U.S. Fish & Wildlife Service

Water Resource Inventory and Assessment

Kanuti National Wildlife Refuge

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Prepared by

[1]U.S. Fish and Wildlife Service
1011 East Tudor Rd
Anchorage, Alaska 99503
907/786-3967

[2]Alaska Center for Conservation Science
University of Alaska Anchorage
Beatrice McDonald Hall
3211 Providence Drive
Anchorage, Alaska 99508
907/786-6350

Authors

[1]Cathy Flanagan, [2]Becky Shaftel, [2]Lindsey Flagstad, [2]Marcus Geist, [2]Dustin Merrigan

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Executive Summary

The mission of the Fish and Wildlife Service (the Service or USFWS) is working with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people. Congress established the Kanuti National Wildlife Refuge (Kanuti Refuge or the Refuge) primarily for the conservation of fish, wildlife, and habitats in their natural diversity. In particular, Congress noted the value for migrating birds in the Pacific Flyway and as habitat for nesting birds and resident wildlife. The Refuge and the species it supports are highly dependent upon the aquatic habitats that dominate the landscape. The rivers, lakes, and wetlands of Kanuti Refuge may be the most important asset for the continued health of habitats that support these species. Managing these resources requires a heightened understanding of the extent, condition, and concerns facing these resources. Success in achieving the mission and purpose of the Service and Kanuti Refuge requires thoughtful management of water.

A national team of Service hydrologists developed the Water Resources Inventory and Assessment (WRIA) model to address the growing need for managing water in a changing environment. The assessments provide reconnaissance-level information to assess the concerns affecting water and refuge resources. Service hydrologists incorporated the datasets compiled for the WRIAs into a national database to evaluate the unique value and condition of a refuge's water resources at national, regional, and local scales. The information collected for the WRIAs informs refuge and habitat management planning, supports resource management at the refuge and regional levels, and provides valuable information about the role of water resources as a critically important element of the National Wildlife Refuge System (NWRS).

The WRIA for Kanuti Refuge compiles information on hydrology; water rights; water availability; water quality; climate; and water monitoring gathered from staff interviews, national, regional, and local data mining, literature reviews, and data analysis. The WRIA presents this information through maps, tables, and discussions. The document brings together threats and issues of concern affecting water resources, and makes recommendations for water resource management on Kanuti Refuge. WRIAs are an important part of the NWRS Inventory and Monitoring (I&M) initiative outlined in the I&M Operational Blueprint as Task 2a (USFWS, 2010).

The WRIA provides an inventory of Kanuti Refuge's water resources (Appendix A), an assessment of current conditions and future issues of concern, and serves as a management decision aid, a national water resource accounting tool, and a reference for biologists, managers, and researchers. It is a living source of information for ongoing water resource management and the development of strategic studies and planning.

A nationally adopted format for conducting WRIAs partitions the report into several categories and sub-categories. The construction of this WRIA follows the national outline:

- Refuge Establishment
- Natural Setting
- Water Resource Inventory Summary and Characterization
- Inventory Results and Discussion
- Characterization of Threats, Issues of Concern, and Needs
- Findings and Recommendations

Recommendations

The recommendations reflect the findings, the current hydrologic condition, and the outlook for the health of the Refuge's natural water resource systems. These suggested actions provide an avenue for protecting and maintaining the freshwater habitats and species managed by the Refuge. They offer a framework for achieving the Refuge's purposes and water management goals, now and in the future.

Natural Settings

- As opportunity arises, contribute to updating the National Hydrography Dataset (NHD) with the Regional Office. The NHD is a georeferenced digital dataset representing the natural and human-altered hydrologic features (rivers, streams, lakes, canals, gages, dams and coastlines) of the United States. In Alaska, the NHD also serves as the primary georeferenced base layer to which most other geospatial data such as land status, vegetation, and wildlife data are spatially registered. An accurate and complete NHD layer is the required base dataset the United State Geological Survey (USGS) will use to develop the data-rich NHD+ dataset required by many current and future ecological analysis models and programs.

- Cooperate (e.g., provide input, ground-truthing, logistical support, or funding) with the I&M Program, the Landscape Conservation Cooperatives (LCC), and National Wetlands Inventory (NWI) to complete or update baseline datasets, including:
    - permafrost inventory,
    - wetland classification (NWI),
    - hydrography dataset (NHD+),
    - soils inventory, and
    - vegetation inventory.

Surface Water

Rivers

- Maintain the stream gage on the Koyukuk River at Old Bettles to create a long-term record of hydrologic flow and behavior.

- Reestablish the gage on the Kanuti River to represent long-term flow patterns for smaller, lower latitude, and lower elevation drainages on the Refuge. Alternatively, consider another river with headwaters at lower latitude and lower elevation that is easily accessible to the Refuge (e.g., Henshaw Creek, which has a previously gaged reach and long-term salmon information from the weir).

- Monitor river and lake phenology (freeze-up, break-up, peak flows, low flows), seasonal water temperatures, and instream wood features (logjams/sweepers/strainers) on the Koyukuk, South Fork Koyukuk, and Kanuti Rivers using water temperature sensors and game cameras.

- Evaluate future development projects for bridge/culvert design, fish passage, and sufficient stream flow (along with water quality, as discussed in the water quality recommendations below).

Lakes

- Create a geospatial data layer of lake basin flow direction from Interferometric Synthetic Aperture Radar (IFSAR) data to determine lake basin types (open versus closed) to inform planning for monitoring (note also that NHD+ incorporates flow direction).

- Incorporate the lake depth results of 11 Refuge lakes reported by Glesne et al. (2011) into the lake basin map developed from ISFAR to begin delineating deep and shallow lakes to guide monitoring studies.

- Overlay habitat use for species of concern (known through observation or biological surveys) on the lake basin map developed from ISFAR.

- Develop a long-term study plan to understand the implications of changing climate, including determining aquatic and terrestrial habitats resistant to lake/wetland drying. This study should include both open- and closed-basin systems, as well as systems of varying depths.

Wetlands

- Apply the results of the wetland land cover crosswalk discussed in Appendix E to support the acquisition of improved datasets for soils/permafrost and hydrography in support of wetland mapping.

- Coordinate with NWI to complete wetland classification.

- Overlay geospatial layer(s) of habitat use for species of concern (known through observation or biological surveys) on maps of wetland areas to create a record of important freshwater habitat areas for management.

Groundwater

- Develop methods to inventory and map open water leads, aufeis, and overflow in winter along Refuge streams and lakes as an initial means of mapping groundwater sources.

- Map flow direction from IFSAR data to determine surface water-to-groundwater connections.

- Because freshwater habitats supported by groundwater will likely persist under climate change scenarios to provide long-term high-value habitat, evaluate wetland and lake systems to determine their groundwater connectivity to plan for climate-resilient freshwater habitats across the Refuge.

- Support research for better understanding the interactions between groundwater and permafrost interactions to develop a long-term monitoring plan for groundwater-related habitats.

Water Quality

- Collect data on waters suspected of impairment and nominate those that are impaired to the Alaska Department of Environmental Conservation (ADEC) for inclusion on the 303D list. ADEC accepts nomination during odd years (2017, 2019, etc.).

- Continue water temperature monitoring at the Koyukuk River gaging station in partnership with the NPS, the NWS, and the USFWS Water Resources Branch (WRB).

- Coordinate with TCC to continue water temperature monitoring at Henshaw Creek weir.

- Establish a water temperature-monitoring network for rivers of high fisheries value (Varner et al. 2017) and reaches vulnerable to temperature change (shallow or recently burned reaches without solar shading).

- Follow Alaska Regional Protocol Framework for Monitoring Stream Temperature (Perdue and Trawicki 2016) when establishing stream temperature sampling efforts and coordinate efforts with the WRB of the Regional Office.

- Develop and implement a monitoring plan to establish baseline conditions of radionuclides, rare earth elements, dust, and metals in the extents of the Fish Creek and Jim River basins within the Refuge. Ensure sampling during high- and low-flow events.

- Address water quality and quantity concerns on rivers not previously monitored. Supplement monitoring on systems that were sampled during the 2008–2016 baseline effort to inform concerns raised during scoping and NEPA compliance of large development projects.

- Proactively establish a sampling plan for systems that may be impacted by road or resource development activities. Implement the plan to collect baseline data at least a year prior to projects' inception. Data collection should include:
    - Information on fish, macroinvertebrate, and benthic diatoms
    - Water quality parameters should reflect the type of activity and geology in the affected watershed and may include:
        - Trace metals in areas where soil disturbance exposes sediments to weathering. Special attention should be given to copper since baseline sample results indicated the availability of copper;
        - pH and SC as a continuous or preliminary indicator of contamination or system degradation; and
        - continuous turbidity and temperature on systems adjacent to roads and mining activity.

Water Rights

- Continue to support the Service's efforts to obtain instream flow reservations for protecting a) the habitats, migration, and propagation of fish and wildlife, and b) water quality.

- Document the biological use of rivers and lakes on Kanuti Refuge to support water rights applications:
    - Document the distribution of key aquatic species in Refuge rivers and lakes or major watersheds.
    - Develop fish periodicity charts for Kanuti Refuge's rivers and lakes or major watersheds.

- Document the presence of anadromous fish at various life stages in Refuge rivers, for addition to the AWC.

- Conduct a water rights review every ten years to ensure protection of important or threatened waters.

Climate

- Support the continued operation of the SCAN site at Kanuti Lake.

- Evaluate current snow course aerial survey and snow sampling programs to ensure it provides a reliable index of precipitation in different regions of Kanuti Refuge. Continue to measure snow density at least once per year.

- Work with regional partners to maintain the NWS station in Bettles and the SCAN site at Kanuti Lake to provide data for the northern (wetter) and southern (dryer) portions of Kanuti Refuge, respectively.

- Conduct long-term monitoring of water temperature to identify and explain the biotic changes driven by alteration of hydrologic conditions.
    - Continue measuring continuous water temperature at the Koyukuk River at the Old Bettles gage station.

    - Resume or initiate monitoring continuous water temperature on previously measured rivers (Kanuti Kilolitna River, South Fork Koyukuk River, Holonada Creek, and Kanuti River Tributary Rivers), and rivers and lakes accessible by plane or boat.

    - Follow the Alaska Regional Protocol Framework for Monitoring Stream Temperature (Perdue and Trawicki 2016) when establishing stream temperature sampling efforts and coordinate efforts with the Water Resources Branch of the Regional Office.

General Management

- Participate in planning and review of large-scale development projects.

- Continue to participate in planning efforts addressing the BLM's CYRMP, including addressing the implications of state and Federal mining and transportation within the utility corridor.

- Work with conservation community/partners and researchers (e.g., share results and interpretation) to maximize science across the landscape to achieve conservation success.

- Coordinate activities with the regional Invasive Species program.

- Continue conducting biannual river floats to assess the possible spread of invasive plants along refuge waterways.

- Monitor changes in the occurrence and spread of invasive plants using the *Elodea* map. Coordinate with the Regional Office regarding the applicability of eDNA methods for identifying the presence of *Elodea*.

By implementing these recommendations, the Refuge can begin to address the refuge purposes related to water quality and quantity. It will also help meet the goals established in the Refuge's Comprehensive Conservation Plan (CCP) (U.S. Fish and Wildlife Service 2008); each recommendation contributes to the conservation of the refuge's diversity of wildlife, fish, and habitats through the maintenance of the natural hydrologic cycle (CCP Goal 1) and the natural function and condition of water resources for fish and wildlife populations and habitats (CCP Goal 2).

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Glossary of Terms and Acronyms

AAC	Alaska Administrative Code
ACEC	Areas of Critical Environmental Concern
ACIA	Arctic Climate Impact Assessment
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
AHPS	Advanced Hydrologic Prediction Service
ANHP	Alaska National Heritage Program
ANILCA	Alaska National Interests Land Conservation Act
ANOVA	Analysis of Variance
APRFC	Alaska-Pacific River Forecast Center
AS	Alaska Statute
AWC	Anadromous Waters Catalogue
BLM	United States Bureau of Land Management
CCP	Comprehensive Conservation Plan
CFS	Cubic feet per second
COOP	Cooperative Observer Program
CWA	Clean Water Act
CYPA	Central Yukon Planning Area
CYRMP	Central Yukon Resource Management Plan
DEM	Digital Elevation Model
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOI	United States Department of the Interior

DON	Dissolved Organic Nitrogen
DOT	Department of Transportation
EPA	United States Environmental Protection Agency
ERDAS	Earth Resources Data Analysis System
FGDC	Federal Geographic Data Committee
GHCN	Global Historic Climate Network
GIS	Geospatial Information System
HADS	Hydrometeorological Automated Data System
HUC	Hydrologic Unit Code
IFSAR	Interferometric Synthetic Aperture Radar
I&M	Inventory and Monitoring
IPCC	Intergovernmental Panel on Climate Change
IOC	Issues of Concern
LAS	Land Administrative System for Alaska
LCC	Landscape Conservation Cooperatives
LOESS	Locally Estimated Scatterplot Smoothing
MWAT	Maximum Weekly Average Temperatures
MWMT	Maximum Weekly Maximum Temperature
NCDC	National Climate Data Center
NEPA	National Environmental Policy Act
NHD	National Hydrologic Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	United States Park Service
NRCS	National Resources Conservation Service
NSIDC	National Snow and Ice Data Center

NWI	National Wetlands Inventory
NWIS	National Water Information System
NWRS	National Wildlife Refuge System
NWQL	National Water Quality Laboratory
NWR	National Wildlife Refuge
NWS	National Weather Service
PDO	Pacific Decadal Oscillation
PNA	Pacific/North American teleconnection pattern
PPT	Parts per thousand
RAWS	Remote Automated Weather Stations
RCAT	Refuge Climate Analysis Tool
RHI	Region of Hydrologic Influence
RLGIS	Refuge Lands Geographic Information System
RMP	Resource Management Plan
ROS	Regression on Order Statistics
SC	Specific Conductance
SCAN	Soil Climate Analysis Network
SNOTEL	Snow Telemetry
SOI	Southern Oscillation Index
STATSGO2	State Soil Geographic Digital General Soil Map
TCC	Tanana Chiefs Traditional Tribal Consortium
TDS	Total Dissolved Solids
T&E	Threatened and Endangered
The Refuge	Kanuti National Wildlife Refuge
TKQ	Kanuti River Tributary
TMDL	Total Maximum Daily Load

TON	Total Organic Nitrogen
TR	Total Recoverable
TWUP	Temporary Water Use Permit
USFWS	United States Fish and Wildlife Service (The Service)
USHCN	US Historical Climatology Network
USGS	United States Geologic Survey
WERC	Water and Environmental Research Center University of Alaska Fairbanks
WRB	Water Resources Branch
WRCC	Western Region Climate Center
WRI	Water Resources Inventory
WRIA	Water Resources Inventory and Assessment

http://water.usgs.gov/wsc/glossary.html

http://water.epa.gov/scitech/swguidance/standards/criteria/nutrien

1. Introduction: The WRIA

The National Wildlife Refuge System is the world's premier system of public lands and waters set aside to conserve America's fish, wildlife, and plants. Water is a vital component of this system. The WRIA is the first step to ensure that water of sufficient quantity and quality is available for each refuge.

The WRIA is a comprehensive evaluation tool. The WRIA compiles and summarizes existing information on water resources to guide the management of Kanuti Refuge. It provides findings and recommendations to aid the achievement of water resource-related purposes and goals identified in the Refuge's CCP.

WRIAs provide a current and accurate inventory of water resource data to support the acquisition, management, and protection of adequate supplies of clean, fresh water for National Wildlife Refuges (NWR). An accurate water resources inventory enables the prioritization of resource management decisions and prescriptive actions consistent with the established refuge purposes.

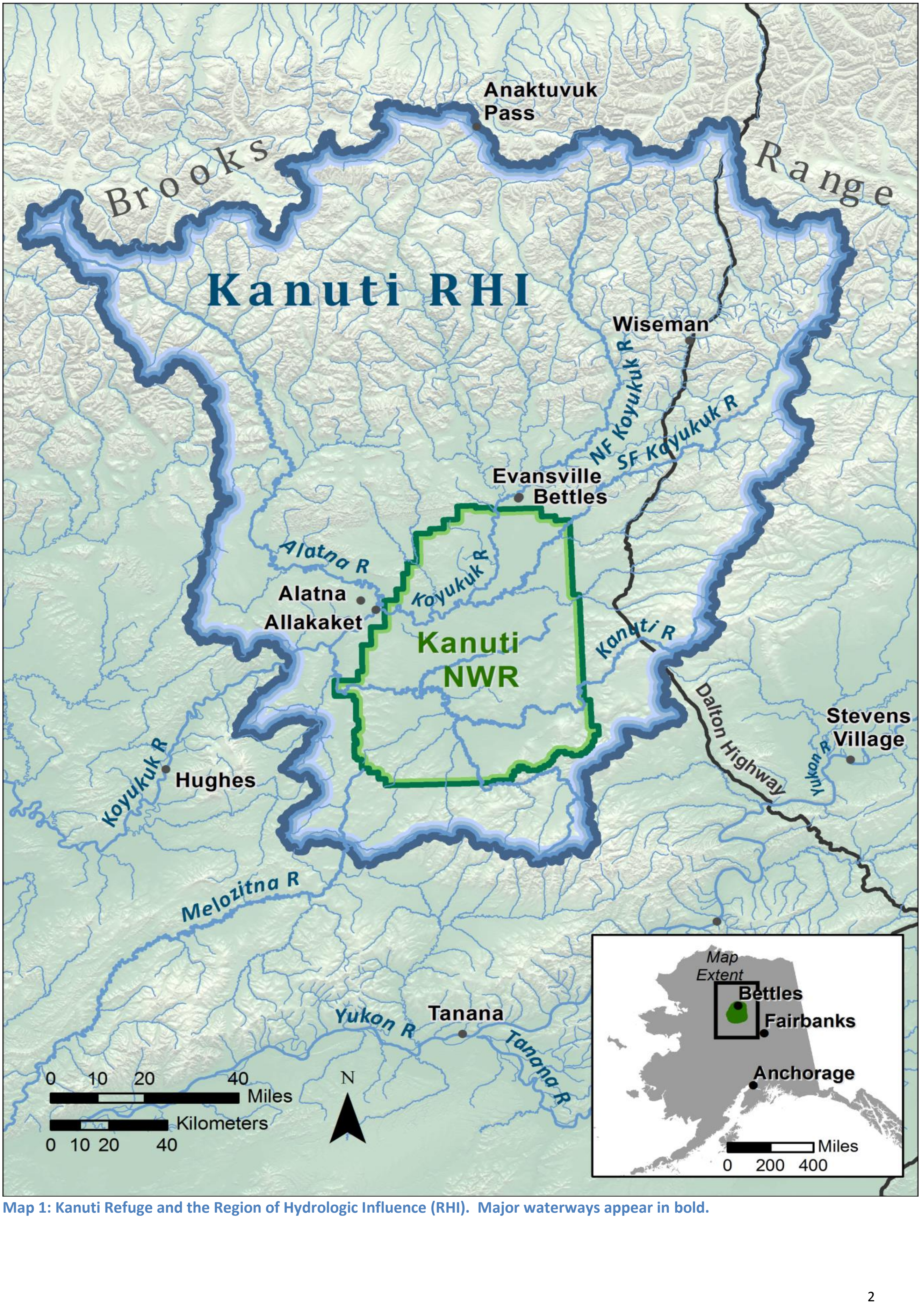
The Inventory (Appendix A) serves as a source of data and a reference for ongoing water resource studies. The inventory summarizes information on climate, surface water and groundwater, water management infrastructure, water quality, water rights, and issues of concern. The inventory presents information gathered from refuge staff interviews, local, national, and regional databases, and geospatial datasets. The geospatial data processing for the WRIA uses two boundaries: the Kanuti Refuge boundary and the Region of Hydrologic Influence (RHI) (Map 1). The RHI is defined as "the area(s) upstream/up gradient or downstream/down gradient, from refuge lands and relevant to water and resource management of the Refuge" (Esralew 2012) and was delineated with input from Refuge staff.

The Assessment of the inventory information evaluates the status and trends of water resource conditions that affect the natural diversity of fish and wildlife habitats and populations. The assessment discussion identifies management issues affecting the achievement of Kanuti Refuge's purposes.

This is a living, digital document. Links provide access to websites and digital sources where possible. The data associated with this WRIA include information gathered from sources prior to December 2015. Methods - Appendix B provides a more detailed discussion of the inventory and assessment methods.

The products associated with the inventory and assessment provide useful information:

- **Data Source Tables** list the databases discovered and accessed to obtain the inventory data found in the Water Resource Inventory (Appendix A). Each table lists the database source and the website link or a point of contact to access the data. The tables identify the inventory status of each data source to inform the reader of the databases queried for the inventory and assessment.



Map 1: Kanuti Refuge and the Region of Hydrologic Influence (RHI). Major waterways appear in bold.

- **Inventory Tables** list the results of the data collected from sources listed in the Water Resource Inventory (Appendix A). Features “within Kanuti Refuge” fall within the Refuge boundary. Features “within the RHI” fall within the RHI boundary but outside Kanuti Refuge boundary. This means that the count sum of the length or area of features “within the RHI” does not include the sum of the features “within Kanuti Refuge.” This manner of accounting for water resources avoids double counting the features located “within Kanuti Refuge.”
- **Maps** graphically display the resources discussed in each inventory table. The maps in this document provide a first glance at the water resources of Kanuti Refuge and the geospatial information used to compile this document. They provide a geographically relevant listing of the information collected via the data inventory.
- **A large format, interactive GeoPDF map poster** accompanies this document and provides a detailed and interactive view of the data (See Appendix C for access and instructions on use). The GeoPDF format used to construct the map poster allows the user to manipulate data layers, zoom in and out, and view information associated with the geospatial features.

2. WRIA Methods- Overview

A Water Resource Inventory (WRI) (Flanagan and Cunanan 2013) identified climate, water resources, infrastructure, water quality, water monitoring, and threats data available from national and regional databases. The WRI presented this information through a series of detailed tables and maps.

This WRIA is the final product that combines the results of the WRI (Appendix A), the local interviews and data discovery, and an assessment of this information (Figure 1).

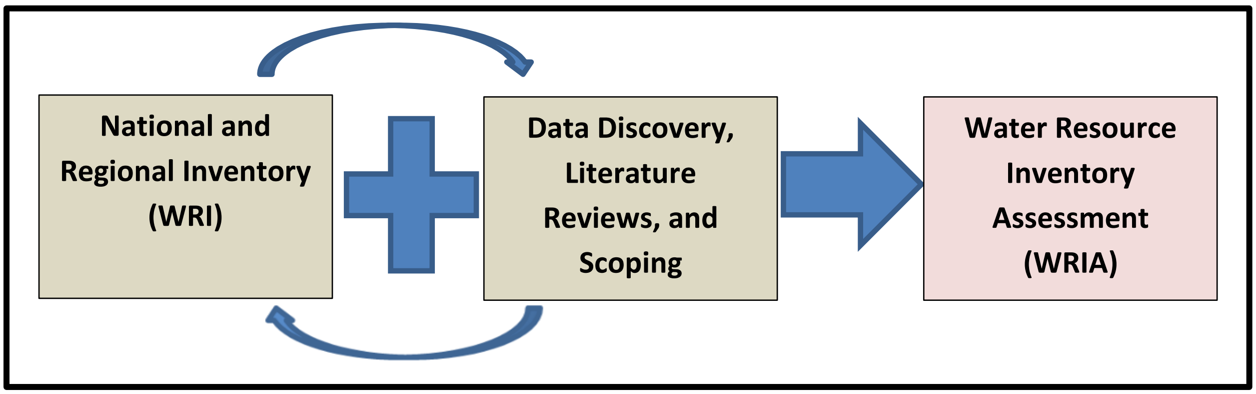


Figure 1: The Water Resource Inventory and Assessment process model.

The WRIA for Kanuti Refuge gathered available information on water resources through:

- studies and reports on relevant water resources investigations and research publicly available through the internet or from hard-copy refuge files;
- publicly available data for surface water, water quality, and groundwater from local, state, and national agencies available on the internet; and
- interviews with Refuge and USFWS regional office staff.

The process identified spatial and non-spatial information and entered that information into a database. The database links each source with the subject area of the WRIA (climate/weather and monitoring sites, surface water, groundwater, water quality, water rights, and threats) to provide subject-related data source lists for this report. Appendix D lists the source information used in the creation of the WRIA's geospatial and tabular data. Data capture occurred through one of three methods: web services, scheduled download, or data calls. Web services databases provide a live link to the actual database interactively queried to provide up-to-date information; queries pull data of interest. Data accessed via a scheduled download provide a time-stamped copy of data downloaded to a local computer via the internet; periodic downloads provide new copies of the data and data updates. Data not available online were obtained via a data call by requesting copies from a point of contact or database manager.

The WRIA geodatabase utilized available geospatial data sources. ArcGIS version 10 software (Environmental Systems Research Institute 2010) supplies the tools to create the Geographic Information

System (GIS) datasets and maps. Refuge Lands GIS (RLGIS) standards provide the basis for the geodatabase structure and database dictionary, with modifications to meet the specific needs of Alaska Refuges. The geodatabase is available via the R7 web "Lands Mapper." The large format, interactive GeoPDF that accompanies this document provides access to the data features. The poster is a stand-alone Adobe PDF file delivered with this document. Instructions for accessing this GeoPDF are located in Appendix C. Direct questions regarding geospatial data access to the Refuge WRB (907-786-3474).

3. Kanuti Refuge Establishment

Established by the Alaska National Interest Lands Conservation Act (ANILCA), 94 Stat. 2386, on December 2, 1980, Kanuti Refuge encompasses approximately 1,430,300 acres of federally managed public lands.

ANILCA established major purposes for the management of the Refuge. The purposes of Kanuti Refuge are:

> (i) To conserve fish and wildlife populations and habitats in their natural diversity including, but not limited to, white-fronted geese and other waterfowl and migratory birds, moose, caribou (including participation in coordinated ecological studies and management of the Western Arctic caribou herd), and furbearers;
>
> (ii) to fulfill the international treaty obligations of the United States with respect to fish and wildlife and their habitats
>
> (iii) to provide, in a manner consistent with the purposes set forth in sub paragraphs (i) and (ii), the opportunity for continued subsistence uses by local residents
>
> (iv) to ensure, to the maximum extent practicable and in a manner consistent with the purposes set forth in paragraph (i), water quality and necessary water quantity within Kanuti Refuge.

Kanuti Refuge Revised Comprehensive Conservation Plan (USFWS, 2008) outlines the Refuge's vision and goals. Goals 1 and 2 highlight the importance of understanding the natural state and function of water resources across the refuge landscape:

> Goal 1: Conserve the Refuge's diversity of wildlife, fish, and habitats, while allowing natural processes, including wild land fire and the natural hydrologic cycle, to shape the environment.
>
> Goal 2: Ensure the natural function and condition of water resources necessary to conserve fish and wildlife populations and habitats in their natural diversity.

The goals provide direction for water-related management activities that help the Refuge achieve their water resource-related goals.

4. Natural Setting

Kanuti Refuge encompasses a broad basin between the Brooks Range to the north and the Ray Mountains to the south. The Koyukuk and Kanuti Rivers traverse this basin (Map 1). The lands and waters within the Refuge drain into Yukon River and then into the Bering Sea. The roadless landscape consists primarily of rolling hills, wetlands, ponds, and streams. Several habitats dominate the boreal forest ecosystem: upland spruce-hardwood forest, low shrub and muskeg-bog, lowland spruce-hardwood forest, alpine tundra, bottomland spruce-poplar forest, freshwater lakes, moist tundra, and miles of freshwater riverine ecosystem (Joint Federal State Landuse Planning Commission for Alaska 1973). Elevations range from 500 feet to over 3,000 feet. The Arctic Circle passes through the center of the Refuge.

The physiography, geology, soils, vegetation, and weather provide the context for Kanuti Refuge's hydrologic systems, creating the form and pattern that drive the behavior of waters through the landscape. The natural setting of the Refuge controls the movement and ponding of water across Refuge lands. Descriptions of the components that form the hydrologic systems provide the explanation of water resource function. Managing the continued health of these resources for fish and wildlife populations is impossible without this underlying understanding.

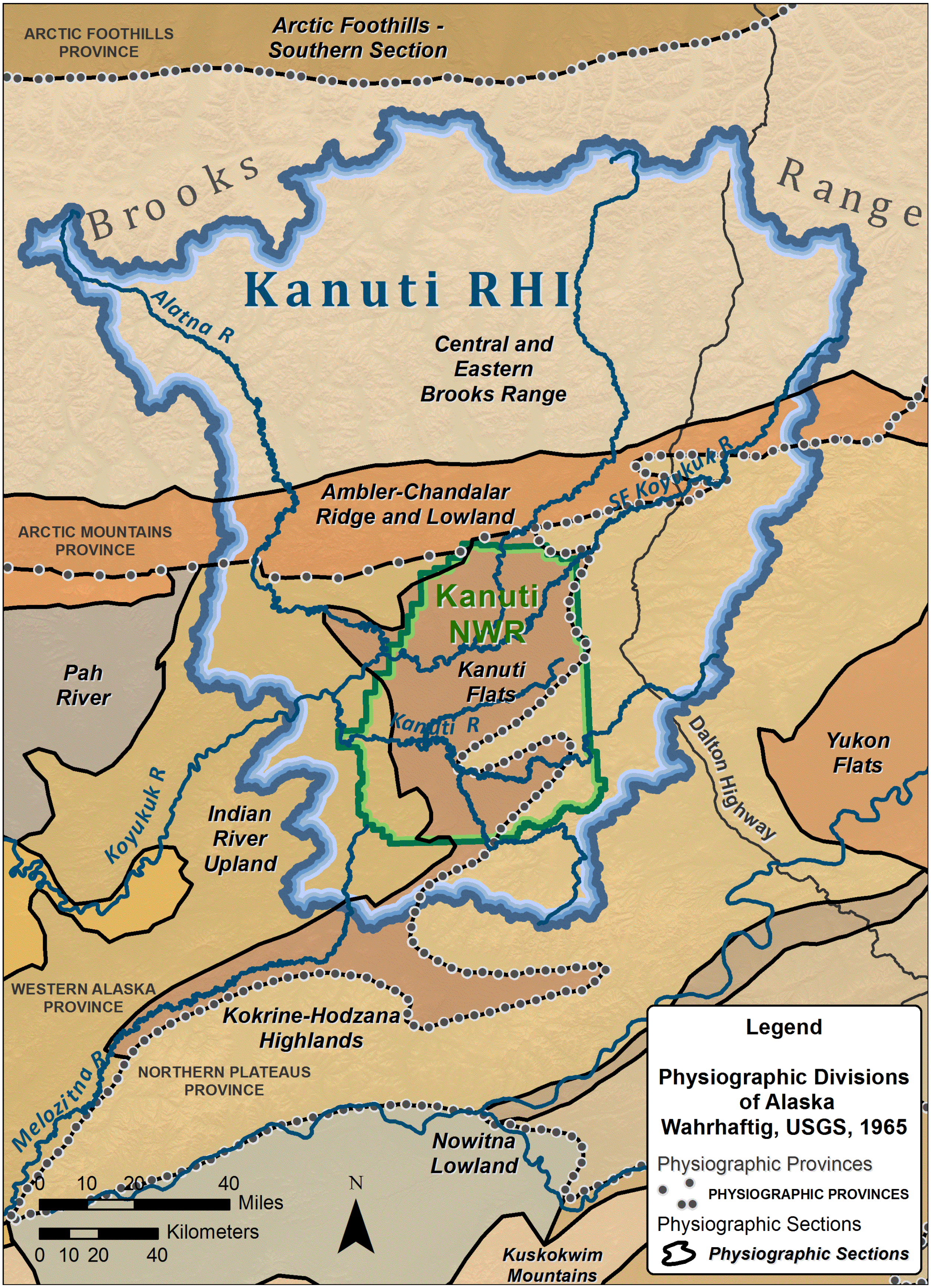
4.1. Physiography

The characteristics of the different physiographic provinces create the hydrologic landscape that controls the flow of water across the Kanuti National Wildlife Refuge. Alaska is divided into four physiographic divisions (Wahrhaftig 1965). The Refuge is within the Intermountain Plateaus Division, which is divided into 12 physiographic provinces and 60 smaller sections. The Refuge lies almost completely within the Kanuti Flats section of the Western Alaska province (Map 2). The RHI extends to more rugged terrain and northern latitudes in the Arctic Mountain Province.

Continuous permafrost dominates the Kanuti Flats section. Consequently, lake-dotted plains (400–1,000 ft. elevation) above permafrost dominate the majority of Kanuti Refuge (Wahrhaftig 1965). Permafrost is generally continuous but may be discontinuous or absent under the larger lakes, rivers, and the mountainous portions of Kanuti Refuge within the Indian River Uplands and Kokrine-Hodzana Highlands (Wahrhaftig 1965).

The RHI extends into the Arctic Mountain Province, dominated by the rugged, historically glaciated peaks of the Endicott Mountains in the central Brooks Range. A few cirque glaciers remain in the higher parts of the range. Most of this region lies within the continuous permafrost zone (Ferrians 1965; Wahrhaftig 1965).

The Koyukuk and South Fork Koyukuk Rivers originate in the high latitude, high elevation mountains of the Arctic Mountain Province; their streamflow is driven by runoff of rain events and snowmelt accumulated throughout the mountain range. Rivers that originate in areas of lower elevation and latitude experience different precipitation and melt timing, such as the Kanuti River and Henshaw Creek.



Map 2: The Physiographic provinces and sections of Kanuti Refuge and RHI

4.2. Geology

The geologic history of Kanuti Refuge, including tectonic, volcanic, glacial, and erosive activities, shapes the physical features and affects the hydrology, morphology, water quality, and ecological function of the Refuge's streams and lakes.

The state of Alaska is composed of lithotectonic terranes accreted onto the North American continent and rotated into their present positions. Kanuti Refuge lies across two of these terranes, the Koyukuk and the Ruby Terranes.

The Koyukuk Terrane underlies the Kanuti Flats. Arc-related volcanic and volcaniclastic rocks compose the terrane, which is the basement of the Yukon-Koyukuk basin. Conglomeratic rocks from erosion of oceanic and metamorphosed continental rocks lay atop this terrane.

The Ruby Terrane is a geanticline composed of metamorphosed continental margin assemblage. The Ruby Terrane forms the Kokrine-Hodzana Highlands in the southern and eastern portions of the Refuge. Granitic plutons intrude into both the Koyukuk and the Hodzana Terranes (Dusel-Bacon et al. 1989; Hamilton 1989; Plafker and Berg 1994; U.S. Fish and Wildlife Service 2008).

Deposits from five glaciations, which include phase I and II of the Itkillik age glaciation, that came down the three major valleys, the Koyukuk, John, and Alatna from the southern Brooks Range, lie over most of the bedrock geology within the Refuge (U.S. Fish and Wildlife Service 2008). These deposits form the current landscape of the Refuge and drive the form and function of its ecological system by affecting drainage courses, the high density of lakes, and the permafrost distribution that creates unique aquatic habitats.

The oldest glaciation is the Gunsight Mountain glacial advance of Tertiary age. Drifts from this glaciation are visible in a few isolated places along the hills in the southern portions of Kanuti Refuge. In other areas, drift materials eroded or were buried under 100–130 ft. of silt (Hamilton 2002; U.S. Fish and Wildlife Service 2008).

The Anaktuvuk River age glaciation advanced to the area just south of the Koyukuk River 0.8 million years from the present. The moraine deposits of this advance form the divide between the Koyukuk River and Kanuti Chalatna Creek. The glacier terminated in a large proglacial lake. Lake deposits are found across Kanuti Flats and extend up the river valleys. In addition to the glacial lake sediments, drift and moraine deposits and outwash gravel deposits occur (Hamilton 2002; U.S. Fish and Wildlife Service 2008).

The Sagavanirktok River age glaciation from the middle Pleistocene advanced down the Koyukuk River to the area above the confluence with the South Fork Koyukuk River. It also advanced down the South Fork Koyukuk drainage to the area just above Jim River where it terminated in a proglacial lake. Deposits from the lake extend into the Kanuti Kilolitna River drainage, the Kanuti River drainage, Fish Creek drainage, and the Alatna River drainage. There are also extensive deposits across Kanuti Flats (Hamilton 2002; U.S. Fish and Wildlife Service 2008).

The Itkillik age glaciation occurred in the late Pleistocene in two phases, only the first of which left significant deposits within Kanuti Refuge. The glacial advance of Phase I terminated in the John River drainage at the confluence with the Koyukuk River. The only deposits within the Refuge itself are outwash gravels found along the South Fork and above the confluence of the Main Stem Koyukuk Rivers (Hamilton 2002; U.S. Fish and Wildlife Service 2008).

4.3. Soils

Soils form over time from weathered rock and minerals; parent geologic materials, climate, vegetation, time, and topography affect the formation process. The resulting soil profile influences the flow and characteristics of water across Kanuti Refuge and affects the quality of habitat available to species. A reconnaissance survey and mapping of Alaska's soils was performed by Rieger from 1967–1973 (Rieger et al. 1979). Rieger's study found that continuous permafrost underlies large parts of the Refuge, but noted that areas of discontinuous permafrost exist below large lakes and rivers and other areas where vegetation, soil type, and snow cover influence soil temperatures.

More recent soil work includes the Natural Resource Conservation Service's (NRCS) State Soil Geographic Digital General Soil Map (STATSGO2) mapped at the scale of 1:1,000,000. The level of mapping of STATSGO2 is designed for broad planning and management uses rather than local analysis of soil condition. NRCS, assisted by the Refuge, ground-truthed the STATSGO2 data in 2010 with 32 soil test pits located in the Refuge boundary and 1 soil pit located in the RHI in Bettles (personal communication with Josh Rose, 11/21/2016). The NRCS has not completed the more detailed NRCS dataset, Soil Survey Geographic (SSURGO), for the RHI/Refuge region.

A general review of soils based on the existing data revealed that the soils of Kanuti Refuge differ between northern and southern exposures. South-facing areas have dry, well-drained, gravelly soils. North-facing slopes contain wet, gravelly soils with permafrost, which mantle the valley slopes and scattered hills. The wet soils of the valley floors adjoin the river terraces and are gravelly and loamy with thick overlying tundra mats and continuous permafrost. Sandy, well-drained terrace soils consist of deeply interbedded gravels, sands, and silts (JointFederalStateLandusePlanningCommissionforAlaska 1973).

Soil types on Kanuti Refuge belong to a broad order of soils called Inceptisols. Inceptisols have undergone relatively little change from their parent material during the soil-forming process and thus do not have multiple layers or horizons found in other regions. There are multiple soil map units/soil associations within the Inceptisol order. Most of the soils on Kanuti Refuge belong to two associations: IQ2-Histic Pergelic Cryaquepts and IQ4-Histic Pergelic Cryaquepts-Typic Cryorthents (Rieger et al. 1979).

Histic Pergelic Cryaquepts soils have thick accumulations of organic matter in the soil. The soil surface is commonly irregular, with many low mounds, solifluction lobes, and evidences of soil movement. This soil type is very extensive in lowland and hilly areas of interior, arctic, and western Alaska, and dominates the lowlands of the Refuge (Rieger et al. 1979). The soil texture ranges from very gravelly sand to clay, and parent material includes volcanic ash, alluvium, loess, lacustrine deposits, and weathered rock. The thick organic layer effectively insulates the lower layers from summer heat and protects the shallow permafrost that underlies much of the Refuge's lake habitat (Wortham 1995). The soils typically support sedge tussocks, mosses, low shrubs, and other tundra plants (Rieger et al. 1979).

The Histic Pergelic Cryaquepts-Typic Cryorthents soils occupy parts of the Kanuti Flats and the adjoining low rolling hills and terraces (Rieger et al. 1979). In this subgroup of soil, the organic matter has no stratification or is irregularly distributed. It occurs over bedrock, is thicker than 20 inches, and has a mean annual temperature above freezing (Rieger et al. 1979). This soil type characterizes the low rolling moraine hills and knolls, broad shallow depressions and drainage ways, and muskeg areas that typify Kanuti Refuge.

4.4. Wetlands and Vegetation

Alaska has more area covered by wetlands—approximately 170 million of its 367 million acres—than the total area of wetlands in the other 49 states combined (Dahl 1990). Alaska's wetland complexes differ in size, function, and type, and include wetland types that are rare in other states, like the expanses of treeless tundra that exist on Kanuti Refuge.

The Refuge's wetland complexes play an important role in hydrologic and biological functions. Wetlands provide forage for caribou and moose, as well as food and habitat for beaver, muskrat, mink, and river otter. They provide habitat and forage for large flocks of waterfowl and shorebirds during spring and fall migration, and resident species of birds throughout the year. Wetland plants help control erosion of mineral soils by decreasing wind and water velocities near the ground and by holding soil particles together with their roots. In permafrost areas, wetland vegetation reduces erosion by preventing the warming and thawing of ice-rich soils. In floodplains, the same vegetation removes some suspended sediment from floodwaters pushing through the system. Wetlands transform and retain nutrients and toxic compounds that attach to the organic and fine mineral soils. Plants, phytoplankton, fungi, and bacteria use those nutrients and degrade some of the contaminants. The form and function of wetlands are essential to the continued health of the Refuge's habitat.

A land cover analysis conducted by the Alaska Center for Conservation Science (formerly the National Heritage Program in Alaska) for the USFWS (Flagstad 2016) concluded that wetland distribution across the Refuge and RHI is underestimated due to the limitations of the available data. The underestimate of wetland habitats underscores the need for refined wetland, soil/permafrost, land cover, and hydrography datasets. This analysis characterizes the Refuge as 81% upland, 15% wetland, and 4% deepwater habitats. In the combined area of the Refuge and RHI, 86% of the mapped area is classified as upland, 12% as wetland, and 2% as deepwater habitat (Flagstad 2016).

Dominant cover types thought to represent wetland habitats (and referred to here as "wetland" land cover types) within the Refuge are Fire Scar - Low Shrub Tussock Tundra, Low Shrub - Tussock Tundra, and Clear Water; these three types combined represent over 80% of the habitat mapped as wetland or deepwater. Dominant upland cover types within the refuge are: Open Needleleaf, Woodland Needleleaf, Fire Scar, Open Mixed Needleleaf/Deciduous, and Closed Deciduous, which together represent 62% of the habitat mapped as upland (Flagstad 2016).

Dominant wetland cover types comprising approximately 65% of wetland habitat within the RHI are Low Shrub - Tussock Tundra, Upland Organic-rich Moist Acidic Dwarf Birch-Tussock Shrub, Lowland Organic-rich Wet Acidic Black Spruce Forest, and Fire Scar - Low Shrub Tussock Tundra. Dominant upland cover types within the RHI are Alpine Rocky Dry Dryas Dwarf Shrub, Open Needleleaf, Upland Rocky-loamy Moist White Spruce Forest, Woodland Needleleaf, Upland Moist Dwarf Birch-Ericaceous-Willow Low Shrub, and Low Shrub, which together represent 53% of the habitat mapped as upland (Flagstad 2016).

4.5. Weather and Climate

Weather and climate are significant components of the hydrology and water-related habitats of Kanuti Refuge.

Weather is the mix of events that happen each day in our atmosphere, including air temperature, rainfall, and humidity. Weather drives daily hydrologic behavior; annual weather patterns drive annual flow patterns of rivers and lakes.

Regional climate is a summation of the inter-annual variability of weather patterns over many years. The hydrologic regime varies within a predicable range of average daily, monthly, and annual flow based on the regional climate conditions of temperature and precipitation. As a result, hydrologic response is sensitive to changes in both weather and climate.

The Refuge experiences a strong continental climate due to its location between the Alaska Range to the south and the Brooks Range to the north (Gallant et al. 1995; Stewart et al. 2013). These mountain ranges act as barriers to coastal air masses, producing a continental climate with cold winters and warm summers. The climate is dry with nearly half of the precipitation occurring in the summer. Variation in temperature, precipitation, and daylight across the region occurs primarily due to differences in topography and/or latitude, as evident in the regional weather records (Table 1a). Spatial variation in climate parameters influences flow characteristics of rivers and the hydrologic responses of the river drainages within the Refuge and the RHI.

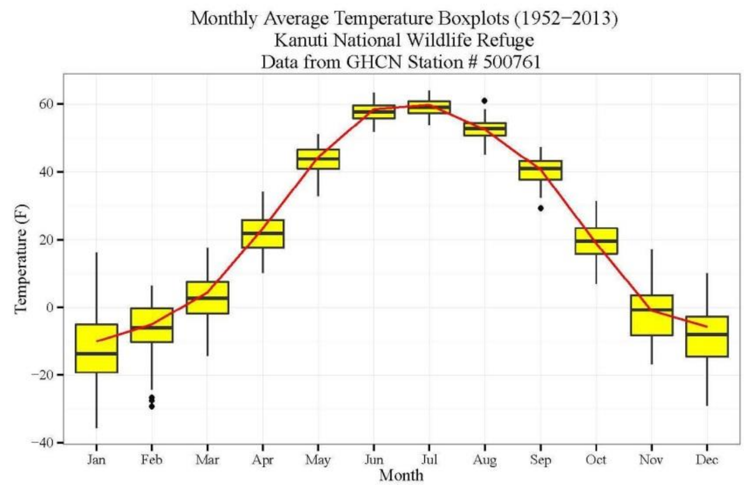
Data from the National Climate Data Center (NCDC) for Bettles, Alaska, from 1952–2013 were used to describe the climate of the Refuge and to compile annual, monthly, and extreme climate statistics. The Western Regional Climate Centers (WRCC) provided calculated climate statistics from weather stations in Allakaket, Anaktuvuk Pass, Coldfoot, and Wiseman, all of which help describe the variation in climate across the broad and varied RHI (Table 1a).

Table 1a: Mean annual and extreme temperatures (°F), mean annual precipitation (inches), and average total snowfall from five climate stations across Kanuti RHI (Western Regional Climate Center (WRCC)).

Location	*Average air temperature(°F)*	*Extreme high temperature (°F)*	*Extreme low temperature (°F)*	*Average total precipitation (inches)*	*Average total snowfall (inches)*
Allakaket	18.6	94	-75	12.4	61.3
Anaktuvuk Pass	13.9	91	-47	9.8	57.7
Bettles	22.3	93	-70	17.3	83.3
Coldfoot	19.4	88	-74	15.8	93.6
Wiseman	22.3	87	-65	13.6	73.6
Average	**19.3**	**91**	**-66**	**13.8**	**73.9**

Air temperature varies widely between summer and winter in interior Alaska. The mean annual temperature is 23.3°F at the Bettles Airport (1952–2013). The warmest month is July, averaging 60.0°F. The coldest month is January, averaging -12.0°F. Extreme temperatures range from -70°F in January to +93°F in July. Figure 2 (bottom) presents a plot of the mean distribution of monthly temperatures at the Bettles Airport. The plot emphasizes the temporal variability of temperature from month to month and year to year.

Precipitation is lightest in April and heaviest in August. Average annual precipitation is 14.80 inches at Bettles, 35% of which falls as snow (McAfee et al. 2013). Most summer and winter precipitation comes from major frontal systems that cross the state, but



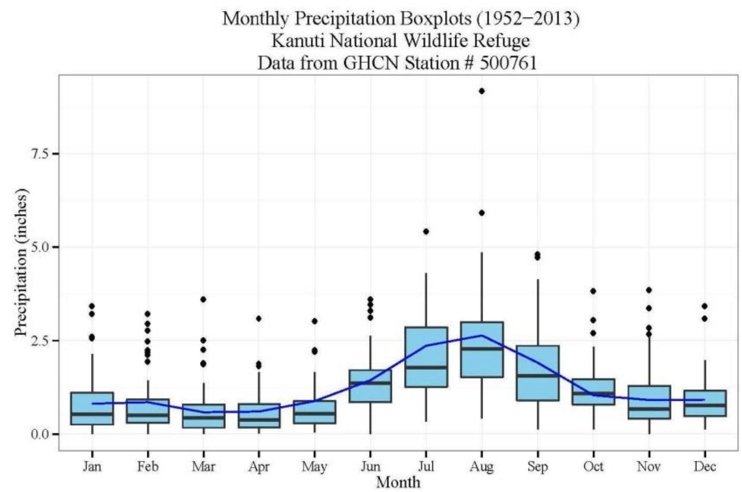


Figure 2: Box plots of mean distribution of precipitation (top) and temperature (bottom) at Bettles Airport station (GHCN Co-op ID 500761).

convective storms add significantly to summer precipitation (Hinzman et al. 2006).

Precipitation events occur throughout the summer months (June, July, and August) with high spatial variability. September rain events follow wet summer conditions. Although precipitation occurs throughout the summer, 76 to 100 percent is lost to evapotranspiration (Dingman 1966), which affects river flow and surface water retention in lakes, ponds and wetlands. Studies have shown that much of the summer precipitation comes from water recycling as it evaporates from land (Serreze and Etringer 2003). Figure 2 (top) presents a plot of the mean distribution of monthly precipitation at the Bettles Airport.

Historically, snow covers the ground from mid-October until mid-April or May and is an important climate and ecological factor in the Refuge's boreal forest ecosystem (Hinzman et al. 2006). Snowmelt occurs in the late spring (typically May) and does not usually occur during the winter. The snowmelt/breakup period is a major weather-driven hydrologic event each year. According to data from the (NWS Alaska Pacific River Forecast Center breakup database, dates for the average, earliest, and latest breakup of the Koyukuk River at Bettles are 10 May, 25 April, and 27 May, respectively, from 1917–2016. The average, earliest, and latest breakup dates of the Koyukuk River at Allakaket are 11 May, 26 April, and 27 May, respectively, from 1940–2016.

The average annual snowfall in Bettles is 83.3 inches per year, creating an average snowpack depth of 26.0 inches by mid-March to early May, based on precipitation data from the Bettles Airport (1952–2013). Kanuti Refuge monitors six NRCS aerial snow markers. Two NRCS SNOTEL sites lie outside the Refuge at Bettles Field (Station 1182) and Gobblers Knob (Station 962). The Bettles Field Station also has a snow course/aerial marker (Station 51R01). Table lb. lists the aerial snow marker sites along with the average snow depth per month, and the total average snowfall per year at these sites. These data emphasize the spatial variability of snow precipitation within the Refuge (Figure 3). Service employees divide the Refuge into wet (north) and dry (south) precipitation zones, which is somewhat suggested by these data (Personal Communication with Josh Rose 2016).

Table 1b: Mean snow depth (in) from 6 aerial snow marker sites across Kanuti Refuge/RHI

Station Name	***Bettles Field***	***Kaldolyeit***	***Kanuti Chalatna***	***Kanuti Kilolitna***	***Minnkokut***	***Nolitna***
NRCS Snow Course Site ID	***51R01***	***51R02***	***52R02***	***52R04***	***51R03***	***52R03***
Period of Record	***1967–2014***	***1999–2016***	***1999–2016***	***1999–2016***	***1999–2016***	***1999–2016***
Nov	--	11.0	7.0	6.2	9.6	9.4
Dec	--	11.9	12.7	10.2	12.5	12.7
Jan	19.0	15.5	22.0	16.5	22.5	22.0
Feb	26.4	23.9	21.8	19.3	27.5	23.4
March	29.9	21.1	29.6	21.1	30.1	25.5
April	31.3	24.1	27.0	20.0	33.1	26.1
May	20.0	10.4	11.9	8.1	20.8	11.6
Position in Refuge	N (just outside Refuge in RHI)	NE	NW	S	N	SW
Elevation (ft.)	640	750	670	550	580	560

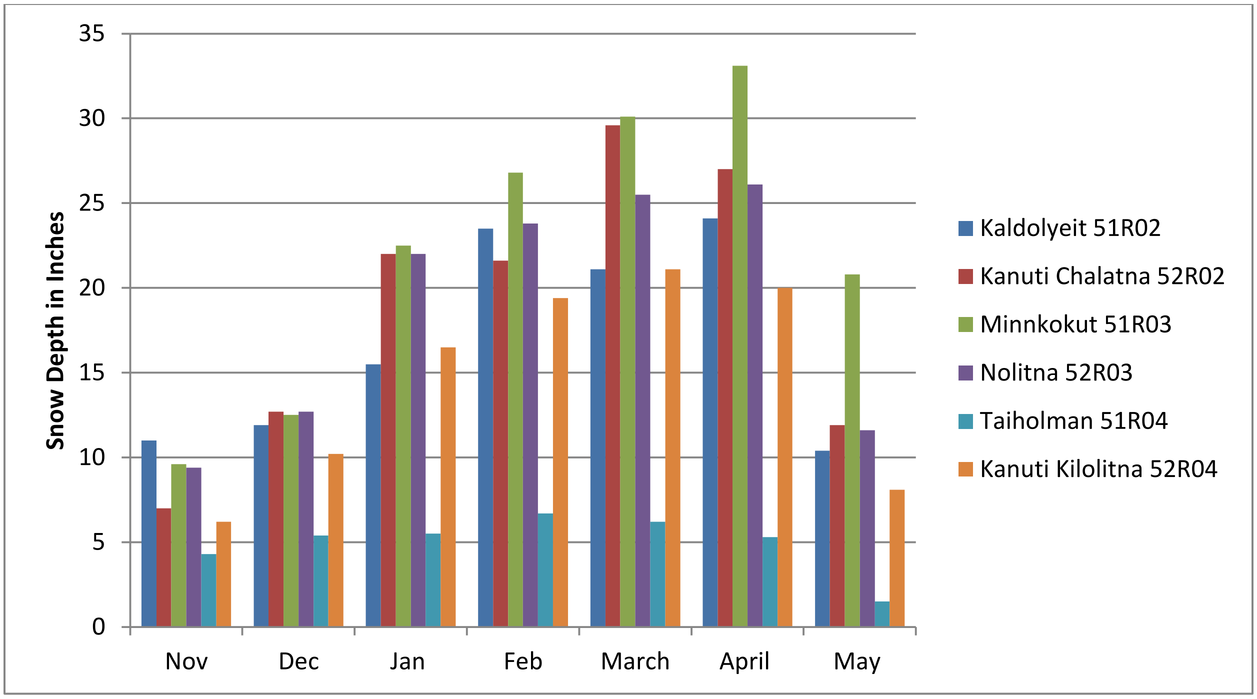


Figure 3: Monthly snow depth (in) at snow course sites within Kanuti Refuge and RHI. Note that the Taiholman marker was moved (see text for details).

Data from the Taiholman site (station 51R04; Figure 3), located in the southeastern portion of the Refuge, was not included in the table due to data abnormalities from snow drifting. The Refuge moved the Taiholman marker after 2014 due to the chronic drifting issue. The marker is now located at north of its original location to Gel Lake (N66.44820 x W151.69842 at an approximate elevation of 170m). NRCS installed a SCAN site at nearby Kanuti Lake in 2014; it currently best captures snowfall in the southeastern portion of the Refuge.

The effects of variation in temperature, precipitation, and snowmelt in the headwaters of the Refuge's river systems result in unique breakup and runoff patterns between the Refuge's rivers. The arctic climate in the Brooks Range differs from the conditions found within Kanuti Refuge. Differences in latitude and elevation of the Brooks Range and the mountains surrounding the Refuge create micro-climatic variations that drive differences in river flow behavior.

5. Water Resources Inventory Summary and Characterization

This section summarizes and characterizes water resource conditions and issues influencing Kanuti Refuge's purpose of maintaining the natural diversity of fish and wildlife habitats and populations.

5.1. Surface Water

5.1.1. Riverine Habitat

The rivers and streams flowing through Kanuti Refuge (Map 3) are part of the Koyukuk River Basin. The Koyukuk River and its major tributary, the Kanuti River, drain the Refuge. This discussion summarizes the extent (Table 2) of the systems managed by the Refuge and describes their annual and seasonal flow patterns. Map 3 and Table 2 also include rivers in the RHI with special designation as Anadromous Waters (through AWC) and Wild and Scenic Rivers.

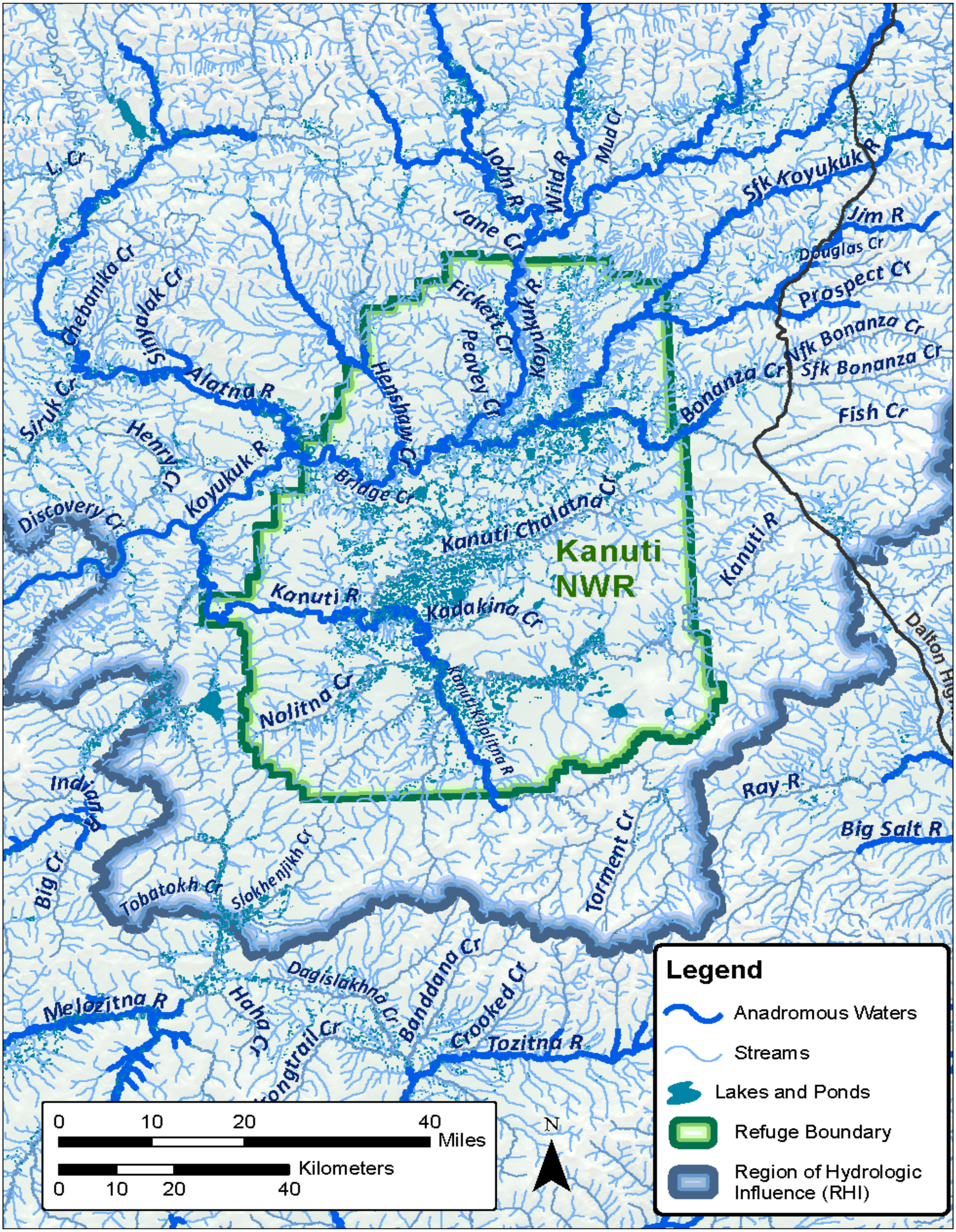
Table 2: Length of named, unnamed, and specially designated rivers in Kanuti Refuge/RHI

Name	*Within External Boundary of Kanuti Refuge (miles)*	*Within RHI Buffer (miles)*
Named Rivers	398	2801
Unnamed Rivers	1915	9772
Anadromous Rivers	141	503
National Wild and Scenic Rivers	0	281

The Refuge purposes include ensuring water quality and necessary water quantity within the Refuge to conserve fish and wildlife populations and habitats in their natural diversity. The magnitude, timing, duration, and frequency of flow in rivers drive the formation of in-channel, floodplain, and upland habitats, biological productivity, and ecological diversity of river systems (Poff et al. 1997).

Annual hydrographs (Figure 4) of rivers monitored for flow in Kanuti Refuge from 2008–2015 illustrate the similarities and differences in annual and seasonal flow patterns of the Refuge's rivers. In general, annual high flows occur during spring snowmelt and/or breakup in late May. Following the snowmelt or breakup peak, the volume of flow in these systems recedes steadily through June. Summer and intermittent fall rain events contribute runoff and create small peaks in the hydrographs. Occasionally these rainfall events can generate the peak flow of the year. River flows recession continues into September and October as ice cover encompasses the rivers by mid-October to November and eventually recedes to winter base flows in March.

Most rivers in the Refuge remain ice-covered or frozen to substrate through the end of April unless they are influenced by groundwater inputs. Some reaches of the Kanuti Kilolitna River, Henshaw Creek, and portions of the South Fork Koyukuk just outside of the Refuge and downstream of the Dalton Highway, show groundwater influence and remain open and flowing throughout the winter (USFWS, 2015).



Map 3: Rivers in Kanuti Refuge and a portion of the RHI.

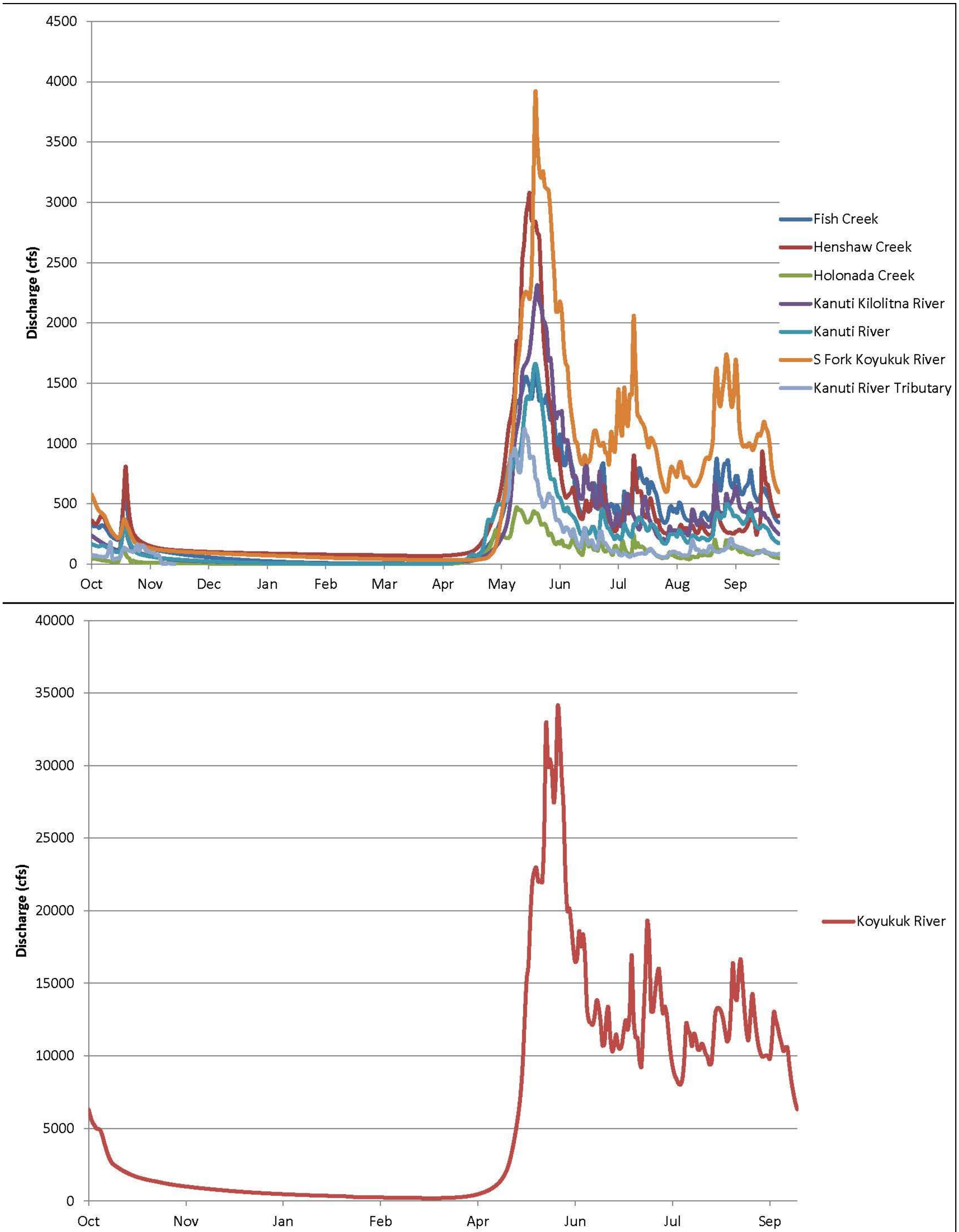


Figure 4: The upper pane is the period of record (POR) hydrograph for seven rivers in Kanuti Refuge. Flow of the Koyukuk River is an order of magnitude greater and therefore the period of record hydrograph is plotted in a separate view below (lower pane) for clarity.

Variations in the seasonal flow patterns among the rivers of the Refuge, visible in the annual hydrographs (Figure 4), result from differences in headwater locations, basin topography, and basin weather. Precipitation and snowmelt drive the hydrology of these systems. The Koyukuk River (both north and south forks) originates in the Brooks Range and drains the northern portion of Kanuti Refuge. The Kanuti River, originating at lower elevations in the Hodzana Highlands and the Ray Mountains, drains the southern portion of the Refuge.

The Koyukuk and South Fork Koyukuk Rivers are subject to the influences of weather and snowmelt in the high elevation mountains of the Brooks Range. In some years, the difference in headwater elevation and latitude translates to peak snowmelt flows that lag two to three days behind the rivers at lower elevations and latitudes. These higher systems often experience an ice flushing breakup event followed by a snow melt-off event.

Flow in systems at lower latitudes and elevations (e.g., Henshaw Creek, Holonada Creek, Kanuti River, Kanuti Kilolitna River, and Fish Creek) is influenced by earlier snowmelt and less dramatic precipitation events in the hills surrounding the Refuge. These lower elevation/latitude systems are more likely to see one snowmelt-breakup peak.

Ice jams are a significant event in interior river systems and cause significant bank erosion, deforestation, and overbank flooding. According to the Army Corps of Engineers' Alaska Baseline Erosion Assessment (USACE 2007), "flooding and associated erosion caused by ice jams is a common occurrence in Allakaket. Major flood events occurred in 1937, 1938, 1939, 1964, 1966, 1968, 1989, and 1994." The significance of ice jam flooding warrants the NWS Alaska-Pacific River Forecast Center (APRFC) to monitor breakup and issue flood and navigational hazard warnings.

Hydrographs for the period of record (2009–2015 water years) (Figure 4), demonstrate the natural variability of streamflow magnitude between rivers. Hydrologic statistics provide another way to compare, contrast, and understand the natural flow patterns that sustain the riverine and upland habitats of Kanuti Refuge. Table 3 and Table 4 provide hydrologic statistics to quantify the difference between average and instantaneous river flows of eight rivers on Kanuti Refuge. The Koyukuk River gage was not established until the end of the 2009 water year and continues to be operated, but data associated with the Koyukuk is limited to the 2009–2015 water years for the purpose of comparison with gages that were removed from the Refuge at the end of the 2015 water year.

Mean annual streamflow for the Koyukuk River is 6,880 cubic feet per second (cfs) for the water years 2009–2015, one to two orders of magnitude larger than the other sites. The next largest gaged stream is the South Fork Koyukuk River with a mean annual streamflow of 592 cfs. Fish Creek, Henshaw Creek, and the Kanuti Kilolitna River are all comparably sized streams with mean annual stream flows between 294 and 378 cfs. The Kanuti River, TKQ (a tributary of the Kanuti River 7.5 miles downstream from the outlet of Tokusatatquaten Lake oulet), and Holonada Creek all have mean annual streamflow below 234 cfs. The amount of total discharge captured each year in the peak discharge event ranged from 1.0% for Fish Creek in 2011 to 6.5% for the Kanuti River and Henshaw Creek in 2012. Maximum discharges for all sites generally occurred during breakup in the spring on an annual basis, with exceptions in 2010 and 2014 when late June and July flows slightly exceeded breakup flows, and 2015 when fall flows exceeded breakup flows. Excluding the Koyukuk River, the South Fork Koyukuk had the largest peak discharge event each year except 2013, when Henshaw Creek's peak discharge exceeded the peak on the South Fork Koyukuk.

Table 3: Hydrologic statistics, including flow in cfs (cubic feet per second), for eight gaged rivers within Kanuti Refuge. Period of record (POR) is 2009–2015 water years.

Gaged River at site location	*Drainage Area (mi^2)*	*Average Annual Flow (cfs) for the POR*	*Peak Instantaneous Flow (cfs)*	*Date of Instantaneous Peak Flow*	*Maximum Average Daily Flow (cfs)*	*Date Max Ave Daily Flow*	*Average Annual Run Off Depth (cfs/mi^2)*
Fish Creek	524	345	4,820	7/15/2014	4,570	5/24/2011	0.66
Henshaw Creek	522	378	7,660	5/19/2011	7,070	5/26/2013	0.72
Holonada Creek	156	73.8	1,810	7/15/2014	1,470	7/15/2014	0.47
Kanuti Kilolitna River	505	294	4,330	6/20/2014	3,950	5/28/2013	0.58
Kanuti River	348	215	4,430	5/28/2013	4,870	5/25/2013	0.62
Koyukuk River[a]	6,930	6,880	134,000	5/26/2013	76,500	7/15/2014	0.99
South Fork Koyukuk River	868	592	12,000	7/15/2014	11,200	7/15/2014	0.68
TKQ[b]	218	NA[b]	1,560	6/19/2014	NA[b]	NA[b]	NA[b]

[a] Koyukuk River period of record begins in 2010 (2010–present)

[b] Winter results and average annual statistics not yet available.

Table 4: Maximum and mean daily discharge (in cfs) for eight rivers in Kanuti Refuge. Includes both annual and period of record (POR: 2009–2015) data.

Monitoring Site	**Water Year (Oct 1-Sept 30)**	**2009 (cfs)**	**2010 (cfs)**	**2011 (cfs)**	**2012 (cfs)**	**2013 (cfs)**	**2014 (cfs)**	**2015 (cfs)**	**POR Mean Daily**
Fish Creek	Max. Daily discharge	2,100	1,130	4,570	2,590	2,890	4,200	4,060	1,637
	Mean daily discharge	388	127	403	405	244	571	277	345
Henshaw Creek	Max. Daily discharge	4,370	2,750	6,740	5,370	7,070	6,260	4,900	3,076
	Mean daily discharge	318	223	318	567	386	510	328	378
Holonada Creek	Max. Daily discharge	826	726	978	868	932	1,470	1,090	470
	Mean daily discharge	54.1	47.9	76.2	75.1	51.3	129	83.1	73.8
Kanuti Kilolitna River	Max. Daily discharge	3,260	2,400	3,570	3,430	3,950	3,750	2,940	2,313
	Mean daily discharge	242	165	352	345	244	451	261	294
Kanuti River	Max. Daily discharge	1,140	890	3,320	1,870	4,870	2,340	1,940	1,663
	Mean daily discharge	173	86.9	242	237	209	383	176	215
Koyukuk River[a]	Max. Daily discharge	NA[a]	52,300	72,100	47,600	61,300	76,500	49,200	34,033
	Mean daily discharge	NA[a]	9,550	5,590	8,380	4,020	8,510	5,200	6,875
South Fork Koyukuk River	Max. Daily discharge	5,530	5,580	10,300	6,320	6,930	11,200	6,340	3,917
	Mean daily discharge	501	414	575	814	414	948	479	592
TKQ[b]	Max. Daily discharge	541	787	806	1,280	1,230	1,330	NA[b]	NA[b]
	Mean daily discharge	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]

[a] Period of record begins in 2010 for Koyukuk River

[b] Winter results and average annual statistics not yet available Results for 2015 water year are preliminary

5.1.2. Lacustrine Habitats (Lakes and Ponds)

The open water lakes and ponds of Kanuti Refuge provide critical habitat and productive food sources for migratory birds and waterfowl, including white-fronted geese (Harwood 2006; 2007; 2008; 2009; 2010; 2012; 2014; 2015; Kafka 1988; Marks 2016; Marks and Fischer 2015). River systems that connect to these waterbodies support Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. kisutch*) and Chum Salmon (*O. keta*), Inconnu (*Stenodus leucichthys*), and other whitefish species.

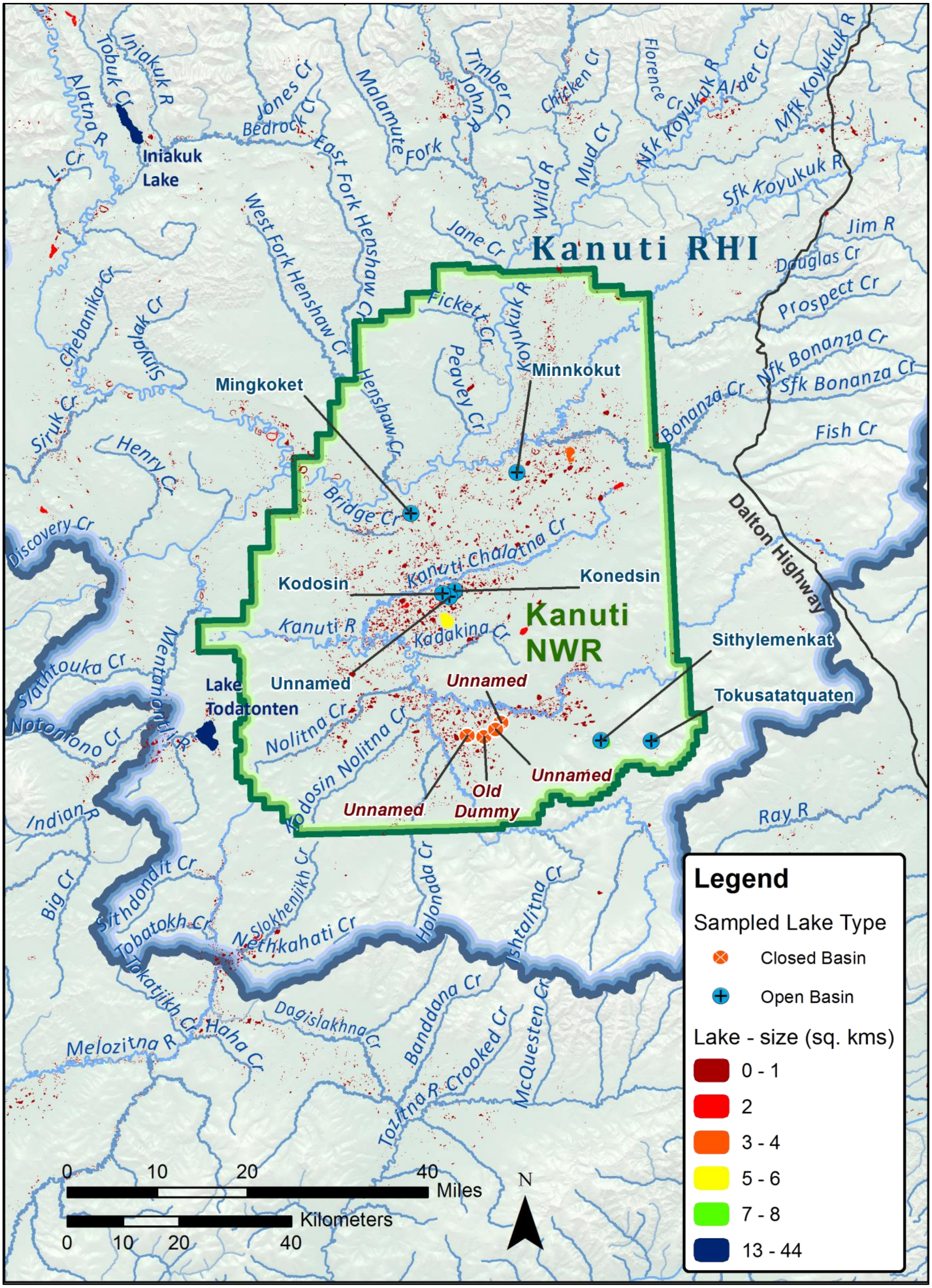
The lake and pond habitats of the Refuge cover approximately three percent of the landscape (WRIA geodatabase). The Refuge contains the majority of the Kanuti Lake District—one of twenty major lake districts in Alaska identified by Arp and Jones (2008). An abundance of small lakes characterizes the Refuge and the Lake District (Arp and Jones 2008; Kafka 1988) (Map 4). Lowlands to be dominated by shallow lakes (<3 ft.) less than 10 acres (4 hectares, 0.01 km^2 or 0.004 miles^2) in surface area dominate the Refuge lowlands (USFWS, 1986). While most of the deeper ponds are relatively small (USFWS, 1986), large, deeper (>3 ft., but up to >23 ft.) lakes exist, including Old Dummy Lake, Kanuti Lake, Kaldolyeit Lakes, Clawanmenka Lake, and Fish Creek Lake, but do not dominate the landscape (Kafka 1988). Table 5 presents the classification of lakes and ponds in the Refuge by surface area. Map 4 shows the spatial distribution of these lakes and ponds within the Refuge and the RHI.

Table 5: Classification of lakes and ponds by surface area within Kanuti Refuge and RHI.

Area Class (acres)	*Refuge Count*	*Refuge Sum of Area (acres)*	*RHI Count*	*RHI Sum of Area in RHI not including the NWR (acres)*
0–250	6,403	45,443	6,596	34,842
490– <740	1	692	1	618
740–990	3	2,965	0	0
1,240–1,480	1	1,507	1	1,557
1,730–1,980	0	0	2	4,398
3,210–10,8700	0	0	2	6,499
Total	6,408	50,607	6,602	47,914

The Refuge and the Lake District are underlain by continuous permafrost (Arp and Jones 2008; Rieger et al. 1979), which drives a prevalence of relatively shallow lakes and wetlands across the boreal forest (Brown et al. 1998, revised 2001; Jorgenson et al. 2008). The permafrost layer affects surface and sub-surface hydrology by acting as an aquiclude, which prevents surface water from percolating into groundwater (Swanson 1996). The result of this barrier is the retention of water above the permafrost layer as shallow lake systems (Roach 2011). While these groundwater-impervious lakes and ponds are common on the landscape of Kanuti Refuge, many large shallow lakes maintain groundwater connection through thaw bulbs below the lake bed (Minsley et al. 2012).

No systematic studies of the hydrologic behavior of lakes/ponds within Kanuti Refuge have been completed, though some studies note the hydrologic condition or behavior of discrete areas of lakes and ponds and provide observational information (Glesne et al. 2011; Kafka 1988; Roach 2011; Wortham 1995). Roach (2011) hypothesized the principal lake types in the lowland Boreal Forest to include a) thermokarst systems formed in depressions of thawing permafrost or b) areas affected by fluvial systems processes and river course change based on research and mapping completed by Arp and Jones (2008) and Manley and Kaufman (2002) respectively. The vast majority of the Refuges' lakes connect to rivers



Map 4: Lake and pond habitats within Kanuti Refuge and a portion of the RHI. Sampled lake types are associated with the 1980s lake and fisheries study (Glesne et al. 2011).

through a network of shallow channels, with many containing emergent vegetation (Personal Communication Josh Rose 2016). The water level in some lakes rise when spring flooding and overbank flows of the riverine systems connects low-lying lakes (Kafka 1988; Wortham 1995).

The extent and condition of permafrost not only drives a prevalence of relatively shallow lakes and wetlands across the Refuge, it plays an important role in the behavior and permanence of many Alaskan lakes (Arp and Jones 2008). Studies attribute some of the broad-scale losses in lake number and area in the arctic and sub-arctic boreal forest over the past ~50 years to changes in permafrost condition (Labrecque et al. 2009; Riordan et al. 2006; Smith et al. 2005). Roach (2011) found that shallow, closed-basin lakes occurring in regions of relatively ice-poor permafrost are more susceptible to losses in lake area due to fine-scale mechanisms. Although many of the shallow lakes across the lowlands of the Refuge are open to surface water inputs, the loss of permafrost may open alternative subsurface flow paths, allowing lakes to drain, and altering lake and wetland habitats.

Permafrost loss is not the only contributor to lake area change across Alaska; recent studies hypothesize multiple causes associated with these changes (Arp et al. 2016; Arp et al. 2013; Arp et al. 2015; Arp et al. 2012; Surdu et al. 2014). Arp et al. (2015) showed that the timing of lake ice out events in arctic and sub-arctic regions correlates with surface area loss of lakes over time due to the extended period of open water evaporation. In northern Alaska, ice out on lakes that freeze to substrate—like the small, shallow lakes that dominate Kanuti Refuge and Lake District (Arp et al. 2013)—occurred on average 17 days earlier than deeper lakes with floating ice (Arp et al. 2015). The effect of these results on the Refuges' lakes is complicated by the findings that changes in winter climate may be shifting lakes that currently freeze to substrate into lakes with floating ice regimes and later ice out timing (Arp et al. 2012; Surdu et al. 2014). This change in ice regime may also cause degradation of permafrost below the previously frozen systems, losing what is thought to protect the integrity of lake-bed permafrost (Arp et al. 2016). The interaction of lake ice, permafrost, and climate, as described through the research discussed above, makes it difficult to determine the cause(s) of lake change and thus emphasizes the need for lake area monitoring.

The Service conducted a large-scale study of lakes and fisheries in interior Alaska refuges from 1984–1986. Eleven lakes (Map 4) were randomly selected to represent the hydrologic behavior of open- and closed-basin lake systems across Kanuti Refuge (Glesne et al. 2011). This study is one of the only empirical studies of hydrologic behavior of lakes on Kanuti Refuge. These lakes provide a starting point for long-term monitoring of open- versus closed-basin systems in the Refuge. Mapping lake basin flow patterns using available IFSAR data will improve any efforts to monitor change in different lake system types (open versus closed-basin systems) in the Refuge. Monitoring the change in water chemistry, temperature, area, and ice out timing of a subset of systems over time may help us predict habitat availability and permafrost condition of lakes in the Refuge in a warming climate.

5.1.3. Wetland Classification

Wetlands, such as fens, bogs and marshes (palustrine habitats) and open water lakes and ponds (lacustrine habitats), dominate the landscape of Kanuti Refuge and RHI. None of the Refuge and only 14% of the RHI are currently classified by the NWI, despite the fact that wetlands throughout the Refuge provide critical habitat to white-fronted geese and other waterfowl and migratory birds (Harwood 2006; 2007; 2008; 2009; 2010; 2012; 2014; 2015; Kafka 1988; Marks 2016; Marks and Fischer 2015).

Available literature sources do not lend much useful information regarding wetland densities or classes on the Refuge but do provide some general information regarding characteristics of the dominant wetlands. Kafka (1988) and Wortham (1995) characterized a small number of lakes by connectedness and the influence of beavers. In regional studies, Glesne *et al.* (2011) characterized a small number of lake systems by topographic position and connectedness and Roach (2011) characterized a broader suite of lakes by heterogeneity in lake area through time. Beyond these general grouping there has not been a concerted effort to delineate and classify wetlands habitats across Kanuti Refuge. Consequently, there is very little information available for managing these critical habitats.

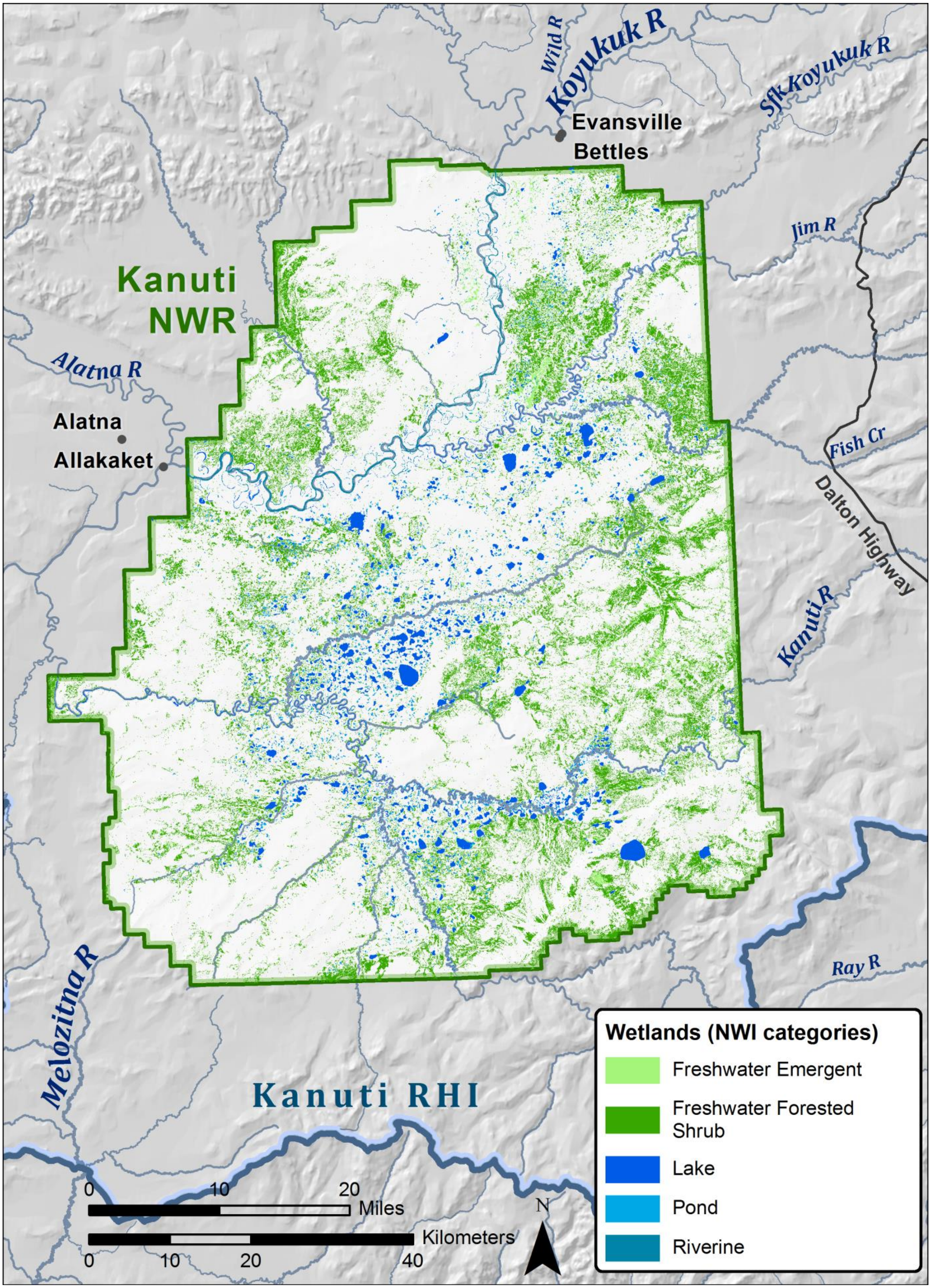
The WRIA prompted an analysis of the Refuge and RHI that categorized wetlands through a crosswalk of the NWI and existing land cover layers (Appendix E). The results of this wetland-land cover crosswalk provide a habitat-based delineation of wetland and upland systems, which underestimated the percent of wetland habitat across the landscape (Map 5) due the coarseness of the available land cover data. The crosswalk delineated the Refuge as 81% upland, 15% wetland, and 4% deepwater habitats. The RHI (including the Refuge) was classified as 86% upland, 12% wetland, and 2% deepwater habitats (Flagstad 2016). Tables 6 and 7 provide summaries of the broad wetlands types for the RHI and Refuge, respectively. Cowardin et al. (1979) provided the hierarchical classification system for wetlands that was the basis for the habitat-based delineation.

Table 6: Generalized categories of upland/wetland/deep-water habitats within Kanuti RHI listed in decreasing order of mapped area

Generalized Category	*Mapped Area (Acres)*	*Mapped Area (%)*
Upland	9,870,705	86.1
Freshwater Forested Shrub	1,337,888	11.7
Lake	99,090	0.9
Freshwater Emergent	69,527	0.6
Riverine	57,830	0.5
Pond	22,788	0.2
Grand Total	11,457,828	100

Table 7: Generalized categories of upland/wetland/deep-water habitats within Kanuti Refuge, listed in decreasing order of mapped area

Generalized Category	*Mapped Area (Acres)*	*Mapped Area (%)*
Upland	1,326,887	81.1
Freshwater Forested Shrub	212,788	13.0
Lake	48,696	3.0
Freshwater Emergent	28,977	1.8
Riverine	13,151	0.8
Pond	6,336	0.4
Grand Total	1,636,834	100



Map 5: Wetland habitats within Kanuti Refuge.

Determining use of wetland habitats by migratory birds and wildlife falls under the purposes of the Refuge. The limitations of existing land cover, soils, wetlands, and hydrography datasets make it difficult to accurately characterize the percentages of wetland versus upland habitat in the Refuge and the RHI, as noted by the shortfalls of the wetland-land cover crosswalk (Flagstad 2016). The lack of a properly representative wetland classification reduces the Refuge's ability to monitor and manage the extent, changes, and fish and wildlife use of these systems. Observed limitations to the wetland-crosswalk present a strong argument for the completion of the NWI and pursuit of better land cover, better soils, and updated hydrography datasets for the Refuge. Completing the NWI, supporting an update to NHD to include flow paths, and developing a wetland habitat map based on wetland class, ice content, and open/closed systems would enable the Refuge to meet its wetland purpose by allowing realistic delineation of wetlands. These products may also assist in determining areas most likely to remain wet and productive for migratory bird and wildlife during a time of warming climate and changing precipitation patterns.

A detailed discussion on the methods and results of the NWI-land cover crosswalk is available in Appendix E.

5.3. Groundwater

Many factors control the flow of water on Kanuti Refuge, including the contribution of groundwater to the hydrologic process. In a generalized model of the hydrologic cycle, surface water percolates through soil layers, contributes to groundwater as recharge, and flows back to rivers and lakes as base flow. The location of the Refuge in a zone of continuous and discontinuous permafrost complicates this loop of the hydrologic cycle since permafrost can create barriers to groundwater recharge (Ferrians 1994; Rieger et al. 1979).

Areas of groundwater that discharge to surface water provide a source of continuous flow, reduce seasonal variability in water temperatures, and enhance dissolved oxygen levels during winter months by maintaining ice-free conditions, which may allow for the aeration of flowing waters. The physical characteristics produced by groundwater contribution to surface water affect aquatic habitat availability, create overwintering habitats, increase macro-invertebrate diversity, and provide preferred habitat for some species in the Refuge's lake and rivers.

As noted earlier in this document, permafrost limits groundwater movement on Kanuti Refuge (Roach 2011), but it does not completely preclude recharge. Hinzman et al. (2006) found that spring snowmelt and ice breakup are a primary source of groundwater recharge in interior Alaska, with infiltration occurring through the ground in areas without ice-rich permafrost. Groundwater reaches deep aquifers through unfrozen areas that perforate the permafrost, like areas beneath streams, lakes, and summits/slopes of lowland hills (Williams 1970). Groundwater is also available from floodplain and terrace alluvium on the Refuge (Williams 1970) and generally in unfrozen unconsolidated soil deposits and bedrock above, within, and beneath the permafrost (Cederstrom et al. 1953; Tolstinkhin 1941).

Areas of groundwater availability—where groundwater is contributing to surface water—throughout Alaska and the Refuge are identifiable during winter months by open water leads in river ice and areas of overflow ice on rivers and lakes (Hopkins et al. 1955; Kane et al. 2013). The hydrologic inventory of Kanuti Refuge revealed several reaches of the Kanuti Kilolitna River and Henshaw Creek in the Refuge where open water leads indicate the presence of groundwater upwellings or springs (USFWS, 2015). Service staff also observed open water areas on the South Fork Koyukuk River just upstream of the Refuge during winter. This portion of the South Fork most likely receives groundwater inputs from tributary streams off the Jack White Range and the large glacial deposits at the southwestern end of the range (USFWS, 2015).

Inadequate empirical information on permafrost and groundwater limits the explicit understanding of interactions between groundwater and surface water across Kanuti Refuge. Changes in the extent and thermal condition of permafrost will directly affect the chemical composition and residence time of groundwater exports to river systems, the state of groundwater-influenced lakes and wetlands, extent of shallow lakes and wetlands, seasonal river-ice thickness, and stream temperatures (Walvoord et al. 2012). The magnitude of these changes on the extent and suitability of available summer and winter habitat for waterfowl, fish, aquatic invertebrates, and diatoms are difficult to predict without a clear understanding of the underlying processes of surface water and groundwater interaction. A better understanding of this relationship requires the investigation of groundwater and permafrost dynamics in the Refuge.

5.4. Infrastructure

Infrastructure refers to the manmade systems and structures associated with the movement and management of water resources. Kanuti Refuge currently has no water management infrastructure.

Many refuges in the lower 48 states manage water resources via a complex system of water control structures, canals, and dikes, and must account for the specific volumes of water associated with water rights. The Refuge is fortunate to have natural and free-flowing water resources that do not rely on such a network.

This report considers culverts, bridges, boat launches, and fuel storage within 100 meters of a waterbody as threats and are mapped and discussed in the threats/issues of concern portion of this report.

5.5. Water Quality

The physical and chemical characteristics of rivers and streams, collectively known as water quality parameters, are important measures and indicators of aquatic and terrestrial ecosystem health. Preserving the quality of water that moose, caribou, migratory waterbirds, raptors, and fish populations rely upon is a founding purpose of Kanuti Refuge under ANILCA and a management concern.

Surface water resources on the Refuge exist in their natural state. As discussed in the inventory, there are no impaired waters listed on the 303(d) list (ADEC, 2012b) in the Refuge or RHI. The Service conducted baseline assessments of water quality at selected sites on the Refuge from May 2010 to September 2015 (Map 6). The water quality assessment establishes the normal background range of biological, physical, and chemical water quality parameters in Fish Creek (FCR64), Holonada Creek (HLD68) Henshaw Creek (HSH69), Kanuti Kilolitna River (KKR67), Kanuti River (KNT65), Koyukuk River (KYK61), South Fork Koyukuk River (SFK62), and Kanuti River Tributary (TKQ66). These systems represent examples of riverine habitats on the Refuge. Lacustrine and palustrine habitats were not included in the assessment.

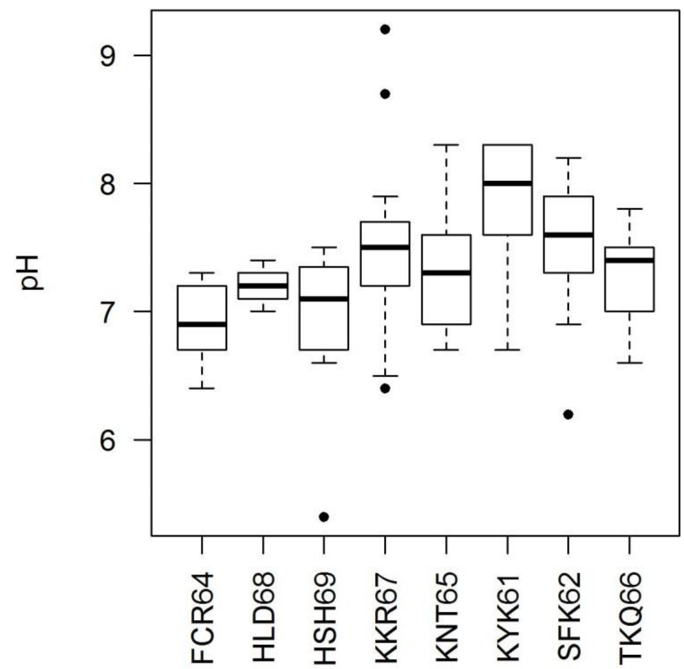
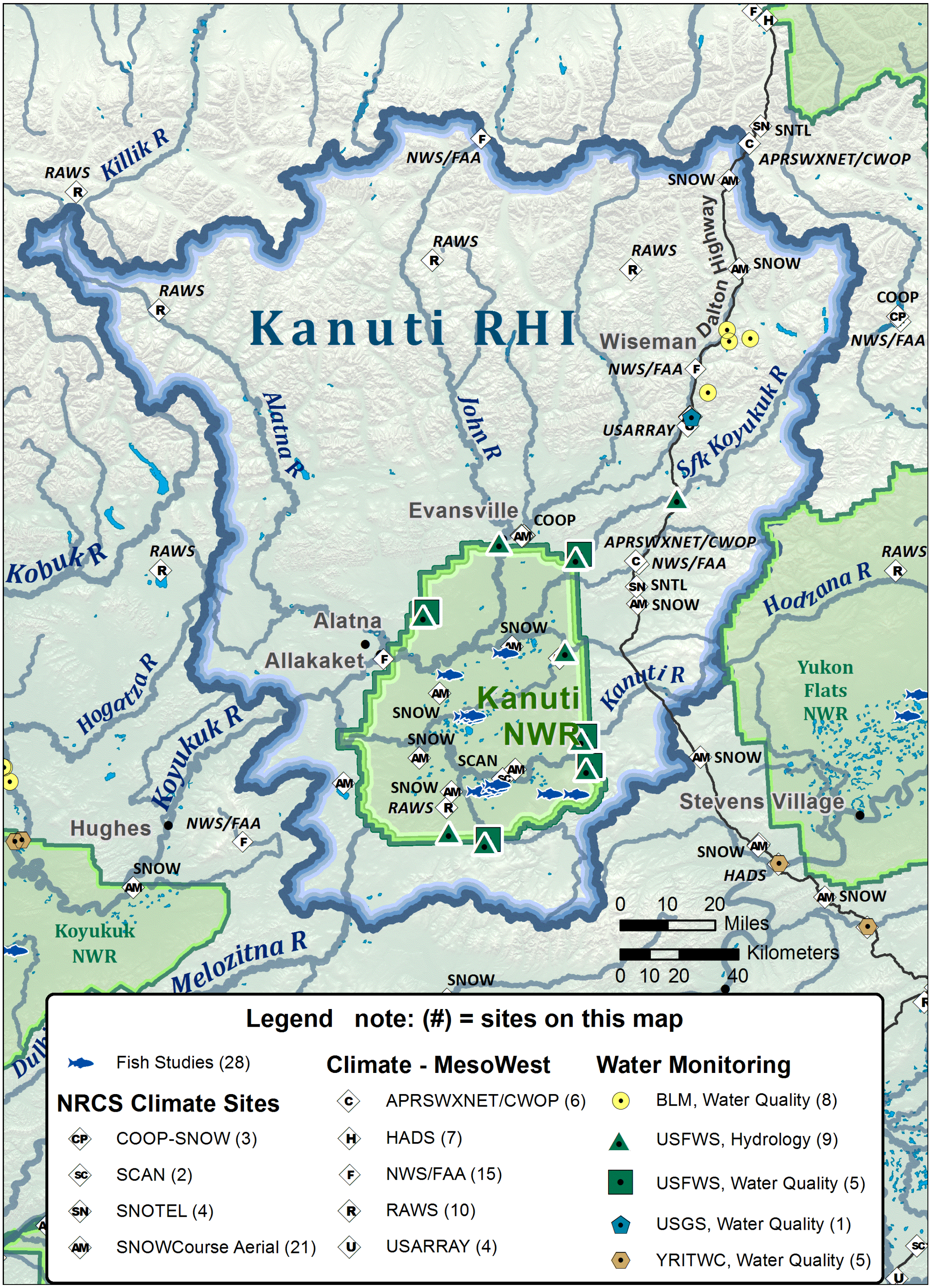


Figure 5: Box plot of pH data for water quality sites on Kanuti Refuge, May 2010–September 2015.

The monitored systems illustrate the variability of riverine systems across Kanuti Refuge. Sampling revealed waters dominated by a calcium-magnesium bicarbonate ionic profile with neutral to slightly basic pH (6.5–8.5) (Figure 5). This pH range falls within the State of Alaska water quality standard suitable for aquatic life (ADEC, 2012a). Waters characterized by calcium-magnesium bicarbonate profiles typically exhibit a strong buffering capacity that resists the change in pH from neutral to acidic levels, measured by alkalinity, and discussed in the next paragraph.

Alkalinity measures the buffering capacity of water by measuring the concentration of carbonates and bicarbonates expressed as calcium carbonate ($CaCO3$) in milligrams per liter (mg/L). To provide adequate acid neutralizing capacity to protect aquatic life, alkalinity should be at least 20 mg/L as Ca/CO3 (Wurts and Durborow 1992). The range of field-measured alkalinity in Kanuti Refuge rivers



Map 6: Current and historical water (quantity and quality) and climate monitoring sites within Kanuti Refuge and RHI distinguished by site type and agency. Bold rivers are included in the Anadromous Waters Catalogue.

was between 18.0–52.2 mg/L Ca/CO3 (Figure 6). As suggested by the calcium/magnesium bicarbonate profiles of these systems, it would take a large acidic input to affect the general water composition to acidic levels that would be harmful to aquatic life.

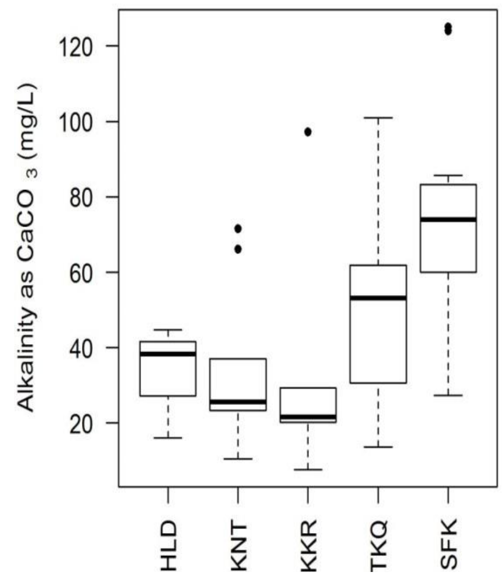


Figure 6: Box plot of field alkalinity data for water quality sites on Kanuti Refuge, May 2010–September 2015.

Alkalinity, pH, and other parameters including hardness, temperature, dissolved organic carbon (DOC), and ionic composition all influence the health of organisms in water. These parameters influence the toxicity of metals ingested or absorbed by aquatic organisms. The following paragraphs discuss the sampling results for these parameters, which represent Kanuti Refuge's water quality and suitability for aquatic life.

Hardness is a measure of the quantity of divalent ions (cations with two positive charges) such as calcium, magnesium, and/or iron in water. The cations calcium and magnesium dominate the water chemistry analyses for Kanuti Refuge and contribute to higher hardness. Alkalinity results were low to moderate (18.0–52.2 mg/L Ca/CO3) and generally met the 20 mg/L as Ca/CO3 level for healthy aquatic life (Wurts and Durborow 1992) (Figure 7). Hardness values varied between 8.5–165 mg/L as Ca/CO3, falling on the low side of the recommended hardness range for aquatic life of 63–250 mg/L as Ca/CO3 (Wurts and Durborow 1992).

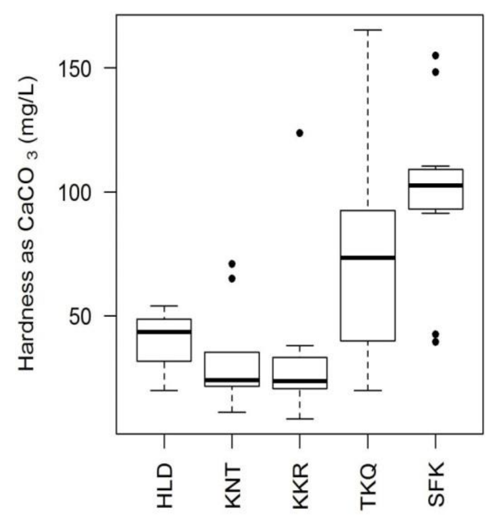


Figure 7: Box plot of hardness data for water quality sites on Kanuti Refuge, May 2010—September 2015

Together, the alkalinity and hardness results provide a more reliable picture of a system's ability to sustain organisms if acidity increases. The waters of Kanuti Refuge have both moderate hardness and buffering capacity. Increases in hardness can benefit aquatic organisms that will still be sensitive to harmful increases in pH (McFadden et al. 1962; Russell-Hunter et al. 1967). There is often confusion about alkalinity and hardness because they both report mg/L as Ca/CO3, but it is important to remember that alkalinity measures anions while hardness measures cations. If limestone, which is Ca/CO3, is the dominant mineral input to a system, the values for both hardness and alkalinity will be similar, if not identical. In the case of the Refuge, sodium bicarbonate ($NaHCO_3$) is the dominant constituent responsible for alkalinity levels.

Temperature, like alkalinity and hardness, influences the health of organisms in water. Table 8 presents maximum weekly average temperature (MWAT) and maximum weekly maximum temperature (MWMT)

Table 8. Maximum weekly average water temperature (MWAT) and maximum weekly maximum water temperature (MWMT) for three water quality sites within Kanuti Refuge.

Monitoring Site	*MWAT (C)*				*MWMT(C)*			
	2010	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**
Kanuti River Trib. (TKQ)	13.4[a]	12.4	NA	13.1	14.9[a]	13.9	NA	15.1
S.F. Koyukuk River (SFK)	NA	15.0	16.0	16.2[a]	NA	16.9	18.6	18.3[a]
Kanuti River (KNT)	17.5[a]	16.3	15.6[a]	16.6[a]	20.3[a]	18.3	17.8[a]	19.2[a]

[a] Values may be low because one or more summer months (June, July, and August) are missing temperature data or have incomplete records (>10% of days are missing).

for three water quality sites on Kanuti Refuge. For at least two years, MWMT values at the South Fork Koyukuk and Kanuti Rivers were marginally above the United States Environmental Protection Agency's (EPA) recommended maximum summer temperature criterion of 18˚ C for salmon and trout migration (ADEC, 2012a); however these readings were not of sufficient duration to present an issue to the health of aquatic species. Extended exceedances of the recommended summer temperature would be an issue of concern. Winter water temperatures reached 0.0˚ C but did not reduce the availability of dissolved oxygen (DO) in these systems below the 7 mg/L limits recommended by the ADEC for anadromous or resident fish (ADEC, 2012a).

DOC is important to the health of organisms in water because it affects the bioavailability of metals. Metals form extremely strong complexes with DOC, enhancing metal solubility, while also reducing metal bioavailability. DOC concentrations on Kanuti Refuge were high (4.5–7.1 mg/L) (Figure 8), but well within the range of arctic rivers. The range of DOC found in these systems does not enhance the bioavailability of metals to aquatic organisms (Holmes et al. 2013).

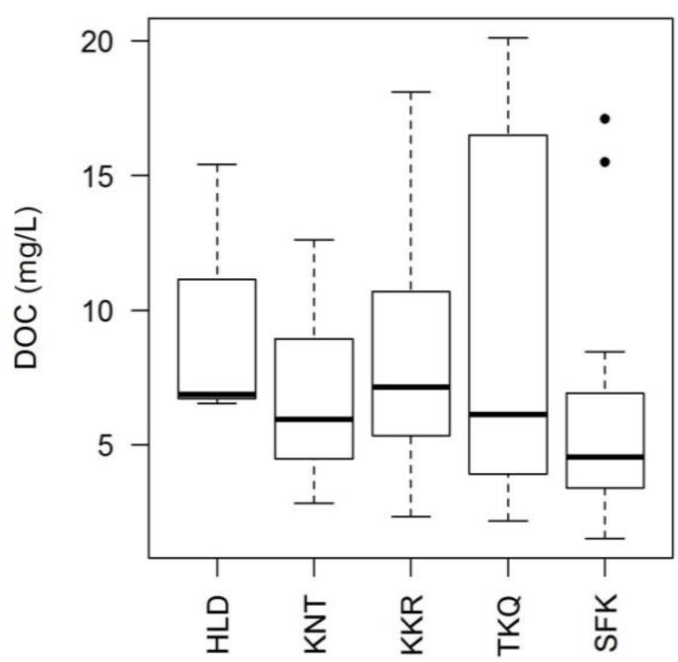


Figure 8: Box plots of dissolved organic carbon data for water quality sites on Kanuti Refuge, May 2011—September 2015

Nitrogen and phosphorus affect the health of organisms in water and are essential nutrients for the growth, nourishment, and reproduction of plants and riverine species. The concentrations of both in Refuge waters are low but within the range of natural waters in arctic environments (Frey et al. 2007; Holmes et al. 2012).

Vertebrate and invertebrate species in aquatic systems require oxygen like terrestrial species. DO levels in Refuge waters ranged from 10.0–12.3 mg/L, which is a healthy level for aquatic species (Cavanagh et al. 1998). This range of DO also meets the State of Alaska's water quality criterion for anadromous and resident aquatic species (ADEC, 2012a).

Total dissolved solids (TDS) are a broad parameter used to measure materials in water smaller than 2 microns in size. TDS concentrations that are too high or too low may limit the growth of aquatic life. The parameter is the sum of all the minerals, metals, and salts dissolved in the water and a good indicator of water quality. The median TDS concentrations for the five water quality sites range from 55–132 mg/L (Figure 9), which are within the State's water quality criteria for aquatic life (<1,000 mg/L) (ADEC, 2012a). Higher TDS values in a natural environment may indicate elevated levels of ions such as arsenic, copper, lead, and nitrate. Although measured TDS levels did not suggest elevated ion levels, we evaluated results of individual ions and trace metals (see below) to obtain baseline information.

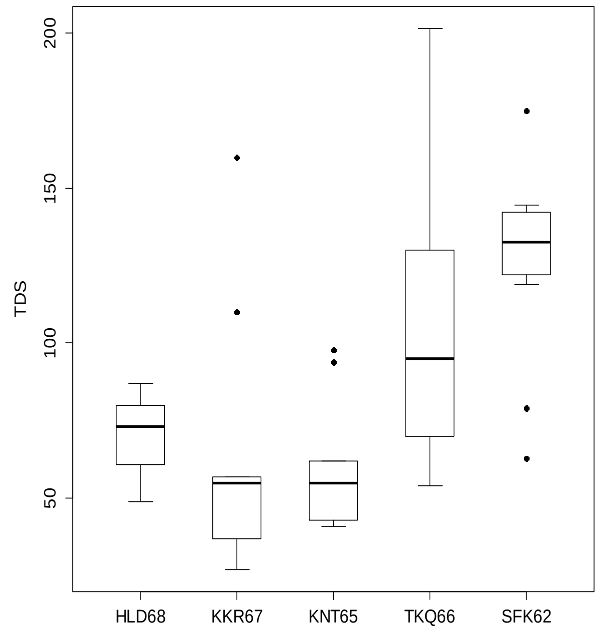


Figure 9: Box Plots of total dissolved solids concentration data for water quality sites on Kanuti Refuge, May 2011—September 2015

Specific conductance provides a broad indicator of system health and is used as an alternative or complementary measure of TDS. Specific conductance measures the ability of water to conduct an electric current and provides an estimate of the total ion concentration in the water. The greater the content of ions in the water, the more current the water can carry. Since ions include dissolved metals and other dissolved materials, higher conductance correlates with higher TDS. For these same reasons, higher SC is also an indicator of groundwater contributions or higher natural metal concentrations.

The range of mean SC on Kanuti Refuge was 81–217 micro siemen (µS) for all the systems except the Koyukuk River, which had a median value of 571 µS. The higher SC values on the Refuge occurred during base flow periods when groundwater contributions are highest, not during the high water periods when flows mobilize sediments. The higher levels may be related to groundwater contributions. When high levels of SC occur, it is necessary to evaluate the results of individual metal constituents since conductivity may not correlate directly to ionic concentrations in highly concentrated solutions (see below).

The majority of the results for trace metals were below the detection limits for our methods. The majority of the detectable results were below Alaska's water quality criteria for toxics (ADEC, 2012a). Although TDS levels did not imply elevated ion levels, trace metal sample results did show elevated aluminum values at each of the monitoring sites during the sampling period. Aluminum is not a serious threat to system health unless pH is low, so it is not currently a threat to the Refuge's aquatic systems. Samples collected in May 2012 at Kanuti Kilolitna River and the Tributary to the Kanuti River exceeded the "chronic" criteria for copper (calculated separately for each site and date based on hardness). These exceedances occurred during annual high flow snowmelt/breakup events capable of mobilizing and exposing copper. The elevated results may relate to excess sedimentation associated with the spring high flows, which were the second highest at the Kanuti Kilolitna River and highest at the Tributary to the Kanuti River. Copper is essential for all plant and animal nutrition but at higher concentrations it becomes toxic to most forms of aquatic life (Cavanagh et al. 1998). The isolated copper results suggest the availability of copper in Refuge soils and indicate copper as a potential contaminant to fresh water from development projects that cause soil disruption. Copper and aluminum results for all other samples fell within the State's criteria for aquatic life and do not suggest a systemic concern for the aquatic systems of Kanuti Refuge.

Water quality results for Kanuti Refuge's flowing waters indicate ionic constituents and physical parameters within the range of natural water capable of supporting healthy aquatic systems. The Refuge's waters have moderate hardness and moderate buffering capacity. The range of pH on the Refuge (6.5–8.5) is narrow but represents the range where organisms typically thrive. The Refuge's waterways provide high-quality aquatic habitat that supports diverse benthic invertebrate and diatom populations similar to communities in other interior Alaskan streams (Bogan 2014). The waters show no apparent signs of anthropogenic contamination and are comparable to other natural surface waters within interior Alaska. As noted previously, the extreme outlying results of copper and aluminum may be an indication of the availability of metals in unexposed sediments exposed to weathering by mining or other anthropogenic factors.

5.6. Water Rights

Water rights establish the legal right to a quantity of water for specific “beneficial” uses. Maintaining water levels and flow patterns for Refuge rivers and lakes is crucial to sustaining fish and wildlife species and habitats, and achieving the founding purposes for Kanuti Refuge. The magnitude and timing of seasonal water levels and flow patterns of the Refuge’s wetlands, lakes, and rivers maintain natural aquatic and riparian systems suitable for fish, migratory waterbirds, and other wildlife (Poff 1997). Policy (403 FW1-3) states “the Service works within the realm of state government to obtain water rights.”

The State of Alaska’s Department of Natural Resources (ADNR) generally manages water rights in Alaska regardless of land ownership. The State administers three types of water right: subsurface water rights, consumptive surface water rights, and reservations of instream flow. Subsurface water rights authorize groundwater withdrawal from a well. A consumptive surface water right authorizes diversion, impoundment, or withdrawal of water from lakes, ponds, or rivers for a specific use. An instream flow reservation ensures sufficient water in the system to maintain a specific flow in a portion of a stream or a specific water level in a lake (and may limit withdrawals by other water users). An instream flow reservation can be made for the purposes of: protection of fish and wildlife habitat, migration, and propagation; recreation and parks; navigation and transportation; and sanitation and water quality. These purposes are described by 11 Alaska Administrative Code (AAC) 05.010(a).

The State of Alaska also authorizes the temporary use of surface and subsurface water under a temporary water use authorization granted through a temporary water use permit (TWUP). The ADNR grants temporary water use authorizations when the amount of water used is a significant amount (according to 11 AAC 93.035(a) and (b)), the use continues for less than five consecutive years, and the water used does not conflict with existing water right holders and fisheries.

Kanuti Refuge has explicit, but unquantified federal reserved water rights (dated 2 December 1980) established under ANILCA “to ensure, to the maximum extent practicable and in a manner consistent with the purposes of the Refuge, water quality, and necessary water quantity within the Refuge.” Despite the protective quality of these water rights, it is the Service’s policy (403 FW 1-3) “to comply with the State’s water laws, regulations, and procedures in obtaining and protecting water rights, both for Service facilities [Kanuti Refuge] and for trust fish and wildlife resources on lands not owned by the United States, except where the application of State statutes and regulations does not permit Federal purposes to be achieved”. By working within the State system, the Refuge does not forfeit its federal reserved water rights.

Although the availability of freshwater across Kanuti Refuge is not currently threatened, future uses of water or climate-related responses might affect water quantity or quality. An assessment of the location, types of water rights, and the amount of water associated with the water rights surrounding Kanuti Refuge provides insight into the impact of current withdrawals on the Refuge’s waterways and waterbodies. Map 7 shows water rights, permits, and reservations within the RHI/Refuge by location and type (Map 7). If a surface water right is located upstream of the Refuge, the location, purposes, and quantity of water

Map 7: Water rights and anadromous waters within Kanuti Refuge and RHI.

requested or granted was evaluated. This water right review used the ADNR's Land Administration System (LAS) (2017)as a source of information and appraised each upstream water right for potential to harm the availability of water in the Refuge. Table 9 summarizes the findings of the water rights assessment.

Table 9: Evaluation of water rights or use permits for rivers, lakes, and wells within the Kanuti Refuge or RHI

Water right type	*Features type (River, Lake, Well)*	*Number of water rights*	*Total Protected Length River (miles)*	*Total protected Area Lakes (acres)*	*Total number of protected wells*	*Position*
Instream Reservation	River	1	2594	0	NA	Refuge
Instream Reservation	River	2	13923	0	NA	RHI
Subsurface Water Right	Well	7	NA	0	7	RHI
Surface Water Right	River	13	NA	0	13	RHI
Surface Temp Use Water Permit	Pond	2	NA	NA	NA	RHI
Subsurface Temp Use Water Permit	Well	3	NA	NA	NA	RHI

Table 10 lists consumptive water rights and TWUPs with the location of the water right in relation to Kanuti Refuge. The table also identifies the amount of water granted for issued/adjudicated water rights, the requested/suggested amount of water associated with TWUPs, and water rights pending adjudication. Upstream water rights extract water before it reaches the Refuge and are of particular interest since they may reduce the availability of water flowing into the Refuge's rivers, lakes, and wetlands.

The analysis of the water rights inventory data in Table 10 revealed 13 consumptive surface water rights upstream of Kanuti Refuge boundary along the Middle Fork of the Koyukuk, South Fork Koyukuk, Jim, John, and Alatna Rivers. Eight adjudicated and quantified surface water rights exist. The small quantities of water granted under these water rights do not jeopardize the volume of flow in these rivers or downstream waters. The volume of water requested with the remaining upstream and unadjudicated water rights does not adversely affect the availability of water for the maintenance of freshwater habitats in the Refuge. The seven subsurface wells and five TWUPs listed in Table 10 do not pose a threat to the current availability of water flowing in the Refuge.

Table 11 presents instream flow reservations flowing into Kanuti Refuge along with their requested minimum flows. There are three unadjudicated instream flow reservations on the Jim River, upstream of the Refuge. ADF&G holds two of the unquantified reservations and the BLM holds the other. One of these reservations applies to waters of the Jim River ending at the boundary of the Refuge. The intention of the reservations is to maintain a volume of flow in the river channel that will preserve the instream and upland habitat for fish and wildlife. ADF&G and BLM use a method for determining the volume of flow that is similar to the method used by the Service

Table 10: Volume of water granted/proposed for consumptive Water Rights and TWUPs within Kanuti Refuge/RHI

Water Feature	*Water Right Type*	*LAS number*	*Owner*	*Location*	*Amount*
Well on Jim Creek Drainage	Subsurface	ADL401822	ALYESKA PIPELINE SERVICE COMPA, NY	RHI-Upstream	1000 gal/day Certificate issued
Well on Jim Creek Drainage	Subsurface	ADL64151	ALYESKA PIPELINE SERVICE COMPA, NY	RHI-Upstream	7500 gal/day Pending adjudication
Well near mainstem Koyukuk	Subsurface	ADL75890	ALLAKAKET CITY OF,	RHI-downstream	3500 gal/day Certificate issued
Well on Birch Creek a tributary to Wild River	Subsurface	LAS1489	MANNS, ALBERT OR CECILIA	RHI-Upstream	500 gal/day Certificate issued
Well near mainstem Koyukuk	Subsurface	LAS19758	ALATNA TRIBAL COUNCIL,	RHI-downstream	1200 gal/day Certificate issued
Well near mainstem Koyukuk	Subsurface	LAS19981	ALLAKAKET CITY OF,	RHI-downstream	1125 gal/day Certificate issued
Well on Contact Creek tributary to John River	Subsurface	LAS20235	NORTH SLOPE PUBLIC WORKS,	RHI-Upstream	17000 gal/day Certificate issued
Takahula Lake on Takahula River a tributary to Alatna River	Surface	ADL400050	HELMERICKS, HARMON R	RHI-Upstream	500 gal/day Pending adjudication
Prospect Creek/Bob's Pup tributary to Jim Creek	Surface	ADL400065	FRYAR GOLD MINING GROUP VENTUR, E	RHI-upstream	250 gal/day Certificate issued
Unnamed tributary to Alatna River	Surface	ADL400071	KEIM, CHARLES J	RHI-upstream	600 gal/day Pending adjudication
Linda Creek tributary to the Middle Fork Koyukuk River	Surface	ADL400169	COMPASS MINING INC,	RHI-Upstream	3 cfs Pending adjudication
Lake Creek tributary to Wild Lake on Wild River	Surface	ADL400628	BROOKS RANGE EXPL. II, LLC,	RHI-upstream	200000 gal/day Pending adjudication
Hammond River, Vermont Creek tributary to Middle Fork Koyukuk River	Surface	ADL402336	ALMINCO AK MINING CO., INC.,	RHI-upstream	5 cfs Certificate issued
Dam on Emma Creek tributary to Middle Fork Koyukuk River	Surface	ADL403549	NORDEEN, WILLIAM H	RHI-upstream	5 cfs Pending adjudication
Hammond River tributary to Middle Fork Koyukuk River	Surface	ADL407935	WEISZ, LARRY	RHI-upstream	480 gal/day Certificate issued
Nolan Creek tributary to Wiseman Creek and Middle Fork Koyukuk River	Surface	ADL46238	SILVERADO GOLD MINES INC.,	RHI-upstream	3 cfs Certificate issued
Slate Creek tributary to Middle Fork Koyukuk River	Surface	ADL46334	SWENSON, LLOYD D	RHI-upstream	1.1 cfs Certificate issued
Archibald Creek tributary to Wiseman Creek and Middle Fork Koyukuk River	Surface	ADL47928	SILVERADO GOLD MINES INC,	RHI-upstream	3.4 cfs Certificate issued
Seward Creek tributary to Wild River	Surface	LAS11734	HIGHTOWER, EVERETT R	RHI-upstream	250 gal/day Certificate issued
Seward Creek tributary to Wild Lake on Wild River	Surface	LAS13319	HIGHTOWER, EVERETT R	RHI-upstream	250 gal/day Certificate issued
Well at Pump Station 5	TWUP-Subsurface	P2012-3	Alyeska Pipeline	RHI-upstream	20000 gal/day at Well at pump station 5
Well at Pump Station 5	TWUP-Subsurface	P2012-3	Alyeska Pipeline	RHI-upstream	20000 gal/day at Well at pump station 5
Well at Pump Station 5	TWUP-Subsurface	P2012-3	Alyeska Pipeline	RHI-upstream	20000 gal/day at Well at pump station 5
Seasonal Pond at Pump Station 5	TWUP-Surface	P2010-7	Alyeska Pipeline	RHI-upstream	35,000 gal/day from mile post 260
Seasonal Pond at Pump Station 5	TWUP-Surface	P2010-7	Alyeska Pipeline	RHI-upstream	35, 000 gal/day from mile post 275

Table 11: Monthly minimum flows for instream flow reservations within Kanuti RHI

Water Feature	*Water Right Type*	*LAS number*	*Owner*	*Location*	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*	*1-Jul*	*1-Aug*	*1-Sep*	*1-Oct*	*1-Nov*	*1-Dec*
Jim River	Instream Reservation Pending adjudication	LAS13700	ADF&G SPORT FISH DIV	RHI (just upstream of Refuge)	21.0	21.0	21.0	25.0	436	436	388	436	436	140	64.0	25.0
Jim River	Instream Reservation Pending adjudication	LAS13700	ADF&G SPORT FISH DIV	RHI (just upstream of Refuge)	21.0	21.0	21.0	25.0	436	436	388	436	436	140	64.0	25.0
Jim River	Instream Reservation Pending adjudication	LAS26581	DOI BLM	RHI (just upstream of Refuge)	88.0	69.0	56.0	50.0	648	896	343	825	617	273	160	150

to request flows for the same purpose. The Service will comment on the ability of the reservation to maintain habitats when the adjudication takes place at some future time.

The Service maintains senior unquantified federal reserved water rights for all waters within the boundary of the Kanuti Refuge. None of the State-issued water rights precede the federal reserved water rights established with the creation of the Refuge in 1980. The Service does not intend to assert its federal reserved water rights at this time, but will work with the State to obtain instream flow water rights on Refuge's rivers to meet the purposes of ANILCA. Baseline monitoring of multiple rivers within the Refuge was completed and will be used to apply for state instream flow reservations for the protection of fish and wildlife on the Koyukuk River, the Kanuti River, the South Fork Kanuti River, the Kanuti Kilolitna River, Fish Creek, Henshaw Creek, Holonada Creek, and the Kanuti River Tributary. Granting of State water rights will not have any effect on the right of the United States to assert federal reserved water rights, nor will such granting quantify, diminish, or otherwise affect any future or past federal reserved water rights claims.

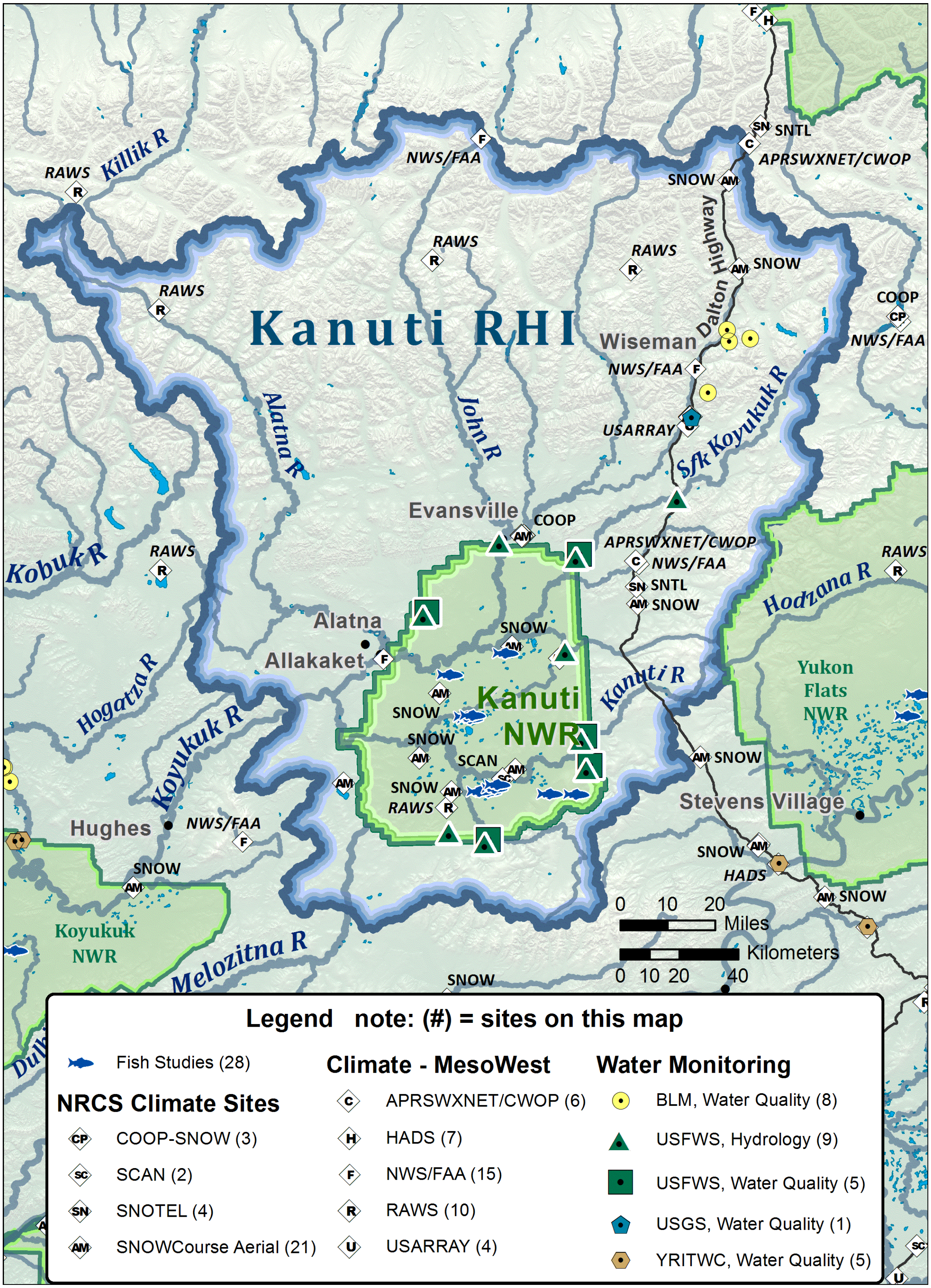
5.7. Climate Trends on Water Resources

According to the Intergovernmental Panel on Climate Change (International Panel on Climate Change 2007), "water resource issues have not been adequately addressed in climate change analyses and climate policy formulation." Although Alaska is the focus of many climate change discussions, information on potential changes in the hydrologic response to climate change is lacking across the state.

Section 4.5 discussed recent weather conditions and provided a description of the climatically driven hydrologic systems of Kanuti Refuge. Data from the Bettles Airport (Coop ID 500761) provide the basis for the climate discussion of the Refuge (Map 8). McAfee et al. (2013) evaluated climate stations in Alaska for statistical homogeneity. The study regarded the Bettles Airport dataset statistically reliable for the analysis of trends in precipitation (McAfee et al. 2013). This dataset was used for air temperature and precipitation climate analysis based on McAfee's confidence in data homogeneity and completeness. This analysis did not employ the Kanuti Refuge Remote Automated Weather Stations (RAWS) station (1990–2016). The period of record for the RAWS data does not include the time-frame of decadal shifts known to affect Alaska and discussed below. The NRCS established a SCAN site ~50 miles south of Bettles within the Refuge in 2014. The Kanuti RAWS and SCAN sites will be useful for future analysis of climate trends and these trends' effects on soil temperature and permafrost change.

Data show that the change in annual and seasonal air temperature at the Bettles Airport is similar to changes observed throughout the state. Average annual statewide temperatures have increased by nearly 4º F from 1949—2005 (USGS, 2012). Figures 10 and 11 show average annual and average seasonal temperature for the period 1949–2013. The black lines in Figure 10 and the red lines running through the curves in Figure 11 are LOESS (Locally Estimated Scatterplot Smoothing) regression lines. The LOESS lines display a smooth trend line for the entire range of data (Cleveland and Devlin 1988). Just viewing the linear trend indicated by the LOESS line can mask some important variability characteristics in the time series. Both Figures 10 and 11 show large variations in temperature from year to year and season to season as well as an increase in the 1980s indicating non-linear trends in temperature over time. The shift appearing in the temperature data in the 80s corresponds to a known phase shift of the Pacific Decadal Oscillation (PDO) (Mantua et al. 1997) from a negative phase to a positive phase known to affect Alaska (Hartmann and Wendler 2005).

The PDO is a pattern of Pacific climate variability that persists on a multi-decadal level (20–30 years) (http://jisao.washington.edu/pdo/) (Mantua et al. 1997). The PDO oscillates between warm and cold phases that alter upper-level atmospheric winds. Two full cycles of the PDO have occurred in the past century. A cool PDO regime prevailed from 1890–1924 and again from 1947–1976, while warm PDO regimes dominated from 1925–1946 and from 1976 through the mid-1990s. During warm phase PDO phases, winter temperatures are higher than usual in the Pacific Northwest and Alaska and winter precipitation is higher than usual in Alaska. Appendix G contains a more detailed discussion of the decadal and multi-decadal oscillations affecting Alaska.



Map 8: Weather/climate and water (quality and quantity) stations within Kanuti Refuge and RHI.

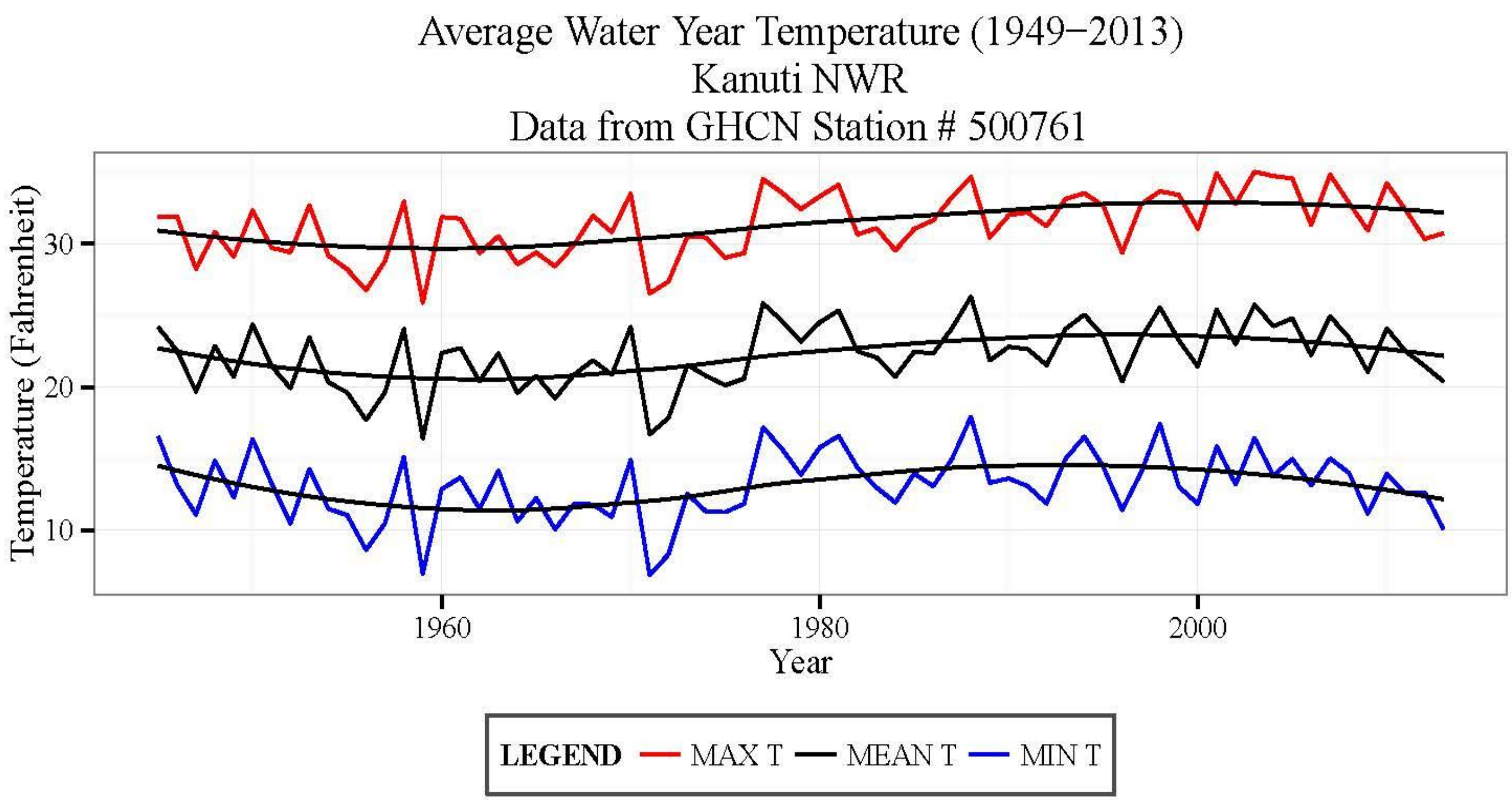


Figure 10: Average (mean), minimum (min), and maximum (max) temperatures over time (1949–2013) at Bettles Airport GHCN Climate Station.

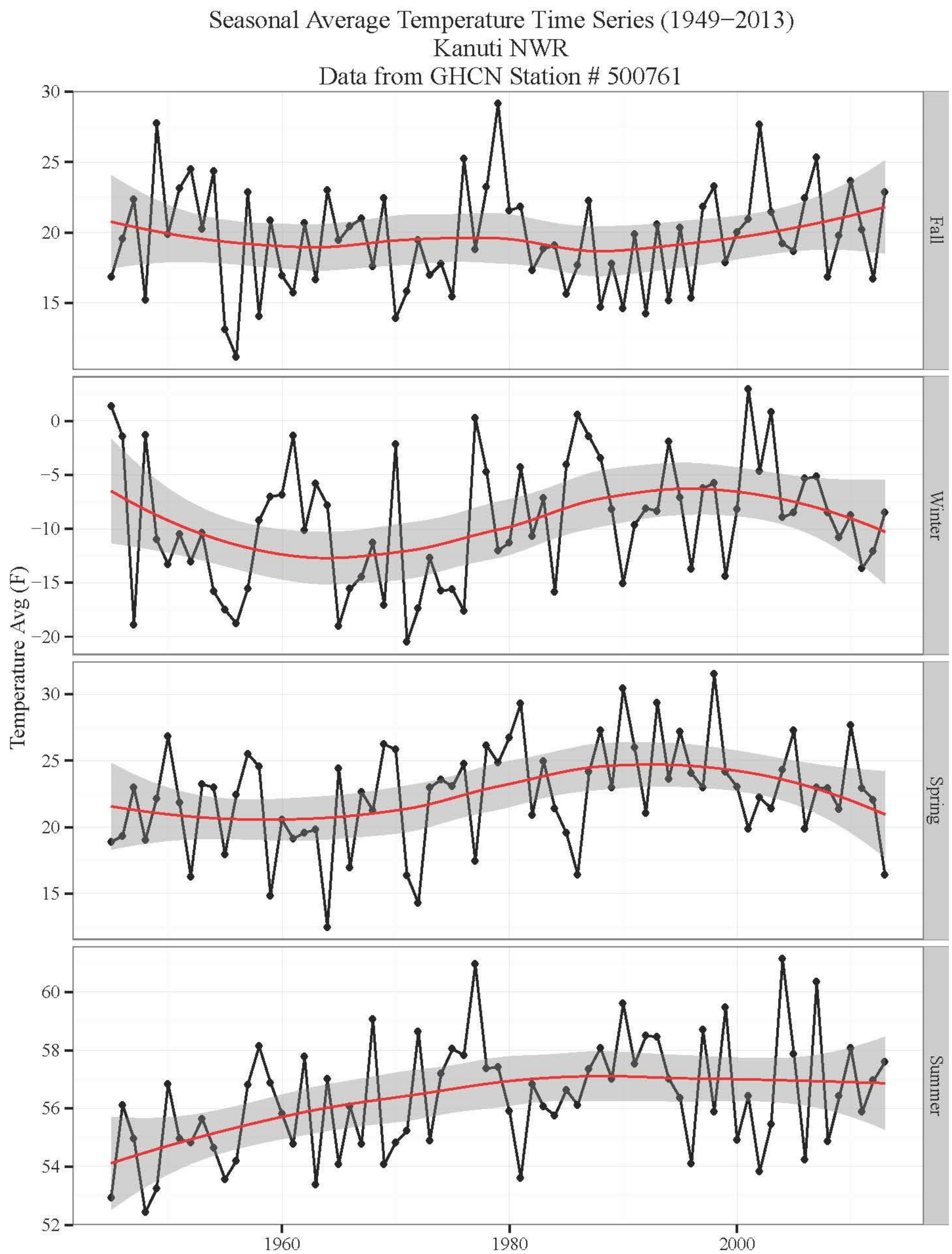


Figure 11: Seasonal average temperature over time (1949–2013) at Bettles Airport GHNC Climate Station.

To capture the non-linear nature of the changing climate noted in the previous discussion, we consider the change in average and seasonal temperatures from the long-term mean. Table 12 lists the departure of annual and seasonal temperatures from the long-term mean for two time periods at the Bettles Airport. The period of 1949 to 1975 was substantially warmer than the period from 1977 to 2014; however since 1977, little additional warming has occurred in Alaska with the exception of at Barrow and a few other locations (ACRC, 2016).

Table 12: Total change in mean seasonal and annual temperature (°F) for two periods (1949—1975 and 1977–2013) at Bettles Airport, Alaska (ACRC, 2016)

Location	*Winter*	*Spring*	*Summer*	*Autumn*	*Annual*
Bettles Airport (1949-1975)	*7.7*	*4.2*	*1.5*	*2.0*	*3.7*
Bettles Airport (1977-2013)	*-0.7*	*-0.5*	*-0.6*	*1.9*	*0.0*

Climate change is also likely affecting the timing and amount of precipitation on Kanuti Refuge. Across Alaska the USGS (2012) noted a 10% increase in annual precipitation between 1949 and 2005 in the United States National Climate Assessment. At Bettles Airport, McAfee et al. (2013) found a unquantified but positive increase in annual and winter precipitation between 1950 and 2010 and noted a positive trend in spring and winter precipitation between 1980 and 2010 (Figure 12) . The United States National Climate Assessment (2012) predicts this general increases in mean seasonal precipitation (except summer) to increase each decade in all regions of Alaska with the largest percent increases in the northern and western portions of the State. These future increases for northern Alaska agree with statewide scenarios that suggest continued future precipitation increases (7–12% per century), with the largest changes in autumn and winter (Hulme et al. 1998; International Panel on Climate Change 2007; Jones and Hulme 1996).

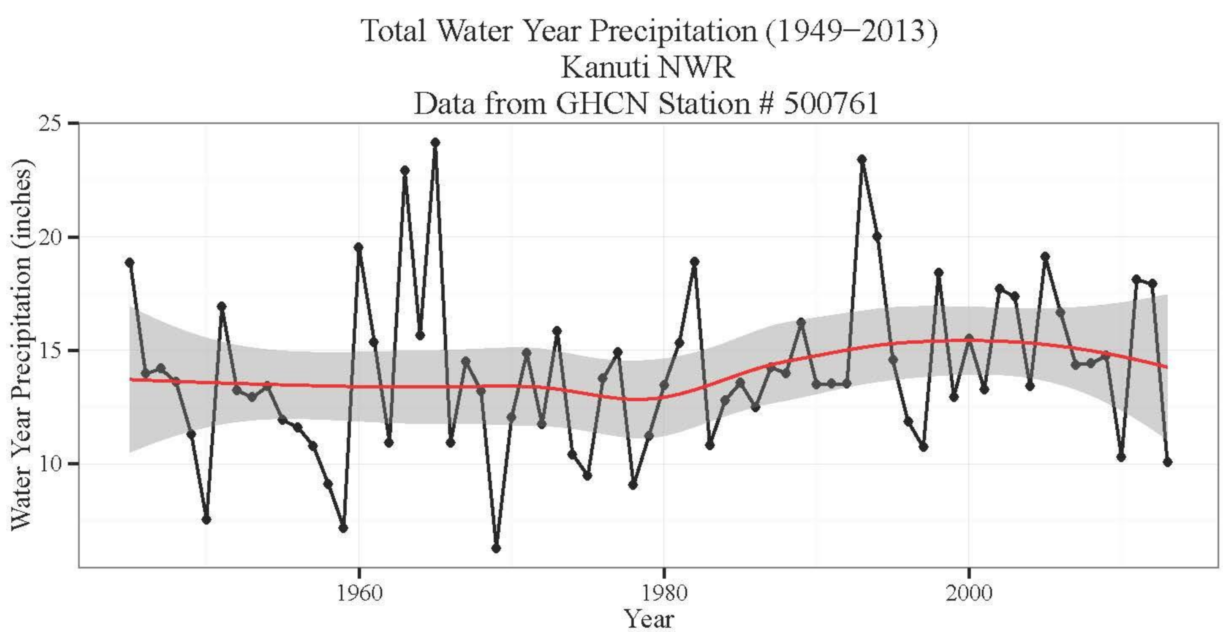


Figure 12: Total water year precipitation (1949–2013) at Bettles Airport GHCN Climate Station. The red line represents the LOESS line and the shaded area represents the 95% confidence interval around the LOESS line.

The effects of increasing air temperature and precipitation on Kanuti Refuge will influence habitats and species in a variety of manners. Increasing water temperatures associated with climate change may affect aquatic species by changing dissolved oxygen levels, pH, conductivity, oxidation-reduction potential, and the rate of biogeochemical reactions (Bates et al. 2008; Environmental Protection Agency 2012). Increased water temperatures also accelerate the rate of geochemical reactions and the geologic weathering of parent materials in natural systems. The resulting alteration in the balance of pH, ionic levels, and trace metal concentrations may have effects that mimic the negative impacts of mining activity (Bates et al. 2008; Whitehead et al. 2009). These and other cumulative changes in arctic temperature and precipitation will alter the hydrologic regimes and affect habitat suitability and distribution patterns of many aquatic species (Bates et al. 2008). The most significant changes projected include rising spring peak river flows and a shift in the timing of spring peak flow; declining snow cover, especially in spring due to increased warming; thawing near surface permafrost by the end of this century affecting groundwater (Chapin et al. 2014), lakes and wetlands size and extent; and diminishing lake and river ice with later freeze up and earlier breakup.

Monitoring how changing climate affects Kanuti Refuge's hydrologic processes and landscape is the key to dealing with the effects that may not be avoided, but may be managed over time. Beginning to understand the implications of these changes will guide management decisions and support long- term planning for the water resources of the Refuge.

A more detailed discussion of the weather and climate on Kanuti Refuge is available in Appendix G.

6. Characterization of Threats, Issues of Concern, and Needs

This chapter summarizes the threats listed in the geodatabase, presents the issues of concern (IOC) identified by Kanuti Refuge staff, and identifies needs or actions to ensure the Refuge continues to fulfill its purposes now and in the future.

6.1. Threats

The inventory of national and regional data resulted in a geodatabase that identifies individual threats (Appendix A), georeferences threats in a GeoPDF poster, and allows a cumulative view of threats to the water resources important to Kanuti Refuge.

Individual threats identified in the inventory follow a national classification system that identifies each threat's type, sub-type, and cause. The threat type is the parent threat class, which includes water quality, water quantity, and aquatic habitat. Sub-types are the second-tier threat class; for example, nutrient pollution is a sub-type under the water quality parent heading. Causes are activities or conditions (e.g., industrial effluent, invasive species, surface water diversions, existing water rights, and change in precipitation patterns) that created the threat. The classification also assigns attributes to each threat that include threat severity, period, and feasibility to address. Appendix I contains the Water Threat Classification and Attributes.

The inventory identified more than 3,088 individual threats (Appendix A). Tables 13 (within Kanuti Refuge) and 14 (within the Kanuti RHI) summarize threats from the geodatabase based on timeframe, cause, and class. The number of occurrences in the geodatabase listed in these tables is referenced when discussing IOCs identified by Kanuti Refuge staff, literature, and the WRIA process.

Map 9 displays the distribution of active mines, mining claims, non-authorized trails, proposed mining exploration, and the proposed Ambler Road. Map 10 represents the distribution and density of invasive plant species, as well as lakes that could be vulnerable to *Elodea* infestation based on lake axis length and surface area (i.e., potentially long and large enough for floatplane landing, although having not yet been ground-truthed for sufficient depth)). Map 11 shows the distribution of sites with the potential to contaminate waters in the Refuge and RHI. Not all threats from the geodatabase are depicted on Maps 9 and 10, but they can be viewed in the GeoPDF poster. The three maps show that most threats occur from activities outside the refuge boundary. The GeoPDF poster allows the visualization of areas where concentrations of individual point sources may present a cumulative threat to the Refuge (e.g., invasive plant species along the Dalton Highwayor mining claims in the South Fork Koyukuk River drainage). The maps and geodatabase can assist in the development of proactive management strategies, such as monitoring lakes potentially vulnerable to *Elodea* infestation, that address current and potential threats.

Table 13: Summary of threats to water resources within Kanuti Refuge and inventoried in the WRIA geodatabase

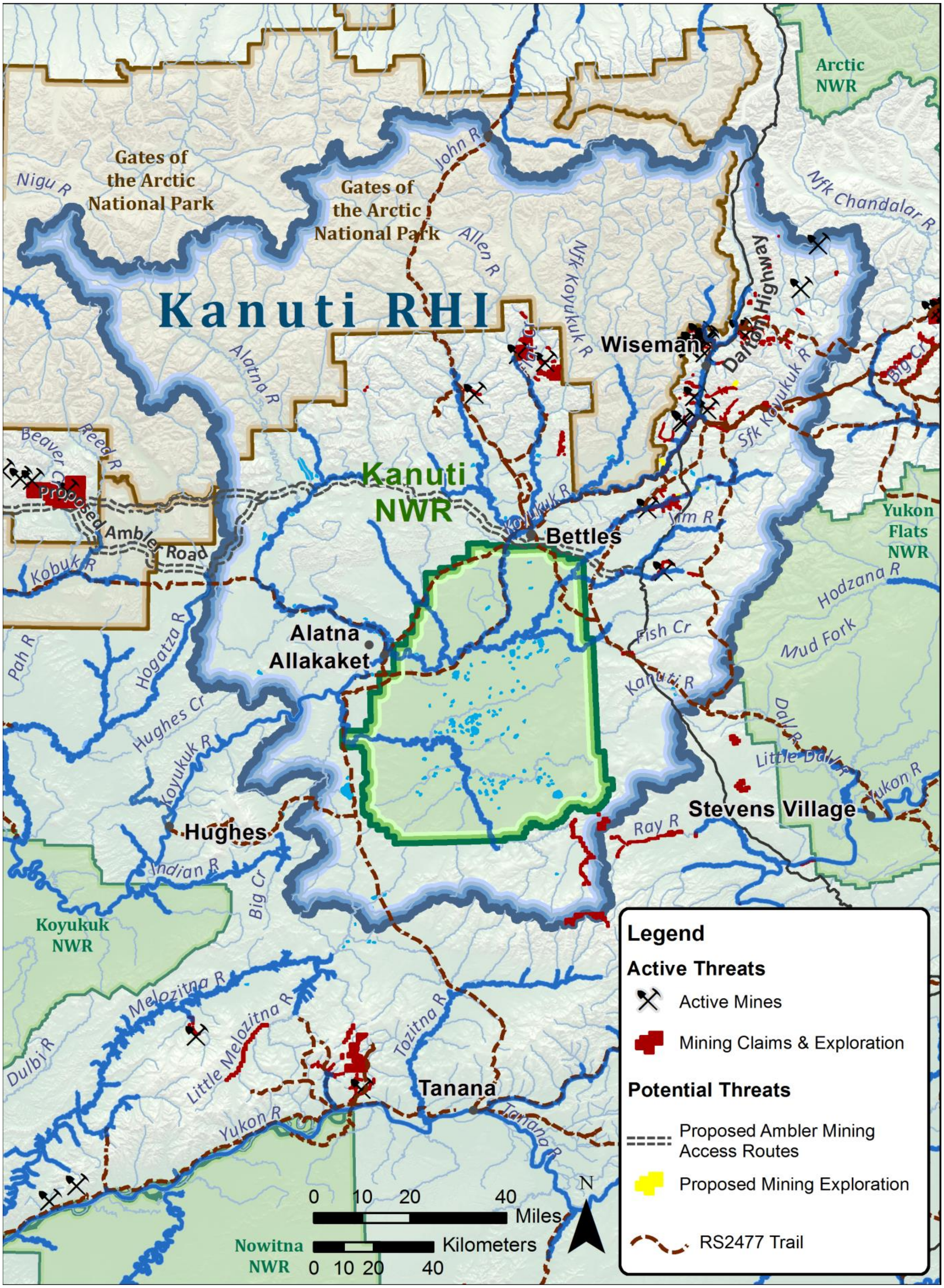
Threat Type	*Threat Class*	*Threat Cause*	*Threat Timeframe*	*Source Database*	*Occurrences in geodatabase*
Water quality threats	Contaminant Pollution	Mining	Medium Term	USGS Alaska Resource Data File	2
Water quantity threats	Altered Ecological Flows	Dams	Medium Term	Alaska Energy Authority Sites Evaluated for Potential Hydropower or Existing Hydroelectric Sites	1
Aquatic habitat threats Water Quality Threat	Sedimentation Contaminant Pollution	Roads	Medium Term	RS2477 Trails Database	102 miles
Aquatic habitat threats	Loss/Alteration of floodplain habitat	Invasive Species	Medium Term	R7 WRIA Potential Elodea Mapping	**Class A=105 **Class B=457

** Class A is a lake with a long axis of >0.6 miles and Class B is a lake with a long axis >0.3 miles and ≤0.6 miles.

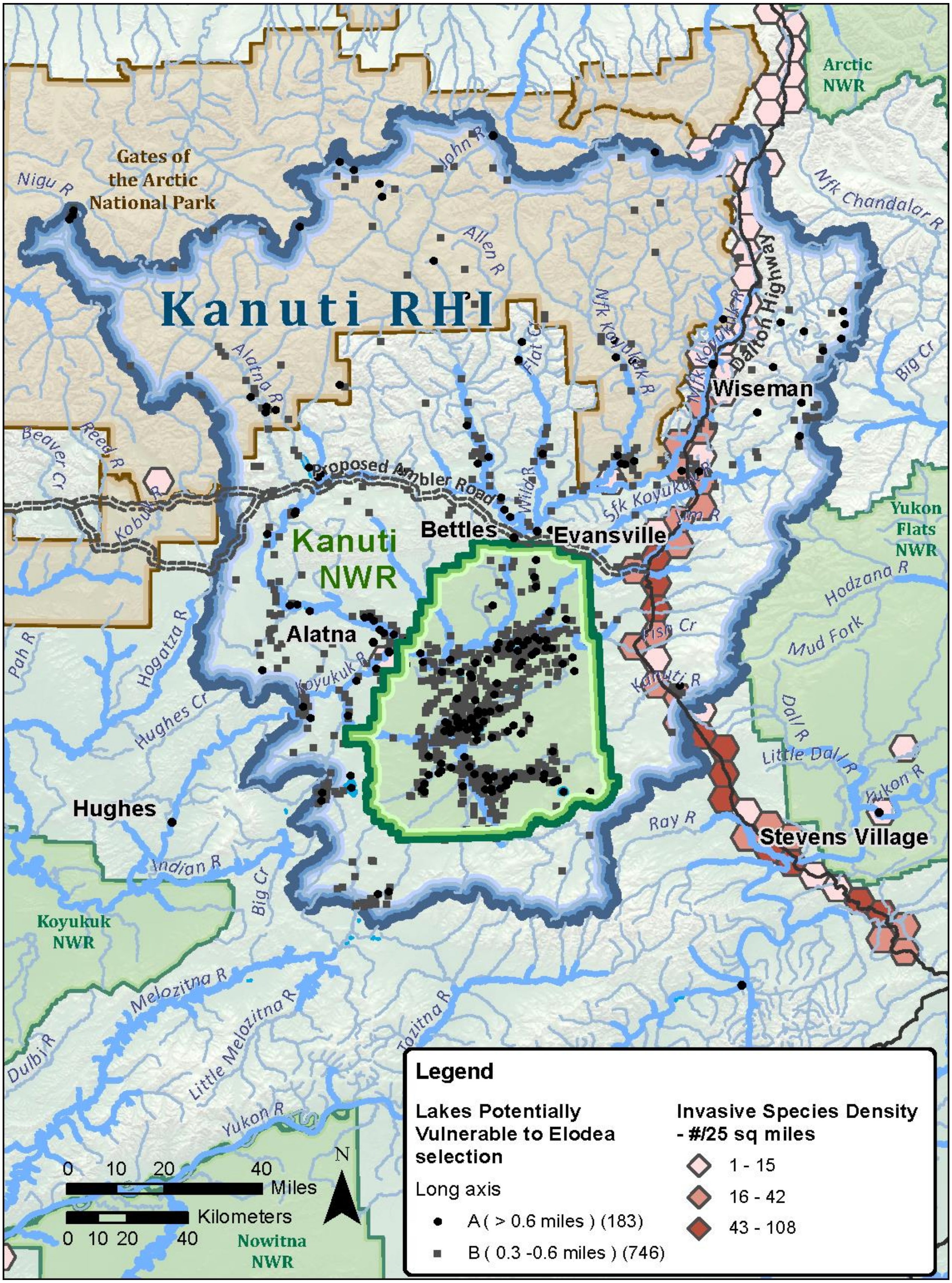
Table 14: Summary of threats to water resources within the Kanuti Region of Hydrologic (RHI) Influence and inventoried in the WRIA geodatabase

Threat Type	*Threat Class*	*Threat Cause*	*Threat Status*	*Source Database*	*Occurrences in geodatabase*
Aquatic habitat threats	Impaired Stream Connectivity	NA	Existing	Alaska Department of Fish and Game Fish Passage Inventory	48 passage occurrences
Aquatic habitat threats	Impaired Stream Connectivity	NA	Medium Term	Alaska Department of Fish and Game Fish Passage Inventory	53 passage occurrences
Aquatic habitat threats	Impaired Stream Connectivity	NA	Unknown	Alaska Department of Fish and Game Fish Passage Inventory	7 passage occurrences
Aquatic habitat threats	Impaired Stream Connectivity	NA	Unknown	Alaska Department of Transportation Bridges	28 bridges
Aquatic habitat threats	Loss/Alteration of floodplain habitat	Invasive species	Active	Alaska Exotic Plants Information Clearinghouse	760 exotic plants
Aquatic habitat threats	Loss/Alteration of floodplain habitat	Invasive species	Medium Term	R7 WRIA Potential Elodea Mapping	741 miles (with additional 102 miles in Refuge)
Water quality threats	Contaminant Pollution	Mining	Existing	Bureau of Land Management Federal Mining Claims	928 mining claims
Water quality threats	Contaminant Pollution	Mining	Medium Term	Bureau of Land Management Federal Mining Claims	19 mining claims
Water quality threats	Contaminant Pollution	Contaminant Pollution	Unknown	Alaska Department of Natural Resources Trans-Alaska Pipeline System	4 pipeline sites
Water quality threats	Contaminant Pollution	Industrial Effluent	Existing	Alaska Department of Environmental Conservation Contaminated Sites	19 contaminated sites
Water quality threats	Contaminant Pollution	Industrial Effluent	Existing	EPA Facility Registry System	5 registered sites
Water quality threats	Contaminant Pollution	Industrial Effluent	Closed	Alaska Department of Environmental Conservation Contaminated Sites	47 contaminated sites
Water quality threats	Contaminant Pollution	Industrial Effluent	Medium Term	EPA Facility Registry System	1 registered sites
Water quality threats	Contaminant Pollution	Mining	Existing	Alaska Department of Natural Resources State Mining Claims	747 mining claims
Water quality threats	Contaminant Pollution	Mining	Existing	DOI Office of Surface Mining Abandoned Mine Lands Inventory System	1 abandoned mines
Water quality threats	Contaminant Pollution	Mining	Existing	USGS Alaska Resource Data File	23 mines, prospects, and mineral occurrences
Water quality threats	Contaminant Pollution	Mining	Medium Term	USGS Alaska Resource Data File (Descriptions of mines, prospects, and mineral	248

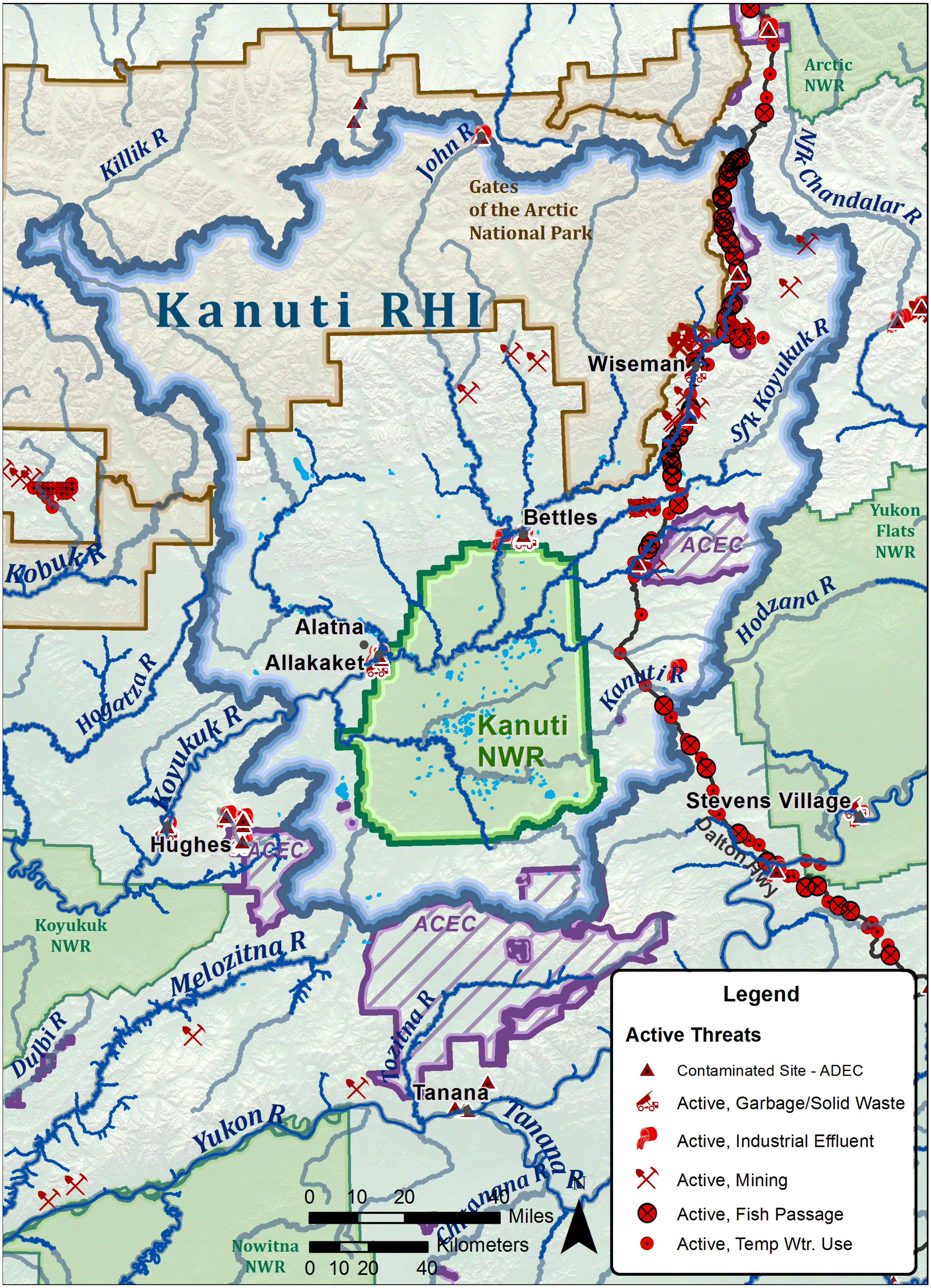
Threat Type	*Threat Class*	*Threat Cause*	*Threat Status*	*Source Database*	*Occurrences in geodatabase*
				occurrences)	
Water quality threats	Nutrient Pollution	Garbage/Solid Waste	Existing	Alaska Department of Environmental Conservation Solid Waste Sites	3 solid waste sites
Water quality threats	Nutrient Pollution	Garbage/Solid Waste	Closed	Alaska Department of Environmental Conservation Solid Waste Sites	9 solid waste sites
Water quantity threats	Altered Ecological Flows	Dams	Medium Term	Alaska Energy Authority Sites Evaluated for Potential Hydropower or Existing Hydroelectric Sites	19 potential hydropower sites
Water quantity threats	Water rights/Legal	Unspecified water use	Existing	Alaska Department of Natural Resources Temporary Water Use Permits (TWUP)	48 TWUP
Water quantity threats	Water rights/Legal	Unspecified water use	Medium Term	Alaska Department of Natural Resources Temporary Water Use Permits (TWUP)	67 TWUP



Map 9: Locations of active and potential mining sites and roads within Kanuti Refuge and RHI. Anadromous waters are emphasized in bold.



Map 10: Locations of threats from invasive plant species and lakes susceptible to *Elodea* infestation within Kanuti Refuge and RHI. Anadromous waters are emphasized in bold.



Map 11: Locations of contaminant threats within Kanuti Refuge and RHI.

6.2. Issues of Concern

The IOC are problems affecting the management and continued health of Kanuti Refuge's water-related habitats. During the WRIA interviews, results of the inventory and the GeoPDF poster were presented to refuge staff. Following the presentation, Kanuti Refuge staff identified IOCs. The IOCs address isolated concerns and issues with a cumulative potential to harm water resources (e.g., number of mines in the South Fork Koyukuk drainage, proposed Ambler Road) or the entire refuge/RHI (e.g., altered permafrost conditions). The WRIA process and literature reviews identified additional IOCs presented in Table 15.

Table 15 summarizes the IOCs. As noted in the previous paragraph, many of the IOCs directly relate to the threats identified from the geodatabase and were identified as IOCs because of the cumulative effects of several individual threats (see the column titled, "Occurrences in Geodatabase" in Table 15). Table 15 also includes attributes (current severity, time frame, and feasibility of the Service itself addressing the concern) associated with the national threat classification. Kanuti Refuge staff initially defined the attribute levels during the WRIA interview process, which were reviewed and revised to ensure consistency at a national level.

Attributes:

Severity categories range from high to unknown based on *current conditions* and the following criteria:

- High: Prevents fulfillment of refuge purpose(s) or NWRS mission; threatens public safety; threatens Threatened and Endangered (T&E) species; results in adverse legal consequences; threatens infrastructure;
- Moderate: Hinders completion of one or more management objectives (e.g., degrades habitat for non-T&E species, inadequate infrastructure for habitat management);
- Low: directly or indirectly affects refuge operations, but does not hinder refuge purposes or management objectives. Potentially of concern; or
- Unknown: insufficient information to determine severity.

Time frame is qualified according to the following criteria:

- Existing: currently a threat;
- Medium-term: anticipated threat within next 10 years (e.g., potential encroaching development or a groundwater contamination plume moving toward Kanuti Refuge); or
- Long-term: anticipated threat that is more than 10 years out (e.g., climate change).

Service control was classified as follows:

- Yes: mitigation measures are entirely within FWS control and do not require outside assistance; or
- No: mitigation measures are partially or entirely outside of FWS control; requires collaboration/partnerships.

Table 15: Issues of Concern (IOCs) and associated threats to the water resources of Kanuti Refuge/ RHI.

IOCs		*Threat type*	*Threat Cause*	*Current Threat Severity*	*Time Frame*	*Can FWS address alone*	*Occurrences in Geodatabase*	*Source of Information*	*Comment*
1.	Continued wetland/lake drying will alter fire regime and fire regime change will result in long-term hydrologic alteration.	Water Quantity Related Threats ; Aquatic Habitat Related Threats	Climate change	Moderate	Existing	No	0	Refuge interviews	Can address it in the short term but cannot stop the change. Address fire component in FMP.
2.	Change in water regime/water temperature will alter habitat suitability (species expansion/trophic mismatch i.e. willow, alder, beaver, northern pike, etc.)	Aquatic Habitat Related Threats; Water Quality Related Threats	Climate change	Low	Long-Term	No	0	Refuge interviews Water quality analysis	Cannot address it or stop the change but can monitor change.
3.	Increase of sedimentation causes changes in water quality/temperature. Note that fish kills due to increased river temperatures have occurred in Innoko NWR (personal communication with Josh Rose).	Water Quality Related Threats Aquatic Habitat Related Threats Contaminant Pollution; Altered water chemistry and pH; Sedimentation	Road building; Mining	Low	Existing	Yes	28 DOT bridges 842 miles trails 1 Proposed Ambler road 1 Dalton Hwy 1 Bettles winter road	Refuge interviews	Based upon what we know and currently existing roads
4.	Kanuti Refuge staff identified sites as potential contaminated sites: Bettles fuel spills, Allakaket sewer lagoon, excess silt/sedimentation from gold mine on Prospect Creek and into Jim River, pump stations spills, and leaks along the Alaska pipeline.	Water Quality Related Threats	Road building; Mining; Human Waste	Low	Existing	No	12 Solid waste sites 4 sections of Alaska Pipeline 66 ADEC contaminated sites 6 EPA contaminated sites	Refuge interviews	Can prepare sampling plan to determine contamination but becomes EPA/ADEC issue.
5.	Point source releases of radionuclides, rare earth elements, dust, and metal from open pit mining of rare earth minerals in the upper South Fork Koyukuk River, Fish Creek, Jim River, and the upper Kanuti River basins.	Water Quality Related Threats	Road building; Mining	Moderate	Medium-term	No	2 sties identified in reports	Jones et al. 2015	Mining claims are existing but have not yet been developed into working mine sites. The threat of mining is therefore medium term. If claims do develop into mines, the severity of the threat would increase.
6.	Increased discharge of copper and aluminum due to more frequent, large precipitation events, mining, and road building	Water Quality Related Threats Water Quantity Related Threats	Road building; Mining; Climate change	Moderate	Medium-term	No	947 Federal mining claims 747 State mining claims 271 USGS potential mining sites 28 DOT bridges 842 miles trails 1 Proposed Ambler road 1 Bettles winter road 1Dalton Hwy	Water quality analysis	Instances of high copper and aluminum were found in water quality samples, meaning there is natural availability in soils/geology for mobilization.
7.	Change in timing and magnitude of flow on rivers due to altered climate	Water Quantity Related Threats Water Quality Related Threat	Climate change	Low	Existing	No	0	Climate analysis	Severity will increase with time and climate change. Can monitor to assess change.
8.	Insufficient surface water and groundwater during critical habitat and function periods due to removal or diversion associated with road construction, mining, and water export	Water Quantity Related Threats Aquatic Habitat Related Threat	Road Building; Mining	Low	Medium-term	No	108 fish passage impediments 842 miles trials 1 Proposed Ambler road 1 Bettles winter road 1Dalton Hwy 115 Temporary water use permits	Geospatial threats analysis, and Refuge interviews	Based upon what we know and currently existing roads, mining claims, and current occurrences of water export

IOCs		Threat type	Threat Cause	Current Threat Severity	Time Frame	Can FWS address alone	Occurrences in Geodatabase	Source of Information	Comment
9.	Change in lakes and wetland characteristics (depth and area) that serve as freshwater species and bird habitat.	Water Quantity Related Threats Aquatic Habitat Related Threats	Climate change	Moderate	Existing	No	0	Climate analysis	Can monitor and explain the change. Develop a monitoring plan to assess species use change.
10.	Loss of closed-basin lakes and wetlands habitats (closed-basin lakes are more susceptible to drying).	Water Quantity Related Threats Aquatic Habitat Related Threats	Climate change	Moderate	Existing	No	0	Climate analysis and Refuge interviews	Are closed-basin lakes more numerous than open-basin lakes? Updates to NHD would help to identify surface water connection.
11.	Uncertainty of landscape level habitat changes (loss of permafrost and lake area/depth, and changes in soils, vegetation, etc.).	Water Quantity Related Threats Water Quality Related Threats Aquatic Habitat Related Threats	Climate change	Moderate	Existing	No	0	Climate analysis and Refuge interviews	
12.	Loss of permafrost, loss of high water table, and loss of groundwater transmission zones in rivers, lakes, and wetlands	Water Quantity Related Threats	Climate change	High	Existing	No	0	Refuge interviews	Biological concern for loss of fish overwintering habitat, bird habitat, and moose habitat
13.	Loss of permafrost/soils affecting the water quality by nutrient loading, carbon increases, and sedimentation.	Water Quantity Related Threats Aquatic Habitat Related Threats	Climate change	Low	Medium-term	No	0	Refuge interviews	Biological concern for loss of fish overwintering habitat, bird habitat, and moose habitat.
14.	Increase of invasive plant species from road building, floatplane use, and climate change.	Water Quantity Related Threats Aquatic Habitat Related Threats	Road building; Floatplane use; Climate change	Moderate	Existing	No	760 (Invasive Species loss of veg roots) 108 fish passage impediments 842 miles RS2477 trails	Geospatial threats analysis	
15.	Harm to "very high-value fisheries" (BLM) in large portions of the South Fork Koyukuk River upstream of Kanuti Refuge from "high" (BLM) vulnerability mining and road building sites.	Water Quantity Related Threats Aquatic Habitat Related Threats	Mining; Road building	High	Existing	No	No exact count	BLM report (Varner et al. 2015)	

The WRIA does not “rank” threats or IOCs, nor does it rank the danger of threats to specific rivers or watersheds. The analysis of threats and IOCs intends to provide a foundation for understanding the challenges of managing Kanuti Refuge’s water resources now and in the future.

During the development of this document, federal agencies released two reports related to mining in the Central Yukon Planning Area (CYPA). Kanuti Refuge and RHI are within the CYPA. BLM Central Yukon Field Office released the draft results of their Land Use Planning and Aquatic Resource Assessment (Varner et al. 2017) and the USGS, in cooperation with the Alaska Division of Geologic and Geophysical Surveys, released a GIS-based identification of areas with mineral resource potential for six deposit groups in the CYPA (Jones et al. 2015). The BLM ranked watersheds (level 6 Hydrologic Unit Code (HUC) from the NHD) on aquatic resources value, watershed condition, and watershed vulnerability. The USGS report ranked watershed (level-12 HUCs) based upon their mineral development potential. Both assessments applied rankings to a variety of data layers to determine a final rank for the assessment categories.

The USGS report ranked the Fish Creek and Jim River basins within the larger upper South Fork Koyukuk/Koyukuk Basin with a high potential for rare earth mineral exploration (Jones et al. 2015). According to the BLM process, large portions of the South Fork Koyukuk River also received a “very high” fisheries value, “high” vulnerability value, and a “fair” condition value. The high vulnerability value relates to the mining potential identified by the USGS report and the proximity of the area to the Dalton Highway. The USGS report also ranked areas in the upper Kanuti River Basin with high potential for rare earth mineral exploration (Jones et al. 2015). This area was given a “low” fisheries value, “good” condition value, and “moderate to low” vulnerability value through the BLM process. The mineral exploration ranking and proximity to the Dalton Highway increases the likelihood of future mining in these areas. Further, the upstream proximity of these areas to Kanuti Refuge makes such development there a threat to Refuge water resources. Special attention should be paid to planning and development activities in the areas.

The BLM is also in the process of updating the Central Yukon Resource Management Plan (CYRMP). The Resource Management Plan (RMP) process includes identifying Areas of Critical Environmental Concern (ACEC). ACECs are special management areas designated to protect significant historical, cultural, or scenic values; fish and wildlife resources; natural process or systems; and/or natural hazards. The RMP proposes to more than double the area of ACECs surrounding the Refuge and within the RHI but notably would not include the upper Kanuti River watershed as an ACEC. The ACECs within the RHI received their designation for scenic, geologic, fish, wildlife, or subsistence values and encompass 140,000 square miles of the RHI (90-million acres).

The findings of Jones et al. (2015) and Varner et al. (2017) provide additional information on threats and contribute to the IOC findings and recommendations provided in the discussion that follows. They corroborate the findings of this report and reinforce the recommendations associated with monitoring and water rights in and around Kanuti Refuge.

6.3. Needs

The WRIA interview process elicited information and management needs associated with water resources that will be input into the national WRIA database (Table 16). The discussion of needs relates to the IOCs and threats identified in Sections 6.1 and 6.2 above. However, needs are not necessarily associated with individual threats or IOCs, and not all IOCs or threats result in a need. A single need may address multiple threats or IOCs. Some needs results from findings of the WRIA process and lead to recommendations for the management of Kanuti Refuge's water resources.

The assessment organizes needs according to a national classification scheme that includes water-related infrastructure, monitoring and measurement, water management, modeling and research, mapping and geospatial analysis, water rights, planning and coordination, and mitigation and habitat improvement (Appendix I). The classification system assigns attributes (severity, effort required, timeline, and feasibility) to assist planning of management actions.

The attributes are described as:

Severity:

- High (1): Necessary to fulfill refuge purpose(s) or NWRS mission; necessary to protect public safety, infrastructure, or to avoid serious legal consequences; necessary for survival of T&E species;
- Moderate (2): Necessary to complete one or more management objectives, or protect/restore habitat for non-T&E species; or
- Low (3): Information helpful for refuge operations, but not critical to refuge functions.

Effort Required:

- Major (1): Requires more staff and/or funding than can be provided by refuge and Regional Office (requires outside support); or
- Minor (2): Can be accomplished with existing staff and budget (refuge and RO), although it may require re-prioritization of personnel or funding.

Timeline: defines timeframe for addressing the need:

- Short-term (1): less than 2 years;
- Medium (2): 2–5 years; or
- Long-term (3): greater than 5 years.

Feasibility: Can the Service can address this alone.

- Yes (1): Successful resolution entirely within FWS control and does not require outside assistance; or
- No (2): obtainment measures are partially or entirely outside of FWS control; requires collaboration/partnerships.

Table 16: Needs and associated IOCs applicable to the water resources of Kanuti Refuge/RHI

Action/Need	*Need Category*	*IOC*	*Priority*	*Effort Required*	*Timeline*	*Can the Service address*	*Source of Information*
Maintain long-term gage on (main stem) Koyukuk River	Monitoring and measurement	IOC 7 - Change in timing and magnitude of flow on rivers due to altered climate	High (1)	Minor (1)	Short-term (1)	No (2)	Assessment process
Maintain long-term gage on Kanuti River	Monitoring and measurement	IOC 7 - Change in timing and magnitude of flow on rivers due to altered climate	High (1)	Minor (1)	Short-term (1)	No (2)	Assessment process
Evaluate the current snow monitoring program for efficiency and effectiveness	Monitoring and measurement	IOC 12 - Change in water regime/water temperature will alter habitat suitability (species expansion/trophic mismatch i.e. willow, alder, beaver, northern pike, etc.)	Low	Minor	Short-term	Yes	Refuge interviews
Avoid water quality conditions for lakes and rivers that result in an EPA/ADEC 303d listing.	Water Quality	IOCs 4, 5, and 6 – Large-scale mining, road building, rare earth minerals mining, and contaminated sites.	Moderate (2)	Major (1)	Short-term (1)	No (1)	Refuge interviews
Include WRIA water quality reporting in planning documents since Contaminant Assessment Planning (CAP) is not available	Water Quality Planning	IOCs 4, 5, and 6 – Potential contamination from large-scale mining, road building, rare earth minerals mining, and contaminated sites.	Moderate (2)	Minor(1)	Short Term (1)	Yes (1)	Refuge interviews
Plan monitoring for impacts from the Bettles winter road; archive such data in the WRIA geodatabase.	Mapping and Geospatial Data/Analysis	IOCs 8, 14, and 15 - Road building impacts.	High(2)	Minor(1)	Short Term (1)	Yes (1)	Refuge interviews
Continue current stream temperature monitoring	Monitoring and measurement	IOC 2 and 3 - Increased **temperatures** in rivers and lakes	High (1)	Minor (1)	Short-term (1)	Yes (1)	Assessment process
Obtain water rights on streams gaged by Service	Water Supply/Water Rights	IOC 8 - Insufficient surface water and groundwater during critical habitat and function periods due to removal or diversion from winter and summer road building, mining, and water export.	High (1)	Major (2)	Medium-term (2)	Yes (2)	Refuge interviews
Map extent and thickness of permafrost and refine soils mapping.	Mapping and Geospatial Data/Analysis	IOC 1, 9, 10, 11, 12, and 13. Change in, water quality, and landscape features due to extent of permafrost	Moderate (2)	Major (2)	Medium-term (2)	No (2)	Refuge interviews
Complete NWI classification and mapping for the Refuge	Water Quality Mitigation/Habitat Improvement	IOC 9, 10, 11 – Loss of lake and wetland area, depth, and number	High (1)	Major (2)	Long-term (3)	No (2)	Assessment process
Identify open- and closed-basin lakes with high habitat value	Monitoring/Measurement	IOC 10 – loss of closed-basin wetland and lake systems	High (1)	Moderate (2)	Short Term (2)	Yes (1)	Assessment process and refuge interviews

Action/Need	*Need Category*	*IOC*	*Priority*	*Effort Required*	*Timeline*	*Can the Service address*	*Source of Information*
Develop plan to identify and provide long-term monitoring of open- and closed- basin lakes, including determining those most susceptible to drying or loss of surface area	Planning Mapping and geospatial data analysis	IOC 10 – loss of closed-basin wetland and lake systems	Moderate (2)	Minor(1)	Short Term (1)	Yes (1)	Assessment process and refuge interviews
Use the NEPA process to monitor flow on rivers and lakes affected by mining	Monitoring and measurement	IOCs 5, 6, and 15 - mining impacts.	High (1)	Minor (1)	Long Term (2)	No (2)	Assessment process
Monitor for copper and aluminum, along with other water quality parameters of interest, in systems where mining is occurring upstream of Refuge	Monitoring and measurement	IOC 6 – increase in availability of copper and aluminum due to mining and road building	High (1)	Moderate (1)	Long Term (1)	No (1)	Assessment process
Monitor turbidity, TDS, and SC in systems adjacent to areas susceptible to road building	Monitoring/Measurement	IOC 3, 4, 5, 6, 8, 14, and 15 - Increase in suspended solids and fine sediments	High (1)	Minor (1)	Short-term (1)	Yes (1)	Assessment process and refuge interviews
Monitor rare earth mineral contaminants (radionuclides, rare earth elements, dust, and metals) in basins rated high for rare earth mineral mining, including the Fish Creek and Jim River basins, Holonada, and the upper Kanuti Basin.	Monitoring/Measurement	IOC 5 - Point-source releases of radionuclides, rare earth elements, dust, and metal from open pit mining of rare earth minerals in the upper South Fork Koyukuk River, Fish Creek, Jim River, and the upper Kanuti River basins.	High (1)	Moderate (1)	Medium term (2)	No (1)	Assessment process; Jones et al. 2015
Map areas of open water in winter, aufeis, and overflow as a starting point for cataloguing known areas of groundwater contribution	Monitoring/Measurement	IOC 12 - Loss of permafrost, high water table, and groundwater transmission zones in rivers, lakes, and wetlands	Moderate (2)	Minor (1)	Short Term (1)	Yes (1)	Assessment process
Review State water rights every 10 years. Pursue federal reserved water rights as required to ensure needed water quantity	Water Rights	IOC 1, 7, and 8 – change in timing, magnitude of flow and availability of water	High (1)	Minor (1)	Long-term (3)	Yes (1)	Assessment process
Continue to participate in planning and management activities at the landscape scale.	Planning	IOC 11 – Landscape-level changes (permafrost, lake area, soils, vegetation, etc.) due to climate change.	High (1)	Moderate (2)	Short-term (1)	Yes (1)	Assessment process

7. Findings and Recommendations

The assessment process led to the findings and recommendations listed below. The findings characterize the waters, identify gaps and inconsistencies in data, and highlight the significant threats to Kanuti Refuge's water resources. The recommendations reflect the findings, the current hydrologic condition, and the outlook for the health of Kanuti Refuge's natural water resource systems. The recommendations identify actions to maintain the freshwater habitats and species to achieve the Refuge's ANILCA purposes and water management goals. The extent to which climate change will alter natural hydrologic systems is unknown, but implementing these recommendations should help the Refuge's efforts to maintain the water quality and quantity necessary to conserve fish and wildlife populations in their natural diversity. Implementing these suggestions will require a multifaceted approach to the management of the rivers, lakes, wetlands, and groundwater of the Refuge.

The findings and recommendations follow the chapters/subject headings of the document. Not every finding has a recommendation, nor does each recommendation correspond to a specific finding.

Natural Settings

Finding: Baseline inventories and mapping of hydrography, permafrost, wetlands, vegetation, and soils are incomplete, outdated, or mapped at an inappropriate scale. Improving, completing, or updating these inventories will enhance Kanuti Refuge's ability to evaluate the ecological impacts of climate change and natural resource/infrastructure development.

Notable Natural Settings Observations

- **IFSAR is complete for Kanuti Refuge.**

Recommendations:

- As opportunity arises, contribute to updating the NHD with the Regional Office. NHD is a georeferenced digital dataset representing the natural and human-altered hydrologic features (rivers, streams, lakes, canals, gages, dams & coastlines) of the United States. In Alaska, the NHD also serves as the primary spatially georeferenced base layer to which most other geospatial data such as land status, vegetation, and wildlife data are spatially registered. An accurate and complete NHD layer is the required base dataset the USGS will use to develop the data-rich NHD+ dataset required by many current and future ecological analysis models and programs.

- Cooperate with the I&M program, LCCs, and NWI to improve, complete, or update baseline datasets, including:
  - permafrost inventory,
  - wetland classification (NWI),
  - hydrography dataset (NHD+),
  - soils inventory, and
  - vegetation inventory.

Surface Water

Rivers

Recommendations:

- Maintain long-term stream gage on the Koyukuk River at Old Bettles.

- Reestablish the gage on the Kanuti River to represent long-term flow patterns for smaller, lower latitude, and lower elevation drainages on the Refuge. Alternatively, consider another river with lower latitude and elevation headwaters and with easy accessibility to Kanuti Refuge, such as Henshaw Creek, which also has long-term salmon information from the weir.

- Monitor river and lake phenology (freeze-up, break-up, peak flows, low flows), seasonal water temperatures, and instream wood features (logjams/sweepers/strainers) on the Koyukuk, South Fork Koyukuk, and Kanuti Rivers using water temperature sensors and game cameras.

- Evaluate future development projects for bridge/culvert design, fish passage, and sufficient stream flow (along with water quality, as discussed in the water quality recommendations below).

Surface Water Observations

- **The flow of the Koyukuk River is an order of magnitude greater than the other gaged systems within the Kanuti and Koyukuk drainages.**
- **The higher elevation and latitude headwaters of the Koyukuk and South Fork Koyukuk Rivers result in a different hydrologic regime than other rivers within Kanuti Refuge. The timing, magnitude, frequency, and duration of hydrologic events differ. It is likely that hydrologic response to a changing climate will differ in the Koyukuk drainage from other Kanuti Refuge drainages.**
- **Changing temperature and precipitation patterns will alter the timing and magnitude of ice up, ice out, and flow of Kanuti Refuge's riverine systems and the species that have adapted to these patterns.**
- **Flow data on systems not previously monitored will be particularly important, especially on systems where temporary water use authorizations allow water extraction for industrial use.**

Lakes

Finding: Shallow lakes in areas of relatively ice-poor permafrost are most susceptible to losses in surface area as climate warms (Roach 2011).

Finding: Closed-basin lakes are more susceptible to drying than river-connected lakes under scenarios of a warming climate (Roach 2011).

Finding: Information is limited concerning open- and closed-basin lakes, extent/thickness of permafrost, and lake habitat value.

Recommendations:

- Create a geospatial data layer of lake basin flow direction from IFSAR data to determine lake basin types (open versus closed) to inform monitoring planning (note also that NHD+ incorporates flow direction).

- Incorporate the lake depth results for 11 lakes captured by Glesne et al. (2011) on the lake basin map developed from ISFAR to begin delineating deep and shallow lakes.

- Overlay habitat use for species of concern (known through observation or biological surveys) on the lake basin map developed from ISFAR.

- Develop a long-term study plan to understand the implications of changing climate, including determining aquatic and terrestrial habitats resistant to lake/wetland drying. This study should include both open- and closed-basin systems, as well as systems of varying depths.

Wetlands

Finding: The acreage/percentage of wetlands derived from an analysis of existing land cover and wetland datasets presented in this WRIA is an initial assessment. The results of this crosswalk analysis underestimated wetland habitat on the Refuge. This work emphasizes the need for improved hydrography and wetlands (NWI) mapping.

Finding: The results derived from the crosswalk analysis group Kanuti Refuge into one upland (81%) and 13 wetland (19%) classes.

Recommendations

- Apply the results of the wetland-land cover crosswalk to support the acquisition of improved soils/permafrost and hydrography datasets in support of wetland mapping.
- Coordinate with NWI to complete the wetland classification.
- Overlay geospatial layer(s) of habitat use for species of concern (known through observation or biological surveys) on maps of wetland areas to create a record of important freshwater habitat areas for management.

Groundwater

Finding: The hydrologic inventory of Kanuti Refuge revealed several locations where open water leads indicate the presence of groundwater upwellings or springs in reaches of the Kanuti Kilolitna River, Henshaw Creek, and portions of the South Fork Koyukuk River just upstream of the refuge and downstream of the Dalton Highway.

Groundwater Observations

- **Changes in the extent and the thaw sequences of permafrost may affect the chemical composition and residence time of groundwater flow to river systems, the state of groundwater-influenced lakes and wetlands, extent of shallow lakes and wetlands, seasonal river-ice thickness, and stream temperatures.**
- **Loss of permafrost may result in the loss of high water tables and groundwater transmission zones associated with rivers, lakes, and wetlands.**

Recommendations:

- Develop methods to inventory and map open water leads, aufeis, and overflow in winter along Refuge streams and lakes as an initial means of mapping groundwater sources.
- Map flow direction from IFSAR data to determine surface water-to-groundwater connections.
- Because freshwater habitats supported by groundwater will likely persist under climate change scenarios to provide long-term high-value habitat, evaluate wetland and lake systems to determine their groundwater connectivity to plan for climate-resilient freshwater habitats across the Refuge.

- Support research for better understanding the interactions between groundwater and permafrost interactions to develop a long-term monitoring plan for groundwater-related habitats.

Water Quality

Finding: There are no listed EPA 303(d) impaired waters in Kanuti Refuge or RHI (ADEC, 2012b).

Recommendation: Collect data on waters suspected of impairment and nominate those that are impaired to for inclusion on the 303D list. ADEC accepts nomination during odd years (2017, 2019, etc.).

Water Quality Observations

- **A large acidic input would be necessary to shift the general water composition of riverine systems to acidic levels that are harmful to aquatic life.**
- **The high levels of copper and aluminum may be an indication of the availability of metals in unexposed sediments susceptible to weathering.**
- **Mining of rare earth elements occurs through open pit mining, creating point sources for the release of four major contaminants: radionuclides, rare earth elements, turbidity, and metals. Periods of high flow (spring breakup/snowmelt and large summer/fall rain events) create the potential for mobilizing these contaminants.**

Finding: The natural waters of Kanuti Refuge exhibit a calcium-magnesium bicarbonate-dominant ionic profile that typically exhibits a strong buffering ability.

Finding: Macro-invertebrate and benthic diatom communities found in Refuge streams are broadly similar to those in other interior Alaska streams (Bogan 2014).

Finding: Sample results for trace metals found incidences of high levels of copper (Kanuti Kilolitna River and Kanuti River Tributary in May 2012) and aluminum (all sites at different points in the sampling period).

Finding: MWMT at the South Fork Koyukuk and Kanuti Rivers were marginally above the EPA's recommended maximum summer temperature criterion of 18˚ C for salmon and trout migration (ADEC, 2012a).

Recommendations:

- Continue water temperature monitoring at the Koyukuk River gaging station in partnership with the NPS, the NWS, and the USFWS Water Resources Branch (WRB).
- Coordinate with TCC to continue water temperature monitoring at Henshaw Creek weir.
- Establish a water temperature-monitoring network for rivers of high fisheries value (Varner et al. 2017) and reaches vulnerable to temperature change (shallow or recently burned reaches without solar shading).
- Follow Alaska Regional Protocol Framework for Monitoring Stream Temperature (Perdue and Trawicki 2016) when establishing stream temperature sampling efforts and coordinate efforts with the WRB of the Regional Office.

Finding: Areas of the Fish Creek and Jim River basins, within the larger upper South Fork Koyukuk/Koyukuk Basin, have high potential for rare earth minerals according to USGS (Jones et al. 2015).

Recommendation:

- Develop and implement a monitoring plan to establish baseline conditions of radionuclides, rare earth elements, dust, and metals in the extents of the Fish Creek and Jim River basins within the Refuge. Ensure sampling during high and low flow events.

Finding: New roads, placer mining (Koyukuk and South Fork Koyukuk Rivers), and development projects have been proposed in and adjacent to Kanuti Refuge since scoping for the water resources monitoring occurred in 2007.

Recommendations:

- Address water quality and quantity concerns on rivers not previously monitored. Supplement monitoring on systems that were sampled during the 2008–2016 baseline effort to inform concerns raised during scoping and NEPA compliance of large development projects.
- Proactively establish a sampling plan for systems that may be impacted by road or resource development activities. Implement the plan to collect baseline data at least a year prior to projects' inception. Data collection should include:
  - Information on fish, macroinvertebrate, and benthic diatoms
  - Water quality parameters should reflect the type of activity and geology in the affected watershed and may include:
    - Trace metals in areas where soil disturbance exposes sediments to weathering. Special attention should be given to copper since baseline sample results indicated the availability of copper;
    - pH and SC as a continuous or preliminary indicator of contamination or system degradation; and
    - continuous turbidity and temperature on systems adjacent to roads and mining activity.

Water Rights

Finding: There are no State of Alaska-granted water rights within Kanuti Refuge.

Finding: There are State-granted water rights for multiple owners and uses in the RHI. None of these water rights has a priority date that precedes the federal reserved water rights established with the creation of Kanuti Refuge.

Recommendations: Continue to support the Service's efforts to obtain instream flow reservations for protecting a) the habitats, migration, and propagation of fish and wildlife,

Water Rights Observations

- **Kanuti Refuge maintains explicit, but unquantified, federal reserved water rights with a priority date of 2 December 1980.**
- **ADF&G and BLM hold instream flow water reservations on reaches of the Jim River outside the Kanuti Refuge boundary. These reservations limit withdrawals by other upstream water users, ensuring sufficient water in this system to maintain specified flows for the purposes of fish and wildlife.**
- **The availability of freshwater across the refuge is not currently threatened, but climate change and future development may limit water availability.**

and b) water quality.

- Document the biological use of rivers and lakes on Kanuti Refuge to support water rights applications:
    - Document the distribution of key aquatic species in Refuge rivers and lakes or major watersheds.
    - Develop fish periodicity charts for Kanuti Refuge's rivers and lakes or major watersheds.
- Document the presence of anadromous fish at various life stages in Refuge rivers, for addition to the AWC.
- Conduct a water rights review every ten years to ensure protection of important or threatened waters.

Climate

Finding: Precipitation trends and climate model predictions suggest increases in precipitation of 7–12% each century, with the largest changes in autumn and winter.

Recommendation:

- Support the continued operation of the SCAN site at Kanuti Lake.
- Evaluate current snow course aerial survey and snow sampling programs to ensure it provides a reliable index of precipitation in different regions of Kanuti Refuge. Continue to measure snow density at least once per year.
- Work with regional partners to maintain the NWS station in Bettles and the SCAN site at Kanuti Lake to provide data for the northern (wetter) and southern (dryer) portions of Kanuti Refuge, respectively.

Climate Observations

- **Warming climate will result in the loss of permafrost, affecting the vegetation and freshwater landscape.**
- **Thawing permafrost will likely contribute to increased turbidity and total dissolved solids (TDS) levels from erosion and changes in carbon and nutrient cycling.**
- **Increases in air temperatures will drive increases in water temperature affecting dissolved oxygen, pH, conductivity, oxidation-reduction potential, and the rate of biogeochemical reactions.**

Finding: Data showing increases in annual and seasonal air temperatures at the Bettles Airport agree with statewide trends of nearly four degrees Fahrenheit from 1949 to 2005.

Recommendations:

- Conduct long-term monitoring of water temperature to identify and explain the biotic changes driven by alteration of hydrologic conditions.
    - Continue measuring continuous water temperature at the Koyukuk River at the Old Bettles gage station.
    - Resume or initiate monitoring continuous water temperature on previously measured rivers (Kanuti Kilolitna River, South Fork Koyukuk River, Holonada Creek, and Kanuti River Tributary Rivers), and rivers and lakes accessible by plane or boat.

- Follow the Alaska Regional Protocol Framework for Monitoring Stream Temperature (Perdue and Trawicki 2016) when establishing stream temperature sampling efforts and coordinate efforts with the Water Resources Branch of the Regional Office.

General or Management

Recommendation: Participate in planning and review of large-scale development projects.

Recommendation: Continue to participate in planning efforts addressing the BLM's CYRMP, including addressing the implications of state and Federal mining and transportation within the utility corridor.

Recommendation: Work with conservation community/partners and researchers (e.g., share results and interpretation) to maximize science across the landscape to achieve conservation success.

Finding: Lakes susceptible to *Elodea* infestation have been mapped from the WRIA geodatabase.

Recommendations:

- Coordinate activities with the regional Invasive Species program.
- Continue conducting biannual river floats to assess the possible spread of invasive plants along refuge waterways.
- Monitor changes in the occurrence and spread of invasive plants using the *Elodea* map. Coordinate with the Regional Office regarding the applicability of eDNA methods for identifying the presence of *Elodea*.

By implementing these recommendations, the Refuge can continue to improve management of the water-related refuge purposes and will address the goals established in the CCP (U.S. Fish and Wildlife Service 2008). Each of these recommendations contributes to the conservation of the Refuge's diversity of wildlife, fish, and habitats through the maintenance of the natural hydrologic cycle (CCP Goal 1) and the natural function and condition of water resources for fish and wildlife populations and habitats (CCP Goal 2).

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