



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

Natural Resource Report NPS/ARCN/NRR—2018/1708



**ON THIS PAGE**

Photograph of Lake Selby in Gates of the Arctic National Park

Photograph courtesy of the National Park Service (Jon O'Donnell, Arctic Network, National Park Service, Anchorage Alaska)

ON THE COVER

Aerial photograph of the Kurupa Lake in Gates of the Arctic National Park.

Photograph courtesy of the National Park Service (Jon O'Donnell, National Park Service, Fairbanks, Alaska)

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

Natural Resource Report NPS/ARCN/NRR—2018/1708

Jonathan A. O'Donnell¹ and Scott D. Miller²

¹National Park Service
Arctic Inventory and Monitoring Network
240 W. 5th Avenue
Anchorage, AK 99501

²National Park Service
Arctic and Central Alaska Inventory and Monitoring Networks
240 W. 5th Avenue
Anchorage, AK 99501

August 2018

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

The National Park Service Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Arctic Network website](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

O'Donnell, J. A. and S. D. Miller. 2018. Lake communities and communities and ecosystems monitoring protocol for the Arctic Network, Alaska. Natural Resource Report NPS/ARC/NRR—2018/1708. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	vi
Tables.....	vi
Abstract.....	vii
Acknowledgments.....	viii
1. Introduction.....	1
2. Lake Thermal Dynamics.....	4
2.1 Background.....	4
2.2 Sampling Design	4
2.3 Data Processing	5
2.4 Analyses and Reporting.....	5
2.5 Operational Requirements	5
3. Lake Chemistry.....	7
3.1 Introduction	7
3.1.1 Basic Water Quality Parameters.....	7
3.1.2 Dissolved Organic Carbon (DOC)	7
3.1.3 Dissolved Inorganic Carbon and Alkalinity	7
3.1.4 Nitrogen and Phosphorous (N & P).....	8
3.1.4 Major Cations and Anions.....	8
3.1.5 Chlorophyll a in the Water Column	9
3.2 Sampling Design	9
3.2.2 Sample Timing and Frequency.....	11
3.3 Field Methods.....	11
3.3.1 Field Season Preparations.....	11
3.3.2 Field Measurements.....	12
3.3.3 Water Sample Collection and Processing.....	12
3.3.5 End-of-season Procedures	13

Contents (continued)

	Page
3.3.6 Safety in the Field.....	13
3.4 Analyses and Reporting.....	14
3.5 Operational Requirements	14
4. Data Management	16
4.1 Data Management Life Cycle.....	16
4.2 NPS Standards	17
4.2.1 Data Quality.....	17
4.2.2 Freedom of Information Act.....	17
4.2.3 Records Management	17
4.3 Core Functional Model.....	18
4.4 Data Sensitivity Statement	19
4.5 Roles and Responsibilities.....	19
4.6 Quality Assurance	19
4.7 Data Collection.....	19
4.7.1 Deliverables Schedule	19
4.7.2 Deliverable LL01: Field Sheets.....	20
4.7.3 Deliverable LL02: Site photos.....	20
4.7.4 Deliverable LL03: Chemistry – Discrete	20
4.7.5 Deliverable LL04: Profiles - Discrete	20
4.7.7 Deliverable LL05: Temperature – Continuous.....	20
4.8 Data Entry/Import.....	21
4.9 Quality Control.....	21
4.10 Product Archival and Documentation	21
4.10.1 IRMA Data Store.....	22
4.10.2 Reports.....	23
4.10.3 Data.....	23

Contents (continued)

	Page
4.10.4 Resource Brief	24
4.10.5 Products Publication	24
4.10.6 Metadata	24
4.10.7 Line of Sight	24
4.10.8 Dataset Integration with National Databases.....	25
4.10.9 Database Design	25
4.10.10 Data and Information Security	25
4.11 Closeout.....	26
4.12 Certification.....	26
5. Literature Cited	28

Figures

	Page
Figure 1. Map of 20 study sites sampled during 2013-2014 across the five ARCN park units.....	2
Figure 2. Long-term monitoring project data management life cycle.....	16
Figure 3. The ARCN Core Functional Model overview.....	18
Figure 4. Vital Sign Project reference architecture in the IRMA Data Store.....	23
Figure 5. Each informational component informs and is informed by other components.....	24
Figure 6. Overview of database architecture and system data flow.....	25

Tables

	Page
Table 1. Study sites from 2013-2014 pilot studies in the Arctic Network.....	10
Table 2. Lake Communities and Ecosystems monitoring data deliverables schedule.	20

Abstract

Lakes are an important component of the Arctic, playing a significant role in biogeochemical cycling and serving as critical habitat for fish and wildlife. Recent climate change in the Arctic has altered lake ecosystems, both through the direct effects of warming on surface water and by altering ecosystem processes and disturbance within lake basins. Large uncertainties exist regarding the spatial extent of these changes and the timing of lake-ecosystem responses to projected climate change. Here, we present a long-term monitoring protocol for the Lake 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 Lake Communities and Ecosystems vital sign focuses primarily on large, deep lakes (generally >5 meters), complementing the ARCN Shallow Lakes vital sign.

The overarching goal of our monitoring protocol is to detect long-term change in physical, chemical, and biological components of arctic lake 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 results from pilot studies, we have identified 18 lakes across the network for long-term monitoring. Our sampling design includes lakes that vary with geologic setting and surface water chemistry, and includes several unique maar lakes located in Bering Land Bridge National Preserve. 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 Chris Arp and Josh Koch who served as reviewers of the protocol and greatly improved the quality of the finished product.

1. Introduction

Lake ecosystems are sensitive to climate change, both through the direct effects of temperature on lake structure and function and through the indirect effects of climate change on the surrounding terrestrial landscape. Recent findings in high-latitude regions have documented changes in lake area (Smith et al. 2005; Swanson 2013), lake ice dynamics (Arp et al. 2013), and lake temperature (Prowse et al. 2006; Jones et al. 2014). As a result, researchers have viewed lakes as sentinels of climate change (Adrian et al. 2009; Williamson et al. 2009). In addition to changing thermal structure and ice phenology, lake chemistry can also serve as a critical indicator of changing climate. Long-term shifts in the chemical composition of lakes may serve as an indicator of changing terrestrial processes. For instance, changing nutrient concentrations or ratios may reflect climate-driven changes in terrestrial net primary production (NPP), precipitation runoff, or disturbance (e.g., fire, erosion). Dissolved organic carbon (DOC) concentration in lakes has also been used as an indicator and integrator of terrestrial ecosystem change (Lapierre et al. 2015). Chemical changes can also occur through internal lake processes, such as changes in lake temperature regimes, thermal stratification, or rates of aquatic NPP.

A shift in lake chemistry may have important implications for aquatic organisms, greenhouse gas emissions, and ecosystem services. In the Arctic, changes in lake temperature and chemical composition have caused shifts in lake biological communities (Smol et al. 2005). Laboratory and field experiments have documented significant nutrient limitation of NPP by phytoplankton in Arctic lakes (Levine and Whalen 2001), which is a primary control on invertebrate and fish production in many high-latitude lakes (Hershey 1992). Lake chemistry is also an important control on the emission of greenhouse gases (e.g., carbon dioxide and methane) to the atmosphere (Kling et al. 1991; McDonald et al. 2013), which can function as a positive feedback to the climate system and account for a significant portion of the high-latitude carbon budget (McGuire et al. 2010). Ecosystem services may also be impacted by shifts in lake chemistry. For instance, eutrophication due to increased nutrient loading may reduce water quality and fish productivity, and in turn, negatively affect recreational and subsistence activities (Adrian et al. 2009; Carpenter et al. 2009).

The National Park Service (NPS) Arctic Inventory and Monitoring Network (ARCN) 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).

Lake Communities and Ecosystems is one of 19 vital signs currently monitored by ARCN. The overarching goals of vital signs monitoring are to (1) determine status and trends of selected

indicators that reflect ecosystem condition, which will allow managers to make informed decisions, (2) provide early warning of abnormal conditions and impairment, and (3) provide data to improve understanding of ecosystem function and to meet legal and congressional mandates.

Water resources are an important component of the ARCN park units, and include 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). O'Donnell et al. (2015a) conducted a two-year pilot study to characterize chemistry of large lakes in BELA, GAAR, and NOAT. They sampled 20 large lakes that ranged in watershed properties, genesis, and surface water composition (Figure 1). The results of this pilot study have been useful for the development and implementation of the Lake Communities and Ecosystems monitoring protocol outlined herein.

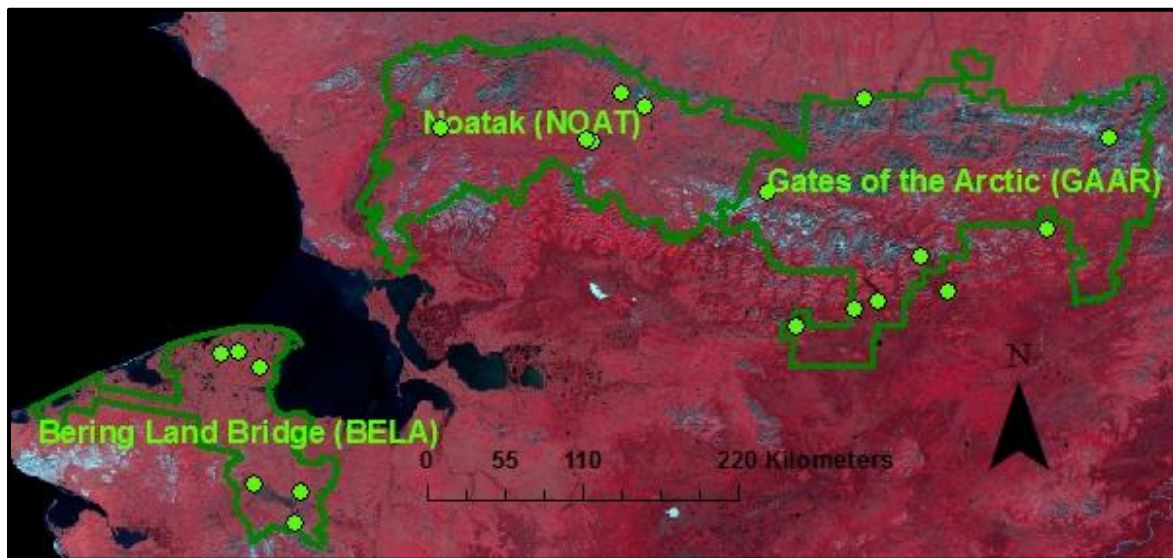


Figure 1. Map of 20 study sites sampled during 2013-2014 across the five ARCN park units. We excluded the two lakes outside of the ARCN park boundaries for this monitoring protocol.

The Lake Communities and Ecosystems vital sign is primarily focused on the monitoring of large, deep lakes (generally >5 meters deep) within the ARCN. It serves to compliment monitoring conducted in association with the ARCN Shallow Lakes vital sign (Larsen et al. 2011), which examines trends in small, shallow lakes (<5 meters deep), including a variety of thermokarst lake types (Larsen et al. 2017). Beyond the structural differences between the large, deep lakes and shallow lakes, these lake differ with respect to thermal regime, genesis, biota, and subsistence use. For the Lake Communities and Ecosystems vital sign, we have identified three primary monitoring goals:

1. Detect long-term trends in the thermal regime of lakes by monitoring lake temperature profiles,

2. Detect long-term changes in the chemical composition of lakes by monitoring lake water chemistry, and
3. Monitor and evaluate the effects and implications of physical and chemical changes for lake biota.

2. Lake Thermal Dynamics

2.1 Background

Lake thermal dynamics are an important control on lake stratification, chemistry, biotic community structure, and productivity. At the global scale, lake surface water temperatures have warmed by $0.34^{\circ}\text{C decade}^{-1}$ between 1985 and 2009 (O'Reilly et al. 2015). Warming of deep water in lakes has also been documented (Ambrosetti and Barbanti 1999), and may serve as an indicator of climate change. Long-term warming of lake waters may result in changes to the thermal structure of lakes (i.e. stratification and mixing; Boehrer and Schultze 2008), which can alter nutrient and oxygen concentrations and the distribution of biota (Adrian et al. 2009). Warming will also influence the phenology and thickness of lake ice (Williams and Stefan 2006), a critical component of high-latitude lakes.

Stratification is a process that separates the lake into three separate zones, and is mediated by climate conditions and lake depth. Lake stratification develops in response to surface warming, which creates a temperature and density gradient between surface and deep waters. This temperature-density gradient is resistant to mixing by wind-induced currents and heat transfer from the lake surface. The *epilimnion* is the surface layer that is often turbulent and exchanges gas and energy with the atmosphere. In the epilimnion, primary production typically exceeds heterotrophic respiration. The *hypolimnion* is the deep water zone, and is typically separated from contact and exchange with the atmosphere. Respiration typically dominates over primary production in the hypolimnion, and is driven by utilization of organic matter transferred from the epilimnion. The *metalimnion* is the transition zone between the epilimnion and the hypolimnion, and is characterized by a temperature gradient known as the thermocline. During autumn, cooling of surface waters reduces the temperature and density difference between the epilimnion and hypolimnion, and the lake becomes less resistant to mixing.

In the Arctic, lakes are covered by ice for a considerable portion of the year (60-80% of year; Brown and Duguay 2010), which strongly influences gas and energy exchange with the atmosphere. Lakes in the Arctic Network are generally ice-free during the summer and early autumn. The number of ice free-days is strongly correlated to mean annual air temperature and lake depth (Shuter et al. 1983). Given recent warming in the Arctic, it follows that the number of ice-free days has also increased and will continue to increase over time. While few long-term data sets exist, it appears that many lakes in Canada have exhibited earlier spring break-up in recent decades, while freeze-up during autumn is quite variable (Duguay et al. 2006). Evidence also indicates that lake ice dynamics are changing in shallow Arctic lakes in northern Alaska (Arp et al. 2013), yet little is known about the thickness and seasonality of large lakes in the Arctic Network (for exception, see report by Jones and Arp 2014). Lake surface area is also changing in the Arctic, and is being actively monitored by the Terrestrial Landscape Patterns and Dynamics vital sign (Swanson 2013).

2.2 Sampling Design

Lake temperature profiles will be continuously monitored using a profile of thermistors (see Continuous Lake Temperature Monitoring SOP). Discrete measurements of lake temperature profiles

will also be conducted during visits to all monitoring sites using a multi-parameter probe (as described below in section 3.3: Field Methods). We are planning to monitor lake temperature profiles year-round at two large lakes in BELA (South Killeak and Kuzitrin Lakes). These lakes were selected for a couple reasons. South Killeak Lake was selected for monitoring because prior monitoring was conducted there in recent years (Jones and Arp 2014). South Killeak is also a large maar lake (>50 meters deep), a unique feature of several large lakes in BELA, which formed in response to the interaction of flowing lava and permafrost (Beget et al. 1996). Kuzitrin Lake represents a contrast relative to South Killeak Lake, both in terms of genesis, depth (max depth = 10 meters), and thermal regime. Both lakes are easily accessible from Kotzebue or Nome, Alaska. Over time, we will plan to add additional lakes to our monitoring plan, pending funding. We aim to add future lakes in Noatak National Preserve and Gates of the Arctic National Park to cover a broader spatial extent. Near the lake surface, thermistors are arranged at finer depth increments (e.g., every 0.25 m in the top two meters) than at depth (e.g., every two meters below two meters).

2.3 Data Processing

Raw temperature data will be downloaded from the Beaded Stream web server and imported into Aquatic Informatics Aquarius data management software or something similar in order to process data (Figure 6). Aquarius provides a platform for management time-series data, including specifying site data, adding field visit data, conducting manual and automated data corrections, and employing other quality assurance/quality control (QA/QC) techniques.

2.4 Analyses and Reporting

We will monitor lake temperature using both continuous measurements at a small number of large lakes and discrete temperature measurements at a more extensive series of large lakes. For continuous measurements, we will report trends in mean annual temperature and mean monthly temperature at a number of depths (e.g., surface vs. deep). In addition to lake temperature trends, we will use near-surface lake temperature data to calculate and determine trends in lake ice seasonality (break-up timing, freeze-up timing, and ice-free days), lake ice depth, and thermocline depth. To test for significance of trends, we will use the Mann-Kendall test and also calculate Sen slopes (O'Reilly et al. 2015) using the “openair” package in R (Carslow and Ropkins 2012) or similar statistical software. We will also examine spatial patterns in temperature dynamics across lake basins using descriptive statistics and analysis of variance. The lake temperature database will be updated annually, and examined in annual reports, technical reports, or peer-reviewed journal articles.

2.5 Operational Requirements

Following initial deployment of lake temperature buoys, “real-time” lake temperature data will be uploaded and housed at a personalized website maintained by Beaded Stream, Inc. Follow-up site visits will be scheduled as needed. The project manager will need strong data processing and analytical skills, because the continuous temperature sensors will generate a large dataset. Data processing will require experience with Aquarius data management software, and statistical analysis will require experience with R statistical software. For each lake where temperature profiles will be monitored, the costs of all equipment is approximately \$8,000. Additional costs include float-plane flight hours and travel to sites. The project manager will spend approximately 30% of their time on

the Lake Communities and Ecosystems vital sign, and the temperature component accounts for approximately 25% of that time.

3. Lake Chemistry

3.1 Introduction

The chemical composition of lake 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 lake chemistry, which in turn can impact lake biota. To characterize lake chemistry, collected water samples will be analyzed for dissolved carbon (C), nutrients, and major ions. Below is an introduction to and rationale for measuring each chemical constituent.

3.1.1 Basic Water Quality Parameters

The NPS Water Resources Division has mandated that four water quality parameters be measured in the field for vital signs monitoring of 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}). Instantaneous measurements of these parameters will be conducted using a multiparameter sonde along lake profiles from the surface to the bottom of each lake during site visits. Collection of these field measurements will ensure consistency and comparability across sites at the regional and national level, given that all monitoring networks will measure these parameters at surface-water sites.

3.1.2 Dissolved Organic Carbon (DOC)

DOC is a critical component of aquatic ecosystems, as it functions to influence 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.

Soils of the northern circumpolar permafrost region store approximately 1300 petagrams (Pg) of organic C (Hugelius et al. 2014). Thus, permafrost thaw may result in the release of previously frozen C from catchment soils to lakes. 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. In other words, as the climate warms, permafrost thaw will accelerate, as will rates of C release from soils and surface waters to the atmosphere. Given the important role of inland waters for the global C cycle and the climate system (Raymond et al. 2013), both DOC and dissolved inorganic C (DIC) concentration will be actively monitored.

3.1.3 Dissolved Inorganic Carbon and Alkalinity

Dissolved inorganic carbon (DIC) is an important component of and influence on lake biogeochemistry. In most lakes, DIC is primarily derived from gas exchanges with the atmosphere, and secondarily through hydrologic delivery from terrestrial ecosystems as either carbon dioxide (CO_2) from soil respiration or bicarbonate (HCO_3^-) from weathering processes. *In situ* mineralization

of dissolved organic matter (DOM) in surface waters can also contribute to the production of DIC. Alkalinity is a measurement that represents the capacity of a water sample to neutralize a strong acid. Researchers near Toolik Lake on Alaska's North Slope have observed a long-term increase in lake-water alkalinity, likely reflecting weathering inputs from previously frozen glacial till (Kling et al. 2014).

3.1.4 Nitrogen and Phosphorous (N & 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 et al. 1991; Heimann and Reichstein 2008). N occurs in various forms in lake 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. 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).

P inputs to lakes are typically low due to effective retention by terrestrial vegetation and mineral soils (Schlesinger 1997). Much of the P in lake surface water occurs in phytoplankton biomass, as determined by total (or particulate) P measurements. Increased loading of inorganic P (phosphate, or PO_4^{3-}) to lakes typically results in increased net primary productivity rates (Schindler et al. 1978), reflecting P limitation. Anthropogenic P loading (e.g., from agriculture) via runoff from watersheds has caused eutrophication in lakes, driving algal blooms and hypoxia. In Arctic lakes, most P is in organic forms, and PO_4^{3-} concentrations are typically at or below analytical detection limits (O'Donnell et al. 2015a; Luecke et al. 2014).

3.1.4 Major Cations and Anions

Measuring the concentration of major cations and anions in lake 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 major 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^-) and/or bicarbonate (CO_3^{2-}) depending on pH. The concentrations of base cations and anions in lake water typically reflect watershed lithology and weathering reactions of parent materials (e.g., Frey et al. 2007). Base cations and some anions (e.g., Cl^-) often behave conservatively in Alaskan freshwater ecosystems, 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). In shrinking lakes of interior Alaska, base cation concentrations increase due to the concentrating effects of evaporation (Lewis et al. 2015). Lakes impacted by permafrost thaw and thermal erosion often have elevated base cation concentrations (Kokelj et al. 2009; Larsen et al. 2011).

3.1.5 Chlorophyll a in the Water Column

Lake ecosystems are sensitive to changing physical and chemical drivers, particularly changes in nutrient loading and primary productivity. For the ARCN Lake Communities and Ecosystems vital sign, we will monitor chlorophyll a concentrations in the photic zone. Phytoplankton are primary producers and thus contain substantial quantities of chlorophyll a, 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.

3.2 Sampling Design

We have selected 18 large lakes in ARCN park units for intensive monitoring in association with the Lake Communities and Ecosystems vital sign (Table 1). These lakes are large with respect to surface area (3-80 km²) and volume (35 to 2,297 m³ x 10⁶; LaPerriere et al. 2003), and function to compliment monitoring conducted under the Shallow Lake vital sign (<https://science.nature.nps.gov/im/units/arcn/vitalsign.cfm?vsid=133>; Larsen et al. 2011).

Lakes were selected for monitoring based on the following criteria:

1. *Unique qualities:* We have proposed sampling three maar lakes (Devil Mountain, South Killeak, and White Fish Lakes) on BELA. These lakes formed following massive eruptions due to the interaction of lava and permafrost, and are the largest known maars on Earth (Beget et al. 1996). We are also sampling non-maar lakes that are in basins dominated by basalts, with extensive surface lava flows (Imuruk and Lava Lakes).
2. *Prior research:* A number of monitoring sites have been previously studied, and our monitoring efforts can build off existing data sets. Prior limnological surveys have been conducted at most of the GAAR lakes (LaPerriere et al. 2003). Lake temperature monitoring has been conducted in BELA (Jones and Arp 2014). Some lakes have been the sites of paleoclimate and paleoecological studies using lake sediment cores (e.g., Imuruk Lake; Noltimier and Colinviaux 1976).
3. *Potential for disturbance:* Some lakes are located in regions that may be susceptible to anthropogenic disturbance (e.g., roads). The proposed Ambler mining road would likely run through a portion of the Kobuk boot region of GAAR, adjacent to Lake Selby, Nutavukti Lake, and Walker Lake.
4. *Subsistence and recreational use:* A number of these large lakes have sustain fish populations that are of interest to subsistence and recreational users (e.g., Walker Lake in GAAR).
5. *Access:* All monitoring lakes are remote, and will require float plane or helicopter access. However, some sites are more remote than others (Kurupa and Summit Lake in GAAR) and may not be accessible every year, pending funding and weather.

Table 1. Study sites from 2013-2014 pilot studies in the Arctic Network.

Park Unit Name	Site Name	Sampling Date*	Lat (°N)	Long (°W)
Bering Land Bridge National Preserve	Devil Mountain Lake	6/22/13	66.40362	-164.48818
	Imuruk Lake	6/21/13	65.58905	-163.18683
	Kuzitrin Lake	6/21/13	65.38450	-163.21787
	Lava Lake	6/21/13	65.58996	-163.90928
	South Killeak Lake	6/23/13	66.32813	-164.10563
	White Fish Lake	6/22/13	66.37863	-164.74520
Gates of the Arctic National Park	Kurupa Lake	8/6/14	68.35879	-154.60695
	Lake Matcharak	6/26/14	67.74715	-156.21262
	Lake Selby	8/7/14	66.89298	-155.65584
	Nutuvukti Lake	8/7/14	67.01337	-154.73245
	Summit Lake	8/8/14	68.07008	-150.47092
	Takahula Lake	6/26/14	67.35014	-153.66048
Noatak National Preserve	Walker Lake	8/7/14	67.06375	-154.34215
	Desperation Lake	9/16/13	68.33031	-158.74584
	Feniak Lake	9/16/13	68.24775	-158.31337
	Lake Kangilipak	9/16/13	68.00064	-159.15975
	Lake Narvakrak	6/27/13	67.99990	-161.72104
	Okoklik Lake	9/16/13	68.01392	-159.27007

* Sampling date" refers to prior visits to study lakes, as reported in O'Donnell et al. 2015a.

All large lakes 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 and Frequency

We plan to collect water samples for chemical analyses from all large lakes listed in Table 1 once per year. Every fourth year, we will take a year off to analyze data and write a technical report or peer-reviewed publication. All samples will be collected in July or August during the ice-free season, when most arctic lakes are stratified.

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 ensure 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, vegetation, animal, socioeconomic, human health, and cultural resources, and seeks ways to minimize or mitigate impacts. Further, the compliance process aims to minimize and mitigate possible impacts to subsistence users and activities on NPS lands.

To conduct fieldwork in ARCN parks, workplan proposals must be submitted through the Planning, Environment, and Public Comment (PEPC) online system to facilitate compliance mandates. 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 (SOP) 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.

Field logistics are also a critical component of field season preparations. To conduct fieldwork, there are five 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 the most appropriate way to access study sites. For the Lake Communities and Ecosystems vital sign, there are 18 sites that will be visited on an annual basis. All sites can be accessed via float plane, assuming that weather is conducive. Flight requests should be submitted to the 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 government 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 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 to the Alaska Region Communication Center (ARCC) prior to flying.

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 lake chemistry (See *SOP: Chemical Characterization of Surface Water*). All filtering is conducted *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). The pump is housed in a black case with 12-volt batteries and associated charging and connector cables. 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: Chemical Characterization of Surface Water*.

3.3.2 Field Measurements

Field measurements can be conducted either from a small inflatable boat (e.g., Alpaca packraft) or off the float of a float plane. ARCN staff should wear appropriate safety gear while sampling, including a float coat or some other personal floatation device. To prevent the spread of invasive species, field gear should be cleaned prior to sampling following Hazard Analysis and Critical Control Point planning procedures (<https://www.fws.gov/fisheries/ANS/ANS-HACCP.html>). Field measurements should be conducted in the deepest part of the lake, based on existing bathymetric maps or recent bathymetric surveys. Lake depth can be confirmed *in situ* using a hand-held depth sounder.

Upon arriving at the sampling location on the lake, a secchi depth measurement should be taken to estimate the thickness of the photic zone. The ARCN staff should measure basic water quality parameters (water temperature, pH, specific conductivity, DO). Measurements will be conducted at 0.5-m increments from the lake surface to the lake bottom using a calibrated multi-parameter probe. 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 final three measurements on the field sheet.

3.3.3 Water Sample Collection and Processing

We will collect water samples from the epilimnion and hypolimnion in the deepest section of each lake based on bathymetric maps using a Van Dorn sampler. 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 filtering water samples through 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 should be stored on ice in a cooler, and then frozen in a freezer, until shipping out for analyses.

Upon returning from the field, all samples (with the exception of DOC samples, which should be refrigerated) should be frozen until shipped to the laboratory for processing. Carbon, nutrient, cation and anion samples should be shipped to the Cooperative Chemical Analytical Laboratory (CCAL) at Oregon State University in Corvallis, OR (<https://ccal.oregonstate.edu>).

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 is 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), will be determined using the ascorbic acid method. Calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and total iron (Fe) concentrations will be measured using flame atomic absorbance spectroscopy on a Shimadzu AA-7000. Chloride (Cl^-), and sulfate (SO_4^{2-}) will be analyzed on a Dionex 1500 ion chromatography system.

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 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 ARCN parks, particularly given the remote location of field sites and the use of helicopters and small fixed-wing aircraft. Safety procedures for the Lake 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 Lake 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

Lake chemical parameters will be analyzed to understand spatial and temporal trends in water quality. Recent work by Larsen et al. (2017) documents the importance of how *spatial* variation in watershed characteristics plays an important role in governing the physical and chemical characteristics of shallow lakes in ARCN and the Central Alaska Inventory and Monitoring Network. O'Donnell et al. (2016) also documented the effects of watershed characteristics, including permafrost and parent material, on stream and river chemistry in ARCN. Analysis of variance (ANOVA) techniques should be used for detecting significant effects of watershed characteristics on lake chemistry, following methods of O'Donnell et al. (2016).

Temporal trends in lake chemistry should be analyzed by individual lake, by lake type (e.g., maar vs. glacial, etc.), and by sample depth (epimnion vs. hypolimnion). 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 lake 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 lake 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>). As of 2017, the

NPS WRD provides approximately \$65,000 per year for the Stream Communities and Ecosystems vital sign and the Lake Communities and Ecosystems vital sign. Approximately half of this funding is used in support of the Lake Communities and Ecosystems vital sign, and is put toward aviation, travel, equipment, and laboratory costs. On an annual basis, the Lake Communities and Ecosystems vital sign should take approximately 30% of the project manager's time, or 312 hours per year.

4. Data Management

4.1 Data Management Life Cycle

Data management for the Lake Communities and Ecosystems vital sign will proceed through an ongoing life cycle (Figure 2; 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 data analysis and reporting (NPS 2008b).

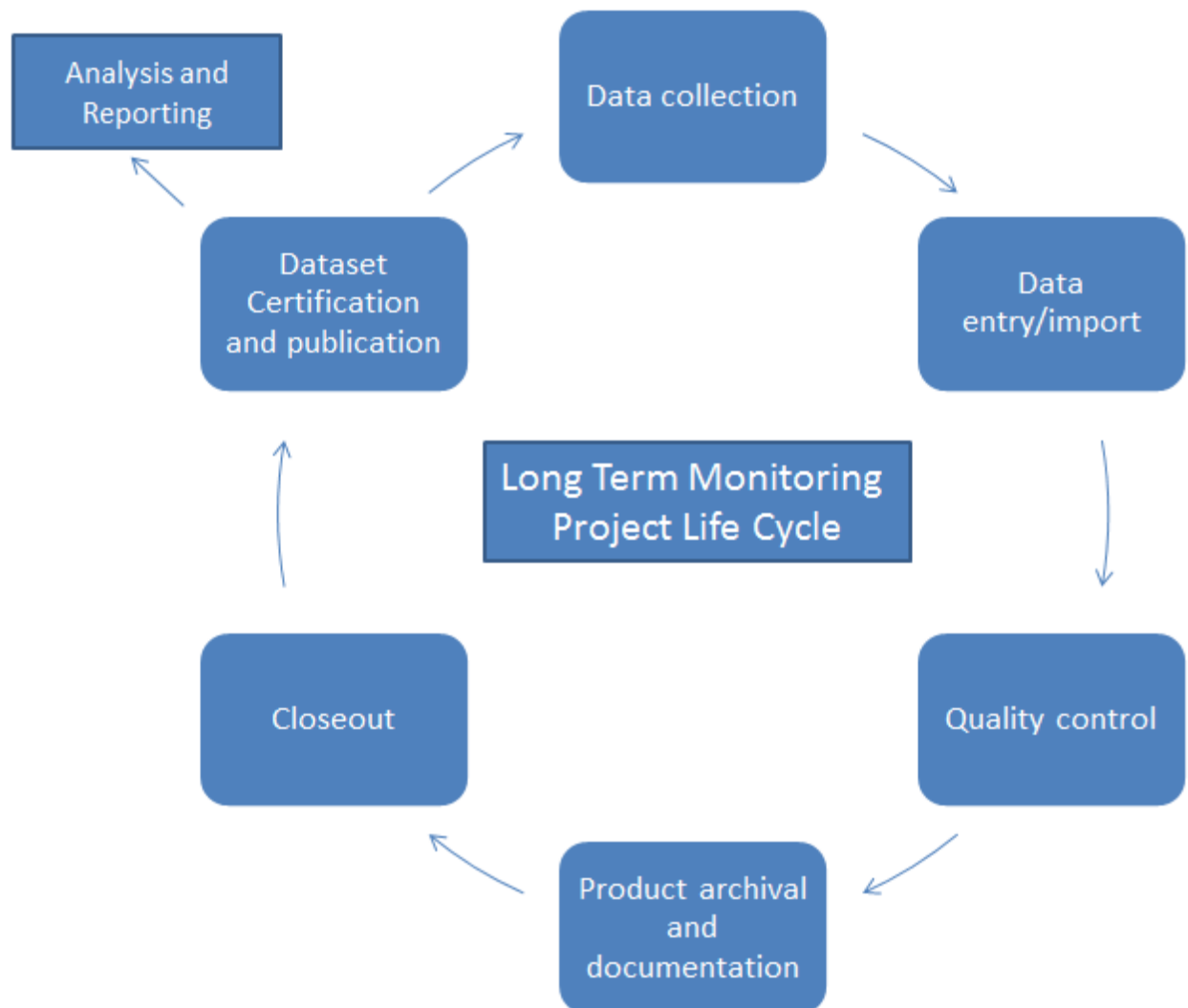


Figure 2. Long-term monitoring project data management life cycle.

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 Lake Communities and Ecosystems vital sign are managed according to the Core Functional Model described in Figure 3.

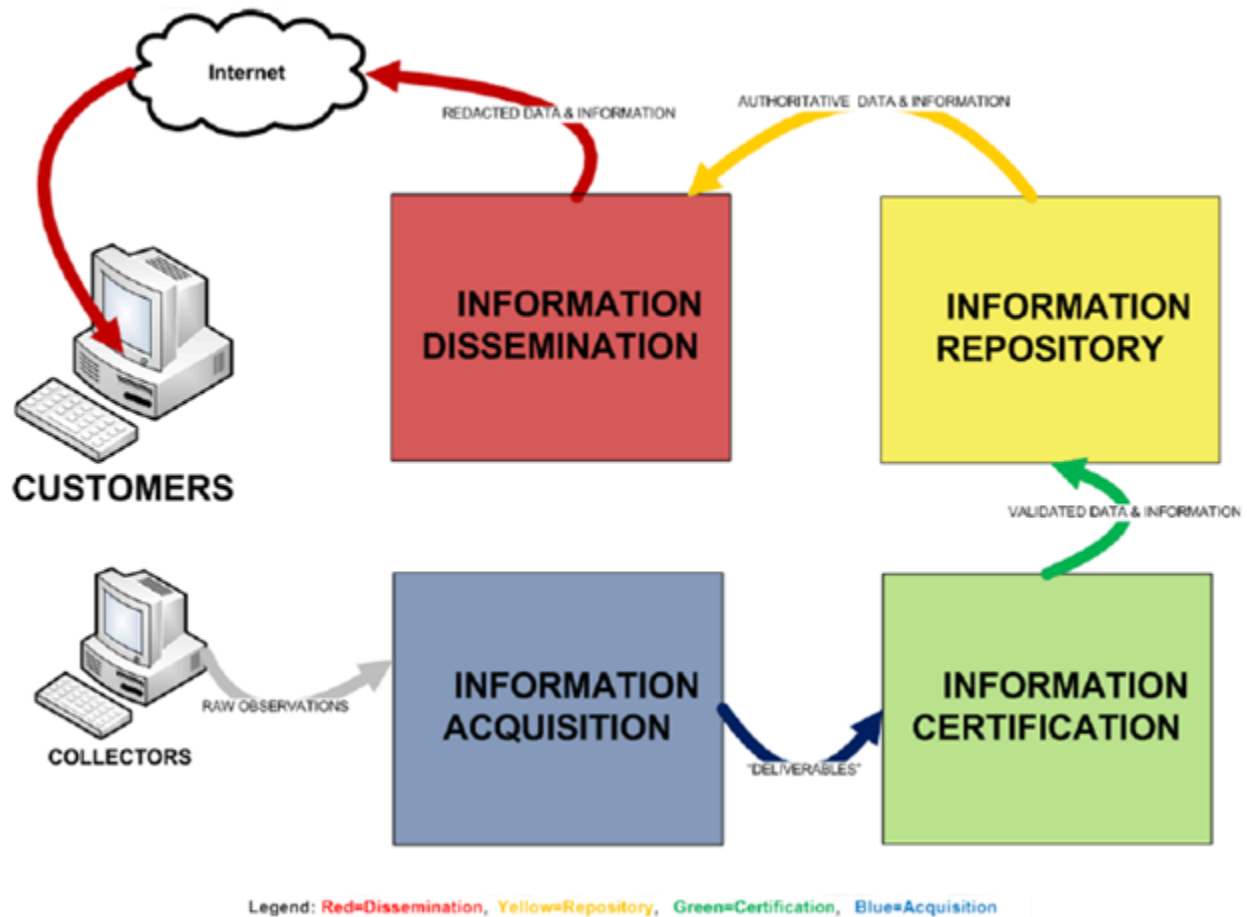


Figure 3. The ARC Core Functional Model overview.

Dissemination services (red, Figure 3) 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 Lake Communities and Ecosystems monitoring protocol does not define the collection of sensitive data and requires no special data handling procedures.

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

- SOPs designed to minimize the introduction of errors during data collection and processing.
- Data quality objectives describing how QA and 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 Lake 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 Lake Communities and Ecosystems monitoring program will create and maintain the data products shown in Table 2.

Table 2. Lake Communities and Ecosystems monitoring data deliverables schedule.

Identifier	Deliverable	Format	Schedule	Responsibility	Description
LL01	Field Sheets	.pdf	Every year	PI	Scanned copies of field sheets that include site descriptions, field observations
LL02	Site photos	.jpg	Every year	PI	Photographs of study sites collected during field work
LL03	Chemistry - Discrete	.csv	Every year	PI	Chemistry data following QA/QC generated by field measurements and grab samples
LL04	Profiles - Discrete	.csv	Every Year	PI	Temperature, pH, specific conductivity, and dissolved oxygen profiles collected during site visits
LL05	Temperature Profiles - Continuous	.csv	Every year	PI	Chemistry data following QA/QC generated by in-situ continuous monitoring probes

4.7.2 Deliverable LL01: Field Sheets

Deliverable LL01 is the scanned copy (.pdf) of all field sheets filled out during monitoring site visits and samplings. See example field sheet *SOP: Field Measurements*.

4.7.3 Deliverable LL02: Site photos

Deliverable LL02 includes all site photos generated during monitoring visits and sampling. More details in *SOP: Field Measurements*.

4.7.4 Deliverable LL03: Chemistry – Discrete

Deliverable LL03 is a dataset generated from the 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 Surface Water*.

4.7.5 Deliverable LL04: Profiles - Discrete

Deliverable LL04 is a dataset generated from discrete *in situ* measurements of water quality parameters (temperature, pH, specific conductivity, dissolved oxygen) along lake depth profiles. The PI is responsible for conducting field measurements, processing data, and updating database on an annual basis. See more details for in *SOP: Field Measurements*.

4.7.7 Deliverable LL05: Temperature – Continuous

Deliverable LL05 is a dataset generated from continuous *in situ* measurements of lake-water temperature along lake depth profiles. Temperature sensors and dataloggers are manufactured by Beaded Stream (Anchorage, Alaska; <http://www.beadedstream.com>). Data are transferred from the field via Iridium satellite technology to a webserver hosted by Beaded Stream. The PI is responsible for deploying temperature arrays, downloading the data from Beaded Stream, and processing and

uploading the data in Aquarius data management software. See more details in *SOP: Continuous Lake Temperature Monitoring*.

4.8 Data Entry/Import

Upon returning from the field, data collected on field sheets will be manually entered into a Microsoft Excel spreadsheet, checked for QC, and imported into the database. Discrete chemistry data are sent electronically as a data report to the PI from the analytical laboratory (e.g., Cooperative Chemical Analytical Laboratory (CCAL) at Oregon State University). Data are then extracted from the reports, checked for QC, and appended to database. Water quality profiles are downloaded from multi-parameter probes, checked for QC, and appended to database. Continuous temperature data are downloaded from the Beaded Stream webserver, uploaded to Aquarius, evaluated for QC, and uploaded to the database. Details regarding data entry and QA/QC can be found in *SOP: Data Management* and *SOP: Data Quality Assurance and Quality Control*.

4.9 Quality Control

Ensuring high data quality is a high priority for the Lake Communities and Ecosystems vital sign. QC procedures focus on verifying data as well as identifying and correcting errors in final data products. Details regarding QC procedures can be found in *SOP: Data Quality Assurance and Quality Control*.

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* temperature 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: 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 of all Lake Community and Ecosystem monitoring databases. A SQL script is built that can recreate the entire database and all the data within it.
- Network file server
- SQL Server data warehousing
- SQL Server snapshot backup packages that can be restored to a server with low latency.
- ARCN database backup files

Lake 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. The FAC uses enterprise-level business continuity processes to maintain their version of the Lake 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 Lake Communities and Ecosystems monitoring program. The Lake 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 4).

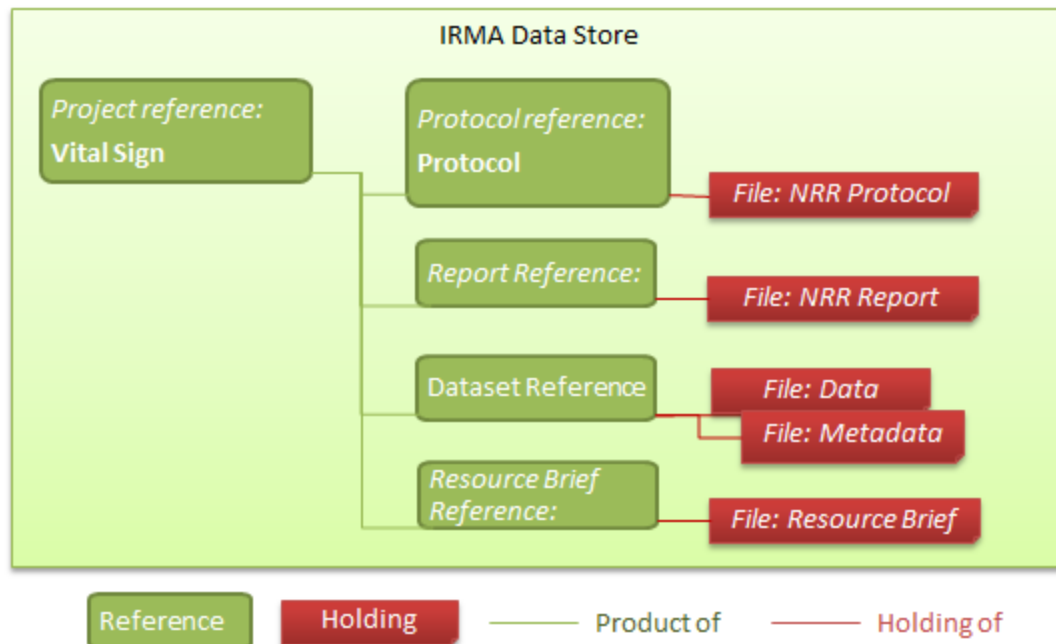


Figure 4. Vital Sign Project reference architecture in the IRMA Data Store.

The public vital sign webpage covering Lake 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 4) and notify interested parties of their presence.

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 Lake 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 4). 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 Lake 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 4).

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 4). Information from these references automatically cascades to the monitoring Network's web site 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 4). 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 (Figure 5). 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.

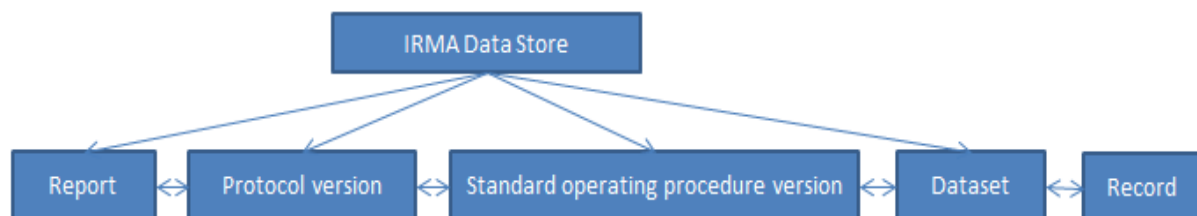


Figure 5. Each informational component informs and is informed by other components. Discovery of one component leads to discovery of all other components in a formalized data management chain of custody.

4.10.8 Dataset Integration with National Databases

4.10.8.1 NPStoret (water quality vital signs only)

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. 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).

4.10.8.2 Aquarius (continuous water quality data)

Continuous water quality data will be archived through the Aquatic Informatics Aquarius data management software.

4.10.9 Database Design

The Lake Communities and Ecosystems monitoring program will have a single, authoritative database built according to I&M standards (Figure 6; Frakes et al. 2015).

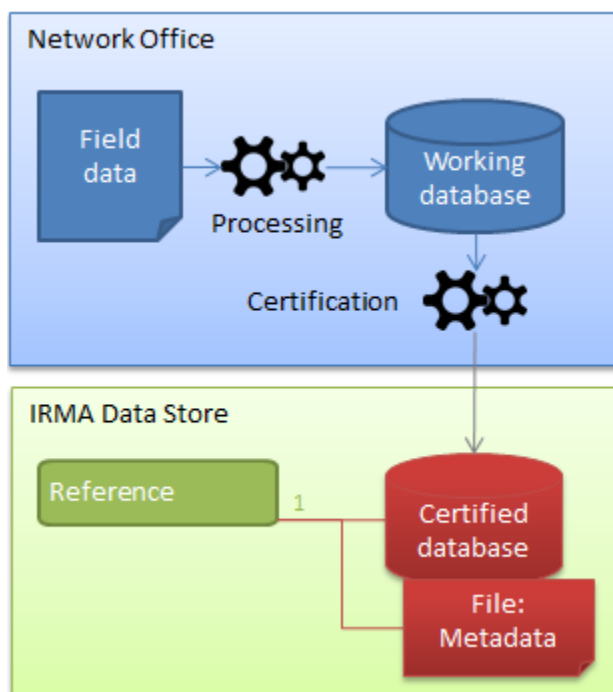


Figure 6. Overview of database architecture and system data flow.

4.10.10 Data and Information Security

Digital products produced by the Lake 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 Lake Communities and Ecosystems monitoring data management life cycle through which seasonal data collection files (deliverables, Table 2) are archived in the IRMA Data Store. Specific closeout procedures are found in *SOP: Data Management* and in ARCN/CAKN DMSOP-1 (Miller 2017). 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 (*SOP: Data Management*). Closeout is complete when the IRMA Dataset's holdings match the 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 Lake Communities and Ecosystems monitoring IRMA Project reference so that it becomes discoverable within the NPS (Miller 2017).

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 Lake 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: Data Quality Assurance and Quality Control* and *SOP: Data Management*. The principal investigator's signature on the data certification form indicates:

- The protocol and SOPs 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.

The Large Lakes monitoring protocol will follow the general procedures in ARCN/CAKN DMSOP-1 (Miller 2017) for dataset certification.

5. Literature Cited

- Adrian, R., C. M. O'Reilly, S. B. Baines, D. O. Hessen, W. Keller, D. M. Livingstone, R. Sommaruga, D. Straile, E. Van Donk, G. A. Weyhenmeyer, and M. Winder. 2009. Lakes as sentinels of climate change. *Limnology and Oceanography* 54: 2283-2297.
- Ambrosetti, W., and L. Barbanti. 1999. Deep water warming in lakes: an indicator of climatic change. *Journal of Limnology* 58, doi:10.4081/jlimnol.1999.1.
- Arp, C. D., B. M. Jones, and G. Grosse. 2013. Recent lake ice-out phenology within and among lake districts of Alaska, U.S.A. *Limnology and Oceanography* 58: 2013-2028, doi:10.4319/lo.2013.58.6.2013.
- Beaulieu, J. J., J. L. Tank, S. K. Hamilton, W. M. Wolheim, R. O. Hall, P. J. Mulholland, B. J. Peterson, L. R. Ashkenas, L. W. Cooper, C. N. Dahm, W. K. Dodds, N. B. Grimm, S. L. Johnson, W. H. McDowell, G. C. Poole, H. M. Valett, C. P. Arango, M. J. Bernot, A. J. Burgin, C. L. Crenshaw, A. M. Helton, L. T. Johnson, J. M. O'Brien, J. D. Potter, R. W. Sheibley, D. J. Sobota, and S. M. Thomas. 2011. Nitrous oxide emission from denitrification in stream and river networks. *Proceedings of the National Academy of Sciences* 108: 214-219, doi:10.1073/pnas.1011464108.
- Beget, J. E., D. M. Hopkins, and S. D. Charron. 1996. The largest known maars on Earth, Seward Peninsula, Northwest Alaska. *Arctic* 49: 62-69.
- Boehrer, B., and M. Schultze. 2008. Stratification of lakes. *Reviews of Geophysics* 46, doi:10.1029/2006RG000210.
- Brown, L. C., and C. R. Duguay. 2010. The response and role of ice cover in lake-climate interactions. *Progress in Physical Geography* 34: 671-704, doi:10.1177/0309133310375653.
- Carpenter, S. R., et al. 2009. Science for managing ecosystem services: Beyond the Millenium Ecosystem Assessment. *Proceedings of the Natural Academy of Sciences* 106: 1305-1312, doi:10.1073/pnas.0808772106.
- Carslow, D. C., and K. Ropkins. 2012. *openair* – An R package for air quality data analysis. *Environmental Modeling & Software* 27-28: 52-61, doi:10.1016/j.envsoft.2011.09.008.
- Cory, R. M., B. C. Crump, J. A. Dobkowski, and G. W. Kling. 2013. Surface exposure to sunlight stimulates CO₂ release from permafrost soil carbon in the Arctic. *Proceedings of the National Academy of Science*, doi:10.1073/pnas.1214104110.
- Duguay, C. R., et al. 2006. Recent trends in Canadian lake ice cover. *Hydrological Processes* 20: 781-801.

- Elser, J. J., E. R. Marzolf, and C. R. Goldman. 1990. Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: a review and critique of experimental enrichments. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1468-1477.
- Federal Geographic Data Committee. FGDC-STD-001-1998. Content standard for digital geospatial metadata (revised June 1998). Federal Geographic Data Committee. Washington, D.C.
- Frakes, B., S. Kingston, and M. Beer. 2015. Inventory and Monitoring Division database standards: September 11, 2015. Natural Resource Report NPS/NRSS/NRR—2015/1035. National Park Service, Fort Collins, Colorado.
- Frey, K. E., D. I. Siegel, and L. C. Smith. Geochemistry of west Siberian streams and their potential response to permafrost degradation. *Water Resources Research* 43, doi:10.1029/2006WR004902.
- Hedin, L. O., J. C. von Fischer, N. E. Ostrom, B. P. Kennedy, M. G. Brown, and G. P. Robertson. 1998. Thermodynamics constraints on nitrogen transformations and other biogeochemical processes at the soil stream interface. *Ecology* 79: 684-703.
- Heimann, M. and M. Reichstein. 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. *Nature* 451: 289-292, doi:10.1038/nature06591.
- Hershey, A. E. 1992. Effects of experimental fertilization on the benthic macroinvertebrate community of an arctic lake. *Journal of the North American Benthological Society* 11: 204-217, doi:10.2307/1467386.
- Hugelius, G., J. Strauss, S. Zubrzycki, J. W. Harden, E. A. G. Schuur, C. L. Ping, L. Schirrmeister, G. Grosse, G. J. Michaelson, C. Koven, J. A. O'Donnell, B. Elberling, U. Mishra, P. Camill, Z. Yu, J. Palmtag, and P. Kuhry. 2014. Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps. *Biogeosciences* 11: 6573-6593, doi:10.5194/bg-11-6573-2014.
- Jones, B. M. and C. D. Arp. 2014. Past, present, and future thermal regime of lakes in Western Alaska. Report to the Western Arctic Landscape Conservation Cooperative.
- Kane, E. S., E. F. Betts, A. J. Burgin, H. M. Clilverd, C. L. Crenshaw, J. B. Fellman, I. H. Myers-Smith, J. A. O'Donnell, D. J. Sobota, W. J. Van Versveld, and J. B. Jones. 2008. Precipitation control over inorganic nitrogen import-export budges across watersheds: a synthesis of long-term ecological research. *Ecohydrology* 1: 105-117, doi:10.1002/eco.10.
- Kling, G. W., G. W. Kipphut, and M. C. Miller. 1991. Arctic lakes and streams as gas conduits to the atmosphere: implications for tundra carbon budgets. *Science* 251: 298-301.
- Kling, G. W., et al. 2014. Land-Water Interactions, in Alaska's Changing Arctic: Ecological Consequences for Tundra, Streams, and Lakes. Oxford University Press.

- Knowledge Network for Biocomplexity. 2015a. Ecological Metadata Language (EML). <https://knb.ecoinformatics.org/#external//emlparser/docs/index.html>. Retrieved December, 13, 2015.
- Knowledge Network for Biocomplexity. 2015b. Tools. <https://knb.ecoinformatics.org/#tools>. Retrieved December, 13, 2015.
- Kokelj, S. V., B. Zajdlik, and M. S. Thompson. 2009. The impacts of thawing permafrost on the chemistry of lakes across the subarctic boreal-tundra transition, Mackenzie Delta region, Canada. *Permafrost and Periglacial Processes* 20: 185-199, doi:10.1002/ppp.641.
- LaPerriere, J. D., J. R. Jones, and D. K. Swanson. 2003. Limnology of lakes in Gates of the Arctic National Park and Preserve, Alaska. *Lake and Reservoir Management* 19: 108-121, doi:10.1080/07438140309354077.
- Lapierre, J.-F., D. A. Seekell, and P. A. del Giorgio. 2015. Climate and landscape influence on indicators of lake carbon cycling through spatial patterns in dissolved organic carbon. *Global Change Biology* 21: 4425-4435, doi:10.1111/gcb.13031.
- Larsen A., J. Houghton, J. Black, D. Verbyla, C. Ruedebusch, R. McGinnis, and H. Kristenson. 2011. Shallow lake limnology monitoring protocol: Central Alaska Network (CAKN) and Arctic Network (ARCN), Version 2.0. Natural Resource Report NPS/AKRO/NRR-2011/347. National Park Service, Fort Collins, Colorado.
- Larsen, A. S., J. A. O'Donnell, J. H. Schmidt, H. J. Kristenson, and D. K. Swanson. 2017. Physical and chemical characteristics of lakes across heterogeneous landscapes in arctic and subarctic Alaska. *Journal of Geophysical Research* 122:989-1008.
- Lawler, J. P., S. D. Miller, D. M. Sanzone, J. Ver Hoef, and S. B. Young. 2009. Arctic Network vital signs monitoring plan. Natural Resource Report NPS/ARCN/NRR – 2009/088. National Park Service, Fort Collins, Colorado.
- Levine, M. A., and W. C. Whalen. 2001. Nutrient limitation of phytoplankton production in Alaskan Arctic foothill lakes. *Hydrobiologia* 455: 189-201.
- Lewis, T. L., M. S. Lindberg, J. A. Schmutz, P. J. Heglund, J. Rover, J. C. Koch, and M. Bertrum. 2015. Pronounced chemical response of Subarctic lakes to climate-driven losses in surface area. *Global Change Biology* 21: 1140-1152, doi:10.1111/gcb.12759.
- Luecke, C., et al. 2014. The response of lakes near the Arctic LTER to environmental change. *Alaska's Changing Arctic: Ecological Consequences for Tundra, Streams, and Lakes*. Oxford University Press.
- McDonald, C. P., E. G. Stets, R. G. Striegl, and D. Butman. 2013. Inorganic carbon loading as a primary driver of dissolved carbon concentrations in lakes and reservoirs of the contiguous United States. *Global Biogeochemical Cycles*, doi:10.1002/gbc.20032.

- McGuire, A. D., D. J. Hayes, D. W. Kicklighter, M. Manizza, Q. Zhuang, M. Chen, M. J. Follows, K. R. Gurney, J. W. McClelland, J. M. Melillo, B. J. Peterson, and R. G. Prinn. 2010. An analysis of the carbon balance of the Arctic Basin from 1997 to 2006. *Tellus B* 62: 455-474.
- Michener, W., J. Brunt, J. Helly, T. Kirchner, and S. Stafford. 1997. Nongeospatial metadata for the ecological sciences. *Ecological Applications* 7(1):330–342.
- Miller S.D. 2017. [Product Archival, Seasonal Closeout and Dataset Certification Procedures for the Arctic and Central Alaska Inventory and Monitoring Networks](#). Standard Operating Procedure. National Park Service Arctic and Central Alaska Inventory and Monitoring Networks. Fort Collins, CO.
- Noltimier, H. C., and P. A. Colinvaux. 1976. Geomagnetic excursion from Imuruk Lake, Alaska. *Nature* 259: 197-200.
- NPS. 2005. Director’s Order #11A: Information and technology management. National Park Service. http://www.nps.gov/policy/DOrders/DO_11A.pdf. Retrieved 2015-08-20.
- NPS. 2005. Director’s Order #11B: Ensuring Quality of Information Disseminated by the National Park Service. National Park Service. <http://www.nps.gov/policy/DOrders/11B-final.htm>. Retrieved 2015-12-08.
- NPS. 2006. Management Policies 2006. National Park Service. Washington, DC.
- NPS. 2012. Director’s Order #11D: RECORDS AND ELECTRONIC INFORMATION MANAGEMENT. National Park Service. http://www.nps.gov/policy/DOrders/DO_11D.pdf. Retrieved 2015-12-08.
- NPS. 2005. NPS REFERENCE MANUAL RM 66B: HANDLING PROTECTED INFORMATION. Unpublished Draft Policy. National Park Service. Washington, DC.
- NPS. 2008a. Data management guidelines for inventory and monitoring networks. Natural Resource Report NPS/NRPC/NRR—2008/035. National Park Service, Fort Collins, Colorado.
- NPS. 2008b. Data and information management plan: Arctic Network Inventory and Monitoring Program. Natural Resource Report NPS/ARCN/NRR—2008/053. National Park Service, Fort Collins, Colorado.
- NPS. [No date] Information Quality – Ensuring Objectivity, Utility, and Integrity of Information Used and Disseminated by the National Park Service. <http://www.nps.gov/policy/DOrders/DO11B--Update.htm>)
- O’Donnell JA, and Jones JB Jr. 2006. Nitrogen retention in the riparian zones of catchments underlain by discontinuous permafrost. *Freshwater Biology* doi:10.1111/j.1365-2427.2006.01535.x.

- O'Donnell JA, Aiken GR, Butler KD, Douglas TA. 2015a. Chemical composition of large lakes in Alaska's Arctic Network: 2013-2014. Natural Resource Data Series. NPS/ARCN/NRDS – 2015/985. National Park Service, Fort Collins, Colorado.
- O'Donnell JA, Aiken GR, Butler KD, Trainor TP, Douglas TA. 2015b. Chemical composition of rivers in Alaska's Arctic Network, 2013-2014. *Natural Resource Data Series*. NPS/ARCN/NRDS – 2015/809. National Park Service. Fort Collins, Colorado. Published Report-2222958.
- O'Donnell JA, Aiken GR, Swanson DK, Panda S, Butler KD, and Baltensperger AP. 2016. Dissolved organic matter composition of Arctic rivers: linking permafrost and parent material to riverine carbon. *Global Biogeochemical Cycles* 30: 1811-1826, doi:10.1002/2016GB005482.
- O'Reilly, C. M. et al. 2015. Rapidly and highly variable warming of lake surface waters around the globe. *Geophysical Research Letters* 42: 10773-10781, doi:10.1002/2015GL066235.
- Panda et al. 2016. High-resolution permafrost modeling in the Arctic Network national parks, preserves, and monuments. Natural Resource Report NPS/ARCN/NRR-2016/1366. National Park Service. Fort Collins, Colorado.
- Prowse, T. D., F. J. Wrona, J. D. Reist, J. J. Gibson, J. E. Hobbie, L. M. J. Levesque, and W. F. Vincent. 2006. Climate change effects on hydroecology of arctic freshwater ecosystems. *Ambio* 35: 347-358, doi:10.1579/0044-7744(2006)35[347:CCEOHO]2.0.CO;2.
- Raymond, P. A., J. Hartmann, R. Lauerwald, S. Sobek, C. McDonald, M. Hoover, D. Butman, R. Striegl, E. Mayorga, C. Humborg, P. Kortelainen, H. Durr, M. Meybeck, P. Ciais, and P. Guth. 2013. Global carbon dioxide emissions from inland waters. *Nature* 503: 355-359, doi:10.1038/nature12760.
- Reynolds, M. and L. M. Clough. 2010. The development of a long-term monitoring protocol for the coastal lagoons of Cape Krusenstern National Monument: pilot sampling July 2009. Natural Resource Data Series NPS/ARCN/NRDS – 2010/127. National Park Service, Fort Collins, Colorado.
- Roulet, N. and T. R. Moore. 2006. Environmental chemistry: browning the waters. *Nature* 444: 283-284, doi:10.1038/444283a.
- Schindler, D. W., E. J. Fee, and T. Rusczyński. 1978. Phosphorus input and its consequences for phytoplankton standing crop and production in the experimental lakes area and in similar lakes. *Journal of the Fisheries Research Board of Canada* 35: 190-196, doi:10.1139/f78-031.
- Schlesinger, W. H. 1997. Biogeochemistry: An Analysis of Global Change. Academic Press, San Diego, CA.

- Shuter, B. J., D. A. Schlesinger, and A. P. Zimmerman. 1983. Empirical predictors of annual surface water temperature cycles in North American Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 1838-1845, doi:10.1139/f83-213.
- Smith, L. C., Y. Sheng, G. M. MacDonald, and L. D. Hinzman. 2005. Disappearing Arctic lakes. *Science* 308: 1429, doi:10.1126/science.1108142.
- Smol, J. P., et al. 2005. Climate-driven regime shifts in the biological communities of arctic lakes. *Proceedings of the National Academy of Sciences* 102: 4397-4402, doi:10.1073/pnas.0500245102.
- Striegl, R. G., M. M. Dornblaser, C. P. McDonald, J. R. Rover, and E. G. Stets. 2012. Carbon dioxide and methane emission from the Yukon River system. *Global Biogeochemical Cycles* 26, doi:10.1029/2012GB004306.
- Swanson, D. K. 2013. Surface water area change in the Arctic Network of National Parks, 1985-2011: analysis of Landsat data. Natural Resource Data Series. NPS/ARCN/NRDS-2013/445.
- Tank, S. E., R. G. Striegl, J. W. McClelland, and S. V. Kokelj. 2016. Multi-decadal increases in dissolved organic carbon and alkalinity flux from the Mackenzie drainage basin to the Arctic Ocean. *Environmental Research Letters* 11, doi:10.1088/1748-9326/11/5/054015.
- Toohey, R. C., N. M. Hermen-Mercer, P. F. Schuster, E. A. Mutter, and J. C. Koch. 2016. Multidecadal increases in the Yukon River Basin of chemical fluxes as indicators of changing flowpaths, groundwater, and permafrost. *Geophysical Research Letters* 43, doi:10.1002/2016GL070817.
- Vitousek, P. M. and R. W. Howarth. 1991. Nitrogen limitation on land and in the sea: how can it occur? *Biogeochemistry* 13: 87-115.
- Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, San Diego California.
- Wilde, F. D. 2008. Guidelines for field-measured water quality parameters (ver. 2.0) U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chapter A6, section 6.0, <http://pubs.water.usgs.gov/twri9A>.
- Williams, S. G. and H. G. Stefan. 2006. Modeling of lake ice characteristics in North America using climate, geography and lake bathymetry. *Journal of Cold Regions Engineering* 20:140-167.
- Williamson, C. E., J. E. Saros, W. F. Vincent, and J. P. Smol. 2009. Lakes and reservoirs as sentinels, integrators, and regulators of climate change. *Limnology and Oceanography* 54: 2273-2282, doi:10.4319/lo.2009.54.6_part2.2273.

Yue, S., P. Pilon, B. Phinney, and G. Cavadias. 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes* 16: 1807-1829, doi:10.1002/hyp.1095.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 953/147863, August 2018

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525