ENTERPRISE-WIDE CLIMATE CHANGE ANALYSIS FOR INRMPs

CLIMATE CHANGE SUMMARIES FOR INCORPORATION INTO INSTALLATION INRMPS

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ACRONYMS

AFCEC	U.S. Air Force Civil Engineer Center
ATP	Army Techniques Publication
CCSM	Community Climate System Model
CIBW	Cook Inlet beluga whale
CONUS	Contiguous United States
CSU	Colorado State University
DoD	Department of Defense
GDD	Average annual accumulated growing degree days with a base temperature of 50 °F
INRMP	Integrated Natural Resources Management Plan
IPCC	Intergovernmental Panel on Climate Change
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
JBER	Joint Base Elmendorf Richardson
LOCA	Localized Constructed Analogs
MC2	Dynamic Global Vegetation Model
NCAR	National Center for Atmospheric Research
NLCD	National Land Cover Database
OCONUS	Outside the Contiguous United States
PRECIP	Average annual precipitation
RCP	Representative Concentration Pathway
SLR	Sea Level Rise
SS	Storm Surge
TAVE	Annual average temperature
TMAX	Annual average maximum temperature
TMIN	Annual average minimum temperature
USAF	U.S. Air Force

1 BACKGROUND

The Air Force Civil Engineer Center (AFCEC) engaged Colorado State University (CSU) to help U.S. Air Force (USAF) installations meet Department of Defense (DoD) requirements for inclusion of climate change in Integrated Natural Resource Management Plans (INRMPs). These requirements are formalized in the following documents.

- DoD Directive 4715.21, Climate Change Adaptation and Resilience states that DoD Component Heads shall: integrate climate considerations into DoD Component policy, guidance, plans, and operations; assess and manage risks to built and natural infrastructure, including changes to natural resource management; and leverage authoritative environmental prediction sources for appropriate data and analysis products to assess weather and climate impacts.
- DoDM 4715.03, Integrated Natural Resources Management Plan (INRMP) Implementation Manual, Enclosure 5 states that INRMP contents should contain an assessment of natural resource management that include effects of climate change. Enclosure 8, Planning for Climate Change Impacts to Natural Resources, provides data sources and processes for including climate considerations into INRMPs.
- AFI 32-7064, Integrated Natural Resources Management, Sections 3.8.2 states the effects of climate change should be included in plans to restore native ecosystems and Section 3.8.3. Climate Change, states:

  > *Changing climate conditions may significantly affect native ecosystems and require the Air Force to adjust natural resources management strategies to support military mission requirements and address the needs of sensitive species. INRMP goals and objectives for ecosystem management and biodiversity conservation must consider projected climate change impacts, and favor an adaptive ecosystem-based management approach that will enhance the resiliency of the ecosystem to adapt to changes in climate. The INRMP will assess climate change risks, vulnerabilities, and adaptation strategies using authoritative region-specific climate science, climate projections, and existing tools. The INRMP should list, or include by reference, installation-specific climate data and region-specific climate projections from the most current quadrennial National Climate Assessment Report, and include other pertinent Federal climate science documents as appropriate.*

This report is set up to serve two purposes:

1. provide text and appendices to be inserted into an installation INRMP and
2. provide information for installation stakeholder consideration as they evaluate management action options to address natural resource issues.

1.1 What did the CSU Team do?

A team comprising CSU climate scientists, ecologists, environmental planners, military land managers and engineers reviewed the INRMP for the installation, generated site-specific downscaled temperature and precipitation climate projections for two future emission scenarios, and used tools and models to assess impacts of future climate on the installation’s natural resources. The CSU assessment is based primarily on publicly available data and augmented with spatial data obtained through AFCEC with appropriate permissions. In addition, the CSU team compiled potential adaptation strategies for installation consideration during goal, objective, and work plan development.

1.2 How was the Climate Data Generated for this Report?

Climate data used in this report were generated originally for international climate assessment reports sanctioned and provided by the Intergovernmental Panel on Climate Change (IPCC-CMIP5) (Hibbard, Meehl, Cox, & Friedlingstein, 2007; Moss et al., 2008, 2010), and subsequently used by the US Fourth National Climate Assessment Report (USGCRP, 2017). Coordinating with AFCEC, a base historical time period was established and two future time horizons and two future emission scenarios were chosen. Emission scenarios are based on assumptions about future worldwide changes in demographic development, socio-economic development, and technological change that result in different greenhouse gas concentrations in the atmosphere. Site-specific temperature and precipitation climate projections were generated.

- Timeframes:
  - 30-year baseline (historical climate between 1980 to 2009 (inclusive) for the bases located in the contiguous United States (CONUS) and 1975 through 2004 (inclusive) outside the contiguous United States (OCONUS) bases
    - The historical climate data represent the 30-year historical reference point used by the IPCC to define climate change scenarios
  - 2030 (climate data from 2026 to 2035 to represent the decadal average for 2030)
  - 2050 (climate data from 2046 to 2055 for the decadal average for 2050)
- Future emission scenarios:
  - Representative Concentration Pathway (RCP) 4.5—moderate emission scenario
  - RCP 8.5—high emission scenario
- Historical climate data source:
  - CONUS: Historical daily climate data used is DAYMET (Thornton, Thornton, & Mayer, 2012) at approximately 1 km spatial resolution. These data were spatially averaged over the base to represent the base average climatology.

  - OCONUS: Historical daily data derived from the HadGEM2-ES dataset provided by the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) archived at the Max Planck Institute for Meteorology (Hempel, Frieler, Warszawski, Schewe, & Piontek, 2013) and are spatially represented at 50 km grid resolution.
- Climate projections:
  - Climate projections do not predict extreme weather events, which are short-term events that are significantly different from the usual weather pattern (hurricanes, flash floods, heat waves). Climate describes trends in temperature and precipitation over a long period of time (usually thirty years) for a given location.
  - Climate projections are based on model runs generated by the U.S. National Center for Atmospheric Research (NCAR) Community Climate Model (CCSM4) simulations prepared for the IPCC-AR5 (Gent & Danabasoglu, 2011; Hurrell et al., 2013; Moss et al., 2008, 2010).
  - Scenario generation: daily climate data are derived from the CCSM4 model projections for a 10-year time period covering 2026 to 2035 and 2046 to 2055. Daily differences for each year compared to the historical 30-year average daily climates were computed. Additionally, a daily anomaly for the selected model scenario (projected year – 30-year average daily base year for each variable of interest) over the 10-year period, 2026-2035 for 2030 and 2046-2055 for 2050 was computed to provide daily climate anomaly records representing the decades centered at 2030 and 2050.
  - CONUS projections: The daily data from the CCSM4 projections have been downscaled to approximately 6 km grid resolution over the U.S. and provide daily climate information from 1900 to 2100. The data source for projections is derived from the Localized Constructed Analogs (LOCA) CCSM4 data at approximately 6 km spatial resolution over the US (Pierce, Cayan, & Thrasher, 2014) and used in the US Fourth Climate Assessment Special Report (USGCRP, 2017).
  - OCONUS projections: CCSM4 projections are derived from the ISI-MIP and are spatially represented at 50 km grid resolution. These data are spatially averaged for each installation.

In summary, data and analyses were generated for four climate change scenarios representing two global carbon emissions levels for two different target years. The **emissions scenarios** are medium emissions (RCP 4.5) and high emissions (RCP 8.5). The two **timeframes** are decades around 2030 (2026-2035) and 2050 (2046-2055). Therefore, the climate change scenarios are:

1. RCP 4.5 2030
2. RCP 8.5 2030
3. RCP 4.5 2050
4. RCP 8.5 2050

Climate simulations were conducted to develop site-specific projections for the two potential emission scenarios over each timeframe. Projected climate data were then used to assess potential impacts to the installation's mission and natural resources.

1.3 Report Contents

1. Summaries for Incorporation into Installation INRMP with text and appendices that can be directly incorporated into the USAF standardized INRMP template. The corresponding INRMP section is shown in each section heading.
2. Appendices containing:
    A. Methodology (Appendix A). The methodology appendices will need to be numbered and incorporated with other installation-specific appendices.
    B. Detailed information on climate projections (Appendix B).
    C. Results of hydrological assessment and adaptation strategies (Appendix C).
    D. Details of ecosystem classification and habitat vulnerability (Appendix D).

Adaptation strategies for projected climate scenarios are also included on the provided DVD for consideration by installations during future planning.

2 SUMMARIES FOR INCORPORATION INTO INRMP TEMPLATE

This document provides an analysis of potential climate impacts derived from downscaled global climate data. It provides summaries of analyses that are intended to be inserted into the U.S. Air Force's (USAF) standardized Integrated Natural Resources Management Plan (INRMP) template. Additional materials, including methodologies and more in-depth analyses, are provided as appendices to this document.

This document focuses on direct and indirect impacts of precipitation and temperature changes associated with climate change. General summaries of climate change and its impacts on the installation's priority resources are provided for inclusion to sections 2.2, 2.3, and 2.4 in the standardized INRMP template; followed by management considerations and adaptation strategies for inclusion in section 7 in the USAF standardized INRMP template.

In contrast to familiar, more linear physical processes, climate models can produce diverse and often counterintuitive projections. The climate system is complex and driven by competing feedbacks and interactions among systems. For example, at a single location, increasing precipitation may be followed by drought and then increasing precipitation over time. Or, a location may experience greater warming in some months than in others. The best-available science is used to develop global climate models from which these downscaled projections are derived. However, there are gaps in data about the influence of phenomena such as changes in globally-significant ice sheets, which add to uncertainty in climate projections (IPCC, 2014). The projections provided here are intended to demonstrate the range of conditions to which a manager may have to adapt.

2.1 Physical Environment (INRMP 2.2)

2.1.1 Climate (INRMP 2.2.1)

Climate projections for Joint Base Elmendorf-Richardson (JBER) (Table 1) suggest minimum and maximum temperatures will increase over time under two emission scenarios – a moderate carbon emission scenario (Representative Concentration Pathway [RCP] 4.5) and a high emission scenario (RCP 8.5). The potential impact of these two climate change scenarios on the site's natural resources was analyzed using extracted climate data from 2026 to 2035 to represent the decadal average for 2030, and extracted data from 2046 to 2055 for the decadal average for 2050.

For the decade centered around 2030, both scenarios project an increase in average annual temperature (TAVE) of between 2.9 °F (1.6 °C) and 3.6 °F (2.0 °C) over the historic average. The two emission scenario projections show higher warming by 2050, with RCP 4.5 expressing a warming of 5.4 °F (3.0 °C). RCP 8.5 expresses a slightly greater warming of 7.3 °F (4.1 °C) for this period.

Average annual precipitation (PRECIP) varies between emission scenarios and over time due to larger interconnected ocean-atmosphere dynamics associated with the NCAR CCSM model. For 2030, the RCP 4.5 scenario projects an increase in PRECIP of 10% while RCP 8.5 shows an increase of 3%. For 2050, RCP 4.5 projects a moderate increase in PRECIP of 15% over historic average while RCP 8.5 shows a larger increase of 24% over the historic average.

Table 1. Summary climate data.

Variable	Historical	RCP 4.5		RCP 8.5	
		2030	2050	2030	2050
PRECIP (inches)	24.8	27.4	28.6	25.6	30.7
TMIN (°F)	29.0	32.9	34.6	32.1	37.0
TMAX (°F)	43.2	46.5	48.4	46.0	49.9
TAVE (°F)	36.1	39.7	41.5	39.0	43.4
GDD (°F)	924	1347	1566	1286	1690
HOTDAYS	0.0	0.0	0.0	0.0	1.1
WETDAYS	0.0	0.0	0.0	0.0	0.0
Notes: TAVE ºF = annual average temperature; TMAX ºF = annual average maximum temperature; TMIN °F = annual average minimum temperatures; PRECIP (inches) = average annual precipitation; GDD ºF = Average annual accumulated growing degree days with a base temperature of 50 ºF; HOTDAYS (average # of days per year) = average number of hot days exceeding 90 °F; WETDAYS (average # of days per year) = annual number of days with precipitation exceeding 2 inches in a day.					

Understanding changes in daily intensity and total precipitation for multi-day precipitation events is helpful to evaluate precipitation patterns in addition to assessment of annual averages. Three-day storm events (design storms) were generated from projected precipitation data based on RCP 4.5 and 8.5 emission scenarios for the 2030 and 2050 timeframes (Table 2 and Table 3). Historical precipitation data were used to calculate a baseline storm event for the year 2000 for comparison. Design storms were used to model stream channel overflow in the hydrology assessment.

Table 2. Design storm precipitation, Eagle River basin.

Design Storm		Baseline	RCP 4.5		RCP 8.5	
		2000	2030	2050	2030	2000
Precipitation (inches)	Day 1	0.81	0.81	0.89	0.96	0.85
	Day 2	1.18	1.09	1.11	1.36	1.46
	Day 3	1.09	0.90	1.29	0.94	1.12
	Total	3.08	2.80	3.29	3.26	3.43
Percent change from baseline			-9%	7%	6%	11%

Table 3. Design storm precipitation, Ship Creek basin.

Design Storm		Baseline	RCP 4.5		RCP 8.5	
		2000	2030	2050	2030	2050
Precipitation (inches)	Day 1	0.64	0.64	0.57	0.66	0.71
	Day 2	0.64	0.74	0.70	0.75	1.10
	Day 3	0.81	0.61	0.70	0.53	0.83
	Total	2.09	1.99	1.97	1.94	2.64
Percent change from baseline			-5%	-6%	-7%	26%

2.1.2 Hydrology (INRMP 2.2.4)

2.1.2.1 Stream Channel Modeling

Modeling of stream channel overflow (or flood modeling) was conducted for JBER to examine the extent of flooding along the Eagle River and Ship Creek associated with climate projections. Flood modeling did not consider flooding of independent surface bodies, stormwater systems, or surface ponding. Flood modeling was conducted using local watershed characteristics and the design storms generated from climate projection data (Table 2 and Table 3). The projected design storms do not represent extreme weather events (e.g., hurricanes, extraordinary storm fronts).

Inundation projections were influenced by two variable inputs: (1) variation in total precipitation between design storms and (2) variation between the daily distributions of precipitation over the three-day period. Within the hydrologic model, projected land cover type intersected with soils and depth to water table dictates the friction, infiltration rate, and run off rate.

Flooding is projected to slightly decrease compared to baseline under the RCP 4.5 scenario in 2030 (Table 4). Stream channel overflow associated with the baseline design storm was estimated to inundate approximately 722 acres along the Eagle River and Ship Creek. Under the RCP 4.5 emission scenario, inundation is projected to slightly decrease in 2030 and then increase by 54 acres in 2050. Under the RCP 8.5 emission scenario, inundation is projected to increase to 766 acres in 2030 and then to 854 in 2050. The spatial extent of projected flooding is depicted in a series of maps included in Appendix C.

Table 4. Projected inundation from stream channel overflow.

	Baseline	RCP 4.5		RCP 8.5	
	2000	2030	2050	2030	2050
Projected inundation (acres)	722	697	776	766	854
Change in inundation area from baseline (acres)		-25	54	44	132
Percent change from baseline		-3%	7%	6%	18%

2.1.2.2 Coastal Zone Modeling

Exposure to sea level rise (SLR) and storm surges (SS) was assessed using a Department of Defense (DoD) site specific scenario database. Details on the development and use of this database are described in Hall et al. (2016). Extreme water level scenarios were based on regional frequency analysis estimates of 20-year and 100-year storm surges. Coastal flooding projections were modeled for RCP 4.5 and RCP 8.5 emission scenarios in 2035 and 2065 in accordance with the DoD scenario database. SLR inundation estimates the new permanent coastline for each scenario and timeframe; SS inundation estimates short term flooding associated with an extreme water level event that is expected to recede after the storm.

The land surface in southern Alaska is moving faster than global sea level is presently changing (Freymueller, 2010). Tectonic uplift and some glacial isostatic adjustment means land is rising 2-4 times faster than sea level rise. Coastal uplift of the local landmass, predicted to be about 2.3 to 3.6 feet (0.7 to 1.1 meters), will counterbalance much of the effect of rising seas, predicted to be 1.3 to 6.6 feet (0.4 to 2 meters). Even if sea level change occurs at the higher end of the estimated range, marshlands will likely keep up with sea levels as they capture sediment and grow vertically. Therefore, loss of coastal area due to SLR inundation is not projected.

Table 5summarizes projected coastal inundation in acres for each scenario. Projections for a 20-yr SS, which have a 5% probability of occurring any given year, estimate possible inundation of between 380 acres (0.5% of the instillation area) for the RCP 4.5 scenario in 2065 to 495 acres (0.7% of the installation area) for the RCP 8.5 scenario in 2035. Projections for a 100-yr SS, which have a 1% probability of occurring any given year, estimate possible inundation up to 1409 acres (1.9% of the installation area) for the RCP 8.5 scenario in 2035. The spatial extent of coastal flooding is shown in a series of maps in Appendix C.

Table 5. Projected SLR and SS inundation.

Climate Scenario		2035		2065	
		Projected inundation (acres)	Percent of installation area inundated	Projected inundation (acres)	Percent of installation area inundated
RCP 4.5	SLR	N/A	N/A	N/A	N/A
	20-yr SS	407.4	0.6%	380.4	0.5%
	100-yr SS	784.7	1.1%	581.7	0.8%
RCP 8.5	SLR	N/A	N/A	N/A	N/A
	20-yr SS	495.2	0.7%	380.4	0.5%
	100-yr SS	1408.5	1.9%	581.7	0.8%

2.2 Ecosystems and the Biotic Environment (INRMP 2.3)

2.2.1 Ecosystem Classification (INRMP 2.3.1)

JBER’s ecosystem is classified within the Polar Domain, Humid Temperate Domain, Coastal Trough Humid Taiga Division and Pacific Coastal Mountain Forest Province (Bailey, 2014). The type of climate in this area shows great seasonal range in temperature. Winters are severe, and the region’s small amounts of annual precipitation are concentrated in the three warm months (June, July and August) (Bailey, 2014).

2.2.2 Vegetation (INRMP 2.3.2)

Five major natural ecosystems on JBER were identified using data from the USAF AFCEC Environmental GIS Project. The ecosystems included alpine zone, coastal halophytic zone, hydrological features, lowland interior forest zone, and subalpine zone. Natural ecosystems as well as developed land and crop/pasture areas are summarized in Table 6.

Table 6. Ecosystem coverage by area.

Ecosystem Type	Area (Acres)	Coverage
Lowland Interior Forest Zone	41352.6	56.6%
Alpine Zone	7842.2	10.7%
Subalpine Zone	5277.8	7.2%
Coastal Halophytic Zone	1491.1	2.0%
Hydrological Features	805.5	1.1%
Artificially Cleared or Disturbed Zone	13813.8	18.5%
Barren Land	2809.1	3.8%

The subarctic climate zone in which JBER is nested, coincides with a great belt of needleleaf forest, often referred to as boreal forest. This vegetation has adapted to the cold winters by greatly reducing their leaf area and responding rapidly to the short summer (Bailey, 2014). Slight changes in temperature and precipitation can substantially alter the composition, distribution, and abundance of species, and the products and services they provide. The extent of these changes will also depend on changes in temperature, precipitation and fire. Rising temperature under different RCP scenarios, enhances soil decomposition, and, together with reductions in rainfall, may reduce plant productivity in large areas. Changes in climate may also alter important biomes such as the forests.

Climate change is projected to alter ecosystem boundaries between tundra vegetation communities by increasing the relative abundances and cover of shrub species (such as birch, willow and alder). Ecosystems located in high-latitudes have experienced warmer temperatures in recent decades, and are projected to continue to warm in the future (Griffith et al., 2005). A large-increase in shrub cover at JBER might change the structure of its tundra ecosystem and alter energy fluxes, regional climate, soil–atmosphere exchange of water, carbon and nutrients, and ecological interactions between species. However, further research at the local level is needed to understand and project future rates of shrub expansion and understand the feedbacks to ecosystem and climate processes (Myers-Smith et al., 2011).

Another important vulnerable habitat at JBER, are open water and hydrological features. These ecosystems will face increases in air and surface water temperatures, alterations in the magnitude and seasonality of precipitation and run-off, and shifts in reproductive phenology and distribution of plants and animals (Cowardin, Carter, Golet, & LaRoe, 1979). Wetlands and marshes are naturally resilient, provide linear habitat connectivity, link aquatic and terrestrial ecosystems, and create thermal refugia for wildlife: all characteristics that can contribute to ecological adaptation to climate change.

In general, forests ecosystems are susceptible to climate change. There is a temperature below which the equilibrium state of the forest appears constant, but above which the equilibrium forest cover declines steadily. This threshold represents a point where some degree of loss of the forest is inevitable. As the threshold is exceeded, there is a gradual increase in the committed die-back, with changes that are more progressive than sudden. Therefore, forest vegetation at JBER may experience some degree of die-back before impacts are observed. For example, if climate was stabilized at 2050, a significant die-back could still occur over the next 100-200 years.

2.2.3 Fish and Wildlife (INRMP 2.3.3)

Climate change is expected to have significant impacts on fish and wildlife species present on JBER. Increased precipitation would be likely to increase aquatic habitat in the area, potentially benefiting fish, macroinvertebrates, and amphibians. Rising temperatures could, however, have a negative impact on aquatic organisms that rely on cooler, well oxygenated water. Lentic systems in particular are susceptible to rapid fluctuations in water parameters. Increasing air temperatures can increase water temperatures, creating more favorable environments for future algal blooms (Paerl, Hall, & Calandrino, 2011). Higher water temperatures due to increased air temperature could also result in decreased dissolved oxygen content, further decreasing habitat quality for fish and amphibians, particularly in lentic systems.

Projected increases in temperature would also affect timing of snowmelt, and aquatic/terrestrial invertebrate emergence could become altered. Both factors are extremely important for fish ecology as well as for birds (Both et al., 2010), which time their migration routes to coincide with the massive release of nutrients provided by emergence of aquatic invertebrates. Fish that may be impacted by these possible changes if their reproductive cycles coincide with macroinvertebrate emergence include rainbow trout, three-spine stickleback, nine-spine stickleback and sculpins. Pacific salmon will likely remain unaffected by increased temperatures as they do not eat after entering freshwater to begin mating. Birds that may be impacted include, but are not limited to, Swainson’s thrush, American robin, yellow-rumped warbler, Alder flycatcher, ruby-crowned kinglet, and white-crowned sparrows.

Vegetation associated with alpine tundra is likely to experience the most significant changes, probably resulting in contraction of alpine tundra habitat on JBER. Animals dependent on tundra habitat that could suffer from habitat loss include the arctic ground squirrel, hoary marmot and tundra shrew. These species may also be harmed by increased temperatures as their hibernation patterns become altered, ultimately decreasing survival rates (Aars & Ims, 2002). Changing vegetation will have a negative impact on specialist wildlife species that have historically depended on specific native plant species for their survival (Dukes & Mooney, 1999). Changing conditions may also create open niches for non-native invasive species to expand onto JBER. Newly arriving invasive species often have the ability to outcompete native species which are already experiencing reduced fitness due to environmental conditions shifting away from historic standards (Hellmann, Byers, Bierwagen, & Dukes, 2008). Rising temperatures could also result in the increased potential for foodborne diseases and incidences of infectious diseases of animals that are transmittable to humans, particularly those carried by foxes, rodents and arthropods such as rabies and West Nile virus (Parkinson & Butler, 2005).

With a projected increase in the number of growing days, vegetation may become lusher, allowing for increased density of herbivores and carnivores. There is potential for some native species to thrive under the predicted conditions, however the potential also exists for invasive species to occupy new niches as the climate warms. Animals such as the rock dove, European starling, house mouse, and feral cats and dogs that already inhabit JBER may experience increased numbers and will likely present negative competition with native species.

2.3 Mission Impacts on Natural Resources (INRMP 2.4)

2.3.1 Natural Resource Constraints to Mission and Mission Planning (INRMP 2.4.1)

The multiparty nature of mission-based activities at JBER require a greater range of natural resources than other Air Force or Army installations. Due to the ground-based nature of Army training, habitats, and both the species and training operations that occur within them will have greater importance at JBER than at most Air Force only installations. Current and future external encroachment will have a major impact on mission operations at JBER, and the effects of climate change will likely intensify these impacts.

The potential exists for negative impacts to mission operations in relation to the Cook Inlet beluga whale (CIBW). The CIBW was found to be highly vulnerable to climate change due to primary effects such as increased water temperature, as well as secondary effects (prey availability, extreme weather, habitat loss). Current protections for the CIBW by JBER have been deemed adequate as to not place any limitations on military training. However, if CIBW population numbers decline substantially due to climate change, combined with the possible increase in future mission capacity at JBER due to additional human activity in the arctic region, the potential exists for additional training restrictions in the vicinity of Cook Inlet. This would affect flight operations that include airspace over CIBW critical habitat as well as artillery training at Eagle River Flats Impact Area. Increased water temperatures may also degrade salmon habitat.

Climate change could also expand the mission of NORAD North Slope and increase the importance of JBER to this vital command. It is anticipated that melting sea ice may result in increased shipping and resource exploration north of Alaska, which will require greater surveillance presence in the region.

Numerous buildings, roads, and other structures are anticipated to be potentially vulnerable to flooding due to increased frequency and intensity of storms. Overall, the effects of climate change on the built environment of this installation could be severe. In the Ship Creek watershed, several roads (Grady Highway, Stephenson Lane, Campos Avenue, and Sockeye Avenue) providing access to and from family housing could be inundated during large rain events. This could potentially affect the mission at JBER due to the inability of mission critical personnel to reach their duty station, as well as decrease morale.

Also, within the Ship Creek watershed, Transmitter Site Access Road, which provides access to the transmitter site between the cantonment and family housing (south of Davis Highway), could become inundated. Vandenberg Road, a major north-south road connecting several sites could be flooded during storm events in the future. Other vulnerable infrastructure that could be affected and impact the military mission at JBER include parts of Eagle Glen golf course, the water treatment building, and the Alasks Department of Fish and Game Hatchery water well.

In the Eagle Creek watershed, Route Bravo and Route Sweat could be vulnerable to flooding. Route Bravo connects several firing sites including LZ-13, LZ-15, a fixed artillery site, and a munition waste disposal site (MMRP Site 02781-166). Route Sweat connects Neibar Drop Zone and Firing Point with an open area on the right bank of the Eagle River, possibly used for riverine operations training. These two routes are vital infrastructure to the mission at JBER and even temporary closures due to flooding would negatively impact military training.

Future impacts to the mission at JBER linked to climate change could include:

- increases in temperature and wind velocity leading to unsafe environmental conditions for the launch of current and planned weapons and equipment, resulting in increased maintenance requirements, requirements for new equipment, or decreased launch capacity (DoD, 2014);
- increased dust generation effecting equipment and visibility (DoD, 2014);
- increased wind velocities damaging vital mission infrastructure (Sydeman et al., 2014);
- increased drought potential (Glick, Stein, & Edelson, 2011);
- potential loss of future training areas that may be needed in light of a changing geopolitical landscape and base realignment.

In addition to these direct effects, climate change has the potential to disrupt the acquisition and transportation of materials required for the maintenance, construction, and storage of the equipment required for these systems (DoD, 2014).

2.4 Fish and Wildlife Management (INRMP 7.1)

Fish and wildlife management on JBER is not likely to change greatly with regard to projected climate change. Stocking programs and fish habitat improvement will likely need to continue to be conducted. Increases in invasive species populations may force management changes. As temperatures increase niches for invasive species will open. Invasive species surveys will need to be conducted frequently and invasive species will need to be dealt with accordingly. Monitoring of invasive species will continue to be important and management plans should be flexible enough to adapt to changing fish and wildlife concerns (Hellmann et al., 2008).

As growing seasons increase, the density of animals on JBER could also increase. Surveys will need to be conducted frequently in order to assess wildlife populations. If wildlife become a nuisance to military operations, such as aggressive moose or increased bird populations presenting BASH concerns, increased hunting programs may need to be implemented as a management tool.

The most at risk species are those that inhabit the alpine tundra and include the arctic ground squirrel, hoary marmot, and tundra shrew. With increasing temperatures and growing days, trees will likely move higher in elevation to take over what is now tundra, displacing those species that rely on alpine tundra. Without the possibility of moving higher in elevation, some species could eventually become regionally extinct. It seems unlikely that any management regime would be realistic in preserving this habitat at JBER.

Potential for algal blooms will increase as temperatures rise, which will further deplete dissolved oxygen content in water, harming freshwater fish and amphibian populations. Management efforts should focus on removal of non-native aquatic plants and algae as well as reducing nutrient rich run-off into water supplies to help maintain stable dissolved oxygen levels, which will reduce the changes of algal blooms. Providing shade through planting of trees around water sources will help to prevent excessive increases in water temperature (Poff, Brinson, & Day, 2002).

2.5 Outdoor Recreation and Public Access to Natural Resources (INRMP 7.2)

Most outdoor recreation and public access to natural resources at JBER should remain unaltered with respect to climate change. Activities such as all-terrain vehicle use, boating, hiking, wildlife viewing, nature and wildlife photograph, biking, berry and mushroom gathering, and limited camping will most likely remain unaffected. Activities such as hunting and fishing will need to be continually assessed and adjusted in accordance to the health of fish and wildlife populations on JBER. In the case that certain species, native or invasive, experience increased populations there is a possibility for increased hunting opportunities.

2.6 Wetland Protection (INRMP 7.6)

Climate change will most likely have a neutral to positive effect on the amount of wetland area in the region. Wetland processes may be altered due to the increase in temperature forecasted for the region. The effects of warming on wetland chemical, physical, and biological processes in southern Alaska should be studied in more detail before making any claims on potential impacts. Potential protection methods include restoring wetlands that have been invaded by non-native species, protecting wetlands from damage, and mitigating wetland losses associated with construction or military activities.

2.7 Wildland Fire Management (INRMP 7.9)

Temperature at JBER is predicted to increase across all scenarios, in some cases dramatically. Average maximum monthly temperatures are expected to increase, by 2.8 to 3.3 degrees F by 2030, and by 5.2 to 6.7 degrees F by 2050, with individual months increasing by as much as 13 degrees F. Warmer temperatures are generally more conducive to increased fire activity, though fuel moisture has a much larger effect.

Total precipitation is predicted to increase in all scenarios, but there is important monthly variability within scenarios. During the predominant fire season at JBER of April through June, accounting for 85% of all fires (Air Force Wildland Fire Center, 2016). Precipitation is estimated to increase in May and June by 14 to 32% in all but May of the RCP 4.5 2030 scenario. Overall, this may lead to reduced ignition frequency, as most ignitions occur in dead fuel and those will be more likely to be moist from recent rains. Conversely, in the RCP 4.5 2050 scenario, April precipitation decreases and May precipitation changes negligibly, while June precipitation increases by 0.42 inches. In this scenario, this could concentrate ignitions in April and May, with higher than current ignition loads during those months, while reducing ignition likelihood in June.

October is also predicted to be drier than present in the RCP 4.5 2050 scenario as well as in the RCP8.5 2030 scenario. However, October precipitation is currently nearly double that of April and May, when most ignitions occur, and even with the reduction will remain considerably higher. However, the RCP 8.5 2030 scenario suggests a decrease of more than 0.3 inches per month on average for September through November. Given the only moderate increase in precipitation of less than 0.2 inches per month from March through August, and the increased temperatures, which will increase evaporation and evapotranspiration, the potential for drought and associated increases in ignitions and fire intensity is high in this same scenario.

Generalized changes vegetation types are likely to include increased shrub cover, particularly birch, increased grasses and grass-like vegetation, and decreased mosses and lichens (Hayward et al 2015). Additionally, afforestation can be expected in alpine areas that are currently predominantly vegetated with grasses. These changes are not expected to substantially alter ignition likelihood, but are likely to increase fire intensity. In the moist climate of JBER, both now and in the future, none of these fuel types are particularly flammable. Further, ignitions are currently much more common where fuels are managed, with over 60% of wildfires occurring on live-fire ranges from mission related activities (Air Force Wildland Fire Center, 2016). These areas are usually mowed grasslands and the vegetation there is not expected to change substantially presuming that management continues. Of the remaining 40% of all wildfire ignitions at JBER currently, most are associated with human-related activities in developed areas, again where vegetation is management and not expected to change substantially. Lightning is not currently a measureable contributor to ignitions at JBER. Presuming vegetation management and land use remain constant, most ignitions will occur in managed fuels, and ignition likelihood is unlikely to change significantly.

The projected increase in shrub birch or graminoid biomass (Hayward et al 2015) is likely to increase potential fire intensity. While grass-fueled fires tend to have higher rates of spread, shrubs add more biomass and heavier fuels that can increase flame lengths and fire intensity. Changes in fire behavior associated with the conversion from tundra to forest are dependent on moisture conditions, but should spruce forest take hold, fire intensity in these areas can be expected to increase. Hayward et al (2015) predict an increase in Sitka spruce, and a corresponding decrease of white and black spruce, which would be expected to decrease fire intensity where white and black spruce currently dominate. There is also a possibility that increased temperatures will lead to greater beetle-related mortality, which could increase standing and down dead fuels (Hayward et al., 2015), both of which would increase potential fire intensity and make firefighting more dangerous and difficult. Where fuels are actively managed, primarily mowed grasses, fire intensity can generally be expected to remain approximately static relative to current day.

The predicted increased temperatures can be expected to increase fire intensity, although this will be partially or completely mitigated, depending on the time of year and the climate scenario, by the corresponding increase in precipitation. Notable examples of temperature increases combined with precipitation decreases include RCP 4.5 2030 August; RCP 4.5 2050 April, May, and October; RCP 8.5 2030 April and September through November; and RCP 8.5 2050 August. Although there are other months with decreased precipitation and increased temperature, the overall conditions in those months are not conducive to wildfire (e.g. RCP 4.5 2030 December). In other months, increased precipitation is expected to mitigate elevated temperatures to varying degrees, resulting in little change to fire intensity.

In summary, by 2030, changes to fire likelihood and fire intensity will depend to a large degree on the climate scenario realized, with the RCP 8.5 2030 scenario potentially producing drought conditions throughout the summer and fall. The RCP 4.5 2030 scenario will likely lead to less fire activity overall. By 2050, temperature increases are likely to overwhelm some of the mitigating impacts of increased precipitation in the RCP 8.5 2050 scenario. This could lead to more fires and more intense fires. Fire activity is likely to decrease overall under the RCP 4.5 2050 scenario. All of these conclusions are relative to the current day fire occurrence baseline which includes few fires annually and no large fires in the historic record. Even with an increase in ignition potential and fire spread potential, fire is likely to remain a relatively rare and small-scale disturbance on the landscape.

2.8 Coastal Zone and Marine Resources Management (INRMP 7.13)

Based on projected inundation, the following set of adaptation strategies have been identified for consideration (Table 7Table 7). Suggested adaptation projects are rated by their difficulty to implement and their relative efficacy. Ease of implementation is ranked from 1 to 3, with 1 being most difficult to implement and 3 being the easiest to implement. Efficacy is ranked from 1 to 3, 1 being the least effective and 3 being the most effective.

The ecological impacts related to adopting each of these projects is stated to be positive if no negative impacts are expected. If these projects are expected to have negative ecological impacts, they are rated one (being as low negative impacts) through three (being high negative impacts).

Table 7. Summary of adaptation strategies to mitigate potential SLR and SS inundation.

Strategy	Implementation	Efficacy	Ecological impacts	Ecological resources
Artificial Breakwaters	1	3	Positive	Harris, 2009
Living Shorelines	1	2	Positive	NOAA Living Shorelines Workgroup, 2015
Riprap	2	2	1	Gittman, Scyphers, Smith, Neylan, & Grabowski, 2016
Erosion Monitoring	1	2	Positive	USDC & NOAA, n.d.
Bulkheads	2	3	1	Hester et al., 2006

3 LITERATURE

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