Western Alaska Airport Resiliency Study

A Component of the Alaska Aviation System Plan

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Table of Contents

Appendices

Abbreviations

AASP	Alaska Aviation System Plan
ACE	air convection embankment
ACRP	Airport Cooperative Research Program
AI	Artificial Intelligence
AIP	Airport Improvement Program
APEB	Aviation Project Evaluation Board
ARC	Airport Reference Code
CIMP	Capital Improvement and Maintenance Program
CM/GC	Construction Manager/General Contractor
DOT&PF	Alaska Department of Transportation and Public Facilities
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FMV	fair market value
FONSI	Finding of No Significant Impacts
medevac	Medical Evacuation
MOS	Modification to Standards
M&O	Maintenance and Operations
NPIAS	National Plan of Integrated Airport Systems
PCI	Pavement Condition Index
PESTLE	Political, Economic, Social, Technological, Legal, Environmental
ROW	right-of-way
SME	Subject Matter Expert
SREB	Snow Removal Equipment Building
SWOT	Strengths, Weaknesses, Opportunities, Threats
SWPPP	Stormwater Pollution Prevention Plan
TAG	technical advisory group
UAF	University of Alaska, Fairbanks
UAS	Unmanned Aircraft System
VDCF	Volume Donating Compressible Filler

Executive Summary

Airports in western Alaska are facing environmental threats that stand to render them unreliable. Thawing permafrost, more frequent flooding and erosion, material source limitations, and increasing precipitation, coupled with funding limitations and staffing challenges, make it challenging to maintain a resilient airport system.

This Resiliency Study evaluates potential solutions to those threats; identifies opportunities for building resilience into airport development; and outlines additional studies and research needed to fill data gaps. The report also identifies opportunities for regulatory changes that would support greater resiliency in the aviation system.

The study team, comprising RESPEC planners and engineers, conducted a literature review to find solutions that other cold regions are using to combat issues like those faced by Alaska's airports. This research was supplemented with an analysis of 29 airports across western Alaska, interviews with stakeholders, and a review of historical funding. Five of the 29 airports were selected for in-depth analysis to link airport problems to potential causes.

This study's findings suggest that many variables affect an airport's long-term stability and resilience. Funding is a major driver of design and construction choices and will continue to be so unless changes are made to how funding can be spent on airports.

The recommendations in this study include all phases of airport development: planning, design, construction, and operations. A combination of policy changes, engineering choices, construction techniques, and maintenance procedures are needed to ensure resilience is built into Alaska airports. The top recommendations are summarized as follows:

1. **Monitor and Repair Damage Early.**
   a. Regularly inspect runways and address issues while they are still minor.
2. **Prevent Embankment Settlement.**
   a. Redefine standards for geotextile use and runway widening and lengthening. Remove ice-rich soils and redirect drainages.
3. **Evaluate Dust Palliatives.**
   a. Explore the use of dust palliatives in the top several inches of soil rather than as a surface treatment.
4. **Update Drainage Structure Standards and Guidance.**
   a. Ensure culverts and drainage structures are appropriately sized for large storm events.
5. **Plan for Field Conditions.**
   a. Include contingency plans in design and construction documents.
6. **Update Runway Expansion Standards and Guidance.**
   a. Redefine standards for geotextile use and runway widening and lengthening.
7. **Improve Project Closeout Procedures.**
   a. Ensure lessons learned are documented and shared by developing a construction closeout questionnaire.

Introduction

Airports are critical to the movement of goods and people across Alaska. Eighty-two percent of communities are not connected to the contiguous road system and rely on aviation for connection to the rest of the state and points beyond [DOT&PF, 2023]. As such, maintaining a resilient aviation system is imperative to the health and well-being of residents.

WHAT IS RESILIENCY?

This study defines resiliency as an airport's preparedness for changing conditions and capacity to recover from disruptive events.

Investments in an airport should improve the airport's preparedness and recovery capacity by creating infrastructure that is physically, financially, and environmentally sustainable.

Damage to airport infrastructure can have significant consequences. Without working lighting systems, pilots cannot land safely in the dark. When runways are too soft or rutted, planes risk losing control on landing. During natural disasters, airports are needed for emergency response and evacuation.

The climate in Alaska is warming two to four times faster than the average rate of warming in the rest of the United States [Rantanen, et al., 2022; Thoman and Walsh, 2019; Wuebbles, et al., 2017]. This warming is causing permafrost to thaw, vegetation to grow quicker, and types of vegetation to change within ecosystems [Wuebbles, et al., 2017; Roland, 2023; Potter and Alexander, 2020]. Climate change is also causing more frequent and severe weather events, including heavier rainstorms, winter rain, storm surges, and more frequent river flooding [Struzik, 2024; Zellen, 2024]. Although many of these phenomena occurred before Alaska's climate began rapidly warming, increasing average temperatures in Alaska are resulting in more severe impacts. For airports, this means more embankment failures, more coastal erosion, and the need for more frequent vegetation clearing.

Study Overview

This report focuses on the conditions of airports in western Alaska, ranging from Chignik Lagoon in the south to Point Hope in the north. Western Alaska was chosen as the study area because anecdotal evidence indicated that the airports in this region experience a range of challenges (e.g., erosion, permafrost, construction logistics) that are common to many airports in Alaska. A single region was selected for simplicity of comparison during analyses.

All 29 airports analyzed in this study are owned by the Alaska Department of Transportation and Public Facilities (DOT&PF) and were identified for review by a technical advisory group (TAG). The airports were selected as examples of recurring infrastructural issues or of good performance. The conditions of the natural and built environment, infrastructure investments, and design and construction choices were analyzed to identify common causes of failures and resiliency. Several common environmental conditions and resulting physical issues are shown in Figure 1. Additionally, non-physical factors such as legal and political considerations were assessed to ensure recommendations to increase resiliency were feasible within the broader social context of the airports.

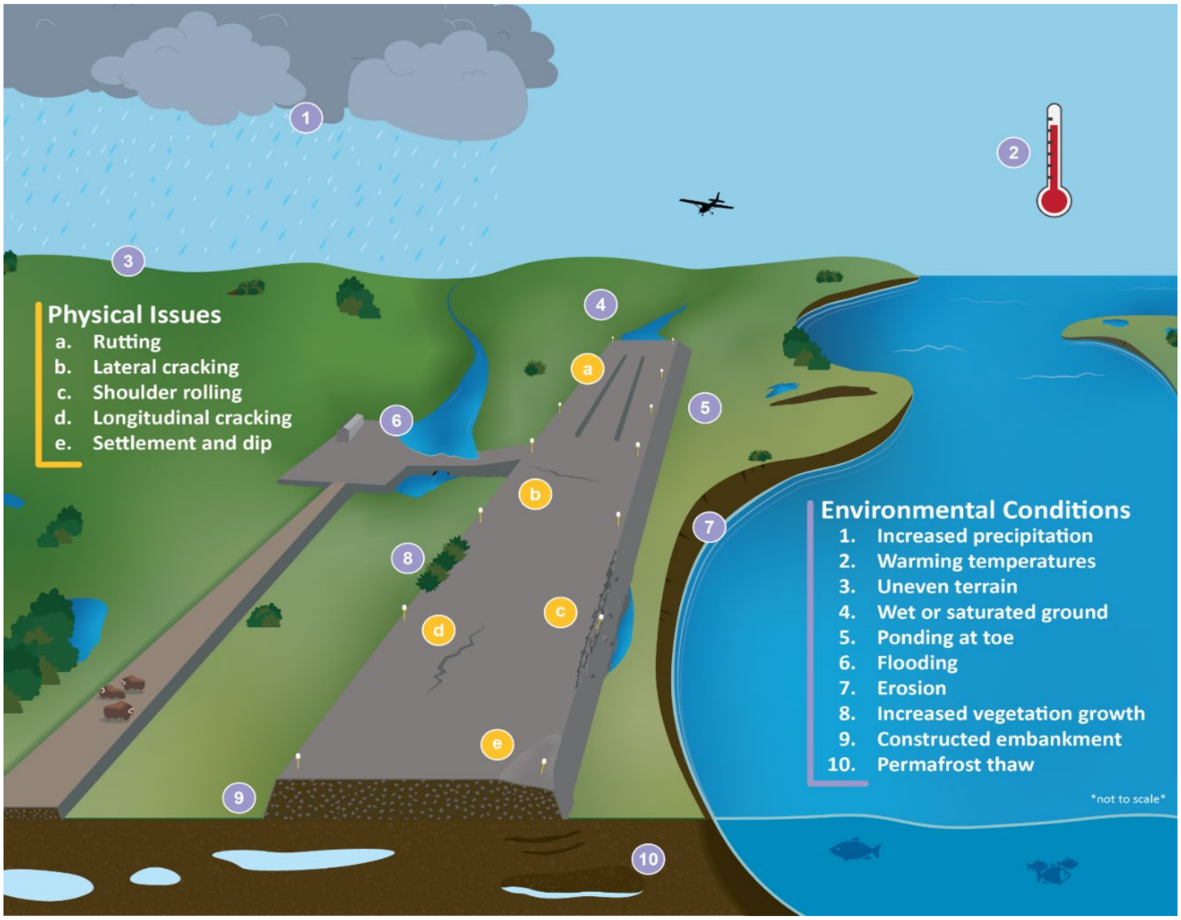


Figure 1. Diagram of Common Environmental Impacts Experienced by Airports in Western Alaska.

This Resiliency Study:

- Provides an overview of the social, political, and legal constraints on airport development.
- Describes the conditions of the natural and built environment that contribute to airport infrastructure failures.
- Reviews the data sources used in this study.
- Summarizes the key analyses performed.
- Suggests sustainable design practices and critical design choices for resilient airport infrastructure in subarctic and arctic environments.
- Identifies how investments in the aviation system can be optimized to allow the system to last longer and become more resilient in a rapidly changing climate.

Airport Selection

The 29 airports included in this study were selected through discussions and collaboration with pilots, air carriers, DOT&PF personnel, and community members. These airports, shown in Figure 2, represent the conditions many Alaska airports face. The Yukon-Kuskokwim Delta is a bellwether for climate change as the region is experiencing rapid permafrost thaw, increasing storms, and changing weather patterns.

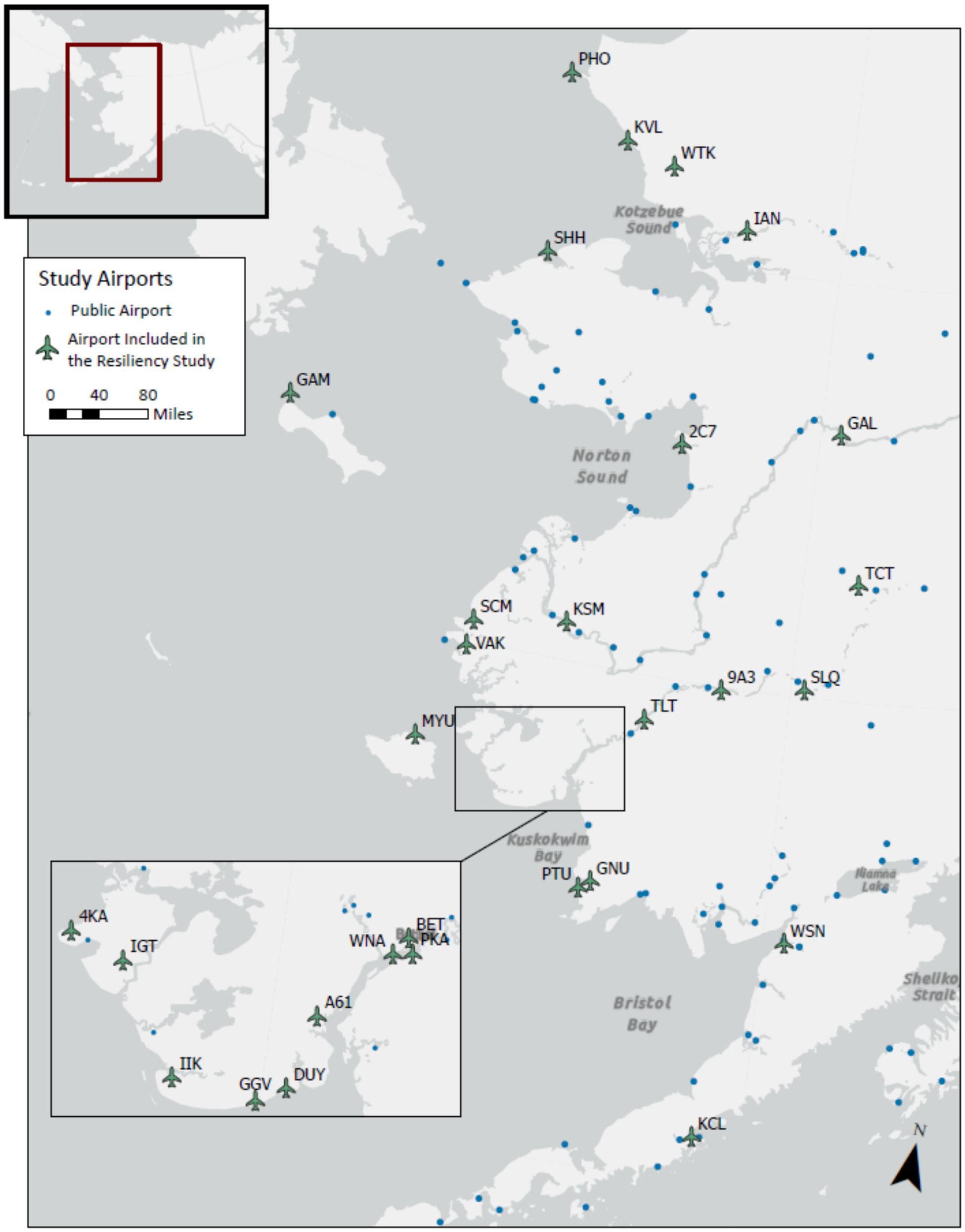


Figure 2. Western Alaska Airports.

From the list of 29 airports, 5 case study airports were selected for a more in-depth analysis and comparison: Tununak (4KA), Nightmute (IGT), Chevak (VAK), Kipnuk (IIK), and Tuntutuliak (A61). These airports were selected because they had the most available data and shared key similarities for direct comparison while being different enough to evaluate a range of characteristics. For example, the runways have similar lengths and widths but vary in their embankment depths.

Data Sources

Subject Matter Experts

Several interviews and group meetings with subject matter experts (SMEs) were held to direct and inform the study, as shown in Table 1. A TAG was established early in the project to identify the study airports and confirm the recurring issues the study needed to address. The TAG included members of the Aviation Advisory Board, Federal Aviation Administration (FAA) staff, and DOT&PF staff.

Table 1. Interviews and Meetings Summary.

Interview Subject	Date	Interview/Meeting Summary
TAG	January 10, 2022	Brainstormed potential airports to study Identified issues to address
	February 24, 2022	Confirmed the airport list and the issues
DOT&PF planners	October 25, 2023	Brainstormed factors to include in the Strengths, Weaknesses, Opportunities, Threats (SWOT)/Political, Economic, Social, Technological, Legal, Environmental (PESTLE) matrix
	January 4, 2024	Discussed the draft SWOT/PESTLE analysis Reviewed planning-level recommendations
DOT&PF geotechnical engineering staff	September 12, 2023	Discussed study purpose and role of geotechnical issues in building resilience
Daniel Phillips, Northern Region M&O	December 11, 2023	Discussed Maintenance and Operations (M&O) issues and how DOT&PF was addressing them given funding and staffing limitations
LJ Evans, former Bethel Airport Manager	December 8, 2023	Gained firsthand experience from an airport manager on the issues stemming from a changing climate and potential solutions
Airport site visits (DOT&PF, FAA, consultant team)	August 20, 2024	Conducted visual observations for Tununak, Nightmute (IGT), Kipnuk (IIK), and Tuntutuliak (A61) airports, which are included in the list of case study airports. A drone captured imagery where the weather allowed. Napaskiak (PKA) airport was also visited.
Site visit debrief and draft report discussion (DOT&PF, consultant team)	September 2, 2024	Discussed site visit observations with engineering, geotechnical, and M&O staff who were unable to attend the site visit and developed recommendations for this report.

DOT&PF Records
Data, reports, and other documents from DOT&PF were used for both the engineering and funding analyses. Appendix 1: "DOT&PF Data Gap Analysis" shows the specific sources obtained for the engineering analysis. Some information obtained through the engineering analysis was also used in the funding analysis.

Construction Documents

Construction as-builts of previous airport development projects were reviewed to identify site conditions not captured during the design development, such as the presence of unfavorable or unanticipated subsurface conditions like the presence of ice lenses or ice-rich soils, requiring over-excavation.

Geotechnical Reports

Geotechnical reports provided our team with knowledge of the expected subsurface condition upon which the runway was constructed. The geotechnical reports often included material source investigations, which provided an expectation of what materials were available for the construction of the airports' improvements; however, not all construction projects had documentation stating whether the contractor used the material sources investigated in the geotechnical reports.

Miscellaneous Reports

Additional documents, including hydraulic reports, airport evaluations, relocation studies, and environmental impact studies, were evaluated to identify any conditions that may have contributed to the performance of the embankment. These documents were not available for every airport considered for this report; however, those that were available provided valuable information on the potential causes of embankment failures.

Airport Improvement Program (funding analysis only)

The Airport Improvement Program (AIP) is a grant program managed by the FAA. Airports included in the National Plan of Integrated Airport Systems (NPIAS) may apply for AIP grant funding for certain eligible projects, such as projects to preserve the airport, enhance safety, or improve service. AIP grant funding data were obtained from the Alaska Aviation System Plan (AASP) online database for 2001 through 2022. AIP grant funds were filtered to only include grants related to runway condition and improvements:

- Various Grant Rehabilitate Runway
- Construct New Airport
- Construct Runway
- Construct Runway Plan
- Extend Runway
- Improve Airport Drainage
- Improve Airport Erosion Control
- Reconstruct Runway
- Rehabilitate Runway
- Relocate Airport
- Strengthen Runway
- Widen Runway

All funding amounts were converted to 2022 dollars to account for inflation. More information about the AIP project development process is available on the AASP website [AASP, 2022].

Operational Expenses (funding analysis only)

Operational expenses encompass funds spent on personnel, utilities and fuel for equipment, runway lights, and some buildings. They do not include FAA capital or maintenance grants, badging fees, or ramp fees[1]. Data about operational expenses for each airport were obtained from the AASP database for 2010 through 2022; operational expenses data were not available before 2010. All funding amounts were converted to 2022 dollars to account for inflation.

Airport Performance Measures (funding analysis only)

DOT&PF tracks 26 performance measures for all DOT&PF-owned airports in Alaska using data from sources such as the National Flight Data Center, Pavement Condition Index (PCI) reports, and inspections. Airports receive a "report card" that indicates whether each measure was met, not met, or not applicable. The information on these report cards relating to runway condition and lighting were used for the funding analysis.

Cold Regions Research

This review of airport resiliency studies, included as Appendix 2, was conducted to gather information about best practices for cold climate airports. A central theme in recently published papers is the importance of adapting infrastructure and operational practices to climate change impacts. Reviewed documents provided general information about climate-related threats that high latitude airports face, methods to assess vulnerability and prepare infrastructure, and examples of operational strategies and engineering technologies to mitigate threats.

The literature widely recommends a proactive approach to resiliency and adaptation planning. Adaptation and mitigation should be incorporated into new projects at the start and integrated into existing planning frameworks during updates.

Assessing the vulnerability of airport infrastructure to climate change is a first step in guiding resiliency planning, but a lack of baseline data can limit organizations' abilities to assess vulnerabilities. Systemic collection, storage, and sharing of infrastructure performance and environmental data is critical to understanding the historical and ongoing conditions impacting an airport and evaluating the efficacy of interventions.

One prominent example of resilience planning, exemplified as a case study in several airport resilience studies, was permafrost thaw mitigation measures at the Iqaluit International Airport (CYFB) in Nunavut, Canada. For this study, extensive data on permafrost conditions were collected and used to identify potentially problematic locations of existing and proposed infrastructure. Decisions informed by this effort included the relocation of a runway and the use of an insulated barrier under the taxiway, drainage improvements, and the use of thermosyphons under buildings.

Implementation of innovative engineering technologies from recent and ongoing research can enhance the resilience of airport infrastructure (Recommendation 7). For example, the Center for Environmentally Sustainable Transportation in Cold Climates (University of Alaska, Fairbanks [UAF]) has published numerous relevant studies. Research topics include the application of bio-wicking fabrics to

[1] From AASP internal database data description

address pavement damage caused by moisture and methods to mitigate permafrost thaw resulting from thermal imbalances (Recommendation 19).

Analyses Performed

Numerous analyses were conducted using the data described previously. These analyses, in conjunction with the Cold Regions Research and discussions with DOT&PF staff, formed the basis of the recommendations at the end of this chapter.

SWOT/PESTLE Analysis

The combined SWOT (strengths, weaknesses, opportunities, and threats) and PESTLE (political, economic, social, technological, legal, environmental) analysis used information from the Cold Regions Research and SMEs to identify key factors that impact resilience at western Alaska airports. The factors identified as Weaknesses and Threats were assigned likelihood and severity rankings to prioritize the focus of recommendations and future actions. The full SWOT/PESTLE Analysis is included as Appendix 3.

High-Level Engineering Analysis

A high-level comparative analysis of geotechnical reports, construction documents, and other relevant reports and plans was conducted for all 29 airports included in this study. The conclusions of this analysis are discussed in the *General Trends* section of this chapter.

High-Level Funding Analysis

A simple analysis of operational expenses (state funding), AIP grant funding (federal funding), and airport condition data was conducted for 28 of the airports included in this study; Bethel Gravel (the gravel runway located at Bethel Airport [BET]) was removed because funding data did not separate the gravel strip from the rest of the airport. The conclusions of this analysis are discussed in the *General Trends* section of this chapter. The airport condition data used in this analysis are from the Airport Performance Measures available on the AASP internal database.

Further Analysis: Case Study Airports

Additional analyses were conducted for the five case study airports (Chevak [VAK], Kipnuk [IIK], Nightmute [IGT], Tuntutuliak [A61], and Tununak [4KA]) using the same data as the high-level analysis. The conclusions and additional discussion of these analyses are included in the *Case Studies* section of this chapter.

Environmental Context

A runway's embankment is the single largest element of a rural airport. As a result, the natural and built environment near and beneath the embankment significantly influence the resiliency of an airport. The embankment is essentially the foundation of the runway and must be designed and constructed to maximize long-term stability. When embankments fail, lighting systems can be damaged, the runway surface may be compromised, and aircraft may not be able to safely use the runway. Though the specific issues impacting runway embankments vary by location, the issues are generally the result of poor existing ground conditions, low-quality construction materials, inadequate construction, or a combination of these factors. The ground conditions typically have the biggest impact on embankment performance. Precipitation, flooding, and vegetation growth can also cause problems for embankments.

Figure 3 compares an ideal runway embankment design with a more typical embankment, as constructed in western Alaska. The differences between the ideal design and the constructed embankment can contribute to physical and safety issues.

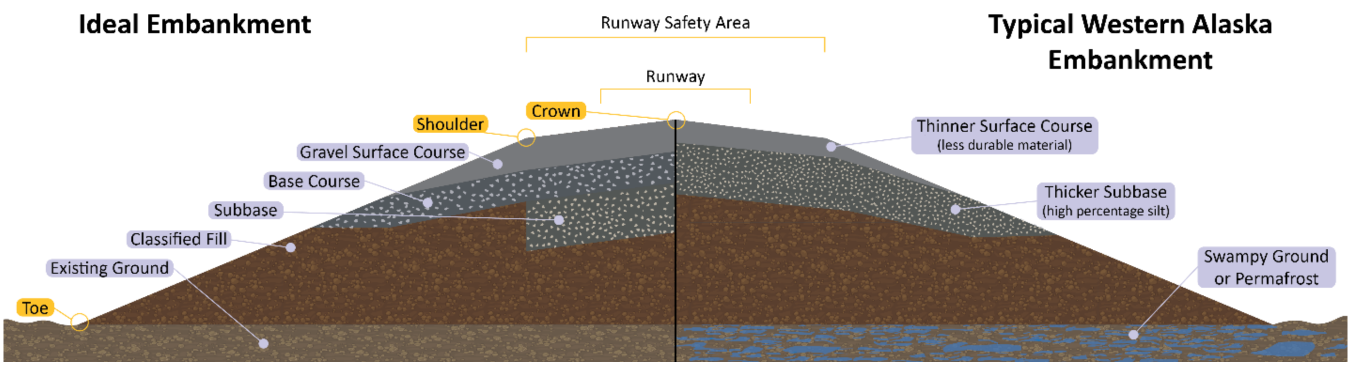


Figure 3. Typical Runway Embankment Design.

The damage seen at an airport is often caused by an underlying issue that is not always obvious. This section describes these natural and built environmental conditions and the physical and safety issues they cause, summarized in Table 2.

Table 2. Physical Issues and the Safety Issues They Cause.

Physical Issues	→	Safety Issues
Differential Settlement, Soft Surface, Rutting Cracking Shoulder Sloughing, Slope Failure	→	**Uneven Landing Surface Lighting Problems**
Differential settlement results in heaves, dips, and cracks in the runway surface and cracking and rolling of the embankment shoulder. Thaw settlement, consolidation, and subsidence are synonyms when addressing settlement of a facility because of thawing ice-rich permafrost or frozen organics.	→	Damage to the runway surface makes landing an aircraft more difficult and potentially unsafe. Uneven runways do not provide the stable and hardened surface that is needed for aircraft operations, which can lead to damage to landing gear, prop-strikes, or even crashes. Cracking and shoulder rolling can also damage the lighting system and make low-visibility landings difficult. This is especially problematic in Alaska, where many communities experience periods of little to no sunlight during the winter.
Erosion Instability Shoulder Sloughing, Slope Failure	→	**Weakened Embankment**
Erosion can lead to instability and failure of runway embankments. Embankments generally rely on a minimum grade on shoulders to ensure embankment stability, with a commonly used grade ratio of 4 horizontal to 1 vertical as measured from the top of runway shoulder to the limit of fill of toe. When erosion occurs adjacent to an embankment it removes material from the toe of slope (bottom-up erosion), thus shortening the horizontal component of the slope ratio and steepening the foreslope. This process of removal and slope shortening continues until the soil can no longer maintain a stable slope, at which point slope failure occurs. Slope failures will generally result in portions of soil in the embankment disconnecting and falling, narrowing the top surface of the embankment. Erosion can also be top down when water concentrates at one location because of settlement or grading operations. The accumulated water then finds an outlet or path down the slope, and the increased volume and velocity causes washouts. The top of these washouts can work their way toward the centerline, essentially narrowing the safe, usable portion of the runway safety area. Erosion is especially common in fine grain soils (silty sand or sandy silt) predominant in western Alaska.	→	Entire sections of an airport operating surface can be eroded away, making it impossible to land or operate. Even if the embankment surface remains intact after a flooding event or concentration of water, the embankment may be undermined or washed away, eventually impacting the lighting system and/or landing surface.

Physical Issues	→	Safety Issues
Instability	→	**Inaccessible Airport** **Weakened Embankment**
Flooding and precipitation can erode the embankment, wash out fine materials, and ultimately reduce the structural stability of the embankment.	→	During a flooding event, water may overtop the runway and cause it to become unusable. This issue is further compounded because these types of flooding events can correspond with a higher need for medical evacuation (medevac) operations and aircraft delivery of supplies, both of which are significantly more difficult or not possible to safely perform if there is water on the runway. The physical impacts of flooding and severe precipitation can reduce the weight capacity for aircraft landings, over time.
Encroaching Vegetation	→	**Uneven Landing Surface** **Inaccessible Airport**
Encroaching vegetation growth can accelerate runway cracking.	→	In addition to creating an uneven surface by contributing to runway cracking, vegetation can obscure visual aids and lighting. If the obstructions are severe enough, the airport may be inaccessible.

DESCRIBING PERMAFROST

Throughout this chapter, we refer to the layers, extent, temperature, ice-richness, and thaw stability of permafrost. Each of these characteristics factors into whether it is advisable to build on permafrost.

Layers
The ground has an "active layer" at the surface that thaws in the summer and freezes in the winter, as shown in Figure 6. If the ground beneath the active layer has been frozen for at least 2 consecutive years, it is considered permafrost. The depth of the active layer varies, and a permanently thawed zone may exist between the active layer and the permafrost.

Extent
Permafrost can be continuous, discontinuous, sporadic, or isolated. These terms are listed from the greatest extent of ground in an area that is frozen year-round to the least amount—"continuous permafrost" means most or all of the area is permanently frozen, whereas "isolated permafrost" means only small patches remain frozen.

Temperature
Permafrost is considered "warm" if the ground temperature is consistently at or near 32 degrees Fahrenheit (°F), in contrast to "cold" permafrost that stays below 30°F. Cold permafrost is more resistant to induced heat than warm permafrost.

Ice-Richness
Permafrost refers to frozen ground, *not* a sheet of ice. Different areas of permafrost have different frozen water content, which means they will react differently if they thaw.

Thaw Stability
The thaw stability of permafrost refers to the expected behavior of the ground if the permafrost were to thaw. Thaw unstable permafrost typically has either high ice or high organic content. Soil with high ice or organic materials has a high settlement potential when thawed. Thaw-stable permafrost typically contains sands and gravels with little to no free or massive ice. In some areas, thaw-stable permafrost may be frozen dry silt. The components of thaw-stable permafrost are expected to settle more uniformly with fewer structural deficiencies than thaw-unstable permafrost.

Related Subsurface Features
Pingos are hills formed by ice pushing up the ground within an area of permafrost.

Ice lenses are subsurface ice formations containing little to no soil; if an ice lens thaws, the water will drain, and a void will be left in the ground.

Thaw bulbs are areas of thawed ground below or around a structure built on or in permafrost.

Thawing Permafrost

Physical Issues	*Safety Issues*
Differential Settlement, Soft Surface, Rutting *Shoulder Sloughing, Slope Failure* *Cracking*	*Uneven Landing Surface* *Lighting Problems*
Impacted By Climate Change	

Permafrost is a layer of subsurface soil that remains frozen year-round and is insulated by the soils and structures above it. The thickness and composition of the insulating material changes the insulating effects; for example, an embankment provides more insulation at the shoulder (full thickness) than at the toe (thinnest layer). This results in an uneven thawing of the permafrost, which creates differential settlement between the embankment shoulder and side slopes. This behavior is often referred to as shoulder rolling, where the differential settlement causes the shoulder to separate and roll away from the embankment. Key visual cues of this behavior are surface cracks parallel to the runway centerline, which can be seen in Figure 4, and increased ponding at the embankment toe.

Figure 4. Shoulder Rolling Interfering With the Lighting System at Noorvik Airport (D76) [DOT&PF, 2019].

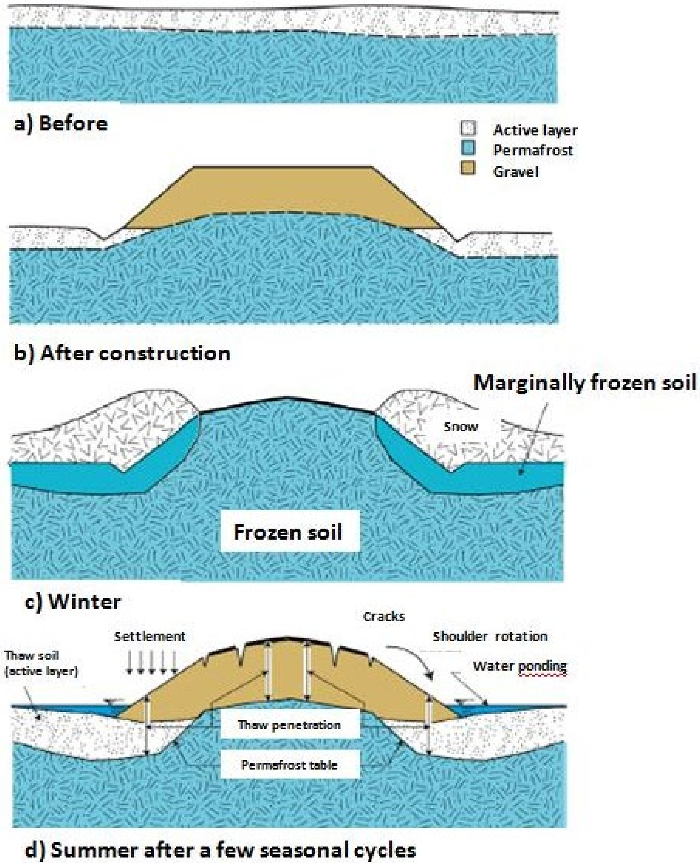


Figure 5. Permafrost Impacts on Embankment [Malenfant-Lepage, et al., 2012].

Uneven thawing can occur throughout the frozen subgrade, even where the overlying embankment thickness is consistent. This is because the permafrost may be discontinuous or the amount of frozen water within the soil material may vary. Other environmental conditions, such as one part of the embankment being in constant shade from a mountain or other obstruction, insulation from snow banks, or water ponding at the embankment toe can also cause uneven thawing that creates differential settlement. On the surface, this can present as rolled shoulders, cracks, heaves, and dips, as illustrated in Figure 5. Uneven thawing can be very localized; one area may be frozen at a shallow depth, while just feet away the soil is frozen very deep. The area that has a shallow freeze depth can thaw much more quickly, resulting in abrupt differential settlement.

Water ponding at the toe can prevent seasonal freezing in the underlying material, resulting in more thawing in the area year-round. This is especially true with winters having fewer degree days of freezing.

Geotechnical investigations and thermal analyses are typically conducted to help predict how permafrost will react once an embankment is placed on it. Accurate predictions over the entirety of a large embankment are limited by:

- Availability of local historical weather data
- Forecasting of climate change
- The variability of subgrade materials (e.g., ice content)
- Embankment material quality and thickness

Wet or Saturated Ground

Physical Issues	*Safety Issues*
Differential Settlement, Soft Surface, Rutting *Shoulder Sloughing, Slope Failure* *Cracking*	*Uneven Landing Surface* *Lighting Problems*

Flat ground is favorable for constructing airports, however much of Alaska's flat terrain is low-lying and often consists of soft, saturated materials interspersed with wetlands, streams, rivers, and ocean coastlines. Soft materials are not ideal for constructing a runway embankment but are often the most feasible option when good quality materials are far away. In rural Alaska, embankments are generally built with locally available materials (e.g., gravel, silt). Much of the Yukon-Kuskokwim Delta lacks high-quality material sources. This often means that well-drained, granular material ideal for long-term performance can only be sourced from distant locations, requiring costly transportation.

Additionally, building a runway across a drainage is not a best practice. Water must be routed around or under the runway via culverts. Drainage along the runway toe can cause erosion leading to slope damage while routing culverts under a runway often results in differential settlement or heave.

Swampy conditions hinder construction equipment from traversing wetlands when thawed. To account for this, a common construction technique is to "end dump" material, which is then pushed forward with a bulldozer or similar equipment as a thick initial lift of material. This technique mitigates some issues with traversing wetlands; however, achieving the desired 95 percent compaction is generally not possible, especially in the initial thick lift. Excessive rolling or wheel tracking on the embankment causes water from the subgrade to pump upward through the embankment, saturating the embankment and causing it to weaken. Successive layers of embankment can be placed thinner to achieve more optimal compaction. However, as subsequent layers are placed in the embankment, differential settlement occurs between the initial lift and thinner subsequent lifts. The grade changes from this initial differential settlement can be smoothed out as the construction advances but long-term settlement continues, potentially extending years past completion of construction. Embankments constructed on wet or swampy ground in this manner benefit from phased construction as discussed in the "General Considerations and Recommendations" section.

Uneven Terrain

Physical Issues	*Safety Issues*
Differential Settlement, Soft Surface, Rutting *Shoulder Sloughing, Slope Failure* *Cracking*	*Uneven Landing Surface* *Lighting Problems*

Embankments are commonly built over ground with differing subsurface soil conditions, terrain, and often crossing small/micro drainages. Total avoidance of less-than-ideal or poor ground conditions is not always possible as the location and orientation of the runway is driven by prevailing winds, airspace considerations, and the ability to acquire land for construction.

The ideal placement for an airport is relatively flat ground, with uniform subgrade; however, not all communities in Alaska are in areas of level and obstruction-free terrain, optimal for the siting of a runway. More often it is irregular and hilly terrain requiring varying embankment thicknesses, often resulting in differential settlement from thicker embankments inducing heavier weight on subsurface soils. Another common condition is rolling terrain, which often includes drainages and wetlands that require extra consideration. Ultimately, this varying terrain increases the likelihood of differential settlement because subgrade materials compress differently when loaded with embankment materials, which can lead to surface cracking, as shown in Figure 6.

Figure 6. Longitudinal Cracking at Kiana Airport (IAN) [DOT&PF, 2023].

The composition of the subgrade materials also influences compression and resulting settlement. Ideally, subgrade materials for runways should consist of uniform, low-moisture soils associated with an alluvial gravel valley bottom or even a stabilized silty loam ridge line. However, a subgrade more commonly consists of a mix of materials varying in both material composition and thickness. This variability ultimately results in inconsistent soil strength and resistance, often resulting in differential settlement.

Erosion

Physical Issues	Safety Issues
Erosion Instability	Weakened Embankment Lighting Problems
Impacted By Climate Change	

Coastlines and riverbanks are in constant change, with erosion being a normal part of a waterbody's life cycle. Erosion generally occurs as water flowing along a soil face slowly degrades it, removing material. This process is more common in portions of a waterbody where the flow of water is faster, such as the outer bank of a river curve. Over time, this slow removal of material from a soil face can result in major topography changes and widening or redirection of waterbodies. This process is illustrated in Figure 7.

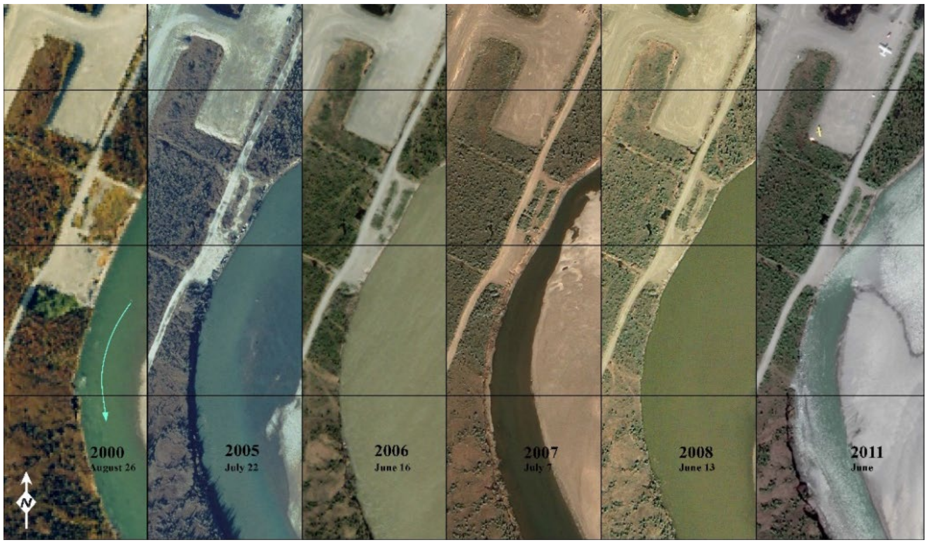


Figure 7. Noatak Riverbank Erosion, 2000–2011 [DOT&PF, 2013].

The erosion process and waterbody movement are naturally occurring; however, it often presents a conflict with large structures such as runways, where change and movement can severely impact aircraft operations and safety.

Flooding and Precipitation

Physical Issues	Safety Issues
Erosion Instability	Weakened Embankment
Impacted By Climate Change	

Flat ground is favorable for constructing airports, however much of Alaska's flat terrain is low-lying and often consists of soft, saturated materials interspersed with wetlands, streams, rivers, and ocean coastlines, as shown in Figure 8. While flat terrain is beneficial for aircraft operations and procedures, waterways and saturated ground put runways at higher risks for flooding. Flooding creates a combination of oversaturation and high flow rates, which can wash out the finer sand, silt, and clay particles from the embankment and create voids. As the embankment dries, these voids can reduce its overall structural capacity.

Figure 8. Flooding Along Rivers is a Common Threat to Communities and Airports; (Photograph of Napakiak Airport [WNA] taken by DOT&PF on June 6, 2023).

Changes in precipitation patterns also impact embankment integrity. More frequent precipitation and more severe storms can increase the rate at which fines are washed out of the embankment, and locations that receive more winter precipitation may experience less ground freezing because of the insulation of accumulated snow. Increased precipitation can also create soft runway surfaces, which can lead to ruts, as shown in Figure 9.

Figure 9. Rutting of the Runway Surface at St. Mary's (KSM) (Photograph taken by DOT&PF, 2021].

Vegetation Growth

Physical Issues	*Safety Issues*
Encroaching Vegetation *Cracking*	*Uneven Landing Surface* *Lighting Problems*
Impacted By Climate Change	

Areas of Alaska that were historically dominated by tundra vegetation and low, shrubby plants, such as western Alaska, are seeing increased growth of taller, woody vegetation. This encroachment of taller plants on an airfield requires additional maintenance in the form of brush cutting. Rural airports in western Alaska do not have equipment to deal with this new vegetation and are relying on the sporadic availability of specialized equipment. In the meantime, vegetation is advancing into runway safety areas (RSAs) and along runway embankments.

As the climate continues to warm, the encroachment of taller vegetation into western Alaska will only speed up. While this is primarily a maintenance concern currently, it can turn into a safety issue in the future.

Construction Materials

Physical Issues	*Safety Issues*
Shoulder Sloughing, Slope Failure *Erosion* *Cracking*	*Uneven Landing Surface* *Weakened Embankment* *Lighting Problems*

Construction material is defined as the soil material used to construct airport embankments. Ideally, embankments are constructed of granular material (gravel and sand); however, fine-grained materials (sand and silt) are often used. Two characteristics of construction material determine the long-term stability of an airport embankment:

1. Frost susceptibility
2. Quality

The frost susceptibility of a material determines how likely that material is to heave or weaken because of freeze-thaw events. Highly frost-susceptible soils are composed of more fines (i.e., silt) than non-frost-susceptible soils. In the Yukon-Kuskokwim region, much of the soil is composed of 20-95 percent fines, which is highly frost-susceptible and commonly leads to ice formation. A review of past construction projects showed that airports constructed of fine-grained materials that were wet and/or frozen or contained organic materials performed especially poorly; however, a low-quality embankment can perform reasonably well if it is placed over stable ground and the embankment material is uniform in quality and moisture content.

The quality of a material source is determined by how easily the material degrades. Materials that degrade easily will become more frost susceptible as the constituent rock breaks down into finer material. DOT&PF publishes degradation values, as well as abrasion resistance and sodium sulfate requirements for material sources. Minimum values vary based on the use of the material (e.g., surface course, base course). In recent years, DOT&PF changed from using degradation values to Micro-Deval tests; however, most of the material investigation reports reviewed in this study reported degradation values.

Poor-quality materials can be mitigated, to some extent, by using geotextiles, which can help improve stability when the subgrade is weak or when isolated areas of differential settlement need to be bridged.

Subbase and Surface Course

Subbase consists of hard durable particles or fragments of granular aggregates. It is placed on prepared subgrade, below the surface course material.

Surface course is the top or finish course of the embankment on which aircraft operate.

Many Alaska airports are remote and not on the contiguous road system. As such, local embankment construction material is the most economical option and, in many cases, the only option. Bringing material in by barge is typically financially impractical except in limited quantities (such as for surface course). Consequently, runways, especially in western Alaska, have been built on wet, saturated silty sand and built from those same materials. Often, the local material is pushed up or dredged and left to drain for a period to become as dry as possible. Not all local material sources are as poor as those commonly found in the Yukon-Kuskokwim region, but very few airports have ideal local material sources, and the designers and contractors must use what is available. Subbase and surface course materials are needed in smaller quantities and, although very expensive, have been imported via winter road or by barge. Giving a range of comparison costs is challenging because each airport generally has its own set of circumstances (e.g., barging to Kongiganak [DUY]).

Design and Construction

Physical Issues	*Safety Issues*
Shoulder Sloughing, Slope Failure *Cracking*	*Uneven Landing Surface* *Lighting Problems*

Embankment design and construction techniques, such as the following, significantly impact resilience. Frost heaving and differential settlement can often be attributed to subsurface conditions; however, construction considerations such as embankment material composition, frozen materials, and site drainage can lead to negative outcomes. Unfortunately, these techniques may seem unavoidable at the time of design or construction because of a lack of suitable land, funding limitations, and timing constraints.

- ***Building over swampy ground.*** As discussed in the wet or saturated ground section above, over compaction of saturated subgrade materials can impact the compaction of embankment material. While that section discussed water pumping up from the subgrade into the embankment material, the same impact can occur if the embankment materials used are overly saturated. This is generally a byproduct of constructing with embankment materials containing high fines (silt) that are prone to holding more moisture. Further, construction during wet weather conditions is also detrimental to achieving optimal embankment compaction.

- ***Building in freezing conditions.*** Freezing conditions also impact the long-term stability and construction of embankments. Frozen materials or excess moisture present in the materials during a freeze can reduce or limit the maximum compaction of an embankment. If kept frozen, these embankments can perform well; however, the primary impact occurs during thawing events, where the frozen water contained in the embankment thaws and overly saturates the material. This saturation softens the embankment and creates an environment more likely to suffer from differential settlement.

  Additionally, when the embankment thaws, it is generally soft and any surface loading, such as an aircraft wheel, can cause a rut, as shown in Figure 10. This process is cyclical and worsens over time as water that cannot drain infiltrates through the surface course material further wetting the subgrade, resulting in more softening when it freezes then thaws. If the ruts are removed (graded) during the dry season, this is helpful but if not recompacted by the fall/early winter, rain or snow melt will penetrate the unconsolidated surface likely deeper than the previous season, then the freezing/thaw action previously discussed will be deeper.

- ***Installing culverts under runways.*** An additional construction consideration is the installation of culverts within the embankment (under a runway). A common issue observed on runways is differential settlement of the embankment on either side of the culvert. As a general design principle, the materials under culverts are over-excavated and backfilled with material that provides a solid foundation, and bedding is placed around the culvert. This is accomplished because heave or settlement under a culvert can cause its failure, which can be catastrophic in comparison to minor surface cracks or shoulder sloughing. Ultimately, because culvert sections are built to be more durable than the adjacent embankments that naturally compress and settle or may heave, a bump on the surface often occurs.

Figure 10. Takotna (TCT) Runway Cross Culvert Failure Caused by Differential Settlement.

- ***Site drainage.*** If an embankment is placed such that it impedes overland flow, care must be given to assure the water is not trapped at the toe of the embankment. Similarly, runoff from the crowned embankments or melting snow berms needs to be managed. As noted in previous sections, water at the toe can increase permafrost thaw and induce embankment failure.

- ***Runway widening and lengthening.*** Issues can also arise when new embankments are placed adjacent to existing embankments on a lengthening or widening project. A crack frequently occurs because the original ground under the existing embankment has settled, whereas the settlement under the new embankment will take time.

General Trends

Details about all 29 airports included in this study are shown in Table 3. Data about runway conditions, lighting, and funding were reviewed to identify high-level trends among the study airports, excluding Bethel Gravel because the available funding data did not separate the gravel strip from the rest of the airports. This section includes a discussion of these high-level trends, as well as descriptions of the 24 airports that were not selected as in-depth case studies. These airports are grouped by location type: coastal (near a tidally influenced waterbody; 8 airports), inland (not near a waterbody; 9 airports), and riverine (near a riverbank; 7 airports).

Table 3. Airport Conditions and Locations.

Airport	LOC ID	Runway Length (feet)	Performance	Primary Deficiency	Surface	Location Type
Bethel Gravel	BET	1,858	Good	None	Gravel	Inland
Chevak	VAK	3,220	Poor	Soft surface	Gravel	Inland
Chignik Lagoon	KCL	2,200	Good	None	Gravel	Coastal
Chuathbaluk	9A3	3,400	Poor	Heaves, dips, slope erosion	Gravel	Inland
Galena	GAL	6,000/2,600	Good	Flooding	Asphalt	Riverine
Gambell	GAM	4,500	Poor	Flooding	Asphalt	Coastal
Goodnews	GNU	3,300	Good	None	Gravel	Coastal
Kiana	IAN	4,000	Poor	Erosion	Gravel	Inland
Kipnuk	IIK	3,200	Poor	Soft surface	Gravel	Riverine
Kivalina	KVL	3,000	Poor	Slope erosion	Gravel	Coastal
Kongiganak	DUY	2,400[2]	Poor	Soft surface, heaves, dips, cracking, slope erosion	Gravel	Inland
Kwigillingok	GGV	1,835	Poor	Soft surface, heaves, dips, ponding, slope erosion	Gravel	Riverine
Mekoryuk	MYU	3,001	Good	None	Gravel	Inland
Napakiak	WNA	3,248	Poor	Soft surface, potholes, ponding	Gravel	Riverine
Napaskiak	PKA	3,000	Poor	Dips, heaves, soft surface	Gravel	Riverine
Nightmute	IGT	3,200	Poor	Heaves, dips, cracks, river erosion	Gravel	Riverine
Noatak	WTK	3,992	Poor	Slope erosion	Gravel	Riverine
Platinum	PTU	5,000	Good	None	Gravel	Coastal
Point Hope	PHO	4,000	Good	None	Asphalt	Coastal
Scammon Bay	SCM	3,000	Poor	Slope erosion	Gravel	Riverine
Shaktoolik	2C7	4,001	Poor	Flooding, erosion	Gravel	Coastal
Shishmaref	SHH	4,997	Poor	Slope erosion	Asphalt	Coastal
Sleetmute	SLQ	3,100	Poor	Soft surface, heaves, dips, cracks	Gravel	Riverine
South Naknek	WSN	2,264/3,314	Poor	Soft surface	Gravel	Inland

[2] DUY extension in progress (2022 bid).

St. Mary's	KSM	6,008/1,520	Poor	Soft surface; rutting	Gravel	Inland
Takotna	TCT	3,300	Poor	Heaves, dips, cracks	Gravel	Inland
Tuluksak	TLT	3,300	Poor	Heaves, dips, cracks	Gravel	Inland
Tuntutuliak	A61	3,005	Good	None	Gravel	Riverine
Tununak	4KA	3,300	Poor	Soft surface, heaves, dips, cracking	Gravel	Inland

Gray shading indicates a case study airport.

Data from multiple sources were evaluated to assess the relationship between airport conditions and funding received. This analysis considered AIP grants from 2001 through 2022, operational expenses from 2010 through 2022, and runway and lighting conditions from the airports' performance measures report cards as of January 2024. To meet the Primary Runway Condition measure, conditions must be reported as "good" for gravel runways and 70 or higher for paved runways. To meet the Primary Runway Lighting measure, hub and regional airports must have High Intensity Runway Lights, whereas community class and local high-activity airports must have Medium Intensity Runway Lights.

As shown in Table 4, overall, inland airports received the most AIP grant funding at an average of $20 million per airport, followed by coastal airports ($12 million) and riverine airports ($10.6 million). Average operational expenses were similar across all three location types, with riverine airports spending $1.6 million, inland airports spending $1.5 million, and coastal airports spending $1.3 million.

Table 4. Average Funding Received by Location Type, Based on Whether the Airport Met the Primary Runway Condition Performance Measure.

	Meets Measure	AIP Grants	Operational Expenses	Total
All Airports	Yes	$16,367,831.74	$1,359,270.36	$17,727,102.09
	No	$12,073,952.07	$1,552,166.69	$13,626,118.76
	All	$14,374,244.75	$1,448,829.37	$15,823,074.12
Coastal	Yes	$13,667,314.67	$1,164,309.73	$14,831,624.40
	No	$10,249,070.89	$1,425,322.94	$11,674,393.83
	All	$11,958,192.78	$1,294,816.34	$13,253,009.12
Inland	Yes	$21,532,576.28	$1,980,133.43	$23,512,709.71
	No	$17,815,918.30	$683,825.93	$18,499,744.23
	All	$20,045,913.09	$1,461,610.43	$21,507,523.52
Riverine	Yes	$12,330,551.94	$770,203.16	$13,100,755.10
	No	$8,940,284.03	$2,348,314.30	$11,288,598.34
	All	$10,635,417.99	$1,559,258.73	$12,194,676.72

The coastal, inland, and riverine location types each had similar performance rates for the Primary Runway Condition measure, with 50, 60, and 50 percent of airports achieving the measure, respectively. Across all locations, 15 airports met the Primary Runway Performance measure and 13 did not. On average, the airports that met the Primary Runway Condition measure received 30 percent more AIP grant funding and spent 13 percent less on operational expenses than airports that did not meet the measure. This trend generally held true for the coastal and riverine airports, but inland airports that met the runway condition measure spent 97 percent more on operational expenses than inland airports that did not. The average amount of funding per airport for each location type is shown in Table 5.

Most airports in the study (24) met the requirements for the Primary Runway Lighting measure, with only three airports not meeting the requirements and one airport being exempt. All inland airports met the requirements for the lighting measure (South Naknek [WSN] was exempt). One coastal airport (Chignik Lagoon [KCL]) and two riverine airports (Galena [GAL] and Kwigillingok [GGV]) did not meet the measure. No funding trends were identified because of the lack of variation in performance results.

Coastal

Eight airports in this study are identified as coastal, meaning they are located close enough to the shore of a tidally influenced body of water to potentially experience impacts, such as flooding and erosion. These airports include Chignik Lagoon (KCL), Gambell (GAM), Goodnews (GNU), Kivalina (KVL), Platinum (PTU), Point Hope (PHO), Shaktoolik (2C7), and Shishmaref (SHH).

Slope erosion and flooding are the most common issues experienced by these airports. Data about vegetation growth was only available for Chignik Lagoon (KCL), which does experience challenges related to vegetation growth.

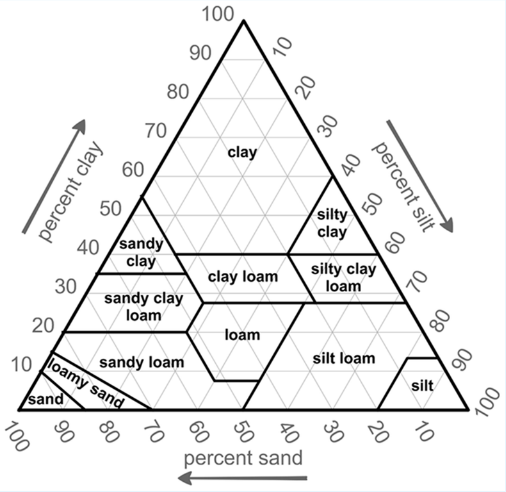
Most coastal airports in this study do not experience soft surface/rutting, frost heaving/dips, longitudinal cracking, or ponding at the embankment toe. Coastal airports do not experience much settlement possibly because they are often built over thawed or uniform ground (consistent soil type, moisture content, and ice content). Near the coast, airports are more likely to be built over and with uniform sands. These sands are often very frost susceptible, but the uniformity results in minimal differential movement and, therefore, better performance. The lack of rutting may also be attributed to the lack of significant grading operations, such as those required to mitigate differential settlement at inland airports. The need for compaction increases with the frequency of grading, but compaction often does not happen at inland airports, leading to soft saturated surfaces and rutting.

All but three airports (Goodnews [GNU], Platinum [PTU], and Shaktoolik [2C7]) experience slope erosion. Most airports have experienced flooding in the past, though historical flooding data were not available for PTU and SHH.

Coastal airports received an average of $13 million in funding in the reviewed timeframes (2001 through 2022 for AIP, 2010 through 2022 for operational expenses)—$12 million of the funding came from AIP grant funds and the remaining $1 million were operational expenses.

Soil Composition

This diagram, known as a texture triangle, shows the makeup of different soil types referenced throughout this chapter [Groenendyk, et al., 2015].



Chignik Lagoon (KCL)

Performance Category: Good

Runway Dimensions: 2,200 × 90 feet

Permafrost: No data

Material Source: Non-local

Chignik Lagoon Airport (KCL) has a gravel runway. The airport is located close to the shore of Chignik Lagoon and is considered coastal with tidal influences, with rugged and forested surrounding terrain.

The runway surface sometimes becomes very soft in spring and during periods of heavy precipitation and has experienced flooding from storm surge. The runway is reported to be performing well.

Gambell (GAM)

Performance Category: Poor

Runway Dimensions: 4,500 × 100 feet

Permafrost: Not present

Material Source: On-site

Gambell Airport (GAM) has a paved asphalt runway. The airport is on a gravel spit on the northwestern coast of St. Lawrence Island. The terrain is volcanic with rolling hills. A large gravel beach is to the west of Sevoukuk Mountain, which has a 600-foot peak. Native soils are entirely rounded beach gravels with free-draining conditions.

Limited documents are readily available to aid in identifying issues at the airport, but general deterioration of the runway has likely occurred. The last pavement rehabilitation grant was issued in 2017, and the current pavement condition is listed as fair. PCI reports between 2002 and 2014 were in the 40–46 range (Rehabilitation). Before 2017, the last reported paving project was in 1985 (per the 2008 *Gambell Airport Pavement Inspection Report* [Horn, 2008]). The runway is performing poorly.

Goodnews (GNU)

Performance Category: Good

Runway Dimensions: 3,300 × 75 feet

Permafrost: No data

Material Source: On-site

Goodnews Airport (GNU) has a gravel runway. The surrounding terrain is relatively flat, consisting of muskeg swamp to the east and sand beaches to the south along the Goodnews River mouth edge. Low hills exist north of the runway. Native soils include silt and organics underlain by gray gravelly silt.

The airport was constructed in 1975, with significant improvements made in 2011. The on-site material source provided good quality construction materials, and organics were not left in place during construction. Overall, the runway is performing well and does not experience any significant issues.

Kivalina (KVL)

Performance Category: Poor

Runway Dimensions: 3,000 × 60 feet

Permafrost: Present

Material Source: No data

Kivalina Airport (KVL) has a gravel runway. The airport is located on a small barrier island between the Chukchi Sea and the Kivalina Lagoon, at the mouth of the Kivalina River. The surrounding terrain consists of rolling hills and gentle slopes underlain by geologically modern coastal beaches, spits, and sand bars composed of alluvial deposits. Native soils consist of fine to gravelly and fine to coarse sand to depths of 15 feet with additional silt below.

Materials used in airport construction consist of fine to coarse sands and gravels with overlain silt. The airport is becoming increasingly susceptible to severe storms, resulting in slope erosion at the airport and the potential for storm debris to impact the runway. The airport relocated once before from the north end of the lagoon to its current site. The community has long considered relocation from its current site to a more protected area approximately 12 miles inland. Safety and long-term viability concerns are causing DOT&PF to explore potential solutions, including the relocation to a more protected area. In 2018, an evacuation road was constructed across the lagoon to provide residents with an egress route in case of severe storms. The road leads to a new school site that is inland and protected from the coast. The runway is performing poorly.

Platinum (PTU)

Performance Category: Good

Runway Dimensions: 5,000 × 75 feet

Permafrost: Present

Material Source: On-site

Platinum Airport (PTU) has a gravel runway and is located on a spit between Goodnews Bay and Kuskokwim Bay. The surrounding terrain is boreal subarctic tundra underlain by permafrost and coastal plains that are frequently inundated by sea tides. Native soils consist of stratified sandy silt and sandy alluvial deposits. Volcanic ash and loess are found in some areas.

Construction materials included glacial till or still water deposits consisting of silty gravel and sand. The runway was relocated in 2012 and is generally performing well, with no major issues.

Point Hope (PHO)

Performance Category: Good

Runway Dimensions: 4,000 × 75 feet

Permafrost: Present

Material Source: On-site

Point Hope Airport (PHO) has a paved asphalt runway and is located on a lowland peninsula extending into the Chukchi Sea. The surrounding terrain is a narrow gravel beach with gravel ridges. Native soils consist of sandy gravel and gravelly sand with frozen material at varying depths.

Construction materials included gravelly sand with low fine contents. The runway stability can be attributed to non-frost-susceptible sandy gravel material and, although permafrost was encountered at a depth of 11 feet back in 1973, no ice was visible. The RSA is facing erosion issues, and the runway and apron have very poor pavement conditions. The airport has experienced flooding in the past. A project to realign the runway was completed in 2024, improving the reported runway conditions.

Shaktoolik (2C7)

Performance Category: Poor

Runway Dimensions: 4,001 × 75 feet

Permafrost: Not present

Material Source: On-site

Shaktoolik Airport (2C7) has a gravel runway and is located on the east shore of Norton Sound. The runway was relocated in 2003. The surrounding terrain is rolling to hummocky poorly drained tundra with numerous thaw lakes, swamps, and a few meandering streams. Native soils consist of thin organics over successive layers of silt, sand, and gravel. Frozen soils have been observed below the ground surface, though the depth of frozen soil varies by report.

Construction materials included sand, gravelly sand, and sandy gravel, and culverts exist within the runway embankment. The runway becomes soft in the spring and during periods of heavy precipitation. It has experienced flooding in the past, notably in 2005, which led to a Federal Emergency Management Agency (FEMA)-funded project in 2008. The runway is performing poorly.

Shishmaref (SHH)

Performance Category: Poor

Runway Dimensions: 4,997 × 73 feet

Permafrost: Present

Material Source: On-site

Shishmaref Airport (SHH) has a paved asphalt runway and is located on the barrier island Sarichef in the Chukchi Sea north of the Bering Strait and 5 miles from the mainland. The surrounding terrain is composed mainly of sand deposited by waves and constantly being built up and/or eroded at various points. Native soils include sand with areas of organic-covered lowlands and continuous underlain permafrost. Construction materials included silty sand and gravel.

The runway, taxiway, and apron were rehabilitated in 2015, which included asphalt paving and a new lighting system. A seal coat on the pavement was applied in 2022. In 2023, a project for rock revetement along the airport access road was completed. Also in 2023, a winter storm caused a substantial amount of ice (about 30 feet tall) to be pushed over the rock revetment onto the road. As of 2024, further rock revetment work is in progress along the road, outside the airport property, which leads to the landfill. The runway is threatened by coastal erosion and is performing poorly.

Inland

Eleven airports in this study are identified as inland, meaning they are not located close enough to a body of water to experience impacts like flooding or erosion. These airports include Bethel (BET), Chuathbaluk (9A3), Kiana (IAN), Kongiganak (DUY), Mekoryuk (MYU), South Naknek (WSN), St. Mary's (KSM), Takotna (TCT), and Tuluksak (TLT), as well as the case study airports of Chevak (VAK) and Tununak (4KA).

Most of these airports experience issues with soft surfaces and rutting (except Tuluksak [TLT], Bethel [BET], and St. Mary's [KSM]) and frost heaving and dips (except Tuluksak [TLT], Bethel [BET], and South Naknek [WSN]). Half of the airports experience longitudinal cracking and only two (Chuathbaluk [9A3] and Kongiganak [DUY]) experience slope erosion. Data about past flooding and vegetation growth were not available for most airports; it is known that Kongiganak (DUY) has not experienced flooding and that Chuathbaluk (9A3) and Kongiganak (DUY) have trouble with vegetation growth.

Inland airports received an average of $21.5 million in funding in the reviewed timeframe (2001 through 2022 for AIP, 2010 through 2022 for operational expenses)—$20 million came from AIP grant funds and the remaining $1.5 million were operational expenses.

Bethel Gravel Strip (BET)

Performance Category: Good

Runway Dimensions: 1,858 × 75 feet

Permafrost: Present (discontinuous)

Material Source: On-site

Bethel Airport (BET) has three runways, but only Runway 12/30 was included in this study. Runway 12/30 is a mostly gravel runway, but it is paved 75 feet eastward from the Runway 12 threshold (the intersection of paved taxiways F and N) and about 500 feet west of the Runway 30 threshold (the intersection of paved taxiways E North and E South). The runway is classified as a B-II runway, which is appropriate considering that crosswind coverage by the primary runway (1L/19R) is less than 95 percent at 13 knots. The 2016 Bethel Airport Master Plan [DOWL, 2016] recommended extending runway 12/30 to 3,300 feet. The terrain is flat and surrounded by marsh and ponds. Native soils consist of sand and silt.

Organics were removed before runway construction and culverts exist within the embankment. Based on interviews with state aviation managers and data review, Runway 12/30 is performing well. The good condition of the airport is likely based on the removal of organics, consolidation of the native materials, and placement of sound and stable embankment materials.

AIRPORT REFERENCE CODES

Airport Reference Codes (ARCs) comprise a letter (the aircraft approach category) and a Roman numeral (the airplane design group). These are determined by the "design aircraft" of an airport.

An ARC of B-II means BET is designed for an approach speed of 91-120 knots and aircraft with a wingspan of 49-78 feet.

Chuathbaluk (9A3)

Performance Category: Poor

Runway Dimensions: 3,400 × 60 feet

Permafrost: Present

Material Source: On-site

Chuathbaluk Airport (9A3) has a gravel runway located about ¾ mile from the Kuskokwim River. The runway was relocated in 2006. The surrounding area is generally flat and vegetated.

There are no culverts in the embankment. The runway has frost heaves and dips in several locations and a recurring dip at the runway/taxiway intersection experiences ponding. The taxiway/apron intersection has significant erosion, and surface cracking is occurring nearby. Shoulders along the runway are also eroding. The cause of current rutting and frost heaving is inconclusive based on available data. Design sections from the 2002 Runway Relocation project seem reasonable in material depth and proposed excavation limits. Material used for relocation was taken from adjacent material sources which is likely susceptible to frost heaving. The runway is performing poorly.

Kiana (IAN)

Performance Category: Poor

Runway Dimensions: 4,000 × 75 feet

Permafrost: Present (discontinuous)

Material Source: Local, off airport

Kiana Airport (IAN) has a gravel runway located on a bluff above the Kobuk River. The surrounding landscape is low, swampy stream valleys and rolling hills. Native soils include sandy silt and silty sand beneath the runway, taxiway, and apron.

Organics were not removed before airport construction, and there are no culverts in the embankment. The runway was realigned and lengthened in 2019. The embankment material was of decent quality (for rural airports). The lower section of the new embankment was constructed with materials containing up to 50 percent silt, followed by a 5-foot granular layer and topped with subbase and base course material. A local material site located 3 miles northwest of the airport was developed for this project construction. The westernmost 1,000 feet of runway are currently experiencing settlement, which is causing cracking and sinkholes. The runway has experienced a soft surface and rutting, frost heaving and dips, and longitudinal cracking. The runway experiences ponding at the toe and is performing poorly.

Kongiganak (DUY)

Performance Category: Poor

Runway Dimensions: 2,400 × 75 feet

Permafrost: Present (abundant ice)

Material Source: On-site

Kongiganak Airport (DUY) has a gravel runway located about 1,200 feet from the Kongnignanohk River. The surrounding terrain is generally flat with several interspersed lakes. Native soils consist of organics, peat, silt, and sand with some visible ice.

The airport is currently under construction to expand the runway to 3,300 feet long by 75 feet wide. The original construction materials consisted of silty sand with gravel. Before reconstruction, the runway surface was soft and had heaves, dips, and longitudinal cracks. Embankment slopes were also experiencing erosion and vegetation growth was noted as an issue. The runway was performing poorly.

Mekoryuk (MYU)

Performance Category: Good

Runway Dimensions: 3,001 × 75 feet

Permafrost: No data

Material Source: No data

Mekoryuk Airport (MYU) has a gravel runway, which was built on a lake bed that was artificially drained before construction. The subsurface geology consists of peat and organic soil over silt and sand over weathered basalt bedrock. Drilling at the airport has indicated frozen soils are present in the runway embankment and in the underlying soil.

The runway has performed well for a long time, with the last major rehabilitation project occurring in 1984 with a minor preservation project in 2012. Over time the surface course material has degraded, and the embankment has started showing signs that the underlain frozen soils are thawing. A letter from the community states that the runway is sinking into the tundra [Williams, 2016]. Funds for a rehabilitation project for the airport have been obligated at the time of this study. The runway is performing poorly.

South Naknek (WSN)

Performance Category: Poor

Runway Dimensions: 2,264 × 60 feet; and 3,314 × 60 feet

Permafrost: Present (isolated masses)

Material Source: On-site

South Naknek Airport (WSN) has two gravel runways and is located about 4,000 feet inland from the mouth of the Naknek River and Kvichak Bay. The surrounding terrain is wetlands underlain by isolated masses of permafrost. Data about native soils and the materials used in airport construction are lacking.

Both runways were resurfaced in 2020. Before the runway rehabilitation project, one runway (05/23) was closed, and the usable length of the other runway (13/31) was shortened because of soft surface conditions and severe rutting. The rehabilitation project did not restore the original full length of Runway 13/31. The final length was approximately 560 feet longer than the pre-rehabilitation runway. The runways are performing poorly.

St. Mary's (KSM)

Performance Category: Poor

Runway Dimensions: 6,008 × 150 feet; and 1,520 × 60 feet

Permafrost: Present (discontinuous)

Material Source: On-site

St. Mary's Airport (KSM) has two gravel runways and is located on a bluff above the Yukon River. The surrounding terrain is lowland between the mouths of the Yukon and Kuskokwim Rivers, consisting of lake and pond wetlands with muskeg and tundra at higher elevations. Native soils vary with topography and include tundra mat with peat and/or silty organics below, slightly organic silt, gravelly silt/silty gravels, and bedrock.

Construction materials included siltstone, shale, and sedimentary sandstone, and there are culverts in both embankments. Soft spots on the runway have been investigated and silt, a thick organic layer, visible ice, and permafrost thaw features exist below the runway fill.

An improvement project is currently under construction that will address deficiencies in FAA RSA standards, runway surface degradation, and drainage issues. Much of the construction work was performed in 2024 and will be completed in 2025. Before construction, the airport was performing poorly.

Takotna (TCT)

Performance Category: Poor

Runway Dimensions: 3,300 × 60 feet

Permafrost: Not present

Material Source: On-site

Takotna Airport (TCT) has a gravel runway and is located along the Takotna River, with surrounding terrain characterized by rolling hills and valleys with muskeg bogs. Native soils consist of brown silt with some organics overlying brown silty gravel.

The 2020 Aviation Project Evaluation Board (APEB) nomination form notes that the culverts in the embankment are inadequate. Since being relocated in 2009, the runway has experienced settlement and drainage issues. The runway, taxiway, apron, and access road have cracks, dips, bumps, rutting, ponding, and soft spots. The runway is performing poorly.

Tuluksak (TLT)

Performance Category: Poor

Runway Dimensions: 3,300 × 60 feet

Permafrost: Present

Material Source: Local

Tuluksak (TLT) has a gravel runway and is located inland near the Kuskokwim River. The surrounding terrain is lowlands and wetlands along the Kuskokwim River. There were no available geotechnical reports, but native soils are assumed to be river-deposited and overlain with vegetation.

The as-built drawings indicate that organics were left in place during airport construction and there are no culverts in the embankment. Materials used in runway construction included sand from a sandbar at the confluence of the Tuluksak and Kuskokwim Rivers.

The airport was relocated in 2009 onto relatively flat ground, with the runway grade set at 0 percent. The embankment thickness is approximately 8 feet. Data to help understand the underlaying issues for this airport were not readily available. The runway is performing poorly.

Riverine

Ten airports in this study are identified as riverine, meaning they are located close enough to the bank of a river to potentially experience impacts such as flooding. These airports include Galena (GAL), Kwigillingok (GGV), Napakiak (WNA), Napaskiak (PKA), Noatak (WTK), Scammon Bay (SCM), and

Sleetmute (SLQ), as well as the case study airports of Kipnuk (IIK), Nightmute (IGT), and Tuntutuliak (A61).

Most of these airports experience issues with soft surfaces and rutting, except for Tuntutuliak (A61) and Noatak (WTK). Most riverine airports do not experience longitudinal cracking or slope erosion. Limited data are available about past flooding and vegetation growth, but it is known that Scammon Bay (SCM) and Noatak (WTK) have both flooded and Sleetmute (SLQ), Tuntutuliak (A61), and Napakiak (WNA) experiences problematic vegetation growth. Data about airport issues were not available for Galena (GAL).

Riverine airports received an average of $12.2 million in funding in the reviewed timeframes (2001 through 2022 for AIP, 2010 through 2022 for operational expenses)—$10.6 million of the funding came from AIP grant funds and the remaining $1.6 million were operational expenses.

Galena (GAL)

Performance Category: Good

Runway Dimensions: 6,000 × 100 feet; and 2,600 × 50 feet

Permafrost: Present (sporadic)

Material Source: No data

Galena Airport (GAL) has two runways, a 6,000-foot-long paved asphalt runway (08/26) and a 2,600-foot-long gravel runway (06/24). The airport is immediately adjacent to the Yukon River within a diked area to protect it from flooding and erosion but there is concern about the long-term stability of this dike. The surrounding terrain is floodplain, with native soils described as gray-brown micaceous silt with various amounts of sand and 30 percent visible ice in thin ice lenses. In deeper regions, the soil is gravelly sand and gravel. The pavement at the airport is generally performing well.

Kwigillingok (GGV)

Performance Category: Poor

Runway Dimensions: 1,835 × 40 feet

Permafrost: Present

Material Source: On-site

Kwigillingok Airport (GGV) has a gravel runway and is located along the Kwigillingok River, which has a tidal influence. The surrounding terrain is flat with numerous thaw lakes and branching slough channels affected by Kuskokwim Bay tides. Native soils include wet silts with organics to depths of 6 feet. Organic and moisture content varies between 7 and 23 percent and 40 and 100 percent, respectively.

Construction materials included silty sand with gravel for the airport surface, sandy silt with sand fill (existing subgrade) and sandy silt or silt with sand. Organics were left in place during construction the original construction. Minimal drainage ditching exists, which causes the embankment materials to remain wet and soft.

The runway has numerous humps and dips, as well as extensive ponding. Ongoing embankment erosion is occurring, particularly at the south end. At 1,835 feet long, the runway is scheduled for reconstruction and lengthening pending acquisition of adjacent private property. Air carriers discontinue service to the airport regularly when runway conditions are poor. In 2018, a small amount of surface course material was imported as part of an emergency rehabilitation project. The material was used to level the runway to allow continued aircraft operations. The runway is performing poorly.

Napakiak (WNA)

Performance Category: Poor

Runway Dimensions: 3,248 × 60 feet

Permafrost: Present

Material Source: On-site

Napakiak Airport (WNA) has a gravel runway and is located along the Kuskokwim River, surrounded by lake-dotted, marshy plains.

Construction materials included silty fine sands with trace organics, and there are culverts within the embankment. Vegetation growth was noted as an issue. The runway was reconstructed in 2002 and currently faces issues with soft surface conditions, potholes, and ponding. The runway is performing poorly.

Napaskiak (PKA)

Performance Category: Poor

Runway Dimensions: 3,000 × 60 feet

Permafrost: Present

Material Source: On-site

Napaskiak Airport (PKA) has a gravel runway and is located along the Kuskokwim River with surrounding terrain consisting of lowlands within the delta formed by the Yukon and Kuskokwim Rivers. The airport was relocated in 1973 and underwent runway reconstruction in 1995. Native soils consist of saturated organic silt.

The runway has soft surface conditions, differential settlement-related heaves and dips, and is susceptible to flooding during the spring. The August 2024 site visit allowed for a quick stop at PKA. The airport surface was in good condition. A 2018 surface maintenance project had removed previously reported heaves and dips. The surface irregularities have not reappeared, indicating that minor surface maintenance projects may be an effective solution to surface issues at some airports.

Although the runway surface was in good condition, the following other issues were noted by the site visit team:

Figure 11. Debris Inside the Light Line of the Runway at PKA.

- Debris is inside the light line along the edge of the runway, as shown in Figure 11, indicating that high water is encroaching on the runway.
- Vegetation is encroaching on the runway, despite being cut the previous year (as noted by the Bethel M&O manager), indicating the need for more frequent vegetation maintenance and dedicated equipment at the airport.
- The lighting system is in fair/poor condition.

Noatak (WTK)

Performance Category: Poor

Runway Dimensions: 3,992 × 60 feet

Permafrost: Present

Material Source: On-site

Noatak Airport (WTK) has a gravel runway and is located along the Noatak River surrounded by broad, flat tundra containing thaw lakes and pingos 25 to 300 feet high crisscrossed by forested floodplain.

The airport's location is threatened by river erosion from the adjacent Noatak River and experiences slope erosion and flooding. DOT&PF has proposed relocating the airport. An Environmental Assessment, which had a Finding of No Significant Impacts (FONSI), was signed on September 27, 2024. The project is now moving forward with permitting, right-of-way (ROW) acquisition, and final design. The current runway is performing poorly.

Scammon Bay (SCM)

Performance Category: Poor

Runway Dimensions: 3,000 × 75 feet

Permafrost: Present

Material Source: On-site

Scammon Bay Airport (SCM) has a gravel runway and is located along the Kun River, which has a tidal influence. The surrounding terrain is a lowland delta formed by the Yukon and Kuskokwim Rivers. Native soils consist of organics over varying thicknesses of organic silts and clays. Large ice pingos (275 feet in diameter by 3 feet to 10 feet high) exist within the area of the runway.

There are culverts within the embankment and ponding occurs at the runway toe. The airport is susceptible to flooding from the Kun River and experienced significant flood events in 2004 and 2013. The airport needs improvements to mitigate the risk of flood damage. Additional issues with runway conditions include surface erosion on both sides of the runway, ponding, deep ruts, and very soft conditions in spring and during periods of heavy precipitation. The runway is performing poorly.

Sleetmute (SLQ)

Performance Category: Poor

Runway Dimensions: 3,100 × 60 feet

Permafrost: No data

Material Source: No data

Sleetmute Airport (SLQ) has a gravel runway and is situated inland along the Kuskokwim River. The surrounding terrain is low and relatively flat with mountains located about a mile to the east. Native soils consist of shallow organics over organic silts to a depth of 2.5 feet underlain by fine-grained soils.

The runway underwent a reconstruction project in 1983 and a resurfacing project in 2010. The runway, apron, and access road are currently not well compacted and have soft spots and dips. A 1983 investigative report indicated long-term differential settlement should be expected where the runway was to cross an old meandering slough. A project to rehabilitate the runway, taxiway, and apron, and expand the RSAs to address these issues is scheduled for completion in September 2024. Vegetation growth was also noted as an issue at this airport. The runway is performing poorly.

Case Studies

Five airports were selected as more in-depth case studies to help determine causes of failures or long-term stability of these runways. The airports were selected for the following reasons:

Extensive data allows comparison and analysis of potential failures.

Similarities between these airports allows for control factors when analyzing the failures.

- Dimensions (length and width)
- Gravel surface
- Permafrost presence
- Large capital projects within the last 20 years
- Geotextile used in construction
- Embankment settlement issues

Differences of key components permits an analysis of underlying causes of failures (or reasons for long-term stability).

- Embankment thickness
- Material sources
- Embankment slopes
- Phased construction
- Ponding along embankment toe

Chevak (VAK)

Location Type: Inland

Performance Category: Poor

Runway Dimensions: 3,220 x 75 feet

Permafrost: Present

Material Source: On-Site

Chevak Airport (VAK) has a gravel runway and is located in the Yukon-Kuskokwim Delta. The airport was relocated to its current location through a two-phase construction program in 1999 (Phase 1) and 2005 (Phase 2) using AIP grant funding.

The runway has historically become soft and rutted during the spring breakup season but is now experiencing rutting and softening during regular rain events year-round and did not meet the requirements for the Primary Runway Condition performance measure. Air carriers cease operations at this airport when severe softness and rutting conditions occur.

Soft surface and rutting likely occurred because the embankment was constructed:

1. On low-quality subsurface material, as documented in comments in the Phase 2 as-builts (the material was replaced during Phase 2, but it is reasonable to assume that there are still low-quality materials within the embankment subsurface)
2. Using sandy surface course material, which is prone to raveling, especially because the fines content is diminished over time from wind and water

The project team was unable to visit this airport during the August 2024 trip.

Chevak (VAK) received four runway-related AIP grants related in the period for which data were available. Table 6 shows the year, amount (adjusted to 2022 dollars), and description of each grant.

Table 5. AIP Grants Received by Chevak Airport (VAK).

Year	Amount (adjusted for inflation)	Description
1999	$10,019,409.71	Construct New Airport
2005	$5,106,240.35	Construct New Airport Phase 2 (Surfacing)
2007	$269,382.00	Construct New Airport Phase 3
2011	$13,619.20	[Various Grant] Rehabilitate Runway 02/20 Various Surface Preservation

Figure 12 shows the amount of operational expenses reported at Chevak (VAK) from 2010 through 2022. The star indicates the year in which the most recent runway-related AIP grant was received, and the dashed yellow line shows the amount of operational expenses reported for that year ($43,300). In 2010 and 2011, an average of approximately $55,000 was spent on operational expenses at this airport. After 2011, an average of $46,000 was spent per year. Although this is an overall decrease, the actual amount fluctuated each year.

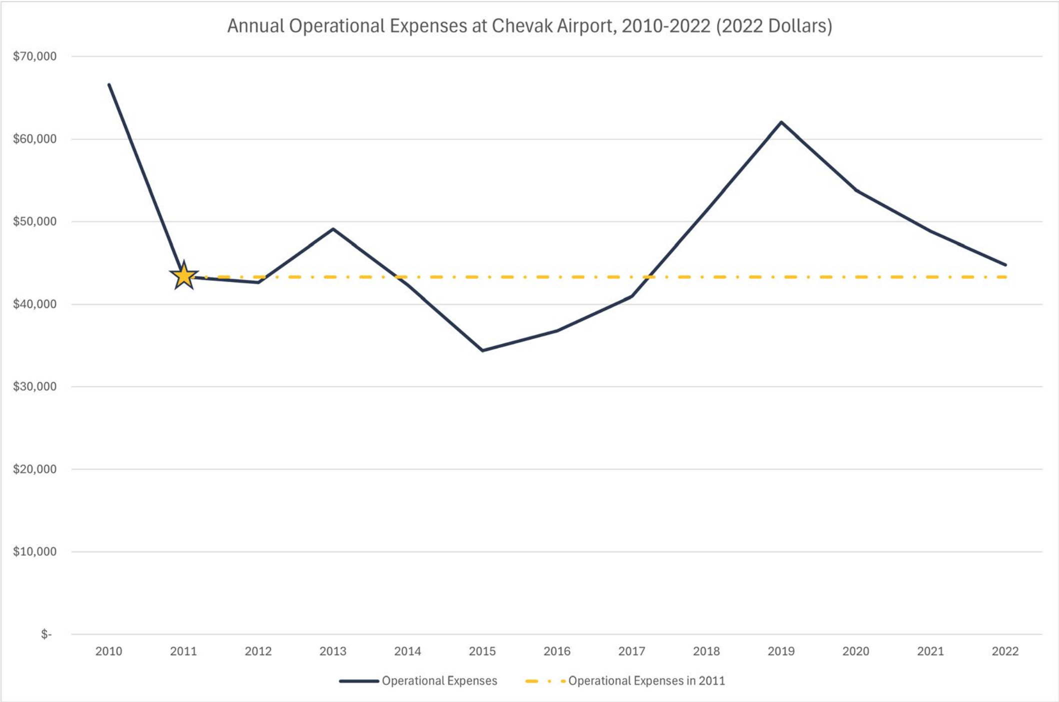


Figure 12. Annual Operational Expenses at Chevak (VAK), 2010–2022 (adjusted for inflation).

Kipnuk (IIK)

Location Type: Riverine

Performance Category: Poor

Runway Dimensions: 3,200 x 60 feet

Permafrost: Present

Material Source: On-site

Kipnuk (IIK) has a gravel runway that was constructed in 2010. The airport is located along the Kuguklik River about 3 miles from the Bering Sea coast, resulting in a strong tidal influence. The surrounding terrain is generally flat and a poorly drained river delta with tundra grasses and moss. Native soils include organic materials underlain by silt and fine sand, with the silt often containing organics.

Organics were not left in place during construction, and there are no culverts within the embankment. The runway experiences soft surface conditions, bumps, and potholes. The air carriers cease operations when conditions are severe.

The embankment settlement rate was defined in a 2006 thermal analysis at 0.0083 to 0.033 feet to feet of thawed soil if no ice lenses. Further thermal analysis models identify that soil temperatures vary throughout the embankment; however, actual temperatures are likely to exceed the design model. Based on these comments, we assume that varying subsurface temperatures are resulting in differential settling of the embankments. This assumption is also based on the thermal graphs of the embankment, which identify interlaid layers of frozen soils, unfrozen soils, and ice lenses within the embankment.

The Resiliency Study team site visit to the airport occurred just days before the final project inspection was completed (August 2024). The project widened the runway; resurfaced the runway, taxiway, and apron; and installed a new lighting system. The team made visual observations and discussed the recently completed project with the DOT&PF Construction Manager. The following were points of interest:

- All materials for the project were imported from Platinum. The surfaces looked well graded and tight. All operational surfaces were treated with dust palliative.
- All slopes were covered with rock (non-erodible), which was a change to the design. This was done 1) to allow closure of the Stormwater Pollution Prevention Plan (SWPPP) rather than waiting for 70 percent vegetive coverage, which required weekly inspections; and 2) to slow the growth of vegetation, especially alders, on the slopes, which will reduce M&O costs to clear the vegetation. Erosion and vegetation growth at IIK should be monitored and documented to assess the effectiveness of this strategy.
- During landing and takeoff, there was a nearly 90-degree crosswind with gusts reported to be close to 30 miles per hour. The 1996–1998 wind data referenced in the airport layout plan shows that winds at that speed in a crosswind direction occurred less than 0.1 percent of the time. Conducting a new wind study to determine if wind speeds and directions have changed may be worthwhile. Wind data from the on-airport AWOS may be available for an updated analysis.
- The airport did not appear to sustain any damage from the storm event that occurred a few days before the site visit, despite flooding in the nearby village.

Kipnuk (IIK) received five runway-related grants in the period for which data were available, as shown in Table 7.

Table 6. AIP Grants Received by Kipnuk Airport (IIK).

Year	Amount (adjusted for inflation)	Description
2000	$7,039,434.59	Construct New Airport
2010	$10,640,769.39	Construct Runway Plan-1 Construct runway Phase 2 (A)
2010	$9,868,571.55	Construct Runway Plan-1 Construct runway Phase 3 (C)
2012	$13,020.00	[Various Grant] Rehabilitate Runway 15/33 Various Surface Preservation Maintenance (Kipnuk)
2021	$12,306,022.92	Widen Runway, including resurfacing and a new lighting system

Figure 13 shows the amount of operational expenses reported each year from 2010 through 2022. As noted in Table 7, the airport received an AIP grant in 2010 to complete construction of the runway, another in 2012 for runway rehabilitation, and most recently in 2021 to widen the runway. The yellow dashed line in Figure 13 shows the amount of operational expenses reported for the previous AIP grant year, so operational expenses for subsequent years can easily be compared. Operational expenses have generally increased since 2010, peaking in 2019 at $78,084.

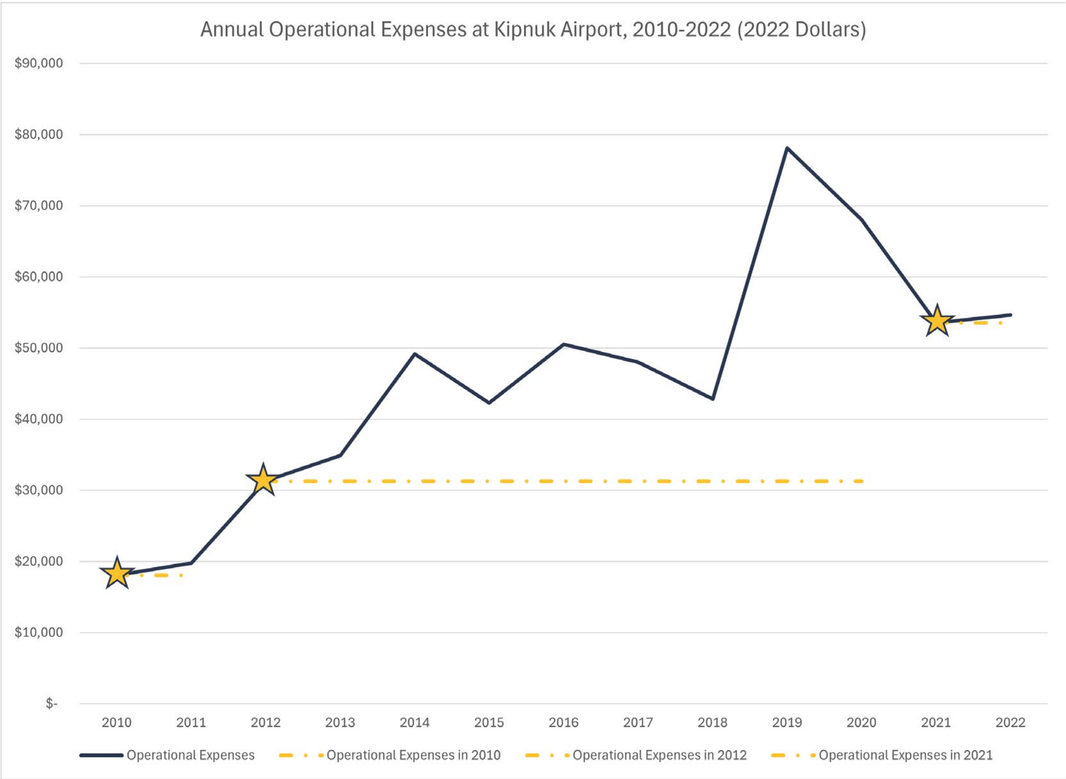


Figure 13. Annual Operational Expenses by Year for Kipnuk Airport (IIK), 2010–2022 (adjusted for inflation).

Nightmute (IGT)

Location Type: Riverine

Performance Category: Poor

Runway Dimensions: 3,200 x 75 feet

Permafrost: Present (high ice content)

Material Source: Local

Nightmute Airport (IGT) has a gravel runway and is located along the Toksook River, surrounded by expansive areas of near-sea level marsh and shallow lowland lakes within isolated islands of bedrock forming low hills. Native soils include permanently frozen river silt that is slightly organic with ice-rich conditions immediately beneath the surface organics mat.

The embankment materials include a crushed aggregate surface course on top of 15 inches of high-quality crushed rock, which is on a material with a high fines content.

The runway underwent renovations beginning in 2007, with as-builts completed in 2012. The improvements included the lengthening of the runway from approximately 1,600 feet to 3,200 feet and widening from 60 feet to 75 feet. The safety area was also widened from 120 feet to 150 feet. Despite these improvements, the runway is in poor condition because of settlement-related damage and did not meet the requirements for the Primary Runway Condition performance measure. The runway has depressions, humps, cracking, and ponding, as well as shoulder erosion. The airport is included in the poor performance category for this study.

Current impacts on the runway likely result from differential settlement and thawing of the embankment and subsurface. The differential settlement issues are likely a result of the embankment expansion in 2007. The thermal analysis identified that the surrounding water features and wet local terrain are causing localized thawing and associated settlement where water is ponding at the toe of the embankment.

The pre-2007 runway was surrounded by water, indicative of a thaw bulb at the toe of the embankment, much like what is occurring again 15 years after the most recent construction project. The 2007 design appears to have anticipated differential settlement issues and attempted to mitigate them using an air convection embankment (ACE) in the thaw ponds at the toe, stabilizing geotextiles, and slope benching. The small area where riprap was placed on the shoulder appeared to be performing better than the rest of the embankment because no embanking cracking was observed at the expansion interfaces. The thermistors installed to monitor performance of the design were destroyed, and data ended up being inconclusive.

The following were points of interest during the August 2024 site visit:

- The pilot transporting the team indicated it was one of the worst airports (if not the worst) being served out of the Bethel area. Although Tununak's (4KA) settlements are more dramatic, the bumps are more visible from the air and, therefore, easier to avoid, whereas, at Nightmute (IGT), the humps and bumps are more frequent and less noticeable on approach, making them more difficult to avoid.
- There was no cracking in the embankment.
- Settlement areas coincide with very narrow/shallow water courses that historically drained to the river, resulting in concentrations of water ponding at the toe of the embankment.
- A geotechnical engineer suggested that, rather than filling the toe thaw pond with rock in 2007, the construction team should have excavated the thawed material and backfilled it. This would have helped avoid the consolidation of the thawed material under the embankment. In addition, a thaw bulb has formed at the toe of the expanded embankment.

Nightmute (IGT) received two runway-related AIP grants in the period for which data were available, as shown in Table 8. Operational expenses dropped briefly after the 2012 runway rehabilitation project, but have risen since, as shown in Figure 14.

Table 7. AIP Grants Received by Nightmute Airport (IGT).

Year	Amount (adjusted for inflation)	Description
2007	$16,974,803.71	Extend Runway 02/20
2012	$13,020.00	[Various Grant] Rehabilitate Runway 03/21 Various Surface Preservation Maintenance (Nightmute)

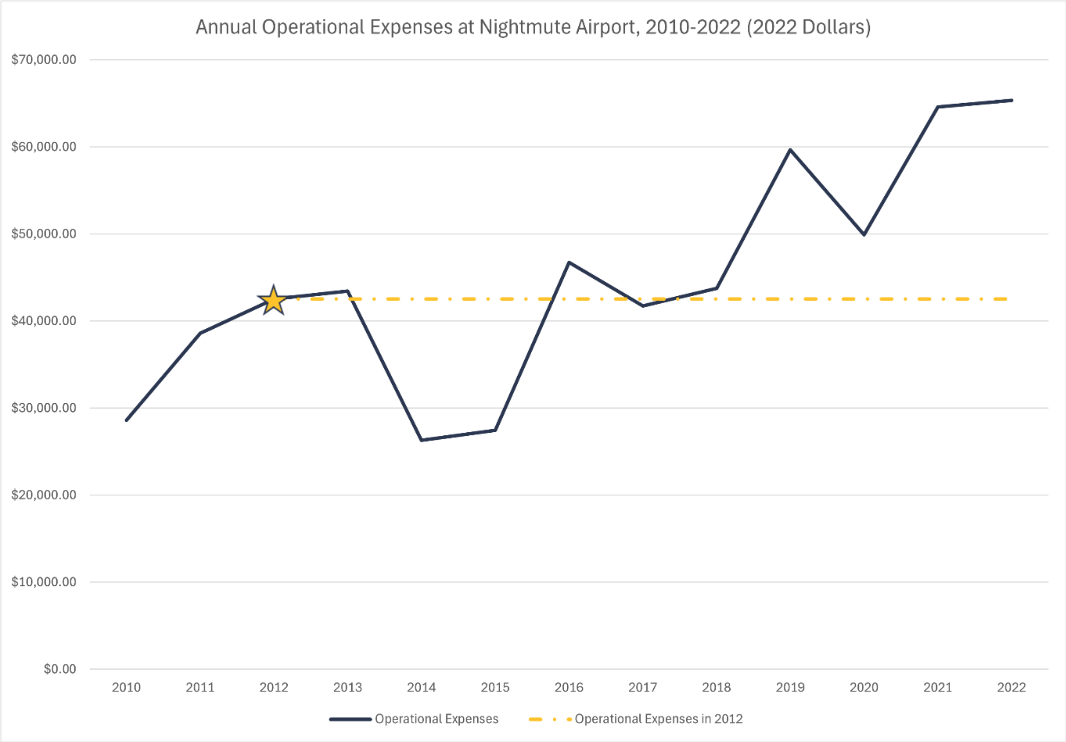


Figure 14. Annual Operational Expenses at Nightmute Airport (IGT), 2010–2022 (adjusted for inflation).

Tuntutuliak (A61)

Location Type: Riverine

Performance Category: Good

Runway Dimensions: 3,005 x 75 feet

Permafrost: Present (ice-rich)

Material Source: On-site (embankment) and imported (surface)

Tuntutuliak Airport (A61) has a gravel runway and is located along the Kinak River, with surrounding terrain that is characterized by numerous lakes, meandering streams, and marsh underlain by shallow discontinuous permafrost. Native soils are saturated generally organic silt and silt with fine-grained sand underlain by variable thawed and compressible or warm thawed unstable ice-rich permafrost.

On-site materials (wet/frozen silt with organics) were used in construction of the embankment but imported sand and gravel was used for the airport surface. This airport was initially included in the good performance category for this study, but further analysis revealed numerous performance issues. The 2021 Capital Improvement and Maintenance Program (CIMP) inspection report did not identify any major failures but did note that there was not a good balance of fines in the runway and dust palliative was not being used. The 2022 APEB nomination form states that the runway safety area has experienced sinking and cracking.

The airport was relocated in 2010. No significant runway deterioration has occurred since relocation. The airport does face erosion threats from the adjacent Kinak River, and the RSA needs to be widened to align with a change in its critical aircraft designation.

The airport was relocated using AIP funding. The new airport was constructed in two phases, Phase 1 used local material (bid in 1998, as-builts dated 2002) and Phase 2 involved imported good quality subbase and surface course materials (bid 2006, as-builts dated 2010). The airport received another AIP grant in 2012 for runway rehabilitation and, as of 2024, meets the requirements for the Primary Runway Condition performance measure. However, a 2022 Project Information Sheet noted that the runway has experienced severe erosion from the adjacent Kinak River and reported sinking and settling of the RSA on one end.

Based on the runway's proximity to the river, marshes, and ponds, subsurface soils are likely being impacted by high water tables resulting in seasonal movement during periods of thawing. The 2022 Project Information Sheet stated that the most recent erosion evaluation report estimates the western end of the runway will be overtopped by 2075 without intervention. The runway embankment will likely be impacted by 2035.

Tuntutuliak (A61) was built on organic-rich soils, similar to Kipnuk (IIK) and Chevak (VAK), but has performed better than either airport, possibly because of the higher embankment depth (greater than 15 feet thick) and the longer time period between construction phases, which provided a greater surcharge. The more recent challenges are mostly related to changes to the river creating flood related issues.

The following were points of interest during the August 2024 site visit:

- Significant settlement has occurred along the sides of the runway. Some areas of the light line are estimated to be up to 1.5 to 2 feet lower than the centerline. Beyond the light line, the shoulder and safety area have subsided even more, making the cross slope substantially out of design specifications. The subsidence appears to be relatively uniform.
- Soft shoulders and longitudinal cracks were observed; these failures were visually obscured by vegetation.
- The profile was fairly smooth, with no substantial longitudinal settlement.

Figure 15. Encroaching Vegetation is Obscuring Edge Lights at Tuntutuliak (A61). The yellow oval photograph indicates the location of the lights.

- Significant vegetation along the edges of the runway was observed, obscuring some of the edge lights, as shown in Figure 15.

One of the models in the 2006 thermal analysis indicated that, by 2020, the embankment could be above 32°F at depths of 8 to 10 feet. The observed settlement could be caused by this thawing penetrating through the embankment to the original ground, meaning the thawing trend will continue. Borings into the original ground revealed ice-rich soils of varying ice content, indicating that further thawing will not be uniform.

The airport recently became eligible for a rehabilitation project. The geotechnical and thermal studies for this project should review the previous studies to assess the accuracy of the modeling and performance expectations.

Tuntutuliak (A61) has received three runway-related AIP grants in the period for which data were available, as shown in Table 9.

Table 8. AIP Grants Received by Tuntutuliak Airport (A61).

Year	Amount (adjusted for inflation)	Description
1998	$7,319,228.88	Construct New Airport 05-23
2006	$26,371,450.48	Construct New Airport (Includes SREB) Phase 2
2012	$13,020.00	[Various Grant] Rehabilitate Runway 02/20 Various Surface Preservation Maintenance (Tuntutuliak)

Operational expenses at the airport have generally increased since 2012, as shown in Figure 16. The yellow dashed line on the chart shows the amount of operational expenses reported in 2012 ($30,550) so the amounts in subsequent years can be easily compared.

Figure 16. Annual Operational Expenses at Tuntutuliak Airport (A61), 2010–2022 (adjusted for inflation).

Tununak (4KA)

Location Type: Inland

Performance Category: Poor

Runway Dimensions: 3,300 x 75 feet

Permafrost: Present

Material Source: On-site

Tununak Airport (4KA) has a gravel runway and is located inland near Tununak Bay. The surrounding terrain is a wide flat river floodplain bordered by gentle to moderate slopes below a flat-topped mountain. Native soils include fine-grained soils, predominantly silt with a wide range of organic content, overlaying coarse-grained soils (sand and gravel with fines), above sedimentary bedrock (siltstone and claystone).

On-site material sources were used for airport construction, including from the airport site (bedrock consisting of mudstone and sandstone layers) and the Ugchirnak Mountain source (basalt, gravel with silt, sand, cobbles, and boulders), was the source of high-quality subbase and surface course material.

The runway was relocated inland from the coastal shore with construction completed in 2015. The runway is still experiencing settlement and grading issues. It has been reported that the airport was built on an ice lens, and thaw has caused a sink hole that must be filled every spring. Settlement and drainage issues are extensive; soft spots, ponding, and dips in the runway have been so severe that they have caused runway closures.

The issues are likely the result of multiple compounding causes, like the following:

- Varying embankment thickness because of uneven terrain
- Ice-rich frozen ground with area of thawed/unconsolidated soils
- Areas where shallow bedrock exists

Review of the 2015 as-builts shows a mix of cut and fill to traverse the terrain, which resulted in variable embankment thickness, ranging from approximately 9 feet to 22 feet. Further, the geotechnical recommendations indicated an 8-foot embankment depth was expected to protect from permafrost thaw. However, it is reported that thawing of subgrade permafrost and ice lenses have been observed as recently as 2020. This thawing is likely occurring at a differential rate because of the varying embankment thickness and thaw depths.

A deeper dive into this relocation project shows that the shoulders were expected to have settlement issues, and the preliminary design included a widened slope or toe berm feature to protect the structural shoulder, but this extra measure was removed as a cost reduction measure.

Further, the reported ice lens was not identified in the test holes, nor was it noted on the as-builts. People familiar with the construction of the airport reported that winter construction occurred, which included placing chunky frozen material over frozen ground. In some cases, material was placed over ice-filled ponds, which may be the reported ice lenses.

In the deep fill areas where differential settlement was anticipated a 6-month settlement period was specified. We were unable to verify that these special construction measures were completed.

The following were points of interest during the August 2024 site visit:

- Significant settlement of the embankment was observed extending beyond the runway operational area. Attempts to fill some of the settlement areas were evident, though these attempts did not make a significant difference in surface conditions. Material was evidently taken from the safety areas to fill dips within the runway operational area.
- Water ponding at the toe was evident, mostly on the uphill side. Tununak's (4KA) design called for ditches with rock lining to direct runoff to the culvert under the runway. The ponding may be the result of the ditch slopes failing or the ditching not providing positive drainage because of the thawing of ice-rich soils.
- No noticeable slope failure was observed, despite the ponding at the toe. The embankment material contains a fair amount of rock, which may have helped prevent failure even though the rock is reported to degrade easily.
- Longitudinal cracks were noticed along the runway shoulder.
- Gravel berms, 8 to 10 inches high, were observed. They appeared to be left by grading operations and serving no apparent purpose.
- Lighting system issues caused by settlement were observed.
- Culverts were found to be relatively straight. Straight culverts are good because the embankment is very thick at the culvert locations, which would make replacement difficult.

The embankment failures and settlement are believed to be the result of the use of winter construction practices and inadequate settlement periods. Over-excavating the ice-rich subgrade soils may have yielded better results than trying to keep the subgrade frozen. Additionally, the design should have included more detail to ensure positive draining and avoid ponding at the toe of the embankment.

Tununak (4KA) received two runway-related AIP grants in the period for which data were available, as shown in Table 8.

Table 9. AIP Grants Received by Tununak Airport (4KA).

Year	Amount (adjusted for inflation)	Description
2012	$18,600,000.00	Construct New Airport
2013	$16,619,419.50	Construct New Airport Phase 2

Operational expenses were very high ($120,709) during Phase 2 of the relocation but decreased in subsequent years, as shown in Figure 17. Despite the recent construction, 4KA did not meet the requirements for the Primary Runway Condition performance measure.

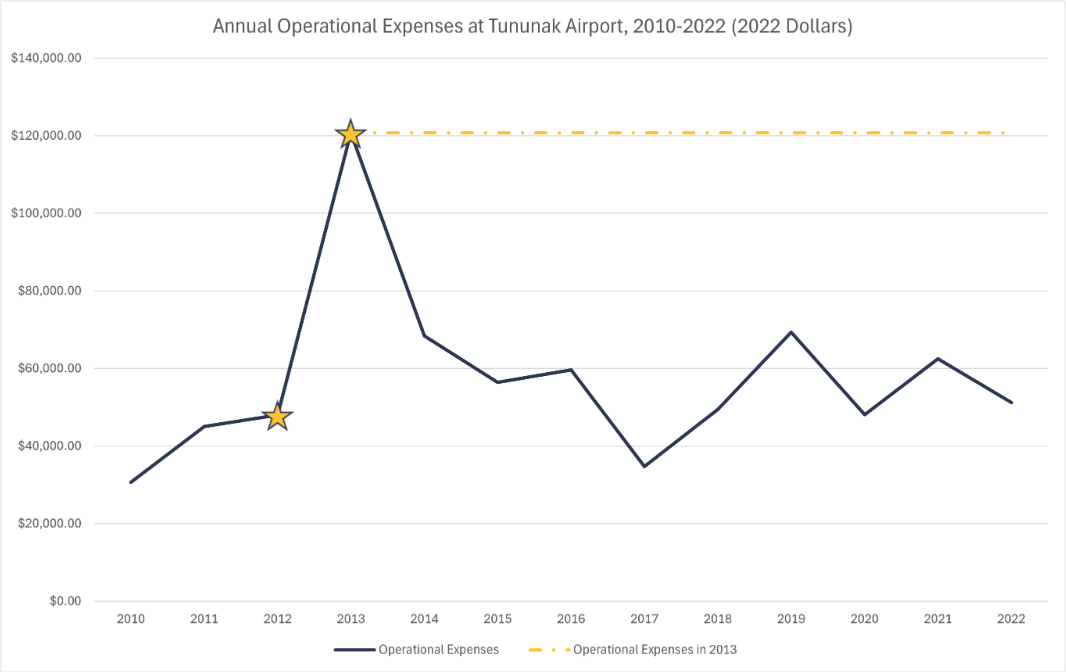


Figure 17. Annual Operational Expenses at Tununak Airport (4KA), 2010–2022 (adjusted for inflation).

Summary of Case Study Findings

Many of the issues experienced by the case study airports stem from poor-quality subsurface materials and in some cases are compounded by the use of poor-quality embankment materials, as well as construction challenges. Based on the experiences of the team, SME interviews, and field observations, these issues likely also stem from decisions made during site selection, design and construction limitations of funding, and environmental constraints. For example, a construction crew may not excavate organic materials or ice-rich soils because of cost constraints and the logistics of disposing of the excavated materials. Leaving organic- and ice-rich soils beneath an embankment can result in differential settlement and cause physical and safety issues for an airport.

Many of these issues can be mitigated by updating best practices. The General Considerations and Recommendations section discusses this in more detail.

General Considerations and Recommendations

To plan, design, construct, and maintain a resilient airport, DOT&PF must balance a broad range of opportunities and constraints that may be at odds with each other. For example, the ideal technology or material source for construction may be very costly up front but could reduce spending in the long term. This section discusses many of the factors that must be considered throughout the life of an airport and provides recommendations for DOT&PF to develop more resilient airports. Throughout every phase of a project, DOT&PF must consider resiliency as a priority when weighing decisions about costs and timelines and evaluate options based on their impacts on the entire life of an airport.

Although constructing new airports does not happen often, climate change impacts will compel several Alaska communities to relocate in the coming decades. These communities will likely need new airports, which will provide DOT&PF with the opportunity to implement many of these recommendations holistically from the beginning of each project. The numbers or letters in parentheses are cross referenced to the prioritization tables listed in the Conclusion section.

Plan

Holistic planning can maximize opportunities for success in subsequent design and construction stages of the airport development process. Many planning activities must also continue after construction to support the long-term reliability of the airport and inform the management of the broader aviation system.

Data Gaps

All airports must navigate some limitations of available data and technology, though they are often more extreme at remote airports like those included in this study. Planning in the Alaska Aviation System must be flexible enough to manage the limits of geotechnical investigations and lack of historical environmental data and aerial photography. While allowing for this flexibility, DOT&PF should take steps to improve data collection and maximize the efficacy of field investigations without overburdening DOT&PF staff. New and emerging technologies, such as Unmanned Aircraft Systems (UAS) and Artificial Intelligence (AI), could make data collection and analysis more efficient and help bridge the gap between data needs and staff capacity (Recommendation 14). DOT&PF should also coordinate with the FAA, the National Weather Service, and the National Oceanic and Atmospheric Administration to expand weather data collection and reporting at remote airports (Recommendation 8).

Land Acquisition

Airport expansions and relocations often require the acquisition of new, constructible land. Acquiring the land can be difficult because AIP funding can only be used to pay fair market value (FMV) plus the cost of relocation assistance, if applicable. If the seller is unwilling to sell for the FMV, the acquisition process becomes much more time-consuming and challenging and may include court condemnation actions, administrative awards, or allocation of State of Alaska funds.

Alaska also faces unique land acquisition challenges beyond the legal constraints around land value. Land in rural communities may have been conveyed through the Alaska Native Allotment Act (enacted in 1906 and amended 1956) or the Alaska Native Claims Settlement Act (1971). When DOT&PF seeks to acquire all or a portion of a Native Allotment, the acquisition involves DOT&PF, Bureau of Indian Affairs, the community, the Native Allottee, and the Native Allotee's heirs. The process may take years, and if no agreement is reached, the land cannot be acquired. The project must then either be stopped entirely or modified to avoid the allotment, which can delay construction.

In some instances, DOT&PF has a management agreement to have an airport on land owned by a different state agency. If that airport needs to be relocated and DOT&PF and the community would like to conduct a land swap, the other state agency must be involved, which creates a more complex legal process.

Funding Constraints

Many of the challenges facing DOT&PF's efforts to maintain a resilient aviation system are rooted in funding. Whether funds are insufficient or have restrictions, the money often does not match the need. This mismatch of funding and needs is driven by federal policies, funding formulas, inflationary pressure, and variable state resources. Airport staffing, design choices, project sequencing, and routine maintenance activities are affected by the consequences of inadequate or unavailable funding.

DOT&PF should reevaluate the prioritization of funding as many projects as possible with available funds, even though none of the projects are "fully" funded (i.e., selected designs sometimes prioritize low upfront cost over long-term performance), versus adequately funding fewer projects and prioritizing techniques and technologies that will improve long-term resiliency, even if they are more expensive (Recommendation 52).

DOT&PF should conduct a study to comprehensively evaluate funding needs and gaps across all aspects of airport management. DOT&PF staff should be interviewed to understand the challenges they face and what ideal funding would look like for their area of airport management (planning, design, construction, and M&O). A working group of staff and SMEs could then be assembled to discuss how to balance the different funding needs within the constraints created by state and federal budgets. The outcome of this study would be a plan to coordinate strategies, priorities, and decision making to increase efficiencies across the state. It would also create a comprehensive list of needs and gaps that would facilitate discussion with the FAA and inform state-level budget decisions (Recommendation 49).

Federal Funding Limitations

A recurring concern among aviation stakeholders is that federal funding limitations dictated by the AIP Handbook, such as the following, do not accommodate Alaska-specific conditions and needs:

- The inability to use federal funds to pay upfront for a stockpile of gravel during a capital project for future maintenance
- Limitations on types of equipment that can be purchased for airport snow removal
- Constraints on purchase of compaction and brush-cutting equipment
- Life expectancies for minor airport elements such as crack sealing

Resolving these limitations will require significant collaboration between DOT&PF and the FAA to study Alaska-specific issues, develop pilot programs, and agree upon solutions that meet FAA standards for safety and efficiency while addressing Alaska's unique environmental context. Leveraging new and changing federal funding programs to fill some of the existing funding gaps (e.g., resiliency-focused grant programs addressing areas where AIP funds cannot currently be used) is also a possibility (Recommendation 37), as well as increasing state funding.

Inflation

Another significant challenge facing airport funding is that funding sources for airport capital improvements, such as AIP entitlements, are not keeping pace with recent inflation. Construction costs were 28 percent higher than engineer estimates in 2022 and are expected to show similar rises in 2023. Rising inflation has essentially nullified the benefit of additional funding from the Infrastructure Investment and Jobs Act, and AIP funds cannot be distributed to as many projects as needed.

Competitive Wages

Wages for rural airport operations staff are often not competitive with private wages offered by contractors, making it hard to retain staff in these areas. State maintenance salaries are not federally funded, and Alaska's tight operations budget does not allow significant increases in those wages. This shortfall leads to higher staff turnover and loss of investments in staff training (Recommendation 21).

Resiliency Assessment Framework

No comprehensive framework exists for evaluating the resiliency of the Alaska Aviation System or individual airports. Such a framework would allow DOT&PF to identify potential threats to infrastructure and develop action plans to create more resilient airports. Although the engineers' estimates were increased for expected inflation, they still fell short. The resources in the "Resiliency Planning Tools" section of Appendix 2 include risk and resilience assessments and examples of adaptation options that could be adapted for an Alaska-specific framework.

When developing a resilient Alaska airport, a multi-discipline advisory group that includes representatives from remote communities should evaluate the following key factors and guide the development of a comprehensive resiliency assessment framework (Recommendation 11).

Local Knowledge

When designing a new airport or significantly altering an existing airport, engage the community to understand environmental conditions and changes in the area. Elders and long-time residents may provide insight that can inform location and design decisions (Recommendation 11). If possible, this should be done through in-person community meetings and site visits.

Orientation and Wind Coverage

Climate change literature indicates wind direction and speed have changed over time. Runways should be oriented for wind coverage and with consideration for terrain features that impact the ultimate approach (Recommendation 31). In areas where extensive historical wind data are available, DOT&PF should analyze the data to evaluate whether there are any long-term trends or changes that should be accounted for in future designs (Recommendation 41). When reconstructing or designing new runways, DOT&PF should consider providing a wider operational surface to accommodate potential changes in wind coverage (Recommendation 38).

PERMAFROST

Avoiding permafrost entirely is not feasible in many areas of Alaska. Constructing an embankment over permafrost may be structurally acceptable if the permafrost is unlikely to thaw or is thaw stable.

Drilling and ground temperature monitoring should be used to evaluate the subsurface conditions and avoid warm, ice-rich, thaw unstable permafrost.

Terrain and Subsurface Conditions

Airports should be sited in a location with relatively flat terrain to limit changes in fill depths and/or cut and fill conditions (Recommendation 47). The location should have a consistent subgrade (Recommendation 50). Ideally, the subgrade should be thawed or thaw stable. Historical and current photographs can be reviewed to identify changes in vegetation, which may indicate differing subsurface conditions warranting a field investigation.

Holistic terrain modeling and ground-penetrating radar can be used in addition to traditional drilling investigations to provide a more complete understanding of a potential airport location's surface and subsurface conditions before design (Recommendation 46). Advanced hydrothermal modeling should also be used in areas with permafrost (Recommendation 48).

If a local backhoe is available, test pits may be a cost-effective initial step in evaluating a new potential site, alignment adjustments, or direction for expansion, as opposed to mobilizing a drilling rig. After test pits have been analyzed and a preferred embankment alignment has been identified, exploratory holes should be drilled based on guidance in the *Alaska Geotechnical Procedures Manual*. An SME recommended drilling holes at regular intervals along each shoulder and the centerline to develop a frozen ground profile section (Recommendation 35).

Waterbodies and Drainages

Ideally, airports should not be located adjacent to meandering rivers or other waterbodies likely to erode the land and encroach on the airport infrastructure (Recommendation 39). Flood-prone waterbodies should also be avoided (Recommendation 32), as well as locations where portions of the fill span in and out of the water (Recommendation 28). Given the location of communities located along the rivers, this is not always practical.

The number of drainage crossings should be minimized (Recommendation 33). If drainage structures within the embankment are required, they should be sized for large storm events (Recommendation 1). Unalakleet Airport (UNK), which was not included in this study, was damaged during Typhoon Merbok because a culvert became plugged with debris, which led to significant losses to embankment and surface materials [DOT&PF, 2022]. The cost of repairs was estimated at $300,000; some of the damage may have been mitigated if the culvert had greater capacity.

Over-excavation under culverts should be required if structures are needed to cross drainages (Recommendation 1). Natural water courses typically contain soft, compressible material that will settle significantly if thawed. If a straight culvert is placed over a meandering drainage, the culvert may cross several soil types that will settle differently. Over-excavation has been shown to have positive impacts on long-term performance of culverts.

Geotechnical Investigations

Geotechnical investigations should include an evaluation of permafrost degradation impacts on embankment performance (Recommendation 18). DOT&PF should develop a standardized approach for this evaluation.

Construction Materials

Airports should be sited in a location where well-graded, optimal moisture embankment material and durable crushed surface course are locally available (Recommendation 51). Importing materials when good quality materials are not locally available may reduce maintenance needs and costs over the lifetime of an airport, though this may not always be financially feasible because of upfront costs.

Design

The design of an airport must consider environmental conditions, engineering standards and best practices, regulations, and material quality while simultaneously planning for unexpected field conditions during construction.

Design Standards

DOT&PF should work with the FAA to reevaluate and redefine design standards with consideration for the changing climate and unique challenges of environmental conditions and construction constraints in Alaska (Recommendation 44). This process should also clarify design priorities, for example, by providing guidance on how to navigate a scenario where it is not possible to have both an ideal orientation with a long-term possible approach *and* an easy-to-maintain, smooth landing surface. "Evaluation of Airport Pavement Designs for Seasonal Frost and Permafrost Conditions," included in Appendix 2, should also be considered.

The following topics should also be discussed when redefining design standards.

Embankment Settlement

Settlement of airport embankments is typically related to thawing ice-rich soil under the embankments. Often, the settlement is uneven throughout the embankment, causing dips and bumps on the surface. The freeze/thaw cycle is changing, and predicting changes to the cycle and the impacts on ice-rich soils is difficult. Unless there is a case-specific reason to leave the ice-rich materials, removing them from the upper layers of the original ground is more effective.

If ice-rich original ground materials are left in place, building the embankment as thick as possible using very conservative thermal analyses (Design Standard J) is best. The following construction sequencing has been effective in ensuring subgrade thaw is not initiated:

- Initial lifts of material should be placed in the spring when the ground has frozen close to the maximum freeze depth.
- Snow should be cleared from the embankment area earlier in the winter to allow for a deeper freeze.
- Embankments should never be placed on exposed ice, such as frozen ponds. Any pond areas must have ice removed before placing material.

- If insulation board is used, it should be placed in frozen conditions with a sand blanket as a protective layer to prevent heating in the spring.
- Construction should be completed in the summer.

Further, as several projects have shown, embankment performance benefits from phased construction that allows for a settlement period before the placement of subbase, surface course, and airport lighting (Recommendations 36 and 43).

Slope Degradation

Degradation of embankment slopes is common in areas with permafrost and soft, swampy ground. If embankments in these areas are built to existing standards, the safety area shoulders may begin to fail much earlier than expected. Clarification is needed to determine whether embankments should be built to existing standards or be overbuilt to ensure the full safety area is functional throughout the expected life of the runway and what level of increased cost is acceptable if embankments must be overbuilt (Design Standard M).

Additionally, existing embankments at airports susceptible to flooding or coastal erosion and for which relocation is not anticipated should be considered for protection and reinforcement (Design Standard R). See “Toolbox for Resilience and Adaptation in Coastal Arctic Alaska” for more information about coastal flooding and adaptation resources [Appendix 2].

Runway Orientation

The key competing considerations for runway orientation are wind and terrain. Aligning for greatest wind coverage provides tolerance for variability in wind direction over time, whereas aligning to the best subgrade and terrain provides a higher probability of surface stability and allows for a wider runway with greater operational tolerance in crosswind conditions (Design Standard O).

Runway Cross Slope

The runway cross slope allows water to run off the runway’s surface, which is important to maintaining a well-consolidated gravel surface that is less susceptible to softening and rutting. A shallow runway crown (e.g., 1 to 2 percent) over a long distance (e.g., 30 to 50 feet) may be adequate for a paved runway but not for a gravel surface. Adjusting design standards to allow for greater cross slopes on gravel runways would reduce maintenance requirements and improve safety of gravel runways (Design Standard L). This would require a Modification to Standards (MOS) of Advisory Circular 150/5300-13B section 3.16.2, Transverse gradient.

Material Sources

DOT&PF geotechnical engineers often investigate potential material sources for airport projects to determine if acceptable quality material is locally available. The FAA specifications for the surface course and base course (known as Deg/MicroDeval) are very stringent and hard to meet in most locations, as are the allowable fines content. DOT&PF often loosens specifications to allow local material in order to have a fundable project.

In remote areas, material sites are often on private land. Mandating the use of a private source requires DOT&PF to obtain a Public Interest Finding (at a minimum), which is an additional time and expense step in the project development process. Further, by requiring the use of a specific material site, DOT&PF takes on risk related to providing adequate quality and quantity of material. DOT&PF avoids mandating material sites because of previous experiences with legal challenges. Because a material source is not prescribed, contractors generally choose a site and accept the risk that a sufficient quantity of acceptable quality materials might not be available. Occasionally, exemptions to material quality standards are made during the construction phase, but this may not be best for the long-term performance of the airport.

DOT&PF should explore whether the restrictions on prescribing a material source for a project can be changed (Design Standard I). Identification of a preferred material source would provide greater assurance that good quality material will be used, reduce the risk for contractors when trying to find usable material sources, and likely lower costs for upfront materials and long-term maintenance.

Good Quality

Ideally, construction material should have low frost susceptibility (low percentage of fines), and high durability.

Material Quality

High-quality materials are often difficult or impossible to obtain at remote airports because of funding limitations and transportation logistics. DOT&PF should consider whether lowering material quality standards and assuming shorter project lifespans is more beneficial than making exceptions to the current standards to stay within budget, while assuming the project will have the same useful lifetime as if it used higher quality materials (Design Standard K). Because AIP funding requires most construction projects to have a minimum useful life of 20 years, DOT&PF should coordinate with the FAA to understand how changing state-level standards will impact federal funding.

Model Storm

Climate change continues to increase the frequency and severity of natural weather events. Recent examples include:

- A cross culvert in the Hooper Bay Airport access road was damaged during Typhoon Merbok (cost unknown).
- Scammon Bay Airport (SCM) has experienced at least three high water events caused by storm surges in 2004, 2013, and 2016. During these events, a runway cross culvert was damaged, and the runway, taxiway, and apron embankments sustained erosion. Repairs and erosion protection were completed in 2016 as part of the 2013 Scammon Bay Airport Flood Permanent Repairs Department of Military and Veterans Affairs/FEMA project.
- Thawing permafrost and differential settlement have caused premature culvert failures at many airports in western Alaska. Two runway culverts at the Takotna Airport (TCT) are failing because of settlement from permafrost thaw. DOT&PF is working on a rehabilitation project that includes replacing or lining these culverts.
- Numerous state and federally declared disasters have occurred in communities along the lower Yukon and Kuskokwim Rivers because of ice jam flooding. Rising temperatures alter spring river-ice breakup, cause more extreme weather events, and accelerate permafrost thaw. These factors can lead to higher flows and unstable banks that contribute to erosion and flooding, threatening airport infrastructure in these communities.

DOT&PF is in the process of updating the *Alaska Highway Drainage Manual*, which provides Alaska-specific criteria, guidance, resources, policies, and information on planning, environmental, coordination, resiliency, design development, project management, and maintenance of hydraulic and infrastructure assets, including highways and airports. Historically, the *Alaska Highway Drainage Manual* has been used for drainage standards on aviation projects, and the new manual will be used in the same fashion.

FAA should review this manual and consider providing a standing MOS, allowing the use of the *Alaska Highway Drainage Manual* rather than the FAA drainage manual (Advisory Circular 150/5320-5D) because it provides the best available climate data (Arctic-EDS or National Oceanic and Atmospheric Administration Atlas 15) for planning and designing airport infrastructure in Alaska. Although DOT&PF can request an MOS to the FAA drainage design standards on a case-by-case basis, it would be more efficient for FAA and DOT&PF to develop a standing MOS to address the impacts on storm severity because of climate change (Design Standard F).

When including a culvert in an embankment, designers should consider the impacts that convective cooling will have and the potential for differential settlement between the material immediately around the culvert and the rest of the embankment (Design Standard G).

Vertical Alignment

If a runway embankment experiences settlement or heaving because it was constructed on permafrost or soft ground, additional material must be placed on the embankment to create a safe operational surface. If the original embankment was constructed to the maximum allowed longitudinal grade or vertical clearance standards, an insufficient tolerance exists for these future adjustments. Designing to the maximum allowed longitudinal grade and vertical clearance standards should be discouraged (Design Standard A).

Widening and Lengthening

Current embankment widening and lengthening specifications allow for new material to be laid over old slopes, provided slopes do not exceed 4:1. The new material will settle faster than the old material, causing surface cracking where they meet. To minimize cracking from differential settlement in embankment expansion projects, standards should 1) require the removal of thawed material from under and around the existing embankment toe, 2) require benching of the existing embankment and subgrade (Design Standard N), and 3) encourage the use of stabilizing geotextiles to integrate the embankments more cohesively (Design Standard B). The timing of construction should allow the new embankment sufficient time to settle before placing finished courses (Design Standard P).

The Nightmute (IGT) expansion project in 2012 included benching and the use of stabilization geotextiles, though the uncompressed thawed material under the widening area was not removed. Nightmute (IGT) does not experience the longitudinal cracking that is common after widening projects.

Embankment Toe Drainage

Water ponding at the toe of an embankment has significant negative impacts on embankment performance. Whenever possible, drainages should be intercepted and redirected around the embankment (Design Standard H). Rock-lined interceptor ditches, interceptor berms, or wide-toe berms should be placed to receive water from the drainage before it reaches the toe of the structural embankment.

Measures that prevent ponding at the embankment toe will reduce the sloughing of embankment material and remove a hydrothermal source that can influence permafrost degradation.

Geotextiles

Design standards should encourage using high-strength geotextiles to bridge areas of discontinuous permafrost and spots of ice-rich soils [Neogi, 1991] (Design Standard E). The use of geotextiles should be monitored over time (Design Standard D), including at Kongiganak (DUY) in the 2022 extension project, which has five layers of geogrid spanning thaw-unstable ground (Recommendation 9).

Phased Construction

Phased construction should be encouraged to allow for adequate settlement of the embankment materials, which is possible by using one large grant spread over multiple years or separate grants for separate phases of construction (Design Standard Q). Often, after a runway has failed, the community applies pressure to have a new runway constructed as quickly as possible. Starting the construction process before total failure of the existing runway will help allow for adequate settlement time without leaving remote communities without airport access (Design Standard S). Additional information can be found in the Embankment Settlement and Timing sections.

Chevak (VAK), Kipnuk (IIK), and Tuntutuliak (A61) each used phased construction, and although all three airports are now performing poorly, the embankments appear to have lasted longer before experiencing issues than Tununak (4KA), where phasing was not an option available to the design team.

Ice-Rich Soils

Unless there is a case-specific reason to leave ice-rich materials in the subgrade soils, removing them from the upper layers of the original ground is more effective. If ice-rich original ground materials are left in place, building the embankment as thick as possible is best (Design Standard J). Also, as several projects have shown, embankment performance benefits from phased construction that allows for a settlement period before the placement of subbase, surface course, and airport lighting. Embankments should never be placed on exposed ice, such as frozen ponds.

Other Structures

Other airport infrastructure, such as snow removal equipment buildings, should also be resiliently designed (Recommendation 12). See “BIM-CFD Integrated Sustainable and Resilient Building Design for Northern Architecture” in Appendix 2 for an example of designing buildings for cold regions.

Unexpected Field Conditions

Even with thorough planning and pre-design activities, field conditions may not match expectations and, therefore, may make certain design details impossible or ill-advised to implement. Making design changes as quickly as possible is often critical because of weather changes and the short construction season. Designers should include contingency details for easily anticipated scenarios, such as needing to over-excavate undesirable subgrades, to allow for fast and safe pivots during construction (Recommendation 6). DOT&PF should also review contract requirements for addressing design changes in the field because a disconnect can exist between construction staff and designers of record.

Preparing for unexpected field conditions and establishing processes for changing design details in the field can minimize construction choices that negatively impact an airport’s long-term M&O. Further, the low bid process is not conducive to developing the close partnerships needed to address field conditions that impact long-term resiliency.

DOT&PF should establish a working group with the Associated General Contractors of America and the FAA to establish best practices for addressing unexpected field conditions and identifying the most effective ways to incorporate expectations into contracts (Recommendation 17). This may include using alternative contracting methods, such as Construction Manager/General Contractor (CM/GC) contracts.

Project Closeout

DOT&PF should develop a questionnaire to be filled out once a design is completed (Recommendation 16). DOT&PF should develop a questionnaire to be filled out once a construction project is completed. This would ensure that comprehensive data is collected about assumptions, constraints, and design choices, which would make future evaluation easier and more accurate. The resiliency frameworks included in Appendix 2 should be reviewed when developing the questionnaire.

Pilot Study Topics

Pilot studies can allow for the experimental use of new technologies or use of technology in new contexts that the FAA would not otherwise permit. DOT&PF should consider conducting pilot studies to evaluate:

- The use of buried thermosyphons in runway embankments (Recommendation 29).
- The use of Volume Donating Compressible Fillers (VDCFs) in lighting systems (Recommendation 20).
- The use of ACEs to mitigate permafrost thaw (Recommendation 34).
- The additional benefit of incorporating dust palliative into the top several inches of surface course during construction, rather than only applying a layer over the surface (Recommendation 4).
- The use of water-wicking fabrics to remove moisture from runway embankments (Recommendation 19).
- The sustainable construction techniques described in "Sustainable Construction in Remote Cold Regions" in Appendix 2 (Recommendation 13).

Collaboration and funding through UAF, the Airport Cooperative Research Program (ACRP), and other transportation research sources should be considered.

Construct

As discussed in the Design section, construction personnel must have adequate information and flexibility to adapt plans according to unexpected field conditions and lower quality materials. Further, construction personnel must be empowered to initiate changes that would improve long-term performance of the airport facilities.

Timing

Timing is a key consideration in the construction phase of an airport project, particularly given Alaska's short construction seasons. Insulation and embankment material should be placed in winter or spring while the ground is still cold and recompacted in late summer after the material has had time to settle (Recommendation 36). Waiting until late summer to recompact the material does create additional pressure to get the lighting system placed quickly because trench backfill compaction becomes more challenging as temperatures drop and freezing begins, but allowing time for settlement before final surface courses are placed is important (Recommendation 43). Seasonal pressures do not warrant non-compliance of the contract specifications, especially those which can impact the long-term performance of the airport. More information is provided in the Embankment Settlement and Phased Construction sections.

Organic Material

The decision to leave or remove organic materials before placing embankment materials depends on multiple factors, including the thickness of the organics, the temperature, gradation, and ice content of the underlying permafrost, and the thickness of the embankment. If the organics layer is left in place, the initial layer of embankment materials should be placed while the ground is cold and left to settle while the ground warms before construction is continued.

Swampy Ground

Where swampy ground impedes the movement of construction equipment and thick embankment lifts are allowed, the area may benefit from surcharging or placing material that creates a load greater than that of the finished design and then removing excess material after a period of settlement (Recommendation 42).

Project Closeout

DOT&PF should develop a questionnaire to be filled out once a construction project is completed (Recommendation 15). This would ensure that comprehensive data is collected about environmental conditions, design changes, challenges, and successes, which would make future evaluation easier and more accurate.

Maintain

Continuous maintenance can increase the longevity and resilience of an airport. This requires adequate equipment, well-trained staff, and routine performance monitoring. Preventative maintenance and proper application of maintenance techniques can also prolong an airport's life.

Equipment

Proper equipment is critical to ensuring effective maintenance at airports. SMEs interviewed for this study recommended providing a small compactor at each airport to allow for compaction after freeze/thaw cycles and grading to reestablish crowns (Recommendation 3). The compacted surface will aid in keeping the surface from becoming saturated and rutting. Effective equipment can also be supported by solutions like dust palliatives to minimize loss of fines (Recommendation 45).

DOT&PF should evaluate the vegetation clearing needs at each airport and determine whether new equipment, attachments for existing equipment, or other solutions are required to ensure adequate clearing (Recommendation 22). During capital projects that include clearing, the ground may require leveling to accommodate M&O's brush-cutting equipment. Clearing with AIP funding can only be done once, so after it is cleared, the ground needs to be a mowable surface for maintenance.

Staff and Contractors

Managing staff turnover and training new employees are common challenges in many industries. DOT&PF should strive to understand why long-term staff have stayed and why some staff leave to identify policy or culture changes that could improve retention.

Training

An SME recommended improving training techniques related to grading and material recovery for staff and contractors. Inexperienced equipment operators may damage the runway surface or not know how to recover and store material moved during normal maintenance activities (Recommendation 25). Training should also emphasize the importance of reestablishing the runway crown and compacting the surface after freeze/thaw cycles (Recommendation 24).

Staff and contractors should also be trained to understand how climate change impacts M&O activities and how techniques and technologies may need to adapt. For example, grading and compacting should be done every fall at gravel airports to mitigate challenges during spring breakup. As Alaska warms, freeze/thaw cycles may happen multiple times during a single winter, making proper pre-winter grading and compaction even more critical than in years past.

DOT&PF should consider hiring a seasonal crew dedicated to grading and compaction in the spring to ensure well-trained individuals are responding to the challenges of spring breakup (Recommendation 40). The FAA does not currently fund summer grading activities, but DOT&PF should discuss with the FAA whether this can change as climate change impacts the needs of airports and maintenance. For short-term, seasonal needs, DOT&PF could hire retired experienced operators, such as members of the International Union of Operating Engineers (IUOE) Local 302.

Performance Monitoring

Airport settlement and movement should be monitored to understand how airports change over time. Monitoring could be accomplished by installing durable ground control survey points that would be referenced by UAS during LiDAR scans every 3 to 5 years. Providing at least three reference points at an airport will ensure scans from different years can be reliably compared and used to assess differential movement and embankment surface changes.

DOT&PF should also collect detailed data on M&O activities and how funds are spent to understand the relative costs and benefits of different techniques and how frequently interventions are required (Recommendation 26). The performance of interventions should also be monitored over time. For example, if dust palliatives are used at an airport, DOT&PF should track the frequency of use, timing and method of application, and duration of the benefits. To streamline this process, a system could be developed that would allow operators to send a text with basic information about activities performed (e.g., "fixed windsock light at Allakaket for two hours, flew to Koyukuk and repaired two runway lights for four hours") that would be processed by an AI-supported database to record the activities, time spent, and related cost (calculated according to who performed the activities, which would be identified based on the phone number that sent the text). Performance could be evaluated, in part, by training an AI program to evaluate the condition of a runway based on photographs. Both the maintenance reports and the photographs would include time and date metadata, allowing for time-based analysis of performance (Recommendation 27).

Inspections

Airport inspections, such as 5010 inspections, help identify issues and failures in the embankment and on the runway surface. The specific location of issues and failures are not typically included in the reports, making it difficult to determine whether a given issue may be related to the presence of a culvert, an old drainage, or other known environmental factors. DOT&PF should encourage or require that inspection reports identify the location of failures (Recommendation 30).

Preventative Maintenance

DOT&PF staff have noted that funding preventative maintenance is difficult. Addressing needs before they become cumbersome to fix or pose a threat to operational safety is important to maintaining a resilient airport. DOT&PF should continue to pursue opportunities to fund preventative maintenance (Recommendation 5). Runway surfaces should be inspected within 2 to 5 years after a large construction project to determine whether surface maintenance is needed (Recommendation 2).

Conclusion

Constructing and maintaining airports in western Alaska has always been challenging. As climate change makes environmental threats and weather events more severe and frequent, many of the challenges are changing or becoming more difficult to manage. Policy changes, innovative use of technology, and other strategic actions can help DOT&PF increase the resiliency of Alaska's airports. This chapter provides many recommendations to make Alaska airports more resilient; however, the feasibility and impact of implementing each recommendation varies. Figure 18 shows the four quadrants of an Impact/Feasibility Matrix. Recommendations that are very feasible (easy to implement) and would have a high impact (significantly improve resilience) should be prioritized for implementation. Recommendations that are easy to implement but would have little impact could be incorporated into other actions, as time and funding allow, but should not be pursued on their own. High-impact but low-feasibility recommendations should be investigated further to ascertain whether steps can be taken to increase feasibility. Actions that would be difficult to implement and have a low impact on airport resiliency are not recommended. Figure 19 and the following sections categorize the recommendations in this chapter according to the four quadrants of the Impact/Feasibility Matrix. The *Design Standards* recommendations are shown separately in Figure 20. The recommendations shown in squares in Figures 19 and 20 are included in the top recommendations in the Executive Summary.

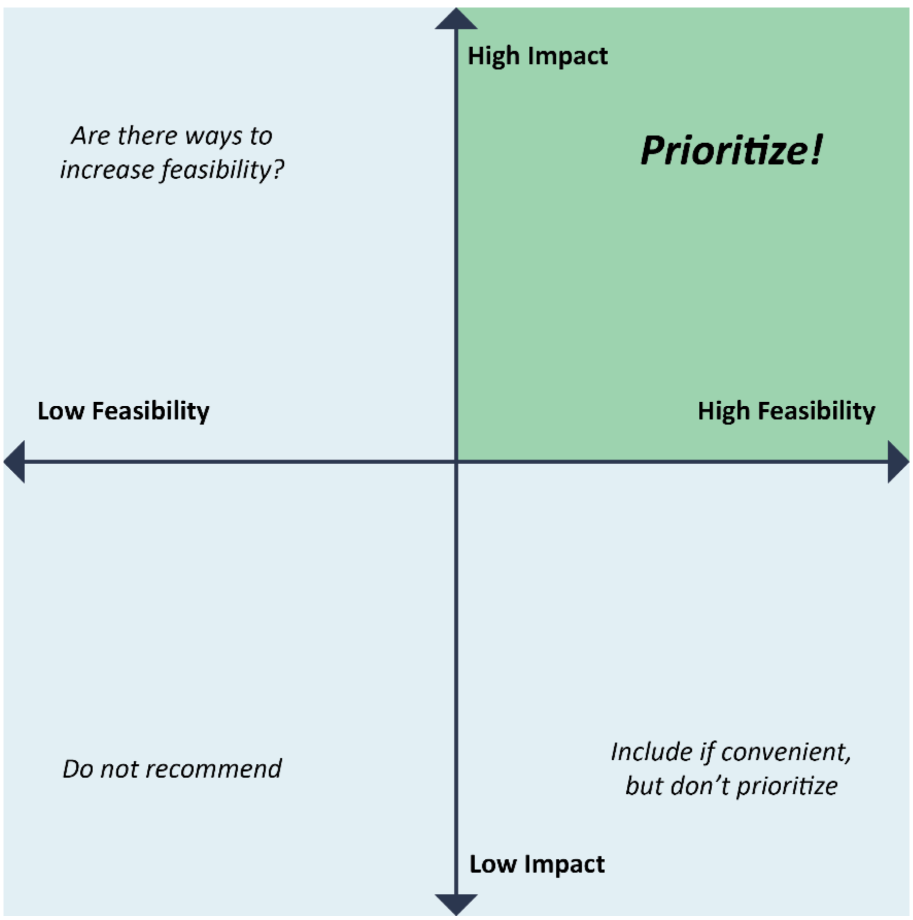


Figure 18. Impact/Feasibility Matrix.

Figure 19. Impact and Feasibility of General Recommendations.

Figure 20. Impact and Feasibility of Design Standard Recommendations.

Top Recommendations

Through collaboration with SMEs, seven actions were identified as the most impactful and feasible for improving resiliency in the western Alaska Aviation System. Each action is associated with one or more recommendations developed through this study.

1. **Monitor and Repair Damage Early.**
    - Recommendation 2: Inspect runways 2 to 5 years after a large construction project to assess the condition of the runway and determine whether surface maintenance is needed.
    - Recommendation 5: Continue to pursue opportunities to fund preventative maintenance activities.
    - Recommendation 14: Use UAS and AI to regularly collect and analyze visual data about runways to aid in monitoring/detecting damage early.
2. **Prevent Embankment Settlement.**
    - Design Standard J: Remove ice-rich subgrade soils or, if removal of ice-rich materials is not possible, increase the embankment thickness.
    - Design Standard B: Redefine standards for runway widening and lengthening to remove thawed material under the toe, bench the existing slopes, and use geotextiles to integrate new and old embankments.
    - Design Standard E: Redefine design standards to encourage the use of high-strength geotextiles to bridge areas of discontinuous permafrost and spots of ice-rich soils.
    - Design Standard H: Prioritize intercepting and redirecting drainages to avoid ponding at the toe.
3. **Evaluate Dust Palliatives.**
    - Recommendation 4: Evaluate the benefits of mixing dust palliatives into the top several inches of surface course during construction rather than only applying over the top.
4. **Update Drainage Structure Standards and Guidance.**
    - Recommendation 1: If drainage structures such as culverts are required within an embankment, size them for large storm events. Over-excavate beneath the culvert to improve long-term performance.
    - Design Standard F: Collaborate with FAA to update standards for weather modeling to ensure culverts are appropriately sized.
5. **Plan for Field Conditions.**
    - Recommendation 6: Ensure designers include contingency plans for common scenarios so construction personnel can quickly and safely make decisions when field conditions do not match expectations.

6. **Update Runway Expansion Standards and Guidance.**
   - Design Standard B: Redefine standards for runway widening and lengthening to remove thawed material under the toe, bench the existing slopes, and use geotextiles to integrate the new and old embankments.
   - Design Standard D: Evaluate the performance of geotextiles over time.
7. **Improve Project Closeout Procedures.**
   - Recommendation 15: Develop a closeout questionnaire to record information about the construction process.

High Feasibility, High Impact

These recommendations should be prioritized. The green-shaded recommendations are those considered "top recommendations" summarized in the previous section.

	Recommendations
1	**Design for resiliency:** If drainage structures such as culverts are required within an embankment, size them for large storm events. Over-excavate beneath the culvert to improve long-term performance.
2	**Perform preventative maintenance:** Inspect runways 2 to 5 years after a large construction project to assess the condition of the runway and determine whether surface maintenance is needed.
3	**Maximize efficiency of equipment:** Provide a small compactor at every airport with a gravel runway.
4	**Maximize efficiency of equipment:** Evaluate the benefits of mixing dust palliatives into the top several inches of surface course during construction rather than only applying over the top.
5	**Perform preventative maintenance:** Continue to pursue opportunities to fund preventative maintenance activities.
6	**Plan for unexpected conditions:** Ensure designers include contingency plans for common scenarios so construction personnel can quickly and safely make decisions when field conditions do not match expectations.
7	**Conduct pilot studies:** Continue to identify new technologies and techniques from emerging research or being used in other cold climate regions, in both airport and road design and construction.
8	**Collect more data:** Continue the expansion of weather observing systems throughout the state and store data for historical analyses.
9	**Conduct pilot studies:** Evaluate the use of installed instrumentation at airports to monitor how airports change (settle) over time.
10	**Provide thorough training:** Ensure staff and operators understand that the changing climate will impact the technologies, techniques, and timing of maintenance activities.
11	**Design for resiliency:** Meet with long-time residents of communities to understand the local environmental conditions and changes that have occurred over time.
12	**Design for resiliency:** Incorporate resilient design into all airport infrastructure, such as snow removal equipment buildings.
13	**Conduct pilot studies:** Explore additional sustainable construction techniques, like those described in Perkins, 2015.
14	**Collect more data:** Use UAS and AI to regularly collect and analyze visual data about runways to aid in detecting/monitoring damage early.
15	**Collect more data:** Develop a closeout questionnaire to record information about the construction process.

	Recommendations
16	**Collect more data:** Develop a closeout questionnaire to record information about the project design process.
17	**Plan for unexpected conditions:** Incorporate details into contracts to ensure all parties involved in design and construction understand responsibilities and obligations related to addressing unexpected field conditions.
18	**Collect more data:** Evaluate the impacts of permafrost degradation on embankment performance when conducting geotechnical investigations.
19	**Conduct pilot studies:** Evaluate the usefulness of water-wicking fabrics in runway embankments.
20	**Conduct pilot studies:** Evaluate the use of VDCFs in airport lighting systems.
	Design Standards
A	Clarify when it is acceptable to design to the maximum allowable grades and vertical clearances.
B	Redefine standards for runway widening and lengthening to remove thawed material under the toe, bench the existing slopes, and use geotextiles to integrate the new and old embankments.
C	Identify preferred material sources based on geotechnical investigations.
D	Evaluate the performance of geotextiles over time.
E	Redefine design standards to encourage the use of high-strength geotextiles to bridge areas of discontinuous permafrost and spots of ice-rich soils.
F	Collaborate with FAA to update standards for weather modeling to ensure culverts are appropriately sized.
G	When including a culvert in an embankment, consider the impacts of convective cooling and the potential for differential settlement.
H	Prioritize intercepting and redirecting drainages to avoid ponding at the toe.
I	Change restrictions to allow DOT&PF to prescribe specific material sources to contractors.
J	Remove ice-rich subgrade soils or, if removal of ice-rich materials is not possible, increase the embankment thickness.

High Feasibility, Low Impact

Incorporate these recommendations when convenient.

	Recommendations
21	**Collect more data:** Conduct surveys and/or interviews to understand why DOT&PF staff stay or leave.
22	**Provide adequate equipment:** Evaluate the vegetation clearing needs at each airport and determine whether new equipment, attachments for existing equipment, or other solutions are required.
23	Not used.
24	**Provide thorough training:** Ensure staff and operators understand the long-term importance of reestablishing the runway crown and compacting the surface after freeze/thaw cycles.
25	**Provide thorough training:** Ensure staff and operators are properly trained to use graders without causing unnecessary damage to the runway surface.
26	**Collect more data:** Record details about how M&O funds are spent.
27	**Collect more data:** Record details about M&O activities, specifically the specific techniques used, timing of activities, and long-term performance of treatments. Consider using AI to automate and streamline this process.
	Design Standards
K	Evaluate whether it is more beneficial to assume a shorter project lifespan to allow the use of lower quality materials and building over poor subgrade.
L	Redefine standards for cross slopes on gravel runways to promote proper drainage.

Low Feasibility, High Impact

Explore opportunities to increase feasibility.

	Recommendations
28	**Design for resiliency:** Avoid siting airports in locations where fill will span in and out of the water or wet swampy ground
29	**Conduct pilot studies:** Evaluate the efficacy of using hairpin thermosyphons in embankments.
30	**Correlate issues with conditions:** Encourage or require inspection reports to document the location of failures and issues on the runway or embankment to facilitate correlating the issue with environmental conditions or other factors.
31	**Design for resiliency:** Orient runways with consideration for wind coverage and terrain features.
32	**Design for resiliency:** Avoid siting airports near waterbodies that may flood the airport.
33	**Design for resiliency:** Avoid or minimize the number of drainage crossings under an airport.
34	**Conduct pilot studies:** Evaluate the efficacy of ACEs to mitigate permafrost thaw.
35	**Collect more data:** Geotechnical investigations should include exploratory holes drilled based on guidance in the *Alaska Geotechnical Procedures Manual* and should include holes drill each (left and right) shoulder and centerline at a common station to develop a frozen ground profile section(s).
36	**Strive for ideal construction timing:** Plan pre-construction activities to maximize the possibility of placing embankments in late summer to allow for immediate settlement in thawed areas.
37	**Collaborate with FAA:** To address funding gaps, DOT&PF and FAA should study Alaska-specific issues, develop pilot programs, and identify solutions that work for Alaska while meeting FAA standards.
38	**Design for resiliency:** When reconstructing existing or designing new runways, consider providing a wider operational surface to accommodate future wind changes.
39	**Design for resiliency:** Avoid siting airports near meandering rivers or other waterbodies likely to erode land and encroach on the airport infrastructure.
40	**Provide thorough training:** Hire a seasonal crew dedicated to grading and compacting after spring breakup.
41	**Design for resiliency:** Analyze historical wind data to identify long-term trends or changes in wind patterns.
42	**Surcharge in swampy areas:** Where swampy ground impedes the movement of construction equipment and thick embankment lifts are allowed, the area may benefit from surcharging.
43	**Strive for ideal construction timing:** Plan pre-construction activities to maximize the possibility of placing lighting systems before the ground begins to freeze in the late construction season to help assure compaction of electrical trench backfill.
44	**Collaborate with FAA:** To address the unique conditions in Alaska and account for the impacts of climate change, DOT&PF and FAA should reevaluate airport design standards. This should include clarification on how to prioritize safety features when compromises must be made.
45	**Maximize efficiency of equipment:** Coordinate use of equipment with other maintenance techniques and technologies, such as using dust palliatives.
46	**Design for resiliency:** Use holistic terrain modeling and ground-penetrating radar in addition to traditional drilling investigations to better understand subsurface conditions.
47	**Design for resiliency:** Site airports in a location with relatively flat terrain to limit variation in embankment depth.

	Recommendations
48	**Design for resiliency:** Use advanced hydrothermal modeling when permafrost is present.
49	**Reevaluate funding priorities:** Conduct a comprehensive study to document aviation funding needs and gaps throughout DOT&PF to identify opportunities for increased efficiencies and facilitate funding and budget related discussions with the FAA and the state.
50	**Design for resiliency:** Site airports in a location with consistent subgrade.
51	**Design for resiliency:** Site airports in locations where good quality construction materials are locally available.
52	**Reevaluate funding priorities:** Fund resilient designs with longer expected lifespans, even if it means funding fewer projects overall.
	Design Standards
M	Evaluate whether embankments in areas with permafrost or soft, swampy ground should be overbuilt to mitigate slope degradation.
N	Redefine standards for runway widening and lengthening to require cutting into the existing embankment before placing the new embankment to minimize differential settlement at the interface between the old and new embankment.
O	Establish protocols for whether runway orientation should be based primarily on wind orientation, which may be impacted by climate change, or terrain features.
P	Redefine standards for runway widening and lengthening to ensure the new embankment has sufficient time to settle before placing the finished course.
Q	Encourage phased construction to allow for adequate embankment settlement before surface course is placed.
R	Explore best practices and new strategies for reinforcing and protecting embankments at airports that are susceptible to flooding or coastal erosion, which may worsen because of climate change.
S	Begin construction on new runways before old runways experience total failure to allow time for adequate settlement.

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Appendix 1

Western Alaska Airport Resiliency Study: Data Gap Analysis

A Component of the Alaska Aviation System Plan

August 11, 2024

Airport	Region	As-builts	Plans No As-builts	w/ Specs	Geotech report			Enviro Document	Aerial Photo Before / After if relocations	ALP Topographic map	Other Docs	Construction Reports/Data
					Airport Site	Material source	Thermal Analysis					Contractor /DOT Engineer'
Bethel - parallel	CR	2023		2019	2019							
Chevak	CR	1999/2005/2015			2005 Relocation & 2012 for extension	2005/2012	2005	1998	within Reports	in Geo Reports /2020 ALP	2021 - 5010 rpt	Bering Pacfic Constr. / Bob Anderson
Chignik Lagoon	SC									on ALP		
Chuathbaluk	CR	1978/1980/2002								on ALP	APEB 2022	
Goodnews	CR	1974/2008			1973/2008	1973	2021		within Reports/	on ALP	APEB 2020	Knik /Jeanette Clungstrom
Kaltag	NR				1982	1984/1990		1991		on ALP		
Kiana	NR		2018	Yes	1973/1979/2017 (Draft)	1979/1990/1995/2013			2017 Hyrdraulic Report	on ALP	APEB 2022	
Kipnuk	CR	2000/2010			1985		1985/2006	2002		on ALP		
Kivalina	NR	1985	2018 Erosion Control	Yes	1984	1982 / 1984	Referenced in 182 Geo	1985/1994		on ALP	2017 Subsurface water	
Kongiganak	CR	2012	2022	Yes	2022	2022	2006 thermal analysis by HDL is missing		in 2022 Geo report	on ALP		
Kwigillingok	CR	1973	2018 Emergency repair	Yes	Design in Progress	Design in Progress		1994		on ALP		
Mekoryuk	CR		2023	Yes	2012 / 2022	2012				on ALP		
Napakiak	CR	1972/1998								on ALP		
Napaskiak		1995			1991					on ALP		
Nightmute	CR	2012			2006	2000	2014			on ALP		
Noatak	NR				1986	1986	1986			on ALP	APEB 2021/site visit report	
Platinum	CR	2009/2014						2002		on ALP		
Scammon Bay	CR	1974/1990/2017			1991			1991		on ALP		
Shaktoolik	NR	1998/2008			1992/1996	1992/1996		1997/2003		on ALP		
Shishmaref	NR	1984	2015/2022	Yes		1984/1994	1994	1982 Erosion Contol 1984/1991 Env Assessment		on ALP	1961 Airport evaluation 1978 Expansion & Relocation Study	
Sleetmute	CR	1983	2022	Yes	1983/2019	2019				on ALP		
South Naknek	SC	1996/2019		Yes,						on ALP		
St Mary's	NR	1993/2022	2022	Yes	1980	1980		1992/1998		on ALP		
Takotna	CR	2013				1977	1977	2007		on ALP		
Tuluksak	CR	2009		Yes,						on ALP	Location Study 2001	
Tununak	CR	2012		Yes	2012	1995/2012		2011	2009 before	2011	Location Study 1991	
Tuntutuliak	CR					1998	2006					

Alaska Aviation System Plan

Appendix 2

Western Alaska Airport Resiliency Study: Cold Regions Research Annotated Bibliography

A Component of the Alaska Aviation System Plan

June 4, 2024

BUILDING RESILIENT INFRASTRUCTURE for ALASKA • ALASKA DOT&PF

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Table of Contents

Table of Contents (Continued)

Acronyms

ACE	air convection embankment
ACI	Airports Council International
ACROS	Airport Climate Risk Operational Screening
ACRP	Airport Cooperative Research Program
APDES	Alaska Pollutant Discharge Elimination System
BIM-CFD	Building Information Modeling-Computational Fluid Dynamics
CISA	Cybersecurity and Infrastructure Security Agency
FAA	Federal Aviation Administration
SAR	search and rescue
SWPPP	Stormwater Pollution Prevention Plan

Introduction

The following literature review summarizes recommended aviation system best practices, resilience planning strategies, and examples of implemented resilience measures with a focus on regions with cold climates. Each resource is identified as being *very relevant, relevant,* or *somewhat relevant* to the topics of Planning, Design and Construction (D&C), and Maintenance and Operations (M&O).

A central theme in recently published airport resilience guidance documents and reports of successful resilience strategies is the importance of adapting infrastructure and operational practices to climate change impacts. Areas at high latitudes are warming at a disproportionate rate. Additionally, coastal airports and airports underlain by permafrost are particularly susceptible to climate change impacts. Challenges that Alaskan airports have historically faced, such as coastal erosion, embankment failure, and extreme weather events, are projected to worsen.

Aviation resilience research has been applied to develop frameworks and guidelines that aviation professionals can use to assess which climate change-related risks specific airports face, how airport infrastructure will be impacted, and effective strategies to make infrastructure more resilient. These resources and tools can be used to identify vulnerable infrastructure and develop actions to improve resiliency. Case studies included within broader guidance documents, as well as studies and articles published by aviation providers and institutions, provide examples of effectively implemented resiliency planning approaches and specific engineering technologies that have been developed.

Resources are divided into five categories:

Section I: Guidance for Airport Resiliency Planning includes sources that provide general information about climate-related threats that airports face, introduces resilience planning frameworks, and provides case studies exemplifying how specific airports have improved resiliency. General themes in resilience planning best practice guidance are the importance of taking a proactive approach, conducting studies to understand climate change risks across all aviation system components, and broad communication and collaboration across all the different entities involved in airport operations.

Section II: Resources to Evaluate Airport Vulnerability summarizes research on how climate change impacts aviation operations. This information provides context for some specific threats that airport infrastructure faces.

Section III: Resiliency Planning Tools includes specific processes, methodologies, and tools developed for airports to conduct risk analyses, establish adaptation methods, and evaluate the financial feasibility of potential infrastructure resiliency projects.

Section IV: Examples of Cold Region Resiliency Practices cites documents that provide examples of resilience planning frameworks that aviation organizations have implemented and specific practices they have used.

Section V: Cold Climate-Specific Technologies/Methods includes research and review papers describing engineering technologies implemented by airports to cope with cold climate-related challenges, including ground subsidence from permafrost thaw and snow removal on runways.

I. Guidance for Airport Resiliency Planning

Toolbox for Resilience and Adaptation in Coastal Arctic Alaska (2017)

Planning: Very Relevant *D&C: Relevant* *M&O: Somewhat Relevant*

Synopsis: This guide includes a selection of tools and success stories from around Alaska, intended to help communities, resource managers, and decision-makers maintain resilience and adapt to change. Content is organized into six categories: Leadership and Communication, Natural Systems, Public Infrastructure, Health and Culture, Other Economic Activities, and Emergency Response. The public infrastructure section focuses on adaptation responses to erosion, flooding, and subsidence (i.e., from permafrost thaw), with a focus on rebuilding damaged infrastructure to be more resilient than what existed previously.

Relevance to Current Effort: This paper does not focus on aviation systems; however, it does provide useful information around the broader context of environmental changes and community changes that Alaska is facing. The Public Infrastructure section includes numerous examples of infrastructure adaptation stories in Alaska, such as protecting infrastructure from flooding, avalanche paths, and eroding coastlines. Additionally, aviation planners can draw from the many listed resources and tools available for resilience planning, which are organized and linked in this report.

Agnew::Beck Consulting. "A Toolbox for Resilience and Adaptation in Coastal Arctic Alaska." Adapt Alaska, October 6, 2016. https://adaptalaska.org/wp-content/uploads/2017/10/ak-adaptation-toolbox.pdf.

Airports' Resilience and Adaptation to a Changing Climate (2018)

Planning: Very Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This policy brief includes information, insights, and guidance to assist with airport resiliency planning. Airport Council International's (ACI's) recommendations include:

- Considering climate change in the development of Master Plans
- Assessing the level of risk to or criticality of operational procedures and infrastructure
- Developing and incorporating resiliency actions early in the planning process for all airport operations
- Ensuring effective, reliable communication between airport staff, stakeholders, and relevant external entities

Relevance to Current Effort: The brief provides a framework for climate resiliency planning at airports and an overview of facilities and operations that may be vulnerable to climate stressors. The following case studies in the policy brief also provide examples of effective resiliency planning, which could be used to guide Alaska's strategy:

- Avinor, the operator of Norway's airports, approaches climate adaptation from the very beginning of project planning (e.g., selecting materials or conducting capacity assessments). Avinor conducts comprehensive risk assessments, uses lessons learned to develop new infrastructure standards and policies, and has established standards for construction so that new infrastructure projects will have a greater emphasis on climate adaptation.

- Early planning and extensive collaboration across airport operations-related organizations are essential for mitigating disruption from storm events, as demonstrated by the Hong Kong Airport's effective response to Typhoon Hato.
- Singapore's government has implemented comprehensive strategies to address potential infrastructure damage by employing targeted approaches for individual airport assets and broader district-level protections. Preventive measures, such as building runways at a higher base elevation and improving drainage capacity, were implemented to improve resiliency.

Airports Council International. "Airports' Resilience and Adaptation to a Changing Climate," September 2018. https://store.aci.aero/wp-content/uploads/2018/10/Policy_brief_airports_adaption_climate_change_V6_WEB.pdf.

Eco Airport Toolkit: Climate Resilient Airports (2021)

Planning: Very Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This toolkit provides a high-level overview of the issues climate change may cause for airports and some strategies for anticipating and preparing for contingencies. The toolkit reiterates the resiliency measures recommended in the Airport Council International policy brief and discusses typical steps to develop a master plan or separate resiliency plan that accounts for climate impacts.

The toolkit also provides guidance on additional considerations, such as establishing communication systems and emergency plans. Communication systems tied to the airlines, tenants, and relevant external parties must be maintained with an accurate and updated contact list. Airports should also have emergency plans and standard operating procedures to address potential storm-related events and regularly engage stakeholders in these efforts.

Relevance to Current Effort: The document introduces tools and several strategies for design and construction that could be employed in Alaska airport resiliency planning, such as using a risk matrix and climate change risk assessment. The toolkit supports the ACI recommendation to address resilience in an airport master plan and provides a discussion and resources for developing climate adaptation measures.

The toolkit also includes case studies of various airports—several of those particularly relevant to cold-climate airports, like the following:

- The Iqaluit International Airport Improvement Project included extensive research and employed a variety of techniques, such as ground-penetrating radar, permafrost core analysis, surficial mapping, and remote sensing, to generate site-specific knowledge about permafrost properties. The data collected have been used to inform infrastructure decision-making. A key finding of this work is that permafrost tends to be subject to greater warming under pavement than embankments (and other "naturalized" surfaces).
- In 2014, the Toronto Lester B. Pearson International Airport experienced significant operational impacts from extreme cold and ice buildup. In response, the Greater Toronto Airports Authority recommended changes, such as improving communication protocols, developing tools to improve communications with passengers, and establishing an Airport Updates webpage.

International Civil Aviation Organization. "Eco Airport Toolkit: Climate Resilient Airports," April 22, 2021. https://www.icao.int/environmental-protection/Documents/Climate%20resilient%20airports.pdf.

A Guide for Resilience Planning at Airports (2021)

Planning: Very Relevant *D&C: Somewhat Relevant* *M&O: Relevant*

Synopsis: This article emphasizes the significance of resilience planning within the aviation industry, especially considering the challenges posed by climate change and the growing complexity of airport systems. Environmental Science Associates recommend developing a resilience management plan using a risk-based approach. The article highlights the importance of addressing shock events (major failures that demand immediate attention) and chronic stressors (smaller events that lead to and exacerbate these significant disruptions). The following principles inform the development of a resilience management plan:

- Create a Project Framework
- Conduct Resilience Management Plan Visioning
- Inventory Strategic Assets and Infrastructure
- Determine Requirements
- Conduct a Risk Assessment
- Identify Strategic Focus Areas
- Develop Focused Management Plans and Processes
- Perform Stakeholder Outreach
- Develop a System for Resilience Management
- Develop Resilience Promotion/Education Programs
- Develop Electronic Resilience Management Tools
- Create a Structure for Regular Reviews

Relevance to Current Effort: The article provides a strategy for mitigating risks to airports from stress events and chronic stressors. In addition to the list of principles, this article also provides general guidance. For instance, resiliency planning should complement existing planning efforts and, instead of starting from scratch, can build off established master plans. The guide also emphasizes that the resiliency planning process requires collaboration across airport departments, airport tenants, and other key external stakeholders, such as the Federal Aviation Administration's (FAA's) Airports District Office, communities surrounding the airport, and regional planning organizations.

Wolfe, N. "A Guide for Resilience Planning at Airports." Environmental Science Associates, 2021. https://esassoc.com/wp-content/uploads/2022/02/Resilience-at-Airports_Full-Article_ESA.pdf.

Statewide Threat Assessment: Identification of Threats from Erosion, Flooding, and Thawing Permafrost in Remote Alaska Communities (2019)

Planning: Very Relevant *D&C: Somewhat Relevant* *M&O: Somewhat Relevant*

Synopsis: This document assesses the relative risk to public infrastructure in rural Alaskan communities from erosion, permafrost thaw, flooding, and the compounded threats arising from the interconnected dynamics of these factors. Additionally, it provides guidance for decision makers to develop effective mitigation or adaptation strategies in response to these challenges. An overview of each threat and a description of the available data are provided. There is a lack of long-term spatially or temporally discrete monitoring throughout Alaska. The paper recommends additional data collection and provides templates outlining the types of data that should be recorded for community resiliency planning. It emphasizes the need for central data repositories, organized by community, and standardized data collection methodology and terminology.

Relevance to Current Effort: Research into the relative threat from flooding, erosion, and permafrost thaw that communities face can help to identify threats that airport infrastructure is exposed to, which can inform mitigation and resiliency considerations. Airport resiliency research and evaluation would also benefit from strategies such as central data repositories and standardized data collection.

II. Resources to Evaluate Airport Vulnerability

Key Climate Change Vulnerabilities for Aviation Organizations (2022)

A component of Climate Change: Climate Risk Assessment, Adaptation and Resilience

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This guidance document provides a table describing how climate change-related impacts (higher average and extreme temperatures, changing precipitation, increased intensity of storms, and sea level rise) are affecting airports, air navigation service providers, and aircraft operations.

Relevance to Current Effort: The guidance document can be used as a reference to evaluate the types of infrastructure damage that Alaskan airports and aircraft operations are susceptible to. This information can be used to identify and prioritize vulnerabilities that Alaska's aviation systems face, such as changing precipitation patterns that will cause flooding and flood damage to runways and infrastructure or increased storm surges and permafrost thaw that threaten airport infrastructure. In addition to ground assets like runways and access roads, vulnerable infrastructure includes power supplies, navigation and communication equipment, and other electronic systems.

International Civil Aviation Organization. "Key Climate Change Vulnerabilities for Aviation Organisations." Climate Change: Climate Risk Assessment, Adaptation and Resilience, 2022. https://www.icao.int/environmental-protection/Documents/Climate%20Risk%20Assessment%20and%20Adaptation%20Report_Key%20Vulnerablities_final.pdf.

Reviewing the Impacts of Climate Change on Air Transport Operations (2022)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Relevant*

Synopsis: This journal review article summarizes evidence that climate change has already impacted air transport and is expected to accelerate in the future. Changing wind direction, reducing wind strength, and increasing temperatures impact airplane take-off performance by increasing take-off distances where a surplus of runway length exists and decreasing available payload where it does not. The paper also discusses research indicating a general trend of increased air turbulence and changes to wildlife patterns, particularly bird activity, which may also impact airplane operations.

Relevance to Current Effort: The article provides an overview of some major aviation operation trends that many airports will experience because of climate change.

Gratton, G. B., P. D. Williams, A. Padhra, and S. Rapsomanikis. "Reviewing the Impacts of Climate Change on Air Transport Operations." *The Aeronautical Journal* 126, no. 1295 (January 2022): 209–21. https://doi.org/10.1017/aer.2021.109.

Outcomes of the 2020 Survey on the Impacts of Climate Change and Variability on Aviation (2020)

Planning: Relevant *D&C: Relevant* *M&O: Somewhat Relevant*

Synopsis: This article reviews the outcomes of the 2020 Survey on the Impacts of Climate Change and Variability on Aviation. Most respondents evaluated the degree of impact of future climate change and variability on aviation to be moderate or greater and believed that climate change impacts may be felt within the next 10 years. Some major trends that were identified include:

- Increased likelihood of airfield flooding caused by heavy rain and/or storm surge
- Longer take-off and landing distances in a warming climate and a reduced runway capacity
- Frequent disruption from extreme weather events and increased fuel consumption because of longer routings
- Increased frequency and severity of turbulence

Relevance to Current Effort: The article provides additional evidence that aviation professionals are concerned about climate change and are experiencing or expect to experience impacts within the near term. The article helps identify some key vulnerabilities that airports and the overall aviation system will likely face.

Standing Committee on Services for Aviation. "Outcomes of the 2020 Survey on the Impacts of Climate Change and Variability on Aviation." World Meteorological Organization, October 2020. https://library.wmo.int/doc_num.php?explnum_id=10387.

Effect of Warmer Minnesota Winters on Freeze-Thaw Cycles (2022)

Planning: Somewhat Relevant *D&C: Somewhat Relevant* *M&O: Somewhat Relevant*

Synopsis: Minnesota winters have been getting warmer, and there are increasing periods with winter temperatures around freezing (32 degrees Fahrenheit). This study investigated how these changes in temperature patterns impact freeze-thaw events of pavement and, consequently, pavement conditions and longevity. The study assessed historical air, pavement, and subsurface temperatures, precipitation, and freeze-thaw depth data collected from Minnesota roads and runways. The study also analyzed correlations between air, pavement, and subsurface temperatures and the occurrence of freeze-thaw events. Climate data indicated a trend of later onsets of freezing temperatures and increased precipitation. Pavement freeze-thaw patterns showed a decrease in freeze-thaw events during early and late winter months, and freeze-thaw events remained sporadic, with more shallow freezing during the middle winter months. The report recommends a follow-up study into how precipitation influences freeze-thaw events for pavement and the integration of pavement condition projections into vulnerability mapping of the state road networks.

Relevance to Current Effort: This study provides an example of collecting data and conducting research to understand how climate change impacts pavement conditions, which is important for sustainable pavement management planning, especially in the context of a changing climate. Further study should be conducted in Alaska as the state continues to experience increased thawing, especially of permafrost.

Ceylan, H., M. Mahedi, D. Rajewski, S. Kim, I. Cho, and E. S. Takle. "Effect of Warmer Minnesota Winters on Freeze-Thaw Cycles." Office of Innovation and Research, Minnesota Department of Transportation, July 2022. https://www.researchgate.net/profile/Masrur-Mahedi/publication/372763895_Effect_of_Warmer_Minnesota_Winters_on_Freeze-Thaw_Cycles_-_Minnesota_Department_of_Transportation/links/64c6d608545060019e3ed8bd/Effect-of-Warmer-Minnesota-Winters-on-Freeze-Thaw-Cycles-Minnesota-Department-of-Transportation.pdf.

III. Resiliency Planning Tools

Key Steps in Aviation Organisation Climate Change Risk Assessment and Adaptation Planning (2022)

A component of Climate Change: Climate Risk Assessment, Adaptation and Resilience

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This guidance document was produced for carrying out a climate change risk assessment and subsequently developing and implementing an adaptation plan intended for use by airports, aircraft operators, and air navigation service providers.

The guide includes step-by-step flowcharts for carrying out a climate change risk assessment and a discussion of each key step, ranging from staff organization and identification of scope, to data collection and assessment of climate impacts, and to identification and assessment of at-risk infrastructure. The guide recommends using a risk matrix to analyze the consequence of potential impacts alongside the probability of occurrence, followed by assessing the existing adaptive capacity of infrastructure and systems that may be impacted to quantify overall airport vulnerability.

Next, the document describes how to apply the risk assessment to climate change adaptation planning. The process is divided into four key steps, with a detailed description of sub-steps for each key stage:

1) Define adaptation and resilience objectives
2) Identify adaptation and resilience measures to address prioritized vulnerabilities
3) Develop and implement a climate adaptation plan
4) Conduct periodic monitoring and review

Relevance to Current Effort: The guidance includes step-by-step information about how to develop a risk assessment, how to develop and implement a climate adaptation plan, and additional planning tools and resources that can be integrated into this process.

The document is also supplemented with best practices/lessons learned during the risk assessment process. For example, when developing a risk assessment scope, less visible or obvious threats are often overlooked. To achieve a more comprehensive approach and avoid overlooking threats, the risk assessment team should engage with asset operators, operational staff, facility managers, and decision-makers at an early stage in the process. Similarly, during the identification of climate impacts stage, engaging the organization’s personnel is essential, such as asset operators, operational staff, and facility managers who have hands-on experience to assess expected impacts.

International Civil Aviation Organization. “Key Steps in Aviation Organisation Climate Change Risk Assessment and Adaptation Planning.” Climate Change: Climate Risk Assessment, Adaptation and Resilience, 2022. https://www.icao.int/environmental-protection/Documents/Climate%20Risk%20Assessment%20and%20Adaptation%20Report_Key%20Steps%20Risk%20Assessment_final.pdf.

Menu of Adaptation Options (2022)

A component of Climate Change: Climate Risk Assessment, Adaptation and Resilience

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This document is a supplement to Climate Risk Assessment, Adaptation and Resilience: Key Steps in Aviation Organisation Climate Change Risk Assessment and Adaptation Planning, with information targeted toward the adaptation action selection process. The document lists operational and infrastructure adaptation practices in response to different climate change impacts and emphasizes the importance of broad collaboration for strengthening climate change resilience.

Relevance to Current Effort: The document offers examples and suggestions for resilience actions that can help airports address the impacts of climate change. Applying this checklist to specific airports will identify which airports are already implementing resilience measures, which can create a baseline for individual airports and be used to evaluate the efficacy of specific strategies for Alaskan airports. Relevant climate impacts that are addressed include increased intensity of storms, changing precipitation patterns, and sea level rise. For example, recommended responses to severe weather events and storm surges include ensuring clear and functional drainage networks, relocating critical infrastructure to higher floors, installing backup power sources, implementing groundwater storage measures, designing facilities to withstand extreme precipitation events, and safeguarding wiring and connections from flooding through relocation, burial, or elevation.

International Civil Aviation Organization. "Menu of Adaptation Options." Climate Change: Climate Risk Assessment, Adaptation and Resilience, 2022. https://www.icao.int/environmental-protection/Documents/Climate%20Risk%20Assessment%20and%20Adaptation%20Report_Menu%20of%20Adaptation%20Measures_final.pdf.

Climate Change Adaptation Planning: Risk Assessment for Airports (2015)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This guidebook helps airport practitioners identify specific climate change impacts, develop adaptation actions, and incorporate actions into the overall airport planning process. The guidebook is organized into the following four parts:

Part 1: Provides an overview and introduces the Airport Climate Risk Operational Screening (ACROS) tool, which offers a streamlined approach to developing a climate adaptation plan (see Part 3 for a description of the ACROS tool) and describes the process of initiating climate adaptation planning. Initiation involves identifying crucial leaders, establishing a stakeholder advisory committee, and setting climate resilience goals.

Part 2: Provides an overview of climate change projections and how airports will be impacted, with a description of commonly used climate change metrics. This section also includes guidance for developing a climate change adaptation strategy independent of the ACROS tool.

Part 3: User guide for the ACROS tool, which is used to provide a screening-level investigation of climate change risks. The ACROS tool contains site-specific information on airport assets for 500 airports nationwide, climate change projection data, and expert-recommended adaptation options.

Part 4: Describes how climate change planning can be integrated into existing planning frameworks. For example, climate impacts can be addressed within Safety Management Systems, disaster, business recovery, emergency response planning, and risk management processes. Climate adaptation planning can be incorporated throughout Airport Master Plan and Airport Layout Plan development and should be done in coordination with broader regional transportation planning efforts.

Relevance to Current Effort: The guidebook outlines the process and provides a tool to guide airports through the Airport Cooperative Research Program's climate adaptation planning process. In particular, the ACROS tool can help airports determine what aspects of climate change will most likely impact them, how these impacts will affect operations and infrastructure, and potential adaptation responses. This tool saves airport staff time and resources when evaluating and prioritizing potential adaptation options and initiating the airport adaptation process. This guidebook also contains tools for developing an adaptation plan without using the ACROS tool. Appendix A of the guidebook includes a list of possible climate stressors and how they will impact specific assets; Appendix E includes a list of resources that provide supplemental information on climate change adaptation planning.

National Academies of Sciences, Engineering, and Medicine. "Climate Change Adaptation Planning: Risk Assessment for Airports." *The National Academies Press*, 2015. https://nap.nationalacademies.org/catalog/23461/climate-change-adaptation-planning-risk-assessment-for-airports

Climate Resilience and Benefit-Cost Analysis: A Handbook for Airports (2019)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Relevant*

Synopsis: This handbook is designed to help airport practitioners assess the benefits, costs, and financial feasibility of infrastructure projects designed to improve resilience to climate change and extreme weather events.

The handbook recommends using an existing software tool, ACROS (see Climate Change Adaptation Planning: Risk Assessment for Airports for more information), to access future climate projections, identify vulnerable infrastructure, and consider ways to reduce impacts through investments in infrastructure or operational changes. The handbook directs users to a tool that will run Monte Carlo simulations using climate model data to evaluate the probability of specific climate events and consequential infrastructure damage. This tool calculates the probability of various severities of infrastructure damage and related costs if no mitigation occurs, compared to the cost of climate impacts to infrastructure if mitigation is implemented. This analysis can help users predict whether a climate mitigation measure will save money.

Relevance to Current Effort: Alaskan airports will likely need to continue to invest in resiliency projects. This handbook and associated software and tools can be used to identify and evaluate the economic feasibility and potential cost savings of climate resilience-oriented infrastructure projects. Following the guidance in the handbook provides a method for making data-supported decisions about which resiliency measures to invest in.

National Academies of Sciences, Engineering, and Medicine. "Climate Resilience and Benefit-Cost Analysis: A Handbook for Airports." *The National Academies Press*, 2019. https://doi.org/10.17226/25497.

An Airport Climate Resilience Assessment Scan (2020)

Planning: Relevant *D&C: Relevant* *M&O: Somewhat Relevant*

Synopsis: This article is a thesis that describes the development of the Airport Climate Resilience Assessment Scan (AirCRAS). This digital method is used to assess airport resiliency at the airport level to gain a holistic view of the climate resilience status of an airport. The tool requires that users provide answers to assessment questions, identifying what climate risks are relevant to the airport in question, and providing details about airport organizations, operations, and infrastructure. The tool will then output a rose diagram describing the airport's resilience status and provide discussion questions aimed at facilitating additional resilience planning.

Relevance to Current Effort: The article describes a method that synthesizes existing airport resilience research into an assessment tool that will evaluate the resiliency status of individual airports. Potential applications of this method include providing insights into the resilience of specific airports in Alaska, providing baseline data for resilience planning, and helping with efforts to identify airports that are most vulnerable to climate change.

Verdijk, P. F. M. "An Airport Climate Resilience Assessment Scan." Netherland Airport Consultants, 2020. http://essay.utwente.nl/85464/1/Verdijk_MA_ET.pdf.

IV. Examples of Cold Region Resiliency Practices

Adapting Airports to a New Climate (2016)

Planning: Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This document discusses risk assessment and climate change adaptation implemented by Avinor, a Norwegian airport operator. It mentions specific challenges and considerations, such as changing wind directions, drainage issues, the vulnerability of navigation infrastructure to flooding, and changes in requirements for runway elevations to combat rising sea levels. The document emphasizes the importance of considering climate change impacts and integrating climate adaptation measures into infrastructure planning and maintenance. The document also highlights the need for conducting risk assessments of airports, including navigation systems and surface access, to identify vulnerabilities and take appropriate actions.

Relevance to current effort: The document provides relevant insights and considerations for Alaska aviation system planning and improving safety in the face of climate change. Alaska has similarities in geography and climate to Norway and is facing similar climate change-related challenges. The emphasis on conducting risk assessments and integrating climate change considerations into infrastructure planning can be valuable for Alaska's aviation systems.

Larsen, O. M. and K. Fjellheim. “Adapting Airports to a New Climate.” International Civil Aviation Organization, 2016. https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2016/ENVReport2016_pg211-213.pdf.

Climate Risks & Adaptation Practices for the Canadian Transportation Sector (2016)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This report reviews climate risks to the Canadian transportation sector and describes different climate vulnerabilities, priorities, practices, and opportunities across Canada’s national transportation system. It is organized into chapters based on geographic region, each of which has a dedicated air transportation section. Summaries of the air transportation information provided in Chapter 3 (Northern Territories) and Chapter 4 (British Columbia) are included herein.

Chapter 3 Northern Territories, Section 6 Aviation System identifies the following key climate issues that northern airports are facing:

- Air Temperature – Permafrost degradation can damage and degrade runways/taxiways.
- Snow – Increased snowfall may cause flooding in the thaw seasons, damaging permafrost under runways/taxiways.
- Blizzards – Blowing snow and winter storms can reduce visibility and delay flight operations.
- Rainfall – Increased rainfall can reduce traction on runways/taxiways. Intense periods of freezing rain can cause delays to flights and could cause airplanes to experience issues with braking and sliding off airstrips.
- Fog – Increased fog episodes may require additional training and procedures for airport personnel to ensure safety. Intense periods of fog can delay flights until visibility improves.

This section also provides an overview of adaptation practices and rationales that are implemented at Northern Canadian airports. For example, ground settlement from permafrost thaw can be more easily corrected in gravel runways by adding embankment material or more easily reconstructed than paved runways. This section also notes that the grooving of paved runways has improved drainage and traction; however, it is relatively costly, and removing snow as quickly as possible can mitigate the risk of permafrost thaw from heavier snowfall.

Chapter 4 British Columbia, Section 6 Air Transportation: This section identifies the key hazards for coastal airports as storm surges increase and sea levels rise. The Vancouver Airport is addressing risks of climate change in a Master Plan update, whereas other airports in the region are taking a more reactive adaptation approach by monitoring weather conditions on an ongoing basis and adjusting practices as changes in weather phenomena are observed.

Relevance to Current Effort: Alaska shares many climate characteristics with Canada and faces similar threats from climate change. The adaptation practices and case studies can provide insight into Alaska's adaptation planning. For instance, the Northwest Territory chapter describes how the Iqaluit International Airport collected data on underlying permafrost conditions to inform infrastructure protection decisions. Extensive maps were produced to identify potentially problematic locations for existing and proposed infrastructure (e.g., thaw-sensitive soils and/or difficult terrain for construction); a taxiway was relocated with an insulated barrier to reduce permafrost damage; the importance of removing thick snow cover in key areas was recognized; thermosyphons were installed beneath airport buildings; and drainage was improved to reduce the infiltration of surface water into permafrost.

Palko, K. G. and D. S. Lemmen. "Climate Risks and Adaptation Practices – For the Canadian Transportation Sector 2016." Transport Canada, 2016. https://natural-resources.canada.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2016/ClimatRisk-E-ACCESSIBLE.pdf.

Arctic Airports and Aerodromes as Critical Infrastructure (2020)

Planning: Very Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This policy primer provides an overview of airport conditions and trends in Nunavut, Canada, and highlights the significance of aviation infrastructure for remote communities, such as the critical role of airports in supporting public health through medical flights. The article provides an overview of aviation infrastructure in the region and discusses challenges faced by airports, including ground instability caused by permafrost thaw and deficiencies in runway lighting and power supply. The policy primer recommends that remoteness be factored into assessments of the importance of existing infrastructure assets and the significance of future investments and the Index of Remoteness, which uses several variables to quantify the remoteness of communities. Remoteness and the conditions of airport infrastructure are both important considerations to inform approaches to community resupply, medical evacuation, and search and rescue (SAR) operations.

Relevance to Current Effort: Many communities in Alaska are similarly remote and reliant on airport infrastructure, making this approach of quantifying remoteness into infrastructure planning decisions relevant. The following additional broad recommendations from this overview may offer insight into Alaska aviation planning:

- Recognizing the increasing frequency of intense storms caused by climate change, it is important to note that navigation system upgrades may facilitate safer landings in difficult weather. For many northern airports and aerodromes, 24-hour weather reporting is not yet available. Runway lighting is absent at many smaller gravel-surfaced airports and NAV CANADA lists many of these same runways as having clearing and surface maintenance concerns. As storms worsen and community pressures grow, investments in technologies are prudent to ensure the safe operation of existing air transportation patterns.
- Investments in weather-monitoring capabilities will be essential as climate change advances.
- Thoughtful analyses of medical travel and SAR operations represent important considerations for the planning of aeronautical infrastructure.

Bouchard, C. "Arctic Airports and Aerodromes as Critical Infrastructure." North American and Arctic Defence and Security Network, October 30, 2020. https://www.naadsn.ca/wp-content/uploads/2020/11/Airports_CI_2020_11_05.pdf.

Yukon Aviation System Review (2017)

Planning: Relevant *D&C: Somewhat Relevant* *M&O: Relevant*

Synopsis: The Yukon Aviation System Review includes a description of existing conditions, aviation forecasting, and the results from a compliance assessment of buildings and airfields for the Yukon Territories. The report then introduces evaluation criteria for infrastructure investment prioritization using a triple bottom line approach. Airports are ranked based on social, environmental, and economic performance; then, airport projects are evaluated to determine investment priority. The model considers the role of the airport, its triple bottom line ranking and scores, the severity of compliance issues, and the general condition and impact on future operations and capacity.

Relevance to Current Effort: The review provides an example of a methodology for assessing safety and performance issues of aviation infrastructure and a framework for prioritizing infrastructure investment decisions. The Yukon Aviation System Review exemplifies how a structured process for determining which aviation projects to invest in has the potential to maximize safety and performance within the broader aviation system.

Thompson, W. "Yukon Aviation System Review." Department of Highway and Public Works – Aviation Branch, Government of Yukon, May 23, 2017. https://yukonflying.com/Documents/YTG%20Aviation%20Review.pdf.

Cambridge Bay Airport Climate Change Vulnerability Assessment (2016)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This report summarizes the Cambridge Bay Airport vulnerability assessment, which followed a standardized protocol prepared by the Public Infrastructure Engineering Vulnerability Committee. The assessment used historical data and climate models to assess climate conditions over the next 30 years. It identified five climate events that may affect airport operations and infrastructure performance: rainfall, visibility, frost, ground thawing index, and climate variability. Current environmental and maintenance baseline data were inadequate for a detailed engineering assessment; this lack of understanding was considered a moderate risk. The following actions were recommended:

- Evaluate the capacity of drainage systems to assess the resiliency of culverts and ditches against higher flows and measure runoff and changes in surface water bodies.
- Systematically collect information on visibility using a detailed logbook/database. Document weather conditions and characteristics of limited-visibility events.
- Collect data on frost formation, such as climate parameters, timing, location, and extent.
- Review frost management procedures.
- Update or develop an asset management system, including an evaluation of current infrastructure service life.
- Monitor local snow accumulation, including spatial (re)distribution, and note limitations to operations.
- Automate measurement of ground temperatures across the airport property.
- Document in a logbook/database climate-related flight delays/cancellations, as well as maintenance and repair activities, including date, location, type, and extent.
- Carry out an initial climate change vulnerability assessment with involvement from several stakeholder groups, including the airport operators, owners, and users, and re-evaluate it every 5 years as new baseline data, infrastructure performance information, and improved climate models become available.

Relevance to Current Effort: The report provides an example of a vulnerability assessment conducted at a northern, coastal airport and stresses the importance of collecting baseline data necessary for engineering and vulnerability assessments of airport infrastructure.

BGC Engineering and Transport Canada. "Cambridge Bay Airport – Climate Change Vulnerability Assessment." Public Infrastructure Engineering Vulnerability Committee, May 17, 2016. https://pievc.ca/wp-content/uploads/2016/05/cambridge_bay_climate_vulnerability_assessment_web.pdf.

Churchill Airport Climate Change Vulnerability Assessment (2016)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This report summarizes the Churchill Airport vulnerability assessment, which followed a standardized protocol prepared by the Public Infrastructure Engineering Vulnerability Committee. The report found that the infrastructure component likely to be most vulnerable to climate change is the natural foundation on which airports are constructed because of heterogeneity in permafrost conditions. Poor visibility caused by changes in atmospheric moisture (e.g., fog, frost, precipitation) was determined to be the climate event most likely to be problematic for airport operations in the future. The precise extent of disruptions from poor visibility or other climate events was difficult to determine because of an inadequate baseline of environmental data and maintenance records. This lack of data and records prevented the performance of a detailed engineering assessment; therefore, the report recommends developing a database that combines infrastructure performance, air traffic operation, and climate events. Recommendations are as follows:

- Develop a database of infrastructure performance and environmental data to assess conditions during climate change-related challenges and document the severity of events.
- Document maintenance and repair efforts in a systematic manner to note changes and highlight infrastructure performance.

- Perform a procedural review by reviewing current operation and maintenance practices and standard operational procedures and evaluating their robustness against future climate conditions.
- Systematically collect information on visibility (e.g., fog and cloud ceiling) to identify potential trends and inform whether upgrades in the current instrumentation are required.
- Evaluate the capacity of culverts and ditches to assess the resiliency of existing drainage systems.
- Monitor local snow accumulation, including spatial (re)distribution, to assess current snow management plans and plan for future requirements.
- Reassess climate change vulnerability every 5 years with involvement from several stakeholder groups, including the airport operators, owners, and users, as more baseline data, infrastructure performance information, and improved climate models become available.

Relevance to Current Effort: Like the Cambridge Bay Airport Climate Change Vulnerability Assessment, this report emphasizes the importance of collecting baseline data for assessing climate change vulnerability and improving resiliency. The report provides an additional example of a vulnerability assessment and airport-specific resiliency actions for a cold climate airport with a gravel strip, though the climate is likely more similar to Southeast Alaska than Western Alaska.

BGC Engineering and Transport Canada. "Churchill Airport – Climate Change Vulnerability Assessment." Public Infrastructure Engineering Vulnerability Committee, May 17, 2016. https://pievc.ca/wp-content/uploads/2021/01/churchill_climate_vulnerability_assessment_web-1.pdf.

V. Cold Climate-Specific Technologies and Methods

Review of Thermosyphon Applications (2014)

Planning: Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This review document describes the history of thermosyphon use in Alaska, the different applications they can be used for, and how the technology has evolved. This review notes that thermosyphon use will likely become increasingly important as temperatures warm and permafrost degrades because of climate change.

Relevance to Current Effort: The review provides a broad overview and insights into thermosyphon use in Alaska. Thermosyphons are already used for permafrost stabilization of runway and airport facilities (for example, Bethel is included as a case study in this review) and will likely become increasingly important. The review discusses the use of buried and hairpin thermosyphons, which may be a viable technology for new airport construction.

Note that this paper is from 2014, so recent advances in technology and applicability are not included.

Wagner, A. M. "Review of Thermosyphon Applications." US Army Corps of Engineers, February 2014. https://dot.alaska.gov/stwddes/research/assets/pdf/erdc-crrel-tr-14-1.pdf.

Loftus Road Extension: ACE & Thermosyphon Design Features (2003)

Planning: Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This article describes the experimental features used in the construction of Thompson Drive in Fairbanks, Alaska. The design of the road included the novel use of hairpin thermosyphons, which are filled with liquid carbon dioxide and buried under the roadbed. It also used air convection embankments (ACE), which utilizes uniformly sized rocks with no fines to allow airflow within the embankment. The article includes diagrams to illustrate how these technologies and techniques were used throughout the road embankment.

Relevance to Current Effort: Hairpin thermosyphons and air convection embankments could be considered for use in the design of new airports. Retrofitting existing airports with thermosyphons would be more difficult.

Local Technical Assistance Program, "." Alaska Department of Transportation and Public Facilities, 2003. https://dot.alaska.gov/stwddes/research/assets/pdf/03v28n1.pdf

BIM-CFD Integrated Sustainable and Resilient Building Design for Northern Architecture (2020)

Planning: Somewhat Relevant *D&C: Relevant* *M&O: Somewhat Relevant*

Synopsis: The practice of elevating buildings is commonly used to decrease permafrost degradation from building heat transfer. Heat from buildings can be transferred into the ground (and the permafrost below) either by physical contact or by wind moving heated air from the building toward the ground; the latter process is known as the downwash effect and is influenced by wind speed and direction. This study analyzed the relationship between building height, wind velocity, and wind direction to determine their impacts on northern building architecture and permafrost. Results revealed that the building downwash effect is a key factor in heat transfer to the ground and raising a building by at least 1 meter reduces the impact of the downwash effect. The study also found, however, that raising a building by 1.5 meters or more increases building heat loss through convective heat transfer.

The study also noted that a building's shadow area (i.e., the area of the ground around the building that is cast in shadow by the building) is highly susceptible to convective heat transfer.

Relevance to Current Effort: Many airport facilities in Alaska must be built on permafrost. This study provides design considerations for preventing damage to permafrost from transfer of heat to ground from buildings. The following design recommendations from this study can be considered for airport facilities on permafrost in northern Alaska:

- Raise buildings 1 meter above the ground to reduce the thermal stresses on the permafrost.
- Avoid implementing pilings foundation and screw jacks in the shadow area under the building frames because they are exposed to the highest heat transfer. Note that these methods are imperfect solutions for permafrost regions because thawing ground can disrupt the structure.
- Use special insulation in building edges and corners to enhance energy savings and significantly reduce the heat transfer from the buildings to the permafrost underneath.
- Consider building orientation in the early design stages to alleviate the building downwash effect on the permafrost.

Younis, M., M. Kahsay, and G. Bitsuamlak. "BIM-CFD Integrated Sustainable and Resilient Building Design for Northern Architecture." In *ASHRAE Topical Conference Proceedings*, 584–91. American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., 2020.

Climate Change Impacts on Frost and Thaw Considerations: Case Study of Airport Pavement Design in Canada (2023)

Planning: Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: This study focused on investigating the potential impacts of climate change on frost/thaw depths and frost heaves in multiple locations across Canada. The study analyzed existing methods to estimate frost penetration depth and used these models to project future frost depth patterns. This information is important to inform the design of resilient pavements in future airport projects.

Evaluation of Frost Depth Calculation Methods: The accuracy of three frost depth calculation methods (developed by the Ministry of Transportation of Ontario, the Ministry of Transportation of Quebec, and Transport Canada Civil Aviation) was assessed. The measured frost depths in nine northern cities in Canada and the United States were compared to the frost depths estimated by these statistical models. The study revealed that the accuracy of the models varied, and the type of soil influenced their ability to predict frost penetration depth accurately.

Frost Depth Projections: The evaluated frost depth models were then used to project future frost/thaw depths and frost heave events under a high emission scenario (RCP8.5). The results indicated a decrease in frost depth penetration across the models.

Implications for Pavement Design: The article concludes that the warming winter temperatures associated with climate change may positively affect pavement conditions in southern areas of Canada. However, northern regions are likely to face challenges because of increased differential thaw settlement, frost heaves, and a decrease in overall pavement strength caused by permafrost thawing and a higher number of freeze-thaw cycles.

Relevance to Current Effort: Knowing how climate change can impact airport pavements' frost and seasonal frost-thaw conditions is essential for planning future transportation infrastructure projects. This study provides insights into the accuracy of some commonly used methods to evaluate frost penetration depth and recommendations for developing more mechanistic methods that better account for site-specific soil properties, to improve accuracy.

When considering pavement design that will be resilient to future warming freeze-thaw patterns, areas underlain by permafrost should be regarded differently than those not underlain by permafrost. For pavement underlain with permafrost, changes to the active layer thickness is the main concern because of projected increases in thaw depth.

Barbi, P. S. R., P. Tavassoti, and S. L. Tighe. "Climate Change Impacts on Frost and Thaw Considerations: Case Study of Airport Pavement Design in Canada." *Applied Sciences* 13, no. 13 (January 2023): 7801. https://doi.org/10.3390/app13137801.

Evaluation Of Airport Pavement Designs for Seasonal Frost and Permafrost Conditions (2023)

Planning: Very Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: Information was gathered and reviewed on the pavement performance issues of three runways with asphalt pavement (Nome, Kotzebue, and Utqiaġvik) and one runway with gravel surface (Noorvik). Data sources included pavement design and construction records, geotechnical investigations, pavement condition surveys, and environmental investigations. The loss of permafrost and thawing of the frost-susceptible pavement layers was the root cause of most airport performance issues. Some failures were attributed to issues with guidance, design assumptions, and construction techniques incompatible with a warming trend. The report presents recommendations for how FAA guidance can be updated to improve airport resiliency to frost and permafrost thaw, including:

- How and to what extent warming temperature trends need to be considered for calculating thaw depth and associated design decisions
- How to assess frost condition of subgrade
- How to base design and construction decisions on the presence, extent, and conditions of underlying permafrost
- How to implement complete frost protection and reduced subgrade strength methods
- When and how to construct insulating panels

Relevance to Current Effort: The evaluation provides an analysis of what causes runway performance issues in Alaskan airports underlain with permafrost and assessment of design considerations and construction best practices that could mitigate frost and permafrost-related performance issues.

Ashtiani, A. Z. and T. Parsons. "Evaluation of Airport Pavement Designs for Seasonal Frost and Permafrost Conditions." U.S. Department of Transportation Federal Aviation Administration, March 1, 2023. https://doi.org/10.21949/1528206.

Use of Cellular Concrete for Air Convection Embankment to Protect Permafrost Foundations in Cold Regions: Feasibility Study (2019)

Planning: Somewhat Relevant *D&C: Very Relevant* *M&O: Relevant*

Synopsis: The use of air convection embankment (ACE) has been demonstrated to provide passive cooling for roadway embankments in permafrost zones. However, in many areas of Interior Alaska, the coarse gravel or crushed rocks needed for ACE construction are not readily available and shipping them to remote areas is cost prohibitive. This research paper investigated the feasibility of using cellular concrete as an alternative to crushed rocks to take full advantage of the ACE design.

The paper included a literature review, testing of different material combinations of cement to assess optimal mixture proportions and material combinations, a simulation to assess the performance of cellular concrete, and an economic analysis. Results indicated that cellular concrete ACE is more effective than crushed rock ACE, and economically more feasible.

Relevance to Current Effort: The use of ACE is also applicable to airport runways that are underlain with permafrost. This study demonstrates that the use of cellular concrete ACE is a structurally- and cost-effective way to address problems related to thaw settlement and ground instability from permafrost thaw. The study also includes insights into the optimum combination of materials for developing cellular concrete considering ACE construction on permafrost foundations in Alaska.

Liu, J. and H. Wu. "Use of Cellular Concrete for Air Convection Embankment to Protect Permafrost Foundations in Cold Regions: Feasibility Study." Center for Environmentally Sustainable Transportation in Cold Climates, University of Alaska Fairbanks, August 2019. http://hdl.handle.net/11122/10673

Laboratory Performance of Wicking Fabric H2Ri in Silty Gravel, Sand and Organic Silt (2016)

Planning: Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: The moisture-wicking geotextile fabric, H2Ri, has been used to remove moisture from roadway embankment. This study tested soil types in which H2Ri is effective. H2Ri was tested using a highly permeable sand and an impermeable organic silt soil. The study also tested if H2Ri will work when length requirements exceed the width of the wicking fabric. A 73-foot flume was used to measure the distance that the H2Ri can move water. Results indicated that the fabric is effective at moving water through a sand soil but ineffective for organic silt; and, in a crushed surface course with 14 percent fines, the H2Ri fabric could move water 73 feet.

Relevance to Current Effort: This study specifically tested the applicability of H2Ri at airports. Airports are wider than roads; the study reasoned that for H2Ri to be effective, it must transport water at least 75 feet for a 150-foot embankment. Using a material that is likely to be encountered at airports (a well-graded material was used with 14 percent fines), this study demonstrated that H2Ri does have the potential to effectively remove water from airport runways.

Connor, B. and X. Zhang. "Laboratory Performance of Wicking Fabric H2Ri in Silty Gravel, Sand and Organic Silt." Alaska Department of Transportation Research, Development, and Technology and Alaska University Transportation Center, May 2016. http://hdl.handle.net/11122/10383

A Bio-Wicking System to Mitigate Capillary Water in Base Course (2016)

Planning: Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: H2Ri geotextile is used to wick moisture from pavement, which is important to mitigate frost heaving and pavement distress. However, long-term issues are associated with using H2Ri and include degradation from sunlight exposure, mechanical damage from grass mowing, loss of function under high suction conditions, and clogging and salt concentration that influence drainage efficiency. This research paper assesses an alternative application of H2Ri geotextile. The previous use of H2Ri involved exposing the fabric along the roadway. In this new approach, the geotextile is buried several inches below the soil surface in the road shoulder and covered with hydroseed. Evaporation then occurs at the leaves of the vegetation instead of directly from the wicking fabric. The article demonstrates that this method improves effectiveness and longevity compared to the traditional H2Ri application method.

Relevance to Current Effort: Application of H2Ri geotextile fabric also has the potential to remove water from airport runways and improve pavement performance. This research article provides insights into a method for applying H2Ri that can improve its effectiveness, which can be considered during runway design to improve the resiliency of paved runways.

Lin, C. and X. Zhang. "A Bio-Wicking System to Mitigate Capillary Water in Base Course." Center for Environmentally Sustainable Transportation in Cold Climates, University of Alaska Fairbanks, November 2016. http://hdl.handle.net/11122/9577

Sustainable Construction in Remote Cold Regions (2015)

Planning: Relevant *D&C: Very Relevant* *M&O: Relevant*

Synopsis: This article identifies sustainable (green) construction techniques appropriate for remote and cold regions, some of which also apply to operations and maintenance. Information is gathered from a review of existing research and guidance about green construction methods and interviews with experts in remote Alaskan construction. The article also evaluates how methods applied to vertical construction projects can also be applied to horizontal construction. It provides a set of 160 guidelines related to construction and a construction management training module.

Construction techniques discussed in the guidelines address environmental issues and cover topics such as energy use, ground clearing, working in permafrost, stormwater management, wildlife protection, and hazardous and solid waste management.

Relevance to Current Effort: Some of the guidelines are directly related to airport construction and maintenance. Consulting and implementing these guidelines, as applicable, during the planning and construction phases of airport projects can reduce negative environmental consequences related to construction and reduce the life cycle cost.

Perkins, R. "Sustainable Construction in Remote Cold Regions." Center for Environmentally Sustainable Transportation in Cold Climates, University of Alaska Fairbanks, December 31, 2015. http://hdl.handle.net/11122/9586

Long-term Stabilization of Disturbed Slopes Resulting from Construction Operations (2018)

Planning: Relevant *D&C: Very Relevant* *M&O: Relevant*

Synopsis: Stabilizing disturbed slopes at construction sites is mandated by law, regulations, and a permitting system. However, establishing vegetation in northern Alaska is challenging and often ineffective because of the arid and cold climate.

Extending the establishment periods may improve success, but it also presents challenges. This study reviewed practices from other states and found that extending the establishment period has not been consistently successful. Nevertheless, the article recommends that ADOT&PF consider experimenting with an additive bid item to assess the cost of extending the establishment period.

This study also provided evidence that, in northern Alaska, there is minimal erosion on embankment slopes where vegetation has failed, which suggests that vegetation may have a limited impact on particulate pollution in nearby waters and wetlands. The article recommends gathering additional data and observations regarding the role of grass establishment in preventing pollution from construction projects in northern Alaska. It also suggests modifying the Construction General Permit to allow for the closure of the Alaska Pollutant Discharge Elimination System (APDES) Stormwater Pollution Prevention Plan (SWPPP) without the requirement of revegetation in regions where sustainable revegetation with grasses is not practical and the erosion potential is low.

Relevance to Current Effort: These recommendations apply to airport construction projects in northern Alaska that must undergo permitting and meet federal Clean Water Act requirements. The article provides recommendations for modifying the stormwater management permitting system to address unique climate challenges related to vegetation establishment, which can improve long-term erosion control.

Perkins, R. A., F. L. Benett, and E. C. Packee Jr. "Long-term Stabilization of Disturbed Slopes Resulting from Construction Operations." Center for Environmentally Sustainable Transportation in Cold Climates, University of Alaska Fairbanks, March 20, 2018. http://hdl.handle.net/11122/9592

Geosynthetics Used to Support Embankments Over Voids: A Thesis (1991)

Planning: Somewhat relevant *D&C: Very Relevant* *M&O: Somewhat relevant*

Synopsis: Geosynthetics can be used to reinforce road embankments and bridge voids in embankment material. The proper geosynthetic material must be selected and multiple layers of material may be required.

Relevance to Current Efforts: Geosynthetics, or geotextiles, can be used to bridge voids in runway embankments caused by excavation or organics or ice lenses.

Neogi, D. "Geosynthetics Use to Support Embankments Over Voids: A Thesis." University of Alaska Fairbanks, February 1991. https://dot.alaska.gov/stwddes/research/assets/pdf/19910203.pdf

Additional, Non-Climate-Related Resiliency Research

Washington State Airports Seismic Resilience Project (2021)

Planning: Relevant *D&C: Relevant* *M&O: Relevant*

Synopsis: Airports are crucial for post-earthquake disaster response. The Cybersecurity and Infrastructure Security Agency carried out an analysis of the ability of Washington State's aviation system to support post-disaster response, recovery, and mobility needs. The research team performed three analytical tasks to evaluate the airport system's capacity and reliance on external infrastructure in responding to earthquakes:

1. An analysis to determine the airport systems' vulnerability to potential impacts related to the Cascadia Subduction Zone (CSZ)
2. A screening analysis to assess the risk of runway pavements being disrupted by liquefaction
3. Discussions with airport personnel

The project revealed that Washington airports would play an important role as post-disaster logistic supply chain hubs to receive, organize, and distribute disaster relief supplies and equipment from around the country to local communities, but that the full resilience of their facilities is not well understood at a local level.

Relevance to Current Effort: The framework and methodology from this study can be applied to evaluate the resiliency of Alaskan airports to earthquakes and the ability of airports to function as critical hubs post-disaster. The study identified a need for better analyses of site-specific geotechnical vulnerabilities to seismic impacts at airports to characterize how ground failures may disrupt airport pavements and facilities. The study also found that airports consistently depend on electric power and external fuel supplies to support their operations; therefore, airports should increase the resilience of on-site fuel storage and fuel supply chains and develop more infrastructure for backup energy generation.

Cybersecurity & Infrastructure Security Agency, Washington State Department of Transportation, and Washington Emergency Management Division. "Washington State Airports Seismic Resilience Project," October 2021. https://mil.wa.gov/asset/634989baeb821.

Guidelines for the Use of Synthetic Fluid Dust Control Palliatives on Unpaved Roads (2017)

Planning: Relevant *D&C: Very Relevant* *M&O: Very Relevant*

Synopsis: This paper developed guidelines for the application and maintenance of synthetic fluid dust control palliatives on unpaved roads. A study was conducted using field and laboratory methods to test the effectiveness of dust palliatives and develop recommendations for effective use. These recommendations focus on guidance-related road design, including considerations for good drainage and material selection, application methodology, and maintenance practices.

Relevance to Current Effort: Although this study focused on roads, dust management is also an important issue for unpaved runways, making this technical guidance applicable to airports as well. The article presents background information about the use of dust control palliatives, including context about why they are needed and in which situations they are necessary. Some of the guidelines provided for road synthetic fluid dust control are also relevant for runways, such as the importance of good drainage design and application methods.

Barns, D. and B. Connor. “Guidelines for the Use of Synthetic Fluid Dust Control Palliatives on Unpaved Roads.” Center for Environmentally Sustainable Transportation in Cold Climates, University of Alaska Fairbanks, July 6, 2017. http://hdl.handle.net/11122/8812

Alaska Aviation System Plan

Appendix 3

Western Alaska Airport Resiliency Study: SWOT and PESTLE Analyses

A Component of the Alaska Aviation System Plan

May 29, 2024 - FINAL DRAFT

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Table of Contents

Appendices

Abbreviations

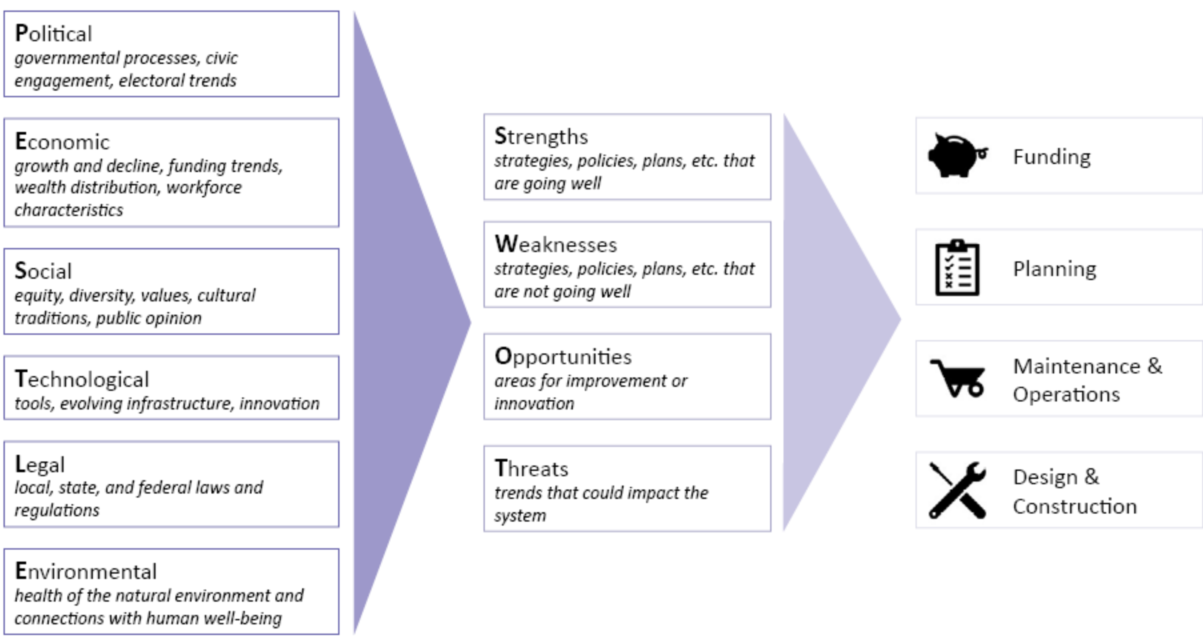
ACE	Air Convection Embankment
ADO	Regional Airports Division and District Office
AIP	Airport Improvement Program
ANC	Anchorage International Airport
APEB	Aviation Project Evaluation Board
ARFF	Aircraft Rescue and Fire Fighting
AWOS	Automated Weather Observing System
D&C	Design and Construction
DMVA	Department of Military and Veterans Affairs
DOT&PF	Alaska Department of Transportation & Public Facilities
EAS	Essential Air Service
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
HMP	Hazard Mitigation Plan
IIJA	Infrastructure Investment and Jobs Act
M&O	Maintenance and Operations
NEPA	National Environmental Policy Act
PESTLE	Political, Economic, Social, Technological, Legal, Environmental
PFAS	Per- and Polyfluorinated Substances
SMART	Strengthening Mobility and Revolutionizing Transportation
SNAP	Scenarios Network for Alaska + Arctic Planning
SWOT	Strengths, Weaknesses, Opportunities, Threats
UAS	Unmanned Aerial System

Introduction

PESTLE and SWOT are two types of analyses that are used to assess the current state of a system or organization and guide decision-making. PESTLE analyses evaluate Political, Economic, Social, Technical, Legal and Environmental factors that impact a system, while SWOT analyses categorize factors as Strengths, Weaknesses, Opportunities, and Threats. By combining these two approaches, an organization can readily identify where successes are occurring, and which domains need the most attention.

Factors included in the analysis were gathered through a desktop review of geotechnical reports, engineering documents and plans, funding data, and best practices literature, as well as meetings with Alaska DOT&PF staff. The combined SWOT/PESTLE matrix used to develop the analysis with DOT&PF planners is included as **Appendix A**. In the Analysis section, each factor is placed in one or more of the PESTLE categories and identified as a strength, weakness, opportunity, or threat. Where appropriate, factors are categorized into the focus areas of Planning, Funding, Design and Construction, or Maintenance and Operations.

Each factor identified as a weakness or a threat has been scored based on the likelihood of its occurrence and the severity of its impact to the system. The most likely and severe factors will be considered in the development recommendations and next steps in the broader Western Alaska Airport Resiliency Study.



Analysis

Political

Governmental processes, civic engagement, electoral trends

Alaska's strategic geopolitical location and increasingly polarized views on climate change in-state and nationally create numerous opportunities and challenges for resilient aviation in the state. Changes to state and federal policy and funding priorities adds an additional challenge to long-term planning and implementation of resiliency measures. For these reasons, bipartisan agreement is critical for funding and creating more sustainable airports.

Historically, legislators at both the state and federal levels have acknowledged the importance of aviation to the nation and in the state of Alaska. In recent years, there has been increased funding and growing bipartisan support for infrastructure resilience, for fiscal, social, and environmental reasons. For example, designing airports to be more resilience to flooding results in facilities staying operational during a flood event, and also saves costs in the long run by avoiding or minimizing costly damage.

Strengths

- Federal interest in resiliency
- Military investment and the National Strategy for the Arctic Region, coordination with military (and other agencies) on needs during airport master plan updates
- Strong support for aviation from the Alaska federal delegation
- DOT&PF leadership's commitment to taking action to improve resiliency

Weaknesses

- Frequent lack of understanding of Alaska's unique needs and realities by the federal government
- No statewide resiliency or climate action plan
- Lack of preventive or deferred maintenance program
- AIP entitlements have not increased to match inflation/rising costs
- Airport relocations and expansions may require land acquisition, which may be met with resistance from landowners

Opportunities

- Increase flexibility in the APEB process to quickly address arising needs
- Improve coordination with Alaska Emergency Management/Response, Department of Military and Veterans Affairs
- Strengthen coordination with tribal entities
- Geopolitical shifts and interest in the Arctic region

Threats

- Politicization of climate change
- FAA not being reauthorized/possible government shutdown
- Policy changes (Essential Air Service, Infrastructure Investment and Jobs Act, bypass mail changes, the next unknown…)
- Changing lease rate structure

Key Political Factors

Weaknesses	No statewide resiliency or climate action plan	!!!!
	Lack of preventative or deferred maintenance program	!!!
	AIP entitlements have not increased to match inflation/rising costs	!!!
	Frequent lack of understanding of Alaska's unique needs and realities by the federal government	!!!
	Airport relocations and expansions may require land acquisition, which may be met with resistance from landowners	!!!
Threats	FAA not being reauthorized/possible government shutdown	!!!!
	Politicization of climate change	!!!
	Policy changes (EAS, IIJA, bypass mail changes, the next unknown…)	!!!
	Changing lease rate structure	!

Likelihood

Very likely *Unlikely*

Severity

!!!!! → !

Most severe *Least severe*

Economic

Growth and decline, funding trends, wealth distribution, workforce characteristics

Aviation is critical to Alaska's economy, especially in rural and remote communities. With 82% of Alaska communities located off the road system, disruptions to airports and the aviation system can be catastrophic. The aviation industry is also impacted by the broader economy, particularly in relation to workforce characteristics. For example, the ongoing national pilot and aviation maintenance staff shortage is having a significant impact on the aviation industry in the state.

Strengths

- Current and planned resource development projects in Alaska require reliable transportation systems, including aviation
- Military presence and the National Strategy for the Arctic Region support long-term investments in Alaska's transportation systems
- Local matching grants
- More resiliency-focused federal funding is now available through the IIJA

Weaknesses

- Limitations on which airports are eligible to receive federal funding and how those funds can be used
  - Projects may not be eligible for funding if they are not deemed justifiable and reasonable; for example, large projects at airports serving fewer than 20 people may not be eligible
- Costs are higher in Alaska than in most areas of the Lower 48
- Master planning at small, rural airports is generally not feasible
- Cost increases and inflation
- Land acquisition challenges may delay or stop a project entirely
  - DOT&PF can only offer fair market value for the land, which may be less than the property owner would like or could get from a different buyer
  - Native Allotment acquisition must go through the Bureau of Indian Affairs and requires consent from all heirs
- AIP entitlements have not increased to match inflation/rising costs
- Cost of oil impacts state finances
- Current lease rate structure limits potential revenue from airport tenant leases
- Not currently a self-sustaining system

Opportunities

- Leverage the need for alternative transportation options and medical and emergency access to obtain funding for airport improvements
- Conduct more relocation studies

- Develop partnerships with land managers for better material site access
- Bundle projects to reduce costs
- Explore innovative ways to be more financially resilient
- Explore new grant opportunities (broaden focus, find new eligibility for projects)
- Strengthen revenue generation at airports
    - Revamp leasing structure to better align with market rates
- Public private partnerships for parking

Threats

- Possibility of reduced federal funding in the future (FAA reauthorization, changing federal priorities with different administrations, etc.)
- Lack of negotiation options with local material source owners, cost of importing materials to construction sites
- Supply chain challenges for equipment
- Cost increases and inflation
- Cost of oil impacts on state finances
- Greater needs than available funding can address
- Federal funding eligibility for communities may be impacted by relocation plans

Key Economic Factors

Weaknesses

Costs are higher in Alaska than in most areas of the Lower 48	!!!
Cost increases and inflation	!!!
Cost of oil impacts state finances	!!!
Not currently a self-sustaining system	!!!
AIP entitlements have not increased to match inflation/rising costs	!!!
Limitations on which airports are eligible to receive federal funding and how those funds can be used	!!!
Master planning at small, rural airports is generally not feasible	!!
Land acquisition challenges	!!!
Current lease rate structure limits potential revenue from airport tenant leases	!!

Threats

Cost of importing materials to construction sites, supply chain challenges for equipment	!!!!
Cost increases and inflation	!!!!
Greater needs than available funding can address	!!!!
Cost of oil impacts state finances	!!!
Possibility of reduced federal funding in the future (FAA reauthorization, changing federal priorities with different administrations, etc.)	!!!!
If a community plans to relocate within the next 50 years, infrastructure projects may not be eligible for federal funding	!!!

Likelihood

Very likely → *Unlikely*

Severity

!!!!! → !

Most severe → *Least severe*

Social

Equity, diversity, values, cultural traditions, public opinion

Aviation plays a significant role in all Alaskans' lives, as a lifeline for rural and remote communities and a key transportation mode for residents and visitors across the state. Additionally, Indigenous communities continue to play a significant role in the environmental stewardship, culture, and values of Alaska. Resilient airport planning should respect this role and draw on traditional knowledge as much as possible. DOT&PF also has its own organizational culture that successfully develops dedicated, knowledgeable, and motivated staff to operate and maintain the aviation system.

Strengths

- Alaska DOT&PF staff are very skilled and knowledgeable of the aviation system and airport needs
- Alaska DOT&PF geotechnical engineers are willing and capable of researching innovative designs and strategies to promote resiliency
- National public interest in a resilient Alaska to support tourism, wildlife and environmental conservation, and resource extraction
- Strong historical and current support for the aviation system in Alaska from the public and elected officials
- Ongoing, open communication with communities
- Partnerships with local communities for UAS training/implementation
- Strong community support for connectivity and air service (jets/access to hub, ANC)

Weaknesses

- Alaska's isolation from the rest of the country can be an obstacle to obtaining broad public support for federal investment in the state
- Hiring, retaining, and training staff; industry-wide staff shortage for pilots/aviation/M&O staff
- The intensive process for cultural resources evaluations is necessary but challenging
- Current lack of shelters at rural airports for people, perishable freight, etc.

Opportunities

- Increasing interest in eco- and cultural tourism requires more frequent and reliable transportation to remote locations
- Integration of local traditional knowledge into airport and aviation system planning
  - Learn from rural and Indigenous communities about changing local conditions, strategies to avoid permafrost thaw, and local recovery efforts after disruptive events
- Future relocations of communities should allow for the design and construction of new, more resilient airports with careful planning

- Taking action as soon as possible will allow for investment in more resilient airports, rather than funding repairs and reconstruction after location and/or climate change-related damage occurs (e.g., coastal and/or wind erosion, snow drifting, flooding, permafrost thaw)
- Strong community support for increased connectivity and more frequent air service
- Continue to support trade schools and trades education
- Support food security through the aviation system
- Alaska DOT&PF divisions reorganization could support resiliency goals

Threats

- Politicization of climate change influences public opinion and increases the potential for public pushback on resiliency investments
- Security of airport facilities and damage caused by unauthorized use, trespass, and wildlife
- Shifting demographics and populations – harder to justify local projects if populations decline and harder to find a local workforce

Key Social Factors

Weaknesses	Hiring, retaining, and training staff; industry-wide staff shortage for pilots/aviation/M&O staff	!!!!
Weaknesses	Current lack of shelters at rural airports for people, perishable freight, etc.	!!!
Weaknesses	Alaska's isolation from the rest of the country can be an obstacle to obtaining broad public support for federal investment in the state	!!!
Weaknesses	The intensive process for cultural resources evaluations is necessary but challenging	!!
Threats	Politicization of climate change influences public opinion and increases the potential for public pushback on resiliency investments	!!!
Threats	Shifting demographics and populations – harder to justify local projects if populations decline and harder to find a local workforce	!!!
Threats	Security of airport facilities and damage caused by unauthorized use, trespass, and wildlife	!!

Likelihood

Very likely … *Unlikely*

Severity

!!!!! → !

Most severe … *Least severe*

Funding Planning Design and Construction Maintenance and Operations

Technological

Tools, evolving infrastructure, innovation

Research and innovation continue to result in new technologies and techniques that can support airport resiliency. Partnerships with research institutions present opportunities for testing new technology, policies, and construction practices in Western Alaska's unique climate.

Strengths

- Other cold regions have identified best practices for airport resiliency
- Some Alaska airports are already using permafrost-protection technologies and strategies to defend against environmental changes, such as thermosiphons, air convection embankment, snow removal, erosion protection, and leaving organics mats in place
- Recent advancements in use of moisture wicking geotextiles
- Expanding use of UAS (e.g., for data gathering) and partnerships with local communities for UAS training/implementation
- SMART grants related to technology are available

Weaknesses

- Gaps in historical data (e.g., temperature, precipitation, as-built documents) and ongoing data collection capacity—difficult to study and address risk from environmental factors without complete data
    - Need weather observation systems, updated flood categories
- Equipment
    - Old equipment with no replacement parts
    - Inadequate or incorrect equipment
    - FAA limits on equipment purchase options
- Lack of facilities, such as passenger shelters, at remote airports
- Outdated engineering and design standards that do not account for climate change and location-specific environmental challenges in Alaska (e.g., coastal erosion, weather pattern changes, freeze-thaw cycles, permafrost thaw)
- Limited and substandard local material sources; high cost of importing better quality materials
- Lack of internet connectivity via broadband, fiberoptic, Star link, etc. (e.g., for communications, weather reporting, drone data collection and monitoring)
- Changes in aircraft fleet mix (airports are currently reacting to these changes)
- Even when Public-Private Partnerships are established for use of material sites, DOT&PF is still liable for the airport and following AIP requirements

Opportunities

- Explore innovation in sustainable design and construction methods to develop and establish new standards
- Cold climate research with University of Alaska or other cold climate regions/countries
- Changes in aircraft fleet mix (developing proactive strategies to adapt)
- Create a process/standard for climate data collection (temperature, precipitation, snow accumulation, visibility, etc.)
- Begin long-term monitoring of infrastructure performance in light of climate change and location-specific environmental challenges
- More widespread use of available technology (e.g., thermosiphons, air convection embankment [ACE], wicking fabric, elevated buildings) and monitoring emerging technologies
- Implement design and construction innovations that have already been approved by the FAA such as cement-stabilized soil and importing cement instead of rock to increase cost savings and performance. Track implementation of these techniques to evaluate whether they should become long-term resiliency solutions.
- Set new engineering standards and tests for resiliency of materials and infrastructure
- Create a decision tree to guide material source selection, with engineering justification, for planners, designers, and contractors
- Collaborate with local landowners/managers (including Native corporations) to establish mutually beneficial partnerships on material sites
- Use of UAS (data collection, delivery of essential goods, emergency response)
- Determine how technology fits into innovative strategies for financial resiliency
- Emerging robot technology
- Seek funding for broadband, fiberoptic, and/or Star link internet connectivity at remote airport locations to support communications, drone data collection, and monitoring
- Use existing regional-level permafrost data as a starting point for geotechnical investigations and to inform planning-level decision-making (Caveat: not yet granular enough for engineering design-level decisions)

Threats

- Outdated assumptions built into current standards (e.g., 100-year floods are happening more frequently)
- Impact of UAS on the airport/aviation landscape
- Change in fleet mix (currently reacting)
    - Expensive technology failures

Key Technological Factors

	Factor	Severity
Weaknesses	Outdated engineering and design standards that do not account for climate change and location-specific environmental challenges in Alaska	!!!!
	Substandard local material sources; high cost of importing better quality materials	!!!!
	Limited good material sources	!!!!
	Gaps in historical data (e.g., temperature, precipitation, as-built documents) and ongoing data collection capacity—difficult to study and address risk from environmental factors without complete data	!!!
	Equipment (old equipment w/o replacement parts, inadequate/incorrect equipment, FAA limits on purchase options)	!!!
	Lack of facilities, such as shelters, at remote airports	!!!
	Poor or no internet connectivity (for communications, AWOS)	!!
	Changes in aircraft fleet mix (airports are currently reacting to these changes)	!!
Threats	Outdated assumptions built into current standards (e.g., 100-year floods are happening more frequently)	!!!
	Impact of UAS on the airport/aviation landscape	!!!
	Expensive technology failures	!!
	Change in fleet mix (currently reacting)	!!

Likelihood

Very likely — *Unlikely*

Severity

!!!!! → !

Most severe — *Least severe*

Legal

Local, state, and federal laws and regulations

Every airport is subject to multiple levels of regulation that are intended to keep passengers and operators safe. Due to the broad nature of federal legislation, Alaska airports often experience unique compliance challenges.

Strengths

- Strong support from Alaska federal delegation for aviation in the state could positively influence FAA requirements in the long term
- There is strong advocacy within the state to find funding and legal solutions that work specifically for Alaska
- Stronger relationship with ADO (local FAA) than in the past

Weaknesses

- Limitations on how federal funding can be used
  - Federal and state procurement laws regulate the types of equipment DOT&PF can purchase
  - DOT&PF is required to pay fair market value during land acquisitions, which may be less than what the property owner could receive from a different buyer
- Need to prove necessity of exceptions to standards to FAA before they will approve, e.g.:
  - Phased funding or construction processes
  - Widening a runway for additional coverage when a crosswind runway is cost prohibitive
  - Only able to justify erosion control/armoring after a bad event or flood has already occurred (reactive)
- Limitations on DOT&PF's authority
- Intense regulatory process for airport construction
- Land acquisition can be a lengthy process. If land cannot be acquired amicably, DOT&PF may need to pursue acquisition through legal action, which may take years or result in the cancellation of the project

Opportunities

- Public-private partnerships
- Work more closely with FAA to conduct studies to identify/justify where alternative design standards and strategies are needed
- This study can help identify Alaska-specific needs and challenges that should be addressed and justify action to FAA *before* damaging events occur
- Combine airport emergency preparedness with broader community-level emergency preparedness frameworks

- Potential updates to the AIP Handbook
- Strong advocacy for Alaska aviation by federal delegation
- Connect aviation system resiliency to FEMA hazard mitigation planning

Threats

- Liability from breaking standards/federal regulations due to Alaska environmental characteristics (e.g., ARFF)
- State-level support for climate action varies with political administrations
- Federal (FAA/AIP) funds have restrictions/limited use
- AIP Handbook has not been updated recently, and does not fully address Alaska-specific conditions and needs
- Meeting all legal requirements is especially expensive in Alaska

Key Legal Factors

	Factor	Severity
Weaknesses	Limitations on how federal funding can be used	!!!!
	AIP entitlements have not increased to match inflation/rising costs	!!!!
	Need to prove necessity of exceptions to standards to FAA before they will approve	!!!
	Limitations on DOT&PF's authority	!!!
	Land acquisition can be a lengthy process. If land cannot be acquired amicably, DOT&PF may need to pursue acquisition legally, which may take years or result in the cancellation of the project	
	Intense regulatory process for airport construction	!!!

	Factor	Severity
Threats	Federal (FAA/AIP) funds have restrictions/limited use	!!!!
	AIP handbook has not been updated recently, and does not fully address Alaska-specific conditions and needs	!!!
	Meeting all legal requirements is especially expensive in Alaska	!!!
	Liability from breaking standards/federal regulations due to Alaska environmental characteristics (e.g., ARFF)	!!!
	State-level support for climate action varies with political administrations	!!!

Likelihood

Very likely *Unlikely*

Severity

!!!!! → !

Most severe *Least severe*

Environmental

Health of the natural environment and connections with human well-being

Though many urban airports may feel removed from the natural environment, airports in Western Alaska are intimately connected to their natural surroundings. Construction and maintenance of facilities is impacted by precipitation, permafrost, erosion, and wildlife and ecosystems are impacted in return. The people in Western Alaska rely on both the airports and the environment for survival, so neither can be considered without the other.

Strengths

- There are some high-quality material sources in the state
- Aviation covers a very wide geographic area; Alaska already has an expansive system that supports access all over the state
- Maintaining a healthy environment supports a strong Alaska tourism industry long-term

Weaknesses

- It is expensive to move high-quality materials if the source is not near the construction site
- Aviation system covers a very wide geographic area; maintaining such an expansive system requires significant long-term investment
- The Alaska aviation system is geographically isolated from the rest of the U.S. and is not fully self-sustaining
- Many airports are rural and disconnected from the road system
  - Logistical challenges/additional expenses when shipping materials, transporting construction and maintenance crews and equipment
  - Residents may rely on ATVs and snow machines for transportation, including getting to the airport
- Cold climate-specific challenges
  - Freeze-thaw damage to pavement, gravel embankments, and/or structural section
  - Snow removal and changing maintenance and operational needs due to climate change
  - Short construction season
  - Increased vegetative growth due to warming climate (vegetative control)
  - Spring break-up and ice jam-related flooding
  - Permafrost thaw and other causes of ground instability make construction challenging and requires extensive maintenance
- Stable land within a reasonable distance from a community's center may not be available for DOT&PF to acquire for airport expansion or relocation
- Wetlands make resilient development challenging (environmental review process)
- PFAS contamination cleanup is onerous and costly

Funding Planning Design and Construction Maintenance and Operations

Opportunities

- Some regions may stop having freeze-thaw cycles
- Increased need for firefighting operations may result in additional funding for resilient airports
- The sooner action is taken, the more can be done to mitigate and adapt to climate change and address Alaska's unique environmental challenges
- Many funding opportunities for "going green" and resiliency
- Explore innovative ways to treat contaminated soils on site and/or reuse existing remediated materials. Avoid costly options for sending contaminated materials out of state for treatment.
- Explore use of landscape fabrics to help slow or prevent unwanted vegetation growth
- Build above the 100-year flood plain as a standard
- Increased coordination with agencies (e.g., streamline NEPA process/wetlands primacy, FEMA HMP coordination)

Threats

- Alaska is warming at least twice as fast as the Lower 48 and is already feeling the effects
- Wildfire activity will continue to increase as temperatures rise
- Permafrost, erosion, challenges with vegetation, more intense storms, increased precipitation and flood risk
    - Positive feedback loops and compounding threats from flooding, erosion, and permafrost thaw (usteq) cause uncertainty and could result in even greater damage
        - Example: loss of sea ice → larger storm surges → storm surges batter and thaw ice-rich permafrost along banks → fragile silt is exposed → erosion occurs more rapidly
- Earthquakes and volcanoes are threats to infrastructure resiliency
- Impacts of inclement weather on technology and navigation
- Wildlife behavior and vegetative growth are changing due to climate change
- Several communities may relocate within the next 20 years
- Coastal airports will experience more frequent and more intense storm surges
- Volatility of spring break-up may be becoming more variable with climate change (unconfirmed)
- High-quality local material sources are scarce and dwindling

Key Environmental Factors

Weaknesses	It is expensive to move high-quality materials if the source is not near the construction site	!!!!
Weaknesses	Aviation system covers a very wide geographic area; maintaining such an expansive system requires significant long-term investment	!!!!
Weaknesses	The Alaska aviation system is geographically isolated from the rest of the U.S. and system is not fully self-sustaining	!!!
Weaknesses	Many airports are rural and disconnected from the road system	!!!
Weaknesses	Cold climate-specific challenges	!!!!
Weaknesses	Stable land within a reasonable distance from a community's center may not be available for DOT&PF to acquire for airport expansion or relocation	!!!
Weaknesses	Wetlands make resilient development challenging (environmental review process)	!!!
Weaknesses	PFAS contamination cleanup is onerous and costly	!!!
Threats	Alaska is warming at least twice as fast as the Lower 48 and is already feeling the effects	!!!!
Threats	Permafrost, erosion, challenges with vegetation, more intense storms, increased precipitation and flood risk	!!!!
Threats	High-quality local material sources are scarce and dwindling	!!!!
Threats	Wildfire activity will continue to increase as temperatures rise	!!!
Threats	Impacts of inclement weather on technology and navigation	!!!
Threats	Several communities may relocate within the next 20 years	!!!
Threats	Coastal airports will experience more frequent and more intense storm surges	!!!
Threats	Volatility of spring break-up may be becoming more variable with climate change (unconfirmed)	!!!

Wildlife behavior and vegetative growth are changing due to climate change	!!
Earthquakes and volcanoes are threats to resiliency	!!

Likelihood		Severity	
Very likely	*Unlikely*	!!!!! *Most severe*	! *Least severe*

Focus Area Evaluation

Below is a summary of policies, programs, and funding based on the SWOT/PESTLE analysis presented above. Detailed analyses of engineering design, construction, and maintenance are included in a separate document.

Funding

Many of the challenges facing DOT&PF's efforts to maintain a resilient aviation system are rooted in funding. Whether it's insufficient funds or restricted funds, the money often does not match the need. This mismatch of funding and needs is driven by federal policies, funding formulas, inflationary pressure, variable state resources, and projects not lasting the 20-year design life as intended. The consequences of inadequate or unavailable funding are felt in airport staffing, design choices, project sequencing, and routine maintenance activities.

State Funding Limitations

The state of Alaska has limited funds for airport improvements and maintenance. All major capital projects are funded by the FAA through the Airport Improvement Program, which does not support routine infrastructure maintenance. The state does not have a preventative maintenance program for airports as it does for highways. As state administrations, priorities, and budgets change, the absence of a dedicated funding program for airport maintenance results in deferred maintenance of airport infrastructure. Once maintenance is deferred, it may be until the next FAA-funded capital project until issues are addressed. DOT&PF's preventative maintenance program for highways could be adapted and implemented for airports as well to ensure that maintenance is funded and timely between capital projects.

Federal Funding Limitations

A recurring concern among aviation stakeholders is that federal funding limitations dictated by the AIP Handbook don't accommodate Alaska-specific conditions and needs. Examples include the inability to stockpile gravel during a capital project for future maintenance; limitations on types of equipment that can be purchased for airport snow removal; and unrealistic life expectancies for major and minor airport elements such as lighting systems, buildings, surfacing, crack sealing and dust palliative reapplications in Alaska's unique environment.

An example of this limitation is the life expectancy for the surface course on rural gravel airstrips. Gravel airstrips across the state are plagued with surface course being degraded or eroded much sooner than the life expectancy outlined in the AIP Guidebook due to both natural (i.e., wind or coastal erosion) and human (snow plowing and grading) processes. Because of this, the FAA is often reluctant to fund another resurfacing project when it is needed within five or ten years, sooner than the life expectancy for these types of projects. DOT&PF has developed some innovative strategies for extending the life of gravel runway surfaces, including applying a dust palliative with every resurfacing project to extend performance and safety on the runway. Applying a dust palliative in the following spring instead of just prior to winter has proven more effective for extending life expectancy of gravel surfaces. Other interventions to minimize the risk of human-caused damage to gravel runways could include additional maintenance and operations staff training to reduce damage from grading and snow plowing operations.

Resolving these limitations will require significant collaboration between DOT&PF and FAA to study Alaska-specific issues, develop pilot programs, and agree upon solutions that meet FAA standards for safety and efficiency while addressing Alaska's unique environmental context. Additionally, there is an opportunity to leverage new and changing federal funding programs to fill some of the existing funding gaps (e.g., resiliency-focused grant programs addressing areas where AIP funds cannot currently be used).

Inflation

Another significant challenge facing airport funding is that AIP entitlements aren't keeping pace with recent inflation. Construction costs increased 28% above engineer estimates in 2022 and are expected to show similar rises in 2023. Despite additional funding from the Infrastructure Investment and Jobs Act, inflation has essentially nullified any benefit from this additional money. The consequence is that AIP money can't be distributed to as many airports as needed.

Increases to entitlement funds would need to be enacted at the federal level.

Competitive Wages

A major threat to maintaining resilient airports in Alaska is that wages for rural airport operations staff are often not competitive with private wages offered by contractors. This makes it extremely hard to retain staff in these areas. State maintenance salaries are not federally funded, and the state's tight operations budget does not allow significant increases in those wages. This shortfall leads to higher staff turnover and significant lost investments in staff training. For example, operators starting out often work for DOT&PF initially to gain experience and receive training before leaving for a private contractor role that offers higher wages.

Increasing wages for state-employed operators would require changes to union contracts. For contractor-maintained airports, contractor employees are not subject to state union contracts, so it is more challenging to address their wages. The DOT&PF could potentially require operator's union certified staff, which would likely increase wages for contracted staff. However, this requirement could also drive-up overall maintenance costs as contractors will submit higher bids to cover higher employee wages. The DOT&PF should partner with the University of Alaska and industry unions to provide training programs in communities.

Policies

Design Standards

Climate change is causing weather patterns and storm frequencies to change. This means that engineering standards and assumptions that rely on historical data are outdated and don't reflect conditions. For example, 100-year floods are already occurring on a shorter recurrence interval. Due to their remoteness, many locations have always had limited weather data such as wind and precipitation, and projections of climate and weather changes were not readily available to designers. Because of these constraints, it was common practice to use data from the nearest site, which in some cases was substantially different than the airport being considered.

DOT&PF is currently updating the highway drainage manual, which integrates recent data on storm events and weather patterns. This research should be applied to airport design standards and decisions so that airport infrastructure is resilient.

Likewise, airport-specific design assumptions should be updated based on more recent historical climate trends and weather patterns. Institutions like the University of Alaska – Fairbanks Geophysical Institute are collecting climate data across much of Alaska and the data are available for more analysis, including climate projections.

As technological opportunities such as fiber optic, broadband, and Star Link internet connectivity become available at rural airports, DOT&PF will have additional opportunities for collecting weather and temperature data in person and remotely via drone technology to better inform future resilient designs.

Finally, DOT&PF should implement a policy that requires the design process to analyze climate change-related impacts such as more frequent storm events and increasing amounts of snowfall. Updating standards to require designing to a 50-year storm instead of a 20-year storm should be considered. Utilizing new data sources for projections such as the University of Alaska - Fairbanks SNAP rainfall values and other data sets can help inform more resilient designs.

Exemptions to Standards

Getting exemptions to FAA standards is challenging and requires significant effort to justify. This is primarily because the AIP Handbook does not provide sufficient flexibility to regional FAA offices.

The current FAA reauthorization bill includes language that allows more flexibility at the regional level. If passed as currently written, this will enable the ADO to work with DOT&PF and their engineers to make exemptions. The DOT&PF should also encourage greater collaboration with the local ADO and identify solutions that can be agreed upon by FAA without seeking exemptions each time the same solution is proposed.

Additionally, DOT&PF and other stakeholders (e.g., University of Alaska) should work with FAA through pilot projects and studies to identify design choices that can qualify for exemptions. By proactively testing and developing options that meet FAA's intent, DOT&PF can move through the exemption process more quickly.

Material Source Data

DOT&PF geotechnical engineers often investigate potential material sites for airport projects to determine if there is acceptable quality material available. However, DOT&PF can't mandate the use of a particular material site, nor do they conduct exhaustive material searches on private land. The consequence of not prescribing a specific material site is that contractors will use the lowest cost material to build the project. The lowest cost material may meet specifications (or require an exemption), but it is not the best material for the long-term performance of the airport.

A potential solution would be to publish all geotechnical information and provide a recommendation for the preferred material source so that contractors could provide bids with the appropriate material source in mind.

Land Acquisition

Airport expansions and relocations often require DOT&PF to acquire new, constructible land. Acquiring the land can be difficult, as DOT&PF is only allowed to pay fair market value. When land cannot be acquired, projects are either stopped entirely or scopes must be changed, which can delay construction; even when land can be acquired, the process may take years if it cannot be done amicably. The FAA does not support airport construction on leased land, so full ownership is required for expansion and relocation projects.

Programs

Maintenance

State funding is insufficient to provide the level of preventive maintenance that is needed to ensure the long-term performance of airports. Federal funding is not available for maintenance activities, yet federal grant assurances require that the airport sponsor maintain the airport. Likewise, regular, routine maintenance can extend the life of airport infrastructure as well as provide resiliency even as climate change-related impacts intensify.

Establishing an annual preventive maintenance program with adequate funding would allow DOT&PF maintenance to conduct work that is currently being deferred. The highway preventive maintenance program is a good model. Implementation would require legislative approval through the annual budget. DOT&PF aviation staff could coordinate with the DOT&PF Pavement Management and Preservation Office leads to learn more about how Alaska's highway preservation program was originally conceptualized, developed, and implemented and any lessons learned so far. Additional input could be gathered from other states or cold regions to develop a framework for a runway surface preservation program that accounts for Alaska's unique challenges and needs. The establishment of such a framework may help create funding opportunities and could highlight the need for additional funding from the FAA.

Pilot Programs

By partnering with FAA and other stakeholders, DOT&PF could implement pilot programs to test new resilient technologies, evaluate alternative design and construction techniques, and conduct long-term monitoring of airport performance. Pilot programs could be implemented in conjunction with an AIP capital improvement project, or separately with the approval of and close coordination with FAA. Resiliency-related pilot programs could provide data and insights on which designs or technologies have potential for enhancing an airport's long-term performance. Long-term monitoring would provide the data collection mechanism to evaluate new or innovative approaches, as well as help identify factors that lead to failures.

An example of a recently completed pilot program is the AWOS expansion project in which Alaska was the first state to design new modular AWOSs for several rural airports across the state, turning them over to the FAA for long-term management after completion. This pilot project was successful due to early planning and ongoing coordination between the DOT&PF, contracted designers, and the FAA before, during, and after the project.

Conclusion

The preceding SWOT/PESTLE analysis informs the final Resiliency Study Report by providing a foundation for recommendations related to funding, planning, design and construction, and maintenance and operations. These recommendations flow from the Opportunities identified in the SWOT/PESTLE and will be expanded upon in the final report. Takeaways from the review of cold climate region resilience strategies will also be integrated into the recommendations provided in the final report.

Appendix A:

Combined SWOT & PESTLE Matrix from DOT&PF Planners' Meeting

		P	E	S	T	L	E
		Political	*Economic*	*Social*	*Technological*	*Legal*	*Environmental*
S	*Strength*	AK representative from this region + familiar; Coordinating with other agencies (military) about needs in airport master plan updates;	Local match grants?; More funding out there with IIJA;	Ongoing, open communication with communities; Partnership with local communities for UAS training/implementation; Strong community support for connectivity and air service (jets/access to hub, ANC); GREAT DOT STAFF!	SMART grants related to technology; Expanding drone/UAS program; Partnership with local communities for UAS training/implementation;	Stronger relationship with ADO than in past (local FAA);	Good enviro = strong tourism industry;
W	*Weakness*	Lack of deferred maintenance program; AIP entitlements have not increased to match costs/inflation;	Cost increases and inflation; Land acquisition challenges: long BIA process; Federal (FAA/AIP) funds have restrictions/limited use; AIP entitlements have not increased to match costs/inflation; Cost of oil - impacts on state finances; Current lease rate structure; Not (yet) self-sustaining system;	Intensive process for cultural resources evaluation, necessary but challenging; Pilot + aviation (M&O) industry staff shortage; Food security; Lack of facilities - for people, perishable freight;	Limited good material sources in region; The need for more data (weather observation systems, updating flood categories); Change in fleet mix (currently reacting); Limited broadband connectivity (for communications, AWOS);	Intense regulatory process for airport construction; AIP entitlements have not increased to match costs/inflation;	Many wetlands in the region that are a challenge for resilient development, enviro review process; PFAS contamination - onerous + costly process/cleanup;
O	*Opportunity*	Hold APEBs 2x per year so can quickly respond to issues; More coordination with SoA Emergency Mgmt/Response (DMVA); More coordination with tribal entities; Geopolitical shifts + interest in the Arctic region;	Need for more funding for relocation studies; Partnerships for better material site access; Bundling projects to reduce costs; Innovative ways to be financially resilient; More eligible grants out there? - broaden the focus; Strengthening revenue generation at airports (add more categories to leasing	Strong community support for connectivity and air service (jets/access to hub, ANC); Push for trades/trades school education; Supporting food security through aviation system; DOTPF divisions reorganization(?);	Partner with local land owners/managers (Native corps) for partnerships on material sites; UAS use (incl. for data collection, delivery of essential goods); Innovative ways to be financially resilient - how tech fits in; Change in fleet mix; Robot technology?	Update to the AIP Handbook?; Strong advocacy for AK aviation by federal delegation;	Lots of funding opportunities for airports "going green"; Building above 100-yr flood plain; Increased coordination w/ agencies (streamlining processes - NEPA, wetlands primacy?);
T	*Threat*	FAA reauthorization/government shutdown; Changes in policy (ex: EAS, IIJA, what's next?); Changing lease rate structure; Bypass mail changes;	Cost increases and inflation; Cost of oil - impacts on state finances; More needs than there is funding to address; Supply chain issues for materials/equip;	Shifting demographics and populations - hard to get projects; Pilot + aviation industry (M&O) staff shortage;	UAS changing the airport/aviation landscape; Lack of data; Change in fleet mix; Technology failures (expensive);	Federal (FAA/AIP) funds have restrictions/limited use; AIP HANDBOOK!; Meeting legal reqs is expensive in AK context;	Erosion, more intense storms, increased precipitation and flooding risk; earthquakes/volcanoes; More inclement weather, impacts on tech + navigation;
		Naples, FL as example of recent flooding/resilience	*How can findings from the resilience study improve the APEB process?*				