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Open File Report #129

Developing Quantifiable Management Objectives from Reference Conditions for Wadeable Streams in the National Petroleum Reserve in Alaska

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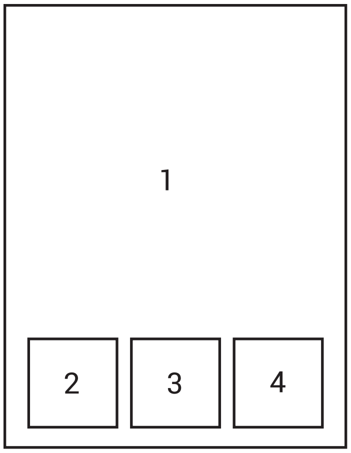

Cover Photographs

1. Aerial view of the National Petroleum Reserve in Alaska.
2. Lotic AIM survey crew collecting data at site TR-008 (Hannah Bear Creek) in 2016.
3. A member of the lotic AIM survey crew setting up site TR-006 (Bill's Creek) in 2016.
4. A member of the lotic AIM survey crew setting up site SS-9204 (unnamed creek) in 2016.

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Introduction

The National Petroleum Reserve in Alaska (NPR-A) is located on the north slope of Alaska within the western portion of the Arctic Coastal Plain ecoregion. Administration of the area is carried out by the Department of the Interior under the authority and direction of the Naval Petroleum Reserves Production Act of 1976 (NPRPA) and Federal Land Policy and Management Act of 1976 (FLPMA). The NPR-A is actively managed by an Integrated Activity Plan (IAP), most recently revised with the signing of a new Record of Decision (ROD) in 2020. Within this ROD, the Secretary of the Interior is tasked with managing these lands to "assure the maximum protection of such surface values to the extent consistent with the requirements of" the NPRPA for exploration of the reserve.

Under the NPRPA, the Secretary is required to conduct oil and gas leasing and development in the NPR-A (42 USC 6506a). The Department of the Interior and Related Agencies' Fiscal Year 1981 Appropriations Act directs the Secretary to undertake "an expeditious program of competitive leasing of oil and gas" in the Petroleum Reserve. The NPRPA provides that the Secretary "shall assume all responsibilities" for "any activities related to the protection of environmental, fish and wildlife, and historical or scenic values" (42 USC 6503(b)) and authorizes the Secretary to "promulgate such rules and regulations as he deems necessary and appropriate for the protection of such values within the Reserve."

The Department of the Interior and Related Agencies' Fiscal Year 1981 Appropriations Act exempted the NPR-A from Section 202 of FLPMA. Section 202 (43 USC 1712) requires the preparation of land use plans (called resource management plans, in regulations—43 Code of Federal Regulations Part 1600—adopted by the BLM). Because of the exemption from FLPMA Section 202 and that the NPRPA is a dominant-use statute, the IAP is not a resource management plan and does not consider sustained yield and multiple use.

Under the FLPMA, the Secretary has broad authority to regulate the use, occupancy, and development of public lands and to take whatever action is required to prevent unnecessary or undue degradation of the public lands (43 USC 1732). Due to the continued demand for oil and gas development and the need to differentiate natural change on the landscape from change induced by oil and gas development, it is important that baseline conditions of wadeable streams and rivers in the NPR-A are quantified. This information serves as a foundation for decision making and is critical in preventing unnecessary or undue degradation of lotic and riparian resources.

Within the NPR-A, the Bureau of Land Management (BLM) manages over 10,220 miles of perennial stream and lotic riparian habitat, as well as almost 1.8 million acres of lakes when only including individual lakes with a surface area greater than 10 acres. These aquatic resources serve as habitat and migration corridors for anadromous and resident fish species in addition to a host of other aquatic species (Hershey et al. 1999; Woo and Guan 2006; Woo and Mielko 2007; Lesack and Marsh 2010; Whitman et al. 2011; Arp et al. 2012). Similarly, aquatic resources in the NPR-A provide many other ecosystem services, such as insect relief areas for wildlife, transportation networks for subsistence users, and recreation. The majority of aquatic resources in the NPR-A and their functions are largely believed to be anthropogenically unaltered (BLM NPR-A IAP 2020).

The BLM applies Required Operating Procedures (ROPs) and lease stipulations to prevent undue and unnecessary degradation (UUD) to surface resource values, including but not limited to streams, rivers, and their floodplains. There are SOPs in place for each step of development, from seismic exploration to exploratory drilling and construction of permanent infrastructure. The NPR-A Fisheries Monitoring Implementation Plan (FMIP; Noel et al. 2008) provides monitoring recommendations for each oil and gas phase to help evaluate the effectiveness of SOPs in the NPR-A IAP ROD (BLM 2020) that are intended to mitigate potential impacts and avoid UUD. Data collected following the BLM's Assessment, Inventory, and Monitoring (AIM) strategy for lotic systems (BLM 2015a) is used to evaluate the effectiveness of SOPs and provides a direct evaluation of the NPR-A's FMIP conceptual models. The BLM's AIM strategy creates a data collection framework to inform decision-making at multiple scales.

Through standardizing data collection and analysis, this framework integrates both local and regional scale aquatic monitoring activities to more effectively inform BLM management decisions and planning activities. As a result, the framework helps ensure maintenance of and improvements to aquatic resource conditions on public lands.

This project also exemplifies one of AIM's foundational principles: being able to use and share data across different agencies (BLM 2015a). Data collection and analysis in the NPR-A was a collaborative effort between the Alaska Department of Environmental Conservation (ADEC) and the BLM. Alaska DEC collected the first year's data in 2015 using the Environmental Protection Agency's (EPA) National Rivers and Streams Assessment (NRSA) protocol. The BLM collected data in 2016 and 2017 using the BLM's Assessment, Inventory, and Monitoring National Aquatic Monitoring Framework (AIM-NAMF, BLM 2017). Select indicators of these two protocols are largely compatible; the specifics can be found in Appendix A of TR 1735-2. While both the EPA and BLM programs primarily sample at randomly selected locations, the BLM collected data at additional targeted sites in areas of proposed oil and gas development infrastructure in the Fish Creek Watershed in 2016 and 2018 to aid in future site-specific monitoring within the watershed.

The primary goals of AIM-NAMF sampling in the NPR-A include:

- Developing quantifiable benchmark values to assess stream condition and trend;
- Establishing quantitative baseline conditions for the chemical, physical, and biological attributes of BLM-managed wadeable streams and river habitats following the applicable Alaska Statewide Land Health Standards (AK IM 2004-023);
- Collecting pre-disturbance data in watersheds with high potential for oil and gas development to evaluate the effectiveness of mitigation measures and Best Management Practices;
- Linking AIM data to long-term monitoring data collected in the Fish Creek Watershed within the NPR-A; and,
- Assessing long-term trends in the chemical, physical, and biological condition of lotic systems within the Arctic Coastal Plain (ACP) ecoregion of the NPR-A.

This report presents information describing the range of chemical, physical, and biological conditions of wadeable waters on the ACP ecoregion within the NPR-A. These results provide a current baseline of lotic aquatic resource conditions for evaluating IAP effectiveness and for future trend monitoring, while at the same time allowing the BLM to differentiate between anthropogenic and natural change over time. This report also demonstrates how lotic AIM data can be paired with long-term monitoring data and the assessment of conditions pre- and post-oil and gas development.

Methods

Study Area

The study area encompasses the ACP ecoregion within the NPR-A from the Chukchi Sea in the west to the Colville River in the east. The ACP ecoregion is underlain by thick continuous permafrost, which causes poor soil drainage and the formation of thermokarst lakes that cover up to half of the region (Gallant 1995). The poorly drained soils support a wet graminoid herbaceous community.

The fluvial landscape of the ACP is driven by permafrost, low-relief topography, and numerous lakes and wetlands (Roulet and Woo 1998; Bowling et al. 2003; Arp et al. 2012). Streams and rivers are frozen from October until late-May when break-up of streams and rivers occurs (Arp et al. 2012, 2015). Break-up accounts for the majority of annual flow throughout the year with summer rainfall events rarely resulting in streams and rivers reaching bankfull discharge (Arp et al. 2012). Streams and rivers throughout the coastal plain are dominated by alluvial and beaded systems. Beaded streams are formed by thermokarst features on the landscape and "initiate mainly from thermokarst lakes and drained thermokarst lake basins" (Arp et al., 2012, 2015; Whitman et al., 2011). Thermokarst features are depressions on the landscape caused by melting permafrost (Jorgensen et al., 2015). Both the alluvial and beaded systems are dominated by sand and silt substrates with alluvial systems having more unstable banks (Arp et al. 2012; NPR-A IAP 2020).

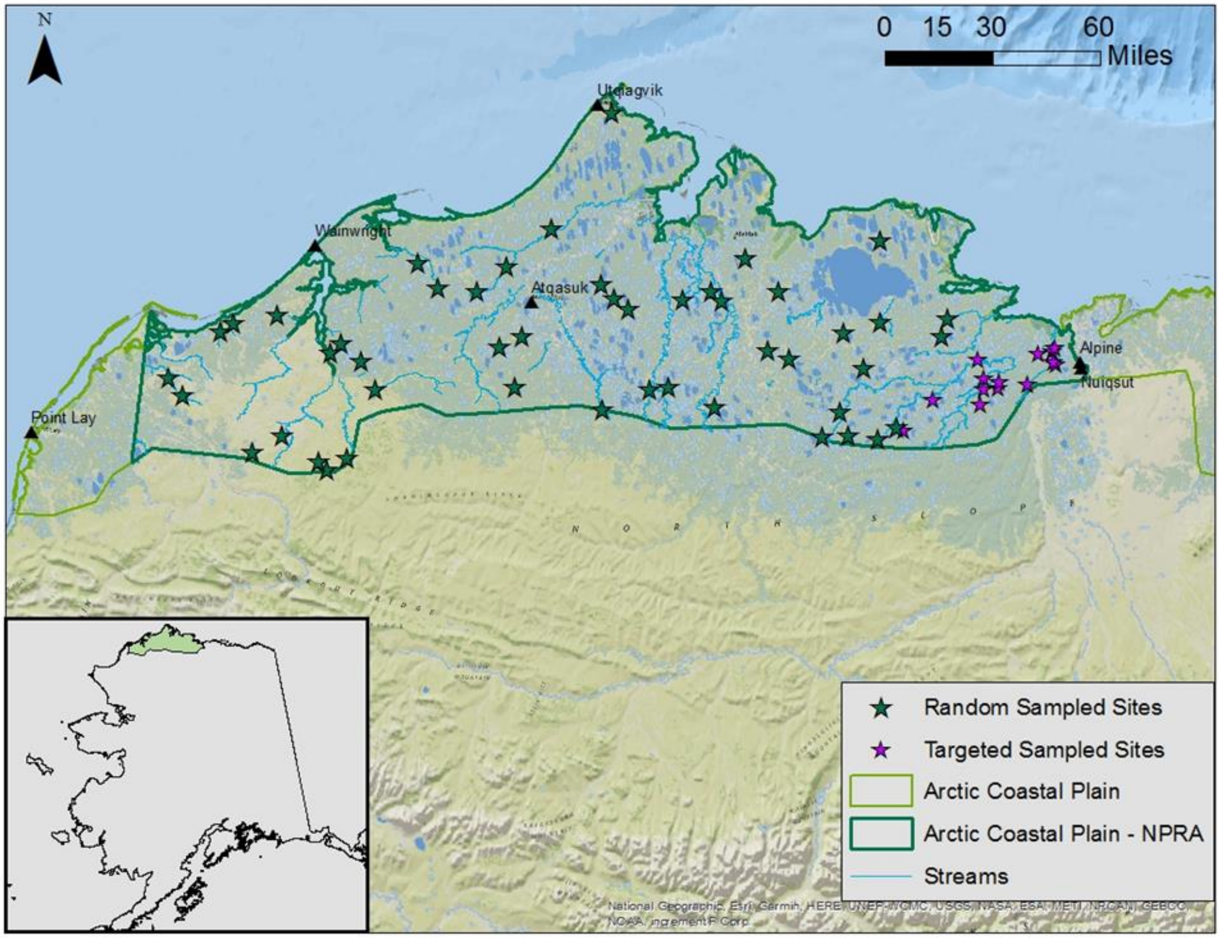

Figure 1. Map of the 2015-2018 lotic AIM sampled sites across the Arctic Coastal Plain in the NPR-A.

Sampling Methodology

To establish quantitative, baseline conditions for the chemical, physical, and biological attributes of streams on the ACP within the NPR-A, we selected a subset of stream reaches for sampling using a probability-based survey design. Specifically, the randomized design allocated 50 points across the landscape in proportion to the linear extent of stream size categories (Olsen 2005; Figure 1). The stream size categories were based off of Strahler stream order where 1st and 2nd order streams are small streams, while 3rd and 4th order streams are large streams (Strahler 1952). Due to weather, time, and logistical constraints, we were able to sample 48 of the 50 randomly distributed points.

BLM crews were also able to collect data at an additional 13 targeted sample sites in the Fish Creek Watershed including the Greater Mooses Tooth 1 and 2 (GMT1 and GMT2) and Willow Creek development (Willow Master Development Plan (MDP)) areas. Seven of the sample points were to tie into existing long-term monitoring locations within the GMT1 development area. Six of the sample points were to collect data in areas expected to have oil and gas development in the Fish Creek watershed. The sample points within the Fish Creek watershed were located immediately downstream of future planned road crossings (Figure 1).

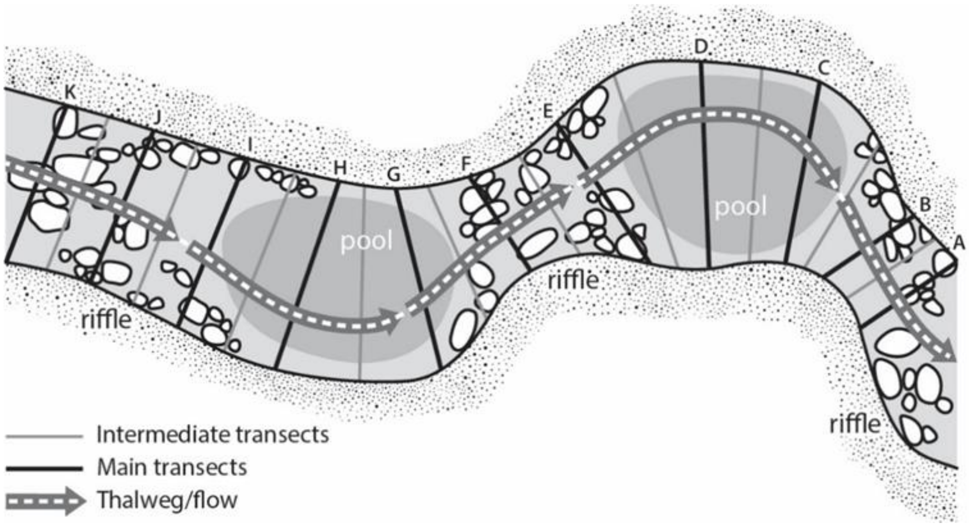

Figure 2. Typical reach setup with 11 main transects (A-K; black lines) and 10 intermediate transects (gray lines) oriented perpendicular to the thalweg. Reach lengths are equal to 20 x bankfull width or a minimum of 150 meters (BLM 2020, USEPA 2009).

Data collection in the NPR-A occurred during the month of July from 2015-2018 and followed the AIM Protocol for Wadeable Lotic Systems (BLM 2020). Increasing sampling efficiency in the field was required to limit the high cost of helicopter operations, so we reduced the standard 210 stream particle size count to 105. Data collection also included environmental (eDNA) sampling as a supplemental method. The eDNA sampling was also part of a larger effort by the BLM, the National Aeronautics and Space Administration (NASA), and Utah State University (USU) to predict fish species distribution in the NPR-A. Preliminary results of the eDNA project are described in the Applications to Land Management and Decision-making section of this report and final results are expected to be published in the future.

Establishing Minimally Disturbed Conditions, Baseline Conditions, and Condition Benchmarks

To determine if the 48 randomly sampled sites represented minimally disturbed conditions, each site was evaluated for anthropogenic impacts upstream. Watersheds were delineated upstream of lotic AIM sites and were evaluated for anthropogenic disturbances using spatial data including North Slope Borough (NSB) camps and cabins, agency field camps, legacy wells, oil and gas development, and the Alaska pipeline. We found that four sites had anthropogenic activities upstream. Of these four sites with anthropogenic activities, three had significant activities upstream including NSB camps and cabins, legacy wells, roads, and large constructed gravel pads. These three sites were sampled during initial field efforts; however, they were removed from the reference distribution. The fourth site with upstream activities had only one legacy well in a 69 square mile watershed and was kept as reference. Based on this screening process, we used the natural range of variability from 45 out of the 48 sites to characterize minimally disturbed conditions (Stoddard et al. 2006). These sites capture the natural range of environmental heterogeneity across the landscape and through time, including naturogenic impacts such as thermokarst dynamics, wildfire (albeit rare on the ACP), floods, etc.

Results from lotic AIM sampling yields values for 68 commonly used indicators. Many other indicators, particularly related to benthic macroinvertebrates, can also be computed. While all of these indicators help characterize the chemical, physical, and biological condition of lotic resources in the ACP portion of the NPR-A, some indicators can be more responsive to land-use effects than others. For example, activities which remove streambank vegetation or alter streambank condition would directly influence metrics related to streambank stability and cover. Conversely, activities which limit floodplain function may contribute to channel incision, which is assessed via the floodplain connectivity metric. Based on the mechanisms of potential impacts from oil and gas activity (Noel et al. 2008; Cott et al. 2015; NPR-A IAP 2020), floodplain connectivity, bank cover/stability, vegetative complexity, water quality, and macroinvertebrate community indicators are expected to yield the most immediate and strongest signals in the NPR-A.

Using these indicators, the range of minimally disturbed conditions was utilized to establish condition benchmarks among the 45 sample sites (Hughes et al., 1986; Paulsen et al. 2008). Monitoring benchmark conditions in areas of oil and gas development will help evaluate the management objective of sustained yield and productivity of aquatic resources on public lands. Benchmark values of indicators for both small and large streams are presented in Appendix A. However, since small streams are predominantly affected by development, this report focuses on the application of setting benchmarks for small streams. Large streams exhibited a wide range of variability for several indicators and additional studies are necessary to further understand indicator variability.

Condition benchmarks are used to determine if observed values at assessed sites are within the range of desired conditions (proper functioning condition), outside the range (nonfunctional) or somewhere in the middle (functional-at risk). For example, for indicators thought to increase in response to disturbance (e.g., fine sediment, turbidity, floodplain connectivity), we used the 75^{th} and 95^{th} percentiles of the minimally disturbed conditions distribution to determine the maximum indicator value a site can have before it is classified as functional-at risk or nonfunctional, respectively (Table 1). Specifically, indicator values less than the 75^{th} percentile represents proper functioning conditions, values between the 75^{th} and 95^{th} percentiles represent functional-at risk conditions, and values >95^{th} percentile are in nonfunctional condition. Similarly, for indicators thought to decrease in response to disturbance (e.g., bank stability, riparian vegetative complexity, etc.) the 25^{th} and 5^{th} percentiles were used to determine the minimum indicator value a site can have before it is classified as functional-at risk or nonfunctional, respectively. The actual percentiles used (e.g., 95^{th} versus 90^{th} percentile for major departure) can change for a particular region based on BLM land use planning (LUP) objectives and tradeoffs of balancing resource use versus conservation. For example, a National Conservation Area designated for its high-quality aquatic resources might require the use of a higher percentile to ensure maintenance of aquatic habitats.

Table 1. Table depicting benchmarks and state water quality standards for the indicators used as examples in this report. Additional indicators and their associated benchmarks can be found in Appendix A.

Indicator	Predicted Response to Stress	Units	Benchmark	Percentile	Beaded Streams	State WQ standard
Floodplain Connectivity	Decrease	None	Moderate	75th	1.56	N/A
			Major	95th	1.88	N/A
Vegetative Complexity	Decrease	None	Moderate	25th	0.88	N/A
			Major	5th	0.76	N/A
Bank Cover/Stability	Decrease	%	Moderate	25th	68	N/A
			Major	5th	56	N/A
pH	Increase	SU	Moderate/Major	75th/95th	7.92/8.4	8.5
	Decrease		Moderate/Major	25th/5th	7.32/6.21	6.5
Temperature	Increase	°C	Moderate	75th	15.4	20
			Major	95th	18.2	20

In locations where sampling can precede oil and gas infrastructure construction, site-specific, pre-disturbance baseline conditions can be established and serve as an additional tool for evaluating potential land use impacts. Using lotic AIM to monitor key ecosystem elements during resource development can help management evaluate the effectiveness of SOPs that are intended to mitigate impacts.

In summary, a key component of implementing a robust environmental monitoring program such as lotic AIM, is to evaluate whether the BLM is maintaining proper functioning conditions of lotic systems and meeting management objectives for permitted activities. This is accomplished by quantifying the current baseline conditions (i.e., reference condition) for the chemical, physical, and biological components of lotic resources. With baseline conditions now established for the ACP ecoregion portion of the NPR-A, the BLM can assess the natural change of lotic systems through time, as well as the change of lotic systems in watersheds with oil and gas development. By comparing the trend of lotic conditions in reference condition watersheds to watersheds with oil and gas development, the BLM will be able to more definitively say whether management policies and mitigation measures are maintaining proper functioning condition lotic systems across the landscape.

Results

Inventory of Perennial Streams and Rivers

We estimated the original target population of wadeable, perennial streams and rivers on lands managed by the BLM in the NPR-A within the ACP ecoregion to be 10,220 miles (USGS NHD). Through site scouting and sampling, we found that about 56% of streams (5,674 miles) were non-target due to factors such as having characteristics of a wetland instead of a stream, or being un-wadeable during baseflow conditions (Figure 3). We re-calculated the potential target population of wadeable streams and rivers on the ACP within the NPR-A by removing the non-target streams and rivers resulting in 4,546 miles of wadeable perennial streams and rivers. Of these 4,546 miles, 10% (450 miles) of streams were inaccessible due to proximity to subsistence camps and to prevent disturbance to caribou herds, so we are unable to definitively determine if these streams are part of the target population. We were able to make inferences to the remaining 90% (4,096 miles) of the potential target population in the NPR-A within the Arctic Coastal Plain.

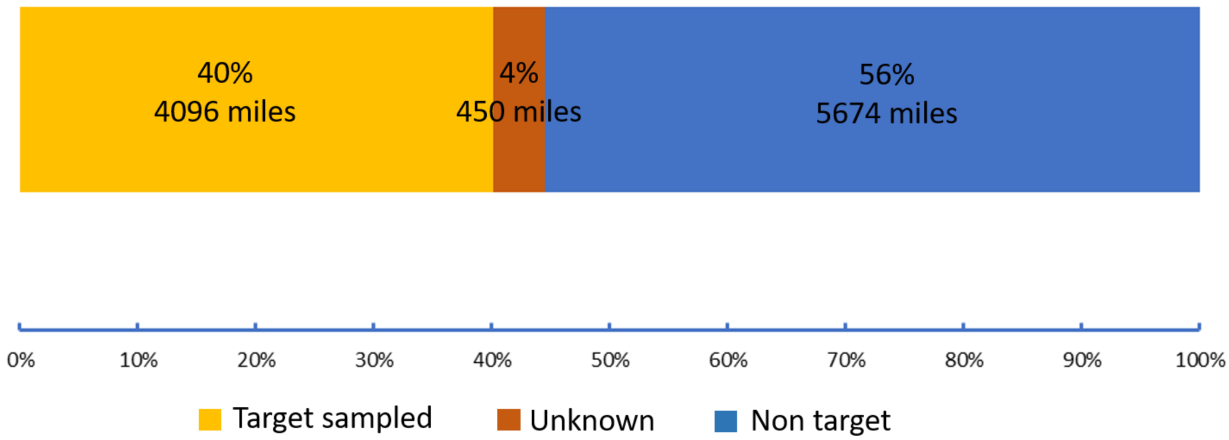

Figure 3. Breakdown of stream miles in the NPR-A that were targeted-sampled, unknown, and non-target as part of the lotic AIM implementation. Estimates are based on the National Hydrography Dataset (NHD) and field sampling.

Characterizing Baseline Conditions

The following indicators (i.e., bank overhead cover and Simpson's diversity index) were chosen as examples to highlight some characteristics of lotic and riparian habitat that will be important to continue monitoring into the future. Many other indicators can and will be used to describe current and future lotic conditions across the ACP. Establishing baseline conditions is the first step in trend monitoring. Repeat sampling using lotic AIM methodologies approximately 10 years from now will show whether lotic and riparian conditions are changing, and if so, how those conditions are changing.

Bank overhead cover directly measures the amount of aerial shade provided by vegetation and other features such as rocks and boulders to provide thermal refugia (Beschta 1997, Johnson and Jones 2000). Measuring bank overhead cover also provides direct information on the amount of potential leaf litter and terrestrial organisms as a food source (Cummins 1974). Bank overhead cover is measured with a convex densiometer displaying 17 intersections, where the observer counts the total number of intersections covered by any form of vegetation or any object that creates shade such as a bridge. Bank overhead cover is the average of all measurements taken at both left and right banks at all 11 main transects (Figure 2) and values can range from zero to 100% (TR 1735-3). We observed a minimum value of 0% cover and a maximum value of 78% cover, with a mean of 14% cover (Figure 4). Sites with higher bank overhead cover values typically have high amounts of sedges and grasses along with some woody vegetation, whereas sites with lower values have banks dominated in cover by tundra matting.

Freshwater macroinvertebrates have long been used in water quality analysis due to their vulnerability to physical and chemical changes in aquatic environments (Hawkins et al. 2000). Diversity measures both the richness and evenness in a community (Gotelli and Ellison 2013) and was calculated using the Simpson's diversity index. The Simpson's diversity index ranges from 0 to 1, with higher numbers representing more diverse communities. We observed a minimum value of 0.16 and a maximum value of 0.84 on the ACP within the NPR-A (Figure 5). The different indices and abundance indicators described in this report will serve as the baseline for monitoring biological communities on the ACP. There is ongoing work towards observed to expected (O/E) and multi-metric index (MMI) models for Alaska, which could potentially be utilized for future analyses, although the timeline for completion and acceptance of such models is unknown.

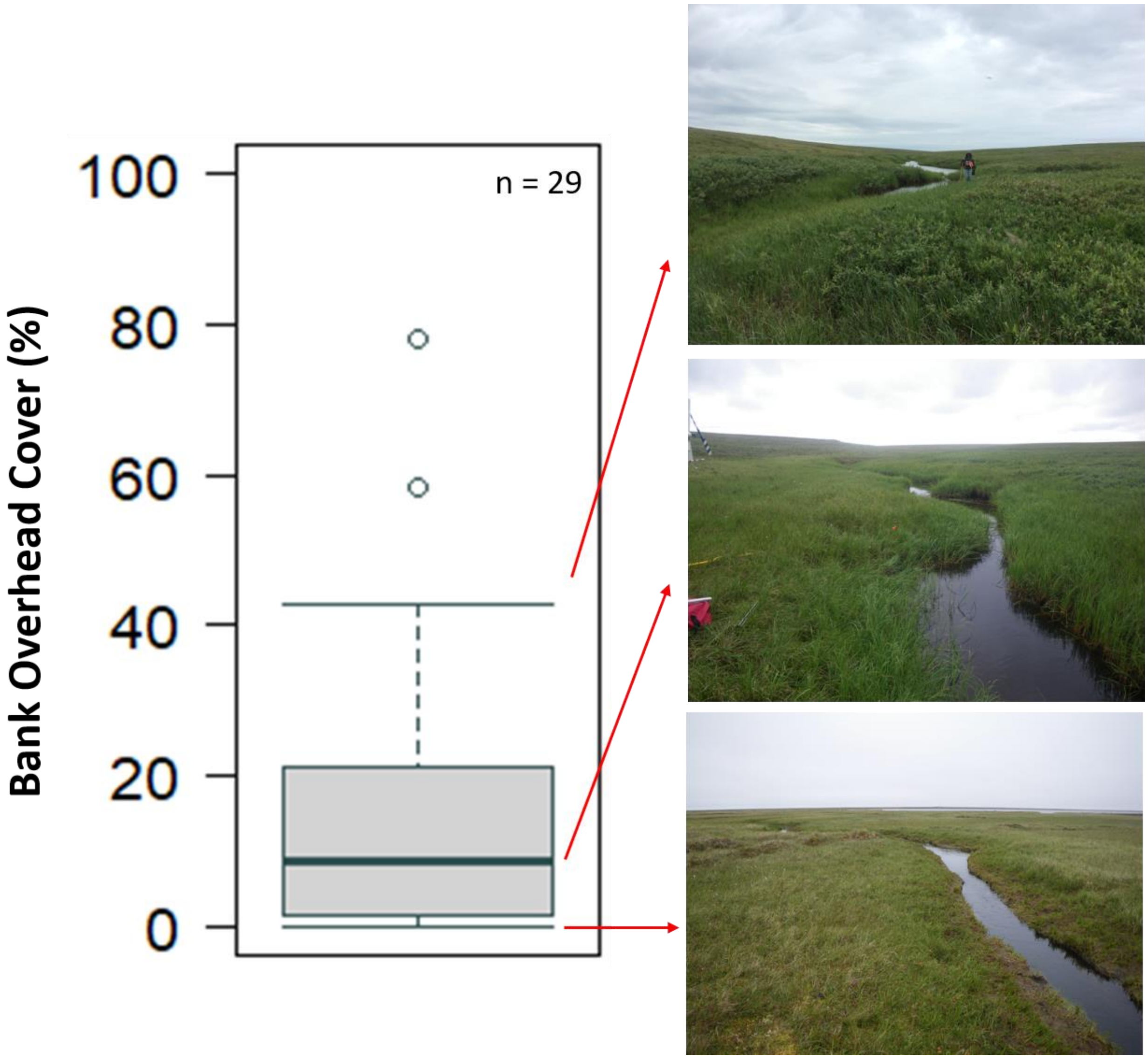

Figure 4. Bank Overhead Cover. The box plot depicts the range of bank overhead cover values for beaded streams observed throughout the ACP within the NPR-A. The images depict the variability of bank overhead cover values across the ACP for the 95th, 50th, and 5th percentiles..

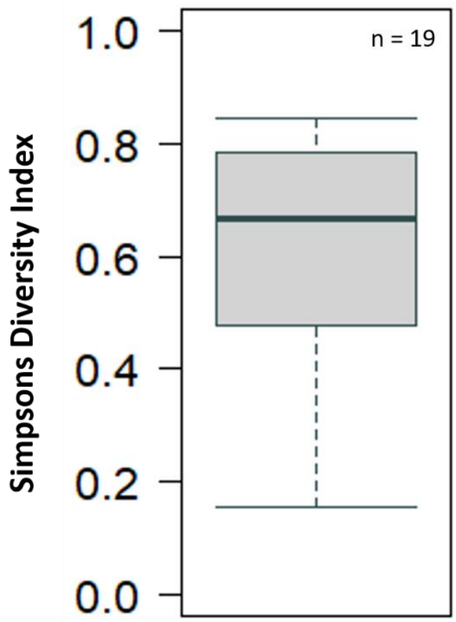

Figure 5. This box plot depicts the range of values for the Simpson's Diversity Index for beaded streams observed throughout the ACP within the NPR-A.

Benchmarks

Low-order streams on the ACP are comprised of beaded and alluvial stream types with the former being the most common. Low-order streams (1st and 2nd) are believed to be the most affected by oil and gas development on the ACP. It is assumed that low-order streams would demonstrate the earliest response to land-use impacts given the greater extent of development relative to drainage area on the NPR-A ACP (Downing et al. 2012; Wohl 2010; Arp et al. 2015; Garrett 2016). Therefore, this report establishes condition benchmarks for vegetative complexity, floodplain connectivity, and bank cover/stability for smaller stream systems only.

Channel incision results in disconnected floodplains and can negatively impact nutrient retention, dissipation of stream energy, riparian ecosystem development and maintenance, and biological diversity (Knighton 1998; Leopold et al. 1992). Floodplain connectivity is computed from the difference in elevation of the bankfull height and the first flat depositional feature at or above bankfull, which typically ranges from 1 (non-incision: low bank height = to bankfull stage) to ~3 (significant incision: low bank height > bankfull stage height) (BLM TR 1735-3). We observed a minimum value of 1.0 and a maximum value of 2.3, with the 75th and 95th percentiles equal to 1.6 and 2.0, respectively, among the 28 beaded streams (Figure 6). Overall, this condition benchmark suggests a low degree of naturally occurring incision throughout the ACP within the NPR-A.

Riparian zones are transitional areas between terrestrial and aquatic ecosystems that provide important habitat for organisms and influence many physical and ecological processes, including flood dissipation, nutrient cycling, shade, and cover to reduce thermal loading (Naiman and Decamps 1997). Maintaining an intact riparian corridor is fundamental to a stable stream channel and supports both chemical and biological stream functions (Harman et al. 2012, Perucca et al. 2007). Riparian vegetative complexity is determined by visually estimating the percentage of aerial cover for the three different layers, or strata, of vegetation (canopy, understory, and groundcover) and can range from zero (<10% vegetation cover) to 3.5 (>87% vegetative cover) for all three strata. We observed a minimum value of 0.41 and a maximum value of 1.83, with the 25th and 5th percentiles equal to 0.86 and 0.64, respectively, among the 29 beaded streams (Figure 7). Sites with higher vegetative complexity values typically have high amounts of sedges and grasses along with some woody vegetation, whereas sites with lower values have banks dominated in cover by tundra matting with some sedges and grasses. With vegetative communities dominated by sedges, grasses, and low-lying shrubs such as willows, dwarf birch, and blueberry, the range of values for vegetative complexity would be expected to be on the lower end. With no trees present on the ACP, the highest possible value a site could have for vegetative complexity is 2.3. Warming temperatures on the ACP could potentially cause an increase in the amount of shrub communities (Sturm et al. 2001; Tape and Sturm 2006; Naito and Cairns 2015). The degree of structural complexity changes within the riparian vegetation community will be explored with future-trend monitoring of sites beginning in approximately 2027.

Bank cover and stability are calculated as one indicator. A bank is considered stable and covered if it has >50% basal cover and lacks features of instability (e.g., fracture, slump block, etc.). The combined bank cover and stability indicator is determined by collecting 44 bank stability and cover measurements at each site. Bank cover and stability can range from 0 to 100%, with lower values indicating banks are susceptible to accelerated erosion. For beaded streams we observed a minimum value of 33% and a maximum value of 100%, with the 25th and 5th percentiles equal to 63% and 44%, respectively (Figure 8). Note that bank cover and stability was not collected in 2015, which limited the number of sites available for analysis. In addition, nine bank cover values were determined to be incorrect during the post-field collection quality control review and were excluded from further analysis. The data suggested that these nine sites had bank cover close to zero, however, a review of site photos suggested banks having cover closer to 100%. We are, therefore, only able to report on eleven stream reaches that have bank cover and stability data. Trend monitoring beginning in 2027 will include repeat sampling of these sites and the addition of new randomly selected sites on the ACP, thus providing greater confidence in the range of bank cover and stability conditions in the region.

Indicators such as pH, specific conductance, temperature, and turbidity are all single-point-in-time measurements taken at the F transect of each site using an in-situ water quality sonde (Figure 2). These water quality measurements are used to detect potential impairments on the landscape from development, used in correlation analyses in regard to freshwater macroinvertebrates, and to assess the attainment of state water quality standards (TR 1735-3). Alaska state water quality standards state that for recreation and aquatic life, pH may not be below 6.5, above 8.5, or vary more than 0.5 above or below background levels. For pH, we observed a minimum value of 6.1 and a maximum value of 8.8, with a mean of 7.5 (Figure 9). Alaska quality standards for freshwater uses state that a stream may not exceed 20 °C at any time. For temperature, there are additional habitat-specific criteria, such as spawning areas, migration routes, rearing areas, and for egg and fry incubation. For instantaneous temperature readings, we observed a minimum value of 6.7 °C and a maximum value of 18.8 °C, with a mean of 13.3 °C (Figure 9).

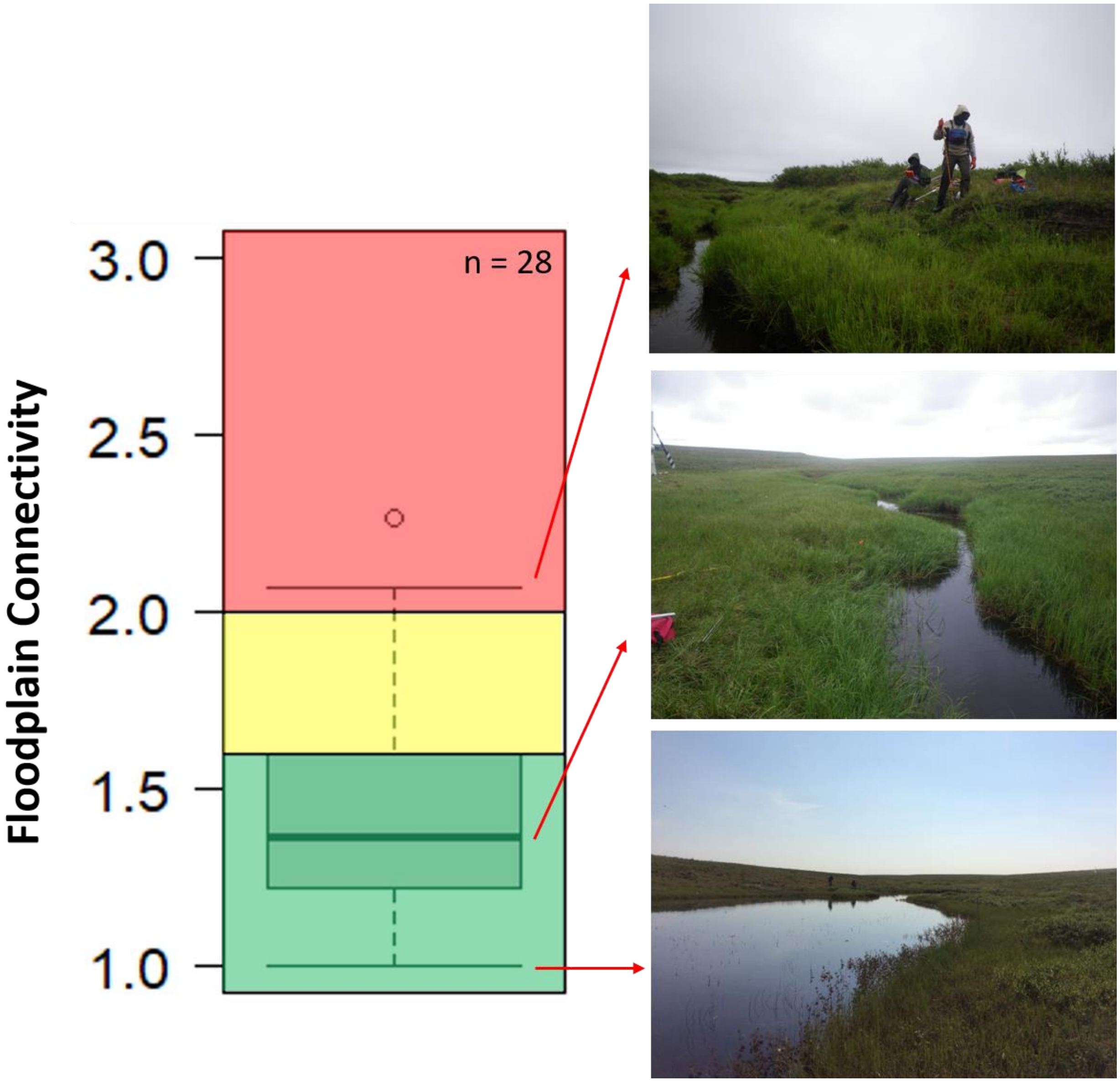

Figure 6. Floodplain Connectivity. The box plot depicts the range of floodplain connectivity values for small streams observed throughout the ACP within the NPR-A. The images depict the variability of floodplain connectivity values across the ACP for the 95th, 50th, and 5th percentiles. Incision values above the 75th percentile and 95th percentiles of minimally disturbed conditions were used as benchmarks for functional-at risk and nonfunctional, respectively.

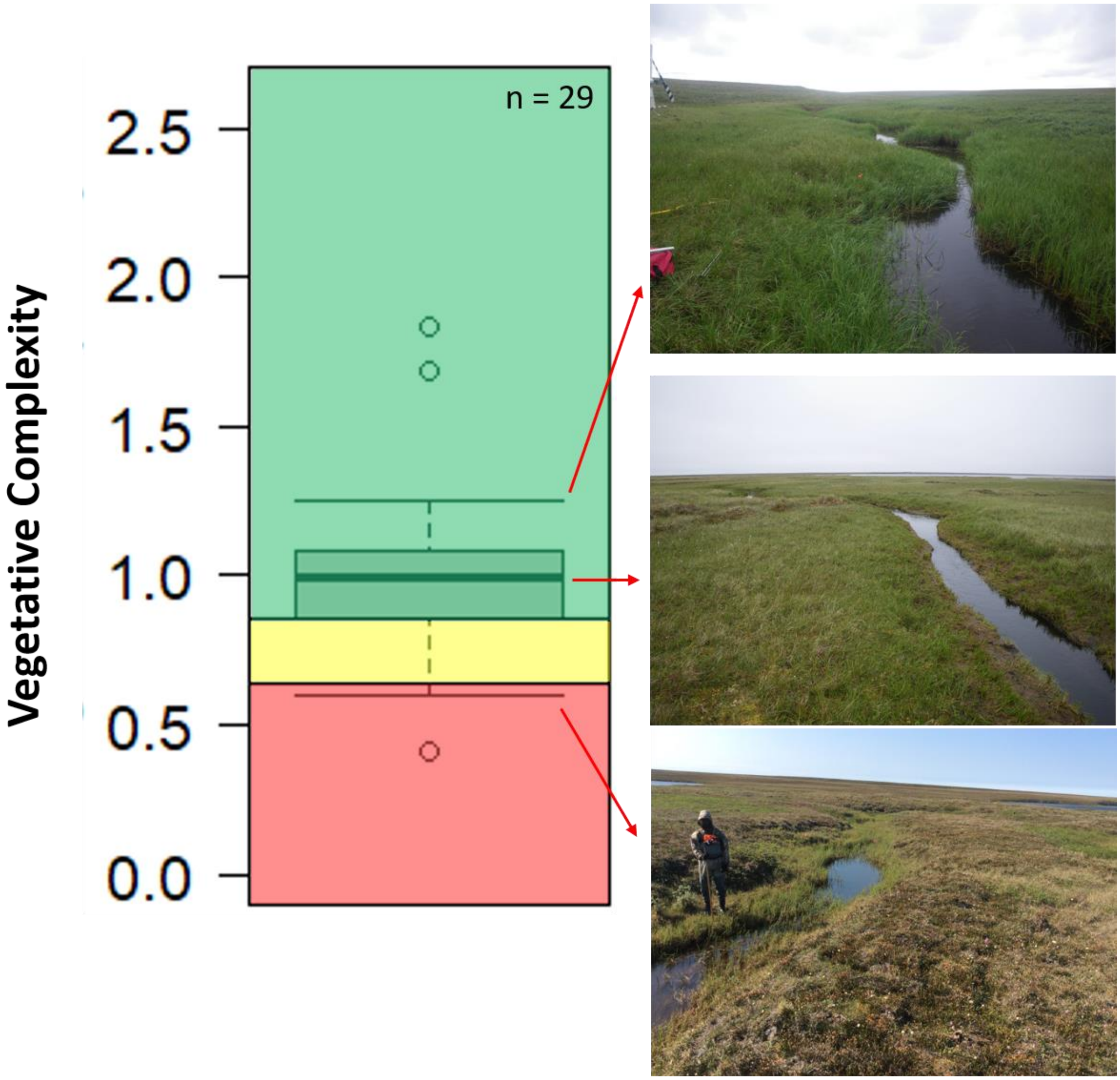

Figure 7. Vegetative Complexity. The box plot depicts the range of riparian vegetation complexity values for small streams observed throughout the ACP within the NPR-A. The images depict the variability of bank overhead cover values across the ACP for the 95th, 50th, and 5th percentiles. Values below the 25th and 5th percentiles of minimally disturbed conditions were used as benchmarks for functional-at risk and nonfunctional, respectively.

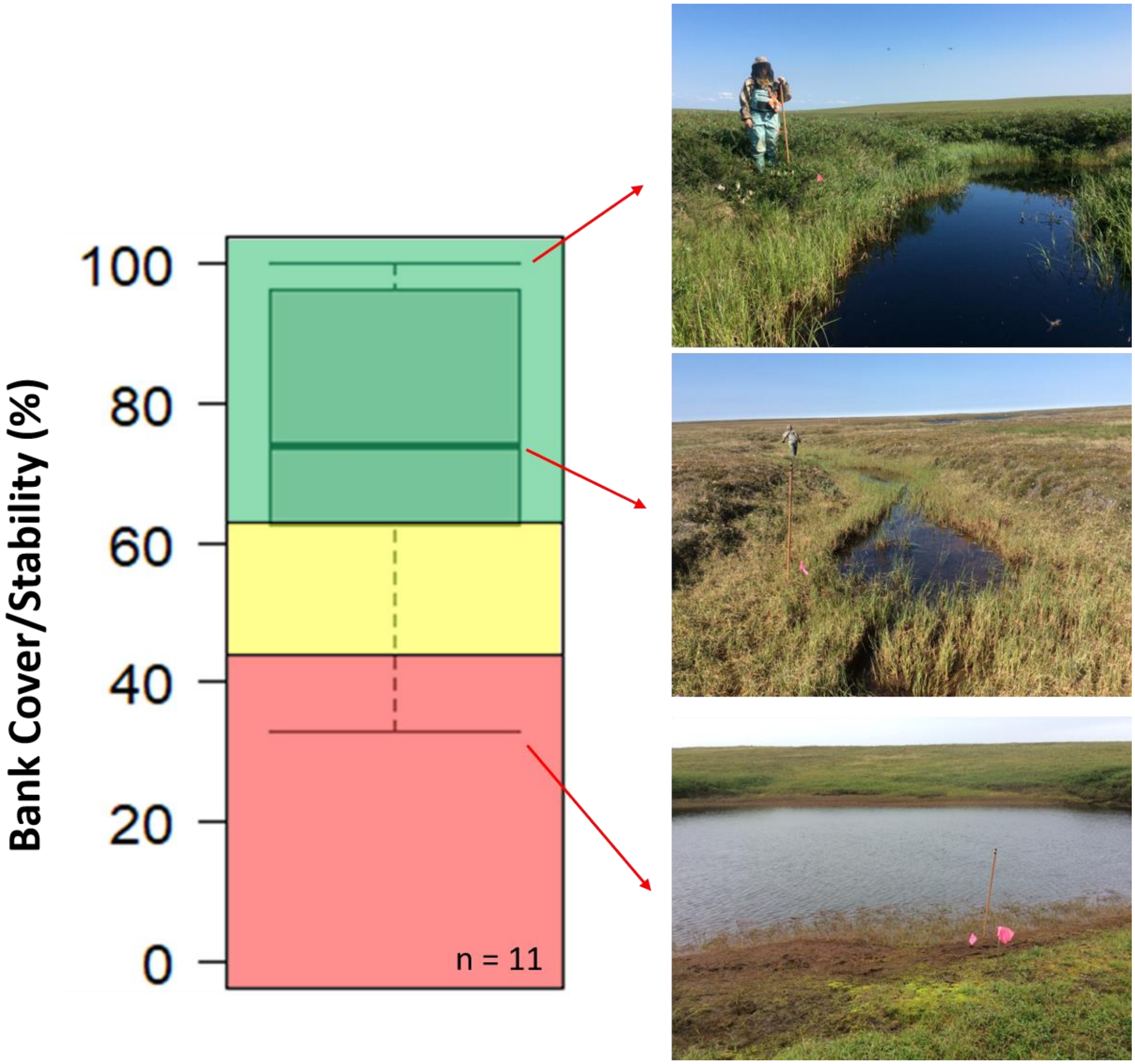

Figure 8. Bank cover and stability. The box plot depicts the range of bank cover/stability values for small streams observed throughout the ACP within the NPR-A. The images depict the variability of bank cover and stability values across the ACP for the 95th, 50th, and 5th percentiles. Bank cover and stability values below the 25th and 5th percentiles of minimally disturbed conditions were used as benchmarks for functional-at risk and nonfunctional ratings, respectively.

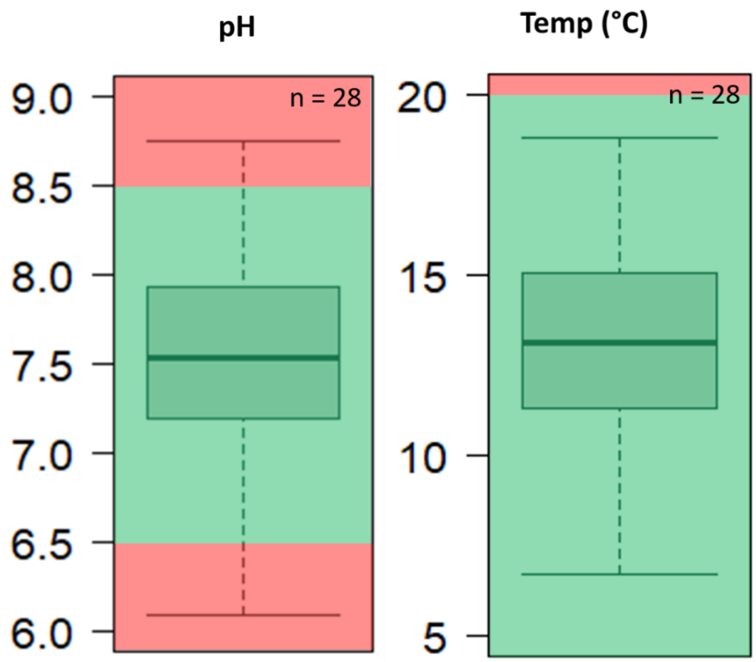

Figure 9. pH and temperature. These box plots depict the range of conditions for pH and instantaneous temperature values for small streams observed throughout the ACP within the NPR-A. For water quality, an indicator is either meeting or not meeting Alaska's water quality benchmarks, denoted by the green and red colors respectively.

Applications to Land Management and Decision-making

The BLM is committed to integrating science into work processes at all levels (BLM 2015b, WO IM 2017-030). The BLM's AIM-NAMF program provides the tools and subsequent data to integrate science efficiently and effectively into decision-making at a variety of scales. In the section above, we described the process for developing benchmarks for the ACP within the NPR-A. Once developed, these benchmarks can be used in a variety of applications from the planning process (e.g., analyzing the management situation, developing potential natural conditions, monitoring LUP effectiveness) to assessments of mitigation measures and reclamation efficacy. Future change can also be detected through repeat monitoring of 50-75% of the randomly sampled sites coupled with additional randomly selected sites within the ACP. Sites added to the original design increase the "inventory" component of the AIM program, which furthers BLM's understanding of the extent of lotic resources. Trend monitoring in the NPR-A is expected to begin after 2027. A trend monitoring plan of 10 years will be implemented due to the remoteness, logistical constraints, and cost of sampling sites in Alaska.

Four examples below demonstrate how the BLM Arctic District Office in Alaska plans to use lotic AIM data to improve transparency in how science is applied, increase confidence in decision outcomes, and enhance stakeholder support. The ability to use a single-field protocol, such as lotic AIM, to meet multiple bureau data needs has the capacity to increase both the efficiency and defensibility of field office monitoring and management decisions.

Example #1 - Collecting pre-disturbance data in watersheds with high potential for oil and gas development (GMT & Willow)

Following a resurgence of Arctic oil and gas exploration beginning in the early 2000s, oil extraction projects are now developing westward into the NPR-A from State-owned lands in the Colville River Delta. Construction on the Greater Moose's Tooth unit was initiated in 2017, and production began in 2018. Infrastructure included gravel drilling pads, pipelines, and a gravel road with culverts and bridges (Figure 10). During the development of this report, the Willow Master Development Plan (MDP) underwent an environmental impact statement (Willow MDP DFEIS 2020) and was approved in 2020. The Willow MDP proposes infrastructure over an extensive geographic area that connects to GMT2 at its eastern terminus. In addition to gravel roads and pipelines far exceeding the magnitude of the GMT development, the Willow MDP will include a central processing facility, domestic water treatment plant, on-site housing accommodations, and an airstrip (Figure 12).

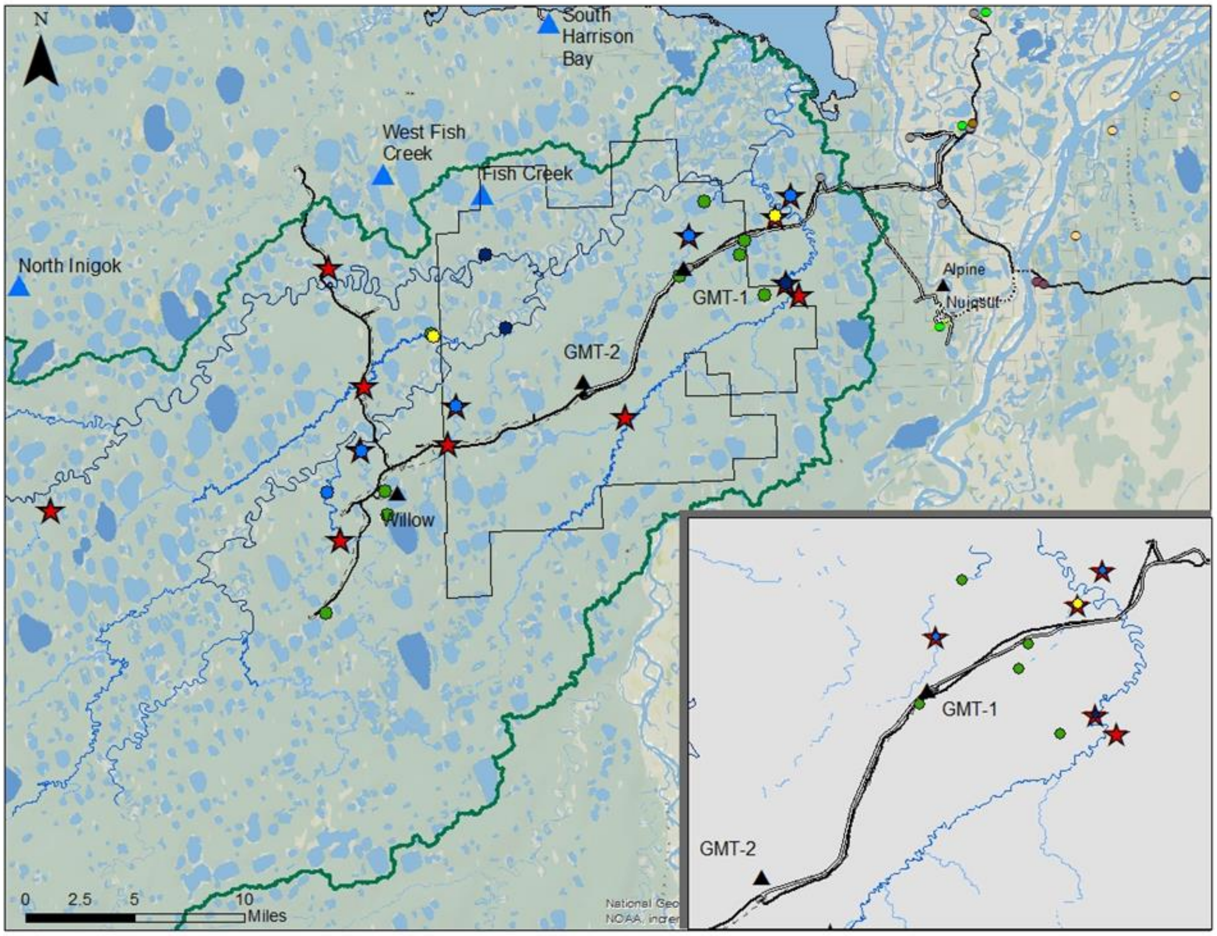

Figure 10. Map of Greater Mooses Tooth (GMT) showing lotic AIM targeted sample sites, established long-term monitoring sites, and details of GMT oil and gas development.

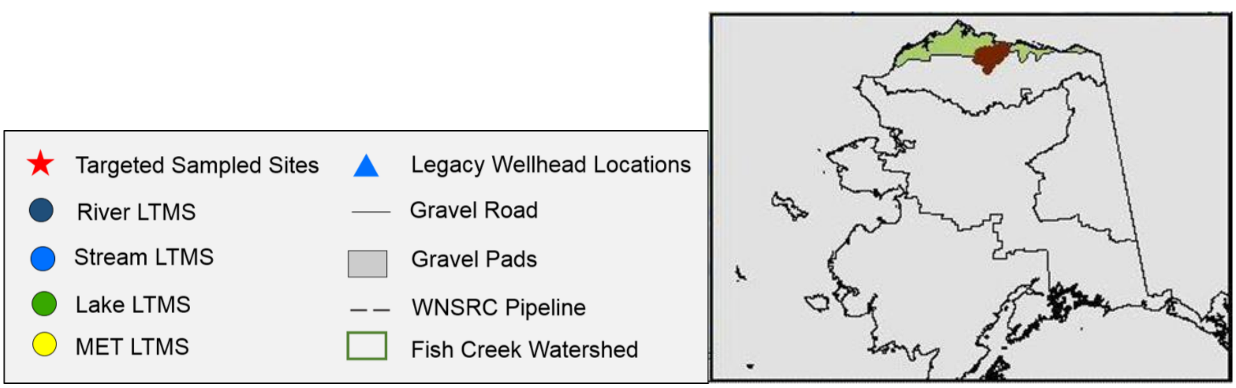

Figure 11. Map legend for figures 11 and 13.

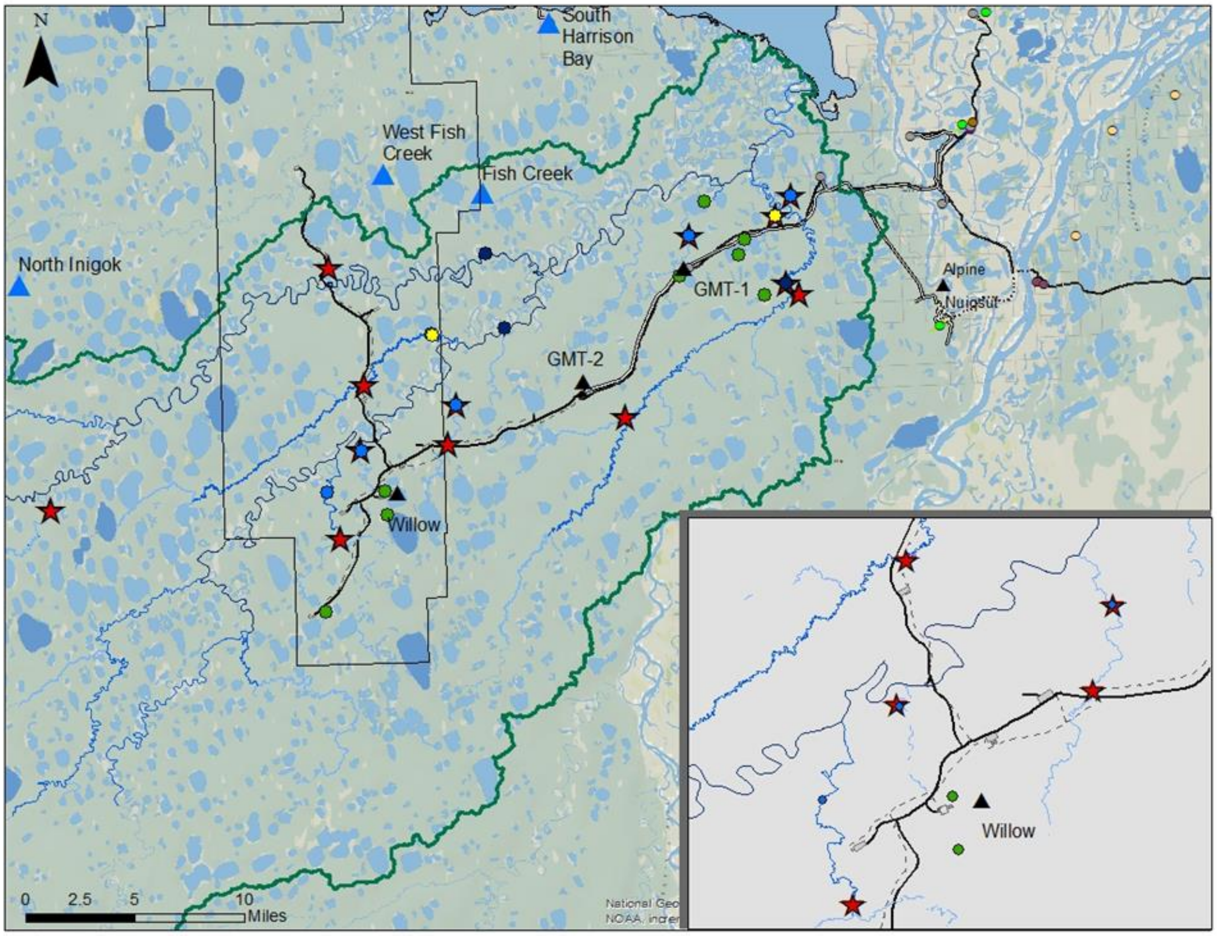

Figure 12. Map of Willow development area, showing lotic AIM targeted sample sites, established long-term monitoring sites (LTMS), and details of proposed Willow oil and gas development.

Both the GMT and Willow developments are in the northeastern NPR-A, with most of the geographic extent in the Fish Creek Watershed (Figures 10 and 12). The Fish Creek Watershed consists of three primary river drainages Fish Creek (2016 km^2), Judy Creek (1647 km^2), and the Ublutuoch River (483 km^2) with varying geologic, lake basin, and topographic compositions. Fish Creek is an alluvial channel that drains mostly low-elevation tundra set atop inactive eolian sand dunes, with many large, deep lakes. Judy Creek is also an alluvial channel and has headwaters in lower bedrock-controlled foothills, with intermediate densities of lakes and drained lake basins. Much of the Ublutuoch River is formed by thermal, rather than alluvial, processes. This results in a beaded stream channel through much of its course over alluvial-marine silt terrain with a high density of thermokarst lake basins. This variability in surficial characteristics on a landscape of deep continuous permafrost results in a unique fluvial landscape within each of the river drainages comprised of interconnected alluvial streams, beaded streams, lakes, and drained thermokarst lake basins (Arp et al. 2012, 2015).

The NPR-A Fisheries Monitoring Implementation Plan (NPR-A FMIP; Noel et al. 2008) developed conceptual models to identify these potential stressors and their associated impacts to guide aquatic habitat management and monitoring (Figure 13). These conceptual models were developed to improve understanding between oil and gas infrastructure and its potential impacts to the chemical, physical, and biological processes of streams and rivers. These models also help to identify effective mitigation measures and SOPs in order to reduce the identified potential impacts which can be monitored using the BLM AIM strategy once implemented. Pre-disturbance data collected using lotic AIM methodology characterizes important physical stream features and relevant water quality indicators. Tracking those measures over time at both reference and developed sites will help determine if any observed changes are resulting from land-use or naturally shifting ecosystem processes. If land-use impacts are detected, then adaptive management will be necessary to reduce those impacts and avoid further degradation.

Figure 13. GMT1 drill site, pipeline, and road.

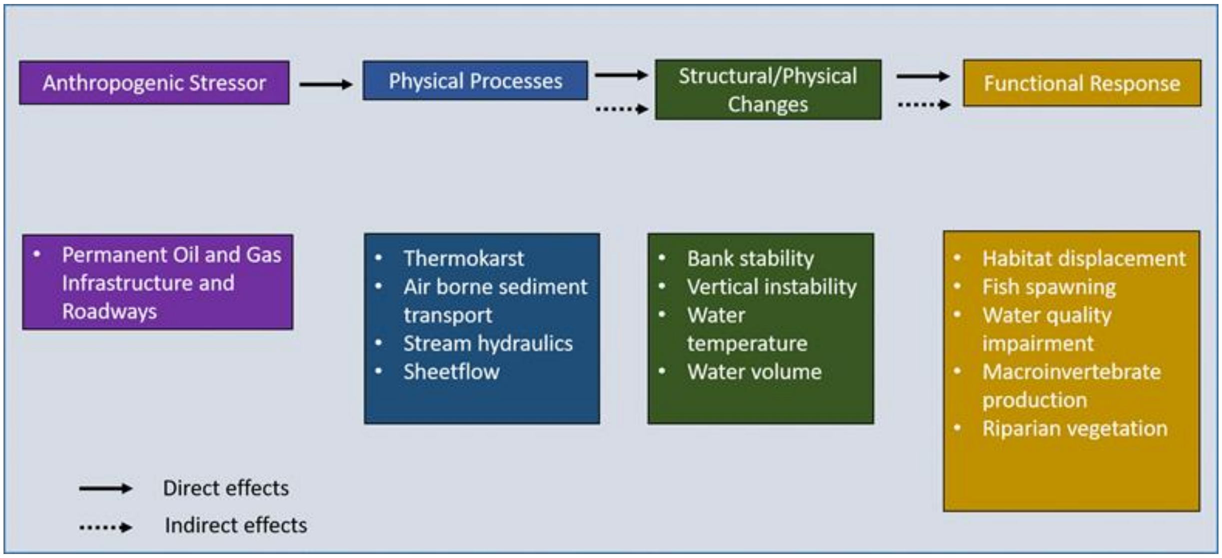

Figure 14. Modified conceptual model from the NPR-A Fisheries Monitoring Implementation Plan (FMIP) showing the expected effects of permanent oil and gas infrastructure on streams and rivers on the ACP. For the purpose of this report, this figure was modified to reduce complexity of the original conceptual model.

For both the GMT and Willow areas, it was determined that gravel roads and pads are the infrastructure features most likely to impact wadeable streams with potentially short- and long-term effects. The road crossing itself can change the physical stream habitat, such as increasing sediment and decreasing vertical channel stability (Meehan 1991; Angermeier et al. 2004; Chen et al. 2009) among other impacts. However, the potential impacts from the remainder of the linear road feature that transects a drainage basin are also important. The linear nature of roads across a drainage and the impervious surface of those roads and associated pads can contribute to an increased runoff response (i.e., flashier flows and less attenuation), impound water that would otherwise reach a stream, and degraded runoff-water quality (Arnold and Gibbons 1996; Angermeier et al. 2004; Chithra et al. 2015). These physical and chemical changes to a stream can, in turn, impact biological communities, including freshwater macroinvertebrates (Chisholm and Downs 1978; Chen et al. 2009; Entrekin et al. 2011) and fish (Meehan 1991; Weaver and Garman 1994; Wang et al. 2001; Cott et al. 2015).

To address these concerns, the BLM placed sample points on wadeable streams and rivers immediately downstream of planned road crossings to characterize baseline stream parameters prior to gravel road, pipeline, and pad construction. Below are two examples of how lotic AIM data will be used to monitor permitted activities and inform future management decisions. Several lotic AIM indicators could be used to monitor the effects of permitted activities, such as oil and gas development; however, we will only use a couple of indicators for the following examples (i.e., floodplain connectivity, Simpson’s diversity index).

Using benchmarks to assess condition of permitted activities

Vertical channel instability, identified in the NPR-A FMIP, is one of the potential structural/physical changes to occur post oil and gas development. This led to developing SOPs and mitigation measures that reduce the likelihood and magnitude of degradation to streams and rivers. Floodplain connectivity is a direct measurement of vertical channel instability and is computed from the bankfull and bench height measurements. Floodplain connectivity was collected at each of the targeted sites downstream of planned road crossings in both the GMT and Willow development areas for a total of 10 sites. These 10 sites will be sampled using lotic AIM methodology again post development, (i.e., road, pipeline, and drill pad construction), to assess whether there have been any impacts to those sites and mitigation measures and management policies were effective. With effective mitigation measures in place, floodplain connectivity values at stream reaches should stay within the range of proper functioning conditions post development. However, if impacts are present, the degree of those impacts can be measured by comparing post development values to the condition benchmarks (Figure 14). Depending on the degree of departure, sites may need to be re-sampled to assess whether there is a positive or negative trend, and in some cases management actions may be taken to address the issue(s).

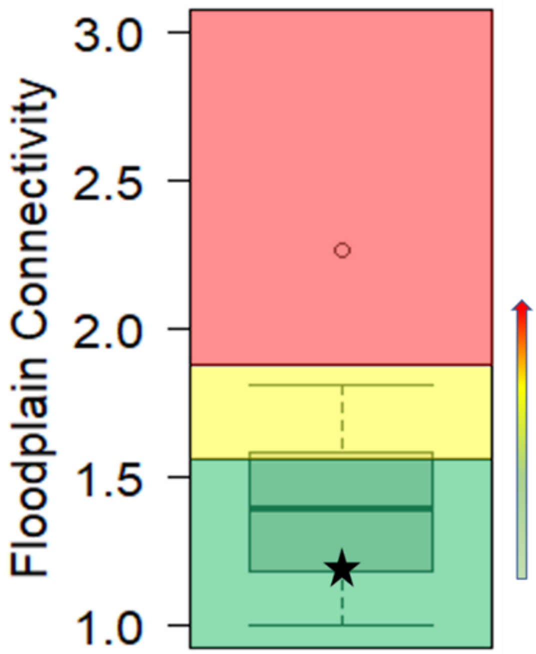

Figure 15. The box plot shows the distribution of floodplain connectivity values from reference sites along with condition benchmarks, which are used to assess the condition of stream reaches post development. The black star is a floodplain connectivity value at a stream reach prior to oil and gas development. The arrow depicts the anticipated direction of negative trend expected to occur in the absence of effective mitigation measures.

Using trend to assess condition through time

A decrease in macroinvertebrate diversity was identified as one of the potential functional responses to oil and gas development in the NPR-A FMIP. Freshwater macroinvertebrate samples were collected at 16 sites within the Fish Creek Watershed using a kick-net for all but one of the samples and following the reach-wide methodology in the lotic AIM field methods manual.

The Simpson’s diversity index is one of many indicators that can be used from the macroinvertebrate samples that are collected at lotic AIM reaches. Simpson's diversity index is a measure of biological diversity that considers both the richness and evenness of species, with higher numbers representing more diverse communities (Morris et al. 2014). The richness is the number of different species in a sample while the evenness is the abundance of each of the different species in a sample. This indicator will be used to assess the potential change in biological diversity at stream reaches below proposed oil and gas development sites (Figure 15). The Simpson's diversity index and other taxonomic indicators are currently used in the NPR-A, while the Simpson's diversity index referenced in this report will be used to see if there is a community change post development. Diatoms might also be useful in assessing biological communities as they have been found to have higher diversities than macroinvertebrates on the ACP (Shaftel et al. 2018).

The impacts from development can be assessed visually, compared against condition benchmarks, and/or tested for statistical significance. With effective mitigation measures in place, freshwater macroinvertebrate diversity is expected to be minimally impacted post development. Implementing a robust environmental program, such as lotic AIM, allows us to differentiate between natural change across the landscape and change caused by permitted activities; in this case, oil and gas development.

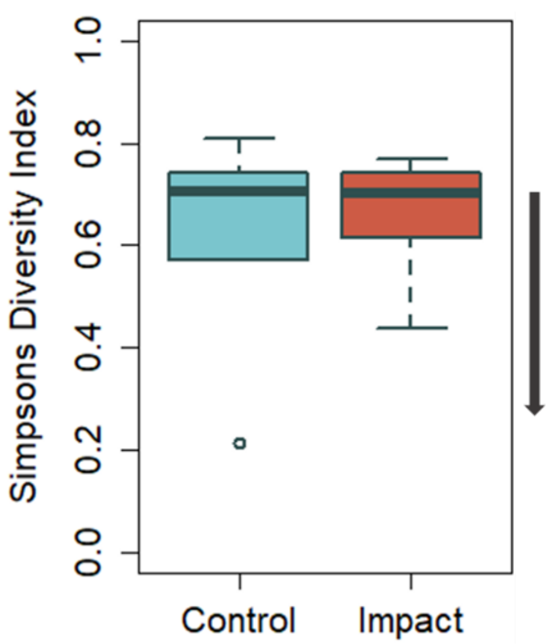

Figure 16. The paired box plots show Simpson's diversity index values for freshwater macroinvertebrates at six control sites and ten impact sites prior to oil and gas development within the Fish Creek watershed. The arrow depicts the anticipated direction of index values if mitigation measures are ineffective at reducing impacts to the macroinvertebrate community.

Continued monitoring of aquatic resources using lotic AIM methodologies will help the BLM and other agencies better understand the effects of oil and gas development on aquatic resources in the ACP. Using both lotic AIM and data collected at long-term monitoring sites will provide multiple lines of evidence to determine if there have been any negative post-development impacts and, if so, what those impacts are. This will empower managers to make more informed decisions and more accurately assess the effectiveness of their land use plans.

Example #2 - Linking AIM data to long-term monitoring sites in the NPR-A (GMT & Willow)

To better understand the ecological processes of the ACP and environmental variability, long-term aquatic monitoring sites have been established on streams, rivers, and lakes in the Fish Creek Watershed (Whitman et al. 2011). These sites are intended to provide time series data and relevant supplemental data to aid in determining if observed changes are likely due to natural environmental factors or oil and gas exploration and development. Wadeable stream sites were established on Crea Creek, Blackfish Creek, Oil Creek, Bills Creek, and the Ublutuoch River in 2008 in both GMT Units, and on Brooks Creek, Snowman Creek, Alaska Creek, and Judy Kayaak Creek in 2018 in the region of the Willow MDP. All of these sites are gauged to document streamflow, recording water level continuously at 15-minute intervals. Water quality parameters have also been collected at the GMT sites using sondes during the summer season, recording conductivity, pH, dissolved oxygen, turbidity, chlorophyll *a*, and temperature. Water samples were collected during the summer of 2010 and analyzed for major ions, trace metal cations, nutrients, organic carbon, and several other organic compounds. To assess the biological components of the long-term monitoring sites, fish studies were conducted in some drainages, and macroinvertebrate samples were collected (Haynes et al. 2014; Heim et al. 2016; McFarland et al. 2018; Laske et al. 2019).

AIM-NAMF data was collected at all of the wadeable streams in the NPR-A long-term monitoring network. Integrating lotic AIM with these established monitoring sites provides additional data to evaluate if the aquatic environment is changing and why, an overarching objective of long-term ecological monitoring programs (Vaughn et al. 2001). The physical habitat and macroinvertebrate components of lotic AIM contribute to a more robust and well-rounded aquatic monitoring program in conjunction with the physical, chemical, and biological data already being collected at the long-term monitoring sites.

The two distinct monitoring efforts increase the potential for early detection of potential deviations in the physical, chemical, and biological attributes of aquatic resources in the Fish Creek Watershed. This will hopefully allow resource managers an opportunity to act early in response to development-related impacts, thereby ensuring that mitigation objectives in management plans are being met. Sites outside of the influence of oil and gas activities can be re-sampled post development to help further evaluate environmental change resulting solely from natural processes. This approach also provides additional lines of evidence by coupling long-term monitoring site data with AIM-NAMF indicators providing a more comprehensive evaluation of the effectiveness of land management decisions.

Example #3 - Cross-agency collaboration with ADEC

The BLM partnered with ADEC to sample wadeable streams and rivers in the ACP within the NPR-A, the first cross-agency collaboration of lotic AIM. The ability to share data across agencies is founded upon two principal ideas and fundamental components of AIM-NAMF: statistically valid sample designs and standardization of aquatic indicators and sampling methodologies (BLM 2015a). USU ran the spatially balanced generalized random tessellation stratified (GRTS) design for the project. ADEC collected data on the ACP in 2015, sampling 26 out of the total 48 sampled sites. ADEC's data collection in the NPR-A was part of the National Aquatic Resource Surveys (NARS) and was a collaboration between the Environmental Protection Agency (EPA), the University of Alaska Anchorage (UAA), the BLM, and USU (Shaftel et al. 2018). The BLM sampled the remaining points from the GRTS design along with 14 targeted sites.

The NARS program is operated by the EPA and consists of four separate projects that evaluate the biological, chemical, and physical components of the nation's streams and rivers, lakes, coastal areas, and wetlands. The wadeable streams and rivers component uses the EPA's National Rivers and Streams Assessment wadeable protocol, which has provided the foundation for the field methodologies of the BLM's lotic AIM program.

Streams and rivers in Alaska are often very remote, and sampling requires the use of aviation, typically helicopters, and extensive field time, which can both be extremely cost prohibitive. The one year of data collection provided by ADEC saved the BLM upwards of $150,000. Both money and time are saved when the responsibility of data collection is shared between agencies. Agency boundaries are also not based on natural environmental breaks or boundaries, often resulting in agencies managing for similar environmental gradients (e.g., ecoregions). The principles of AIM-NAMF allow agencies to combine data across jurisdictional boundaries as it pertains to the biological, chemical, and physical conditions of streams and rivers (BLM 2015a).

Example #4 – Using Fish Environmental – DNA to Map Species Distribution

In 2014, a partnership between the BLM, Utah State University (USU), and Dr. John Olson of California State University, Monterey Bay (CSU) was initiated to obtain a grant from NASA to help investigate fish distribution in the NPR-A using environmental-DNA (eDNA) techniques. It was determined that eDNA sampling for fish species would replace traditional fish sampling techniques while implementing lotic AIM in the NPR-A. This would provide AIM with the benefit of having fish information collected as supplemental data at reaches, while largely fulfilling the BLM's role in the cooperative project to collect enough field samples to make the project viable. During 2015, 2016, and 2017 the BLM coordinated the collection of eDNA samples from across the NPR-A through integration with AIM (Figure 17). While additional samples were collected through other BLM aquatic projects, as well as the Alaska Department of Fish and Game's Freshwater Fish Inventory program, the integration with AIM really made the eDNA work possible.

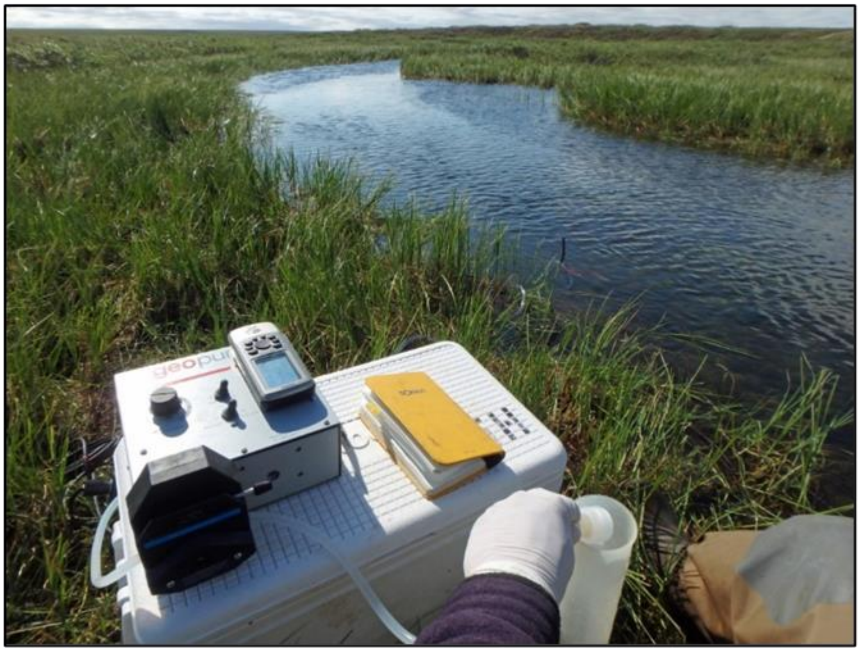

Figure 17. eDNA pump kit used to filter stream water to detect presence of fish species.

To account for potential geographic variation in species-level genetics, fish tissue collected in the Arctic region was used by USU to develop genetic markers for this project. Tissue from preserved fish that were captured in the Arctic was provided by the University of Alaska Fairbanks (UAF) museum collection. To obtain tissue from additional species that were not available from UAF, ConocoPhillips Alaska, Inc. contributed to the effort by obtaining fin clips at their fish inventory stations in the NPR-A (Figure 18). Ultimately, Arctic-specific markers were developed for 19 species. Once these markers were established, USU was able to analyze each of the field samples for the presence of DNA from all of these species. This genetic information will also be archived in a database to be available to the BLM and other agencies for future work.

Figure 18. Fyke net used to capture different fish species on the Arctic Coastal Plain. Fin clippings were taken from these fishes to establish genetic markers. Inset image is of an Arctic grayling.

The final step of the eDNA project that brought all components together was implemented by Dr. John Olson and his team at CSU. Results from the eDNA samples were integrated with a large data set of fish species presence points collected by the BLM and other organizations in the NPR-A while utilizing traditional fish sampling techniques. This information was further integrated with a wide variety of remotely sensed satellite data describing landscape characteristics to produce probability distribution maps for each species (Figures 19-21). For both local and landscape scale land-use proposals, the fish eDNA sampling and associated modeling provides more widespread and comprehensive fish distribution information than what is available from scattered sampling across the vast region.

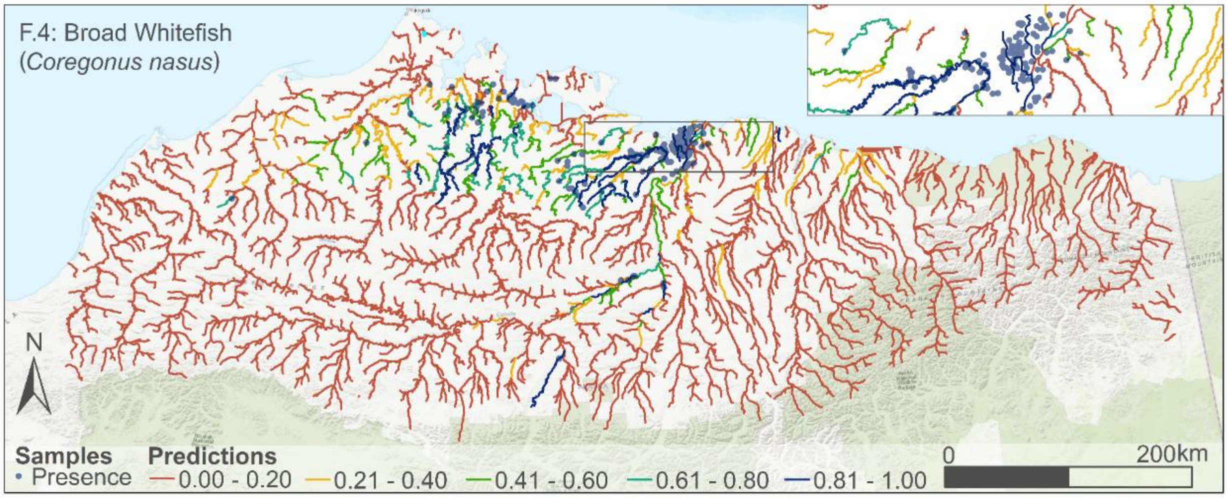

Figure 19. Map showing sampling locations where Broad Whitefish were detected as present. The stream network is displayed with different colors to show model predictions of static datasets utilizing presence/background data for Broad Whitefish. Inset map shows areas of high occurrence density or areas of high variation of probability of Broad Whitefish (Holdera et al. 2020).

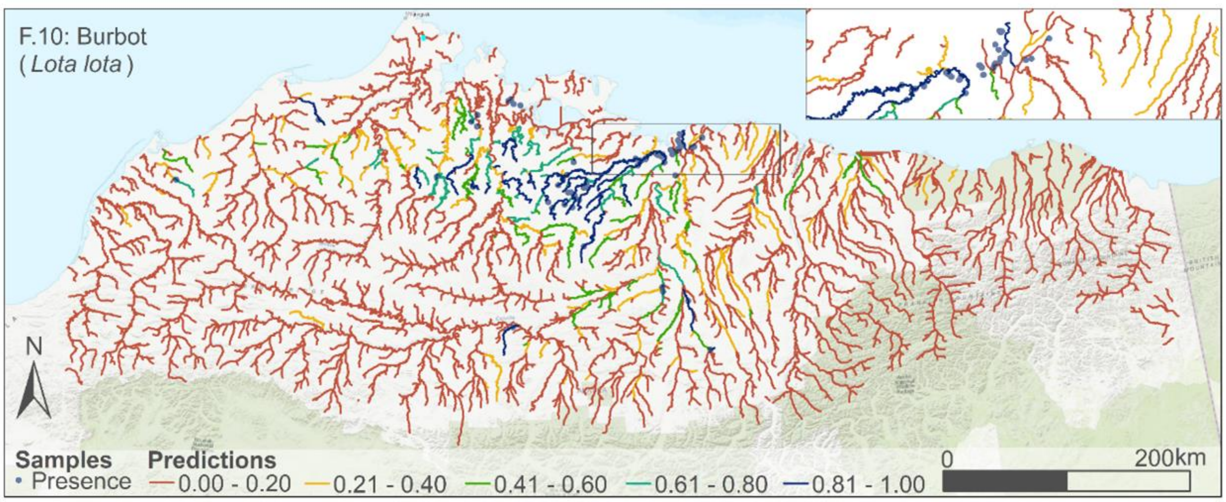

Figure 20. Map showing sampling locations where Burbot were detected as present. The stream network is displayed with different colors to show model predictions of static datasets utilizing presence/background data for Burbot. Inset map shows areas of high occurrence density or areas of high variation of probability of Burbot (Holdera et al. 2020).

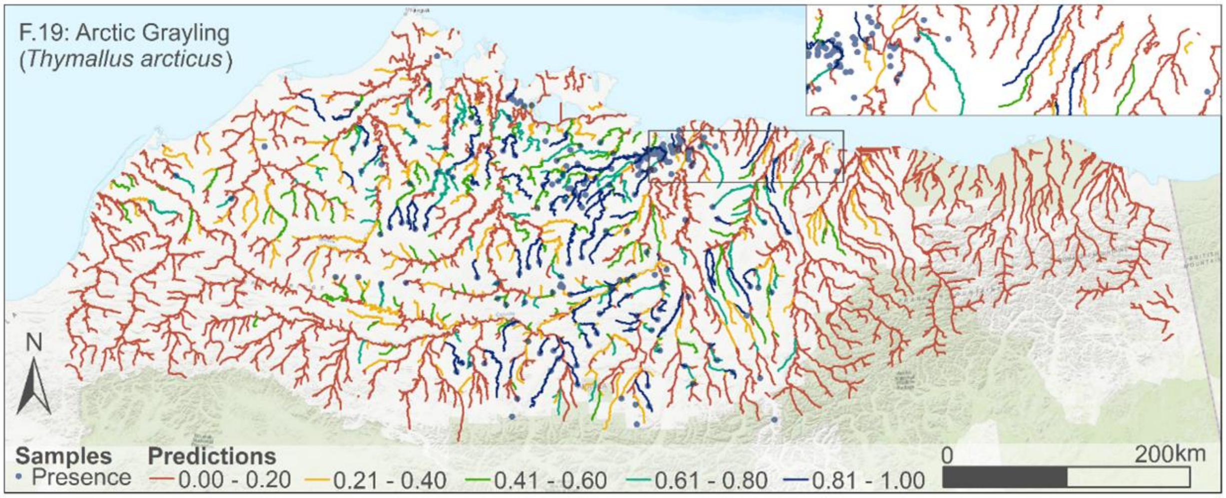

Figure 21. Map showing sampling locations where Arctic Grayling were detected as present. The stream network is displayed with different colors to show model predictions of static datasets utilizing presence/background data for Arctic Grayling. Inset map shows areas of high occurrence density or areas of high variation of probability of Arctic Grayling (Holdera et al. 2020).

Literature Cited/References

Angermeier, P.L., Wheeler, A. P., Rosenberger, A.E. 2004. A conceptual framework for assessing impacts of roads on aquatic biota. Fisheries, Vol. 29, No. 12.

Arnold, C.L., and C.J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62(2): 243-258.

Arp, C.D., Whitman, M.S., Jones, B.M., Kemnitz, R., Grosse, G., and Urban, F.E., 2012. Drainage network structure and hydrologic behavior of three lake-rich watersheds on the arctic coastal plain, Alaska. Arctic, Antarctic, and Alpine Research, Vol. 44, No. 4, pp. 385-398.

Arp, C.D., Whitman, M.S., Jones, B.M., Grosse, G., Gaglioti, B.V., and Heim, K.C., 2015. Distribution and biophysical processes of beaded streams in Arctic permafrost landscapes. Biogeosciences, 12: 29-47.

Beschta, R.L. 1997. Riparian Shade and Stream Temperature: An Alternative Perspective. Rangelands 19:25-28.

Bowling, L.C., Kane, D.L., Gieck, R.E., Hinzman, L.D., and Lettenmaier, D.P. 2003. The role of surface storage in a low-gradient Arctic watershed. Water Resources Research, 39: 1087.

Chen, Y., Viadero, R. C., Jr., Wei, X., Fortney, R., Hedrick, L.B. 2009. Effects of highway construction on stream water quality and macroinvertebrate condition in a mid-atlantic highlands watershed. Journal of Environmental Quality, Vol. 38, July-August.

Chisholm, D., and Downs, S.C. 1978. Stress and recovery of aquatic organisms as related to highway construction along Turtle Creek, Boone County, West Virginia. USGS. Department of the Interior.

Chithra, S.V., M.V. Harindranathan, Amaranth A, and Anjana N.S. 2015. Impacts of impervious surfaces on the environment. International Journal of Engineering Science Invention 4(5): 27-31.

Cott, P.A., A. Schein, B.W. Hana, T.A. Johnston, D.D. MacDonald, and J.M. Gunn. 2015. Implications of linear developments on northern fishes. Environmental Reviews 23(2): 177-190.

Cummins, K.W. 1974. Structure and Function Stream Ecosystems. BioScience 24:631-641.

Downing, J.A., Cole, J.J., Duarte, C.M., Middleburg, J.J., Melack, J.M., Prairie, Y.T., Kortelainen, P., Striegl, R.G., McDowell, W.H., and Tranvik, L.J., 2012. Global abundance and size distribution of streams and rivers: Inland Water, v. 2, p. 229-236.

Entrekin, S., White, M.E., M., Johnson, B., and Hagenbuch, E. 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment, Vol. 9, No. 9 pp. 503-511

Gallant, Alisa L., Binnian, Emily F., Omernik, James M., Shasby, Mark B.1995. Ecoregions of Alaska. United States Department of the Interior Geological Survey.

Gotelli, N.J., and Ellison, A.M. 2013. *A Primer of Ecological Statistics*, 2nd edition. Sinauer Associates, Sunderland, MA.

Hawkins, C.P., Norris, N.H., Hogue, N.J., and Feminella, J.W. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Society of America. Vol. 10, No. 5 pp. 1456-1477.

Haynes, T. B., Rosenberger, A. E., Lindberg, M. S., Whitman, M., and Schmtz, J. A. 2014. Patterns of lake occupancy by fish indicate different adaptations to life in a harsh Arctic environment. Freshwater Biology 59:1884-1896.

Heim, K. C., Wipfli, M. S., Whitman, M. S., Arp, C. D., Adams, J., and Falke, J. A. 2016. Seasonal cues of Arctic grayling movement in a small Arctic stream: the importance of surface water connectivity. Environmental Biology of Fish 99:49-65.

Hershey, A. E., Gettel, G. M., McDonald, M. E., Miller, M. C., Mooers, H., O'Brien, W. J., Pastor, J., Richards, C., and Schuldt, J. A. 1999. A geomorphic-trophic model for landscape controls of Arctic lake food webs. BioScience, 49: 887–897.

Holdera, A.M., A. Markariana, J. M. Doyle, and J.R. Olson. 2020. Predicting geographic distribution of fishes in remote stream networks using maximum entropy modeling and landscape characterizations. Ecological Modeling 433. DOI: 10.1016/j.ecolmodel.2020.109231.

Hughes, R.M., D.P. Larsen, and J. M. Omernik. 1986. Regional reference sites: a method for assessing stream potentials. Environmental management 10:629-635.

Johnson, S.L., and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 57:30-39.

Jorgensen, M.T., Kanevskiy, M., Shur, Y., Moskalenko, N., Brown, D.R.N., Wickland, K., Striegl, R., and Koch, J. 2015. Role of ground ice dynamics and ecological feedbacks in recent ice wedge degradation and stabilization. Journal of Geophysical Research: Earth Surface., 120, 2280-2297.

Knighton, D. 1998. Fluvial Forms and Processes: A New Perspective. Oxford University Press Inc., New York, New York.

Laske, S. M., Rosenberger, A. E., Wipfli, M. S., and Zimmerman, C. E. 2019. Surface water connectivity controls fish food web structure and complexity across local- and meta-food webs in Arctic Coastal Plain lakes. Food Webs 21: e00123.

Leopold, L.B., M.G. Wolman and J.P. Miller. 1992. Fluvial Processes in Geomorphology. Dover publications, Inc, New York, New York.

Lesack, L. F. W., and Marsh, P., 2010: River-to-lake connectivities, water renewal, and aquatic habitat diversity in the Mackenzie River delta. Water Resources Research, 46: 16 pp., http://dx.doi.org/ 10.1029/2010WR009607.

McFarland, J. J., Wipfli, M. S., and Whitman M. S. 2018. Trophic pathways supporting Arctic grayling in a small stream on the Arctic Coastal Plain, Alaska. Ecology of Freshwater Fish 27:184-197.

Meehan, W.R., ed. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. Bethesda, MD. American Fisheries Society Special Publication 19.

Morris, E.K., T. Caruso, F. Buscot, M. Fischer, C. Hancock, T.S. Maier, T. Meiners, C. Muller, E. Obermaier, D. Prati, S.A. Socher, I. Sonnemann, N. Waschke, T. Wubet, S. Wurst, and M. C. Rillig. 2014. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecology and Evolution, 4(18): 3514-3524.

Naito, A. T., and D. M. Cairns. 2015. Patterns of shrub expansion in Alaskan arctic river corridors suggest phase transition. Ecology and Evolution 5:87-101.

Noel, L.E., Moulton, L.L., Whitman, M.S., and Bontrager, L. 2008. NPR-A fisheries monitoring implementation plan. Prepared by ENTRIX for U.S. Department of the Interior, Bureau of Land Management, Arctic Field Office, Fairbanks, AK.

Olsen, A.R. 2005. Generalized random tessellation stratified (GRTS) spatially-balanced survey designs for aquatic resources. Corvallis, OR: U.S. Environmental Protection Agency.

Paulsen, S.G., A. Mayio, D.V. Peck, J.L. Stoddard, E. Tarquinio, S.M. Holdsworth, J. Van Sickle, L.L. Yuan, C.P. Hawkins, A.T. Herlihy, P.R. Kaufmann, M.T. Barbour, D.P. Larssen, A.R. Olsen, and J. Van Sickle. 2008. Condition of stream ecosystems in the US: an overview of the first national assessment. Journal of the North American Benthological Society 27:812-821.

Roulet, N.T., and Woo, M.K. 1998. Runoff generation in a Low Arctic drainage basin. Journal of Hydrology, 101: 213-226.

Shaftel, R., Bogan, D., Merrigan, D., and Jones, L. 2018. Condition of streams in the Arctic Coastal Plain of Alaska: water quality, physical habitat, and biological communities. Alaska Center for Conservation Science, University of Alaska, Anchorage, AK.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16:1267-76.

Strahler, A.N. 1952. Hypsometric (area-altitude) analysis of erosional topology. Bulletin of the Geological Society of America 63:1117-1142.

Sturm, M., C. Racine, and K. Tape. 2001. Increasing shrub abundance in the Arctic. Nature 411:546-547.

Tape, K., and M. Sturm. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. Global Change Biology 12:686-705.

U.S. Department of the Interior, Bureau of Land Management. 2015a. AIM National Aquatic Monitoring Framework: Introducing the Framework and Indicators for Lotic Systems. Technical Reference 1735-1. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

U.S. Department of the Interior, Bureau of Land Management. 2015b. Principles and practices of integrating science into land management. BLM, Washington D.C. IM 2017-030.

U.S. Department of the Interior, Bureau of Land Management. 2015c. Supplemental Environmental Impact Statement for the Alpine Satellite Development Plan for the Proposed Greater Mooses Tooth One Development Project. Record of Decision. BLM, Alaska State Office, Anchorage.

U.S. Department of the Interior, Bureau of Land Management (BLM). 2020. National Petroleum Reserve in Alaska Integrated Activity Plan / Environmental Impact Statement. DOI-BLM-AK-R000-2019-0001-EIS.

Naval Petroleum Reserve Production Act of 1976, 42 USC § 6501 et seq. (1976).

U.S. Department of the Interior, Bureau of Land Management. 2017a. AIM National Aquatic Monitoring Framework: Field Protocol for Wadeable Lotic Systems. Tech Ref 1735-2.

U.S. Department of the Interior, U.S. Geological Survey. 2014. National Hydrography Dataset. https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products

Vaughn, H., Brydges, T., Fenech, A., and Lumb, A. 2001. Monitoring long-term ecological changes through the ecological monitoring network: science-based and policy relevant. Environmental Monitoring and Assessment 67: 3-28.

Wang, L., J. Lyons, and P. Kanehl. 2001. Impact of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28(2): 255-266.

Weaver, L.A., and G.C. Garman. 1994. Urbanization of a watershed and historical changes in a stream fish assemblage. Transactions of the American Fisheries Society 123(2): 162-172.

Whitman, M. S., Arp, C. D., Jones, B., Morris, W., Grosse, G., Urban, F., and Kemnitz, R., 2011: Developing a long-term aquatic monitoring network in a complex watershed of the Alaskan Arctic Coastal Plain. In Medley, C. N., Patterson, G., and Parker, M. J. (eds.), Proceedings of the Fourth Interagency Conference on Research in Watersheds: Observing, Studying, and Managing for Change. Reston, Virginia: U.S. Geological Survey, 15–20.

Woo, M., and Guan, X. J., 2006: Hydrological connectivity and seasonal storage change of tundra ponds in a polar oasis environment, Canadian High Arctic. Permafrost and Periglacial Processes, 17: 309–323.

Woo, M., and Mielko, C., 2007: An integrated framework of lake-stream connectivity for a semi-arid, subarctic environment. Hydrological Processes, 21: 2668–2674.

Appendix A: Alaska's Land Health Standards & AIM NAMF Instream and Riparian Indicator Benchmarks for the Lands Managed by the Arctic District Office

Table 2 - Instream and riparian condition benchmarks for small streams on the Arctic Coastal Plain within the National Petroleum Reserve in Alaska. Benchmarks were set for all indicators with available data; however, the benchmark approach may not be appropriate for all indicators (e.g., Percent Fines). For additional information on this topic, see the Establishing Minimally Disturbed Conditions, Baseline Conditions, and Condition Benchmarks section.

Data Type	Indicator or Column Heading	Description	Predicted response to stress	Units	Range of Values (Min and Max)		5th percentile	25th percentile	75th percentile	95th percentile	Alaska Application Notes
Biodversity and Riparian Habitat Quality	PctOverheadCover	Average % overhead cover provided by stream banks, vegetation, or other objects measured mid-channel (looking 4 directions) across 11 transects (units: %, min: 0, max: 100, n= 44)	Decrease	%	0	23	0	0			
	BankOverheadCover	Average percent overhead cover provided by stream banks (left and right), vegetation or other objects measured at the scour line of the left and right banks across 11 transects (units: %, min: 0, max: 100, n= 22)	Decrease	%	0	78	0	1.4			
	VegComplexity	Aggregate measure of the average vegetative cover provided by three different vegetative height category: Canopy (>5m), Understory (0.5-5m), and Ground (<0.5m). Each vegetative height category is then divided into two vegetation types (e.g. woody or nonwoody). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) per vegetation type, summed across the three heights, and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 2.6, n= 132)	Decrease	None	0.41	1.83	0.64	0.86			
	RiparianVegCanopyCover	Measure of the average riparian vegetative cover provided by canopy vegetation (>5m). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 0.88, n= 22)	Decrease	None	0	0	0	0			Only available for sites collected in 2016 and on
	RiparianVegUnderstoryCover	Measure of the average riparian vegetative cover provided by understory vegetation (0.5-5m). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 0.88, n= 22)	Decrease	None	0.29	0.88	0.42	0.61			Only available for sites collected in 2016 and on
	RiparianVegGroundCover	Measure of the average riparian vegetative cover provided by the ground cover vegetation (<0.5m). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 0.88, n= 22)	Decrease	None	0	0.65	0	0.02			Only available for sites collected in 2016 and on
	NonNativeWoody	Percent of 22 vegetation plots with invasive woody vegetation present (units: %, min: 0, max: 100, n= 22)	Increase	%	0	0			0	0	Only available for sites collected in 2016 and on
	NativeWoody	Percent of 22 vegetation plots with native woody vegetation present (units: %, min: 0, max: 100, n= 22)	Decrease	%	0	100	33	100			Only available for sites collected in 2016 and on
	NonNativeHerb	Percent of 22 vegetation plots with invasive herbaceous vegetation present (units: %, min: 0, max: 100, n= 22)	Increase	%	0	0			0	0	Only available for sites collected in 2016 and on
	NativeHerb	Percent of 22 vegetation plots with native herbaceous vegetation present (units: %, min: 0, max: 100, n= 22)	Decrease	%	100	100	100	100			Only available for sites collected in 2016 and on
	SedgeRush	Percent of 22 vegetation plots with sedges and rushes present (units: %, min: 0, max: 100, n= 22)	Decrease	%	0	100	4	95			Only available for sites collected in 2016 and on
	InvasiveInvertSp	Presence or absence of invasive macroinvertebrates	Increase	NA							In development
	ObservedInvertRichness	Observed macroinvertebrate richness standardized to model specific operational taxonomic units (OTU) (units: # of taxa)	Decrease	# of taxa							In development
	ExpectedInvertRichness	Expected macroinvertebrate richness in the absence of anthropogenic impacts from the O/E model (units: # of taxa)	NA	# of taxa							In development
	OE_Macroinvertebrate	Biological condition was assessed using an observed/expected (O/E) index. O/E models compare the macroinvertebrate taxa observed at sites of unknown biological condition (i.e., 'test sites') to the assemblages expected to be found in the absence of anthropogenic stressors (see Hawkins et al. 2000 for details). The specific model used can be found in the OE_MMI_ModelUsed column and the model specific metadata can be found at www.usu.edu/buglab/. (units: none, min: 0, max: 1.5)	Decrease	None							In development
	MMI_Macroinvertebrate	Biological condition was assessed using the MMI (MultimetricIndex) model specified in the OE_MMI_ModelUsed column.	Decrease	None							In development

Table 2. Continued.

Data Type	Indicator or Column Heading	Description	Predicted response to stress	Units	Range of Values (Min and Max)		5th percentile	25th percentile	75th percentile	95th percentile	Alaska Application Notes
Biodversity and Riparian Habitat Quality	OE_MMI_ModelUsed	The O/E or MMI model used to determine biological integrity. NAMC currently has the following models available UT, NV, CA, CO, OR, regional models for areas sampled by AREMP or PIBO programs (Northwest Forest Plan or Columbia River Basin), and a West-wide model. Generally, State based models are used if available, otherwise the West-wide model is used.	NA	NA							In development
	MacroinvertebrateCount	This field indicates whether or not the site's environmental gradients were within the range of experience of the model. A fail indicates the model potentially had to extrapolate, rather than interpolate, to accommodate one or more of the habitat variables. O/E scores and condition ratings should be interpreted cautiously if a site failed the test of experience.	NA	# of individuals							In development
	ModelApplicability	Number of macroinvertebrates identified and resampled to a standardized fixed count (i.e. rarefaction). Samples with counts less than 200 macroinvertebrates can result from sampling and/or laboratory processing errors, but low counts can also be a signal of degraded biological condition. Additional samples should be taken to verify Major or Moderate departure from reference. (units: # of individuals, min: 0, max: 400)	NA	NA							In development
Water Quality	SpecificConductance	Measured specific conductance value. The specific conductance is conductivity standardized to 25 degrees C. (units: µS/cm, min: 0, max: 65500, n=1)	Increase	µS/cm	32	263			160	244	
	PRD_SpecificConductance	Site specific predicted values for reference specific conductance values (Olson and Hawkins 2012) (units: µS/cm, min: 0, max: 65500)	NA	µS/cm							In development
	pH	Measured pH value (units: SU, min: 0, max: 14, n=1)	Increase or decrease	SU	6.1	8.8	6.2	7.2	7.9	8.5	
	InstantTemp	Instantaneous water temperature measurement (units: degrees C, n=1)	Increase	°C	6.7	18.8			15	18	
	Turbidity	Average water clarity as measured by the suspended solids in the water column (units: NTU, n=3)	Increase	NTU	0.2	4.4			2.8	4.3	
Watershed Function and Instream Habitat Quality	PctPools	Percent of the sample reach (linear extent) classified as pool habitat as assessed using the core pool method (units: %, min: 0, max: 100, n=1)	Decrease	%					-	-	In development
	ResPoolDepth	Average residual pool depth as assessed using the core pool method (units: m, n= variable depending on number of pools)	Decrease	m							In development
	PoolFreq	Frequency of pools in the reach as assessed using the core pool method (units: # pools/km, n=1)	Decrease	# pools/km							In development
	LWD_Freq	Frequency of large woody debris within the bankfull channel of the reach (units: # pieces/ 100 m, n= 1)	Decrease	# pieces/100 m	0	0	0	0			
	LWD_Vol	Volume of LWD within the bankfull channel of the reach (units: m^3/100 m, n=1)	Decrease	m^3/100 m	0	0	0	0			
	PctFines2	Percent of 210 particles with a b-axis < 2 mm (units: %, min: 0, max: 100, n=210)	Increase	%	48	100			100	100	
	PctFines6	Percent of 210 particles with a b-axis < 6 mm (units: %, min: 0, max: 100, n=210)	Increase	%	49	100			100	100	
	D16	Particle size corresponding to the 16th percentile of measured particles (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	1	1	1			
	D84	Particle size corresponding to the 84th percentile of measured particles (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	25	1	1			
	D50	Particle size corresponding to the 50th percentile of measured particles (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	10	1	1			
	GeometricMeanParticleDiam	Geometric mean bed particle diameter= exponential function[mean(log(particle diameter)]. This is a less frequently used metric of characterizing central tendency of substrate sizes, but is the main metric used by the EPA for determining relative bed stability. It is less variable than a D50 and more biologically meaningful because it is more influenced by fine sediment. (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	2	1	1			
	BankCover	Percent of 42 erosional banks with greater than 50% cover provided by perennial vegetation, wood or mineral substrate > 15 cm (units: %, min: 0, max: 100, n= 42)	Decrease	%	40	100	58	82			Only available for sites collected in 2016 and on

Table 2. Continued.

Data Type	Indicator or Column Heading	Description	Predicted response to stress	Units	Range of Values (Min and Max)		5th percentile	25th percentile	75th percentile	95th percentile	Alaska Application Notes
Watershed Function and Instream Habitat Quality	BankStability	Percent of 42 banks lacking visible signs of active erosion (e.g., slump, slough, fracture) (units: %, min: 0, max: 100, n= 42)	Decrease	%	64	100	82	97			Only available for sites collected in 2016 and on
	BnkCover_Stab	Percent of 42 banks both stable (lacking visible signs of active erosions (e.g., slump, slough, fracture)) and covered (greater than 50% cover provided by perennial vegetation, wood or mineral substrate > 15 cm) (units: %, min: 0, max: 100, n= 42)	Decrease	%	33	100	44	63			Only available for sites collected in 2016 and on
	BnkCoverBasalVeg	Average basal bank cover composed of vegetation (units: %, min: 0, max: 100, n= 42)	Decrease	%	44	99	52	61			Only available for sites collected in 2016 and on
	FloodplainConnectivity	Logarithm of the difference between average bankfull height and average floodplain height= log(FloodplainHeight - BankHeight + 0.1) (units: none, min: -1, max: 2, n=11)	Increase	None	1	2.3			1.6	2	
	InstreamHabitatComplexity	Aggregate measure of average cover provided by boulders, overhanging vegetation, live trees and roots, LWD, small woody debris, and stream banks for stream fishes measured at 11 plots. Proporional cover was binned into four classes (0.875, 0.575, 0.25, and 0.5), averaged across transects, and then summed across six types of cover. (units: none, min: 0, max: 2.3, n= 66)	Decrease	None	0	0.41	0	0.04			
	ThalwegDepthCV	Indicator of bed heterogenity computed as the coefficient of variation of 100-300 thalweg depth measurements (units: none, n= 1)	Decrease	None	0.33	1.17	0.34	0.42			
	ThalwegDepthMean	Mean thalweg depth. Metric of how deep water was at the site. (units: m, min: 0, max: none, n variable depending on reach length (100 - 300))	NA	m	0.13	1.3	0.24	0.5			

Table 3 - Instream and riparian condition benchmarks for large streams on the Arctic Coastal Plain within the National Petroleum Reserve in Alaska. Benchmarks were set for all indicators with available data; however, the benchmark approach may not be appropriate for all indicators (e.g., Percent Fines). For additional information on this topic, see the Establishing Minimally Disturbed Conditions, Baseline Conditions, and Condition Benchmarks section.

Data Type	Indicator or Column Heading	Description	Predicted response to stress	Units	Range of Values (Min and Max)		5th percentile	25th percentile	75th percentile	95th percentile	Alaska Application Notes
Biodiversity and Riparian Habitat Quality	PctOverheadCover	Average % overhead cover provided by stream banks, vegetation, or other objects measured mid-channel (looking 4 directions) across 11 transects (units: %, min: 0, max: 100, n= 44)	Decrease	%	0	2.2	0	0			
	BankOverheadCover	Average percent overhead cover provided by stream banks (left and right), vegetation or other objects measured at the scour line of the left and right banks across 11 transects (units: %, min: 0, max: 100, n= 22)	Decrease	%	0	67.1	0	6.7			
	VegComplexity	Aggregate measure of the average vegetative cover provided by three different vegetative height category: Canopy (>5m), Understory (0.5-5m), and Ground (<0.5m). Each vegetative height category is then divided into two vegetation types (e.g. woody or nonwoody). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) per vegetation type, summed across the three heights, and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 2.6, n= 132)	Decrease	None	0.23	1.76	0.32	0.71			
	RiparianVegCanopyCover	Measure of the average riparian vegetative cover provided by canopy vegetation (>5m). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 0.88, n= 22)	Decrease	None	0	0	0	0			Only collected after 2016
	RiparianVegUnderstoryCover	Measure of the average riparian vegetative cover provided by understory vegetation (0.5-5m). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 0.88, n= 22)	Decrease	None	0.29	0.82	0.34	0.68			Only collected after 2016
	RiparianVegGroundCover	Measure of the average riparian vegetative cover provided by the ground cover vegetation (<0.5m). Proportional cover was binned into four classes (0.875, 0.575, 0.25, and 0.05) and then averaged across the left and right banks of 11 transects. (units: none, min: 0, max: 0.88, n= 22)	Decrease	None	0	0.63	0.008	0.02			Only collected after 2016
	NonNativeWoody	Percent of 22 vegetation plots with invasive woody vegetation present (units: %, min: 0, max: 100, n= 22)	Increase	%	0	0			0	0	Only collected after 2016
	NativeWoody	Percent of 22 vegetation plots with native woody vegetation present (units: %, min: 0, max: 100, n= 22)	Decrease	%	41	100	63	95			Only collected after 2016
	NonNativeHerb	Percent of 22 vegetation plots with invasive herbaceous vegetation present (units: %, min: 0, max: 100, n= 22)	Increase	%	0	0			0	0	Only collected after 2016
	NativeHerb	Percent of 22 vegetation plots with native herbaceous vegetation present (units: %, min: 0, max: 100, n= 22)	Decrease	%	41	100	65	100			Only collected after 2016
	SedgeRush	Percent of 22 vegetation plots with sedges and rushes present (units: %, min: 0, max: 100, n= 22)	Decrease	%	0	100	0	41			Only collected after 2016
	InvasiveInvertSp	Presence or absence of invasive macroinvertebrates	Increase	NA							In development
	ObservedInvertRichness	Observed macroinvertebrate richness standardized to model specific operational taxonomic units (OTU) (units: # of taxa)	Decrease	# of taxa							In development
	ExpectedInvertRichness	Expected macroinvertebrate richness in the absence of anthropogenic impacts from the O/E model (units: # of taxa)	NA	# of taxa							In development

Table 3 continued.

Data Type	Indicator or Column Heading	Description	Predicted response to stress	Units	Range of Values (Min and Max)		5th percentile	25th percentile	75th percentile	95th percentile	Alaska Application Notes
Biodversity and Riparian Habitat Quality	OE_Macroinvertebrate	Biological condition was assessed using an observed/expected (O/E) index. O/E models compare the macroinvertebrate taxa observed at sites of unknown biological condition (i.e., 'test sites') to the assemblages expected to be found in the absence of anthropogenic stressors (see Hawkins et al. 2000 for details). The specific model used can be found in the OE_MMI_ModelUsed column and the model specific metadata can be found at www.usu.edu/buglab/. (units: none, min: 0, max: 1.5)	Decrease	None							In development
	MMI_Macroinvertebrate	Biological condition was assessed using the MMI (MultimetricIndex) model specified in the OE_MMI_ModelUsed column.	Decrease	None							In development
	OE_MMI_ModelUsed	The O/E or MMI model used to determine biological integrity. NAMC currently has the following models available UT, NV, CA, CO, OR, regional models for areas sampled by AREMP or PIBO programs (Northwest Forest Plan or Columbia River Basin), and a West-wide model. Generally, State based models are used if available, otherwise the West-wide model is used.	NA	NA							In development
	MacroinvertebrateCount	This field indicates whether or not the site's environmental gradients were within the range of experience of the model. A fail indicates the model potentially had to extrapolate, rather than interpolate, to accommodate one or more of the habitat variables. O/E scores and condition ratings should be interpreted cautiously if a site failed the test of experience.	NA	# of individuals							In development
	ModelApplicability	Number of macroinvertebrates identified and resampled to a standardized fixed count (i.e. rarefaction). Samples with counts less than 200 macroinvertebrates can result from sampling and/or laboratory processing errors, but low counts can also be a signal of degraded biological condition. Additional samples should be taken to verify Major or Moderate departure from reference. (units: # of individuals, min: 0, max: 400)	NA	NA							In development
Water Quality	SpecificConductance	Measured specific conductance value. The specific conductance is conductivity standardized to 25 degrees C. (units: µS/cm, min: 0, max: 65500, n=1)	Increase	µS/cm	50	813			220	405	
	PRD_SpecificConductance	Site specific predicted values for reference specific conductance values (Olson and Hawkins 2012) (units: µS/cm, min: 0, max: 65500)	NA	µS/cm							In development
	pH	Measured pH value (units: SU, min: 0, max: 14, n=1)	Increase or decrease	SU	6.15	8.75	7.01	7.44	7.93	8.49	
	InstantTemp	Instantaneous water temperature measurement (units: degrees C, n=1)	Increase	°C	10.2	17.9			15.9	17.8	
	Turbidity	Average water clarity as measured by the suspended solids in the water column (units: NTU, n=3)	Increase	NTU	0.82	5.27			3.9	5	
Watershed Function and Instream Habitat Quality	PctPools	Percent of the sample reach (linear extent) classified as pool habitat as assessed using the core pool method (units: %, min: 0, max: 100, n=1)	Decrease	%					-	-	In development
	ResPoolDepth	Average residual pool depth as assessed using the core pool method (units: m, n= variable depending on number of pools)	Decrease	m							In development
	PoolFreq	Frequency of pools in the reach as assessed using the core pool method (units: # pools/km, n=1)	Decrease	# pools/km							In development
	LWD_Freq	Frequency of large woody debris within the bankfull channel of the reach (units: # pieces/ 100 m, n= 1)	Decrease	# pieces/100 m	0	0	0	0			
	LWD_Vol	Volume of LWD within the bankfull channel of the reach (units: m^3/100 m, n=1)	Decrease	m^3/100 m	0	0	0	0			
	PctFines2	Percent of 210 particles with a b-axis < 2 mm (units: %, min: 0, max: 100, n=210)	Increase	%	7.6	100			100	100	
	PctFines6	Percent of 210 particles with a b-axis < 6 mm (units: %, min: 0, max: 100, n=210)	Increase	%	7.6	100			100	100	
	D16	Particle size corresponding to the 16th percentile of measured particles (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	20	1	20			
	D84	Particle size corresponding to the 84th percentile of measured particles (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	60	1	60			

Table 3. Continued

Data Type	Indicator or Column Heading	Description	Predicted response to stress	Units	Range of Values (Min and Max)		5th percentile	25th percentile	75th percentile	95th percentile	Alaska Application Notes
Watershed Function and Instream Habitat Quality	D50	Particle size corresponding to the 50th percentile of measured particles (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	30	1	30			
	GeometricMeanParticleDiam	Geometric mean bed particle diameter= exponential function[mean(log(particle diameter)]. This is a less frequently used metric of characterizing central tendency of substrate sizes, but is the main metric used by the EPA for determining relative bed stability. It is less variable than a D50 and more biologically meaningful because it is more influenced by fine sediment. (units: mm, min: 1, max: 4098, n=210)	Decrease	mm	1	4	1	4			
	BankCover	Percent of 42 erosional banks with greater than 50% cover provided by perennial vegetation, wood or mineral substrate > 15 cm (units: %, min: 0, max: 100, n= 42)	Decrease	%	0	93	0	93			Only collected after 2016
	BankStability	Percent of 42 banks lacking visible signs of active erosion (e.g., slump, slough, fracture) (units: %, min: 0, max: 100, n= 42)	Decrease	%	40	100	40	100			Only collected after 2016
	BnkCover_Stab	Percent of 42 banks both stable (lacking visible signs of active erosions (e.g., slump, slough, fracture)) and covered (greater than 50% cover provided by perennial vegetation, wood or mineral substrate > 15 cm) (units: %, min: 0, max: 100, n= 42)	Decrease	%	0	93	0	93			Only collected after 2016
	BnkCoverBasalVeg	Average basal bank cover composed of vegetation (units: %, min: 0, max: 100, n= 42)	Decrease	%	4	74	4	74			Only collected after 2016
	FloodplainConnectivity	Logarithm of the difference between average bankfull height and average floodplain height= log(FloodplainHeight - BankHeight + 0.1) (units: none, min: -1, max: 2, n=11)	Increase	None	1.2	4.5			1.6	3.2	
	InstreamHabitatComplexity	Aggregate measure of average cover provided by boulders, overhanging vegetation, live trees and roots, LWD, small woody debris, and stream banks for stream fishes measured at 11 plots. Proporional cover was binned into four classes (0.875, 0.575, 0.25, and 0.5), averaged across transects, and then summed across six types of cover. (units: none, min: 0, max: 2.3, n= 66)	Decrease	None	0	0.2	0	0.02			
	ThalwegDepthCV	Indicator of bed heterogenity computed as the coefficient of variation of 100-300 thalweg depth measurements (units: none, n= 1)	Decrease	None	0.3	0.62	0.32	0.39			
	ThalwegDepthMean	Mean thalweg depth. Metric of how deep water was at the site. (units: m, min: 0, max: none, n variable depending on reach length (100 - 300))	NA	m	0.23	1.58	0.3	0.39			

Appendix B: Core, contingent, and covariate indicators and their associated measurement location for perennial, lotic systems. Italics indicate a contingent or covariate measurement. This table was borrowed from BLM Technical Reference 1735-2 V2.

	Indicator	Main Transects	Intermediate Transects	Reach Center	Reach Wide
Water Quality	Acidity (pH)			X	
	Conductivity			X	
	Temperature			X	
	Total Nitrogen & Phosphorous			X	
	Turbidity			X	
Physical Habitat (PHAB)	Bank Angle	X			
	Bank Stability & Cover	X	X		
	Bankfull Width	X	X		
	Floodplain Connectivity (Bankfull and Incision Height)	X			
	Floodprone Width[1]				X
	Instream Habitat Complexity	X			
	Large Woody Debris				X
	Pool Dimensions				X
	Slope				X
	Substrate Particle Size	X	X		
	Thalweg Depth Profile				X
	Wetted Width	X			
Biodiversity & Riparian Habitat	Canopy Cover	X			
	Macroinvertebrate Biological Integrity[2]	X			
	Ocular Estimates of Riparian Vegetative Type, Cover, & Structure	X			
Other	GPS Coordinates				X
	Human Influences	X			
	Photographs				X

[1] Floodprone width is only measured at Transects A and K.
[2] Macroinvertebrates will either be sampled at all main transects OR within targeted riffles depending on how many riffles are present within the reach. See TR 1735-2 for more details.

Appendix C: Glossary

alluvial: a stream or river system whose morphology is formed and maintained by the active transport and deposition of sediment within the channel.

anadromous: the migration pattern of certain fishes (e.g., pacific salmon, lampreys) that are born in freshwater, spend most of their lives in saltwater, and return to freshwater to spawn.

anthropogenic: direct and/or indirect human influences on the natural environment.

bankfull: the heigh on the streambanks where water fills the channel and begins to overflow onto the floodplain. This volume of flow occurs every 1.5 years on average and is the channel-forming flow.

beaded stream: a stream channel that is composed of deep regularly spaced pools which are connected by short narrow and often shallow runs. Beaded streams are a common thermokarst feature on the Arctic landscape.

best management practices: operational or procedural practices used to prevent the pollution and degradation of streams and rivers.

environmental DNA (eDNA): the process of filtering water, sediment, etc. to obtain and identify genetic material in a location of interest. The genetic material is cellular material shed from organisms and is used to identify which species are present in the environment.

graminoid: grasses or grass-like plants that include grasses (Poaceae), sedges (Cyperaceae), rushes (Juncaceae), arrow-grasses (Juncaginaceae), and quillworts (Isoetes).

heterogeneity: something (e.g., landscape, population, etc.) that is made up of complexity or diversity.

lotic: a system that contains flowing water with enough energy to form a defined channel, such as streams and rivers.

naturogenic: having a natural cause or change. It is an antonym of anthropogenic.

perennial: a stream channel that has continuous flow on an annual basis except for periods of extreme or abnormal drought.

permafrost: any ground layer that has remained completely frozen for at least two years. It is typically limited to higher latitudes and high-elevation mountainous regions.

strahler stream order: a methodology used to describe the size of perennial stream channels. Headwater streams without any tributaries are designated first-order streams. Two stream channels of equal order must come together to increase the stream order (e.g., two first order streams come together to create a second order stream).

target population: in statistical surveys, the target population refers to the group of individuals or things that one seeks to make inference to (e.g., wadeable streams in Alaska, lakes > 10 acres).

thermokarst: the formation of topographical features on the landscape (e.g., thermokarst lakes, beaded streams) due to melting permafrost and ice-rich soil layers.