order to provide the readers with a summary of the data distribution and level of uncertainty. The individual community rankings and group designations are presented as maps in Chapter 5 and listed by community in Appendix A.

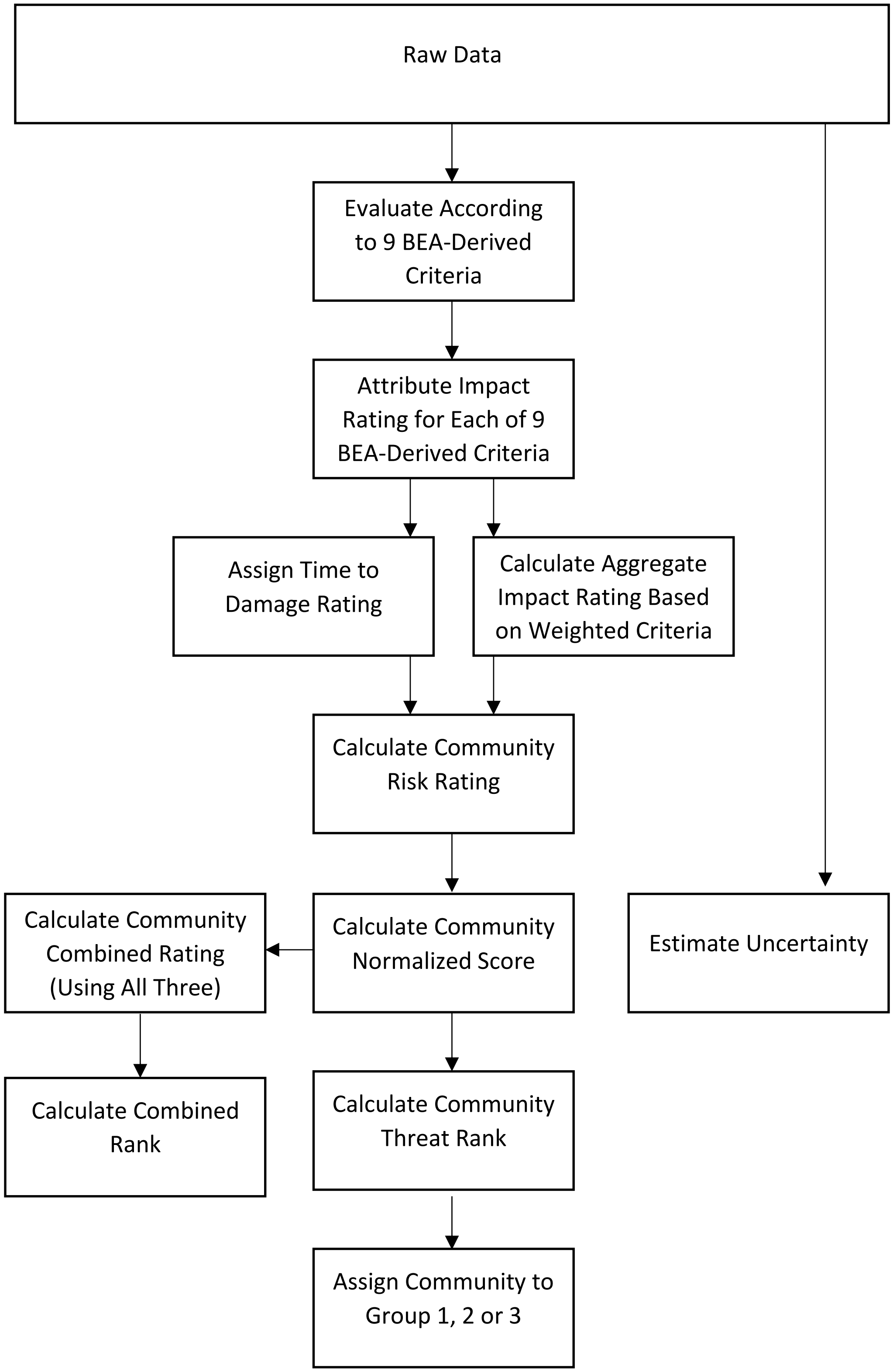

Figure 4-1 Analytical process diagram for evaluating threats from erosion, flood, and thawing permafrost.

4.10 Example of Community Scoring and Ranking

An example of the scoring process is provided here for clarification. For the purpose of this exercise, assume a hypothetical community named MyCommunity which is in Western Alaska and has been scored by the study team using the process described in this report. The scoring for erosion in MyCommunity is provided in Table 4-4.

Scores shown in Column B represent the scores assigned by the study team for each of the nine BEA-derived criteria shown in Column A.

The Impact Ratings in Column B are multiplied by the Factor's Relative Weight to derive the Weighted Impact Ratings shown in Column D. The Relative Weights were obtained from Table 4-3. A summation of the Weighted Impact Ratings results in the Aggregate Impact Rating at the bottom of Column D.

The Time to Damage is short term, so the value assigned is 3. That value is multiplied by the Aggregate Impact Rating to get the Community Risk Rating of 126.

The Normalized Score of 74 is then determined by dividing the Risk Rating by the maximum value for Erosion, 171, and multiplying the result by 100. Comparing the normalized score to the cutoff value of 43, it is determined that MyCommunity lies in Group 1 for erosion. Additional information regarding the development of cutoff values is provided in Sections 5.2 and 5.3.

Figure 5-1 indicates that the erosion threat ranking of MyCommunity would be approximately 23. The ranking is approximate since each time a community is added or altered; the ranking must be updated by including a new community or modifying an existing community and performing the ranking procedures.

This process would then be repeated for flooding and thawing permafrost to determine the Normalized Score for each of MyCommunity's individual threats. The combined score would be the sum of the threat scores for each threat.

Table 4-4. Erosion scoring example for MyCommunity.

A	B	C	D	E	F	G	H
Evaluation Criterion	**Impact Rating**	**Criterion Relative Weight**	**Weighted Impact Rating (B*C)**	**Time to Damage**	**Risk Rating (D*E)**	**Normalized Score (100*(F/ Max Possible Score)**	**Group**
Critical Infrastructure	3	3	9				
Health & Human Safety	2	3	6				
Subsistence & Shoreline Use	1	2	2				
Land Use/Geographic Location	1	1	1				
Population Affected	2	2	4				
Housing Distribution	2	2	4				
Environmental Threat	3	3	9				
Cultural Importance	1	1	1				
Commercial Infrastructure	3	2	6				
Aggregate Ratings			**42**	**3**	**126**	**74**	**Group 1**

Chapter 5.0 Communities at Risk

5.1 Overview

Following development of the normalized community scores and community ranks for each threat, the data were plotted, evaluated, and grouped according to the relative threat level. Communities placed in Group 1 were under the greatest threat from erosion, flood, or thawing permafrost, while communities placed in Group 3 were the least threatened. Group 2 communities were associated with a moderate threat. The distribution of groups is presented in Figure 5-1 through Figure 5-3, and the number of communities within each group is presented in Table 5-1. Note that there are fewer than 187 individual points on those figures because in many cases, an individual point represented an identical score for multiple communities. Criteria for development of each group were based on immediacy, impact, the presence of life safety concerns and required support from outside the region. Those criteria are described more fully in Section 5.2 for erosion and flood threats, and Section 5.3 for the threat of thawing permafrost.

The level of uncertainty associated with the normalized community scores was estimated based largely upon the amount and quality of raw data available. The notion of uncertainty is described more fully in Section 5.4, and the distribution of uncertainty is plotted in Figure 5-4 through Figure 5-6. While uncertainty was not employed as a factor in the calculation of community rankings or groupings, it does provide useful context for the interpretation of results.

No effort was made to parse the combined ranking into groups. Due to the complexity of the threat, the study team did not consider the uncertainty of combined predictions to be comparable to the uncertainty of the report's erosion, flooding, or thawing permafrost threats. However, the combined rankings are useful in identifying those communities which are impacted by multiple threats, thus highlighting the conditions under which usteq may occur. Section 5.5 presents additional information regarding the characterization of usteq, and the ungrouped distribution of normalized combined scores is presented in Figure 5-7.

Section 5.6 presents maps of the community groupings for erosion, flood, and thawing permafrost (see Figure 5-8 through Figure 5-10). In addition, the section provides a map illustrating the distribution of combined rankings across Alaska (Figure 5-11).

5.2 Erosion and Flooding Groupings

The methodology employed to rate the communities by the risk of damages from flooding and erosion was intended to capture the different nature of the two threats. Flooding is typically temporary while erosion is compounding, but one threat does not pose more serious risk to infrastructure than the other. All differences in likelihood and time to damage are captured within the individual risk ratings for each community. As a result, the study team used the same group break points for both flood and erosion. For both, communities with normalized threat scores of 43 or higher were placed into Group 1. Communities with normalized threat scores ranging from 20 through 42 were placed in Group 2, and communities with normalized threat scores below 20 were placed into Group 3. The distribution of these groups is presented in Figure 5-1 and Figure 5-2 for erosion and flooding, respectively.

The designation of the group break points was based largely upon the collective judgment of the study team, as well as upon the distribution of the data. Those break points are visually evident as natural breaks in the curves presented in Figure 5-4 and Figure 5-5. Due to the inherent uncertainties in the analysis, however, a community's group designation should be interpreted as a guide rather than a steadfast descriptor. Communities that fall close to a break point may well merit re-categorization with the addition of more data.

While the impact and time to damage ratings that determined a community's normalized score varied widely from community to community, the members of each threat grouping shared a largely common set of characteristics. The general characteristics of each erosion and flood group are described below:

Group 1 (Erosion and Flooding):
The threat is commonly immediate to critical infrastructure. Damages resulting from a moderate flood or compounding erosion would impact community sustainability, present life safety concerns, affect access to emergency services, and/or require support from outside the region to assist the community in responding to the event. Communities that are included in Group 1 should direct resources towards determining the best response to the threat. Note that a community must have a short or mid-term time to damage rating to be included in Group 1.

Group 2 (Erosion and Flooding):
The threat is not expected to detrimentally impact critical infrastructure in the near term, but the community is still vulnerable to the threat. Damages resulting from a moderate flood or compounding erosion could impact operability for a limited period but would not impact the community's sustainability. An extreme event may cause damages like those described as the impact of a moderate event in Group 1. More research and data collection should be conducted to better understand the threat posed to the community. Note that a community can have a time factor of long or mid-term to be included in Group 2, depending on the severity of damage to critical infrastructure expected if an event occurs.

Group 3 (Erosion and Flooding):
There is no information available that indicates a threat to critical infrastructure or to the viability of a community, or there is low likelihood that a threat will detrimentally impact the community in the near term. If communities in Group 3 experience threats, they should notify officials and collect data to support understanding the impacts. The time to damage is predicted to be long for all communities in Group 3.

5.3 Thawing Permafrost Groupings

Communities threatened by thawing permafrost were grouped by assessing the potential impact of the threat. Included in the assessment were ice content within the soil, the likely distribution of permafrost within the community, the temperature of the permafrost, anticipated thaw settlement, and known problems. Communities with a normalized permafrost threat score of 61 or higher were placed into Group 1. Group 2 was comprised of communities with normalized permafrost threat scores ranging from 42 through 60. Group 3 communities have normalized scores less than 42. The distribution of these groups is presented in Figure 5-3.

Similar to erosion and flooding groups, the communities in each permafrost group tended to share a generally common set of characteristics. These characteristics are described below:

Group 1 (Permafrost):
Risk of damage due to thawing permafrost is high. Ice-rich permafrost is prevalent beneath the community. Thaw settlement is anticipated to be large. Damage to existing infrastructure as a result of thawing permafrost is likely known. The permafrost temperature may be above -2°C but risk of damage also may be extremely high even in the areas with cold permafrost if large near-surface bodies of ground ice (e.g., ice wedges) are affected or may be affected in the future by thermokarst and/or thermal erosion.

Group 2 (Permafrost):
Risk of damage due to thawing permafrost is moderate. Permafrost usually has moderate ice content where thaw settlement is anticipated to be moderate. Reported damage due to thawing permafrost is moderate. Underlying permafrost may be discontinuous.

Group 3 (Permafrost):
Risk of damage due to thawing permafrost is low or nonexistent. Underlying permafrost is sporadic; nonexistent or underlying soils are ice-poor, thaw stable materials such as sandy gravels. No or minor damage has been reported.

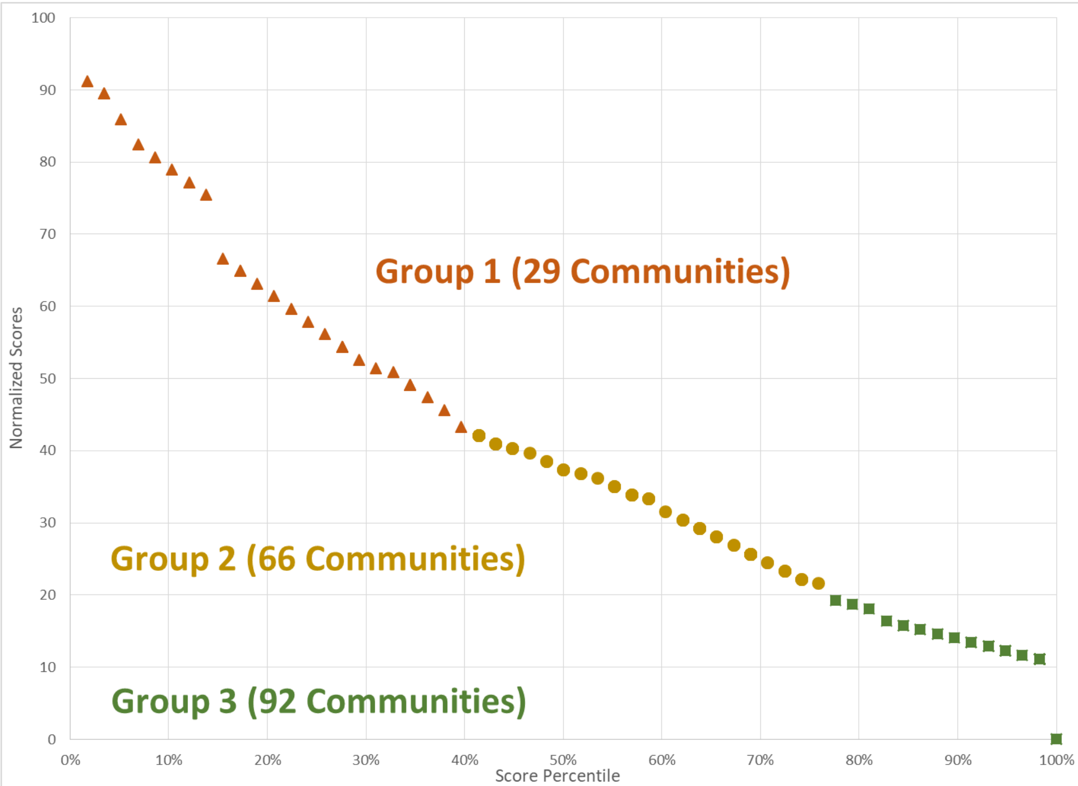

Figure 5-1. Cumulative distribution curve for erosion, illustrating groupings.

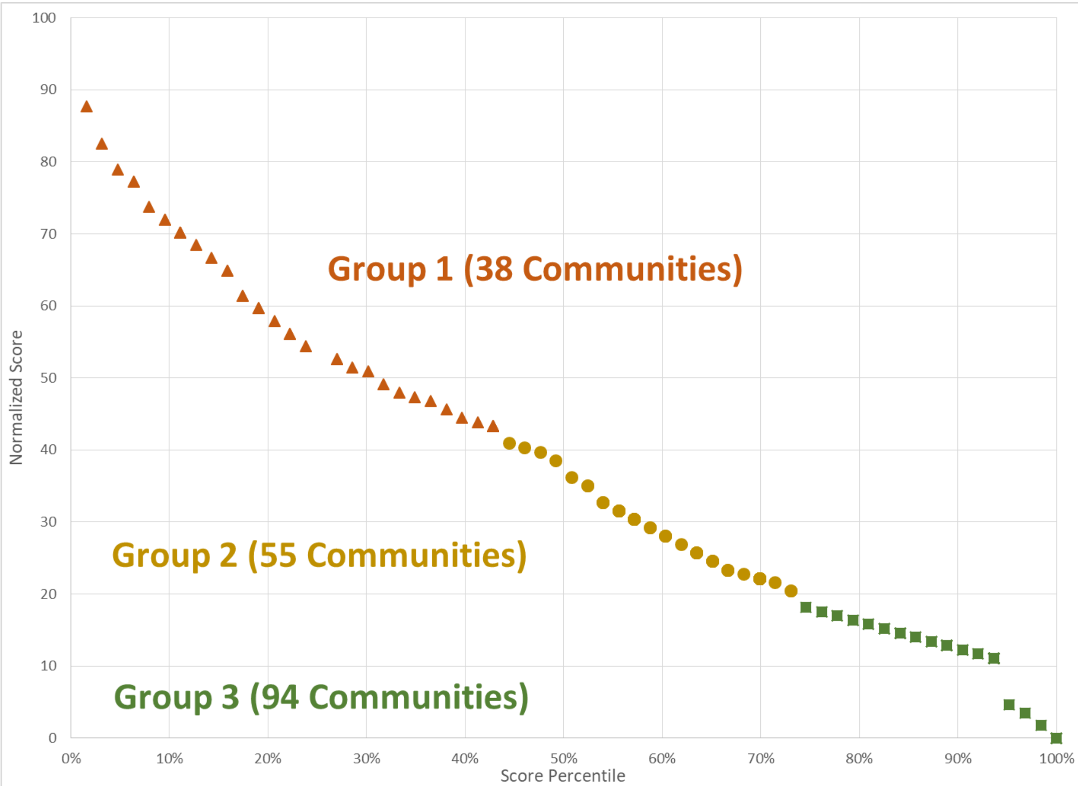

Figure 5-2. Cumulative distribution curve for flooding, illustrating groupings.

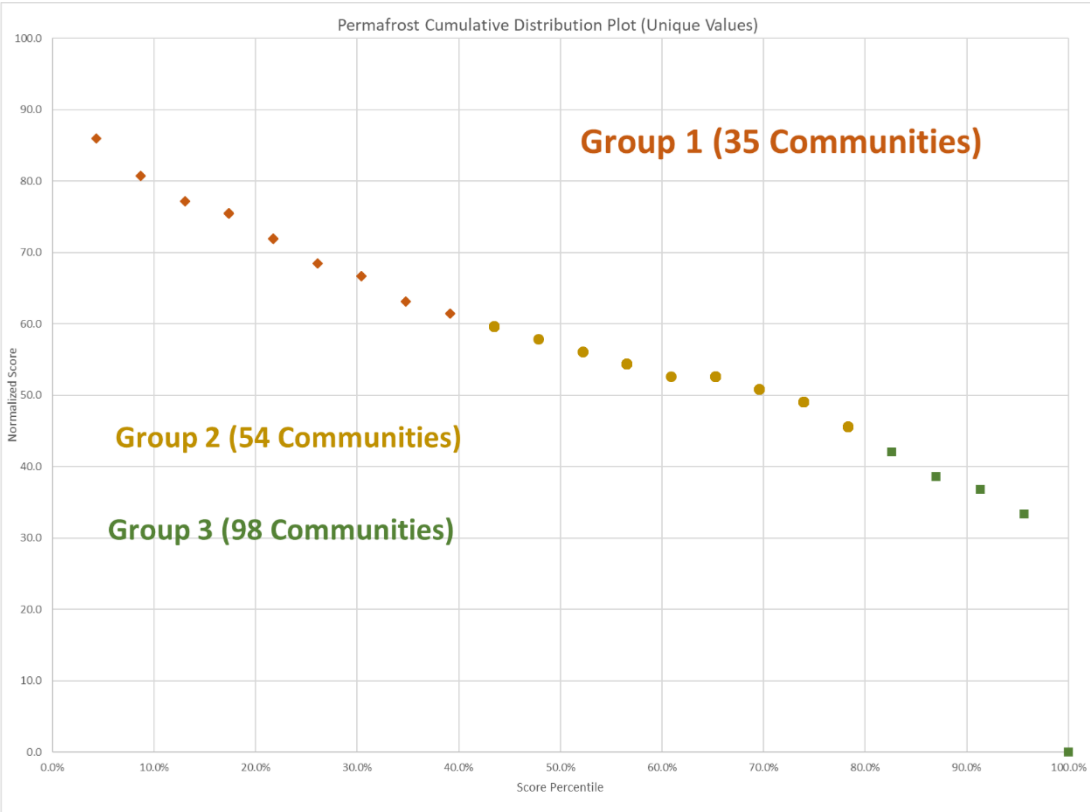

Figure 5-3. Cumulative distribution curve for thawing permafrost, illustrating ratings.

Table 5-1. Number of communities in each group for erosion, flooding, and thawing permafrost.

Communities in Group			
Group	**Erosion**	**Flooding**	**Thawing Permafrost**
Group 1	29	38	35
Group 2	66	55	54
Group 3	92	94	98

5.4 Uncertainty

Uncertainty is directly correlated with the quality and quantity of available data. For each community, an uncertainty "star score" was applied. This method allowed the expert panel to assess communities individually, but to denote any relative uncertainty within the assessment. The uncertainty star scores were converted into percentage of uncertainty. The weighted (excluding time to damage) scores were then multiplied by this percentage to create an uncertainty range for each community. The categories employed to evaluate uncertainty are presented below:

1% (***) Relative high amounts of high-quality data were available.

34% (**) Data were available but lacked either quality or quantity.

67% (*) Relatively little data were available.

Uncertainty does not factor into final groupings. The purpose of including uncertainty estimates in the analysis is to illustrate the point that many communities could potentially fall into a different threat group or be ranked at a different level with the addition of supplementary data.

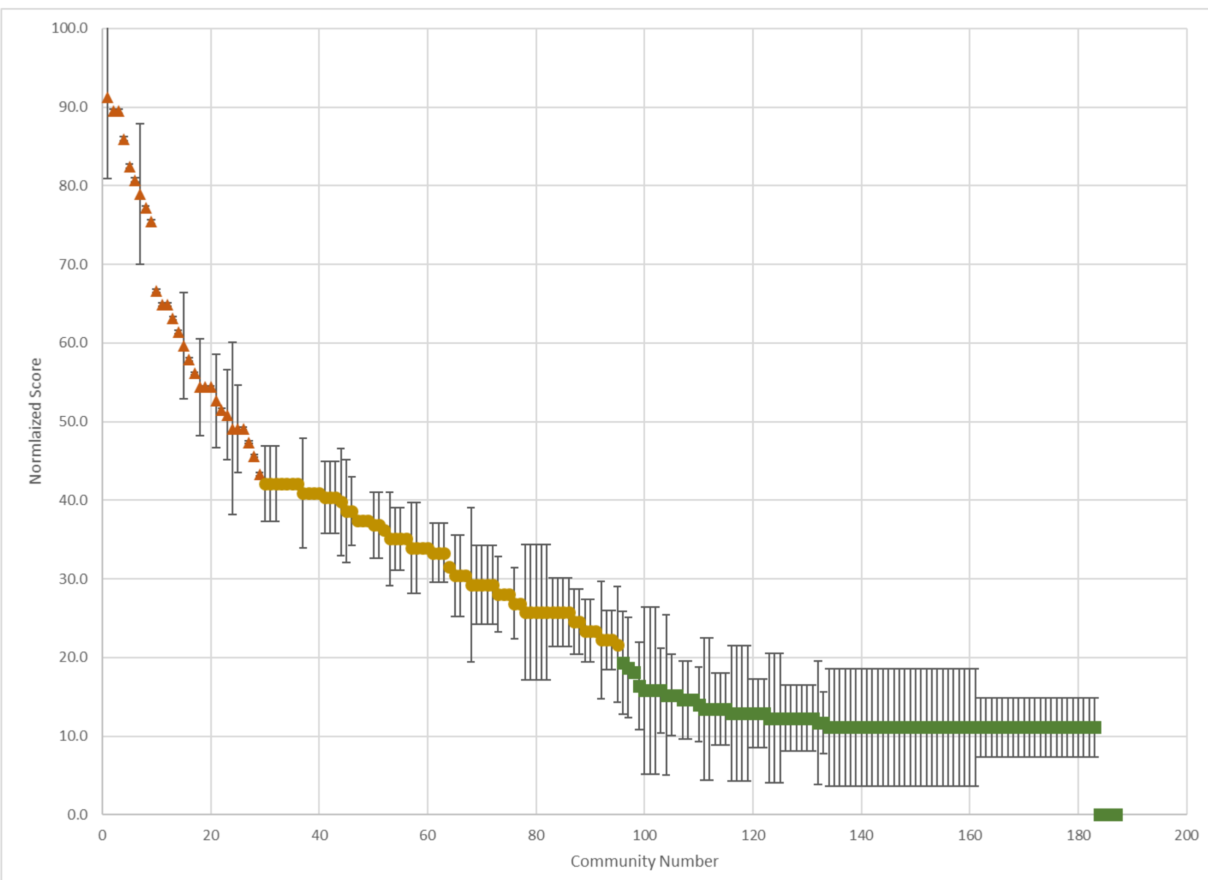

Figure 5-4. Uncertainty estimates associated with erosion.

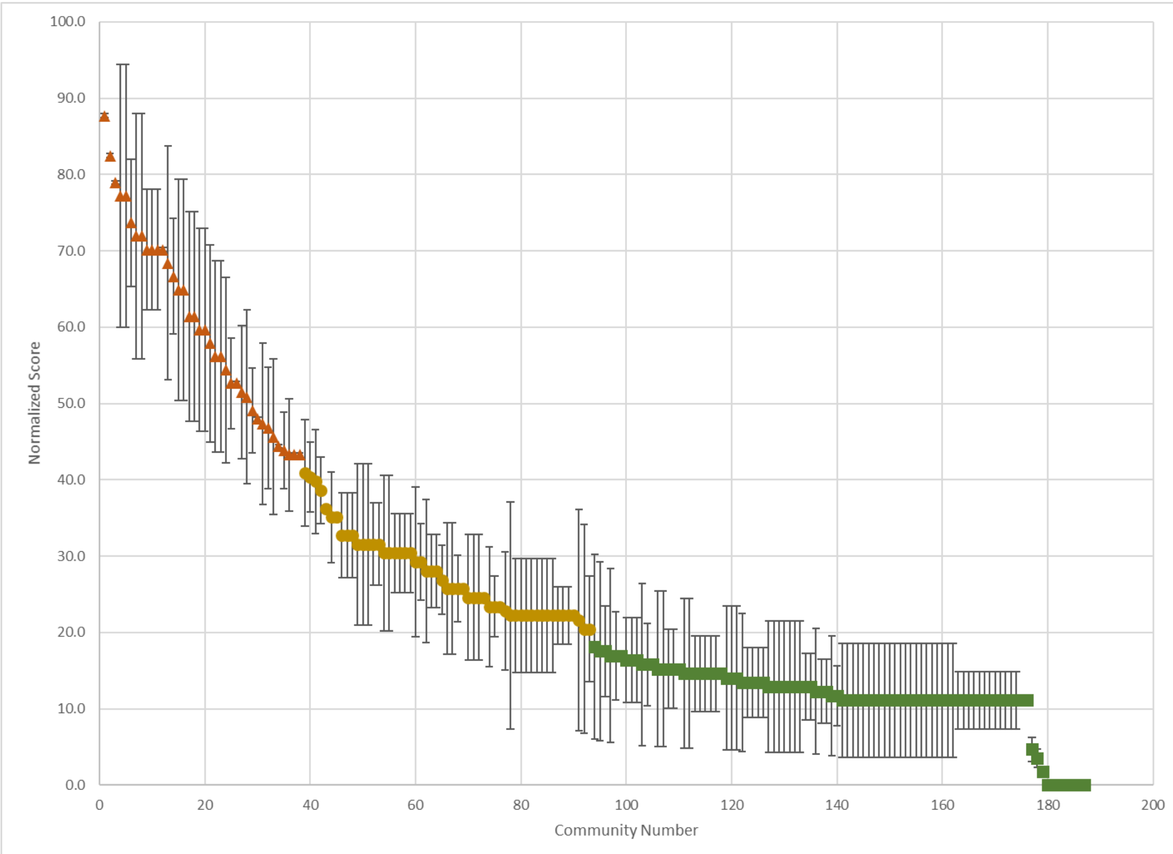

Figure 5-5. Uncertainty estimates associated with flooding.

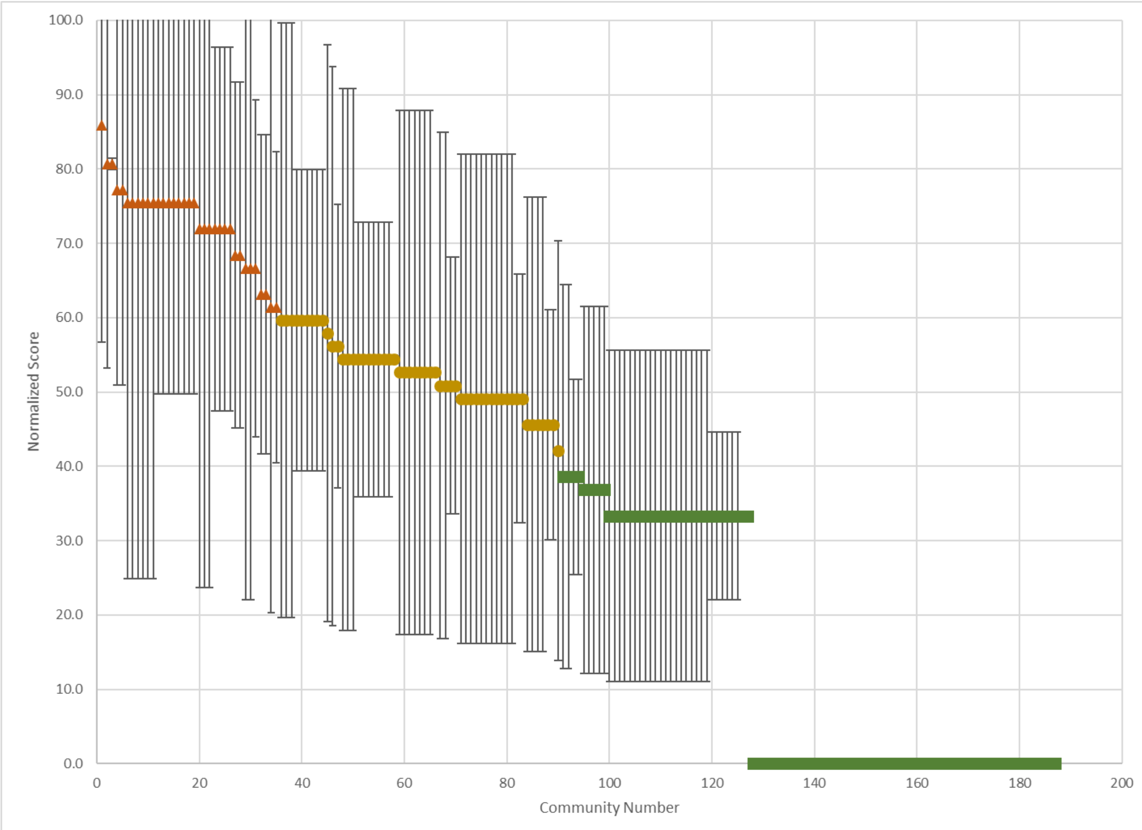

Figure 5-6. Uncertainty estimates associated with thawing permafrost.

5.5 Combined Risk Ratings

Thus far, the focus has been on individual threats. However, it is likely that whenever there are combined threats, the risk of damage may increase because of the escalating feedback between the individual threats. When permafrost is involved, this dynamic has previously been defined as usteq. For example, it is known that permafrost ground ice content is highly heterogeneous, and the amount of ground ice can have a significant effect on the rate of erosion, whether it be massive ice such as observed in ice wedges, or matrix ice binding the soil particles together. There are case studies, including community Hazard Mitigation Plans that document the impacts of usteq, but no literature known to the study team that predicts future processes when erosion, flooding and ice rich permafrost are present. Thus, the characterization of combined risk ratings in this report is not necessarily intended to serve as a predictive tool, but rather as a quantitative description of the conditions under which usteq may occur.

The consensus of the study team was that the ratings of each threat should be added together, though the group recognizes that in some cases this may under-predict the impact of any combination of the threats. However, without additional supporting literature, a simple summation of the normalized threat ratings was deemed appropriate. As described in Section **Error! Reference source not found.**, s cores were normalized prior to summation in order to discount the longer times to damage associated with the permafrost threat alone. When combined with erosion and flood, the permafrost-associated time to damage can be very short. Figure 5-7 presents a plot illustrating the cumulative distribution of combined ratings for the communities evaluated.

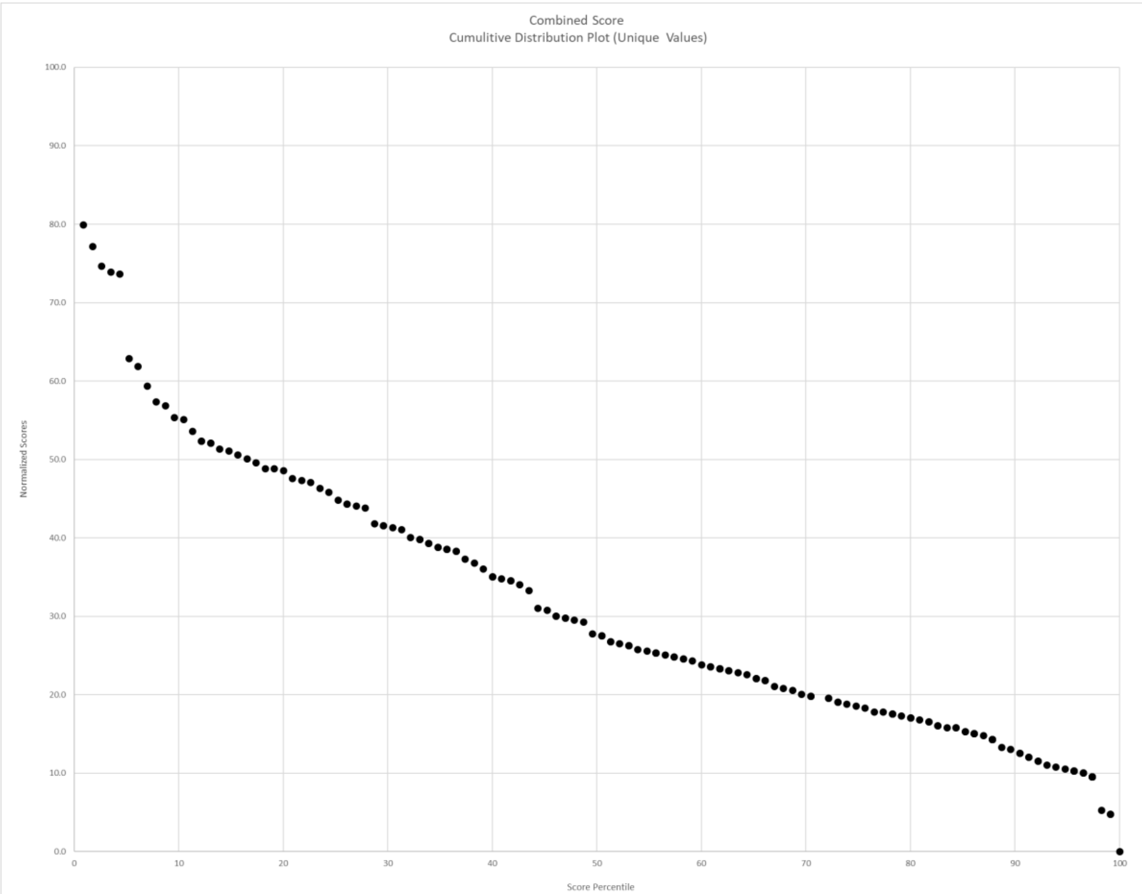

Figure 5-7. Cumulative distribution plot for normalized usteq threat.

The utility and potential drawbacks of the combined ratings are best illustrated through the use of an example. In Figure 5-7, the top five points represent Shaktoolik, Shishmaref, Kivalina, Golovin, and Napakiak. Those communities were attributed with notably higher normalized scores than the other communities. Conspicuously missing is Newtok, which ranks seventh. A closer examination of the individual threat ranking shows Newtok ranks first for the threat of erosion, first for the threat of thawing permafrost, and forty-first for the threat of flooding. Due to its comparatively low score for flood threat, Newtok's resulting combined score was somewhat lower than the top five. However, as noted in Section 4.3, Newtok is clearly impacted by usteq. In Newtok, it is the combination of erosion in ice-rich permafrost that presents an immediate and ongoing threat. While consideration of the combined rating alone would not place Newtok at a higher level of risk compared to the top five, the influence of usteq acts as a driver for Newtok's well-documented erosion threat.

This example illustrates the importance of employing the threat rankings for their intended purpose - to identify those communities that require a detailed investigation of threats from erosion, flooding, and thawing permafrost. The reader is reminded that the groupings of each threat were based on the potential for damage from that threat over time. The combination of threats as represented by the combined ranking provides some insight into how these threats may combine to accelerate or increase the damage. Consequently, those communities with higher combined scores generally have higher potential for damage.

We recommend that information provided in the individual threat ratings and groupings be used to provide an understanding of the risk due to each threat. The combined score can provide insight into how the threats may compound and when usteq might occur. Using the information, policy makers can determine whether additional data and analysis are required to suggest a course of action.

5.6 Maps

Figure 5-8 through Figure 5-11 provide maps indicating the risk ratings for each community evaluated. These maps provide a regional overview and a means with which to compare an individual community with neighboring communities.

The greatest threat of erosion tends to exist along the western coastline and near the mouth of larger rivers (Figure 5-8). This is consistent with the conclusions of the previous reports. It also confirms the impacts of the loss of early and late season sea ice along Alaska's western coastline.

The vulnerability of communities to flooding is a bit less clear (Figure 5-9). Most communities in Group 1 are located along Yukon and Kuskokwim rivers, or along the coast which may flood due to storm surges. Even so, many of the nearby communities have relatively low vulnerability, likely because they are on higher ground.

The distribution of communities in Group 1 for thawing permafrost tend to be located either along the western coastline or in areas of continuous permafrost (Figure 5-10). At first, this appears to be counterintuitive. One would think that the Interior and the Copper River basin would be more susceptible to risks associated with thawing of ice-rich warm permafrost. However, engineers tend to avoid building on permafrost when possible. As a result, most infrastructure in areas of sporadic or discontinuous permafrost are not found on permafrost at all. Moreover, infrastructure that must be built on warm permafrost is often engineered with the expectation that the permafrost will thaw, thus reducing the threat of damage. At the same time, many communities of Group 1 are located in the areas with cold continuous permafrost. They are included in this group because they experience significant problems related to thawing of large ice wedges that form very close to the surface and therefore are extremely vulnerable to thermokarst (Kanevskiy et al., 2019).

Figure 5-11 provides a map of the combined threat for the communities evaluated in this study. The communities with the greatest combined threat are dark red while the communities with the lowest combined threat are shown in dark green. The color gradient shown in the legend depicts the relative ranking of all communities. As might be expected the communities with the greatest combined threats, and the highest potential for usteq, tend to be along the western coastline. The communities that have a combined threat shown in orange tend to be along the Yukon and lower Kuskokwim Rivers. This roughly corresponds with the Group 2 for erosion, flooding and thawing permafrost threats.

These trends are consistent with the trends published in regional maps that have been produced in other studies, such as Hong (2004). However, the detail provided by these maps illustrates the importance of evaluating each community individually rather than relying upon regional generalizations.

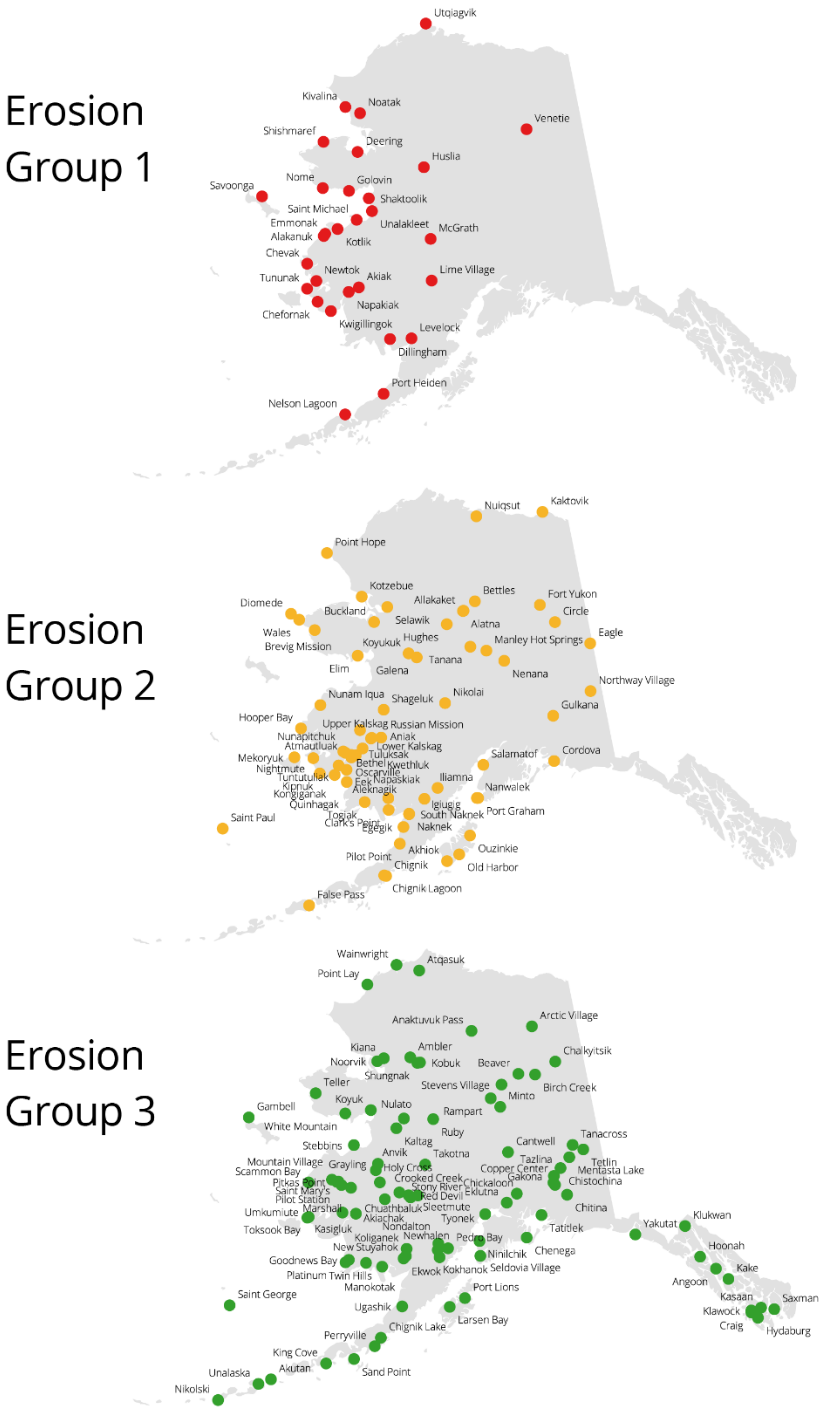

Figure 5-8. Erosion threat risk maps (prepared by Erin Trochim, Alaska Climate Adaptation Science Center).

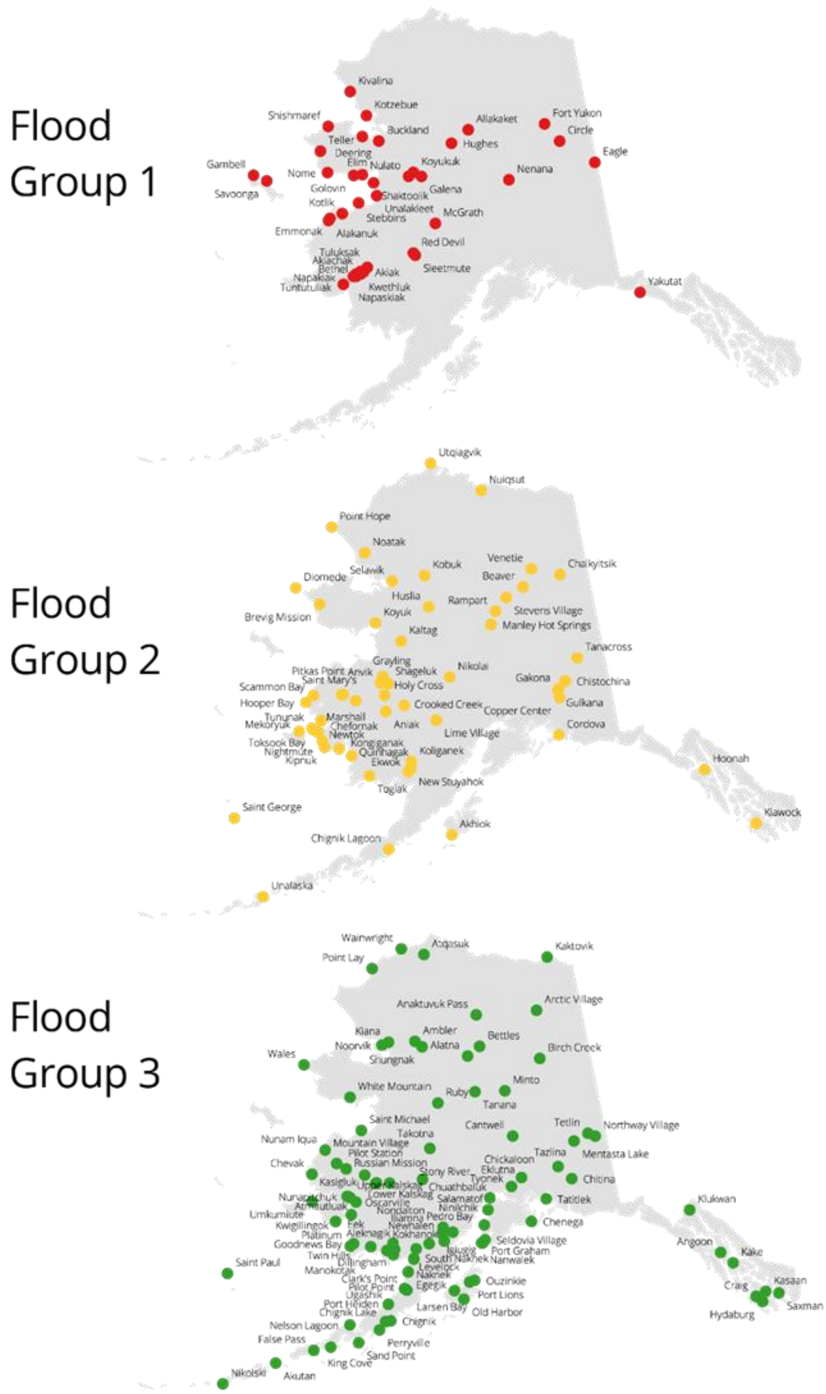

Figure 5-9. Flooding threat risk maps (prepared by Erin Trochim, Alaska Climate Adaptation Science Center).

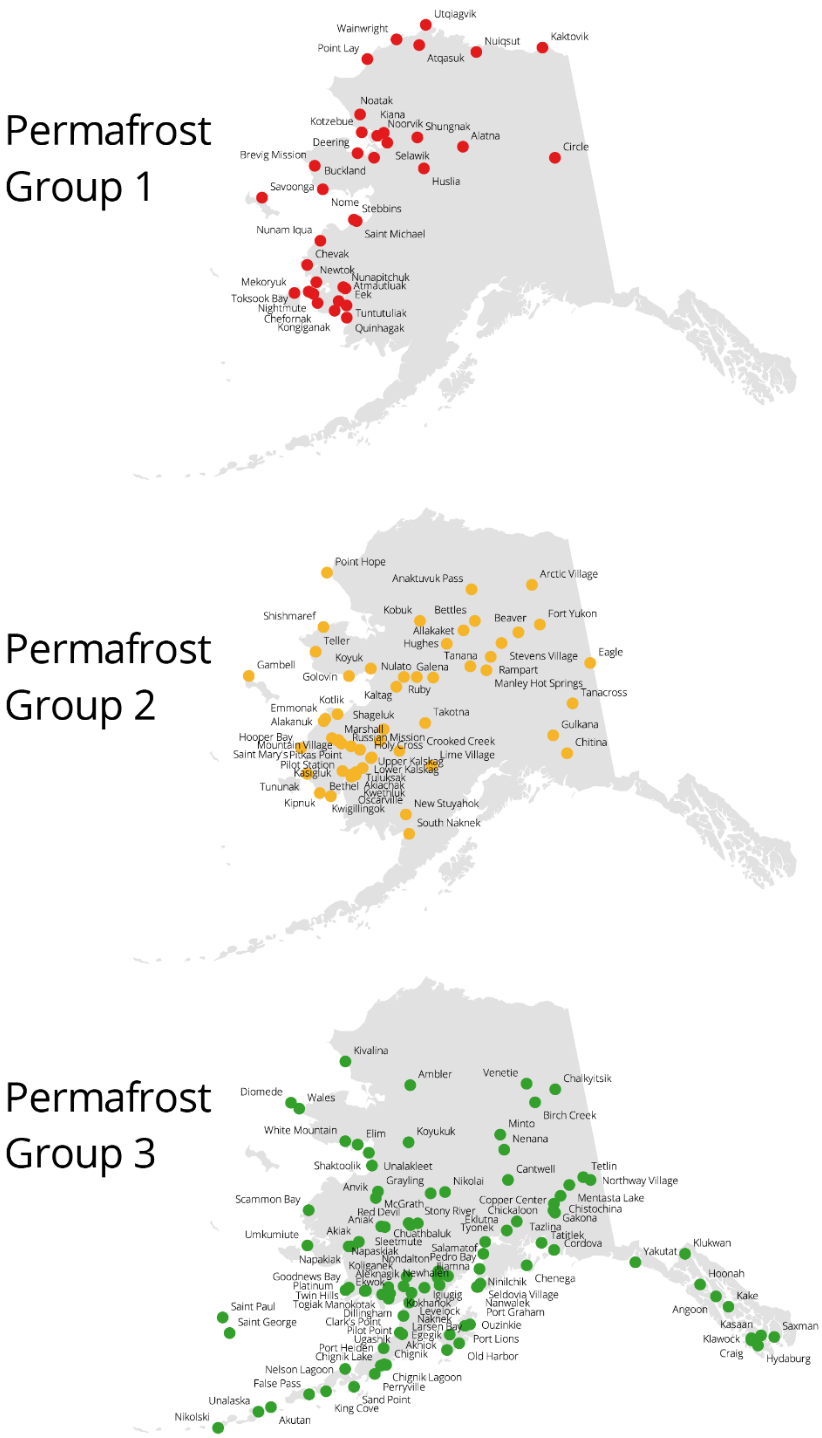

Figure 5-10. Thawing permafrost threat risk maps (prepared by Erin Trochim, Alaska Climate Adaptation Science Center).

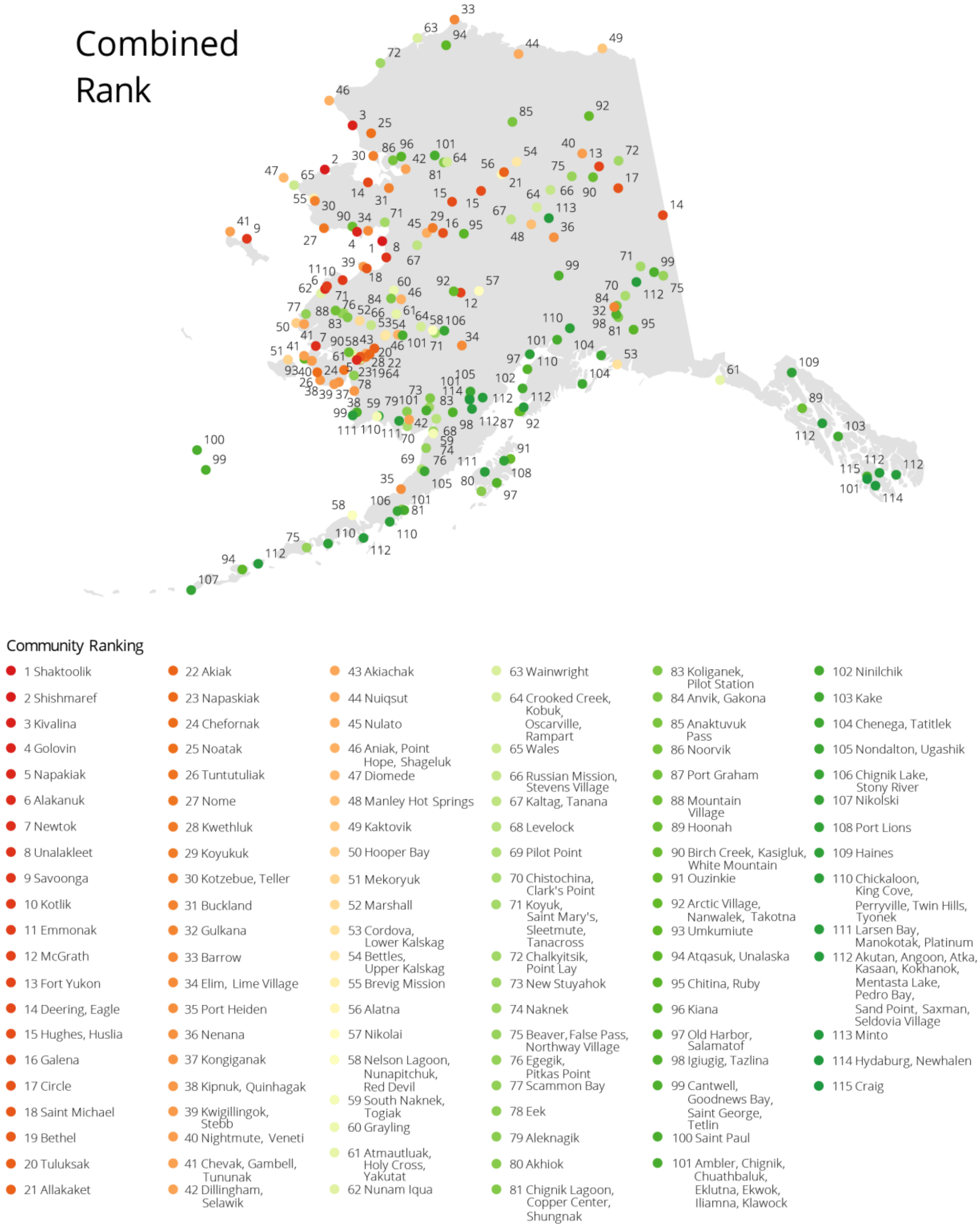

Figure 5-11. Combined threat risk maps (prepared by Erin Trochim, Alaska Climate Adaptation Science Center).

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Chapter 6.0 Recommendations

The purpose of this study was to evaluate the relative risk to rural Alaska communities resulting from erosion, flooding, thawing permafrost and usteq using only existing, readily available data, and to provide guidance regarding how best to measure and further understand those threats. The methodology used protocols developed under the 2009 BEA, with modifications as described in Chapter 4.0.

The data set used in this study will not remain static. As new data become available, the ratings should be periodically updated based on the procedures outlined in this report. The procedures should be reviewed and modified as new data and new knowledge become available, and as new regulations take effect.

It is important that the reader understand that this study does not identify actions necessary to reduce risk due to the rated threats. The study, within the limits of available data, identifies relative risk amongst communities that are facing environmental threats and as a result identifies those that warrant additional analysis to fully understand the nature of the threat and recommend an appropriate course of action. Those communities that are Group 1 due to any of the identified threats should invest additional analysis to parse their community specific threats and identify mitigation actions. If the community is in Group 1 for multiple threats, the data collection plan should account for interaction between the threats.

The following sections describe generalized data collection efforts intended to more fully characterize a threat, or to develop mitigation plans for individual communities. We recommend that federal and state agencies invest in these site-specific studies to aid communities with the development of informed solutions. For instance, such studies would help to evaluate whether it would be more effective for an individual community to relocate, or instead protect in place. Federal and state investment will also help agencies understand the magnitude of the issue in rural Alaska.

The data collection efforts described below should be considered and adopted as appropriate based on existing information and resources available. We recommend the focus be on communities identified as Group 1 communities for each threat and/or for the communities with relatively high combined ratings. It is important that impacts of our changing climate be included in all analysis. Where practical, standards should be established for data collection and analysis to ensure these products are easily compared. Appendices B-D contain suggested scopes of work developed by the Denali Commission to aid communities in the collection of required data. The scopes of work should be modified for each community to capture the data needs of that community. Sections 6-1 through 6-4 provide a suggested list of data elements required for a full analysis of threats and the interaction of those threats.

It is important the community be part of the data collection, analysis and the development of mitigation efforts. Experience has demonstrated that local knowledge provides invaluable information to external planners. Further, the final recommendations require community endorsement.

6.1 Coastal Erosion

Erosion is frequently considered the most critical threat since the consequences are often immediate and typically irreversible. Since the processes for coastal and riparian erosion are different, the recommended next steps will be discussed separately. As discussed in Chapter 3, coastal erosion often occurs in those communities in Western Alaska along the Bering Sea. Wave action, primarily due to fall storms have increased due to the lack of sea ice which has historically protected against the formation of erosive waves. Twenty-two communities located on the west coast have been designated as Group 1 communities threatened by erosion. The following actions are recommended for those communities.

1) Map the existing coastline.
2) Identify the anticipated frequency and severity of storms that may adversely impact those communities. This may be done on a regional basis.
3) Estimate the anticipated water surface elevation for storm surges for the 10%, 4%, 2%, and 1% annual exceedance probability.
4) Estimate erosion for 5, 10, 20 and 30 years into the future considering anticipated changes in climate, sea level rise, tidal data and geology using data available from SNAP at the University of Fairbanks.
5) Identify infrastructure and cultural features that may be adversely impacted.
6) Identify potential mitigation strategies including plans for community growth that reduces those impacts.
7) Update the threat analysis outlined in this report using the data collected

While some of this information is available for some communities, for many, these data are not yet available. When possible an area-wide data collection effort will serve the region. However, when community specific data are required, that data must be collected or estimated. A proposed scope of work which can be used to contract collection of coastal erosion information was prepared by the Denali Commission and can be found in Appendix B.

6.2 Riparian Erosion

Riparian erosion is discussed in Chapter 3. Since Alaskan rivers are generally braided, channels may change rapidly as flows change. The most rapid changes will often occur during periods of increased flow as the result of precipitation, snowmelt, or glacial melt. Prediction of short-term linear erosion rates is relatively straightforward. Prediction of long-term erosion is more difficult; however it is needed in order to inform long term decision making. For example, the maximum extent of predicted erosion will help determine whether a community can mitigate via managed retreat or whether a complete community relocation is required.

1) Map the existing shoreline.
2) Determine historical linear erosion rates and delineate short-term threats to community infrastructure.
3) Identify primary factors driving active erosion (geomorphic and anthropogenic).
4) Estimate flows and velocities at which significant erosion occurs. Note these may be lower than those occurring at flood stage.

5) Identify the annual exceedance probability of these flows.
6) Establish long-term erosion projections based on hydrologic and hydraulic modeling for 5, 10, 20 and 30-year horizons.
7) Identify infrastructure and cultural features that may be impacted.
8) Evaluate the effectiveness and feasibility of structural mitigation measures (barriers and bank stabilization)
9) Evaluate the relative efficacy of non-structural mitigation measures (e.g. managed retreat away from erosion threat) in comparison to structural measures.
10) Determine the long-term viability of the current community site based on model projections.
11) Develop recommendations for both near-term and long-term mitigation measures.
12) Update the threat analysis outlined in this report using the data collected

A proposed scope of work which can be used to contract collection of riparian erosion and flooding information was prepared by the Denali Commission and can be found in Appendix C.

6.3 Flooding

While the exact timing of flooding cannot be predicted, the chances of flooding occurring in any given year can be estimated. The probability of exceeding a specified water surface elevation due to a flood event in any given year is referred to as an annual exceedance probability. Associating the water surface elevation with the annual exceedance probability allows one to relate damage in the community and where that damage may occur. The following recommendations relate to the completion of an analysis to evaluate flood water surface elevation and return period.

1) Collect bathymetric or river cross-section data for the area of interest.
2) Establish a tidal determination for tidally influenced areas or a base flow elevation for interior rivers.
3) Estimate frequency and severity of storm systems and analyze wave dynamics.
4) Estimate relative sea level rise.
5) Utilizing hydrodynamic modeling, estimate the water surface elevation for return periods of the 10%, 4%, 2%, and 1% annual exceedance probability and develop flood maps for each annual exceedance probability.
6) Identify infrastructure and cultural features that will be impacted by elevated water events.
7) Develop a community plan that recognizes these events. Note that the water elevation of concern may vary for different infrastructure. For example, minor drainage structures may be designed for water levels associated with the 10% annual exceedance probability, while major drainage structures may be designed for water levels associated with the 4% or 2% annual exceedance probability. Critical infrastructure such as schools, clinics, and airports should be located above the water elevation associated with the 1% annual exceedance probability.
8) Determine the long-term viability of the current community site based on model projections.
9) Develop recommendations for both near-term and long-term mitigation measures. Identify mitigation strategies that minimize the impact of flooding. This may include improvements to

drainage, protective embankments, establishment of minimum first floor elevations for structures and/or other flood proofing measures, etc.

10) Update the threat analysis outlined in this report using the data collected.

A proposed scope of work which can be used to contract collection of riparian erosion and flooding information was prepared by the Denali Commission and can be found in Appendix C.

6.4 Thawing Permafrost

Evaluation of threats from thawing permafrost is the most data intensive of the three threats because of the spatial variation of soil profiles at many sites. This is the reason geotechnical investigations are required for each public building. Geotechnical data for linear infrastructure, such as roads and airports or utility distribution systems, are generally collected in sufficient detail to characterize segments along the route. Nonetheless, there are still numerous instances in which sufficient geotechnical data have not been collected. Moreover, it is unrealistic to assume the burden of such detailed data collection efforts for all existing infrastructure. However, it is realistic to perform an inventory of the infrastructure to record existing distress and to identify potential future damage. If geotechnical data are available, the data should be included in the analysis. If additional geotechnical data is required, the collection of that information should be tied to a specific purpose.

Detailed understanding of the threat from thawing permafrost requires that a qualified team inspect the infrastructure site. It is suggested that the following data be collected and analyzed.

1) Develop and implement a community geotechnical investigation plan that will incorporate existing geotechnical data along with geophysical data to characterize the soil profiles in the community. The purpose is to identify those areas which contain ice rich permafrost and the location of ice wedges which will likely have sufficient thaw consolidation or loss of bearing capacity that may adversely impact current or future structures. The plan may include soil profile data from drilling, pits and geophysical investigations. The proposed geotechnical investigation plan should be limited only to those data which are necessary to assess the impact of thawing permafrost on the community infrastructure. The plan should include all existing geotechnical data, satellite and aerial photography, and terrain analysis.
2) Inspect public infrastructure and a sampling of residential structures to identify distress related to permafrost. The distress should be characterized as cosmetic, functional or structural. Structural and functional distress may require immediate mitigation due to safety concerns or loss of function, whereas cosmetic distress may be lower priority. Identify the causes of distress including whether the distress is due to poor design/construction or due to changing climate during the life of the structure.
3) Identify the foundation type noting any distress and potential distress in the foundation such as settlement, rotation or loss of bearing capacity.
4) Identify areas of drifting snow, ponded water or drainage features, impacts of structures including utilities or roadways, or any other man-made features which may contribute to thawing of permafrost.

5) Characterize the impacts of climate change over the next 10- and 50-year horizon on thawing permafrost and the potential interaction with engineered features.
6) Identify primary factors driving active permafrost thaw (climactic and anthropogenic).
7) Identify non-structural practices that can be locally implemented to slow or check destructive permafrost thaw.
8) Recommend types of structures and foundations appropriate for these areas.
9) Identify potential community expansion areas which minimize the potential for adverse impacts on infrastructure over the next 50 years.
10) Update the threat analysis outlined in this report using the data collected.

A proposed scope of work which can be used to contract collection of permafrost data was prepared by the Denali Commission and can be found in Appendix D.

6.5 Combined Rankings

The combined ranking is useful for illustrating that a threat exists, and a detailed evaluation is necessary. If the community is at the top of the ranking, there is a high probability that the community is facing multiple threats. For example, Shaktoolik, the community with the highest combined risk rank, is threatened by erosion (ranked 3) and flooding (ranked 1). While there is permafrost in Shaktoolik, the community falls into Group 3 (ranked 20) indicating a relatively low threat. Consequently, data collection efforts should focus on flooding and erosion, with recognition that permafrost may or may not play a role.

This study does not provide recommendations for further data collection or analysis regarding the combined threat as a stand-alone threat. Instead, the potential for damage resulting from combined threats should be assessed on a site-specific basis.

6.6 Final Comments

This document provides a threat evaluation for public infrastructure in 187 rural Alaska communities, as well as guidance for further investigation. The data collection, analysis, and reporting suggested above are intended to serve as a guideline rather than a prescriptive list. Each community is unique due to the geology, hydrology, community layout, and other factors. Consequently, these efforts must be tailored to the community.

As described in the introduction to this report, the study team utilized readily available data to conduct the analyses and did not conduct site visits as part of the study. Detailed community evaluations will require onsite investigations and collection of additional data. We recommend that federal and state agencies commit funding to support practical site-specific research in those communities determined to be most highly threatened. Example scopes of work for such investigations are provided in Appendix B-D.

Several ancillary efforts are ongoing, including identification of communities in peril by the State of Alaska, evaluation of the impact of climate change on erosion, flooding, and thawing permafrost, development of Hazard Mitigation Plans, and economic impacts of environmental threats. Interest in the data set and analysis produced as part of this study is considerable.

A central repository for community specific data would help community planners, engineers and scientists develop community plans, design resilient infrastructure and to understand the relationships between the environment and those living in that environment. Coupled with climate data, user groups will be better able to adapt to the environment of the future.

In order for such a data repository to reach its full potential, standardization of data collection methodology and terminology is necessary. Appendices B-D provide possible templates for additional data sets required for a full understanding of the risk of damage due to erosion, flooding and thawing permafrost.

As a starting point, the geospatial data employed for this study are being made available in the Arctic Data Collaborative database hosted by UAF Scenarios Network for Alaska + Arctic Planning (SNAP). We recommend that this information be incorporated into a managed and updated public data repository to serve as the basis for planning and design tools useful for mitigating threats to rural Alaska's infrastructure.

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Appendix A – Risk Assessment of Alaska Communities

Listed here are the communities sorted by group for each threat: erosion, flooding, and permafrost. The communities within each group are listed by their rank based on the normalized score and listed alphabetically for the convenience of the reader. The rankings of the combined scores are also listed by rank and alphabetically. The reader is encouraged to read the report to understand how the rankings and groupings were derived and to gain insight into their meaning.

Erosion Rankings

Table A-1. Erosion Group 1 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(1) Newtok	(8) Saint Michael	(14) Kwigillingok	(19) Nelson Lagoon
(2) Kivalina	(9) Chefornak	(15) McGrath	(20) Barrow
(2) Napakiak	(10) Huslia	(16) Akiak	(20) Tununak
(3) Shaktoolik	(10) Savoonga	(16) Alakanuk	(20) Venetie
(4) Shishmaref	(11) Kotlik	(16) Lime Village	(21) Emmonak
(5) Port Heiden	(12) Dillingham	(17) Chevak	(22) Levelock
(6) Unalakleet	(13) Noatak	(18) Deering	(23) Nome
(7) Golovin			

Table A-2. Erosion Group 1 (alphabetical with ranking indicated).

(16) Akiak	(7) Golovin	(15) McGrath	(8) Saint Michael
(16) Alakanuk	(10) Huslia	(2) Napakiak	(10) Savoonga
(20) Barrow	(2) Kivalina	(19) Nelson Lagoon	(3) Shaktoolik
(9) Chefornak	(11) Kotlik	(1) Newtok	(4) Shishmaref
(17) Chevak	(14) Kwigillingok	(13) Noatak	(20) Tununak
(18) Deering	(22) Levelock	(23) Nome	(6) Unalakleet
(12) Dillingham	(16) Lime Village	(5) Port Heiden	(20) Venetie
(21) Emmonak			

Table A-3. Erosion Group 2 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(24) Evansville	(29) Bethel	(35) Galena	(40) Northway
(24) Fort Yukon	(29) Kalskag (Lower)	(36) Port Graham	(40) Old Harbor
(24) Gulkana	(29) Kotzebue	(36) Shageluk	(40) Russian Mission
(24) Kaktovik	(30) Aleknagik	(36) Wales	(40) Salamatoff
(24) Kwethluk	(30) Circle	(37) Naknek	(40) Tanana
(24) Pilot Point	(31) Nanwalek	(37) Napaskiak	(40) Tuluksak
(24) Point Hope	(32) Diomede	(37) Nuiqsut	(41) Brevig Mission
(25) Clarks Point	(32) Hughes	(37) Oscarville	(41) Eek
(25) Nunapitchuk	(32) Kalskag (Upper)	(37) Ouzinkie	(42) Koyukuk
(25) Selawik	(32) Kongiganak	(38) Alatna	(42) Saint Paul Island
(25) Tuntutuliak	(33) Eyak	(38) Elim	(42) Nunam Iqua
(26) Aniak	(33) Igiugig	(38) Mekoryuk	(43) Akhiok
(26) Hooper Bay	(33) Nightmute	(39) Buckland	(43) Allakaket
(26) Kipnuk	(33) South Naknek	(39) Eagle	(43) Chignik Bay
(27) Egegik	(34) Iliamna	(40) Atmautluak	(44) Togiak
(28) False Pass	(34) Manley Hot Springs	(40) Chignik Lagoon	
(28) Quinhagak	(34) Nenana	(40) Nikolai	

Table A-4. Erosion Group 2 (alphabetical with ranking indicated).

(43) Akhiok	(38) Elim	(42) Koyukuk	(24) Pilot Point
(38) Alatna	(24) Evansville	(24) Kwethluk	(24) Point Hope
(30) Aleknagik	(33) Eyak	(34) Manley Hot Springs	(36) Port Graham
(43) Allakaket	(28) False Pass	(38) Mekoryuk	(28) Quinhagak
(26) Aniak	(24) Fort Yukon	(37) Naknek	(40) Russian Mission
(40) Atmautluak	(35) Galena	(31) Nanwalek	(42) Saint Paul Island
(29) Bethel	(24) Gulkana	(37) Napaskiak	(40) Salamatoff
(41) Brevig Mission	(26) Hooper Bay	(34) Nenana	(25) Selawik
(39) Buckland	(32) Hughes	(33) Nightmute	(36) Shageluk
(43) Chignik Bay	(33) Igiugig	(40) Nikolai	(33) South Naknek
(40) Chignik Lagoon	(34) Iliamna	(40) Northway	(40) Tanana
(30) Circle	(29) Kalskag (Lower)	(37) Nuiqsut	(44) Togiak
(25) Clarks Point	(32) Kalskag (Upper)	(42) Nunam Iqua	(40) Tuluksak
(32) Diomede	(24) Kaktovik	(25) Nunapitchuk	(25) Tuntutuliak
(39) Eagle	(26) Kipnuk	(40) Old Harbor	(36) Wales
(41) Eek	(32) Kongiganak	(37) Oscarville	
(27) Egegik	(29) Kotzebue	(37) Ouzinkie	

Table A-5. Erosion Group 3 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(45) Wainwright	(54) Nikolski	(57) Chalkyitsik	(57) Perryville
(46) Teller	(54) Saint George Island	(57) Chenega Bay	(57) Pilot Station
(47) Yakutat	(54) Unalaska	(57) Haines	(57) Pitka's Point
(48) Ninilchik	(55) Chignik Lake	(57) Chitina	(57) Rampart
(49) Birch Creek	(55) Chistochina	(57) Chuathbaluk	(57) Ruby
(49) Toksook Bay	(55) Kobuk	(57) Crooked Creek	(57) Sand Point
(49) White Mountain	(55) Koyuk	(57) Eklutna	(57) Saxman
(50) Kake	(55) Larsen Bay	(57) Ekwok	(57) Scammon Bay
(50) Red Devil	(55) Manokotak	(57) Gakona	(57) Seldovia
(50) Stebbins	(55) Point Lay	(57) Goodnews Bay	(57) Shungnak
(51) Gambell	(55) Saint Mary's	(57) Grayling	(57) Sleetmute
(51) New Stuyahok	(55) Ugashik	(57) Holy Cross	(57) Stony River
(51) Tatitlek	(56) Copper Center	(57) Hoonah	(57) Takotna
(52) Port Lions	(56) Platinum	(57) Kaltag	(57) Tanacross
(53) Atqasuk	(57) Akutan	(57) Kasaan	(57) Tazlina
(53) Marshall	(57) Ambler	(57) Kasigluk	(57) Tetlin
(53) Noorvik	(57) Anaktuvuk	(57) Klawock	(57) Twin Hills
(53) Nulato	(57) Angoon	(57) Kokhanok	(57) Tyonek
(53) Stevens	(57) Anvik	(57) Mountain Village	(58) Craig
(54) Akiachak	(57) Arctic	(57) New Koliganek	(58) Hydaburg
(54) Chickaloon	(57) Atka	(57) Newhalen	(58) Mentasta
(54) Kiana	(57) Beaver	(57) Nondalton	(58) Minto
(54) King Cove	(57) Cantwell	(57) Pedro Bay	

Table A-6. Erosion Group 3 (alphabetical with ranking indicated). Table C-6. Group 3 (alphabetical with ranking indicated).

(54) Akiachak	(57) Eklutna	(58) Minto	(57) Saxman
(57) Akutan	(57) Ekwok	(57) Mountain Village	(57) Scammon Bay
(57) Ambler	(57) Gakona	(57) New Koliganek	(57) Seldovia
(57) Anaktuvuk	(51) Gambell	(51) New Stuyahok	(57) Shungnak
(57) Angoon	(57) Goodnews Bay	(57) Newhalen	(57) Sleetmute
(57) Anvik	(57) Grayling	(54) Nikolski	(50) Stebbins
(57) Arctic	(57) Holy Cross	(48) Ninilchik	(53) Stevens
(57) Atka	(57) Hoonah Indian	(57) Nondalton	(57) Stony River
(53) Atqasuk	(58) Hydaburg	(53) Noorvik	(57) Takotna
(57) Beaver	(50) Kake	(53) Nulato	(57) Tanacross
(49) Birch Creek	(57) Kaltag	(57) Pedro Bay	(51) Tatitlek
(57) Cantwell	(57) Kasaan	(57) Perryville	(57) Tazlina
(57) Chalkyitsik	(57) Kasigluk	(57) Pilot Station	(46) Teller
(57) Chenega Bay	(54) Kiana	(57) Pitka's Point	(57) Tetlin
(54) Chickaloon	(54) King Cove	(56) Platinum	(49) Toksook Bay
(55) Chignik Lake	(57) Klawock	(55) Point Lay	(57) Tyonek
(57) Haines	(55) Kobuk	(52) Port Lions	(57) Twin Hills
(55) Chistochina	(57) Kokhanok	(57) Rampart	(55) Ugashik
(57) Chitina	(55) Koyuk	(50) Red Devil	(54) Unalaska
(57) Chuathbaluk	(55) Larsen Bay	(57) Ruby	(45) Wainwright
(56) Copper Center	(55) Manokotak	(54) Saint George Island	(49) White Mountain
(58) Craig	(53) Marshall	(55) Saint Mary's	(47) Yakutat
(57) Crooked Creek	(58) Mentasta	(57) Sand Point	

Flood Rankings

Table A-7. Flood Group 1 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat rating.

(1) Shaktoolik	(7) Napakiak	(13) Gambell	(22) Kwethluk
(2) Shishmaref	(7) Napaskiak	(14) Akiachak	(23) Unalakleet
(3) Eagle	(8) Galena	(14) Elim	(24) Kotzebue
(4) Alakanuk	(9) Teller	(15) Kotlik	(25) Nome
(4) Golovin	(10) Emmonak	(17) Nulato	(26) Savoonga
(5) Tuluksak	(10) Fort Yukon	(17) Stebbins	(27) Sleetmute
(6) Allakaket	(11) Circle	(18) Nenana	(27) Tuntutuliak
(6) Kivalina	(11) McGrath	(19) Buckland	(27) Yakutat
(7) Hughes	(12) Akiak	(20) Red Devil	
(7) Koyukuk	(12) Bethel	(21) Deering	

Table A-8. Flood Group 1 (alphabetical with ranking indicated). Table C-8. Group 1 (alphabetical with ranking indicated).

(14) Akiachak	(10) Emmonak	(22) Kwethluk	(2) Shishmaref
(12) Akiak	(10) Fort Yukon	(11) McGrath	(27) Sleetmute
(6) Allakaket	(8) Galena	(7) Napakiak	(17) Stebbins
(4) Alakanuk	(13) Gambell	(7) Napaskiak	(9) Teller
(12) Bethel	(4) Golovin	(18) Nenana	(5) Tuluksak
(19) Buckland	(7) Hughes	(25) Nome	(27) Tuntutuliak
(11) Circle	(6) Kivalina	(17) Nulato	(23) Unalakleet
(21) Deering	(15) Kotlik	(20) Red Devil	(27) Yakutat
(3) Eagle	(24) Kotzebue	(26) Savoonga	
(14) Elim	(7) Koyukuk	(1) Shaktoolik	

Table A-9. Flood Group 2 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(28) Togiak	(35) Nuiqsut	(40) Noatak	(44) Chefornak
(29) Gulkana	(36) Aniak	(40) Scammon Bay	(44) Ekwok
(30) Grayling	(36) Holy Cross	(40) Unalaska	(44) Gakona
(31) Marshall	(36) Hoonah	(41) Akhiok	(44) Klawock
(32) Eyak	(36) Kobuk	(41) Newtok	(44) Koyuk
(33) Diomede	(36) Rampart	(41) Toksook Bay	(44) Mekoryuk
(33) Shageluk	(36) Venetie	(41) Saint Mary's	(44) New Koliganek
(34) Huslia	(37) Quinhagak	(42) Copper Center	(44) New Stuyahok
(34) Kipnuk	(37) Manley Hot Springs	(42) Point Hope	(44) Pitka's Point
(34) Kongiganak	(38) Kaltag	(42) Selawik	(44) Saint George Island
(35) Chalkyitsik	(38) Nikolai	(43) Tununak	(45) Barrow
(35) Chistochina	(38) Stevens	(44) Anvik	(46) Chignik Lagoon
(35) Crooked Creek	(39) Tanacross	(44) Beaver	(46) Hooper Bay
(35) Nightmute	(40) Lime Village	(44) Brevig Mission	

Table A-10. Flood Group 2 (alphabetical with ranking indicated).

(41) Akhiok	(32) Eyak	(40) Lime Village	(36) Rampart
(36) Aniak	(44) Gakona	(37) Manley Hot Springs	(44) Saint George
(44) Anvik	(30) Grayling	(31) Marshall	(41) Saint Mary's
(45) Barrow	(29) Gulkana	(44) Mekoryuk	(40) Scammon Bay
(44) Beaver	(36) Holy Cross	(44) New Koliganek	(42) Selawik
(44) Brevig Mission	(36) Hoonah	(44) New Stuyahok	(33) Shageluk
(35) Chalkyitsik	(46) Hooper Bay	(41) Newtok	(38) Stevens
(44) Chefornak	(34) Huslia	(35) Nightmute	(39) Tanacross
(46) Chignik Lagoon	(38) Kaltag	(38) Nikolai	(41) Toksook Bay
(35) Chistochina	(34) Kipnuk	(40) Noatak	(28) Togiak
(42) Copper Center	(44) Klawock	(35) Nuiqsut	(43) Tununak
(35) Crooked Creek	(36) Kobuk	(44) Pitka's Point	(40) Unalaska
(33) Diomede	(34) Kongiganak	(42) Point Hope	(36) Venetie
(44) Ekwok	(44) Koyuk	(37) Quinhagak	

Table A-11. Flood Group 3 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(47) Chenega Bay	(53) Tatitlek	(59) Ambler	(59) Port Lions
(48) Alatna	(54) Birch Creek	(59) Angoon	(59) Ruby
(48) Saint Michael	(54) Clarks Point	(59) Arctic	(59) Saint Paul
(49) Dillingham	(54) White Mountain	(59) Atka	(59) Nikiski
(49) Nondalton	(55) Chevak	(59) Chickaloon	(59) Sand Point
(49) Wales	(55) Haines	(59) Chignik Bay	(59) Saxman
(50) Kalskag (Lower)	(55) Nelson Lagoon	(59) Chitina	(59) Seldovia
(50) Kalskag (Upper)	(55) Pilot Point	(59) Chuathbaluk	(59) Shungnak
(50) Pilot Station	(55) Tazlina	(59) Eklutna	(59) South Naknek
(51) Port Heiden	(56) Anaktuvuk Pass	(59) Evansville	(59) Takotna
(51) Stony River	(56) Cantwell	(59) Hydaburg	(60) Noorvik
(51) Ugashik	(56) False Pass	(59) Kasaan	(61) Nanwalek
(52) Kake	(56) Goodnews Bay	(59) Kasigluk	(62) Igiugig
(52) Kwigillingok	(56) Nikolski	(59) King Cove	(63) Atqasuk
(52) Russian Mission	(56) Perryville	(59) Kokhanok	(63) Craig
(52) Tanana	(56) Tetlin	(59) Larsen Bay	(63) Eek
(52) Wainwright	(56) Twin Hills	(59) Levelock	(63) Egegik
(53) Atmautluak	(56) Tyonek	(59) Manokotak	(63) Iliamna
(53) Chignik Lake	(57) Kaktovik	(59) Mentasta	(63) Kiana
(53) Ninilchik	(57) Port Graham	(59) Mountain Village	(63) Minto
(53) Northway	(58) Platinum	(59) Naknek	(63) Newhalen
(53) Nunapitchuk	(58) Nunam Iqua	(59) Old Harbor	
(53) Oscarville	(59) Akutan	(59) Ouzinkie	
(53) Point Lay	(59) Aleknagik	(59) Pedro Bay	

Table A-12. Flood Group 3 (alphabetical with ranking indicated).

(59) Akutan	(63) Egegik	(59) Naknek	(52) Russian Mission
(48) Alatna	(59) Eklutna	(61) Nanwalek	(48) Saint Michael
(59) Aleknagik	(59) Evansville	(55) Nelson Lagoon	(59) Saint Paul Island
(59) Ambler	(56) False Pass	(63) Newhalen	(59) Salamatoff
(56) Anaktuvuk Pass	(56) Goodnews Bay	(56) Nikolski	(59) Sand Point
(59) Angoon	(59) Hydaburg	(53) Ninilchik	(59) Saxman
(59) Arctic	(62) Igiugig	(49) Nondalton	(59) Seldovia
(59) Atka	(63) Iliamna	(60) Noorvik	(59) Shungnak
(53) Atmautluak	(52) Kake	(53) Northway	(59) South Naknek
(63) Atqasuk	(57) Kaktovik	(58) Nunam Iqua	(51) Stony River
(54) Birch Creek	(50) Kalskag (Lower)	(53) Nunapitchuk	(59) Takotna
(56) Cantwell	(50) Kalskag (Upper)	(59) Old Harbor	(52) Tanana
(47) Chenega Bay	(59) Kasaan	(53) Oscarville	(53) Tatitlek
(55) Chevak	(59) Kasigluk	(59) Ouzinkie	(55) Tazlina
(59) Chickaloon	(63) Kiana	(59) Pedro Bay	(56) Tetlin
(59) Chignik Bay	(59) King Cove	(56) Perryville	(56) Twin Hills
(53) Chignik Lake	(59) Kokhanok	(55) Pilot Point	(56) Tyonek
(55) Haines	(52) Kwigillingok	(50) Pilot Station	(51) Ugashik
(59) Chitina	(59) Larsen Bay	(58) Platinum	(52) Wainwright
(59) Chuathbaluk	(59) Levelock	(53) Point Lay	(49) Wales
(54) Clarks Point	(59) Manokotak	(57) Port Graham	(54) White Mountain
(63) Craig	(59) Mentasta	(51) Port Heiden	
(49) Dillingham	(63) Minto	(59) Port Lions	
(63) Eek	(59) Mountain Village	(59) Ruby	

Thawing Permafrost Rankings

Table A-13. Permafrost Group 1 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(1) Newtok	(4) Selawik	(4) Atqasuk	(6) Alatna
(2) Barrow	(4) Nunapitchuk	(5) Huslia	(7) Chefornak
(2) Point Lay	(4) Nightmute	(5) Chevak	(7) Mekoryuk
(3) Tuntutuliak	(4) Kwinhagak	(5) Eek	(7) Brevig Mission
(3) Kongiganak	(4) Nuiqsut	(5) Nunakauyarmiut	(8) Circle
(4) Saint Michael	(4) Buckland	(5) Stebbins	(8) Atmautluak
(4) Savoonga	(4) Sheldon's Point	(5) Kiana	(9) Nome Eskimo
(4) Noatak	(4) Wainwright	(5) Shungnak	(9) Kotzebue
(4) Kaktovik	(4) Noorvik	(6) Deering	

Table A-14. Permafrost Group 1 (alphabetical with ranking indicated).

(6) Alatna	(6) Deering	(4) Nightmute	(4) Savoonga
(8) Atmautluak	(5) Eek	(4) Noatak	(4) Selawik
(4) Atqasuk	(5) Huslia	(9) Nome	(4) Sheldon's Point
(2) Barrow	(4) Kaktovik	(4) Noorvik	(5) Shungnak
(7) Brevig Mission	(5) Kiana	(4) Nuiqsut	(5) Stebbins
(4) Buckland	(3) Kongiganak	(4) Nunapitchuk	(5) Toksook Bay
(7) Chefornak	(9) Kotzebue	(2) Point Lay	(3) Tuntutuliak
(5) Chevak	(7) Mekoryuk	(4) Quinhagak	(4) Wainwright
(8) Circle	(1) Newtok	(4) Saint Michael	

Table A-15. Permafrost Group 2 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(10) Gulkana	(13) Fort Yukon	(15) Pitka's Point	(17) Tanana
(10) Kipnuk	(13) Kalskag (Upper)	(15) Arctic	(17) New Stuyahok
(10) Bethel	(13) Manley Hot Springs	(15) Takotna	(17) Stevens
(10) Galena	(13) Teller	(16) Lime Village	(17) Kobuk
(10) Allakaket	(13) Nulato	(16) Emmonak	(17) Crooked Creek
(10) Marshall	(13) Akiachak	(16) Hooper Bay	(17) Tanacross
(10) Koyuk	(13) Kaltag	(16) Russian Mission	(18) Shishmaref
(10) Holy Cross	(13) Beaver	(17) Point Hope	(18) Kotlik
(10) Anaktuvuk Pass	(13) Pilot Station	(17) Evansville	(18) Alakanuk
(11) Mountain Village	(14) Kwethluk	(17) Kalskag (Lower)	(18) Oscarville
(12) Kwigillingok	(15) South Naknek	(17) Hughes	(18) Chitina
(12) Kasigluk	(15) Gambell	(17) Shageluk	(18) Ruby
(13) Golovin	(15) Saint Mary's	(17) Eagle	
(13) Tununak	(15) Rampart	(17) Tuluksak	

Table A-16. Permafrost Group 2 (alphabetical with ranking indicated).

(13) Akiachak	(15) Gambell	(14) Kwethluk	(16) Russian Mission
(18) Alakanuk	(13) Golovin	(12) Kwigillingok	(15) Saint Mary's
(10) Allakaket	(10) Gulkana	(16) Lime	(17) Shageluk
(10) Anaktuvuk Pass	(10) Holy Cross	(13) Manley Hot Springs	(18) Shishmaref
(15) Arctic Village	(16) Hooper Bay	(10) Marshall	(15) South Naknek
(13) Beaver	(17) Hughes	(11) Mountain Village	(17) Stevens
(10) Bethel	(17) Kalskag (Lower)	(17) New Stuyahok	(15) Takotna
(18) Chitina	(13) Kalskag (Upper)	(13) Nulato	(17) Tanacross
(17) Crooked Creek	(13) Kaltag	(18) Oscarville	(17) Tanana
(17) Eagle	(12) Kasigluk	(13) Pilot Station	(13) Teller
(16) Emmonak	(10) Kipnuk	(15) Pitka's Point	(17) Tuluksak
(17) Evansville	(17) Kobuk	(17) Point Hope	(13) Tununak
(13) Fort Yukon	(18) Kotlik	(15) Rampart	
(10) Galena	(10) Koyuk	(18) Ruby	

Table A-17. Permafrost Group 3 (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(19) Napaskiak	(22) Grayling	(23) Ouzinkie	(23) Hoonah
(20) Kivalina	(22) Chalkyitsik	(23) Chignik Lagoon	(23) Ekwok
(20) Shaktoolik	(22) Anvik	(23) Old Harbor	(23) Klawock
(20) Unalakleet	(22) Gakona	(23) Salamatoff	(23) Chenega Bay
(20) Elim	(22) Tazlina	(23) Saint Paul Island	(23) Nondalton
(21) Napakiak	(22) Cantwell	(23) Akhiok	(23) Stony River
(21) Naknek	(22) Goodnews Bay	(23) Chignik Bay	(23) Haines
(21) Scammon Bay	(22) Tetlin	(23) Togiak	(23) Perryville
(21) New Koliganek	(22) Ambler	(23) Yakutat	(23) Twin Hills
(21) Minto	(22) Eklutna	(23) Ninilchik	(23) Tyonek
(22) Dillingham	(22) Chuathbaluk	(23) Red Devil	(23) Akutan
(22) McGrath	(22) Mentasta	(23) Kake	(23) Angoon
(22) Venetie	(23) Port Heiden	(23) Tatitlek	(23) Atka
(22) Aniak	(23) Akiak	(23) Port Lions	(23) Kasaan
(22) Egegik	(23) Nelson Lagoon	(23) Unalaska	(23) Kokhanok
(22) Diomede	(23) Levelock	(23) Saint George	(23) Pedro Bay
(22) Nenana	(23) Pilot Point	(23) Nikolski	(23) Sand Point
(22) Wales	(23) Clarks Point	(23) Chickaloon	(23) Saxman
(22) Nikolai	(23) False Pass	(23) King Cove	(23) Seldovia
(22) Northway	(23) Aleknagik	(23) Ugashik	(23) Newhalen
(22) Koyukuk	(23) Nanwalek	(23) Chignik Lake	(23) Hydaburg
(22) Birch Creek	(23) Eyak	(23) Larsen Bay	(23) Craig
(22) White Mountain	(23) Igiugig	(23) Manokotak	
(22) Chistochina	(23) Iliamna	(23) Platinum	
(22) Copper Center	(23) Port Graham	(23) Sleetmute	

Table A-18. Permafrost Group 3 (alphabetical with ranking indicated).

(23) Akhiok	(22) Eklutna	(21) Minto	(23) Saint Paul
(23) Akiak	(23) Ekwok	(21) Naknek	(23) Salamatoff
(23) Akutan	(20) Elim	(23) Nanwalek	(23) Sand Point
(23) Aleknagik	(23) Eyak	(21) Napakiak	(23) Saxman
(22) Ambler	(23) False Pass	(19) Napaskiak	(21) Scammon Bay
(23) Angoon	(22) Gakona	(23) Nelson Lagoon	(23) Seldovia
(22) Aniak	(22) Goodnews Bay	(22) Nenana	(20) Shaktoolik
(22) Anvik	(22) Grayling	(21) New Koliganek	(23) Sleetmute
(23) Atka	(23) Haines	(23) Newhalen	(23) Stony River
(22) Birch Creek	(23) Hoonah	(22) Nikolai	(23) Tatitlek
(22) Cantwell	(23) Hydaburg	(23) Nikolski	(22) Tazlina
(22) Chalkyitsik	(23) Igiugig	(23) Ninilchik	(22) Tetlin
(23) Chenega Bay	(23) Iliamna	(23) Nondalton	(23) Togiak
(23) Chickaloon	(23) Kake	(22) Northway	(23) Twin Hills
(23) Chignik Bay	(23) Kasaan	(23) Old Harbor	(23) Tyonek
(23) Chignik Lagoon	(23) King Cove	(23) Ouzinkie	(23) Ugashik
(23) Chignik Lake	(20) Kivalina	(23) Pedro Bay	(20) Unalakleet
(22) Chistochina	(23) Klawock	(23) Perryville	(23) Unalaska
(22) Chuathbaluk	(23) Kokhanok	(23) Pilot Point	(22) Venetie
(23) Clarks Point	(22) Koyukuk	(23) Platinum	(22) Wales
(22) Copper Center	(23) Larsen Bay	(23) Port Graham	(22) White Mountain
(23) Craig	(23) Levelock	(23) Port Heiden	(23) Yakutat
(22) Dillingham	(23) Manokotak	(23) Port Lions	
(22) Diomede	(22) McGrath	(23) Red Devil	
(22) Egegik	(22) Mentasta	(23) Saint George	

Combined Rankings

Table A-19. Communities sorted by combined score rankings (by ranking from highest to lowest). Communities with the same ranking indicates equal threat ratings.

(1) Shaktoolik
(2) Shishmaref
(3) Kivalina
(4) Golovin
(5) Napakiak
(6) Alakanuk
(7) Newtok
(8) Unalakleet
(9) Savoonga
(10) Kotlik
(11) Emmonak
(12) McGrath
(13) Fort Yukon
(14) Deering
(14) Eagle
(15) Hughes
(15) Huslia
(16) Galena
(17) Circle
(18) Saint Michael
(19) Bethel
(20) Tuluksak
(21) Allakaket
(22) Akiak
(23) Napaskiak
(24) Chefornak
(25) Noatak
(26) Tuntutuliak
(27) Nome
(28) Kwethluk
(29) Koyukuk
(30) Kotzebue
(30) Teller
(31) Buckland
(32) Gulkana
(33) Barrow
(34) Elim
(34) Lime Village
(35) Port Heiden
(36) Nenana
(37) Kongiganak
(38) Kipnuk
(38) Quinhagak
(39) Kwigillingok
(39) Stebbins
(40) Nightmute
(40) Venetie
(41) Chevak
(41) Gambell
(41) Tununak
(42) Dillingham
(42) Selawik
(43) Akiachak
(44) Nuiqsut
(45) Nulato
(46) Aniak
(46) Point Hope
(46) Shageluk
(47) Diomede
(48) Manley Hot Springs
(49) Kaktovik
(50) Hooper Bay
(51) Mekoryuk
(52) Marshall
(53) Eyak
(53) Kalskag (Lower)
(54) Evansville
(54) Kalskag (Upper)
(55) Brevig Mission
(56) Alatna
(57) Nikolai
(58) Nelson Lagoon
(58) Nunapitchuk
(58) Red Devil
(59) South Naknek
(59) Togiak
(60) Grayling
(61) Atmautluak
(61) Holy Cross
(61) Yakutat
(62) Sheldon's Point
(63) Wainwright
(64) Crooked Creek
(64) Kobuk
(64) Oscarville
(64) Rampart
(65) Wales
(66) Russian Mission
(66) Stevens
(67) Kaltag
(67) Tanana
(68) Levelock
(69) Pilot Point
(70) Chistochina
(70) Clarks Point
(71) Koyuk
(71) Saint Mary's
(71) Sleetmute
(71) Tanacross
(72) Chalkyitsik
(72) Point Lay
(73) New Stuyahok
(74) Naknek
(75) Beaver
(75) False Pass
(75) Northway
(76) Egegik
(76) Pitka's Point
(77) Scammon Bay
(78) Eek
(79) Aleknagik
(80) Akhiok
(81) Chignik Lagoon
(81) Copper Center
(81) Shungnak
(83) New Koliganek
(83) Pilot Station
(84) Anvik
(84) Gakona
(85) Anaktuvuk Pass
(86) Noorvik
(87) Port Graham
(88) Mountain Village
(89) Hoonah Indian
(90) Birch Creek
(90) Kasigluk
(90) White Mountain
(91) Ouzinkie
(92) Arctic
(92) Nanwalek
(92) Takotna
(93) Umkumiute
(94) Atqasuk
(94) Unalaska
(95) Chitina
(95) Ruby
(96) Kiana
(97) Old Harbor
(97) Salamatoff
(98) Igiugig
(98) Tazlina
(99) Cantwell
(99) Goodnews Bay
(99) Saint George
(99) Tetlin
(100) Saint Paul
(101) Ambler
(101) Chignik Bay
(101) Chuathbaluk
(101) Eklutna
(101) Ekwok
(101) Iliamna
(101) Klawock
(102) Ninilchik
(103) Kake
(104) Chenega Bay
(104) Tatitlek
(105) Nondalton
(105) Ugashik
(106) Chignik Lake
(106) Stony River
(107) Nikolski
(108) Port Lions
(109) Haines
(110) Chickaloon
(110) King Cove
(110) Perryville
(110) Twin Hills
(110) Tyonek
(111) Larsen Bay
(111) Manokotak
(111) Platinum
(112) Akutan
(112) Angoon
(112) Atka
(112) Kasaan
(112) Kokhanok
(112) Mentasta
(112) Pedro Bay
(112) Sand Point
(112) Saxman
(112) Seldovia
(113) Minto
(114) Hydaburg
(114) Newhalen
(115) Craig

Table A-20. Combined score rankings in alphabetical order.

(80) Akhiok
(43) Akiachak
(22) Akiak
(112) Akutan
(56) Alatna
(79) Aleknagik
(21) Allakaket
(6) Alakanuk
(101) Ambler
(85) Anaktuvuk Pass
(112) Angoon
(46) Aniak
(84) Anvik
(92) Arctic
(112) Atka
(61) Atmautluak
(94) Atqasuk
(33) Barrow
(75) Beaver
(19) Bethel
(90) Birch Creek
(55) Brevig Mission
(31) Buckland
(99) Cantwell
(72) Chalkyitsik
(24) Chefornak
(104) Chenega Bay
(41) Chevak
(110) Chickaloon
(101) Chignik Bay
(81) Chignik Lagoon
(106) Chignik Lake
(109) Haines
(70) Chistochina
(95) Chitina
(101) Chuathbaluk
(17) Circle
(70) Clarks Point
(81) Copper Center
(115) Craig
(64) Crooked Creek
(14) Deering
(42) Dillingham
(47) Diomede
(14) Eagle
(78) Eek
(76) Egegik
(101) Eklutna
(101) Ekwok
(34) Elim
(11) Emmonak
(54) Evansville
(53) Eyak
(75) False Pass
(13) Fort Yukon
(84) Gakona
(16) Galena
(41) Gambell
(4) Golovin
(99) Goodnews Bay
(60) Grayling
(32) Gulkana
(61) Holy Cross
(89) Hoonah Indian
(50) Hooper Bay
(15) Hughes
(15) Huslia
(114) Hydaburg
(98) Igiugig
(101) Iliamna
(103) Kake
(49) Kaktovik
(53) Kalskag (Lower)
(54) Kalskag (Upper)
(67) Kaltag
(112) Kasaan
(90) Kasigluk
(96) Kiana
(110) King Cove
(38) Kipnuk
(3) Kivalina
(101) Klawock
(64) Kobuk
(112) Kokhanok
(37) Kongiganak
(10) Kotlik
(30) Kotzebue
(71) Koyuk
(29) Koyukuk
(28) Kwethluk
(39) Kwigillingok
(38) Kwinhagak
(111) Larsen Bay
(68) Levelock
(34) Lime Village
(48) Manley Hot Springs
(111) Manokotak
(52) Marshall
(12) McGrath
(51) Mekoryuk
(112) Mentasta
(113) Minto
(88) Mountain Village
(74) Naknek
(92) Nanwalek
(5) Napakiak
(23) Napaskiak
(58) Nelson Lagoon
(36) Nenana
(83) New Koliganek
(73) New Stuyahok
(114) Newhalen
(7) Newtok
(40) Nightmute
(57) Nikolai
(107) Nikolski
(102) Ninilchik
(25) Noatak
(27) Nome
(105) Nondalton
(86) Noorvik
(75) Northway
(44) Nuiqsut
(45) Nulato
(58) Nunapitchuk
(97) Old Harbor
(64) Oscarville
(91) Ouzinkie
(112) Pedro Bay
(110) Perryville
(69) Pilot Point
(83) Pilot Station
(76) Pitka's Point
(111) Platinum
(46) Point Hope
(72) Point Lay
(87) Port Graham
(35) Port Heiden
(108) Port Lions
(64) Rampart
(58) Red Devil
(95) Ruby
(66) Russian Mission
(99) Saint George Island
(71) Saint Mary's
(18) Saint Michael
(100) Saint Paul Island
(97) Salamatoff
(112) Sand Point
(9) Savoonga
(112) Saxman
(77) Scammon Bay
(42) Selawik
(112) Seldovia
(46) Shageluk
(1) Shaktoolik
(62) Sheldon's Point
(2) Shishmaref
(81) Shungnak
(71) Sleetmute
(59) South Naknek
(39) Stebbins
(66) Stevens
(106) Stony River
(92) Takotna
(71) Tanacross
(67) Tanana
(104) Tatitlek
(98) Tazlina
(30) Teller
(99) Tetlin
(59) Togiak
(20) Tuluksak
(26) Tuntutuliak
(41) Tununak
(110) Twin Hills
(110) Tyonek
(105) Ugashik
(8) Unalakleet
(94) Unalaska
(40) Venetie
(63) Wainwright
(65) Wales
(90) White Mountain
(61) Yakutat

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Appendix B –

PROTOTYPE SCOPE OF WORK[1]
RURAL ALASKA STORM SURGE FLOOD and Erosion ASSESSMENT

Prepared by
Donald Antrobus, PE
CAPT U.S. Public Health Service
Village Infrastructure Protection Program Manager
Denali Commission

September 2019

Background

Many communities throughout rural Alaska are experiencing escalating threats to their lands, infrastructure, and personal property due to the increasing risk of coastal flooding events. Impacts consist of water damage to homes, snow machines, ATV's and public facilities, damage to transportation systems, contamination of water supplies, dispersion of wastewater and solid waste throughout the community and inaccessible or lost land resources. There are multiple factors influencing flood risk including severity and frequency of storms, relative sea level rise and reduced sea ice during fall and winter storm seasons needed to dissipate storm energy. Typically, there is insufficient data available to community decision makers to fully understand community vulnerability to flood related life-safety risks and damage to critical infrastructure. Both site-specific analysis of historical flood magnitude and frequency as well as modeling of future conditions are necessary for understanding flood risk and to inform long-term community decision making regarding flood mitigation, managed retreat, and/or relocation.

The goal of this assessment is to provide essential site-specific information needed to precisely quantify flood threats to community security and to inform near-term and long-term decision making regarding the development of flood mitigation measures. Specifically, this assessment has the following objectives:

- Identify and analyze historical flood and storm data.
- Collect additional baseline data required for flood modeling.
- Forecast relative sea level rise (based on existing research).
- Develop and calibrate a nearshore hydrodynamic model of storm surge, waves, and wave run-up at the specific community location in order to forecast future water levels and sediment transport.
- Produce predictive flood scenarios maps layered on a community elevation model.
- Evaluate effectiveness and feasibility of structural measures to mitigate flood risk based on modeling. Consider shoreline and bank stabilization, flood resistant building techniques and renovations, and establishment of first floor build elevations.
- Determine long-term viability of the community site (75+ years) based on model projections and the potential to effectively mitigate risks.
- Evaluate the relative efficacy of non-structural mitigation measures (e.g. managed retreat away from flood threat) in comparison to structural measures.

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[1] This is a generic scope of work intended as a reference document that can be used to guide the development of a detailed community specific scope of work.

- Develop recommendations for both near-term and long-term mitigation measures.

Scope of Work

The following tasks will be implemented in order to accomplish the objectives of this project. Professional coastal engineers, scientists, and community planners shall be engaged to complete Tasks 2 to 8 in direct consultation with the community.

Task 1: Project Management (Provided by Community)

A. Develop and implement a solicitation process to contract for the professional services required to carry out the project. In the event that the community already has access to professional engineering services procured in accordance with funding agency requirements, then this task will not be required.

B. Conduct all general project management activities including award management, contract management, scheduling, meeting coordination, and other project activities.

Task 2: Preliminary Assessment

- Conduct a teleconference with community leadership to identify key community contacts and concerns; gather local knowledge about flooding; identify available technical reports and data; and obtain input on the assessment methodology.

- Identify and review existing information including but not limited to the following:
  - Historical imagery and digital elevation or surface models
  - Bathymetric and topographic data sets for the study area
  - Tidal datums
  - Sea ice observations
  - Wind and storm data
  - Wave information: National Buoy Data Center (NBDC) and U.S. Army Corps of Engineers (USACE) Wave Information Studies (WIS)
  - Geotechnical reports from infrastructure projects (school, sanitation facilities, clinic, airport, etc.)
  - Summarize historical and projected climate data for the community using Scenarios Network for Alaska/Arctic Planning (SNAP) resources (https://www.snap.uaf.edu/tools-data/data-downloads)
  - Flood information from local hazard mitigation plan and other hazard analysis reports
  - USACE Floodplain Management resources
  - Alaska Water Level Watch (https://www.facebook.com/AlaskaWaterLevelWatch/ and https://aoos.org/alaska-water-level-watch/)
  - Denali Commission threat assessment database
  - Other relevant technical studies and data sources relating to historical shoreline change, wind, waves, tides, storm surge, sea ice, and sea level rise

- Interpret historical flood elevations from available collated flood data via analysis of photos, ortho-imagery and elevation data to identify co-registered data points of flood height and/or flood extent.

- Create a preliminary map of historical floods on a community elevation model. Identify ground elevations that would result in minor, moderate, and major flooding (in accordance with NOAA National Weather Service definitions) at various storm stages.

- Conduct a geotechnical desktop review of available climate projections and subsurface data for the purpose of estimating ground settlement associated with permafrost thaw.

- Identify additional baseline data required to complete a hydro-dynamic model.

- Submit storm photographs to Alaska DGGS for upload to the photo database at http://maps.dggs.alaska.gov/photodb/; add storm elevations to AOOS Alaska Water Level Watch portal.

Task 3: Site Visit and Field Investigation(s)

The consultant's team (engineers, scientists, surveyors) shall travel to the community to conduct field assessment(s) as described below. The field assessment(s) will consist of the following:

A. Kick-off meeting with community stakeholders (including but not limited to the Tribe, City, and Corporation) to present the preliminary flood maps; discuss the project; and discuss community observations regarding current and future flood risk.

B. Complete interviews with community members on flood history in and around the community.

C. Conduct a visual inspection of coastal topography to confirm and/or update the limits of historical storm events.

D. Gather additional baseline data needed to conduct flood modeling exercise:
   - Aerial Survey: Gather new or supplemental aerial photography and/or lidar data required to develop both a digital elevation or surface model of the coastline and built community and co-registered ortho-imagery. Horizontal and vertical accuracy of point cloud data on bare earth surfaces will average 0.1 feet.
   - Land Survey: A land survey shall be completed to coordinate horizontal and vertical control of existing data sets, to develop coastal elevation profiles, to measure finished floor elevations of critical infrastructure (school, clinic, power plant, fuel tank farm, water treatment plant, store, city and tribal offices, evacuations centers, etc.) and occupied homes in the community. Existing survey data shall be utilized to the greatest extent possible to eliminate redundant data collection.
   - Bathymetric Survey: Design and conduct a survey to gather near shore and off shore bathymetry sufficient to conduct storm surge and wave runup analysis. Conduct bathymetry utilizing modern multi-beam, single-beam and/or side scan echosounders. If utilizing a single beam echosounder in a soft bottom environment, it is recommended to utilize a dual frequency system to identify soft surface layers and the harder bottom layer. For communities located on barrier island and spit formations, survey coverage shall include the lagoon side of the community and tidal inlets. Horizontal and vertical accuracy of bathymetry data points will average 0.3 feet.
   - Water Level Data: Collect sufficient water level data to establish a local tidal datum based on simultaneous comparison with an existing tide station. Estimate impact on modeling accuracy due to the distance from an authoritative datum.
   - Current and Sediment Data: Collect sufficient current and sediment data required to model sediment transport and coastal erosion processes. Acoustic Doppler Current Profilers shall be deployed to obtain current information at strategic locations. Sediment grab samples shall be

taken along the ocean beach, lagoon beach (if applicable), at accreting portions of the beach, and other specific sites of interest. Grab samples shall be lab tested to determine classification and particle size.

- Note: Consideration of alternate emerging technologies that may reduce the cost of data collection are encouraged (e.g. topo-bathy lidar).

E. Photograph all infrastructure constructed along the shoreline in the active beach zone. Conduct a structural assessment of identified infrastructure to determine if they can be relocated.

Task 4: Hydrodynamic Flood Modeling

This task includes the development of a 3-dimensional coastal hydraulic model after completion of field investigations. The following elements will be included in the modeling exercise.

A. Delineate modeling boundaries and assumptions.

B. Develop model to simulate near shore wave action including wave set-up and run-up in the waters surrounding the community, incorporating collated topographic, bathymetric, storm, wind, and water level data.

C. Calibrate the model via hindcast simulations of historical flood events documented during field reconnaissance.

D. Complete predictive flood simulations (25, 50, 100-year horizons) based on adopted projections of sea level rise, storm, and ice conditions. Develop return interval flood scenarios mapped on community elevation model.

Task 5: Sediment Transport Modeling and Erosion Analysis

This task includes sediment transport modeling to predict coastal erosion and aid in the development of mitigation measures. The following elements will be included in the modeling and analysis.

A. Develop model to simulate near shore sediment transport for past high-water high-wave events and for storm magnitudes predicted in the future, incorporating sediment characteristics based on samples collected during site investigation activities.

B. Quantify erosion rates and formulate predictions of future changes that will impact near term infrastructure mortality (5-10 years) and the long-term stability (75+ years) of the community.

Task 6: Engineering Analysis

This task includes performing the following engineering analysis upon completion of flood and erosion modeling.

A. Establish hydraulic and hydrodynamic forcing criteria required for engineering design of mitigation measures.

B. Develop a list of recommended structural solutions to mitigate damage from flooding and coastal erosion.

C. Compare the feasibility and cost effectiveness of structural solutions with a managed retreat response.

D. Evaluate whether the community can stay and defend at its current site (including managed retreat), or whether complete relocation will be required over the next 75-year horizon. The determination shall be primarily based on livability of the site based on flood modeling projections and the ability to mitigate flood risk in both a feasible and socially acceptable manner.

E. Develop a prioritized list of conceptual-level structural mitigation measures based on community input. For each of the top three priorities, develop a detailed project scope, schedule, and budget sufficient to support an application for grant funding.

F. Develop a list of recommended non-structural best practices that can be immediately implemented by the community to mitigate flood impacts.

G. Cross reference recommended mitigation measures with the community's existing Local Hazard Mitigation Plan (LHMP) in order to develop a list of recommended updates to the LHMP.

Task 7: Reporting

Develop a final report documenting the entire modeling and analysis. The report shall be supported by maps, images, figures, conceptual drawings, and graphics of the model runs in order to maximize the usage of the report as a tool for community planning and decision-making. Upon completion of the report, the consultant will schedule a final meeting in the community to present the results.

The final report shall incorporate the following sections:

A. Introduction and Background: Describe the purpose and scope of the flood assessment.

B. Baseline data: Describe baseline data needs, available information, and supplemental data that was collected as part of the study.

C. Investigation Methodology: Describe the methodology used to develop the flood assessment. Include a description of the desktop evaluation, community meetings and interviews, and field investigations, and modeling.

D. Existing Conditions: Present the results of the study related to current conditions and include a discussion of the following topics: 1) historical flooding; 2) identification of the specific infrastructure found to be imminently threatened; and 3) a summary of the structural assessments of threatened buildings.

E. Projected Future Impacts: Summarize expected flood and erosion impacts based on modeling projections. Delineate community infrastructure that may be at risk based on predicted return interval flooding. Utilize both maps and tables to present the results. (Include poster-sized maps for community presentations.)

F. Best Practices and Solutions: Provide a narrative description of the non-structural practices that can be locally implemented to mitigate flood risk and impacts. Define recommended structural solutions and present the scope, schedule, and estimated cost for the identified priority community projects.

G. Next Steps and Long-term Recommendations: Discuss additional data collection recommendations and provide concluding recommendations that may be used by the community to develop long-term responses to flood hazards.

H. Appendices (Documentation): The report will include appendices as required to capture project records including trip reports, photographs, relevant survey and field notes. The section will include a bibliography of all previous plans, studies, designs, geotechnical reports, and other technical documents identified and used in the evaluation.

Task 8: Records Management

A. All data collected and/or generated by this effort will be archived for public access. Data will be provided both to Alaska Division of Geological and Geophysical Surveys and will be added to the Denali Commission Statewide Threat Assessment geodatabase in ArcGIS.

Project Schedule

\Ideally, this assessment can be completed in 12 -18 months, depending on the magnitude of baseline data collection that is required, availability of funding and the date of the Notice to Proceed (NTP). Under the ideal scenario, the solicitation would be completed in January and February, the preliminary assessment from March to May, field work from June to September, and modeling, analysis and reporting from October to December. The field investigation must take place during summer months free from snow and ice. The schedule and key milestones will be adjusted based on the NTP date to accommodate the field investigation.

A general schedule is presented below.

Task 1A (project management by the community): Months 1-12
Task 1B (engineering consultant solicitation): Months 1-2
Task 2 (preliminary assessment): Months 1-5
Task 3 (site visit): Month 6-9
Tasks 4 - 6 (modeling, analysis, and reporting): Months 9-10
Task 7 (reporting): Months 11-12

Appendix C –

PROTOTYPE SCOPE OF WORK[2]
RURAL ALASKA RIVERINE EROSION ASSESSMENT

Prepared by
Donald Antrobus, PE
CAPT U.S. Public Health Service
Village Infrastructure Protection Program Manager
Denali Commission

September 2019

Background

In 2009, the U.S. Army Corps of Engineers (USACE) completed the *Alaska Baseline Erosion Assessment* (BEA). The report found that most Alaskan communities are facing some level of infrastructure threat due to erosion. Drivers of erosion are variable and include naturally occurring changes in river channels, diminishing winter ice, storm surge, relative sea level rise, flooding, and human activities which impact shoreline ecosystems. The impacts of erosion on Alaskan communities range from minor damage to landscapes, to damage to transportation and utility infrastructure, to loss of individual or multiple structures, up to and including wholescale threats to community viability.

In the BEA, USACE identified 27 Priority Action communities, concluding that additional site-specific data and information was required for these communities in order to develop informed responses to the identified threats. Since 2009, little additional progress has been made to address the information gap identified by USACE. Too often, community decision-makers lack the scientific data and assessments required to fully forecast the magnitude and timing of erosion threats.

The goal of this assessment is to provide essential information needed to precisely quantify erosion threats to community security and to inform near-term and long-term decision making and mitigation measure development. Specifically, this assessment has the following objectives:

- Delineate near term (5-10 years) threats to community infrastructure based on an assessment of historical linear erosion rates
- Identify primary factors driving active erosion (geomorphic and anthropogenic)
- Establish long-term erosion projections based on hydrologic and hydraulic river modeling
- Evaluate effectiveness and feasibility of structural mitigation measures (barriers and bank stabilization) based on design criteria established through river modeling
- Evaluate the relative efficacy of non-structural mitigation measures (e.g. managed retreat away from erosion threat) in comparison to structural measures
- Determine long term viability of the current community site based on model projections
- Develop recommendations for both near-term and long-term mitigation measures

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[2] This is a generic scope of work intended as a reference document that can be used to guide the development of a detailed community specific scope of work.

- Build local capacity to address harmful environmental trends

Scope of Work

The following tasks will be implemented in order to accomplish the objectives of this project. Professional engineers, geologists, and community planners shall be engaged to complete Tasks 2 - 6 in direct consultation with the community.

Task 1: Project Management (Provided by Community)

A. Develop and implement a solicitation process to contract for the professional services required to carry out the project. In the event that the community already has access to professional engineering services procured in accordance with the requirements of 2 CFR 200, then this task will not be required.

B. Conduct all general project management activities including award management, contract management, scheduling, meeting coordination, and other project activities.

Task 2: Preliminary Assessment

A. Conduct a teleconference with community leadership to identify key community contacts and concerns; gather local knowledge about erosion, identify available technical reports and data, and obtain input on the assessment methodology.

B. Complete interviews with key community stakeholders regarding the history of erosion in and around the community.

C. Identify and review existing information including but not limited to the following:
   - Historical aerial imagery datasets.
   - Bathymetric and topographic data sets for the study area.
   - Geotechnical reports for major infrastructure development projects (school, sanitation facilities, clinic, airport, etc.).
   - The current hazard mitigation plan and other reports related to environmental hazard analysis.
   - Denali Commission threat assessment database.
   - Other relevant technical studies and data sources relating to historical shoreline change, wind, waves, tides, storm surge, sea level rise, and river hydrology.

D. Collaborate with relevant agencies and entities to ensure that all available information is considered (Alaska DGGS, Alaska DOT&PF, NOAA, USACE, NWS, VSW and ANTHC).

E. Summarize historical climate data and projected climate scenarios for the community using Scenarios Network for Alaska/Arctic Planning (SNAP).

F. Summarize projected changes to frozen ground and resulting implications for long-term erosion rates using public resources from SNAP, CRREL and UAF.

G. Create a preliminary decadal erosion projection map for the developed community and any surrounding areas proposed for future development. Overlay linear erosion projections on a map of community infrastructure to estimate the timing of the erosion impact on specific community infrastructure. Convert annual rate of change to anticipated time of impact. Use site maps and charts to summarize and communicate the findings.

Task 3: Site Visit / Field Investigation

A team minimally consisting of a structural engineer, a hydrologist or geologist, and surveyors shall travel to the community to conduct a field assessment. It is expected that the assessment will require a minimum of 3 full days in the field. The field assessment will consist of the following:

A. Kick-off meeting with community stakeholders (including but not limited to the Tribe, City, and Corporation) to present the preliminary erosion projections; discuss the project; and discuss community observations regarding current and future erosion threats.

B. Visually survey the reach of river above, below, and through the community.

C. Conduct a visual inspection of site topography and terrain features to confirm and/or update the preliminary erosion projections. Employ additional field investigation techniques, including aerial drone photography, to improve the erosion projections and further document the current shoreline.

D. Complete topographic, bathymetric, and river flow surveys to gather baseline data necessary to conduct hydrologic and hydraulic modeling of the river system.
   - Topographic surveys will be conducted using an Unmanned Aerial Vehicle (UAV) with an on-board survey-grade global positioning system (GPS) technology. Horizontal and vertical accuracy of point cloud data on bare earth surfaces will average 0.1 feet.
   - Bathymetric surveys will be conducted utilizing dual frequency eco-sounder technology to identify soft surface layers and the hard bottom. Horizontal and vertical accuracy of bathymetry data points will average 0.1 feet.
   - Topographic and bathymetric data will be merged and complemented with available LiDAR data to extend the range of upstream and downstream river analysis.

E. Observe and/or investigate daily practices in the community that may contribute to erosion. These practices may include but are not limited to pedestrian and vehicular travel ways, river access, and boat landing and parking.

F. Photograph all infrastructure along the shoreline expected to be impacted within ten years based on the preliminary results and knowledge from the community.

G. Conduct a structural engineering assessment of all infrastructure expected to be impacted within five years in order to determine if structures can be relocated to a new site. If relocation is feasible, provide recommendations on relocation methodology.

H. Coordinate with community stakeholders to identify and evaluate least two new sites within the community or on property immediately adjacent to the exiting community, to which imminently threatened infrastructure may be relocated. Site analysis will include the following considerations:
   - Determination of minimum acreage required based on a review of threatened structures
   - Surface and subsurface characterization with respect to constructability
   - Evaluation of flood, erosion, and permafrost degradation risk
   - Delineation of site control issues
   - Site access
   - Utility service potential
   - Environmental permitting
   - Development costs

- Cultural considerations and/or other factors identified by the community

Task 4: Hydrologic and Hydraulic Modeling and Analysis

Upon completion of the field study, the following tasks will be completed prior to proceeding to the final report.

A. Complete a hydrologic analysis using USGS regression equations for Alaska to estimate river flows.

B. Develop a finite element hydro-dynamic model (RiverFlow2D or equivalent) to analyze river hydraulics. Utilize the model to estimate natural erosion and deposition processes along the river.
   - Consider the intersection of other threats (flooding, inundation, permafrost degradation, wave energy) with historical and projected erosion patterns. The overlay of historical erosion rates, geomorphology, and model-derived data will be used to interpret hot spots and areas of concern under expected future climate conditions.
   - Model future shoreline change across the community to predict infrastructure mortality.

C. Develop a list of recommended structural solutions to mitigate damage from erosion. Utilize the hydraulic model to analyze in-place mitigation measures.

D. Compare the efficacy of structural solutions with a managed retreat response.

E. Make a determination whether the community can stay and defend at its current site (including managed retreat), or whether complete relocation will be required. The determination shall be primarily based on viability of the site based on modeled erosion projections and the ability to mitigate erosion risk in both a feasible and socially acceptable manner.

F. Develop a prioritized list of mitigation measures based on community input. For each of the top three priorities, develop a detailed project scope, schedule, and budget sufficient to support an application for grant funding.

G. Develop a list of recommended non-structural best practices that can be immediately implemented by the community to mitigate erosion impacts.

Task 5: Reporting

Develop a final report documenting the entire evaluation. The report shall be supported by maps, images, figures, conceptual drawings, etc. to maximize the usage of the report as a tool for community planning and decision-making. Upon completion of the report, the consultant will schedule a final meeting in the community to present the results.

The final report shall incorporate the following sections:

A. <u>Introduction and Background</u>: Describe the purpose and scope of the vulnerability assessment.

B. <u>Investigation Methodology:</u> Describe the methodology used to develop the erosion assessment. Include a description of the desktop evaluation, community meetings and interviews, and field investigations, and modeling.

C. Existing Conditions: Present the results of the study related to current conditions and include a discussion of the following topics: 1) historical erosion rates and map; 2) summary of the structural assessments; 3) identification of the specific infrastructure found to be imminently threatened.

D. Projected Future Impacts: Summarize expected erosion impacts based on modeling projections. Delineate community infrastructure that may be at risk over the next 50 years due to projected erosion rates. Utilize both maps and tables to present the results.

E. Best Practices and Solutions: Provide a narrative description of the non-structural practices that can be locally implemented to limit and/or slow destructive permafrost degradation. Define recommended structural solutions and present the scope, schedule, and estimated cost for the identified priority community projects.

F. Next Steps and Long-term Recommendations: Discuss additional data collection recommendations and provide concluding recommendations that may be used by the community to develop long-term responses to environmental hazards.

G. Appendices (Documentation): The report will include appendices as required to capture project records including trip reports, photographs, relevant survey and field notes. The section will include a bibliography of all previous plans, studies, designs, geotechnical reports, and other technical documents identified and used in the evaluation.

Task 6: Records Management

B. All data collected and/or generated by this effort will be archived for public access. Data will be provided both to Alaska Division of Geological and Geophysical Surveys and will be added to the Denali Commission Statewide Threat Assessment geodatabase in ArcGIS.

Project Schedule

Ideally, this assessment can be completed in approximately 12 months, depending on the availability of funding and the date of the Notice to Proceed (NTP). Under the ideal scenario, the solicitation would be completed in January and February, the desktop assessment March to May, field work from June to September, and final reporting from October to December. The field investigation must take place during summer months free from snow and ice. The schedule and key milestones will be adjusted based on the NTP date to accommodate the field investigation.

A general schedule is presented below.

Task 1A (project management by the community): Months 1-12
Task 1B (engineering consultant solicitation): Months 1-2
Task 2 (desktop assessment): Months 1-5
Task 3 (site visit): Month 6-9
Task 4 (analysis and reporting): Months 9-10
Task 5 (reporting): Months 11-12
Task 6 (records management): Months 11-12

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Appendix D –

PROTOTYPE SCOPE OF WORK[3]
RURAL ALASKA PERMAFROST VULNERABILITY ASSESSMENT

Prepared by
Donald Antrobus, PE
CAPT U.S. Public Health Service
Village Infrastructure Protection Program Manager
Denali Commission

September 2019

Background

Many communities throughout Alaska are experiencing significant impacts to infrastructure due to the thawing of permafrost. Impacts include failing structural foundations, damage to water and wastewater facilities, leaning storage tanks, and impassable roads. There are multiple factors driving changes to permafrost conditions including thermal impacts from heated infrastructure; human activities such as vehicular and pedestrian travel across delicate terrain; clearing and stockpiling of snow; warming climate and other natural phenomena such as flooding and erosion. Typically, there is insufficient data available to community decision makers that is needed both to understand community-wide vulnerability of infrastructure to permafrost thaw and to inform the development of long-term responses to these threats.

The goal of this assessment is to provide essential site-specific information needed to precisely quantify threats to community security from permafrost thaw and to inform near-term and long-term decision making regarding the development of effective mitigation measures. Specifically, this assessment has the following objectives:

- Characterize existing permafrost conditions throughout the community
- Define the primary factors driving changes to permafrost
- Identify current permafrost thaw impacts on infrastructure
- Project the potential magnitude of future impacts on infrastructure
- Define structural and behavioral measures to mitigate short-term impacts
- Develop long-term strategies to mitigate threats from permafrost thaw

Scope of Work

The following tasks will be implemented in order to accomplish the objectives of this project. Professional structural and geotechnical engineers and community planners shall be engaged to complete tasks 2-6 in direct consultation with the community.

Task 1: Project Management (Provided by Community)

[3] This is a generic scope of work intended as a reference document that can be used to guide the development of a detailed community specific scope of work.

A. Develop and implement a solicitation process to contract for the professional services required to carry out the project. In the event that the community already has access to professional engineering services procured in accordance with funding agency requirements, then this task will not be required.

B. Conduct all general project management activities including award management, contract management, scheduling, meeting coordination, and other project activities.

Task 2: Desktop Assessment

A. Conduct a teleconference with community leadership to identify key community concerns; gather local knowledge about permafrost conditions, identify available technical reports and data, and obtain input on study methodology.

B. Complete interviews with key community contacts regarding the history of erosion and permafrost thaw in and around the community.

C. Identify and review existing information including but not limited to the following:

- Historical imagery, digital elevation or surface models, and terrain maps
- Current Local Hazard Mitigation Plan (LHMP) and other environmental hazard resources
- Geotechnical reports completed for major infrastructure development projects (school, sanitation facilities, clinic, airport, etc.)
- USACE Floodplain Management resources
- Alaska Water Level Watch (https://www.facebook.com/AlaskaWaterLevelWatch/ and https://aoos.org/alaska-water-level-watch/)
- Denali Commission threat assessment database
- Other relevant technical studies and data sources relating to historical shoreline change, wind, waves, tides, storm surge, sea ice, and sea level rise
- Collaborate with relevant State and Federal agencies (Alaska DGGS, UAF, ANTHC, VSW, NRCS, DOT&PF, NOAA, and NWS) to ensure that all available information is considered

D. Summarize historical and projected climate data for the community using Scenarios Network for Alaska/Arctic Planning (SNAP) resources.

E. Complete a preliminary permafrost characterization for the developed community and immediate surrounding areas identified or proposed for future development. Use site maps and charts to summarize and document the findings. To the extent possible based on existing data, the characterization shall capture general surface and subsurface conditions, soil classifications, depth of organics and depth to permafrost or of the active layer, ice and/or water content, occurrence of groundwater, potential occurrence of massive ice, and permafrost temperature. It is understood that the preliminary map may have significant data gaps.

F. Develop a plan for additional geotechnical or geophysical testing that may be required to supplement the preliminary permafrost characterization, with an emphasis on testing that is essential for determining geographical extent and ice content of permafrost in the community.

Task 3: Site Visit and Field Inspection

A team minimally consisting of a structural and geotechnical engineer shall travel to the community to conduct a field inspection. It is expected that the inspection will require a minimum of 3 full days in the field. The field inspection will consist of both structural and geotechnical assessments as follows:

A. Conduct a kick-off meeting with community stakeholders (including but not limited to the Tribe, City, and Corporation) to present the preliminary site characterization; discuss the project; and confirm community observations regarding current and future threats.

B. Visually inspect and photograph all public infrastructure to document impacts from melting permafrost, including roads, public buildings, sanitation facilities, bulk fuel tank farms, power plants, and other facilities identified by the community to be of concern. Include a minimum of 8 representative residential structures in the inspection.

C. Visually inspect and evaluate community drainage systems including ditches, culverts, and natural waterways.

D. Conduct a physical assessment of buildings including identification of foundation types, foundation cooling systems (e.g. active/passive freezing systems), environmental impacts (e.g. flowing water, ponding, snow drifting), and documentation of observed damage (e.g. detached/cracked foundations, uneven floors, cracked drywall, misaligned doors/windows, differential road or berm settlement, leaning tanks, separating utilidors, deformed/non-functioning culverts, etc.).

E. During the visual inspections, simultaneously document any observed impacts or imminent threats (expected impact in next 5 years) from flooding and erosion. For imminently threatened infrastructure, whether from permafrost thaw, flooding, or erosion, complete a preliminary structural assessment to determine whether the building is competent and able to be moved.

F. Conduct a visual inspection of site topography and terrain features to confirm and advance the preliminary permafrost characterization.

G. Conduct additional field investigation defined in task 2 in order to improve preliminary site permafrost characterization including aerial drone photography, and rod probing to determine depth to permafrost. If it is determined to be beneficial by the consultant and the community, use locally available equipment to pot hole shallow test pits to gain a better understanding of subsurface conditions in areas for which geotechnical information was not available during the desktop study.

H. Coordinate with community stakeholder to identify new sites within the existing community or on property immediately adjacent to the exiting community to which threatened infrastructure may be relocated. Include these sites in the inspection described above. Using similar techniques, develop an initial evaluation of the efficacy of the sites for new construction.

I. Observe and/or investigate daily practices which may have a negative impact on permafrost. These practices may include but are not limited to pedestrian and vehicular travel ways, river access, boat landing and parking, snow plowing and stockpiling, and greywater discharge.

Task 4: Analysis

Upon completion of the field inspection, the following tasks will be completed prior to producing the final report.

A. Update the preliminary permafrost characterization based on field observations and additional data collection.

B. Utilizing existing publicly available climate data, model future behavior of permafrost across the community. Use modeling results to predict the magnitude of future impacts to infrastructure due to permafrost thaw.

C. Develop a list of recommended non-structural best practices that can be implemented by the community to mitigate impacts from permafrost thaw.

D. Develop a list of recommended structural solutions for specific infrastructure to mitigate damage due to permafrost thaw (drainage, active cooling, leveling, elevating, etc.). Prioritize the list based on community input. For each of the top three priorities, develop a detailed project scope, schedule, budget, and implementation plan sufficient to support an application for grant funding.

E. Develop a plan for permafrost monitoring that can be locally implemented in order to continually track permafrost change over the next several decades. The monitoring plan shall be based on the techniques established by the Circumpolar Active Layer Monitoring (CALM) program, adapted for community specific conditions and resources.

F. Develop a list of best practices and recommendations to guide future community growth.

G. Cross reference recommended mitigation measures with the community's existing Local Hazard Mitigation Plan (LHMP) in order to develop a list of recommended updates to the plan.

Task 5: Final Reporting

Develop a final report documenting the entire evaluation. The report shall be supported by maps, images, figures, conceptual drawings, etc. to maximize the usage of the report as a tool for community planning and decision making. Upon completion of the report, the consultant will schedule a final meeting in the community to present the results.

The final report shall incorporate the following sections.

A. Introduction and Background: Describe the purpose and scope of the vulnerability assessment.

B. Baseline data: Describe available information, baseline data needs, and supplemental data that was collected as part of the study.

C. Investigation Methodology: Describe the methodology used to develop the permafrost assessment. Include a description of the desktop evaluation, community meetings and interviews, and field investigations.

D. Existing Conditions: Present the results of the study related to current conditions and include a discussion of the following topics: 1) permafrost characterization for the community site; 2) summary of the structural assessments; and 3) delineation of the specific infrastructure elements found to be immediately threatened.

E. Projected Future Impacts: Summarize the results of permafrost modeling based on future climate projections, considering both rising temperatures and increased precipitation. Delineate community infrastructure that may be at risk over the next 50 years due to projected permafrost thaw.

F. Best Practices and Solutions: Provide a narrative description of the non-structural practices that can be locally implemented to limit and/or slow destructive permafrost thaw. Define recommended structural solutions and report on the identified priority community projects. Delineate any recommendations for updates to the LHMP.

G. Next Steps and Long-term Recommendations: Discuss additional data collection recommendations and provide concluding recommendations that may be used by the community to develop long-term responses to environmental hazards.

H. Appendices (Documentation): The report will include appendices as required to capture project records including trip reports, photographs, relevant survey and field notes. The section will include a bibliography of all previous plans, studies, designs, geotechnical reports, and other technical documents identified and used in the evaluation.

Task 6: Records Management

A. All data collected and/or generated by this effort will be archived for public access. Data will be provided both to Alaska Division of Geological and Geophysical Surveys and will be added to the Denali Commission Statewide Threat Assessment geodatabase in ArcGIS.

Project Schedule

Ideally, this assessment can be completed in 12 -18 months, depending on the magnitude of baseline data collection that is required, availability of funding and the date of the Notice to Proceed (NTP). Under the ideal scenario, the solicitation would be completed in January and February, the preliminary assessment from March to May, field work from June to September, and modeling, analysis and reporting from October to December. This assumes that field investigations can be conducted during summer months that are free from snow and ice. If additional geotechnical testing must be conducted during the winter, then the schedule will be extended. The schedule and key milestones will be adjusted based on the date of the NTP and in order to accommodate field investigations.

A general schedule is presented below.

Task 1A (project management by the community): Months 1-12
Task 1B (engineering consultant solicitation): Months 1-2
Task 2 (preliminary assessment): Months 1-5
Task 3 (site visit and field inspection): Month 6-9
Tasks 4 - 5 (analysis and reporting): Months 9-10
Task 6 (reporting): Months 11-12