



Stream Communities and Ecosystems Monitoring Protocol for the Arctic Network, Alaska

Natural Resource Report NPS/ARCN/NRR—2018/1725





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Cutler River in Noatak National Preserve

NPS/Jon O'Donnell, Arctic Network, National Park Service, Anchorage Alaska

ON THE COVER

Aerial photograph of the Agashashok River in Noatak National Preserve.

NPS/Ken Hill, National Park Service, Fairbanks, Alaska

Stream Communities and Ecosystems Monitoring Protocol for the Arctic Network, Alaska

Natural Resource Report NPS/ARCN/NRR—2018/1725

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September 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

O'Donnell, J. A. and S. D. Miller. 2018. Stream communities and communities and ecosystems monitoring protocol for the Arctic Network, Alaska. Natural Resource Report NPS/ARC/NRR—2018/1725. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	vi
Tables.....	vii
Abstract.....	viii
Acknowledgments.....	ix
1. Introduction.....	11
2. Discharge Analysis	15
2.1 Background.....	15
2.2 Sampling Design	18
2.2.1 Quantitative Discharge Analysis Using USGS NWIS Data.....	18
2.2.2 Qualitative Assessment of Stream Discharge.....	19
2.3 Data Processing	19
2.4 Analyses and Reporting.....	19
2.5 Operational Requirements	20
3. Field Measurements and Stream Chemistry	21
3.1 Introduction	21
3.1.1 Basic Water Quality Parameters.....	21
3.1.2 Dissolved Organic Carbon	21
3.1.3 Dissolved Inorganic Carbon and Alkalinity	24
3.1.4 Nitrogen and Phosphorus (N and P).....	24
3.1.4 Major Cations and Anions.....	25
3.1.5 Benthic Algae and Chlorophyll a	25
3.1.6 Benthic Macroinvertebrate Communities.....	25
3.2 Sampling Design	25
3.2.1 Site Selection	25
3.2.2 Sample Timing, Frequency, and Replication	27
3.3 Field Methods.....	28

Contents (continued)

	Page
3.3.1 Field Season Preparations.....	28
3.3.2 Field Measurements.....	29
3.3.3 Water Sample Collection and Processing.....	30
3.3.4 Continuous Monitoring of Water Quality Parameters.....	30
3.3.5 End-of-season Procedures	31
3.3.6 Safety in the Field.....	31
3.4 Analyses and Reporting.....	31
3.5 Operational Requirements	32
4. Data Management	33
4.1 Data Management Life Cycle.....	33
4.2 NPS Standards	34
4.2.1 Data Quality.....	34
4.2.2 Freedom of Information Act.....	34
4.2.3 Records Management	34
4.3 Core Functional Model.....	35
4.4 Data Sensitivity Statement	36
4.5 Roles and Responsibilities.....	36
4.6 Quality Assurance	36
4.7 Data Collection.....	36
4.7.1 Deliverables Schedule	36
4.7.2 Deliverable S01: Discharge.csv.....	37
4.7.3 Deliverable S02: Field Sheets	37
4.7.4 Deliverable S03: Site Photos.....	37
4.7.5 Deliverable S04: Chemistry – Discrete Sampling.....	38
4.7.6 Deliverable S05: Chemistry – Continuous In Situ Sampling	38
4.7.7 Deliverable S06: Algae.....	38

Contents (continued)

	Page
4.8 Data Entry/Import.....	38
4.9 Quality Control.....	38
4.10 Product Archival and Documentation	39
4.10.1 IRMA Data Store.....	40
4.10.2 Reports.....	40
4.10.3 Data.....	41
4.10.4 Resource Brief	41
4.10.5 Products Publication	41
4.10.6 Metadata	41
4.10.7 Line of Sight	42
4.10.8 Dataset Integration with National Databases.....	42
4.10.9 Database Design	42
4.10.10 Data and Information Security	44
4.11 Closeout.....	44
4.12 Certification.....	45
5. References.....	46

Figures

	Page
Figure 1. Map of 69 stream study sites sampled during the 2013-2015 pilot study across the five ARCN park units.	13
Figure 2. Linear regression relating the timing of peak discharge during spring snowmelt from the mid-1970s through 2012 (modified from Tape et al. 2016).	16
Figure 3. Conceptual model illustrating hydrologic changes associated with permafrost thaw across a hill-slope cross-section (adopted from O'Donnell et al. 2017).	17
Figure 4. Long-term trend in the timing of autumn freeze-up on the Kobuk River near Kiana (O'Donnell, unpublished data).	18
Figure 5. Stream and rivers of ARCN drain heterogeneous landscapes that vary with respect to parent material and permafrost, among other physiographic traits	22
Figure 6. Mean DOC concentration in ARCN rivers draining watersheds dominated by different parent material classes (O'Donnell et al. 2016)	23
Figure 7. Mean DOC concentration in ARCN rivers draining watersheds dominated by different ground ice classes (O'Donnell et al. 2016)	23
Figure 8. Long-term monitoring project data management life cycle.	33
Figure 9. The ARCN Core Functional Model overview.	35
Figure 10. Vital Sign Project reference architecture in the IRMA Data Store.	40
Figure 11. Each informational component informs and is informed by other components	41
Figure 12. Overview of database architecture and system data flow.	43
Figure 13. Data model of Stream Communities and Ecosystems database.	43
Figure 14. Data deliverables are defined in the monitoring protocol and archived in IRMA Dataset references after each remeasurement cycle	44

Tables

	Page
Table 1. River study sites for discharge analysis.	19
Table 2. Monitoring sites across ARCN park units that vary with parent material type.	26
Table 3. Stream Communities and Ecosystems monitoring data deliverables schedule.....	37

Abstract

Streams and rivers are important components of and critical resources within arctic watersheds. Recent climate change in the Arctic has altered the magnitude and seasonality of stream discharge, stream temperature, the chemical composition of stream water, and stream habitat. Still, large uncertainties exist regarding the spatial extent of these changes and the timing of stream ecosystem responses to projected climate change. Here, we present a long-term monitoring protocol for Stream Communities and Ecosystems vital sign, one of 19 vital signs within the National Park Service's (NPS) Arctic Inventory and Monitoring Network (ARCN). The ARCN is comprised of five NPS park units, including Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve.

The overarching goal of our monitoring protocol is to detect long-term change in physical, chemical, and biological components of arctic stream ecosystems. The protocol narrative describes the background and justification for our monitoring design, while the accompanying standard operating procedures (SOPs) provide detailed methods for each component of the protocol. Using findings from prior work in these watersheds, we propose a stratified sampling approach to account for spatial variability in watershed properties (e.g., permafrost ground ice content, and underlying parent material). Through this approach, we will be able to detect long-term changes in streams across space, and to identify watersheds that convey resilience versus those that are vulnerable to climate change and disturbance. Findings from this monitoring program will inform and improve NPS land management and policy.

Acknowledgments

We acknowledge National Park Service Arctic Inventory and Monitoring Network and the Water Resources Division, who provided funding and support throughout the development of this protocol. We acknowledge Jim Lawler and Eric Wald, who served as ARCN program manager during protocol development. We thank George Aiken, Kenna Butler, Sara Breitmeyer, Kathryn Motter, Tom Trainor, and Tom Douglas who helped with laboratory analyses during the pilot studies that have guided protocol development. We also thank David Swanson, Andrew Baltensperger, and Santosh Panda for assisting with remote sensing analyses that helped to inform our monitoring design. The authors also thank Michael Carey and Ylva Sjoberg for the detailed and thoughtful reviews of this protocol, which greatly improved upon earlier versions of the report.

1. Introduction

The Arctic is warming at a faster rate than temperate and tropical regions (Serezze and Francis 2006). Streams and rivers draining arctic landscapes are sensitive to climate warming, both in response to the direct effects of increasing air temperature and to the indirect effects of warming on watershed hydrology and disturbance regimes (e.g., wildfire, permafrost thaw; Rouse et al. 1997, Prowse et al. 2006). Climate-driven changes in stream temperature and hydrology are likely to have profound consequences for stream chemistry and biota. However, the timing and magnitude of these impacts will likely vary across space and time, particularly given the heterogeneous nature of arctic landscapes. In addition to climate-related impacts, human activities (e.g., mining, infrastructure, roads), may also alter stream ecosystems at local to regional scales.

A number of studies have documented changes in watershed hydrology in response to recent warming at high latitudes. For example, the *magnitude* of annual discharge from large rivers has increased in some arctic regions (e.g., Eurasia; Peterson et al. 2002) and decreased in other regions (e.g., North America; McClelland et al. 2006). These increases in freshwater discharge to the Arctic Ocean have the potential to impact salinity, ocean circulation, and climate patterns (Peterson et al. 2006). Changes in the *seasonality* of stream and river discharge have also been observed across the Arctic. In the Yukon River basin of Alaska and Canada, groundwater discharge to stream flow has increased in recent decades (Walvoord and Striegl 2007), likely due to watershed-scale thawing of permafrost. Other studies in the Northwest Territories and Siberia have documented increases in winter baseflow (St. Jacques and Sauchyn 2009) and in minimum daily flow (Smith et al. 2007), suggesting changes in permafrost configuration within watersheds. The open-water period also appears to be changing for some arctic rivers, with earlier onset of the spring snowmelt freshet and later freeze-up during autumn (Tan et al. 2011, Tape et al. 2016). These hydrologic shifts may have the potential to alter stream chemistry (e.g., O'Donnell et al. 2012), productivity, and habitat (Vonk et al. 2015).

Arctic stream ecosystems are vulnerable to changing disturbance regimes in surrounding terrestrial landscapes, including impacts from wildfire and permafrost thaw. Wildfire frequency and severity are increasing in response to recent warming at high latitude (Turetsky et al. 2011), which can alter watershed hydrology, erosion rates, and stream chemistry (Shakesby and Doerr 2006, Betts and Jones 2009, Larouche et al. 2015). Permafrost thaw can impact stream ecosystems (Frey and McClelland 2009, Vonk et al. 2015) through watershed-scale changes in active layer thickness, thermokarst, and wholesale permafrost loss (Bowden et al. 2008, Lyon et al. 2009 and 2010, Walvoord et al. 2012). In addition to the effects of thaw on groundwater dynamics, permafrost thaw can enhance erosion and sedimentation into streams and rivers (Balser et al. 2014, Kanevskiy et al. 2016). Wildfire can accelerate permafrost thaw relative to climate change alone (O'Donnell et al. 2011, Brown et al. 2015), but little is known about their combined effects on stream ecosystems.

The chemical composition of stream and river water is a reflection of physical, chemical, and biological processes occurring within the watershed. In high-latitude watersheds, subsurface hydrology is an important control on stream chemistry (Maclean et al. 1999, Jones et al. 2005,

O'Donnell et al. 2014). In watersheds underlain by permafrost, groundwater discharge from shallow flow paths results in organic-rich stream water with high dissolved organic carbon (DOC) concentrations (Maclean et al. 1999). Where permafrost is absent, deeper flow paths contribute to stream water with lower DOC concentrations and higher mineral solute concentrations (e.g., calcium, magnesium, etc.).

In prior studies, Streams have been classified into different types based on watershed hydrology source-water contributions to flow, such as blackwater, clearwater, and glacial streams (Striegl et al. 2007). These different stream types also have unique chemical “fingerprints” that can be useful for detecting change across space and time (O'Donnell et al. 2010). Terrestrial processes that alter soils and watershed hydrology (e.g., climate, permafrost thaw, wildfire, erosion) will likely be reflected by a change in stream chemistry. Thus, long-term monitoring of stream chemistry is a useful and practical approach for detecting change over time. In-stream processes (e.g., microbial transformations, primary productivity, etc.) can also modify stream solute concentrations (Cole et al. 2007), and must be accounted for when interpreting trends in chemistry.

Physical and chemical changes associated with a warming climate or altered disturbance regime can have significant implications for aquatic biota. For instance, variation in the magnitude or seasonality of stream discharge can have a profound impact on stream habitat (Prowse et al. 2006), potentially altering primary production, invertebrate and fish communities. Dissolved organic matter (DOM) can influence stream pH, redox conditions, the transport and reactivity of trace metals (e.g., mercury, copper), and nutrient availability. The relative importance of DOM in aquatic systems varies with its chemical composition, which is expected to change under projected warming and permafrost thaw (O'Donnell et al. 2012, 2014). In most arctic streams, phosphorus (P) is the primary limiting nutrient governing primary production (Peterson et al. 1985). For example, long-term P fertilization of the Kuparuk River near the Toolik Field Station in northern Alaska has altered stream ecosystem function, leading to enhanced moss and algal productivity, invertebrate production, and fish production (Slavik et al. 2004). Warming and changing disturbance regimes will likely increase both nitrogen (N) and P inputs to streams from soils (e.g., Bowden et al. 2008), driving bottom-up effects on food web dynamics. Recent evidence also indicates that permafrost thaw, thermal erosion and sedimentation can also impact stream invertebrate communities (Chin et al. 2016).

The National Park Service's (NPS) Arctic Network (ARCN) Inventory and Monitoring (NPS) Program consists of five NPS park units, including Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT; Lawler et al. 2009). ARCN is one of 32 networks in the National Inventory and Monitoring program, and one of four networks in Alaska. ARCN comprises approximately 19.3 million acres, or nearly 25% of the land area of NPS-managed land units in the United States. The primary intent of the NPS monitoring program is to track physical, chemical and biological components of park ecosystems that represent the overall condition of natural resources, such that park lands remain “unimpaired for future generations” (Lawler et al. 2009).

Stream Communities and Ecosystems is one of 19 vital signs currently monitored by ARCN. The overarching goals of all vital signs monitoring are to (1) determine status and trends of selected indicators that reflect ecosystem condition, which will allow manager to make informed decisions, (2) provide early warning of abnormal conditions and impairment, and (3) provide data to improve understanding of ecosystem function while meeting legal and congressional mandates.

Water resources are an important component of the ARCN park units, and including shallow lakes (Larsen et al. 2011, 2017), large, deep lakes (O'Donnell et al. 2015a), stream and rivers (O'Donnell et al. 2015b, 2016), geothermal hot springs (e.g., Serpentine Hot Springs), and coastal lagoons (Reynolds and Clough 2010). There are seven National Wild and Scenic Rivers in ARCN, including the the Alatna, John, Kobuk, Noatak, North Fork of the Koyukuk, Salmon, and Tinayguk Rivers. O'Donnell et al. (2015b) conducted a two-year pilot study to characterize stream and river chemistry across the five ARCN park units. They sampled 57 rivers that ranged in size, source water contribution to flow, and chemical composition. Further analyses indicate the chemical composition of DOM in ARCN rivers is closely linked to parent material (e.g., loess, sand, glacial till, etc.) and ground ice content (O'Donnell et al. 2016: Figure 1). The results of this pilot study have been useful for the development and implementation of the Streams Communities and Ecosystems monitoring protocol outlined herein.

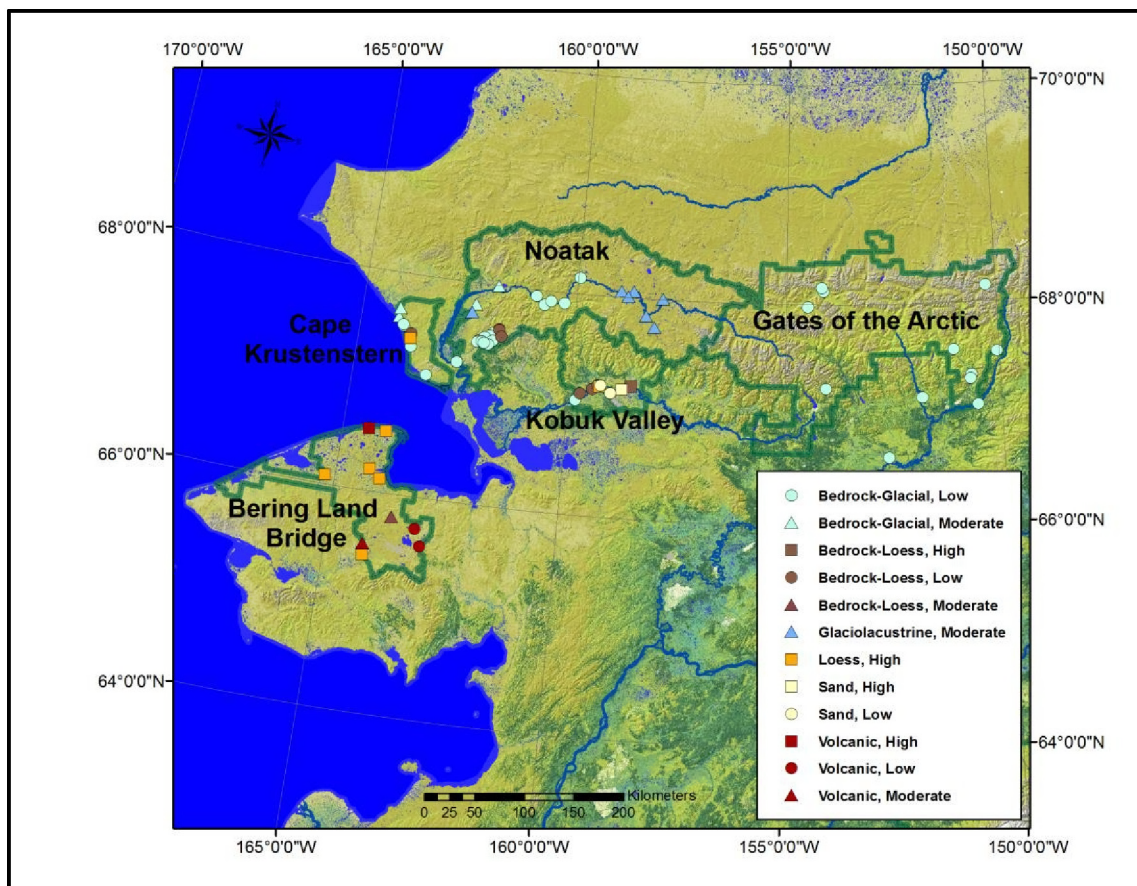


Figure 1. Map of 69 stream study sites sampled during the 2013-2015 pilot study across the five ARCN park units.

For the Stream Communities and Ecosystems vital sign, we have identified three primary monitoring goals:

1. Detect long-term trends in the magnitude and seasonality of stream and river discharge in watersheds draining or adjacent to ARCN park units,
2. Detect long-term changes in the chemical composition of streams and rivers draining watersheds that vary with soil and permafrost properties, and
3. Monitor and evaluate the implications of physical and chemical changes for stream and river biota.

2. Discharge Analysis

2.1 Background

Stream discharge is the volume of water flowing through a section of stream channel per unit time, and is one of the most basic and fundamental characteristics of a stream ecosystem (Gore 1996). Stream power is determined by considering both discharge and the slope of a channel along a stream reach. Stream discharge and power influence wide range of properties, including the flux of particulate and dissolved constituents, habitat characteristics, and geomorphology (e.g., meander patterns, floodplain dynamics). The physical effects of spatial and temporal variability in stream discharge also influence the distribution and abundance of stream biota (Vannote et al. 1980). In this section, I will discuss five components of discharge analysis that are of interest to the ARCN Stream Communities and Ecosystems vital sign monitoring protocol: (1) total annual discharge, (2) timing of peak discharge during spring snowmelt, (3) winter flow (4) discharge trends during open-water period, and (5) timing of river freeze-up during autumn. Detailed methods for evaluating long-term trends in these components of stream discharge can be accessed in *SOP: Discharge Analysis*.

In the Arctic, *spring snowmelt* is the dominant hydrologic event during most years and in most watersheds, and can account for 25% of total seasonal runoff (McNamara et al. 1998). In response to recent warming at high latitudes, the timing of spring snowmelt has shifted, with earlier melting of the terrestrial snowpack (Stone et al. 2002) and subsequent earlier timing of peak discharge (Tan et al. 2011). In northern Alaska, the timing of peak discharge during spring snowmelt has occurred 3.4 days per decade earlier over the last three decades (Tape et al. 2016).

The analyses by Tape et al. (2016) include the Kobuk River at Kiana, a gauge that is downstream from the western park boundary of KOVA (Figure 2). Swanson et al. (2014) examined spatial and temporal patterns of snowpack in ARCN park units using MODIS Terra satellite data, and found no trend in continuous snow season, although the record was only 13 years in length. Still, other observations and model simulations indicate that snow cover extent during spring has declined in recent years (Derksen and Brown 2012), which likely impact the timing and magnitude of river discharge during spring snowmelt.

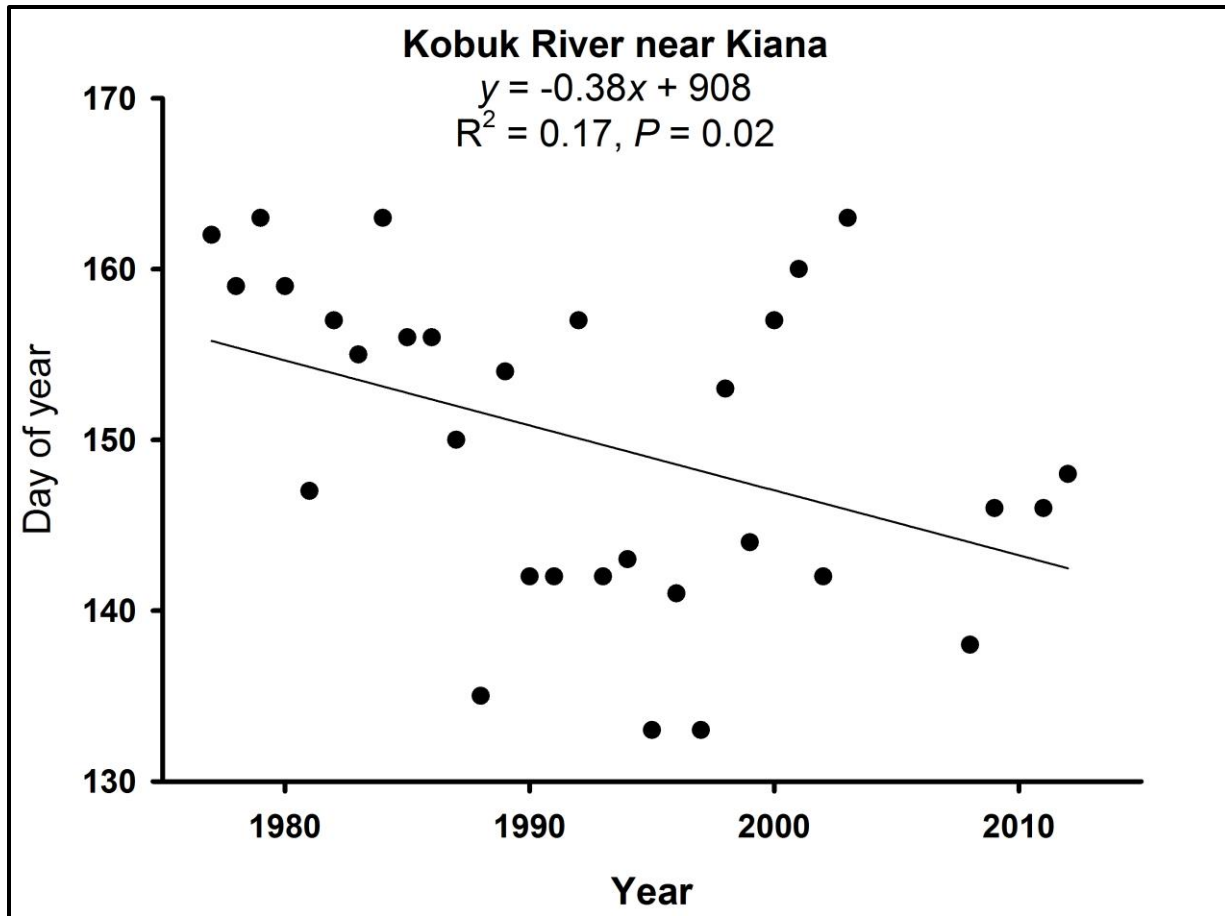
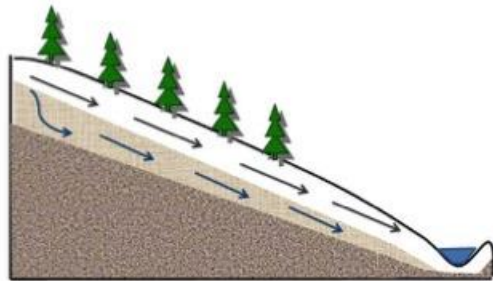


Figure 2. Linear regression relating the timing of peak discharge during spring snowmelt from the mid-1970s through 2012 (modified from Tape et al. 2016).

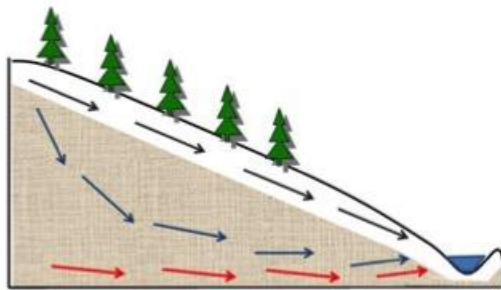
Winter flow or base flow is also an important component of the stream hydrograph as it reflects discharge from groundwater sources. As noted above, a number of studies in high-latitude regions have reported changes in winter flow and baseflow in recent decades (Smith et al. 2007; Walvoord and Striegl 2007; St. Jacques and Sauchyn 2009). This hydrologic shift appears to be due to basin-scale thawing of permafrost, which alters subsurface flow paths and discharge to surface waters (Figure 3; McKenzie et al. 2007). Observations of changing baseflow have mostly been documented in the discontinuous permafrost zone, where permafrost occupies 50-90% of the land area and is relatively warm (Romanovsky et al. 2010). ARCN parks are mostly within the continuous permafrost zone (> 90% of land are underlain by permafrost; with the exception of KOVA), where permafrost is colder (Panda et al. 2016). A comprehensive trend analysis of baseflow dynamics for stream and rivers draining or adjacent to ARCN park units would improve our understanding of watershed hydrology and long-term shifts in permafrost architecture.

Permafrost Thaw and Watershed Hydrologic Response



Early-Stage Thaw

- Increased active layer thickness
- Growing supra-permafrost aquifer
- Closed talik development



Late-Stage Thaw

- Development of open- or intra-permafrost taliks
- Establishment of deep (or sub-permafrost) groundwater flowpaths with longer transit times
- Wholesale permafrost loss

Figure 3. Conceptual model illustrating hydrologic changes associated with permafrost thaw across a hill-slope cross-section (adopted from O'Donnell et al. 2017).

River freeze-up during autumn is also a critical point in the annual hydrograph in the Arctic, and reflects the transition from the open-water to closed-water season. Preliminary analyses of discharge data indicate that the Kobuk River at Kiana has experienced a later autumn freeze-up in recent decades (Figure 4), despite relatively constant trends in autumn air temperature for the region (Stafford et al. 2000). Together with the earlier timing of spring snowmelt, this observation suggests that the Kobuk River is experiencing a longer open-water season in recent decades, which may have strong implications for aquatic habitat and biota. While the timing of spring snowmelt is closely tied to spring air temperatures, the connection to climate is less direct to autumn freeze-up. It's possible that changing permafrost configurations within the Kobuk watershed have allowed for increased groundwater discharge to the river, delaying freeze-up (Walvoord et al. 2012).

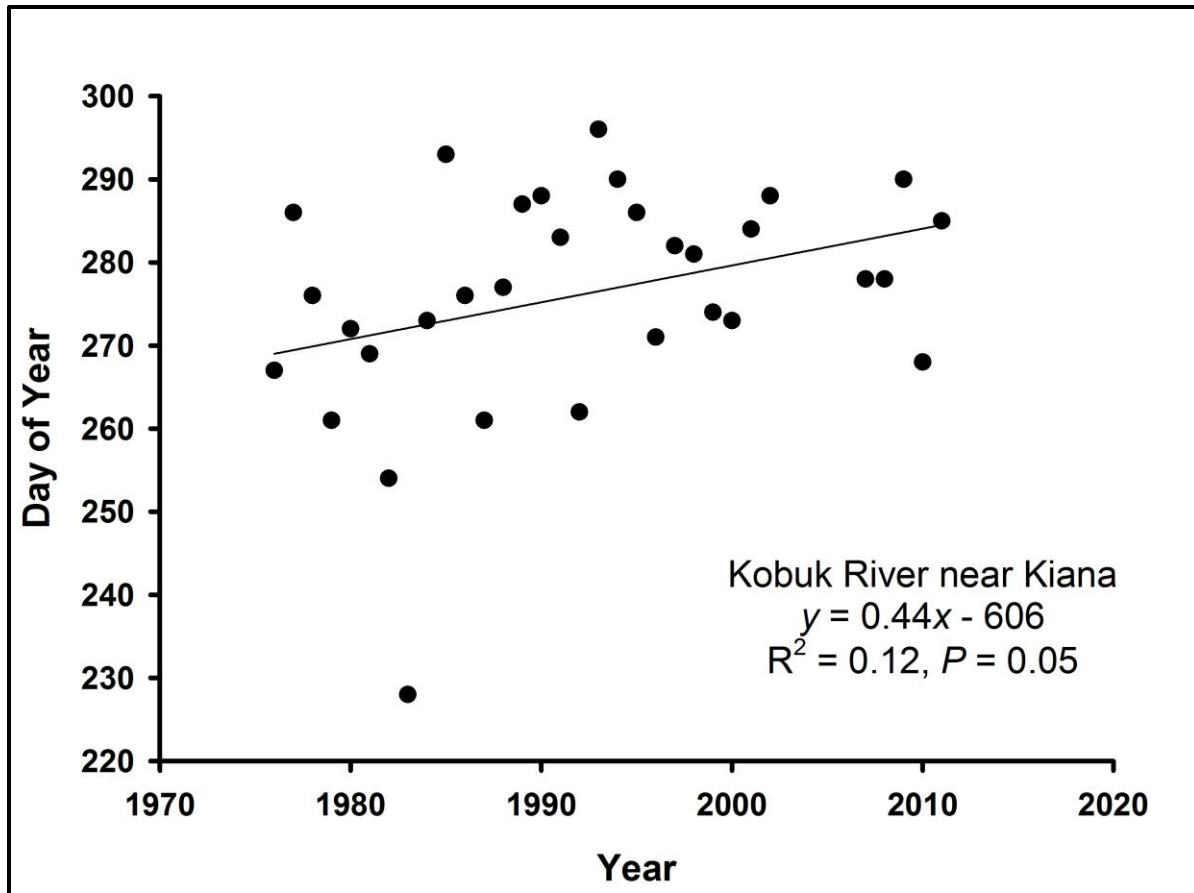


Figure 4. Long-term trend in the timing of autumn freeze-up on the Kobuk River near Kiana (O'Donnell, unpublished data).

2.2 Sampling Design

2.2.1 Quantitative Discharge Analysis Using USGS NWIS Data

Stream discharge is currently monitored by the United States Geological Survey (USGS) at a range of streams and rivers throughout Alaska. Data are regularly updated and hosted by the National Water Information System (NWIS) (<http://waterdata.usgs.gov>). USGS is not currently monitoring discharge within ARCN park boundaries. However, there are a number of rivers that drain or are adjacent to ARCN parklands that can serve as a proxy for hydrologic changes within the parks (Table 1). These sites include the Atigun River (near GAAR), Dahl Creek (near NOAT), the Kobuk River near Kiana (downstream of KOVA), Slate Creek (near GAAR), and the Wulik River (near CAKR). The United States Fish and Wildlife Service and NPS are also monitoring river discharge on the Koyukuk River near Bettles, AK, to the south of GAAR.

Table 1. River study sites for discharge analysis.

Site Name	NWIS Site Number	Latitude (°N)	Longitude (°W)	Drainage Area (km ²)	Length of Record
Atigun R Tr Nr Pump Station 4 AK	15904900	68.37361	-149.31333	84	1976 - Present
Dahl C Nr Kobuk AK	15743850	66.94611	-156.90888	28	1986 - Present
Kobuk R Nr Kiana AK	15744500	66.97361	-160.13088	24552	1976 - Present
Slate C at Coldfoot AK	15564879	67.25479	-150.17333	189	1995 - Present
Wulik R BI Tutak C Nr Kivalina AK	15747000	67.87611	-163.67444	1826	1984 - Present

To conduct discharge analyses, we will analyze trends for the following metrics: (1) total annual discharge, (2) timing of peak discharge during spring snowmelt, (3) winter flow (4) discharge trends during open-water period, and (5) timing of river freeze-up during autumn using established methods (e.g., Brabets and Walvoord 2009; Tape et al. 2016).

2.2.2 Qualitative Assessment of Stream Discharge

Qualitative assessments of flow will be conducted at all study sites where discharge is not being monitored, following recommendations by the NPS Water Resources Division (WRD) (<http://www.nature.nps.gov/water/vitalsigns/assets/docs/wqPartC.pdf>). WRD recommends classifying flow during site visits into one of four categories: (1) low/base flow when < 25% of bank-full condition, (2) intermediate from 25 to 75% of bank-full, (3) high when >75% of bank-full, and (4) over bank/flood. In addition to this qualitative assessment, site pictures will be taken during each visit to document flow conditions.

2.3 Data Processing

The USGS NWIS website (<http://waterdata.usgs.gov/nwis>) hosts daily mean discharge data (in units of cubic feet per second, or cfs), and is updated at regular intervals. Data are open-access, and can be downloaded as text files (.txt) and incorporated into spreadsheets with Microsoft Excel for compiling and analysis. Data have already been checked for quality control and assurance by the USGS, prior to posting on the NWIS database. Other open-access software has been developed by the USGS for downloading and processing NWIS data (Granato 2009), and will be evaluated for its utility for vital sign monitoring purposes.

2.4 Analyses and Reporting

Discharge data from each watershed (Table 1) will be analyzed to track trends in the magnitude and seasonality of stream flow. To track changes in total annual discharge, we will sum the daily mean discharge values for each calendar year, and plot these annual discharge sums over time (year).

Following methods of Brabets and Walvoord (2009), we will also analyze long-term trends in annual discharge and monthly discharge during the open-water season. To determine the timing of peak discharge during spring snowmelt, we will use the methods developed by Tape et al. (2016). Briefly, this approach involves identifying the exact date of the maximum daily discharge rate during the snowmelt period, which typically occurs in May or June in the Arctic. We will report the peak discharge dates in day of year, and plot this metric versus time (in years).

To determine long-term changes in winter flow, we will follow methods developed by Walvoord and Striegl (2007). The changing magnitude of winter flow can serve as a proxy for groundwater discharge to stream flow, which is sensitive to permafrost configuration and thaw. We will define winter as the period from January 1 to March 31, and then sum mean daily discharge rates during that time. Where data are available, we will also identify the annual minimum discharge during winter. This absolute minimum discharge reflects not only the length of winter, but also the available flow paths for groundwater during the freezing period (as determined in part by permafrost). To test for changes in both annual and winter flow, we will use the non-parameteric Mann-Kendall test.

We will determine the timing of freeze-up by identifying the first date in autumn (September – November) when mean daily discharge is consistently qualified with an “e” indicating that stage and discharge is estimated (K. Tape, *personal communication*). The “e” is provided in the NWIS data file, and is identified in the data by USGS personnel as characteristic readings from the stage instrument triggered by water backing-up from ice formation downstream or underneath the gage (Rantz et al. 2005). This does not require personnel on site for determining timing. Linear regression techniques will be used to track long-term changes in both the timing of peak discharge during snowmelt and the timing of freeze-up during autumn.

We will conduct an initial analysis of these five stream discharge metrics for all monitoring rivers for the historic period of record up through the present. The analyses will be repeated every five years as a means of extending the long-term record and to track recent changes in stream flow. Additional analyses will be conducted to evaluate possible environmental and climatic controls on the magnitude and seasonality of discharge. These five-year reports will either be published in a peer-reviewed journal or an NPS technical report.

2.5 Operational Requirements

Discharge analysis requires a person with good database skills and experience with basic statistics and statistical software (e.g., R, <https://www.r-project.org>). Analyses will be relatively straightforward for assessing the magnitude of annual discharge, monthly discharge during the open-water season, and winter flow (80 hours). Conducting analyses to determine the timing of peak discharge during spring snowmelt and the timing of river freeze-up during autumn will take approximately 60 hours. Generating the NPS technical report will take an additional 80 hours every 5 years.

3. Field Measurements and Stream Chemistry

3.1 Introduction

The chemical composition of stream water is a reflection of physical, chemical, and biological processes occurring within the watershed that govern the concentration of different solutes. These processes are constantly interacting, and they vary across space and time. At high latitudes, climate and disturbance (e.g., wildfire, permafrost thaw, erosion) may alter stream chemistry (e.g., Frey and McClelland 2009), which in turn can impact stream biota. To monitor stream chemistry, we will collect water samples, which will be analyzed for dissolved carbon (C), nutrients, and major ions. Below are the chemical constituents and the rationale for measuring.

3.1.1 Basic Water Quality Parameters

The NPS WRD has mandated that four water quality parameters be measured in the field for vital signs monitoring aquatic ecosystems. These parameters include water temperature ($^{\circ}\text{C}$), specific conductivity ($\mu\text{S cm}^{-1}$), pH, and dissolved oxygen (DO, mg L^{-1}). Collection of these field measurements will insure consistency and comparability across sites at the regional and national level. We will take discrete measurements at all monitoring sites and continuous measurements at a subset of headwater streams.

3.1.2 Dissolved Organic Carbon

Soils of the northern circumpolar permafrost region store approximately 1300 petagrams (Pg) of organic C (Hugelius et al. 2014). As a result, high latitude rivers tend to have higher concentrations of DOC than temperate or tropical rivers (Hope et al. 1994). The flux of C in arctic rivers represents an important component of the high-latitude C budget (McGuire et al. 2010), and the magnitude of this flux is expected to change under projected warming and disturbance scenarios (Frey and Smith 2005; Kicklighter et al. 2013). Moreover, inland waters can release C to the atmosphere through microbial and photochemical processes (Kling et al. 1991; Striegl et al. 2012; Cory et al. 2013), which can function as a positive feedback to the climate system. Given the important role of inland waters for the global C cycle and the climate system (Raymond et al. 2013), DOC concentration will be actively monitored.

DOC is a critical component of aquatic ecosystems, as it functions to regulate pH and nutrient availability, and also serves as substrate for microbially mediated reactions (e.g., aerobic respiration, denitrification, methanogenesis). DOC also can influence photochemical reactions and interactions with trace metals and organic pollutants. Increases in DOC concentration have contributed to the browning of surface waters in some high-latitude regions (Roulet and Moore 2006), affecting the photic zone and system productivity. In Alaska, DOC concentration in rivers is sensitive to watershed hydrology (Striegl et al. 2005; O'Donnell et al. 2010, 2012) and permafrost thaw (O'Donnell et al. 2014). Recent work by O'Donnell et al. (2016) also indicates that in ARCN park units, riverine DOC concentration varies with landscape properties, including parent material and ground ice content (Figures 5-7).

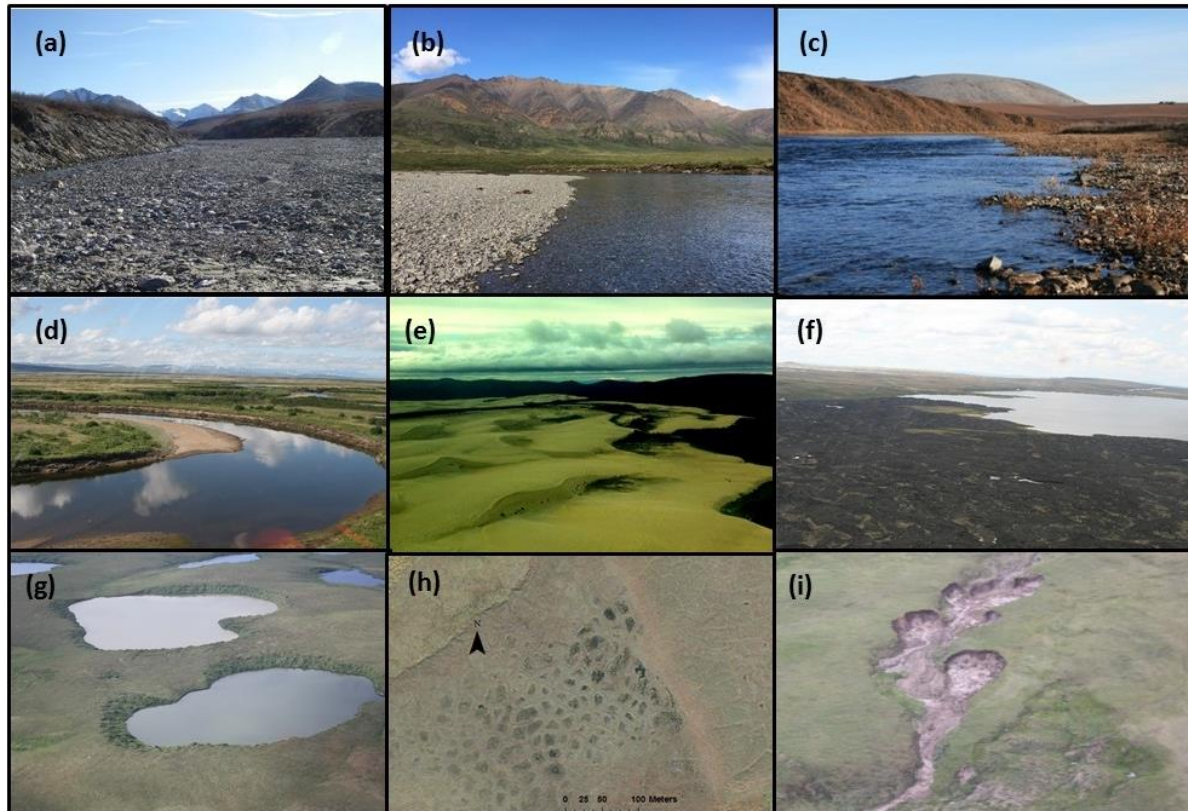


Figure 5. Stream and rivers of ARCN drain heterogeneous landscapes that vary with respect to parent material and permafrost, among other physiographic traits. These pictures highlight variation in dominant parent material: (a) bedrock (Agashashok River in NOAT), (b) coarse-grained glacial (Killik River in GAAR), (c) fine-grained glaciolacustrine (Cutler River in NOAT), (d) loess (Kuzitrin River in BELA), (e) sand (Great Kobuk Sand Dunes in KOVA), and (f) volcanic deposits (Imuruk Lake in BELA). Figure is reprinted from O'Donnell et al. (2016). Pictures g-i represent different features of ice-terrain, including thermokarst lakes (g), polygonal ground (h), and retrogressive thaw slumps (i).

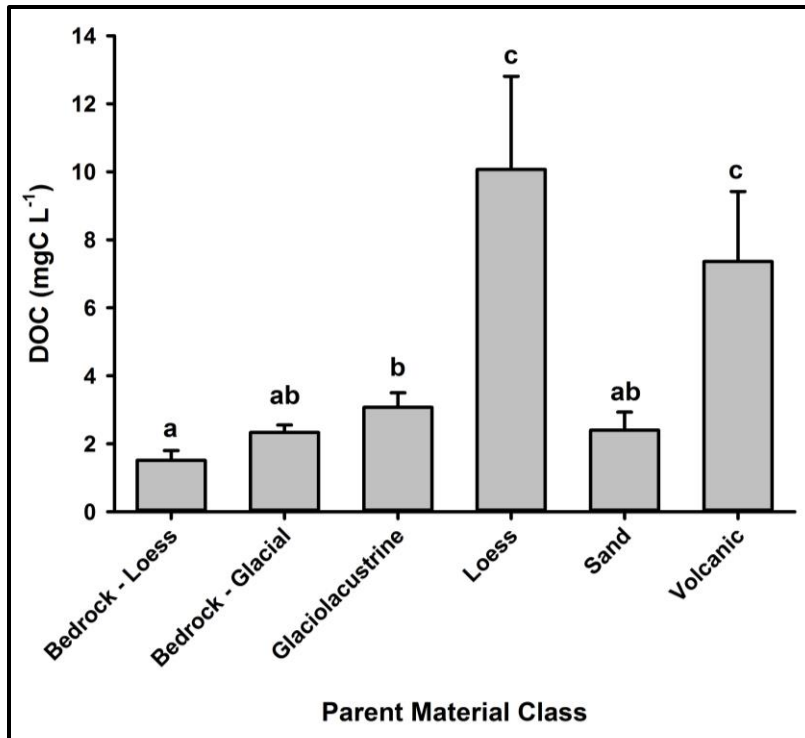


Figure 6. Mean DOC concentration in ARCN rivers draining watersheds dominated by different parent material classes (O'Donnell et al. 2016). Error bars represent one standard error, and letters denote statistical differences among means based on Tukey's post-hoc test.

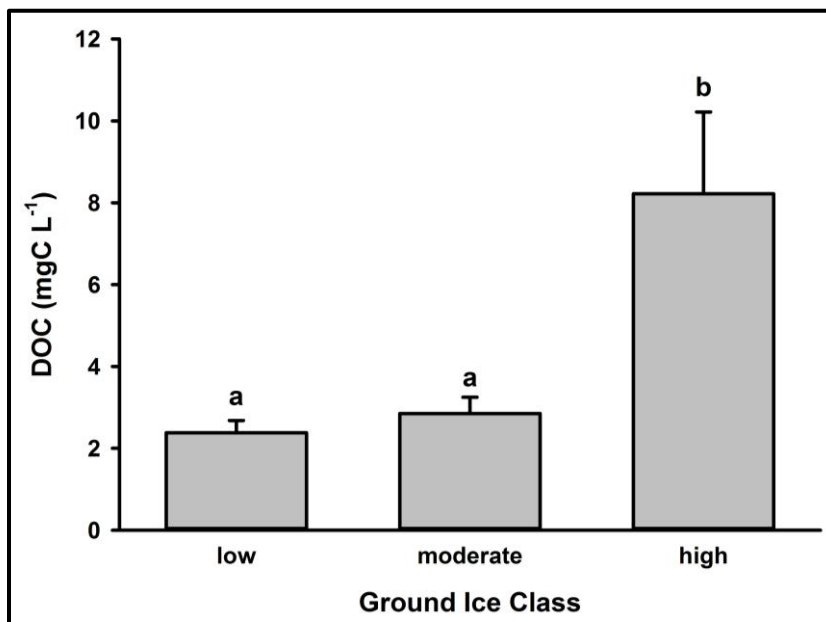


Figure 7. Mean DOC concentration in ARCN rivers draining watersheds dominated by different ground ice classes (O'Donnell et al. 2016). Error bars represent one standard error, and letters denote statistical differences among means based on Tukey's post-hoc test.

3.1.3 Dissolved Inorganic Carbon and Alkalinity

Dissolved inorganic carbon (DIC) is an important component of stream biogeochemical processes (Finlay 2003). In most streams, DIC is primarily derived from terrestrial ecosystems, through the hydrologic delivery of either carbon dioxide (CO_2) from soil respiration or bicarbonate (HCO_3^-) from weathering processes. *In situ* mineralization of DOM in surface waters can also contribute to the production of DIC. In the Arctic, DIC flux in rivers typically increases with the areal extent of carbonate rock and glaciers, and decreases with permafrost extent (Tank et al. 2012). Alkalinity is a measurement that represents the capacity of a water sample to neutralize a strong acid. Recent evidence from the Mackenzie River in western Canada indicates that the flux of alkalinity has increased considerably over the past four decades (Tank et al. 2016).

3.1.4 Nitrogen and Phosphorus (N and P)

N and P are essential nutrients that can govern rates of primary production and microbial-process rates in terrestrial and aquatic ecosystems (Elser et al. 1990; Vitousek and Howarth 1991; Heimann and Reichstein 2008). N occurs in various forms in stream ecosystems, including particulate N, dissolved organic N (DON, e.g., amino acids, proteins, etc.), and dissolved inorganic N (DIN: nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+)). N-containing compounds can cycle between these various forms through microbially mediated reactions, which are typically controlled by reduction-oxidation (redox) state and availability (Hedin et al. 1998). N can also be assimilated by aquatic vegetation, including benthic algae, moss, phytoplankton, and macrophytes. While P typically limits primary productivity in aquatic systems, increased availability of inorganic N can directly limit or co-limit primary production in some systems (Grimm and Fisher 1986). Some microbial processes, such as nitrification (conversion of NH_4^+ to NO_3^-) and denitrification (conversion of NO_3^- to nitrous oxide (N_2O) and dinitrogen gas (N_2)) can result in the loss of N from the system to the atmosphere. N_2O is a greenhouse gas, and emission of N_2O from aquatic ecosystems can function as a positive feedback to the climate system (Beaulieu et al. 2011).

There are three primary sources of P to stream ecosystems. Erosion and sedimentation through changes in watershed land use or disturbance can load P into aquatic systems. In soils, most P is found in particulate forms where organic or inorganic P complexes with mineral particles, such as iron-, aluminum-, or manganese-hydroxides (Schlesinger 1997). Decomposition of soil organic matter by microbes can also release P, both as particulate organic P and mineralized forms (e.g., orthophosphate, PO_4^{3-}). Weathering of parent materials, such as limestone or volcanic deposits, can also contribute P to stream ecosystems. P cycling in streams is controlled by both abiotic processes (e.g., sorption-desorption reactions between surface water and sediments) and biological processes (decomposition of organic matter, assimilation and immobilization in microbial biomass; Hendricks and White 2000).

In most arctic streams, P is the primary limiting nutrient governing primary production (Peterson et al. 1985). For example, long-term P fertilization of the Kuparuk River near the Toolik Field Station in northern Alaska has altered stream ecosystem function, leading to enhanced moss and algal productivity, invertebrate production, and fish production (Slavik et al. 2004). In ARCN streams and rivers, N and P concentrations are very low, and in many cases below detection limits (O'Donnell et

al. 2015b). However, given that permafrost soils store large amounts of N and P (Harden et al. 2012, Ewing et al. 2015), warming and disturbance will likely increase both N and P inputs to streams from soils (e.g., Frey et al. 2007a, Bowden et al. 2008), driving bottom-up effects on food web dynamics.

3.1.4 Major Cations and Anions

Measuring the concentration of major cations and anions in stream water can provide useful information for interpreting watershed hydrology, weathering processes, and cycling of biologically important solutes such as C, N, and P. Base cations include four solutes: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+). Major anions include chloride (Cl^-), sulfate (SO_4^{2-}), and carbonate (HCO_3^-). The concentrations of base cations and anions in stream water typically reflect watershed lithology and weathering reactions of parent materials (e.g., Frey et al. 2007b). The concentration of base cations in Alaskan streams varies with permafrost extent (Maclean et al. 1999) and variation in the source of groundwater contributing to stream flow (O'Donnell et al. 2010). Base cations and some anions (e.g., Cl^-) typically behave conservatively, and can be used as natural tracers of hydrologic and physical processes when compared to solutes that are influenced by biological processes (Jones et al. 2005, O'Donnell and Jones 2006, Kane et al. 2008). Recent work by Toohey et al. (2016) showed a long-term (1982 to 2014) increase in the flux of Ca^{2+} , Mg^{2+} , and Na^+ in the Yukon River (Alaska), likely reflecting changes in watershed hydrology associated with permafrost thaw.

3.1.5 Benthic Algae and Chlorophyll *a*

Aquatic biota are sensitive to changing physical and chemical drivers, with documented impacts on microbial processes (Mann et al. 2015; Spencer et al. 2015), biodiversity (Strayer and Dudgeon 2010), aquatic vegetation production (e.g., Bowden et al. 1992), invertebrates (e.g., Hershey et al. 1988), and fish (e.g., Deegan et al. 1992, Slavik et al. 2004). For the ARCN stream vital sign, we will monitor benthic algal biomass and composition, and also sestonic (i.e. water column) chlorophyll *a* concentrations. Aquatic algae and moss are primary producers, and represent the lowest trophic level of aquatic food webs (Wetzel 2001). Primary producers are sensitive to bottom-up processes (e.g., nutrient inputs) and in turn, have the capacity to influence higher productivity at higher trophic levels (i.e. invertebrates, fish). Thus, detecting change at the lowest trophic level will likely function as an early warning signal for other bottom-up changes that may cascade through aquatic food webs.

3.1.6 Benthic Macroinvertebrate Communities

Benthic macroinvertebrates are a diverse and important component of stream ecosystems. They are sensitive to both bottom-up processes (e.g., changes in primary production) and top-down processes (e.g., predation by fish). Macroinvertebrate species richness and abundance can often serve as an indicator of stream ecosystem health and the state of water quality.

3.2 Sampling Design

3.2.1 Site Selection

We have identified 22 streams and rivers in ARCN park units for intensive monitoring based on the following criteria:

Wild and Scenic Designation: We will monitor all seven rivers that have been designated as National Wild and Scenic Rivers (Table 2) in ARCN, which are all pristine with respect to water quality and will provide a good baseline against future changes.

Parent Material and Ground Ice Distribution: O'Donnell et al. (2016) documented the importance of parent material and ground ice underlying watersheds as a control on stream and river chemistry in ARCN. Other studies in ARCN parks indicate that lithology and parent material may also influence stream biota (e.g., Flinn et al. 2009). Based on the watershed classification scheme developed by O'Donnell et al. (2016), we selected three watersheds from each parent-material class to monitor for the Stream Communities and Ecosystems vital sign (Table 2). These watersheds also represent a gradient in ground ice content (see Figure 1).

Table 2. Monitoring sites across ARCN park units that vary with parent material type.

Material Type	Site Name	Park	Watershed Size (ha)	Latitude (°N)	Longitude (°W)
Bedrock	Asik Creek	NOAT	9	67.47499	-162.23380
	Agashashok River	NOAT	753	67.47396	-162.22501
	Situkuyok River	CAKR	183	67.11598	-163.30933
Glaciolacustrine	Cutler River	NOAT	2764	67.84507	-158.31574
	Imelyak River	NOAT	1175	67.75084	-158.11521
	Makpik River	NOAT	747	68.06024	-158.64146
Loess	Nugnugaluktuk River	BELA	585	66.19823	-164.24932
	Nigeruk Creek	KOVA	79	67.18271	-159.30174
	Pish River	BELA	365	66.12493	-164.00930
Sand	Ahnewetut Creek	KOVA	110	67.16714	-158.78334
	Kaliguricheark River	KOVA	428	67.19281	-159.27368
	Kavet Creek	KOVA	90	67.12818	-159.03391
Volcanic	Fairhaven Ditch	BELA	53	65.72146	-163.08076
	Killuk River	BELA	280	66.56224	-164.41152
	Kugruk River	BELA	123	65.56703	-162.92764
National Wild & Scenic Rivers	Alatna River	GAAR	7948	66.61375	-152.62088
	John River	GAAR	5341	67.15272	-151.83421
	Kobuk River Headwaters	GAAR	257	67.23957	-154.06416
	Noatak River	GAAR/NOAT	-	67.92345	-162.29388

Table 2 (continued). Monitoring sites across ARCN park units that vary with parent material type.

Material Type	Site Name	Park	Watershed Size (ha)	Latitude (°N)	Longitude (°W)
National Wild & Scenic Rivers (continued)	N. Fork Koyukuk River	GAAR	3894	67.30995	-150.70750
	Tinayguk River	GAAR	968	67.58109	-151.06390
	Salmon River	KOVA	1743	67.15444	-159.45956

Size: Watershed size and stream order are important controls on stream ecosystem function (Alexander et al. 2000, Hotchkiss et al. 2015). The relative importance and influence of terrestrial processes versus in-stream processes shifts longitudinally from headwater streams to high-order rivers (Vannote et al. 1980). To account for the effect of size, I selected stream and rivers across a large gradient of watershed sizes, ranging from 9 ha (Asik Creek, a headwater stream) to 7,948 ha (Alatana River).

Access: Nearly all rivers in the ARCN park units are not accessible by road, and must be accessed via fixed-wing aircraft, helicopter, or by foot. For study sites that are going to be intensively monitored, it is critical that NPS scientists be able to access sites on a regular basis. Factors that include access are cost (e.g., flight time), mode of transportation, and typical weather conditions. Most of the study sites selected can be regularly accessed from one or more of the primary bases of operation (Bettles, Dahl Creek, Kotzebue, Nome).

3.2.2 Sample Timing, Frequency, and Replication

The timing of water-sample collection is important, as stream chemistry varies seasonally across the hydrograph. Stream chemistry during spring snowmelt (May-June) is typically characterized by high DOC concentrations and low dissolved mineral concentrations (O'Donnell et al. 2010). Stream chemistry during the summer-autumn period (July-September) varies considerable across watersheds, and can be influence by physical (e.g., storms, permafrost state) and biological processes (e.g., summer primary productivity in terrestrial and aquatic systems). Winter flow (November-March) reflects groundwater contributions to discharge, and typically has a unique chemical signature when compared to the spring or summer autumn period (O'Donnell et al. 2012).

We will collect water samples for all streams between late-July and August. The rationale behind this sampling approach is four-fold. First, this period coincides with the period of maximum annual thaw depth (i.e. active layer thickness; Romanovsky and Osterkamp 1997). Recent evidence indicates that the chemical composition of rivers is sensitive to long-term increases in active layer thickness associated with climate warming and disturbance from wildfire (O'Donnell et al. 2014). Second, this period also following the period of maximum primary production in arctic terrestrial (Swanson 2010) and aquatic ecosystems. Primary productivity rates can influence stream chemistry through increased retention of nutrients and increasing release of root exudates, among other processes. Spatial variability in productivity will likely be reflected in chemistry across monitoring watersheds. Third, the summer-autumn period increases our chances of detecting changes across space and time. While

the timing of spring snowmelt might change, the chemical composition of stream water during the spring flush is not likely to change across space and time. The summer-autumn period is more likely to reflect basin-scale changes (e.g., permafrost thaw, arctic greening, wildfire and erosion effects). And fourth, sampling during the summer-autumn period is easy to plan for, whereas planning for and predicting the timing of snowmelt is challenging.

Water samples will be collected from intensive monitoring streams ($n = 22$) every year during this period. Additional field measurements and water samples will be collected in early June at a subset of sites (to be determined) where water-quality parameters will be continuously monitored. Every fourth year, fieldwork will be taken off to work on data analysis and publication. Quality assurance and quality control (QA/QC) measures will be taken following *SOP: Quality and Assurance and Quality Control*.

3.3 Field Methods

3.3.1 Field Season Preparations

Field season preparations involve three distinct components: (1) compliance, (2) logistics, and (3) prepping sampling gear. The compliance process is designed to insure that proposed activities on parklands are compliant with the National Historic Preservation Act (NHPA) of 1966 and the National Environmental Policy Act (NEPA) of 1969. The compliance process considers impacts on the environment, including air, water, sound, plant, animal, socioeconomic, human health, and cultural resources, and seeks ways to minimize or mitigate impacts.

To conduct fieldwork in ARCN parks, proposals must be submitted through the Planning, Environment, and Public Comment (PEPC) online system. The project manager is responsible for entering project details into PEPC, and is typically due by the end of March each year. An Environmental Compliance Standard Operating Procedure has been developed for both Western Arctic Parklands (WEAR) and GAAR, and these documents provide details about the nature of information to include in project proposals (<https://www.nps.gov/gaar/learn/nature/research-permitting.htm>).

Field logistics are also a critical component of field season preparations. To conduct fieldwork, there are six different documents related to logistics to consider:

1. **Flight Request Form:** After deciding on which sites to visit and when, the next step is to determine to the most appropriate way to access study sites. For the Stream vital sign, there are 21 sites that will be visited on an annual basis. Only three of these sites can be access via fixed-wing aircraft. There is an undeveloped landing strip on a gravel bar along the Agashashok River study site, allowing for wheel-plane access. The Kobuk River near Kiana and the Noatak River at Kelly River study sites can generally be accessed via floatplane during the summer-autumn period. The remaining 18 study sites are only accessible via helicopter. Flight requests should be submitted Northern Hub Aviation Manager in the spring to secure aircraft for sampling in August and September.

2. **Project Aviation Safety Plan (PASP):** A PASP is required for all vendor helicopter flights and for some fleet flights. PASPs must be approved by the project manager's immediate supervisor, the aviation manager, and the park superintendent.
3. **Lodging Request:** Federal housing is available to projects based out of Bettles, Kotzebue, and Nome. Lodging requests and arrangements should be made with the host park well in advance of the start of fieldwork.
4. **Travel Authorization:** A travel authorization must be submitted and approved through the Concur travel website (<https://cge.concursolutions.com>)..
5. **Flight Plan:** A flight plan needs to be submitted prior to flying to the Alaska Region Communication Center (ARCC).

Field season preparations also involve getting sampling equipment ready, which includes prepping (1) water sample bottles, (2) filtering equipment, and (3) a multi-parameter meter to conduct *in situ* measurements. A range of different water bottle types and sizes are required for sampling the full suite of stream chemistry. All filtering is conducted *in situ* using a 0.45-µm high-capacity capsule filter connected to a Geopump Series II Peristaltic Pump (Geotech Environmental Equipment, Inc., Denver, CO). The capsule filter is attached to silicone tubing prior to collecting a sample. More detail regarding all field-season preparations can be found in *SOP: Instrument Calibration for Water Quality Monitoring* and *SOP: Chemical Characterization of Stream Water*.

3.3.2 Field Measurements

Detailed methods for field measurements are described in *SOP: Field measurements*. We will measure basic water quality parameters (water temperature, pH, specific conductivity, DO) during each site visit. Measurements will be conducted simply by placing a calibrated multi-parameter probe in a well-mixed riffle, run, or channel segment. Prior to recording field measurements, it is important that each parameter has stabilized, based on criteria provided by the USGS (Wilde 2008). Once the sensors have stabilized, we will record the median of the final three measurements on the field sheet.

To measure the biomass and community composition of benthic algae, we will use the BenthosTorch (bbe Moldaenke GmbH, Germany; <http://www.bbe-moldaenke.de/en/products/chlorophyll/details/benthostorch.html>). The BenthosTorch measures fluorescence of algal pigments, and provides biomass estimates for cyanobacteria, green algae, and diatoms (Kahlert and McKie 2014). For each study site, BenthosTorch measurements should be collected randomly at three replicate locations within the stream reach. Samples for the measurement of sestonic (i.e. in the water column) chlorophyll-*a* will be collected in the field using standard protocols (Hambrook Berkman et al. 2007).

We will describe characteristics of valley segments, reaches, and channel segments during each site visit. Reach length will be determined by multiplying the mean wetted channel width by 20 (Fitzpatrick et al. 1998). For a given reach length, we will estimate stream depth (wadeable vs. nonwadeable) and extent of geomorphic channel segments (pool, riffle, run). Additional habitat characteristics of interest include bank properties (eroding vs. stable), coarse woody debris (for

branches with diameter > 3 cm), stream substrate, and dominant riparian and upland vegetation. Presence of salmon carcasses will be documented by taking pictures and recording GPS coordinates.

3.3.3 Water Sample Collection and Processing

We will collect water samples in a well-mixed location with at least three river widths of distance below any confluences. All samples will be filtered *in situ* using a 0.45- μ m high-capacity capsule filter connected to a Geopump Series II Peristaltic Pump (Geotech Environmental Equipment, Inc., Denver, CO). Prior to collecting a water sample with capsule filters, we will pre-rinse filters by running approximately 2 L of sample water through each filter. For DOC, cations, anions, and nutrients, filtered water samples will be stored in 500-mL polycarbonate bottles. DIC samples will be collected in 60-mL syringes with luer-lock fittings and a two-way stopcock. Unfiltered water samples will be collected for analysis of total N and P in 250-mL polycarbonate bottles. Samples will be stored on ice in a cooler, and then frozen in a freezer until shipping for analyses.

Upon returning from the field, all samples (with the exception DOC which is refrigerated) will be frozen until shipped to a laboratory for processing. Carbon, nutrient, cation and anion samples will be shipped to the laboratory for analysis.

Unfiltered water samples will be analyzed for total N (TN) and total P (TP) by persulfate digestion (Ameel et al. 1993) followed by colorimetric analysis on a Technicon Auto-Analyzer II (Seal Analytical, Mequon, Wisconsin). Total organic carbon (TOC) will be analyzed by oxidative combustion and infrared analysis on a Shimadzu TOC_VCSH (Shimadzu Corporation, Kyoto, Japan).

Filtered samples will be analyzed for the following constituents. Dissolved organic carbon (DOC) will be analyzed by oxidative combustion and infrared analysis on a Shimadzu TOC_VCSH. Dissolved inorganic carbon (DIC) will be measured by acidification, sparging, and infrared analysis, also on a Shimadzu TOC-VCSH. Alkalinity will be determined by titrating to a pH of 4.5 on a ManTech PC-Titrate Auto Titrator System. Total dissolved N (TDN) and total dissolved P (TDP) will be determined using the persulfate digestion method on filtered water samples. Nitrate + nitrite ($\text{NO}_3^- + \text{NO}_2^-$) will be determined following the cadmium reduction method, and unionized ammonia (NH_3) will be determined following the phenate method. Orthophosphate, or soluble reactive P (SRP), is determined using the ascorbic acid method. Calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and total iron (Fe) concentrations are measured using flame atomic absorbance spectroscopy on a Shimadzu AA-7000. Chloride (Cl^-), and sulfate (SO_4^{2-}) are analyzed on a Dionex 1500 ion chromatography system.

3.3.4 Continuous Monitoring of Water Quality Parameters

In wadeable, headwater streams, we will continuously monitor basic water quality parameters (temperature, SpC, pH, and DO) following standard methods developed by the U.S. Geological Survey (Wagner et al. 2006). Sensors will be deployed following the spring snowmelt period (late May to mid-June) and retrieved prior to freeze-up in September. Sensors will be programmed to log parameters hourly. During site visits, these same four parameters will be measured with portable multi-parameter probes to facilitate QA/QC of *in situ* sensors.

3.3.5 End-of-season Procedures

All instruments and field gear should be cleaned and appropriately stored following fieldwork. Multi-parameter probes should be stored according to manufacturer recommendations. An inventory should be conducted to track the number and location of sample bottles, filters, calibration standards, and other equipment. During sample submission to Oregon State Universities Cooperative Chemical Analytical Laboratory (CCAL), arrangements can be made for sample bottles to be acid washed and returned.

3.3.6 Safety in the Field

Safety is of utmost importance to conducting monitoring work in ARCEN parks, particularly given the remote location of field sites and the use of helicopters and small fixed-wing aircraft. Safety procedures for the Stream Communities and Ecosystems Vital Sign have largely been adapted from the Shallow Lake Vital Sign for the Arctic and Central Alaskan Network (Larsen et al. 2011). Briefly, here is a summary of safety considerations for the Stream Communities and Ecosystem Vital Sign (see Larsen et al. 2011 for more details).

Personnel are required to take a variety of trainings to insure safety in the field. Each year, staff must take bear safety and shotgun training. Wilderness CPR/First Aid is highly recommended for personnel working in the field. A variety of aircraft training is required (or recommended in some cases), including Aircraft Safety (A-100), Helicopter Crewmember (S-271), and Helicopter Manager (S-372).

Prior to heading to the field, the project manager will submit a PASP to their supervisor and Northern Hub Aviation Manager. The PASP includes extensive information regarding the field work, including location of the study sites, emergency contacts, and risk assessment protocols and risk mitigation.

Automated flight following (AFF) is conducted through the ARCC for all aircraft with NPS personnel on board. The project manager is required to call ARCC prior to all take-offs, after landings, and every hour during longer flights. These calls are primarily to insure that the aircraft is positive for AFF and to keep ARCC staff informed of activities in the backcountry.

Field staff should be aware of wildlife while in the backcountry, particularly of bears. To reduce encounters with bears, it is important to appropriately store food, to work in groups of at least two, and to make noise whenever possible. In the case of a bear encounter, staff should always have either a shotgun or bear spray on their person.

3.4 Analyses and Reporting

Stream chemical parameters will be analyzed to understand spatial and temporal trends in water quality. Recent work by O'Donnell et al. (2016) documents the importance of how spatial variation in watershed characteristics governs DOM composition in arctic streams and rivers. It is likely that these landscape controls may also influence other chemical constituents (e.g., NO_3^- , as reported by Harms et al. 2016). The Stream Communities and Ecosystems monitoring protocol uses a stratified sampling design, where intensive monitoring sites are sampled across different watershed types

(Table 2). Identifying true replicates for watershed studies is challenging (e.g., Likens et al. 1977), due to high spatial heterogeneity. Further, our study sites span a broad and remote region of arctic Alaska, where access is expensive and sometimes limited by weather. Spatial variability in stream chemistry should also be analyzed by stream order and watershed size, which varies considerably across intensive monitoring sites. Analysis of variance (ANOVA) techniques should be used for detecting significant effects of watershed characteristics on stream chemistry, following methods of O'Donnell et al. (2016).

Temporal trends in stream chemistry should be analyzed (a) by individual streams and (b) by watershed type. To evaluate statistical significance of temporal trends, the Mann-Kendall test should be conducted on time series of all chemical constituents (e.g., Tank et al. 2016; Toohey et al. 2016). All data should be evaluated for serial correlation using the pre-whitening technique developed by Yue et al. (2002).

A series of supplemental statistical analyses should be conducted to examine other possible controls on stream and river chemistry. Possible explanatory variables could include air temperature, precipitation, normalized difference vegetation index (NDVI), and wildfire parameters (wildfire extent, severity).

3.5 Operational Requirements

Conducting fieldwork and characterizing stream chemistry requires someone with good organizational skills, experience in backcountry settings, a background in aquatic ecology and chemistry, and experience with statistics and statistical software (e.g., R, <https://www.r-project.org>). On an annual basis, the Stream Communities and Ecosystems vital sign should take approximately 30% of the project manager's time, or 312 hours per year. The project manager is also responsible for the Lake Communities and Ecosystems vital sign (O'Donnell and Miller, in review), which requires an additional 30% of the project manager's time. As of 2017, the project manager typically receives \$65,000 from the NPS Water Resource Division for each fiscal year, which is divided equally between both the Stream and Lake Communities and Ecosystems vital sign.

4. Data Management

4.1 Data Management Life Cycle

Data management for the Stream Communities and Ecosystems vital sign will proceed through an ongoing life cycle (Figure 8; NPS 2008a). Major stages of the life cycle include data collection, data entry and import, quality control, data product documentation and archival, seasonal closeout, dataset certification and publication, and data analysis and reporting (NPS 2008b).

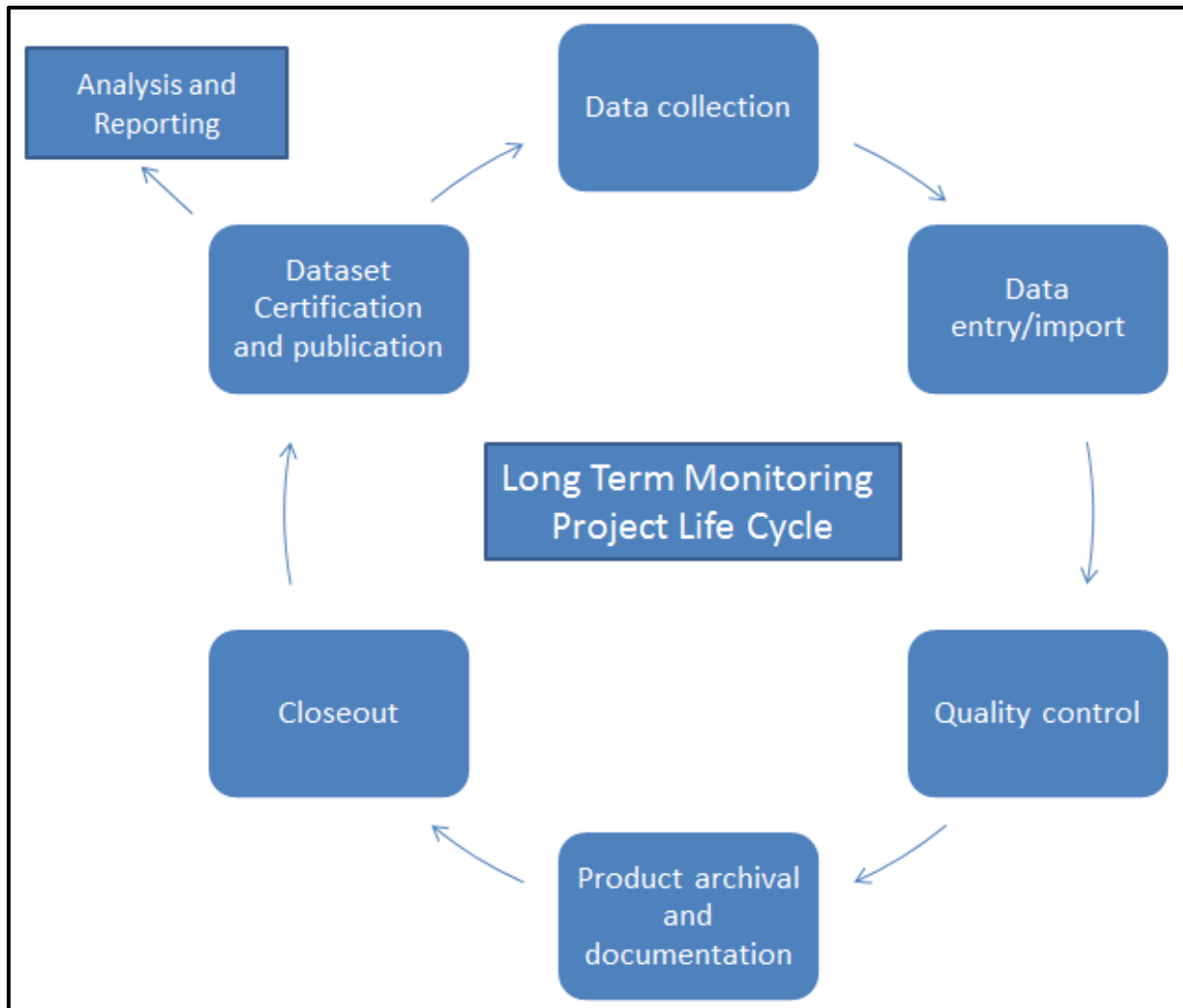


Figure 8. Long-term monitoring project data management life cycle.

An overview of each component of the data management life cycle follows with specific procedures given in SOPs.

4.2 NPS Standards

4.2.1 Data Quality

Director's Order #11A section 5.8: Data Integrity Standards outlines the NPS policy for accuracy, completeness and review:

All information owners will maintain all official NPS records and data in a manner which meets the highest data integrity standards, including timeliness, accuracy and completeness (also see DO #19). Each information owner will take whatever steps necessary to ensure that NPS systems have sufficient data quality reviews and audits from both an internal system perspective, as well as externally thorough control reviews.

Director's Order #11B mandates a high level of information quality from the service's scientific programs:

The National Park Service will ensure that information it releases will be developed from reliable data sources and will otherwise ensure information quality at each stage of information development. The NPS's methods for producing quality information will be made transparent, to the maximum extent practicable, through accurate documentation, use of appropriate internal and external review procedures, consultation with experts and users, and verification of the quality of the information disseminated to the public. The NPS will also keep users informed about corrections and revisions.

Information will be developed only from reliable data sources based on accepted practices and policies utilizing accepted methods for information collection and verification. It will be reproducible to the extent possible. Influential information will be produced with a high degree of transparency about data and methods.

Adherence to the data management procedures in this monitoring protocol will ensure compliance with DO#11B.

4.2.2 Freedom of Information Act

The I&M Network will comply with all FOIA restrictions regarding the release of data and information as instructed in NPS Director's Order #66B.

4.2.3 Records Management

Direction for managing physical and digital materials is provided in NPS Director's Order 11D.

The NPS has a strong business need for excellent records management, in that the Service's mission is to care for natural and cultural resources so that they are left "unimpaired" for future generations. This requirement for managing resources in perpetuity sets a high standard for record keeping. No resources can be managed well in the future without complete records of how they were managed in the past. Because the NPS manages some of America's most significant cultural and natural resources, the public also has a significant interest in our records. Section 1.9.2 of NPS Management Policies 2006 (NPS, 2006) states that the future of the Service depends on the availability, management, dissemination, and

preservation of information, and directs the agency to implement professional quality programs to manage information resources.

4.3 Core Functional Model

Data generated by the Stream Communities and Ecosystems vital sign are managed according to the Core Functional Model described in Figure 9.

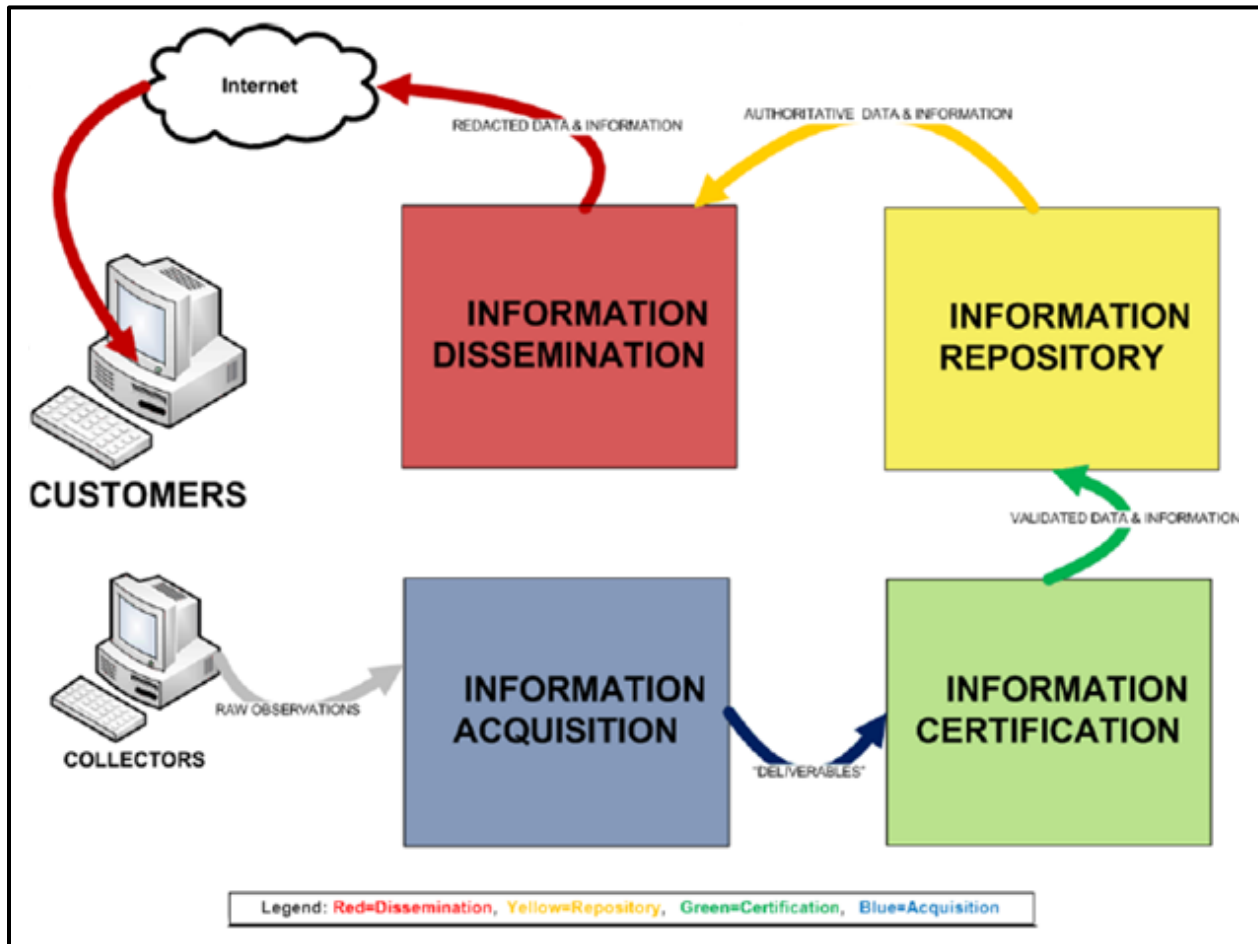


Figure 9. The ARC Core Functional Model overview.

Dissemination services (red, Figure 9) provide all deliverables to all customers using internet web sites and web services through the NPS Integrated Resource Management Applications (IRMA) Data Store. Repositories (yellow) store the certified inventory and monitoring products called for in the protocols. Certification processes (green) assure repositories have the highest quality data and that sensitive items are restricted to authorized users. Data acquisition processes (blue) led by park staff and cooperators include a wide array of tasks, ranging from collecting raw data to composing reports on long-term trends.

4.4 Data Sensitivity Statement

The ARCN Stream Communities and Ecosystems monitoring protocol does not define the collection of sensitive data and requires no special handling procedures.

Network staff will ensure that all references to protected information are removed or obscured in any reports, publications, maps, or other public forum. Following the standard for Freedom of Information Act (FOIA) requests, the Network will segregate the non-releasable information and where practical will not withhold associated releasable information. Metadata for that dataset and the IRMA citation will also be updated to reflect that the associated data are sensitive. Network staff will ensure that all references to protected information are removed or obscured in any reports, publications, maps, or other public forum.

The project leader is responsible for maintaining the security of data released to any NPS dataset catalog and ensuring confidentiality agreements are in place before sharing data with any non-NPS entity.

4.5 Roles and Responsibilities

The project leader is responsible for the timely completion of all data management tasks outlined in this protocol. The Network data manager maintains the hardware and software platform in support of the vital sign's data stream, provides for data security, accessibility and longevity and gives technological support and guidance in all aspects of data management activities.

4.6 Quality Assurance

The Stream Communities and Ecosystems vital sign plans for quality assurance by proactively deploying a system of administrative procedures and technological safeguards including:

- Standard operating procedures designed to minimize the introduction of errors during data collection and processing.
- Data quality objectives describing how quality assurance (QA) and quality control (QC) will be implemented
- Field crew training.
- Standard database security and integrity functions and data integrity constraints (Frakes et al., 2015) to enforce compliance with the vital sign's logical data model.
- Application level data entry checks and business rule enforcement.
- Periodic automated data quality audits and reports.

4.7 Data Collection

4.7.1 Deliverables Schedule

The Stream Communities and Ecosystems monitoring program creates and maintains specific data deliverables. Each deliverable is disseminated directly from the IRMA Data Store, the single

authoritative source for Network products. In the event that a data product ever diverges from that in the IRMA Data Store the latter version should be considered authoritative.

The Stream Communities and Ecosystems monitoring program will create and maintain the data products shown in Table 3.

Table 3. Stream Communities and Ecosystems monitoring data deliverables schedule.

Identifier	Deliverable	Format	Schedule	Description
S01	Discharge	.csv	Every 5 years	Discharge trends derived from USGS NWIS for rivers draining ARCN park units
S02	Field Sheets	.pdf	Every year	Scanned copies of field sheets that include site descriptions, field observations
S03	Site photos	.jpg	Every year	Photographs of study sites collected during field work
S04	Chemistry – Discrete Sampling	.csv	Every year	Chemistry data following QA/QC generated by field measurements and grab samples
S05	Chemistry – Continuous In Situ Sampling	.csv	Every year	Chemistry data following QA/QC generated by <i>in situ</i> continuous monitoring probes
S06	Algae	.csv	Every year	Algal composition and abundance data generated from BenthosTorch measurements

4.7.2 Deliverable S01: Discharge.csv

Discharge.csv is a dataset derived from the U.S. Geological Survey's (USGS) National Water Information System (NWIS; <https://waterdata.usgs.gov/nwis>). Every five years, it is the Principle Investigator's responsibility to extract discharge data from NWIS for streams draining or adjacent to ARCN parklands (Atigun River, Dahl Creek, Kobuk River, Slate Creek, and Wulik River). Following *SOP: Discharge Analysis*, the PI will derive and report the following parameters in Discharge.csv: (1) total annual discharge, (2) timing of peak discharge during spring snowmelt, (3) winter flow (4) discharge trends during open-water period, and (5) timing of river freeze-up during autumn. Details regarding NWIS data processing can be found in *SOP: Discharge Analysis*

4.7.3 Deliverable S02: Field Sheets

Deliverable S02 is the scanned copy (.pdf) of all field sheets filled out during monitoring site visits and samplings. See example field sheet and other details in *SOP: Field Measurements*.

4.7.4 Deliverable S03: Site Photos

Deliverable S03 includes all site photos generated during monitoring visits and sampling. More details in *SOP: Field Measurements*.

4.7.5 Deliverable S04: Chemistry – Discrete Sampling

Deliverable S04 is a dataset generated from discrete *in situ* measurements of water quality parameters (temperature, pH, specific conductivity, dissolved oxygen) and chemical analysis of water samples collected during site visits. The PI is responsible for collecting samples/measurements, making arrangements for sample processing, and updating database on an annual basis. See more details for in *SOP: Chemical Characterization of Stream and River Water*.

4.7.6 Deliverable S05: Chemistry – Continuous In Situ Sampling

Deliverable S05 is a dataset generated from continuous *in situ* measurements of water quality parameters (temperature, pH, specific conductivity, dissolved oxygen). The PI is responsible for deploying and retrieving probes, processing data, and updating database on an annual basis. See more details in *SOP: Continuous Monitoring of Stream Water Quality*.

4.7.7 Deliverable S06: Algae

Deliverable S06 is a dataset generated from *in situ* measurements of benthic algae using the BenthosTorch (bbe Moldaenke GmbH, Germany; <http://www.bbe-moldaenke.de/en/products/chlorophyll/details/benthostorch.html>). The PI is responsible for conducting field measurements, processing data, and updating database on an annual basis. See more details in *SOP: Field Measurements*.

4.8 Data Entry/Import

Discharge data will be extracted every five years from the USGS NWIS webserver. Discharge analyses will generate multiple time-series data sets (see *SOP: Discharge Analysis*) that will be entered in a spreadsheet and imported to the database as a .csv file. Upon returning from the field, data collected on field sheets (*SOP: Field Measurements*) will be manually entered into a Microsoft Excel spreadsheet, checked for quality control (QC), and imported into NPStoret (see *SOP: Data Management*). Chemistry data generated from discrete samplings are sent electronically as data report to the PI from the analytical laboratory (e.g., CCAL at Oregon State University). Data are then extracted from the reports, checked for QC, and uploaded and processed in NPStoret (see *SOP: Chemical Characterization of Stream and River Water* and *SOP: Data Management*). Water quality data generated from continuous *in situ* monitoring are downloaded from multi-parameter probes upon returning from the field. Time-series data generated from these sensors are evaluated for QC (possibly using Aquarius software), and uploaded to the database (see *SOP: Continuous Monitoring of Stream Water Quality* and *SOP: Data Management*). Benthic algae concentrations and composition will be downloaded from the BenthosTorch upon returning from the field, checked for QC, and uploaded to the database.

4.9 Quality Control

Ensuring high data quality is a high priority for the Stream Communities and Ecosystems Vital Sign. QC procedures focus on verifying data as well as identifying and correcting errors in final data products. Quality control safeguards include:

- Collection of QC samples (e.g., field blanks, field replicates) to measure sources of bias and variability that affect water samples.

- Correction of continuous *in situ* water quality data using calibration methods and correcting for instrument drift.
- Data verification and spot checking.
- Automated programmatic range, domain or impossible value checking.
- Graphical and statistical approaches to identify outliers.
- Statistical methods to analyze bias and variability in chemical parameters.
- Data quality audits and reporting.
- Dataset certification.

4.10 Product Archival and Documentation

Director's Order #11D states that all records of natural and cultural resources and their management are considered mission-critical records (necessary for fulfillment of the NPS mission) and must be permanently archived. Mission critical deliverables are considered to be archived when they are uploaded to the IRMA Data Store. With few exceptions IRMA is the only authoritative repository for mission critical I&M products.

Data archiving is done in concert with seasonal close out and data certification (*SOP: Quality Assurance and Quality Control* and *SOP: Data Management*). All data are archived in the following ways:

- IRMA Data Store. Formats may include:
 - Raw and processed data files described in this protocol's deliverables schedule.
 - Human readable text file or Microsoft Excel files of all Stream Communities and Ecosystems monitoring databases.
 - Network file server
 - ARCN database backup files

Stream Communities and Ecosystems monitoring program data are maintained on a network file share and SQL Server database located in the Fairbanks Administrative Center (FAC) in Fairbanks, Alaska. The certified database content is backed up to off-site storage and also copied to a database server at the NPS Natural Resource Stewardship and Science Directorate (NRSS) in Denver, Colorado. The NRSS and FAC use enterprise-level business continuity processes to maintain their version of the Stream Communities and Ecosystems database. In the event of catastrophe at one site, the original data may be restored from the other.

4.10.1 IRMA Data Store

The NPS IRMA Data Store is the primary organizational repository and publication platform for information related to the Stream Communities and Ecosystems monitoring program. The Stream Communities and Ecosystems vital sign has a single master IRMA project reference (<https://irma.nps.gov/App/Reference/Profile/2219172> to which all products are related (Figure 10, *SOP: Data Management*).

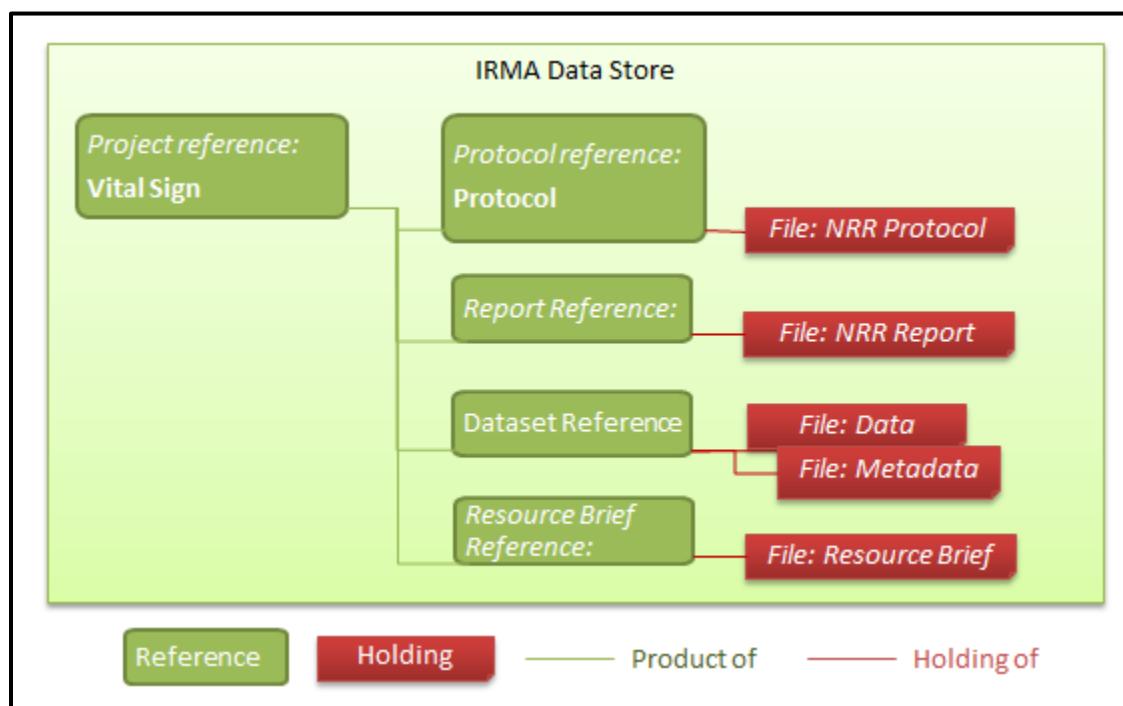


Figure 10. Vital Sign Project reference architecture in the IRMA Data Store.

The public vital sign webpage covering Stream Communities and Ecosystems monitoring will publish the releasable contents of this reference and its related references via web services. It is the joint responsibility of the PI and the data manager to keep the system of related IRMA Data Store references up-to-date.

4.10.2 Reports

Reports are published in the NPS Natural Resource Report publication series (<http://nature.nps.gov/publications/nrpm/index.cfm>) or professional journals. Reports and journal articles reporting analytical results will be published in tandem with the dataset that was used.

Natural Resource Reports are automatically tracked and announced to Network program managers and data managers but journal articles are not. The PI will create Data Store references for journal articles related to monitoring, link them to the vital sign's IRMA Project reference (Figure 10, 11) and notify interested parties of their presence.

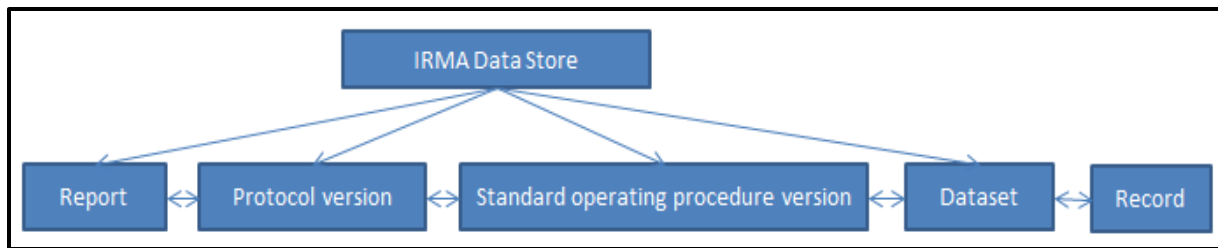


Figure 11. Each informational component informs and is informed by other components. Discovery of one component leads to discovery of all other components in a formalized data management chain of custody.

4.10.3 Data

All reports providing statistical results will also publish the data on which they were based. Metadata will be provided, as well as a link to the certified original dataset (NPS, 2005). Data are made available through IRMA in machine readable formats according to Director's Order #11A and as mandated by the Federal Open Data Initiative (Executive Order No. 13642).

The Stream Communities and Ecosystems vital sign will have a single public dataset reference in the IRMA Data Store to which certified data will be published (Figure 10). This reference will be the only authoritative data source available to the public.

4.10.4 Resource Brief

The I&M resource brief is the primary outreach document for the Stream Communities and Ecosystems monitoring program. The PI will revise any existing resource brief after new findings to reflect current understanding of the resource's trend and implications for park management. Resource briefs are archived in the IRMA Data Store and then linked to the main vital sign Project reference as a product (Figure 10).

4.10.5 Products Publication

Reports, datasets and other monitoring products are published to the IRMA Data Store and linked as products of the vital sign's Project reference (Figure 10). Information from these references automatically cascades to the monitoring Network's website via web services. This framework is the primary method for publishing monitoring products. Authoritative products will only be distributed through the IRMA Data Store.

4.10.6 Metadata

All project datasets, including spatial and non-spatial data, are archived in the IRMA data store with metadata (Figure). The mandate for adequate metadata comes from Director's Order #11A:

All NPS data systems will develop data dictionaries and conform to available NPS organization-wide dictionaries. Geographic Information and Metadata must meet all Federal standards, DOI standards and NPS standards.

Spatial metadata will be in Federal Geographic Data Committee (FGDC 1998) format. Tabular metadata will be developed in Ecological Metadata Language (KNB 2015, Michener et al. 1997) using Morpho (KNB 2015b) or similar tool.

4.10.7 Line of Sight

Line of Sight is the informal name given to the I&M program's philosophy that every datum should be inextricably linked in a traversable way to the standard operating procedure and protocol version that guided its collection. This custodial chain is maintained through metadata columns in the main monitoring database coupled with metadata maintained in each protocol and standard operating procedure's IRMA reference. A data consumer will be reliably able to access a data record and discover the standard operating procedure version that defined its collection and processing.

4.10.8 Dataset Integration with National Databases

STORET (STOrage and RETrieval) is an interagency water quality database developed and supported by the Environmental Protection Agency (EPA) to house local, state, and federal water quality data collected in support of managing the nation's water resources under the Clean Water Act (of 1972). NPS Director's Order 77 indicates that the NPS should archive water quality data in STORET, and the NPS Water Resources Division (WRD) requires that any data collected as part of a funded WRD project be archived in STORET. NPSTORET (also known as Water Quality Database Templates) is the NPS master database designed to facilitate park-level standardized reporting for STORET (Principal Investigator/Data Manager).

4.10.9 Database Design

The Stream Communities and Ecosystems monitoring program will have a single, authoritative database built according to I&M standards (Figures 12 and 13; Frakes et al. 2015).

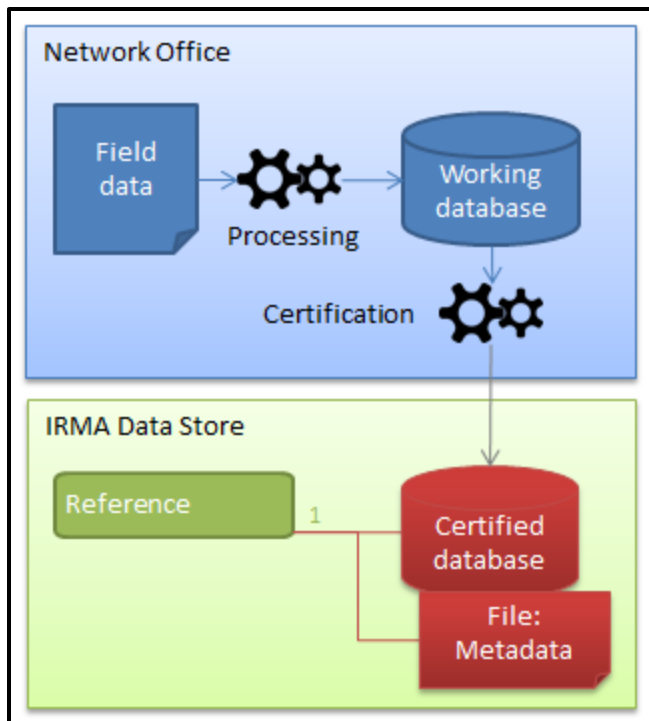


Figure 12. Overview of database architecture and system data flow.

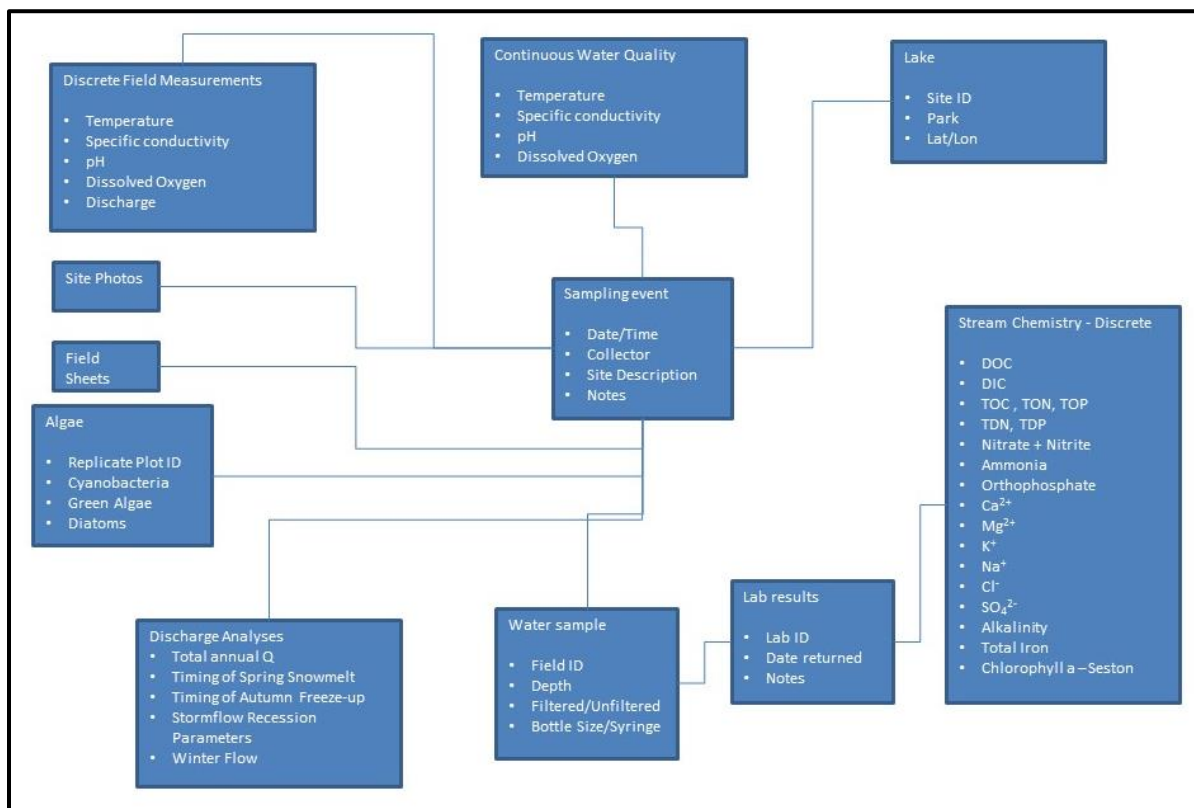


Figure 13. Data model of Stream Communities and Ecosystems database.

4.10.10 Data and Information Security

Digital products produced by the Stream Communities and Ecosystems monitoring program will be stored in the IRMA Data Store, databases on I&M and/or local servers, and the Network file server. Under no circumstances will any mission-critical information reside on individual I&M staff computers whether they are assigned to monitoring personnel by the NPS or not. Project materials will be secured and available on I&M servers at all times. The data manager, in conjunction with IT staff at FAC and with the Network support office in Ft. Collins, CO is responsible for backups, security and longevity of monitoring data.

4.11 Closeout

Closeout is the part of the Stream Communities and Ecosystems monitoring data management life cycle through which seasonal data collection files (deliverables, Table 3) are archived in the IRMA Data Store. Specific closeout procedures are found in *SOP: Data Management*. Closeout happens after a remeasurement cycle when data files have been collected, processed and integrated into the main monitoring database. After field data are integrated with the master monitoring database they are archived as holdings of private IRMA Dataset References. Closeout is complete when the IRMA Dataset's holdings match the deliverables schedule (Figure 14).

Protocol Narrative

Table 1 shows the field data deliverables that will be collected seasonally.

Table 1. Data deliverables schedule

Identifier	Deliverable
DS01	Field database file
DS02	Field data collection forms
DS03	Survey Photos
DS04	Tracklogs
DS05	Waypoints
DS06	NRDS Report

Closeout is complete when the deliverables in the deliverables schedule are available in the IRMA Data Store

REFERENCE: 2173037

IRMA Portal Integrated Resource Management Applications

[Portal](#) > [Home](#) > [IRMA Applications](#) > [Data Store](#) > [Profile](#)

Scientist, A. 2012. Title of remeasurement dataset. Dataset. National Park Service XXXX Inventory and Monitoring Program. Fairbanks, AK. Generic Dataset-2222131.

Reference Status as of 07/31/2015: Active
Visibility: Internal

Holdings

DS01 FieldDatabase.zip (.shp, 134kb)
DS02 Field data collection forms (pdf, 320kb)
DS03 SurveyPhotos-2011.zip (.jpg, Compressed archive, 300Mb)
DS04-05 Tracklogs-Waypoints.zip
DS06 NRDS Report (link)

Figure 14. Data deliverables are defined in the monitoring protocol and archived in IRMA Dataset references after each remeasurement cycle. Closeout is complete when the holdings in the remeasurement Dataset reference match the deliverables in the protocol's data deliverables schedule.

After closeout, all permissions are removed from the seasonal IRMA Dataset reference except for the project leader and data manager. The dataset reference will then be linked to the main Stream Communities and Ecosystems monitoring IRMA Project reference so that it becomes discoverable within the NPS and by the public.

The closeout method described above will ensure that all data objects collected during a remeasurement cycle are accounted for, documented and available for perpetuity should the need arise to re-use or revisit the data.

4.12 Certification

Certification is the phase of the Stream Communities and Ecosystems monitoring data management life cycle where the principal investigator formally confirms that the vital sign's dataset is ready for analysis. Certification also affirms the scientific, administrative and technical integrity of the program. Certification procedures are defined in *SOP: Quality Assurance and Quality Control*. The principal investigator's signature on the data certification form indicates:

- The protocol and standard operating procedures are current. All technical changes are up to date and documented.
- Raw and intermediate data deliverables have been processed via quality control procedures, have been integrated with the vital sign's database or data management system and have been archived and documented appropriately for posterity.
- Each data record is traceable to the protocol version and SOP version that guided its collection.
- All closeout activities have been performed.
- The certified database or data files have been published to the vital sign's public Dataset reference in the IRMA Data Store.
- The vital sign's IRMA Data Store references and cross-links are complete.
- The dataset is of sufficient quality that analyses may be performed on it and the results published.

A data certification form is signed by the principal investigator during certification after the dataset is complete. A copy of the form is then attached to the vital sign's public IRMA Dataset reference.

5. References

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NPS 953/148256, September 2018

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