Developing a Long-Term Aquatic Monitoring Network in a Complex Watershed of the Alaskan Arctic Coastal Plain

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Abstract

The Arctic Coastal Plain (ACP) of northern Alaska consists of an extremely low gradient, lake-rich landscape that is characterized by a complex network of aquatic habitats and surface features strongly influenced by permafrost dynamics. Much is unknown about the form, function, and ecological conditions in this unique hydrologic setting. Amplified climate change and landscape responses in the Arctic further complicate the capacity to separate natural variability from land use effects that may occur with petroleum development. A comprehensive, multi-disciplinary review and analysis of recent studies and initial inventory and monitoring in the Fish Creek watershed on the ACP provided guidance to develop a framework for future aquatic monitoring and integrated research. The result is an established network of stream and lake sites for physical, chemical, and biological data collection that is intended to be sustainable over a long-term period and contribute to understanding Arctic aquatic ecology in the context of climate change and assist science-based land management decisions.

Keywords: Arctic coastal plain, fish, lakes, permafrost, streams, watershed monitoring

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Introduction

Watershed responses to climate change in the Arctic are of increasing interest for managing land use and forecasting affects on fish and wildlife. Greater snow and rain precipitation coupled with increased winter sublimation and summer evapotranspiration (Serreze et al. 2003, Richter-Menge et al. 2008) make projecting annual and seasonal water balance uncertain. In areas of continuous permafrost, such as northern Alaska's Arctic Coastal Plain (ACP), the dynamic hydrologic cycle is constrained near or at the surface, causing expansive, complex, and intermittently connected surface water drainage networks. For example, lakes expand and coalesce in some areas and drain in others (Smith et al. 2005, Jones et al. 2009, Marsh et al. 2009). Similarly, the duration and timing of stream-lake connectivity has been shown to be shifting in opposite directions in various Arctic regions (Woo and Guan 2006, Lesack and Marsh 2007). Permafrost warming and thermokarst erosion play a critical role in such drainage network response to climate change with water availability and temperature acting as important feedbacks (McNamara et al. 1999, Lawrence and Slater 2005). Despite the anticipation of continuing hydro-climatological shifts, few watersheds on the ACP in Alaska have long-term comprehensive environmental monitoring, accentuating the need to establish sustainable watershed observatories in this region.

The Fish Creek watershed (4,676 km^2) in the northeast National Petroleum Reserve - Alaska (NPR-A; Figure 1) is representative of the hydrologically complex ACP, characterized by deep continuous permafrost with a shallow active layer, a high density of thermokarst lakes, drained thermokarst lake basins (DTLB), low-order beaded streams along thermally degraded ice wedges, and higher-order alluvial channels that flow into the Beaufort Sea. These

physiographic characteristics, oil and gas exploration and planned development, and the presence of established climate stations made the Fish Creek watershed an advantageous location to pursue a multi-disciplinary observation network.
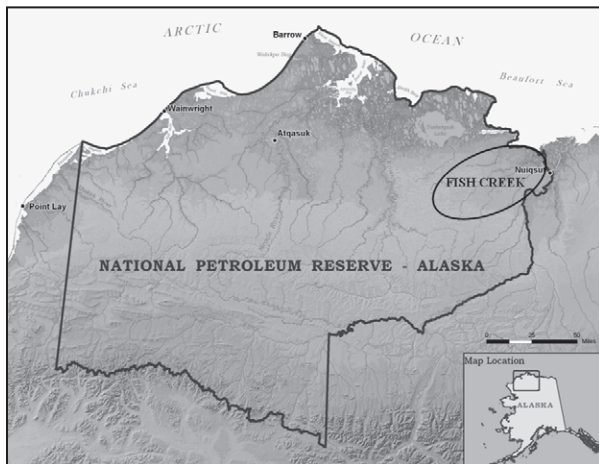

Figure 1. Location of Fish Creek watershed in Alaska.

We utilized a variety of work in the watershed over the past decade to improve understanding of the complex aquatic habitats, establish baseline datasets, evaluate protocols, and identify parameters best suited to the objectives of assessing land use effects and climate change effects on the ACP. Conceptual modeling of Arctic ecological processes related to climate change (Martin et al. 2009) and oil and gas activities (Noel et al. 2008) provided guidance. Initial sites were selected to capture the array of aquatic habitat types in catchments with varying degrees of anticipated development. Ultimately, an assessment of scientific information, land-use projections, operating costs, and anticipated future supporting resources led to the network of sites in place for 2011.

An approach of incremental implementation and refinement was fundamental in developing a valid monitoring network intended to be sustainable over a long time period. Described here are a selection of some of the studies that we used to do this, which included work that focused on drainage network structure, geomorphology, streamflow regimes, water quality, and biological communities.

Methods

A spatial analysis of the Fish Creek watershed drainage network quantified the variability and extent of waterbody types. High-resolution aerial photography was used in conjunction with the U.S. Geological

Survey (USGS) National Hydrography Dataset in a geographic information system (ArcMap) to analyze stream and lake extent. Stream channels were categorized as beaded, alluvial, colluvial, or unclassified. Lake basins and drained lake basins were categorized as headwater (outlet only) or flowthrough (inlet and outlet).

The geomorphology of beaded stream systems was investigated to improve understanding of formative processes and variability among streams of this type. This study was accomplished by combining reach-scale topographic and thaw-depth surveys, aerial reconnaissance, and analysis of high-resolution aerial photography. Descriptive characteristics of the five gaged systems were generated based on drainage area; gradient; pool (bead) size, density, shape, and depth; thermokarst conditions (thaw depths); the relative position and area of interconnected lakes; and runoff.

Three main channel (higher-order) alluvial streams have been gaged since 2002 (Fish and Judy Creeks and the Ublutuoch River). Additionally, five beaded tributary streams (Bills, Oil, Crea, Blackfish, and Bear Trio Creeks) have been gaged since 2008. Pressure transducers record water level every fifteen minutes, with discharge measurements made throughout the annual hydrologic cycle.

Water quality studies included continuous monitoring with sondes (Yellow Springs Instruments 6600-V2) as well as broad-scale laboratory constituent analyses. Sondes were deployed in five beaded streams during the open-water season from 2008 to 2010. Sensors included conductivity, pH, dissolved oxygen, turbidity, chlorophyll *a*, and temperature. Water samples were collected (U.S. Geological Survey, variously dated) during the summer of 2010 at five beaded streams and one lake outlet. Samples were analyzed for major ions, trace metal cations, nutrients, organic carbon, and a suite of organic compounds at the USGS National Water Quality Laboratory in Denver, CO.

Because of oil and gas activities, fish studies were conducted in the watershed primarily by industry contractors and Alaska Department of Natural Resources (ADNR). Species inventories conducted from 2000 to 2010 largely consisted of sampling with fyke nets (e.g., MJM Research 2004). In coordination with early inventory efforts, ADNR conducted radio telemetry work on Arctic grayling (*Thymallus arcticus*), broad whitefish (*Coregonus nasus*), and burbot (*Lota lota*) (Morris 2003).

Macroinvertebrate samples were collected from streams in 2006 and 2010. A Petite Ponar dredge was used to collect three subsamples from the streambed at study sites (Burton and Pitt 2001). Each subsample was rinsed through a 500-µm mesh sieve, composited into a single sample, and preserved with 95 percent ethanol. A D-frame kick net (500-µm mesh) was used to collect three subsamples from emergent vegetation (adapted from U.S. Environmental Protection Agency 1997). A sweep sampling technique was utilized with each subsample consisting of approximately three 1-m sweeps. Subsamples were composited for each site and preserved with 95 percent ethanol. Samples were processed at the Bureau of Land Management–Utah State University National Aquatic Monitoring Center.

Phytoplankton was collected for chlorophyll *a* analysis by pumping stream water through a 0.7-µm glass fiber filter and adding $MgCO_3$ to prevent degradation of chlorophyll (Moulton et al. 2002). Different quantities of water (≤1.0, 1.5, and 2.0 L) were filtered during 2004, 2006, 2009, and 2010 to help determine the minimum volume required for acceptable detection limits during laboratory processing. Three samples were collected at each location and frozen until they were processed at Alaska Department of Fish and Game, Division of Habitat in Fairbanks, AK, or Analytica, Inc., in Juneau, AK.

Results

The spatial analysis of the Fish Creek watershed drainage network showed a channel drainage density of 0.48 km/km^2 and lake surface area of 17 percent, with much of the remaining land surface covered by DTLB. Alluvial and beaded channels each account for about 44 percent of the total stream length in the watershed, and lake basins cover 18 percent of the linear drainage distance (Table 1). Most beaded streams initiate from thermokarst lakes (61 percent) or DTLBs (29 percent). Approximately 53 percent of beaded streams terminate in alluvial channels, while others terminate in oxbow lakes, thermokarst lakes, or fluvial transition zones.

Evaluation of beaded stream geomorphology revealed that about half have coalesced or irregular pools indicative of older channels with greater thermokarst degradation, while the others have distinct pools or a series of connected thaw pits that likely denote younger or slowly developing channels. Channels with more coalesced beads had lower gradients and occurred in catchments with lower lake area extent. In the five gaged beaded stream systems, there was considerable

Table 1. Drainage network classification for Fish Creek watershed.

Class	Percent class	Subclass	Percent subclass	Length (km)
Stream channels	77.4	--	--	2,345
		Beaded	44.0	1,031
		Colluvial	2.0	47
		Alluvial	44.7	1,048
		Unclassified	9.3	219
Lake basins	18.4	--	--	557
		Headwater	26.9	150
		Flowthrough	73.1	407
Drained lake basins	4.2	--	--	129
		Headwater	60.2	78
		Flowthrough	39.8	51

variation in baseflow-runoff, which also corresponded to bead coalescence (r=-0.79) and percent lake area (r=+0.90).

Most annual runoff in ACP alluvial and beaded streams occurs during spring breakup. Typically, there are few, if any, substantial rainfall peaks during the summer in these low gradient watersheds. Flow generally recedes from snowmelt peakflow through freeze-up, although in some years late summer rain is heavy enough to result in a water level rise (Figure 2). Baseflow conditions are most consistent from mid-July to mid-August, which is the targeted indicator period for collecting annual discrete samples of various types.
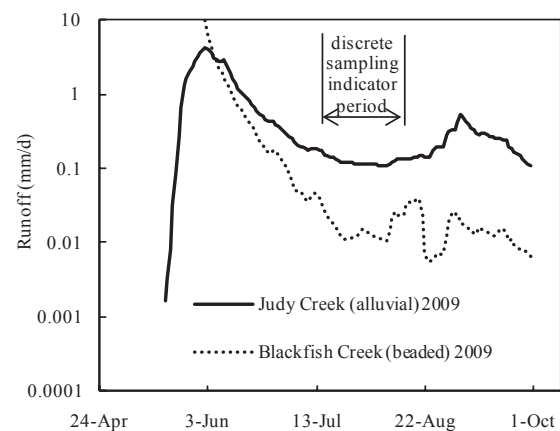

Figure 2. Open-water hydrograph for 2009 of a higher-order alluvial stream and a tributary beaded stream.

Select results from continuous water quality monitoring are presented in Table 2. Various water sample results from the five gaged beaded streams related to productivity include phosphorous (mean = 0.005 mg/L), orthophosphate (mean = 0.008 mg/L), total nitrogen (mean = 0.374 mg/L), and organic carbon (mean = 5.84 mg/L). All organic compound results

were less than reportable values, except for a detection of trichloromethane at 0.2 µg/L in the sample and the replicate from Oil Creek.

Table 2. Select results for continuously monitored water quality parameters (June 14 to August 26, 2010).

Site	Temp[1] (°C)	Turb[2] (NTU)	SC[3] (µS/cm)	Chl a[4] (RFU)
	Minimum–Maximum			
Blackfish Creek	3.4–17.7	≤0.1–1.9	68–149	≤0.1–1.90
Crea Creek	2.8–18.6	≤0.1–6.5	76–160	≤0.1–3.60
Bear Trio Creek	2.2–17.8	0.3–15.8	78–177	≤0.1–2.00
Oil Creek	2.0–19.2	≤0.1–7.4	98–261	≤0.1–2.00
Bills Creek	3.0–18.9	≤0.1–3.2	87–201	≤0.1–2.10

[1]Temperature (±0.15), [2]Turbidity (±0.3), [3]Specific conductivity (±1.0), [4]Chlorophyl *a* (relative fluorescence units, ±0.1%)

A total of 16 fish species have been captured in the watershed, with Arctic grayling, broad whitefish, least cisco (*Coregonus sardinella*), and ninespine stickleback (*Pungitius pungitius*) being most prevalent. Dolly Varden (*Salvelinus malma*) and Pacific salmon (chum, pink, chinook, and sockeye) (*Oncorhynchus* spp.) are only found occasionally. Other species include humpback whitefish (*Coregonus pidschian*), Arctic cisco (*Coregonus autumnalis*), round whitefish (*Prosopium cylindraceum*), burbot, lake trout (*Salvelinus namaycush*), Alaska blackfish (*Dallia pectoralis*), and slimy sculpin (*Cottus cognatus*). Notably, species detection at a given location often varied greatly. Telemetry helped explain the variability of fish presence, with Arctic grayling, burbot, and broad whitefish making frequent movements among multiple habitats (Figure 3).
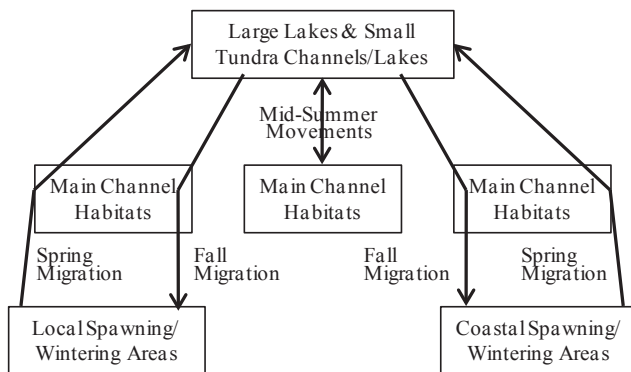
Figure 3. Simplified diagram of typical broad whitefish seasonal movements (adapted from Morris 2003).

Macroinvertebrate community richness was significantly different between emergent vegetation and streambeds at the genus (p<0.001) and family (p<0.001) level (Figure 4), with emergent vegetation being the richest habitat. This habitat also had higher

diversity (p<0.01). Chironomidae dominated streambeds, while emergent vegetation communities were dominated by Valvatidae, Chironomidae, and Limnephilidae.
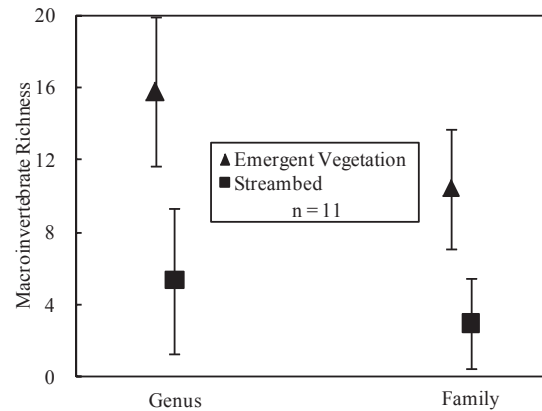
Figure 4. Mean macroinvertebrate richness (±1 standard deviation) for emergent vegetation and streambeds (2006).

Phytoplankton samples consisting of ≤1.0 L of filtered stream water did not contain enough absolute chlorophyll *a* in the extraction solution to satisfy a minimum reporting limit (MRL) based on a detection level of 0.1 mg/m^3 (Figure 5). Filtering either 1.5 or 2.0 L largely resulted in valid samples, with only a small proportion being <MRL. However, samples collected by filtering 2.0 L of water were substantially more difficult to collect in the field because of filter clogging. Among the valid samples, the mean summer chlorophyll *a* concentration for Fish Creek watershed streams is 1.58 mg/m^3.
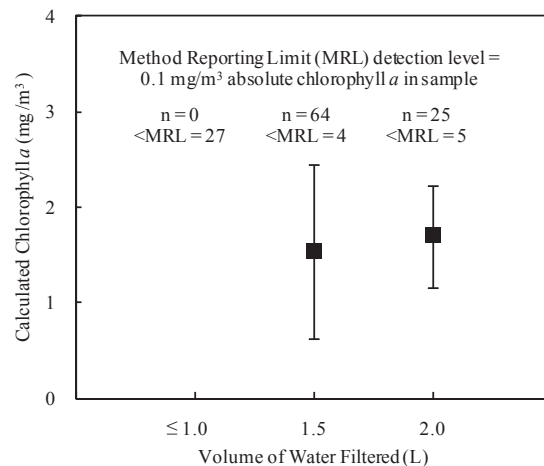
Figure 5. Mean chlorophyll *a* concentrations (±1 standard deviation) for phytoplankton samples at different volumes.

Table 3. Number of fixed monitoring sites where annual data is intended to be collected.

Aquatic habitat	Total sites	WL[1]	D[2]	T[3]	SC[4]	pH	DO[5]	Turb[6]	Chl a trend[7]	Chl a lab[8]	Nutr[9]	OC[10]	MI[11]	Zoop[12]	Fish	AL[13]
Alluvial stream	3	3	3	3	2	2	2	2	2	3	2	2	2	--	--	--
Beaded stream	5	5	5	5	5	5	5	5	5	5	5	5	5	5	1	5
Headwater lake	4	4	--	4	1	1	1	--	1	4	1	1	4	4	--	--
Flowthrough lake	3	3	--	3	1	1	1	--	1	3	1	1	3	3	--	--

[1]Water level, [2]Discharge, [3]Temperature, [4]Specific conductivity, [5]Dissolved oxygen, [6]Turbidity, [7]Chlorophyll *a* probe, [8]Chlorophyll *a* sample, [9]Nutrients, [10]Organic carbon, [11]Macroinvertebrates, [12]Zooplankton, [13]Active layer depth

Conclusions

The drainage network classification, geomorphology analysis, and streamflow monitoring collectively contributed to insights regarding watershed-scale hydrologic behavior, waterbody connectivity, and formative processes, concepts principle to evaluating potential ecosystem shifts related to climate change or land use effects. The initiation of most beaded streams from thermokarst lakes or DTLBs suggests that lakes are the dominant control on initial channel formation and evolution. The strong correlation of beaded stream baseflow runoff with bead coalescence and percent lake area indicates that proportionally higher lake area results in higher water yield in the short term and is indicative of older or more developed drainage networks in the long term. The classification of waterbodies also guided site refinement to make the network more representative of the hydrological processes occurring in ACP watersheds.

Water quality parameters monitored in situ showed that beaded streams generally have low productivity and low suspended sediment loads throughout the summer season based on relative fluorescence and turbidity values. Higher turbidity values observed at Bear Trio Creek were attributed to unstable banks in the upper catchment that were identified as the origin of the sediment inputs. Among all parameters, upper temperature limits are likely the primary constraining factor for fish suitability in beaded streams. Future water quality monitoring will largely involve tracking parameters by instrumentation, with expanded efforts to evaluate alluvial stream sites. Water sampling will vary based on yearly resources, although a set of priority constituents most relevant to climate change projections was selected for annual monitoring and includes nutrients and organic carbon.

While fish community is utilized in many regions as an indicator of stream health (Simon 1998), it is not a suitable option on the ACP because of high spatial and temporal variability. The best strategy for evaluating ecological relationships involving Arctic fish is focused research within the scope of the monitoring framework. Other biological studies provided baseline data and helped identify sampling best suited to ACP aquatic habitats. For example, long-term macroinvertebrate sampling will focus on emergent vegetation. Richest-habitat targeting is a well-founded option for monitoring (Karr and Chu 1999) and is more cost effective than multi-habitat sampling.

The strategy of the Fish Creek watershed aquatic monitoring program from 2011forward includes maintaining a set of fixed sites (Table 3), establishing an intensive sampling study catchment, and continuing integrated research. The fixed-site network includes streams and lakes characteristic of the primary habitat types in the watershed. Parameters not monitored continuously at those locations will be collected during a baseflow indicator period, which is a sound monitoring program approach (Karr and Chu 1999). More frequent sampling to investigate temporal trends will occur in the intensive sampling catchment, Crea Creek. As integrated research is an essential component of an effective monitoring program (Mulder et al. 1999), this will continue in Crea Creek and, as resources allow, at a greater spatial extent throughout the watershed.

Acknowledgments

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