U.S. Department of the Interior
National Park Service

Natural Resource Program Center

Southwest Alaska Freshwater Flow System Monitoring Protocol Narrative

Southwest Alaska Network

Version 1.0, January 2011

Natural Resources Report NPS/SWAN/NRR—2011/XXX

On The Cover
Lake Kontrashibuna with Lake Clark in the background in Lake Clark National Park and Preserve
Photograph by: Jeff Shearer, Southwest Alaska Network

Southwest Alaska Freshwater Flow System Monitoring Protocol Narrative

Version 1.0, January 2011

Natural Resources Report NPS/SWAN/NRR—2011/XXX

Jeff Shearer
Southwest Alaska Network
240 W. 5th Ave.
Anchorage, AK 99501

Claudette Moore
Southwest Alaska Network
Katmai National Park and Preserve
PO Box 7
King Salmon, AK 99613

January 2011

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; monitoring protocols; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly-published newsletters.

Views, statements, findings, conclusions, recommendations and data in this report are solely those of the author(s) and do not necessarily reflect views and policies of the U.S. Department of the Interior, National Park Service. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service. This report is available from the Natural Resource Publications Management Web site (http://www.nature.nps.gov/publications/NRPM) or directly from the Southwest Alaska Network website (http://science.nature.nps.gov/im/units/swan/).

Please cite this publication as:

Shearer, J., and C. Moore. 2011. Southwest Alaska Freshwater Flow System Monitoring Protocol Narrative, Southwest Alaska Network. Natural Resource Report NPS/AKR/SWAN/NRR—2011/XXX. National Park Service, Fort Collins, Colorado.

NPS D-XXX, January 2011

Change History

Original Version #	Date of Revision	Revised By	Changes	Justification	New Version #

1. "Version numbers increase incrementally by hundredths (e.g., version 1.01, version 1.02, …etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0…). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making changes along with the new version number.
2. Notify the SWAN Date Manager of any changes to the Protocol Narrative or SOP so that the new version number can be incorporated in the Metadata of the project database.
3. Post new versions on the internet and forward copies to all individuals with a previous version of the Protocol Narrative or SOP. A list will be maintained in an appendix at the end of this document.

Note: Standard operating procedures (SOPs) are bound in a separate accompanying document:

SOP 1: Field Season Preparation, Training, and Safety
SOP 2: Geographic Information Systems GRTS Points Development
SOP 3: Physical Water Quality Instrument Calibration and Maintenance
SOP 4: Vertical Lake Profile, Continuous, and In Situ Sampling for Physical Water Quality Parameters
SOP 5: Wadeable Stream Flow Measurement
SOP 6: Boat-Based Stream Discharge Measurements Using Current Meter
SOP 7: Water Level Measurements
SOP 8: Moored All-Season Temperature Array
SOP 9: Equipment Decontamination of Aquatic Invasive Species
SOP 10: Data Processing
SOP 11: Water Quality and Hydrologic Data Management
SOP 12: Data Quality Assurance and Quality Control
SOP 13: Water Quality and Hydrologic Data Analysis and Reporting

Contents

Page

Figures vii

Tables viii

Executive Summary ix

Acknowledgements x

Background and Objectives 1

Introduction 1

Rationale for selecting this resource to monitor 2

Description of and Rationale for Monitoring Key Variables of Interest 4

Surface Hydrology 4

Water Quality 6

Summary of Historical Water Quality and Hydrologic Data and Description of Resources 10

Measureable Objectives 11

Surface Hydrology 11

Water Quality 11

Sample Design 15

Rationale for Selecting this Sampling Design over Others 15

Freshwater Flow System Sampling Design and Lake Selection 15

Sample Location Selection 19

Sample Frequency and Replication 20

Field Methods 23

Field Season Preparation 24

Data Collection 24

Contents (continued)

Page

Water Quality 26

Surface Hydrology 30

Post-Collection Processing 31

End of Field Season 32

Data Management, Analysis, and Reporting 35

Metadata Procedures 35

Database Design 35

Data Reporting and Analysis 37

Personnel Requirements and Training 41

Roles and Responsibilities 41

Qualifications and Training 41

Operational Requirements 45

Annual Workload and Field Schedule 45

Equipment Needs 45

Water Quality Equipment and Supplies 45

Surface Hydrology Equipment and Supplies 46

Budget 47

Staff Salaries and Expenses 47

Literature Cited 49

Figures

Page

Figure 1. Map of National Park units included within the Southwest Alaska Inventory and Monitoring Network 1

Figure 2. Conceptual model of projected landscape-level changes in SWAN parks due to climate change (Bennett et al. 2006) 6

Figure 3. IKONOS Landsat color imagery of Naknek Lake and Lake Brooks (B), KATM 9

Figure 4. Lake systems within KATM monitored by SWAN. 17

Figure 5. Lake systems within LACL monitored by SWAN 17

Figure 6. Lake and river systems within KEFJ monitored by SWAN 17

Figure 7. Lake and river systems within ANIA monitored by SWAN 17

Figure 8. Potential GRTS sites generated from 1-km^2 cell grid system developed for Lake Clark, LACL. 19

Figure 9. Final GRTS sample sites developed for Lake Clark, LACL. 19

Figure 10. Water quality monitoring sites for Tier 1 lakes in LACL 25

Figure 11. Water quality monitoring sites for Tier 1 lakes in KATM 25

Figure 12. SWAN Water Quality Data Flowchart 36

Figure 13. Simplified database schema for SWAN's continuous water quality database 37

Figure 14A. Box and whisker plot displaying range of Secchi depths in three Naknek Lake basins and Lake Brooks. 40

Figure 14B. Depth profile of water temperature and specific conductivity in upper Lake Clark 40

Figure 14C. Isotherm displaying water temperature stratification in Lake Clark 40

Figure 14D. Bivariate plot displaying near-surface water temperature in Lake Clark 40

Figure 15. Southwest Alaska Network organizational chart 42

Tables

Page

Table 1. SWAN surface hydrology and freshwater chemistry vital sign variables. 5

Table 2. Summary of previous limnological and fisheries studies conducted in SWAN park units where physical and chemical water quality data were collected.....12

Table 3. Characteristics of SWAN lakes and rivers selected for water quality and hydrologic sampling 16

Table 4. Sampling frequency of SWAN freshwater flow systems 21

Table 5. Summary of SWAN's freshwater flow system sample design approach for water quality and surface hydrology vital signs 22

Table 6. Approximate timeline of activities in preparation for field work for freshwater flow systems monitoring 26

Table 7. Stabilization criteria (from NFM, 1998) and WRD recommended instrument specification criteria for recording field measurements.....28

Table 8. File naming conventions for aquatic monitoring data collected with automated data loggers 33

Table 9. Example of descriptive data summary for water temperature from Lake Clark, Lake Clark National Park and Preserve 39

Table 10. Network staff roles and responsibilities for freshwater flow systems monitoring.....43

Table 11. Annual operational schedule for freshwater flow system monitoring.....46

Table 12. Operational budget for water quality and surface hydrology monitoring 47

Executive Summary

The Southwest Alaska Network (SWAN) is one of 32 Inventory and Monitoring Networks covering 270 national park units within the National Park Service. These Networks serve an important role in providing park resources managers with important scientific data on the status and condition of vital park resources. This role was established in the Natural Resource Challenge which directed parks to place a greater emphasis on natural resource stewardship in meeting the National Park Service mission "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations."

SWAN covers a diverse range of national park units, including Alagnak Wild River, Aniakchak National Monument and Preserve, Katmai National Park and Preserve, Kenai Fjords National Park, and Lake Clark National Park and Preserve, spanning 3.8 million hectares across the Kenai and Alaska Peninsulas. Alpine, glacial, marine, coastal, boreal, tundra, and freshwater ecosystems are all represented within the bounds of the SWAN. Park staff and subject matter experts recognized the diversity and relatively unaltered state of these ecosystems when identifying important park resources for long-term monitoring. The long-term monitoring plan established by the SWAN (Bennett et al. 2006) focuses on geology and physical science (glaciers, climate and weather), marine nearshore, vegetation, wildlife, landscape processes, and freshwater components of these five southwest Alaska parks.

The freshwater resources of these landscape are impressive ranging from countless small streams to five designated Wild Rivers to large, complex lake systems. This protocol along with the accompanying standard operating procedures (SOPs) provides the details of how SWAN will monitor these vast freshwater resources. We ask that readers recognize this document may be revised as we continue to gather monitoring data and improve our methods. We will take a careful, conservative approach in modifying SOPs to ensure that the scientific credibility of the data we collect is upheld. We anticipate that as data are collected and synthesized new questions will arise leading to more in-depth research and analysis. Our hope is that this document will assist the National Park Service in carrying out its mission and lead to a greater understanding of the freshwater ecosystems of southwest Alaska.

Acknowledgements

We wish to thank National Park Service staff Dan Young, Troy Hamon, Chuck Lindsay, Fritz Klasner, Bill Thompson, Cuyler Smith, Dorothy Mortenson, Pete Penoyer, Roy Irwin, Michael Shephard, Amy Larsen, Trey Simmons, Dave Thoma, and Eric Starkey for their thoughts and insight in developing this protocol. Additionally, we thank to Dr. Sonia Nagorski (University of Alaska Southeast), Drs. Chris Arp and Erik Beever (USGS Alaska Science Center), Chad Smith (USGS WRD), and Sue Mauger (Cook Inletkeeper) for insight and advice on monitoring design. Cuyler Smith and Russ Frith (Southwest Alaska Network) are credited with drafting the Data Management SOP within this document. Much of the groundwork for this protocol was established by Laurel and Alan Bennett (retired, National Park Service), we are especially grateful for their efforts. Comments and reviews were provided by Amy Larsen, Dan Young, and Scott Pavey of the National Park Service.

Background and Objectives

Introduction

The Southwest Alaska Network (SWAN) is one of four networks established within Alaska as part of the National Park Service (NPS) Inventory and Monitoring (I&M) Program. It consists of five units of the NPS (Figure 1): Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Lake Clark National Park and Preserve (LACL). Collectively, these units comprise 3.8 million hectares (9.4 million acres) and extend over 650 km (400 miles) of the Alaska and Kenai Peninsulas.

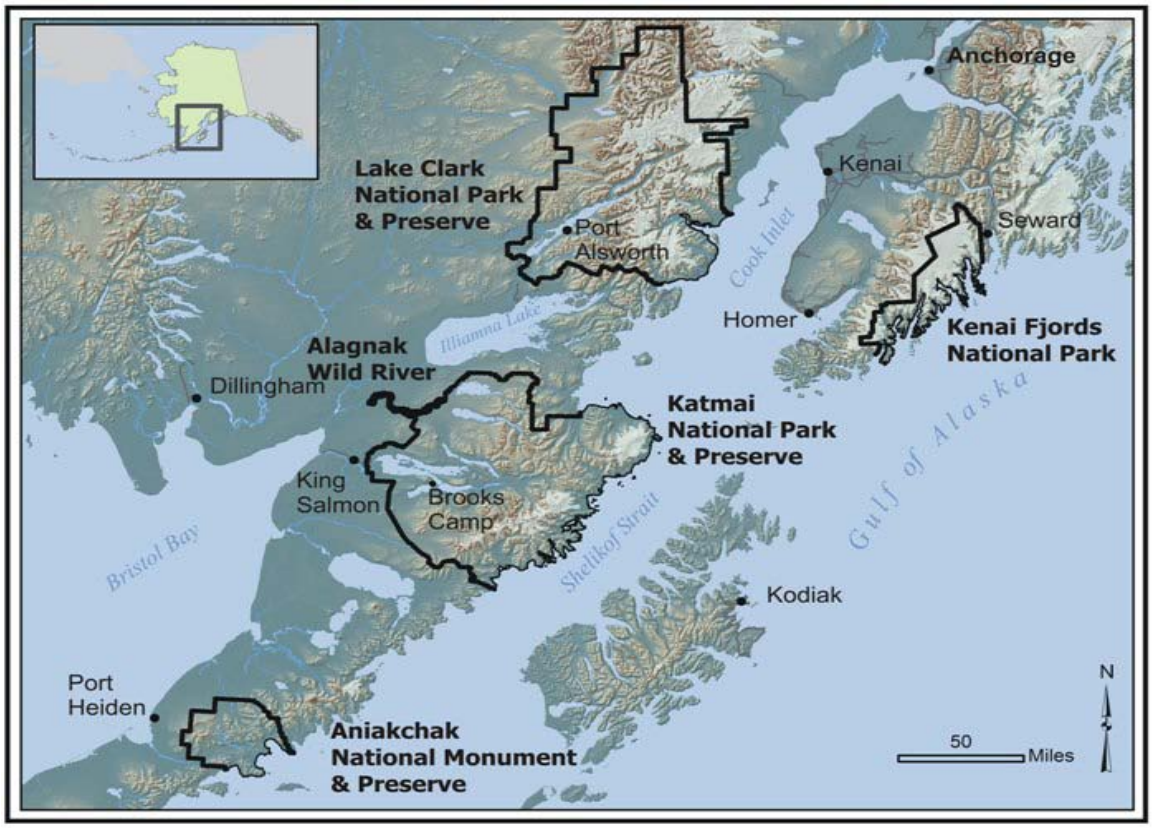

Figure 1. Map of National Park units included within the Southwest Alaska Inventory and Monitoring Network.

The Vital Signs Monitoring Program was established in 2001 to assess the status and trends in selected resources representing the overall health of the park. These resources are considered especially vulnerable to alteration by stressors or have important human values. Understanding the range of natural variation in park ecosystems serves as a basis for detecting long-term changes to park resources, and informs management decisions towards maintaining the integrity of park ecosystems. During monitoring development workshops, scientists from universities and state and federal agencies identified freshwater chemistry and surface hydrology as two resources of aquatic systems that warranted long-term monitoring in SWAN park units (Bennett et al. 2006).

The Freshwater Flow System protocol narrative and 13 Standard Operating Procedures (SOPs) provide in-depth information on monitoring water quality and surface hydrology in aquatic systems within SWAN. A summary of the background, justification, sampling methodology, and procedures are detailed in this protocol narrative. The SOPs are meant to provide step-by-step instructions for all tasks associated with field preparation and training, instrument programming and use, data collection, data management, analyses, and reporting.

Rationale for selecting this resource to monitor

As integrators of water, energy, nutrients, solutes, and pollutants from the landscape and atmosphere, lakes and rivers are interactive components of their environment (Minshall et al. 1985, Soranno et al. 1999, Riera et al. 2000). As a result, lakes and rivers serve as ideal sentinels of environmental change on the surrounding landscape (Williamson et al. 2008, Adrian et al. 2009, Schindler 2009). Specific to lotic systems, the inter-connected relationship between flowing water and the landscape was succinctly characterized by Leopold et al. (1964), "rivers are the gutters down which run the ruins of continents." Lakes were studied early on as microcosms (Forbes 1887). Scientists later recognized the value in examining variables beyond the shoreline to describe findings within the lake itself (Vollenweider 1968, Hynes 1975, Likens 1984). The integrated *flow system* comprised of lakes and their watershed components (e.g., outlets, inflowing tributaries, contributing lakes) was recognized in later years (Likens 1984). The flow system concept describes a spatial template for relationships between the water and land, and is important for understanding the regional connectivity of physical, chemical, and biological processes across ecosystems.

SWAN aquatic systems are represented by two of the largest lakes in the National Park system, Naknek Lake (58,824 hectares) in KATM and Lake Clark (31,117 hectares) in LACL, numerous multi-lake systems, and thousands of kilometers of rivers, including five designated "Wild Rivers." The Naknek Lake and Lake Clark systems are so extensive that their watersheds cover 48.6% and 31.6% of the land area within their respective parks. In establishing these parks, Congress recognized the cultural, ecological, recreational, and economic importance of aquatic resources with reference to protecting and maintaining rivers and/or lakes in their natural state in the enabling legislation for ALAG, ANIA, KATM, and LACL (ANILCA 1980). Specifically, §201(7) of ANILCA established LACL … *to protect the watershed necessary for perpetuation of the red salmon fishery in Bristol Bay; to maintain unimpaired the scenic beauty and quality of the Alaska Range and the Aleutian Range, including… wild rivers, lakes, waterfalls … in their natural state.* Although KATM was originally created as a National Monument in 1918 (Presidential Proclamation No. 1487, 40 Stat. 185; September 24, 1918), subsequent enlargements were to …*include all of Naknek Lake for protection of ecological and aquatic resources*. Additionally, § 202(2) of ANILCA cites …*the monument addition and preserve* (of KATM) *shall be managed for the following purposes, among others: …to maintain unimpaired the water habitat for significant salmon populations*. Legislation for KEFJ gives special reference to the Harding Ice Field (ANILCA 1980) which serves as the water source for most streams and lakes within the park.

Currently, aquatic systems within SWAN park units are pristine in that (i) natural watershed processes are operating, including disturbances such as floods and seasonal changes in flow; (ii) water quality is, by national standards, unimpaired (i.e., no 303(d) surface waters exist within SWAN, ADEC 2006), although near-field and far-field influences have in all likelihood introduced small but unknown amounts of contaminants; and (iii) aquatic fauna diversity and productivity naturally vary on temporal and spatial scales. Aquatic systems in the interior of KATM and LACL are so extensive that they form the physical template upon which nearly all biological systems are organized (Bennett et al. 2006). The vast freshwater flow systems of SWAN parks provide the back drop for a "veritable living natural museum" punctuated by Pacific salmon and the people these fish have sustained for hundreds of years throughout the Bristol Bay region (Branson 2007). The return of spawning Pacific salmon (*Oncorhynchus* sp.) from the ocean to lakes and rivers is a classic example of a critical biological phenomenon that links aquatic systems in SWAN parks within a broader regional context.

After spawning, Pacific salmon die, providing a source of marine-derived nitrogen and carbon (Kline et al. 1993) that can heavily influence nutrient dynamics throughout the watershed (Gende et al 2002, Naiman et al. 2002, Schindler et al. 2003). This process occurs primarily through remineralization – the uptake of nutrients through primary production (Mathisen et al. 1988). Flora and fauna across all trophic levels in aquatic (Kline et al. 1990, Bilby et al. 1996, Wipfli et al. 1999, many others) and terrestrial systems (Hilderbrand et al. 1999, Helfield and Naiman 2001, Bartz and Naiman 2005, many others) benefit from this annual influx of nutrients. Thus, salmon serve as biological conveyor carrying critical nutrients across ecosystem boundaries (e.g., marine, estuarine, and freshwater) to their spawning areas via a network of flow systems. Maintaining the ecological integrity of freshwater flow systems in SWAN park units is vital to ensuring the long-term preservation of Pacific salmon, a key function recognized in the enabling legislation for two SWAN parks.

Albeit remote and expansive, freshwater systems of SWAN park units are still susceptible to anthropogenic influences, particularly climate change and contaminants. Research indicates that freshwater systems in arctic and subarctic regions are especially sensitive to changes in climate (McDonald et al. 1996, Schindler 2001, Wrona et al. 2005, Schindler and Smol 2006, Woo et al. 2006, Smol and Douglas 2007, Francis et al. 2009). A recent synthesis of the Arctic Council, an intergovernmental forum representing most northern nations, predicts major changes to arctic and subarctic freshwater ecosystems over the next century due to climate change (ACIA 2004). Temperatures are increasing in Arctic areas at about twice the global average rate, with an expected 4 - 7º C increase within the next 100 years. The report concludes that changes in the annual hydrologic cycle and water quality are likely to alter the productivity, diversity, and community composition of freshwater ecosystems.

More regionally, the Alaska Regional Assessment Group of the U.S. Global Change Research Program (1999) has documented climate changes over the past 100 years with noticeable changes since 1940. Subsequent with warmer air temperatures has been

increased precipitation (Groisman and Easterling 1994), glacial melting (Sapiano et al. 1998), and a longer growing season (Keyser et al. 2000). Kyle and Brabets (2001) used model predictions based on increasing air temperatures to evaluate river reaches susceptible to a 3º C or greater increase in water temperature among rivers in the Cook Inlet Basin of south central Alaska. Of the 32 sites evaluated, 15 sites were predicted to experience water temperatures $\geq$ 3º C, an increase considered significant for the incidence of fish diseases (Kyle and Brabets 2001). The hydrologic and water quality alterations resulting from changes in stream flow, ice cover, evapotranspiration, and water storage in snowpack, glaciers, and lakes will undoubtedly have a profound impact on ecosystem structure and function within SWAN park units and across southwest Alaska.

While we recognize the inter-connectedness and importance of all surface and ground waters in any given watershed, freshwater monitoring will be directed primarily towards large lake systems because these waters are iconic resources for most SWAN park units, have important ecological, cultural, and recreational value, are of high management concern with direct legislative requirements, and can be logistically easier to access. However, our goal is not to examine large lakes as isolated basins, but to recognize these waters as flow systems. As such, we will incorporate all components within these large lake flow systems into our monitoring design, including outlets, inflowing tributaries, contributing lakes, and a spatially-balance coverage of the lake basin itself.

Description of and Rationale for Monitoring Key Variables of Interest

The NPS Water Resources Division staff recommended that a set of core water quality parameters (water temperature, dissolved oxygen, pH, specific conductivity) and water flow / level (i.e., discharge and stage) be measured in all NPS I&M Network park units as part of the aquatic vital signs monitoring efforts (NPS 2002). Due to the glacial influence of many flow systems in SWAN park units, we chose to include additional measurements for turbidity at lotic sites and water clarity (e.g., Secchi depth) at lentic sites. A more complete suite of parameters, including measures of nutrients, major ions, metals, dissolved organic carbon, and chlorophyll *a*, may be considered in the future but is not planned at this time. A summary of surface hydrology and freshwater chemistry variables to be monitored is provided in Table 1.

Surface Hydrology

Hydrology and geology are the two principle drivers that dictate structure and function of all aquatic systems (Leopold et al. 1964). In the broadest sense, hydrology encompasses the distribution and movement of water and its interactions on the surrounding environment whether in the ground, on the landscape, or in the atmosphere. Discharge and water level (or stage) measurements are two hydrologic parameters critical to understanding the biophysical patterns observed in aquatic systems. Discharge refers to the longitudinal movement of water and is measured as the volume of water that moves past a given point over a unit of time (commonly expressed as cubic feet per second). Water level or stage refers to the vertical movement of water. These two parameters dictate a wide variety of physical, chemical, and biological interactions that structure

Table 1. SWAN surface hydrology and freshwater chemistry vital sign variables. Ecological significance and stressors synthesized from Wetzel (2001).

Physical Parameters	Ecological Significance	Stressors
Water Temperature	A basic control on rates of biological and chemical activity.	Altered hydrology, air temperature, canopy shading, and glacial extent.
Specific Conductivity	An index of ion concentration, including those affecting pH buffering capacity	Changes to hydrology affecting sediment load. Acidification. Volcanic ash deposition
Dissolved Oxygen	Required for aerobic metabolism. Deficit levels may be harmful to aquatic biota and drive redox transformations.	Changes in aquatic respiration, ice cover, and lake circulation.
Turbidity	Reduces light transmission and can influence primary productivity. Suspended sediments in turbid waters can clog or abrade fish gills resulting in stress or death.	Changes to hydrology affecting sediment load. Changes to organic inputs. Volcanic ash deposition.
pH	A basic influence on ion chemistry. Most biota are adapted to fairly narrow pH ranges.	Changes in decomposition. Volcanic ash deposition (short term). Nitrification. Changes in metals states.
Water Flow - Discharge	Primary driving force in structuring all flowing waters. Affects all physical, chemical, and biological functions in rivers and streams.	Changes to precipitation patterns, air temperature, and evapotranspiration rates.
Water Level - Stage	Used in conjunction with discharge to calculate hydrographs, loading rates, mass balance budgets, and water storage.	Changes to precipitation patterns, air temperature, and evapotranspiration rates.

freshwater flow systems from nutrient loading to the timing and success of fish spawning. Anthropogenic disturbances that alter the timing and magnitude of hydrologic features within SWAN park units will likely have a trickledown effect and impact all freshwater flow system interactions.

Climate warming is changing arctic and sub-arctic hydrology in several ways affecting the timing and magnitude of stream flows (Wrona et al. 2005):

- Snow cover has declined by 10% over the past 30 years and is predicted to decrease an additional 10 - 20% by 2070. This reduces water storage contributing to spring snowmelt.

- Earlier snowmelt has changed the timing of peak river flows, with peaks in the annual hydrograph occurring as much as three weeks earlier.

- Precipitation, occurring mostly during the summer, has increased 8% over the past century and is predicted to increase about 20% over the next 100 years in Arctic areas.

- Decrease in lake and river ice cover and melting of glaciers contribute to changing sources and timing of stream flows and decreased flooding caused by ice jams. Giffen et al. (2007) reported a decrease in glacial extent of 2.3% for KEFJ and 7.7% for KATM since 1986.

According to the Arctic Council report (ACIA 2005), the net effect of these changes is likely to be a warmer, wetter environment with less seasonal variation in stream flow for at least the next century. A more stable hydrograph and reduced winter snow storage will likely result in reduced flood disturbance and a shift in hydrograph timing, ultimately reducing the disturbance events that dictate quality and quantity of aquatic habitats (Wrona 2005). Figure 2 provides a conceptual model of projected landscape-level changes anticipated for SWAN parks in relation to climate change.

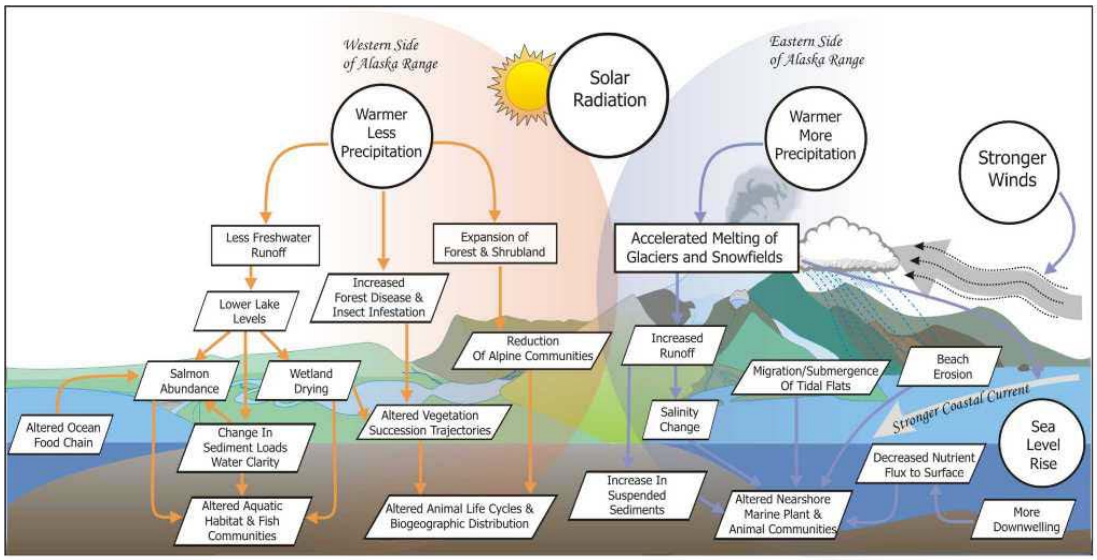

Figure 2. Conceptual model of projected landscape-level changes in SWAN parks due to climate change (Bennett et al. 2006).

Water Quality

SWAN park waters are relatively pristine, with no lakes or rivers listed as impaired pursuant to section 303(d) of the Clean Water Act (ADEC 2008). Most lakes and streams are oligotrophic, with low biological activity, low nutrient loads, and low to moderate acid buffering capacity (Chamberlain 1989, LaPerriere 1996, Brabets 2002, Bennett 2004). However, water quality in these parks is vulnerable to moderate changes in environmental conditions, inputs of nutrients, or contaminant inputs from external sources. Potential agents of change to water quality include climate warming, inputs of contaminants from atmospheric and near-field sources including biological conveyors, such as salmon and volcanic activity.

Many factors contribute to the impacts of climate change on water quality, including altered hydrology, precipitation, primary productivity, and decomposition (Wrona 2005). Change may be experienced through gradual shifts in water quality parameters or through abrupt shifts as climatic variables cross threshold points (Chapin et al. 1995). Changes in ocean circulation patterns may also affect warming rates for a given area (National Research Council 2002). For at least the next century, freshwater resources are predicted to become warmer, more turbid, enriched in nutrients and organic matter and more productive, which will significantly alter water chemistry and the availability of suitable

habitat and food resources available to fish and wildlife populations dependent on aquatic food supplies in SWAN freshwater systems (Wrona et al. 2005).

Increased export of dissolved organic carbon (DOC) from wetlands in recent decades has been linked to climate change (Freeman et al. 2001) and is expected to accelerate over the next century (ACIA 2004). An enhanced supply of carbon may have both positive and negative effects on water quality. For instance, biota may benefit from increased energy and nutrients sources; however, primary productivity may be inhibited by increased turbidity (Williamson et al. 1999). Although low biological activity is mostly a function of temperature, evidence for both nitrogen and phosphorus limitation of algal production has been observed in SWAN lakes (LaPerriere 1996, Chamberlain 1989). Wilkens (2002) reported both turbidity limiting algal production in the glacial inlet end of Lake Clark and nutrient limitation to algal production in the outlet end of Lake Clark. Primary production would likely respond to enhanced nutrient inputs or shifts in turbidity, especially in glacially-influenced lakes.

Nitrogen and carbon availability are also likely to be influenced by changes in terrestrial and riparian vegetation (Walther et al. 2002). Cover of nitrogen-fixing green alder (*Alnus crispa*) in southwest Alaska is greatly influenced by climate (Hu et al. 1995). In addition to providing an often-limiting nutrient, high rates of N-fixation often result in soil acidification, and historical climate-related variation in alder cover has been related to changes in aquatic productivity and geochemistry. Hu et al. (2001) documented the influence of increased alder distribution during the Holocene period in southwestern Alaska on increased primary production in Grandfather Lake. Within KATM, alder comprises nearly 20% of the vegetative cover, but a combination of native defoliators (a noctuid moth - *Sunira verberata*) and pathogens (alder canker – *Valsa melanodiscus*) has resulted in the decline or death of at least 7% of the stands. Implications for nutrient dynamics within the surrounding watersheds are unknown at this time, although research is ongoing to document the ecological consequences of such large-scale mortality. While this pattern in plant phenology is not yet well-understood, records on lake ice phenology are beginning to show trends associated with warming air temperatures.

Lakes in the northern hemisphere are showing a trend towards later freeze-up dates and earlier break-up dates associated with increased air temperatures (Magnuson et al. 2000, Latifovic and Pouliot 2007). Longer ice-free seasons on lakes will likely result in more pronounced lake stratification patterns (Wrona et al. 2005). Previous studies have shown SWAN lakes to be only weakly (Chamberlain 1989, Wilkens 2002) or discontinuously (LaPerriere 1996) stratified, and Wilkins (2002) reported that in some years, stratification only lasted through July. Planktonic production is strongly influenced by lake stratification, and altered stratification patterns may influence productivity, food web dynamics and other physical and chemical variables (Wetzel 2001, Wrona et al. 2005).

Persistent organic pollutants and heavy metals have been widely distributed into northern freshwater systems by long-range atmospheric transport in the last 100 years (Rognerud et al. 1998) and especially over the past several decades (Barrie et al. 1998, Landers et al. 2008). Although atmospheric pollution and the threat of acid rain have declined

markedly in most of the continental United States, Alaska receives much of its air mass from Eastern European and Asian sources where future trends in air quality are far less certain. "Asian Haze" is a term used to describe large concentrations of airborne particulates originating from industrial and agricultural processes in Asia, which drift over northern latitudes (Shaw 1982).

The Western Airborne Contaminants Assessment Project was initiated as a collaborative effort between NPS Air Resources Division, federal agencies, and universities to evaluate the concentration of airborne contaminants in western National Parks and the ecological impacts that may be generated from deposition of atmospheric pollutants. Project results for lake trout (*Salvelinus namaycush*) tissue analyses revealed that mercury concentrations routinely exceeded piscivorous animal thresholds, and human thresholds for some individual fish, in test lakes within Gates of the Arctic National Park and Preserve and Noatak National Preserve in northern Alaska (Landers et al. 2008). Study lakes within these parks were non-anadromous (i.e., did not support a salmon population). In addition to these atmospheric sources of contaminants anadromous lake systems within the SWAN are also susceptible to aquatic sources of contaminants.

Pacific salmon serve not only as important nutrient sources, but as vectors in the transport of oceanic contaminants to freshwater systems (Ewald et al. 1998, Zhang et al. 2001). These contaminants are then amplified through freshwater foodwebs (Krummel et al. 2003). Many Alaskans rely on fish (both anadromous and non-anadromous species) as a main source of food (Jewett and Duffy 2007). Thus, the transport of contaminants into SWAN park units via migrating salmon is not only a potential water quality concern, but a concern of human health (Arnold and Middaugh 2004). In addition to the role of far-field sources, such as atmospheric deposition and biological transport, the introduction of contaminants from mining activities is of concern. The potential near-field influences of the proposed Pebble Mine, a large-scale gold and copper mine located adjacent to the southwest boundary of LACL (http://www.ndmpebblemine.com), is of particular concern. Impacts to aquatic systems by mining activities are well-documented (Buhl and Hamilton 1991, Saiki et al. 1995, Goldstein et al. 1999, Barry et al. 2000, many others) and impacts to park resources in Alaska from large-scale mines have occurred (Ford and Hasselbach 2001, Hasselbach et al. 2005).

Natural disturbances, such as climate and weather, floods, and biological episodes (e.g., insect outbreaks), can play an even larger role in structuring aquatic ecosystems than anthropogenic disturbances due to the scale and magnitude at which natural events occur. SWAN park units are located along the convergence of the Pacific Plate with the North American Plate. As such, tectonics and associated landscape features play a very active role in structuring SWAN freshwater systems. SWAN lakes and rivers bordering the Aniakchak, Redoubt, Iliamna and Katmai / Novarupta volcanoes bare the legacies of blast, lahars, and intense inputs of pyroclastic sediments within recent history (Dorava and Miller 1999, Waythomas et al. 2000). Much larger areas are affected by deposition of windblown ash. Ashfall is a frequent occurrence (de Fontaine 2002) as highlighted most recently by eruptions in March and April 2009 of Mt. Redoubt in LACL. Leaching of volatile compounds from volcanic ash following deposition can alter stream chemistry

and lower pH for periods typically lasting for days to weeks (Witham et al. 2005). The most common leachates are chloride, sulfate, sodium, calcium, potassium, magnesium, and fluorine, with fluorine occasionally occurring in concentrations toxic to biota (Witham et al. 2005). Schaefer et al. (2008) documented a catastrophic flood event of sulfurous, clay-rich debris and acidic waters generated from volcanic activity on Mount Chiginagak in southwestern Alaska that killed all aquatic life in Mother Goose Lake in 2005. Turbidity reduced the volume of water supporting algal production by 70% following the 1990 eruption of Mt. Redoubt (Stottlemyer 1990). A significant fertilization effect is sometimes observed on riparian and aquatic primary productivity for periods lasting several years (Gregory-Eaves et al. 2004). LaPerriere and Jones (2002) noted most lakes within KATM are phosphorus-limited; however, they along with Goldman (1960) indicate that nitrogen may be limiting in the Iliuk Arm of Naknek Lake where runoff from nearby ash fields provide a source of phosphorus (Figure 3).

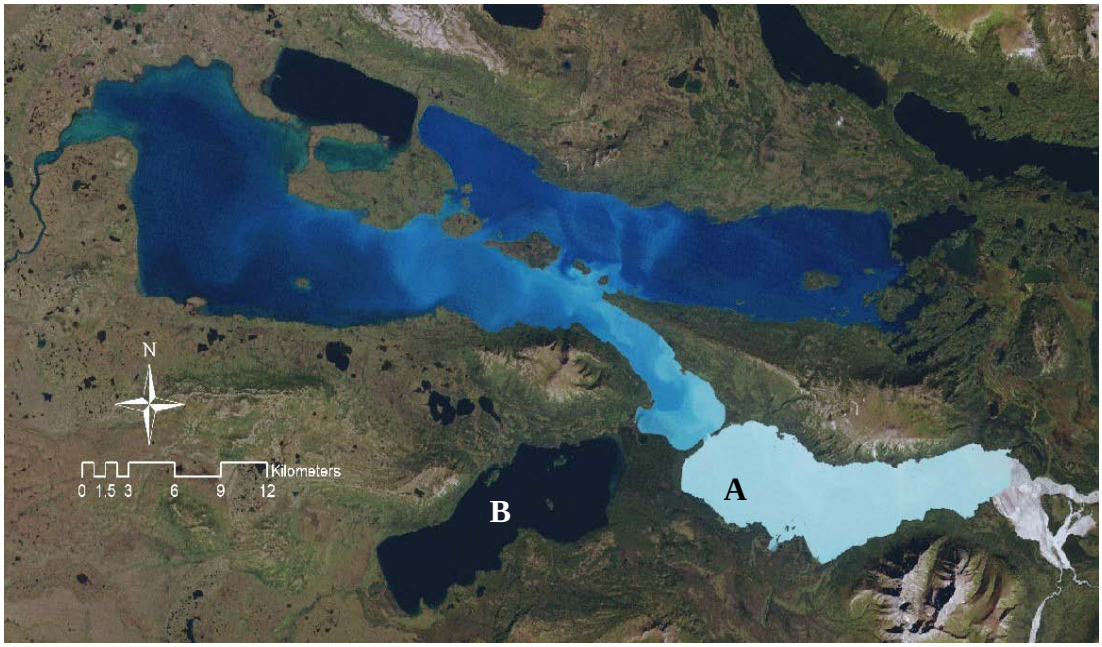

Figure 3. IKONOS Landsat color imagery of Naknek Lake and Lake Brooks (B), KATM. Note the stark contrast in water color between the Iliuk Arm (A) receiving surface runoff laden with volcanic ash and glacial silt and Lake Brooks (B) which receives surface water free of volcanic or glacial inputs.

Given the integrated role aquatic systems have within the environment, we have chosen to monitor surface hydrology and freshwater chemistry in freshwater flow systems as vital signs to assess the potential ecosystem-scale changes that can be induced by both natural and anthropogenic sources in a relatively pristine environment. This protocol addresses monitoring of freshwater flow systems to assess change in limnological and hydrological parameters for the purpose of tracking changes in water quality and quantity over time. The timing of lake ice freeze-up and break-up and ice cover duration will be monitored under the landscape processes vital sign (Bennett et al. 2006). Monitoring

resident lake fish and salmon, two other SWAN aquatic vital signs, will be addressed in a separate protocol.

Summary of Historical Water Quality and Hydrologic Data and Description of Resources

There have been several studies of baseline water quality conditions in SWAN park units, including inventories of ANIA (Bennett 2004, Cameron and Larson 1992), KATM (Goldman 1960, Gunther 1992, Keith et al. 1990, LaPerriere 1996), KEFJ (Bennett 2005) and LACL (Dale and Stottlemyer 1986, Stottlemyer and Chamberlain 1987, Chamberlain 1989, Brabets 2002, 2004, Wilkens 2002). Several fisheries studies also collected basic water quality data in SWAN park units including ANIA (Mahoney and Sonnevil 1991, Wagner and Lanigan 1988), KATM (Harry et al. 1964), and LACL (Russell 1980). The vast majority of these investigations have focused on the Naknek and Lake Clark watersheds, primarily due to the expanse of these systems, their importance as fisheries, and management priorities at the park level. See Table 2 for a more detail summary of water quality studies. Overall, these studies describe near-pristine systems bearing the imprint of glacial activity, geothermal activity and parent lithology. Lakes and rivers sampled were low in nutrients and dissolved carbon, with many carrying moderate to high mineral loads. Many of these data were evaluated relative to EPA and NPS WRD water quality criteria in summary reports for KATM (National Parks Service 1997a) and LACL (National Parks Service 1997b). Several streams had pH measurements below EPA criteria for protection of aquatic life. Concentrations of arsenic, lead, copper, chloride and sulfate exceeded EPA drinking water and/or aquatic life criteria at several monitoring stations. Isolated measurements of elevated cadmium, selenium, beryllium, zinc, and nitrite were also reported. Although low pH and high mineral concentrations were attributable to geothermal inputs in most cases, rapid weathering of glacial debris or volcanic ash may also be involved. Turbidity exceeded EPA criteria for aquatic life in a few streams near glaciers or volcanic ash deposits. To date, no long-term water quality monitoring programs have been initiated in SWAN park units.

Existing data to assess baseline stream flow relationships in SWAN park units are scant. No continuous stream gaging stations are currently maintained by the USGS Water Resource Division (USGS WRD) in SWAN watersheds. Historical stream flow data are available (online at waterdata.usgs.gov/nwis) for the following gaging stations: Nuka River below KEFJ park boundary (1984-2004), Johnson River near Lateral Glacier (1995-2004), Tanalian River (1951-1956), Tazimina River (1981-1986), Newhalen River (1951-1986), Eskimo Creek (1973-1984), and Kvichak River at Igiugig, AK (1967-1987). The River Forecast Center, a program within the National Oceanic and Atmospheric Administration, currently maintains a real-time gaging station on the Resurrection River at the boundary of KEFJ (http://aprfc.arh.noaa.gov/ahps2/hydrograph.php?wfo=pafc&gage=resa2). Seasonal interpretive staff at the Exit Glacier Visitor's Center (KEFJ) also record Exit Creek stage once per day and report stage readings to the River Forecast Center. Additional stream flow data collected in connection with water quality studies are available for several streams in KATM (LaPerriere 1996), LACL (Brabets 2002, Brabets and Riehle 2004, Brabets and Ourso 2006a, 2006b), and ALAG (Curran 2003).

Measurable Objective

The overall goal of SWAN's freshwater flow system monitoring program is to provide park managers with information needed to make management decisions that will maintain the ecosystem integrity that characterizes the large lake systems within southwest Alaska park units. Freshwater monitoring objectives address data needs to detect long-term trends in water quality (freshwater chemistry) and quantity (surface hydrology). For most parameters, measurements made during *index periods* will serve as a basis for inferring long-term patterns. Water level and temperature profiles will be continuously monitored in selected lakes to serve as indicators of long-term trends in intra-annual variability in lake level and temperature stratification. More quantifiable objectives will be developed after several years of data collection when natural variation can be estimated to set trend detection limits and power.

Surface Hydrology

Objectives for hydrological monitoring will be directed toward answering the broad question: how are the timing, duration, and magnitude of river discharge and lake level changing in key SWAN systems?

Objectives:

- Determine trends in the timing, duration, and magnitude of summer inflow (in select tributaries) and outflow (lake outlet) in the Lake Clark and Naknek Lake flow systems.
- Determine trends in the timing, duration, and magnitude of peak summer lake levels for select SWAN flow systems.

Water Quality

Water quality objectives are designed to address data needs for detecting changes in physical parameters of water throughout the lake basin. The core parameters, temperature, DO, pH, and specific conductance, drive chemical activity and influence the capacity of water to support life. Turbidity is an important indicator of light penetration, which affects productivity.

Objectives:

- Monitor the inter-annual variability, both vertically throughout the water column and spatially across the lake basin, of core parameters during the mid-summer index period for high-priority lake systems, and less frequently for other SWAN flow systems.
- Monitor inter- and intra-annual variability in lake temperature, duration and depth of thermocline, stratification patterns, and warming and cooling patterns in high-priority lake systems.
- Monitor the temporal variability of core parameters at select high-priority lake outlets during the ice-free period (approximately late May through September).

Table 2. Summary of previous limnological and fisheries studies conducted in SWAN park units where physical and chemical water quality data were collected.

Park	Source	Period of Record	Water Quality Parameters (Water bodies)
ALAG	Johnson and Berg 1999	1998	Aromatic compounds and hydrocarbons (Alagnak River)
	Curran	2003	Channel stability and water quality
ANIA	Wagner and Lanigan 1988	1984	Core parameters collected in conjunction with fisheries study (Meshik Lake).
	Mahoney and Sonnevil 1991	1987-1988	Core parameters collected in conjunction with fisheries study (7 locations on Surprise Lake)
	Cameron and Larsen 1993	1988-1989	Water temperature, Secchi depth, major cations and anions (Surprise Lake)
	Bennett 2004	2003	Core suite, major ions, DOC, chl *a*, TN, TP, TSS, TDS, metals. Advanced suite only collected at 8 sites. (Surprise Lake and tributaries, Meshik Lake, Aniakchak R., Willow Cr., Albert Johnson Cr., Iris Cr.)
KATM	Goldman 1960	1957	Algal plankton, nutrients, major cations and anions (Naknek Lake)
	Burgner et al. (1969)	1961-1962	Water temperature, DO, alkalinity, total dissolved solids, mineral analysis (Kukaklek, Nonvianuk, Colville, Grosvenor, and Naknek Lakes)
	Dahleberg 1976	1972-1976	Water temperature, pH, alkalinity, conductivity, Secchi depth (Naknek Lake)
	Gunther 1986 and 1992	1984-1986	Alkalinity, pH, major anions and cations (Battle, Kulik, Kukaklek, Iron Springs, Pirate, Nonvianuk, Murray, Hammersley, Coville, Idavain, Tony Malone, Pecker, and Lake Brooks)
	Cameron 1993	1989	Water temperature, Secchi depth, major cations and anions (Katmai and Kaguyak Crater Lakes, Brooks and Naknek Lakes)
	LaPerriere 1996 and 1997	1990-1992	Major anions and cations, nutrients, Secchi depth (Brooks, Coville, Grosvenor, Hammersly, Idavain, Murray, Naknek, Battle, Kukaklek, Kulik, and Nonvianuk Lakes)
	Keith et al. 1992	1979 – early 1990s	Physical and chemical water properties (Valley of Ten Thousand Smokes: River Lethe, Knife and Windy Creeks)
	Johnson and Berg 1999	1996-1997	Aromatic compounds and hydrocarbons (Kulik and Grosvenor Lakes)
	Frenzel and Dorava 1999	1998	Conductivity, pH, DO, chemical water analysis (Kamishak River)
KEFJ	Edmunson and Mazumder 2001	1981, 1986-1987, 1997	Water temperature, DO, irradiance, Secchi depth, major cations and anions, nutrients (Delight and Desire Lakes)
	Cieutat et al. *undated*	1993	Water temperature, pH, metals (Ferrum and Babcock Creeks, unnamed streams)
	Griffiths et al. 1999	Mid-1990s	Metals, arsenic, mercury, selenium, and chromium (Ferrum and Babcock Creeks)
	York and Milner 1999	1992-1994	Water temperature, conductivity, DO, pH, nutrients (Delusion Lake)
	Bennett 2005	2004	Temperature, pH, DO, specific conductivity, turbidity (Resurrection River, and freshwater lakes an d streams of Aialik Bay, Northwestern Fjord, Two Arm Bay, McCarty Fjord, and Nuka Bay)
LACL	Burgner et al. 1969	1961-1962	Water temperature, DO, alkalinity, total dissolved solids, mineral analysis (Kukaklek, Nonvianuk, Colville, Grosvenor, and Naknek Lakes)
	Mathisen and Poe 1969	1961	Secchi depth (Lake Clark)
	Dale and Stottlemyer 1986	1985-1987	Water temperature, DO, pH, alkalinity, specific

			conductivity, major cations and anions, heavy metals, nutrients (Lake Clark, Twin, Telaquana, Turquoise, Lachbuna, Kijik, Upper and Lower Tazimina, Portage, Kontrashibuna, Two Lakes, Tlikakila, Kijik, Tanalian, Chulitna Rivers, Currant Creek, and Lake Clark outlet)
	Stottlemyer and Chamberlain 1987	1985-1987	Water temperature, DO, pH, alkalinity, specific conductivity, major cations and anions, heavy metals, nutrients (Lake Clark, Twin, Telaquana, Turquoise, Lachbuna, Kijik, Upper and Lower Tazimina, Portage, Kontrashibuna, Two Lakes, Tlikakila, Kijik, Tanalian, Chulitna Rivers, Currant Creek, and Lake Clark outlet)
	Chamberlain 1989	1985-1987	Water temperature, DO, pH, alkalinity, specific conductivity, major cations and anions, heavy metals, nutrients (Lake Clark, Twin, Telaquana, Turquoise, Lachbuna, Kijik, Upper and Lower Tazimina, Portage, Kontrashibuna, Two Lakes, Tlikakila, Kijik, Tanalian, Chulitna Rivers, Currant Creek, and Lake Clark outlet)
	Deschu and LaPerriere 1998	1998	Water temperature, pH, DO, specific conductivity, turbidity, major cations and anions, nutrients (Tanalian, Kijik, Chulitna Rivers, Priest Rock Creek, 22-Creek)
	Wilkens 2002	1999-2000	Water temperature, DO, pH, conductivity, redox potential, Secchi depth, turbidity, suspended solids, total nutrients, total dissolved nutrients, true color (Lake Clark)
	Brabets 2002	1999-2001	Water temperature, pH, specific conductivity, DO, alkalinity, major cations and anions, dissolved solids, nutrients, organic carbon, suspended sediment (Lake Clark outlet, Currant Creek, and Tlikakila, Chokotonk, Chulitna, Kijik, and Tanalian Rivers)
	Brabets and Riehle 2003	2000	Water temperature, pH, specific conductivity, DO, alkalinity, nutrients, organic carbon, suspended sediment (Johnson River)
	Brabets and Ourso 2006b	2003-2004	Water temperature, pH, specific conductivity, DO, alkalinity, nutrients, organic carbon, major ions, dissolved solids, iron, manganese, trace elements (Crescent River and Crescent Lake)
	Brabets and Ourso 2006a	2004-2005	Water temperature, pH, specific conductivity, DO, alkalinity, nutrients, organic carbon, major ions, dissolved solids, iron, manganese, trace elements (Kijik and Portage Lake, Kijik and Little Kijik Rivers)

Sampling Design

Rationale for Selecting this Sampling Design over Others

A sampling design should determine the appropriate timing, frequency, and spatial scale at which data are collected to meet monitoring objectives in terms of both statistical and ecological relevance. Obtaining accurate and precise natural resource information can be expensive due to operational costs associated with staffing, travel, and equipment and natural variables, such as inclement weather. This is especially true in Alaska as most park lands are located in remote, wilderness settings where float planes, helicopters or boats provide the only feasible means of access (Bennett et al. 2006). Thus, logistical and budget considerations must be taken into account for any sampling design within SWAN park units.

Typically, three broad categories are considered for monitoring designs: census, targeted, and probabilistic. Census monitoring designs sample all units within a target population (e.g., all lakes within a park). Targeted designs select a target population based on judgment and/or a variety of selection criteria (e.g., stream size, slope, ease of access, etc) and are the most common monitoring designs among state and federal programs. The USGS National Water Quality Assessment Program is an example of a targeted monitoring design (http://water.usgs.gov/nawqa/). Probabilistic or statistical survey designs have gained popularity in recent years among water resource monitoring programs. This type of design ensures that the sample unit represents a random sub-sample of the target population, thus allowing results to be extrapolated beyond the sample unit. The EPA Environmental Monitoring and Assessment Program is an example of a probabilistic sampling design (http://www.epa.gov/emap/). Water resource programs typically use more than one monitoring design depending on the management question being addressed. However, census monitoring designs are rare due to the level of sampling effort and costs involved.

Freshwater Flow System Sampling Design and Lake Selection

Given the logistical challenges and costs in accessing most lakes in SWAN park units, monitoring freshwater flow systems will follow a targeted monitoring design. We realize this targeted approach will inhibit our ability to make statistical inferences to other park waters beyond those systems being monitored, but feel this is the only viable approach given the logistical and cost constraints of accessing most lakes within SWAN parks. Invited experts and SWAN park staff developed a 3-tier sampling design in which major lakes were prioritized within SWAN park units (Table 3). This design will ensure that key flow systems will be monitored annually even if I&M funding is greatly reduced. Prioritization criteria included level of use/management issues, spatial coverage, physical/ecological attributes and ease of access. Physical attributes include geologic source inputs (i.e., glacial and non-glacial sources), which are likely to respond differently to climate change. Ecological attributes, for example, the presence/absence of anadromous salmon, can be used to estimate the contribution of marine-derived nutrients and contaminants in freshwater systems.

Tier 1 (high priority) lakes offer relatively easy access and hence receive the heaviest use and are of greatest management concern. In KATM, Naknek Lake and Lake Brooks, both anadromous, are Tier 1 lakes representative of the Naknek flow system. Tier 1 lakes in LACL include the Newhalen flow system comprised of Lake Clark (anadromous) and Kijik Lake (anadromous). Exit Creek originates from Exit Glacier in KEFJ, an area of management concern for the park due to high visitor use (NPS 2004). Tier 2 (medium priority) lakes are less accessible than their Tier 1 counterparts; these lakes are important for expanding spatial coverage beyond Tier 1 lakes. That is, to compare trends observed at Tier 1 sites with other flow systems in the parks. Tier 3 lakes are the lowest sampling priority based on the categorization criteria, but their inclusion would further expand the spatial scale of park waters being monitored.

Tier 2 and 3 lakes are generally smaller lake systems than Tier 1 lakes and will be sampled less frequently. However, given the vast volume of the Tier 1 lakes, subtle changes in lake chemistry may go undetected for a longer period of time, whereas, these smaller lakes are expected to respond more quickly to climate change and anthropogenic inputs due to their smaller volume. Note, describing lakes as “large” or “small” is a subjective task. All lakes monitored by SWAN, except Delight Lake in KEFJ, are larger than 260 hectares. As we continue to collect baseline water quality data on all selected lakes within the SWAN and define natural variability, smaller lakes that exhibit unusual patterns or trends will alert us to look more closely at all lakes for potential changes.

Table 3. Characteristics of SWAN lakes and rivers selected for water quality and hydrologic sampling.

	Water Body	Park	Water Type	Size (ha)	Elevation (ft)	Anadromous Salmon?	Flow System
Tier 1	Naknek Lake	KATM	Glacial/Clear	58,824	41	Yes	Naknek
	Lake Brooks	KATM	Clear	7,557	72	Yes	Naknek
	Lake Clark	LACL	Glacial/Clear	31,337	263	Yes	Newhalen
	Kijik Lake	LACL	Clear	453	376	Yes	Newhalen
	Exit Creek	KEFJ	Glacial		300-440	No	Resurrection
Tier 2	Surprise Lake	ANIA	Clear	276	1063	Yes	Coastal
	JoJo Lake	KATM	Clear	676	50	No	Naknek
	Grosvenor Lake	KATM	Clear	7,387	118	Yes	Naknek
	Murray Lake	KATM	Clear	263	1660	Yes	Naknek
	Hallo Lake	KATM	Glacial	306	141	No	Coastal
	Delight Lake	KEFJ	Glacial	16	1050	Yes	Coastal
	Nuka River	KEFJ	Glacial		0-290	Yes	Coastal
	L. Kontrashibuna	LACL	Glacial	2,009	484	No	Newhalen
	Lachbuna Lake	LACL	Glacial	333	1342	No	Newhalen
	Crescent Lake	LACL	Glacial	3,958	470	Yes	Coastal
Tier 3	Kukaklek Lake	KATM	Clear	17,372	817	Yes	Alagnak
	Battle Lake	KATM	Clear	1,300	844	Yes	Alagnak
	Dakavak Lake	KATM	Clear	409	294	Yes	Coastal
	Lower Twin Lake	LACL	Clear	838	1984	Yes	Mulchatna
	Telaquana Lake	LACL	Glacial	4,667	1226	Yes	Stony

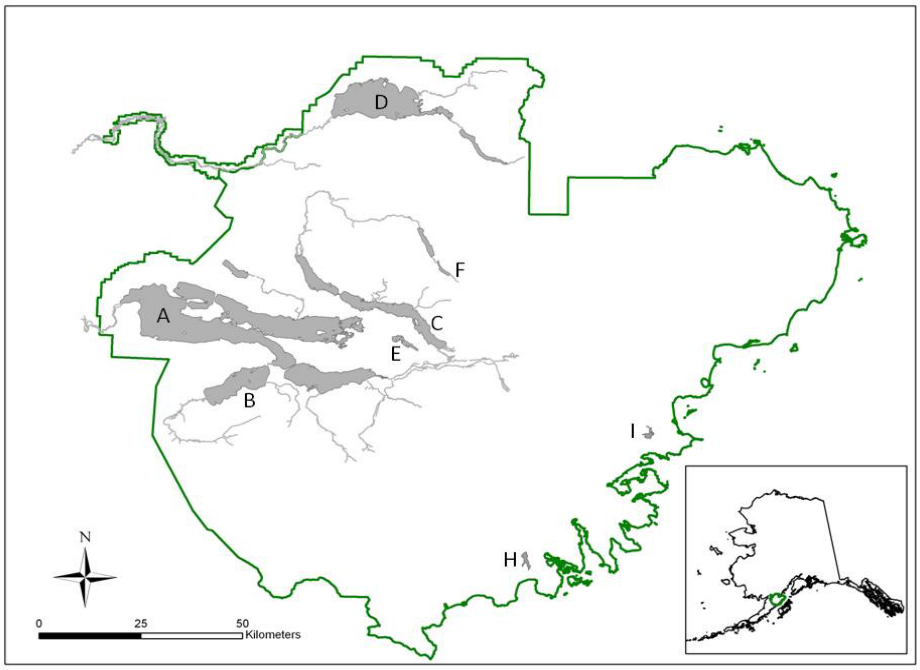

Figure 4. Lake systems within KATM monitored by SWAN. Tier 1 lakes include Naknek Lake (A) and Lake Brooks (B). Tier 2 lakes include Grosvenor Lake (C), Jojo Lake (E), Murray Lake (F), and Hallo Lake (I). Tier 3 lakes include Kukaklek Lake (D), Battle Lake (G), Dakavak Lake (H).

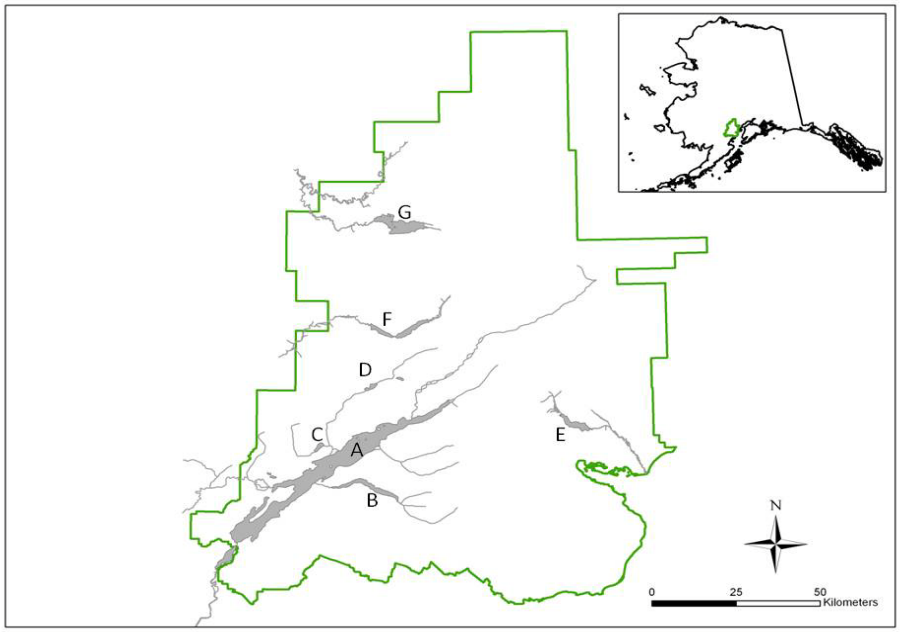

Figure 5. Lake systems within LACL monitored by SWAN. Tier 1 lakes include Lake Clark (A) and Kijik Lake (C). Tier 2 lakes include Kontrashibuna Lake (B), Lachbuna Lake (D), and Crescent Lake (E). Tier 3 lakes include Lower Twin Lake (F) and Telaquana Lake (G).

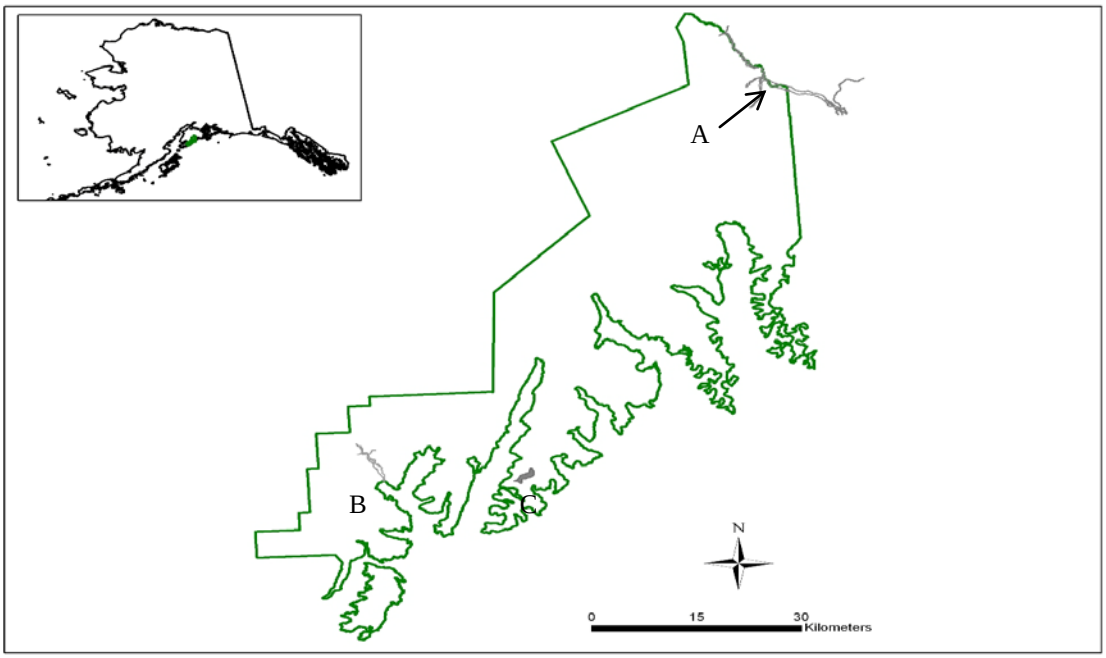

Figure 6. Lake and river systems within KEFJ monitored by SWAN. Tier 1 systems include Exit Creek (A). Tier 2 systems include Nuka River (B) and Delight Lake (C).

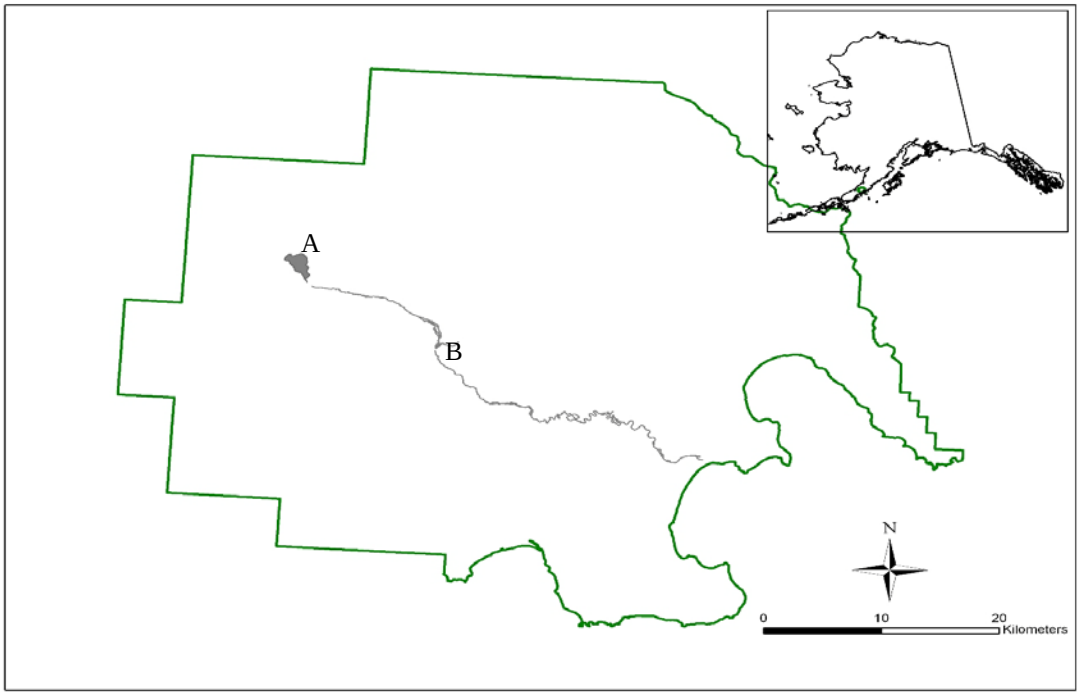

Figure 7. Lake and river systems within ANIA monitored by SWAN. Tier 2 systems include Surprise Lake (A) and Aniakchak River (B).

Sample Location Selection

Within each lake system we will be monitoring a combination of targeted and randomly-selected sites. The lake outlets and inflowing tributary sites will be targeted locations. Inflowing tributaries will be selected based on access and percent contribution to total lake inflow as determined during previous research (e.g., Brabets 2002). We will attempt to include both glacial and non-glacial tributary monitoring sites where applicable.

Random sites within each lake basin, where vertical lake profiles will be recorded, will be selected through a generalized random tessellation stratified process (GRTS; Stevens and Olsen 2004). Each lake basin is overlaid with a grid system comprised of 1-km^2 cells for Lakes Clark, Naknek, and Brooks and 0.25-km^2 cells for all other lakes with a point assigned to the center of each cell in a Geographic Information System (Figure 8). A coordinate list (containing latitude and longitude) for each center point is then generated and a GRTS analysis is applied to the coordinate list. The result is a list of randomly selected, spatially balanced sample locations with corresponding location coordinates (Figure 9). GRTS sites become fixed sample locations during sampling visits in subsequent years. SOP 2 details the process for deriving lake profile GRTS points. We recognize simplicity and utility of mid-lake sampling (Goransson et al. 2004) for lake monitoring programs; however, we feel a GRTS site selection process allows us to provide representative spatial coverage (Anttila et al. 2008) to large lake basins that are bathymetrically complex and influenced by dynamically different inputs (e.g., glacial vs. non-glacial), as illustrated in Figure 3 for Naknek Lake.

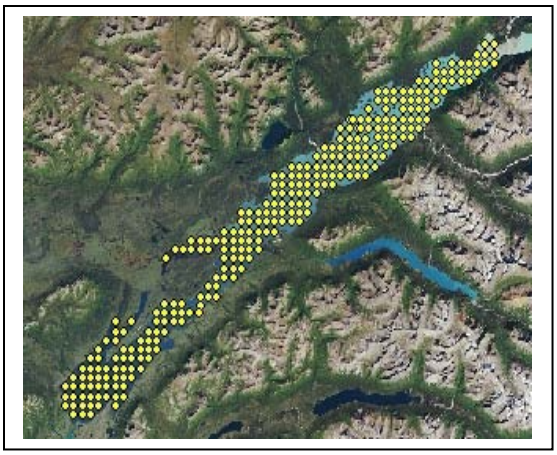

Figure 8. Potential GRTS sites generated from 1-km^2 cell grid system developed for Lake Clark, LACL.

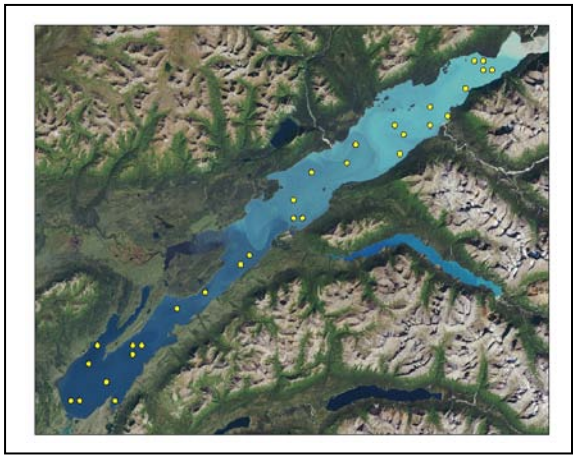

Figure 9. Final GRTS sample sites developed for Lake Clark, LACL.

Targeted sites, such as lake outlets and tributaries, will be selected based primarily on accessibility. For example, lake outlets are relatively easy to access and their stable channel cross-section provides ideal site conditions for monitoring. However, glacial tributaries often form shallow, braided deltas at their confluence with lake systems. While single channel sections of these glacial tributaries do exist, access to these more-stable river reaches is logistically challenging given the necessity to traverse the braided

delta areas. The Tlikakila River and Savonoski River, the largest tributaries in terms of discharge to Lake Clark and Naknek Lake respectively, are examples of large glacial rivers with extensive deltas. Though we may be able to access single channel reaches on these river systems, repeated access will depend largely on flow conditions, thus making sample scheduling difficult especially since both rivers are not gauged. We recognize that all waters vary spatially and temporally and that a sample site should be an integrative reflection of the upstream watershed. To balance the need to select a site that is both integrative but allows safe, reliable access we will conduct cross-sectional profiles of the channel each year during high and low flow conditions based on the equal width incremental design discussed by Wagner et al. (2006). Further details on this method are discussed in SOP 4.

Sampling Frequency and Replication

Detecting long-term trends in hydrologic and water quality parameters is complicated by intra- and inter-annual natural variation unrelated to long-term change induced by anthropogenic influences. Intra-annual variation can be reduced by sampling during an *index period* and making sufficient measurements to characterize the period of interest. Index period sampling is useful if logistical or cost constraints limit the amount of sampling undertaken, and is effective when intra-annual variability is small relative to desired detection level for long-term trends. Late summer is a useful index period for indicators of aquatic productivity, including chlorophyll *a* and total phosphorus in lakes of the upper Midwest (National Research Council 2000), whereas other indicators of ecological interest, including carbon, nitrogen and many rock-derived elements are strongly influenced by seasonal hydrological patterns (Meyer et al. 1988, Kaplan and Newbold 2000). Continuous water temperature monitoring on Lake Clark from August 2006 to September 2009 indicates that the highest annual surface temperatures occur between late July and mid-August (Shearer and Moore 2010). Wilkens (2002) revealed the same pattern in 1999 and 2000. Similarly, Shearer and Moore (2010) reported late July to mid-August as the peak water temperature period for Naknek Lake based on data collected between August 2008 and September 2009. Since temperature, and subsequent water density stratification, is a dominant regulator of most biogeochemical cycles, lake metabolism and productivity (Wetzel 2001), we will define our index period based on a timeframe when water temperatures exhibit the greatest vertical stratification. While index period sampling will satisfy data requirements to monitor inter-annual variability in core parameters throughout the lake water column, objectives to monitor seasonal variation in hydrology and lake temperature will require more frequent sampling.

Monitoring lake levels and seasonal temperature stratification will require more frequent data collection. Data recorders, such as water level pressure transducers and temperature thermistors, provide a dependable, low cost method for continuously monitoring lake stage and temperature (details discuss under Field Methods). Discharge at lake outlets and major inflowing tributaries will be measured several times during the ice-free season. While site access is not always feasible given flow conditions, we will attempt to monitor discharge annually in Tier 1 systems during the rising, falling, and peak phase of the hydrograph. Base flow conditions within SWAN parks often occur in winter or early spring when site access is often not logistically feasible. Continuous monitoring of core

parameters at Tier 1 lake outlets will serve as a temporal surrogate for comparison with lake profile data collected during index periods and will be conducted approximately late May through September.

Tier 1 systems will be sampled annually. Tier 2 systems will be sampled twice over a ten-year period while Tier 3 lakes will be sampled once every ten years (Table 4). We will cluster Tier 2 and 3 lakes together for sampling within any given year depending on their geographic proximity to one another to facilitate float plane transport and reduce operational costs. Sample replication will occur at 10% of GRTS sites (selected randomly at the start of each day) and at all discharge measurement sites. Replicate sampling should occur immediately following the initial sampling and is designed to further our understanding of data variability resulting from field crew and methodology bias.

Table 4. Sampling frequency of SWAN freshwater flow systems. Year 11 repeats with Year 1 sampling schedule.

Tier	**Water Body**	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**	**Yr 6**	**Yr 7**	**Yr 8**	**Yr 9**	**Yr 10**
Tier 1	Naknek Lake	x	x	x	x	x	x	x	x	x	x
	Lake Brooks	x	x	x	x	x	x	x	x	x	x
	Lake Clark	x	x	x	x	x	x	x	x	x	x
	Kijik Lake	x	x	x	x	x	x	x	x	x	x
	Exit Creek	x	x	x	x	x	x	x	x	x	x
Tier 2	L. Kontrashibuna	x	x								
	Lachbuna Lake	x	x								
	Crescent Lake	x	x								
	Grosvenor Lake			x	x						
	Murray Lake			x	x						
	Jojo Lake			x	x						
	Nuka River					x	x				
	Delight Lake					x	x				
	Surprise Lake							x	x		
	Hallo Lake							x	x		
Tier 3	Kukaklek Lake									x	
	Battle Lake									x	
	Dakavak Lake									x	
	L. Twin Lake										x
	Telaquana Lake										x

To summarize, SWAN will address vital sign objectives through a combination of random and targeted sample design approaches on select (tier system based on management priority, access, etc) freshwater flow systems. Both synoptic (once per year) and continuous (hourly, year round) sample schemes will be used to record environmental conditions at lake outlets, inflowing tributaries, and randomly-selected sites throughout the lake basin. Table 5 provides a summary of sample design, location, frequency, and replication based on each monitoring objective. Methods are described in further detail in the Field Methods section and associated SOPs.

Table 5. Summary of SWAN's freshwater flow system sample design approach for water quality and surface hydrology vital signs.

Objective 1: Determine trends in the timing, duration, and magnitude of summer inflow and outflow in the Lake Clark and Naknek Lake flow systems.				
Method	**Location**	**Measurement Frequency**	**Sample Period**	**SOP**
Pressure transducer, discharge measurement	Tier 1 outlets and select tributaries	Hourly	May - September	5, 6, 7
Objective 2: Determine trends in the timing, duration, and magnitude of peak summer lake levels for select SWAN flow systems.				
Method	**Location**	**Measurement Frequency**	**Sample Period**	**SOP**
Pressure transducer	Tier 1 outlets	Hourly	May - September	7
Objective 3: Monitor the inter-annual variability, both vertically throughout the water column and spatially across the lake basin, of core parameters during the mid-summer index period for high-priority lake systems, and less frequently for other SWAN flow systems.				
Method	**Location**	**Measurement Frequency**	**Sample Period**	**SOP**
Vertical lake profiles	All Tiered lakes, GRTS sites	Synoptic; 1x/yr	late July – mid-August	4
Objective 4: Monitor inter- and intra-annual variability in lake temperature, duration and depth of thermocline, stratification patterns, and warming and cooling patterns in high-priority lake systems.				
Method	**Location**	**Measurement Frequency**	**Sample Period**	**SOP**
Moored temperature arrays	Tier 1 lakes	Hourly	Year-round	8
Objective 5: Monitor the temporal variability of core parameters at select high-priority lake outlets during the ice-free period.				
Method	**Location**	**Measurement Frequency**	**Sample Period**	**SOP**
Unattended data sonde	Lake Clark and Naknek Lake outlets	Hourly	May - September	4

Field Methods

Briefly, water quality and surface hydrology monitoring will be composed of the following activities:

1) Vertical lake profiles during the mid-summer index period at each GRTS sampling point using a multi-parameter water quality sonde (e.g., YSI 600QS), hereafter sonde. All vertical profiles cover the upper 50 m of the water column. Measures of water clarity will be made in conjunction with each vertical lake profile using a Secchi disc.

2) Continuous water quality monitoring at the outlets of Lake Clark and Naknek Lake during the open water period (e.g., late May through September) with a sonde (e.g., YSI6600V2 data sonde). Core parameters plus turbidity recorded hourly with monthly site visits for sonde maintenance and data downloads.

3) Continuous water temperature monitoring year round at select locations in Tier 1 lakes. Automated water temperature thermistors (e.g., HOBO Water Temp Pros), programmed for hourly measurements, will be positioned at fixed intervals from near the water surface to 100 m on a moored temperature array. Automated light sensors will be placed at fixed depths within the upper 15 m of the water column. Moored temperature arrays will be retrieved and downloaded once or twice per year.

4) Continuous lake level monitoring at the outlets of Tier 1 lakes using automated water level pressure transducers during the open water period (e.g., late May through September). Pressure transducers will be programmed to record water level and water temperature hourly at a fixed site with a surveyed elevation in reference to a nearby bench mark. Non-vented pressure transducers will be used, thus level readings will be compensated for atmospheric pressure recorded by a nearby barometric logger.

5) Periodic discharge measurements at the outlets of Lake Clark, Lake Brooks, and Naknek Lake during the open water period (e.g., late May through September). Discharge measurements, taken primarily with acoustic Doppler current technology or a Price AA current meter, will be used in conjunction with lake level readings to develop stage / discharge rating curves to estimate lake discharge during the open water period. Approximately four discharge measurements will be recorded at each lake outlet each year timed so that the rising, peak, and falling limbs of the hydrograph are measured.

Detailed field methods for surface hydrology and freshwater chemistry monitoring are found in SOPs 1 (Field Season Preparation, Training and Safety), 3 (Physical Water Quality Instrument Calibration and Maintenance), 4 (Vertical Lake Profile, Continuous, and In Situ Sampling for Physical Water Quality Parameters), 5 (Wadeable Stream Flow Measurement), 6 (Boat-based Discharge Measurement), 7 (Water Level Measurements), 8 (Moored All-Season Temperature Array), 9 (Field Equipment Decontamination of

Aquatic Invasive Species), 10 (Data Processing), 11 (Water Quality and Hydrologic Data Management), 12 (Quality Assurance / Quality Control), and 13 (Water Quality and Hydrologic Data Analysis and Reporting. For the purpose of this protocol narrative, field methods are separated into four areas: 1) field season preparation, 2) data collection, 3) post-collection processing, and 4) end of field season. Figures 10 and 11 provide a layout of sample site locations for Tier 1 waterbodies.

Field Season Preparation

(Summary of SOP 1: Field Season Preparation, Training and Safety)

Sampling remote lakes is expensive and requires a high degree of organization in order to be safe and successful. The field trip leader should review the entire protocol, including SOPs, and resolve all questions concerning methods well in advance of the field season. Scheduling, equipment inspection, and ordering of supplies also must be initiated several months in advance of the field season. Staff should complete required training (e.g., motorboat operator certification course, bear safety, and basic aviation safety) and recommended training (e.g., wilderness first aid, CPR) courses during this time.

Field trip scheduling must be coordinated with LACL, KEFJ, and KATM staff to ensure availability of park planes, boats, and staff quarters. NPS-owned boats are available on Lakes Clark, Kijik, Naknek, Brooks, Telaquana, and Lower Twin. A private boat may be available from a private lodge on Crescent Lake and Grosvenor Lake. Sampling on all other SWAN lakes will be conducted with an inflatable raft. Lakes Clark and Naknek are the only lakes accessible by means other than float plane and Exit Creek is the only SWAN waterbody accessible from the road system. Thus, it is critical to plan sampling of remote lakes well in advance to schedule needed flight times with an NPS or privately-chartered aircraft. Table 6 provides a list of activities to be completed prior to each field season.

Data Collection

As mentioned previously, most field logistics must be completed well in advance of anticipated data collection. However, immediately prior to departing for the field each day it is mandatory that the field crew files a float plan with park headquarters. Float plan details should at minimum include which watercraft is being used, number of passengers on board, destination, and next check-in time. The float plan must be closed upon returning to base camp or headquarters at the end of each day. In addition, prior to each daily departure, ensure that necessary personal and emergency gear (Appendix A in SOP 1) accompanies the field crew.

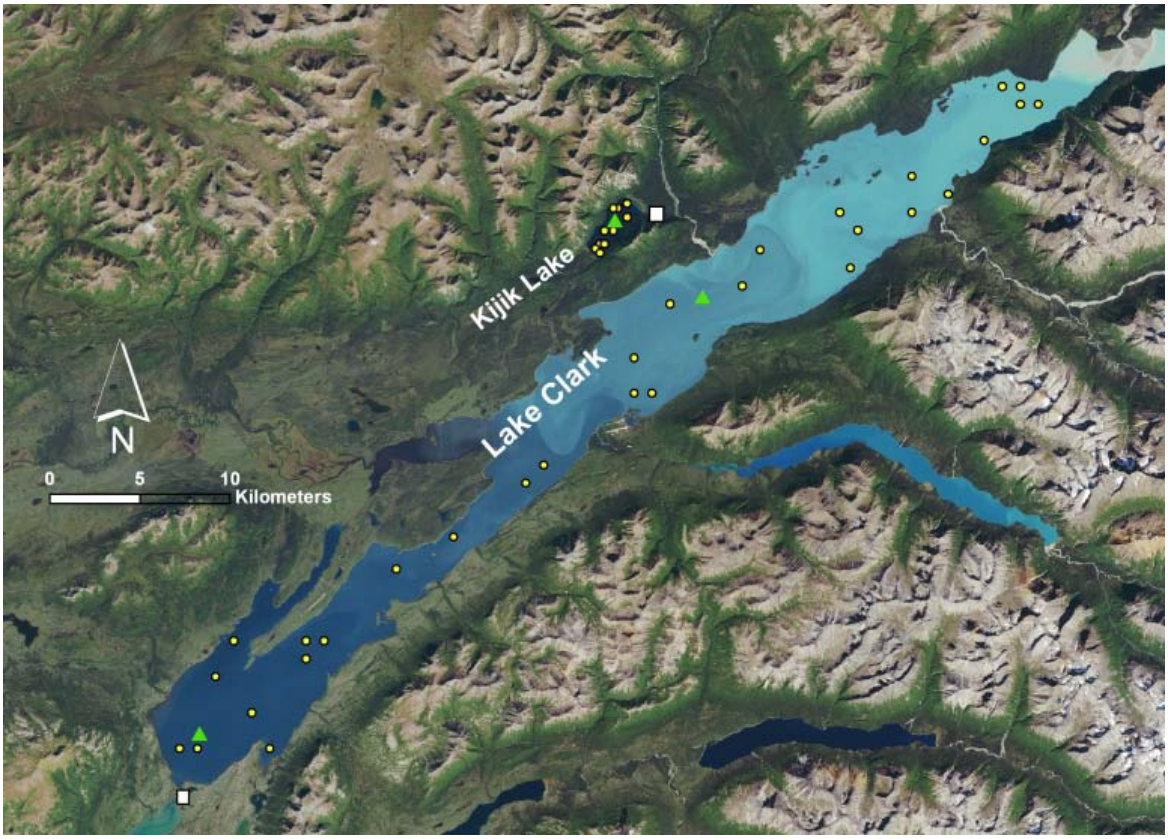

Figure 10. Water quality monitoring sites for Tier 1 lakes in LACL. Lake profile sites (yellow dots), continuous water quality sites (white squares), and moored temperature arrays (green triangles) represented in their approximate location.

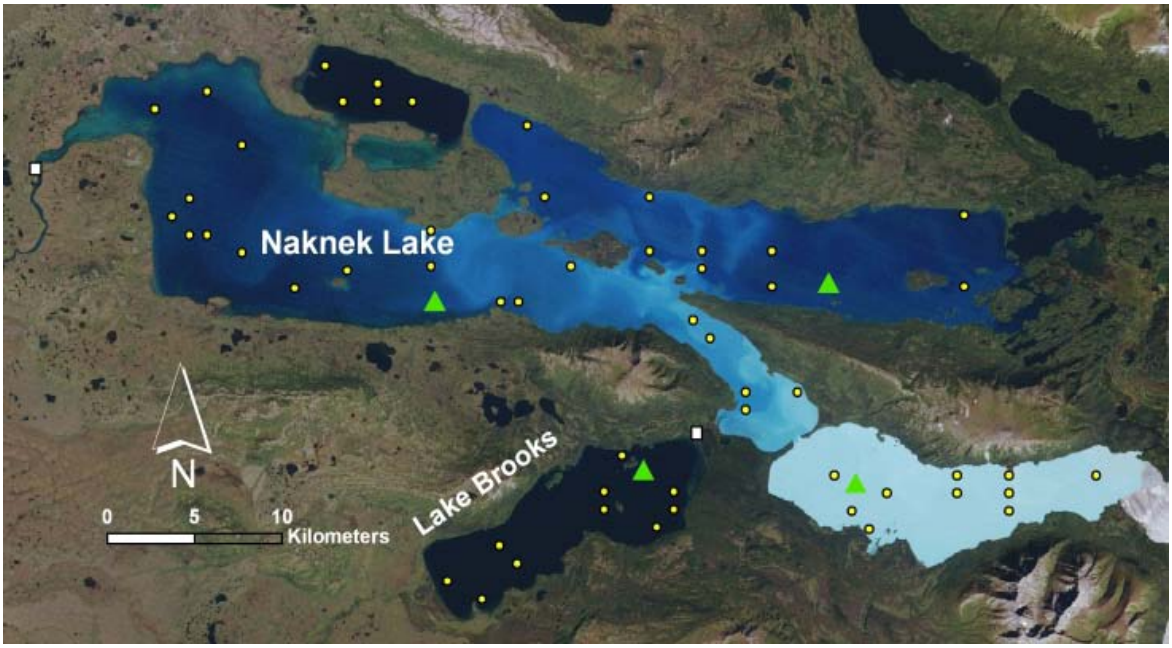

Figure 11. Water quality monitoring sites for Tier 1 lakes in KATM. Lake profile sites (yellow dots), continuous water quality sites (white squares), and moored temperature arrays (green triangles) represented in their approximate location.

Table 6. Approximate timeline of activities in preparation for field work for freshwater flow systems monitoring.

Time Period	Activity	Person Responsible for Completion of Task
Fall / Winter	Review of SOPs and data sets. Make necessary changes to SOPs.	Project manager
February	Obtain Scientific Research and Collecting Permit(s) from each respective park unit where field work is planned.	Project manager
March	Preliminary scheduling of field activities with approximate sampling dates.	Project manager
March	Order necessary supplies, such as water quality instrument calibration solutions.	Crew leader
March / April	Check equipment for proper working order, make necessary repairs.	Crew leader
April / May	Complete all required and recommended safety training	Project manager and crew leader
April / May	Confirm or revise field activities schedule with park staff	Project manager
April / May	Schedule lodging and flight requests with each respective park.	Project manager and crew leader
May	Assemble field folder containing field data sheets, lake maps, site lists with lat/long coordinates, copy of research permit, etc.	Crew leader
late May / early June	Operational training for water quality and hydrology sampling	Project manager and crew leader

Water Quality

(Summary of SOP 3: Physical Water Quality Instrument Calibration and Maintenance, SOP 4: Vertical Lake Profile, Continuous, and In Situ Sampling for Physical Water Quality Parameters, and SOP 8: Moored All-Season Temperature Array)

SWAN will make extensive use of water quality sondes to measure and record core parameters at each sample location. However, proper maintenance, calibration, and error checking are vital to ensure that sonde sensors are operating within manufacturer specifications and that sensor precision and bias are known. We will follow the calibration procedures, discussed in SOP 3 in detail, outlined by the Yellow Springs Incorporated operations manual for 6-series environmental monitoring systems and Gibs et al. (2007).

Due to the remote nature, expense of travel, and weather conditions within SWAN park units, field data will primarily be collected during the open water period (e.g., approximately late May through September) with the exception of automated data loggers that can be deployed year round. After filing a float plan with park headquarters and checking for necessary personal and emergency gear, field collection of data will commence. The sequence of activities in the field will depend largely on the type of data being collected. Data will be collected through one of three methods: mid-summer index period sampling, continuous monitoring with automated data loggers, and in situ sampling during periodic site visits.

Synoptic vertical lake profiles will be collected at randomly selected, spatially balanced locations through each lake basin during the mid-summer index period. Latitude / longitude coordinates of each GRTS lake profile site should be loaded into a handheld GPS unit and, if available, boat-mounted chart plotter. After navigating the boat to the selected lake profile location, site information, such as sample site code, waterbody, weather, and site depth, will be recorded on the field data form (either electronic or hard copy). A sonde will be used to measure core water quality parameters at the lake surface, 1 m, 2 m, 3 m, 4 m, 5 m, and every 5 m until the lake bottom or 50 m depth interval is reached, whichever occurs first. Core parameters will be measured on the descent and ascent, thus generating two measurements at each depth interval. Additionally, all core parameter data will be recorded in duplicate, both on the internal memory of the sonde handheld control (e.g., YSI 650 MDS) and on the field data form. Data files recorded directly to the sonde memory will be used for analysis while duplicate data recorded on field forms will serve as a back-up copy. After the lake profile is measured, Secchi depth will be recorded by lowering a 20-cm white and black disc vertically in the water until the disc disappears and recording the depth to the nearest cm. Next, the disc is lowered farther and then slowly retrieved just until it reappears and the depth is again recorded. This process is repeated two more times, the Secchi depth for the site is the average of all six measurements. A qualitative rating of 1, 2, or 3 is assigned to describe Secchi measurement conditions – 1 being optimal and 3 being poor with heavy wave action or poor lighting. Once measurements are complete the boat is navigated to the next lake profile site and the process is repeated. Details of lake profile data collection are outlined in SOP 4.

Continuous water quality monitoring with a sonde will take place at the outlets of Lake Clark and Naknek Lake. We will use a sonde that meets criteria specified in Table 7 as recommended by Penoyer (2003). Prior to departing, the sonde should be calibrated as detailed in SOP 3. After navigating to the sampling location, site conditions, such as river stage, evidence of site disturbance, and channel morphology, should be noted. Program the sonde to record measurements on a 1-hour interval with a delayed start of one hour after deployment to allow sonde sensors to acclimate to water conditions. Along with core water quality parameters (including turbidity), the sonde should also record date and time, pH millivolts (mV), battery level, barometric pressure (mm Hg), dissolved oxygen charge (if using a rapid-pulse membrane DO sensor), and depth. Battery level, pH millivolts, and dissolved oxygen charge are parameters that can be used during post-processing of data to help assess data grades or suspected errors in sensor

readings. Place the sonde inside a protective PVC housing, attach the anchor cable, and place the sonde housing in the water. The length of deployment will vary depending on site conditions, the amount of fouling on sensors, battery life, and internal memory on the sonde. Based on preliminary data collected during 2009 and 2010, four to six weeks is an acceptable deployment period at SWAN lake outlets and non-glacial rivers as the amount of biofouling on sonde sensors was generally low. Glacial rivers, due to their heavy sediment load, may require shorter deployments between site visits.

Table 7. Stabilization criteria (from NFM, 1998) and WRD recommended instrument specification criteria for recording field measurements (from Penoyer 2003).

Standard Direct Field Measurement	**Stabilization Criteria For Measurements** **(variability/repeatability should be within the value shown)**	**Recommended Instrument Specifications** **A. Range** **B. Resolution/Sensitivity**** **C. Accuracy*****
[1]Temperature: Thermistor Thermometer Liquid-in-glass Thermometer	 ± 0.2°C ± 0.5°C	A. –5 to +45°C B. 0.01°C C. ±0.15°C
[2]Conductivity (Specific Cond.) When ≤ 100 μS/cm When > 100 μS/cm	 ± 5 percent ± 3 percent	A. 0 to 100,000 μS/cm B. 1 to 100 μS/cm (range dependent) C. ± 0.5% of reading +1μS/cm
[3]pH: Meter displays to 0.01	 ± 0.1 unit	A. 0 to 14 pH units B. 0.01 pH unit C. ± 0.2 pH unit
[3]Dissolved oxygen: Amperometric method	 ± 0.3 mg/L	A. 0 to 50 mg/L B. 0.01 mg/L C. 0 to 20 mg/L; ± 2% of reading or 0.2 mg/L, whichever is greater
*[2]Turbidity: Turbidometric method in NTU	 ± 10 percent	A. 0 to 1000 NTU B. 0.1 NTU C. ±5 % of reading or 2 NTU Whichever is greater; depth limit of 200 ft.

*Measurement is not required (i.e. not a "core" parameter)
** Resolution/Sensitivity is a data quality indicator related to detection limits but typically handled differently for field probes than for laboratory parameters. For more information, see Part B (http://science.nature.nps.gov/im/monitor/protocols/wqPartB.doc).
***In the case of field probes, accuracy is typically a "best case" maximum deviation from known correct values (typically based on comparisons with known NIST certified reference materials or standards). True accuracy is a combination of high precision and low bias (see Part B for more details).
[1] Recommended sensor calibration is quarterly
[2] Recommended sensor calibration is daily
[3] Recommended sensor calibration is at beginning and end of sampling at each station (twice a day minimum)

Note that measurement stabilization criteria are not the same as Measurement Quality Objectives (MQOs) listed in the "Core Water Quality (Vital Signs) Monitoring Parameters for Marine and Coastal Parks" produced by the marine work group.

After initial sonde deployment, site visits will be used to check sonde operation, assess the degree of biofouling and sensor drift (with an independent, freshly-calibrated field meter and calibration standards), download data, and conduct routine sonde maintenance and re-calibration, if needed. SWAN's procedures for sonde deployment and site visits are outlined in SOP 4 and follow those guidelines discussed in Wagner et al. (2006).

Water temperature dynamics of Tier 1 lakes will be continuously monitored using moored, all-season temperature arrays equipped with automated temperature thermistors. A moored temperature array consists of vertical anchor and instrument lines connected with a horizontal line. Anchors will hold the vertical lines in place and submersible buoys will keep the lines upright. The horizontal line simply aids in retrieval of the array with a grapple hook. Programmed water temperature thermistors will be attached to an instrument line at 5 m, 10 m, and every 10 m until the lake bottom or 100 m is reached, whichever occurs first, and will record water temperature every hour year-round. Depending on ease of access to a particular temperature array, a surface buoy may be connected to the instrument line in early summer to record water temperature at 1 m, and subsequently removed in early fall prior to lake freeze-up. The vertical spacing of temperature thermistors can be adjusted if a particular depth interval is of special interest and warrants a finer resolution spatial analysis. Additionally, automated light sensors will be attached at 5 m, and possibly 10 m and 15 m depending on annual turbidity conditions, to record light transmittance on a 1-hour interval. Light sensors also provide a duplicate measure of water temperature. Temperature arrays will be retrieved once or twice per year for data downloads and maintenance. Since temperature arrays typically will not be visible on the lake surface it is critical that accurate coordinates are maintained on the location of each array to facilitate retrieval and data recovery. Additionally, a small radio transmitter, such as those used in fisheries research, may be attached to the array to aid in recovery. SOP 8 details the steps needed for constructing, deploying, retrieving, and maintaining moored, all-season temperature arrays.

In situ measurements of core water quality parameters may be recorded in conjunction with or support of several other monitoring activities but comprise a relatively small portion of all water quality data collected in the field. Core water quality parameters will be measured with a sonde calibrated according to details in SOP 3. In general, in situ core water quality measurements will be collected during site visits to check continuously deployed sondes, to provide a cross-sectional channel profile at continuous water quality monitoring sites, or to provide a synoptic measurement of water quality conditions during discharge measurements. Regardless of the activity, it is important that the field crew document site conditions, such as flow, weather, and obviously signs of human or natural disturbance, to provide a context for the conditions under which in situ measurements were recorded. Details of in situ water quality data collection are outlined in SOP 4.

Surface Hydrology

(Summary of SOP 5: Wadeable Stream Flow Measurement, SOP 6: Boat-based Discharge Measurement, and SOP 7: Water Level Measurements)

The primary objectives of surface hydrology monitoring are to track the timing, duration, and magnitude of summer inflows, outflow, and water level of Tier 1 waterbodies. To meet this objective, SWAN will use two monitoring techniques: continuous monitoring of water levels (i.e. stage) using automated pressure transducers and in situ measurement of river discharge. The intent of these monitoring techniques is to develop stage discharge rating curves for each monitored site so that river discharge can be estimated and water budgets calculated.

Discharge is a measure of the volume of water past a channel cross section over a given time interval (often expressed as cubic feet per second). SWAN will collect periodic discharge measurements at lake outlets and select inflowing tributaries to develop stage discharge rating curves for each monitoring site. The intent of these rating curves is to provide a daily estimate of discharge for the open water season based on continuously recorded water level measurements. SOP 5 details SWAN's methodology for using a Marsh McBirney flow meter for measuring discharge at wadeable stream sites. The methods described in SOP 5 are based on the USGS *two-point method* by Buchanan and Somers (1968). However, the vast majority of SWAN's discharge monitoring sites are not wadeable during the summer months and boat-based discharge measurement techniques must be employed. SOP 6 outlines SWAN's boat-based discharge methodology based using a Price AA current meter. This SOP was developed based on techniques outlined in Buchanan and Somers (1968). As of the summer of 2010, SWAN began testing an acoustic Doppler current profiler for estimating river discharge and is in the process of developing an SOP that details the proper calibration and use of this instrument.

Water-surface elevations are recorded with continuously logging (hourly) water level pressure transducers. Pressure transducers will be non-vented, meaning level readings must be corrected for atmospheric pressure. Atmospheric pressure will be recorded hourly with a barometric logger placed near the monitoring site. Pressure transducers should be housed inside a metal pipe for protection and anchored at a monitoring site with rebar driven into the substrate. The transducer should be placed in a location free from sediment deposition or lateral bank scouring. A survey bench mark will be established at each monitoring site and the elevation of the transducer will be surveyed so that changes between annual deployments can be adjusted to maintain a consistent baseline elevation. Leveling, a procedure by which surveying instruments are used to determine the differences in altitude between points, will be used to set the gages and to check them from time to time for vertical movement (Kennedy 1990). Levels will be run periodically to all bench marks, reference marks, reference points, and gages at each station for the purpose of determining if any datum changes have occurred (Rantz 1992). SOP 7 provides further detail on water level measurements using pressure transducers.

Once field activities are completed for a particular waterbody and prior to moving to a new waterbody, all equipment (e.g., rafts, waders, water quality instruments) should be disinfected to minimize the risk of transporting aquatic invasive species. Currently, we are not aware of any established aquatic invasive species populations within SWAN. However, we feel the NPS has an obligation to be proactive in preventing the introduction and spread of invasive species and upfront precautionary measures are only a minor inconvenience to preserve the ecological integrity of NPS resources. SOP 9 lists potential aquatic invasive species to SWAN waters and provides details for cleaning field equipment.

Post-Collection Processing

(Summary of SOP 10: Data Processing)

The use of automated data loggers, such as water level pressure transducers, temperature thermistors, and water quality sondes, to record hourly measurements at multiple locations has the potential to generate a tremendous volume of data. As such, it is imperative that proper data management techniques are employed through all phases of the project. Post-collection data processing is a critical step in SWAN's freshwater flow system monitoring program where raw data are retrieved and processed (e.g., downloaded, archived, corrected, and QA/QC checked) prior to data analysis and reporting.

The pre-deployment programming and post-deployment downloading of automated data loggers is carried out through the use of various proprietary software that accompany data loggers. The user must be familiar with the operation of software prior to programming any data logger to ensure that data are properly recorded, stored, and available for retrieval. SOP 10 provides step by step instructions on the proper use of software needed to program each automated data logger. The general workflow of post-collection processing will be as follows:

1. Retrieve data logger and download electronic data file(s).
2. Label data files according to proper file naming convention (Table 8).
3. Place a copy of all data files on the SWAN Vital Signs network drive (J: drive) at the Alaska Regional Office for archival.
4. Export raw data from proprietary file format to comma separated value (.csv) or text (.txt) format.
5. Import .csv and .txt files into Aquarius Time Series software (http://www.aquaticinformatics.com/main/).
6. Conduct data trimming, correction for fouling / sensor drift, and/or threshold flagging using Aquarius Time Series software.
7. Export QA/QC checked data and correction history log in .csv format from Aquarius Time Series software for import into database and data analysis and reporting.

End of Field Season

Once automated data loggers are removed from the field for data collection, they must be cleaned, maintained, and stored properly to assure reliable operation for the next field season. Water quality sonde sensors should be cleaned, o-rings replaced and lubricated, batteries removed, and stored with a small amount of tap water or pH 4 buffer solution in the calibration cup. Storing the sensors in tap water or pH 4 buffer solution prevents desiccation, never store sonde sensors in deionized water. The pH sensor should be removed from the sonde body and stored separately in pH storage solution. Sondes should be stored inside a hard-sided plastic case to prevent damage. If a sonde needs factory repair or re-calibration, now is the time to send the instrument in for service. Water temperature thermistors and water level pressure transducers should be cleaned and checked to assure they are not actively logging. Temperature thermistors and pressure transducers can be stored at room temperature in a dry location. Batteries should be removed from all other electronic instruments for winter storage to prevent corrosion. All field equipment should be cleaned and disinfected after the field season to prolong equipment durability and to prevent the spread of aquatic invasive species prior to storage.

Table 8. File naming conventions for aquatic monitoring data collected with automated data loggers.

Monitoring Technique	Parameter	Software Needed	File Naming Convention	File Name Example
Temperature Array	Water Temp	Onset BoxCar Pro Onset HOBOWare Pro	"park code_5-letter waterbody code +2-digit site #_3-digit depth+ 'm' _'temp'_ YYYYMMDD+format"	LACL_lclar01_020m_temp_20090613raw
	Light Transmittance	Onset HOBOWare Pro	"park code_5-letter waterbody code +2-digit site #_3-digit depth+ 'm'_'light'_ YYYYMMDD+format	LACL_lclar01_010m_light_20090613qaqc
	Temp Array Level	Solinst Levelogger	"park code_5-letter waterbody code +2-digit site # _ 'array' _'lvl'_YYYYMMDD+format	LACL_lclar01_ array_lvl_20090613export
Vertical Lake Profiles	Core WQ Parameters	EcoWatch	"park code_5-letter waterbody code +1-letter basin ID + 3-digit site #_'profile'_YYYYMMDD+format	KATM_naknle003_profile_20090814export
In Situ Water Quality	Core WQ Parameters	EcoWatch	"park code_5-letter waterbody code + 2-digit site #_'insitu'_YYYYMMDD +format	LACL_chulr01_insitu_20090718qaqc
Continuous Water Quality	Core WQ Parameters	EcoWatch	"park code_5-letter waterbody code +2-digit site #_'continuous'_ 'wq'_YYYYMMDD+format	LACL_chulr01_continuous_wq_20090618raw
Cross Sectional Water Quality Profiles	Core WQ Parameters	EcoWatch	"park code_5-letter waterbody code + 2-digit site #_'xsect'_ 'wq'_YYYYMMDD+format	KEFJ_exitc01_xsect_wq_20090526raw
Water / Atmospheric Pressure Monitoring	Water Level / Barometric Pressure	Solinst Levelogger Win-Situ	"park code_5-letter waterbody code + 2-digit site #_'lvl' OR 'baro' OR'lvl_ compensated'_YYYYMMDD+format	KATM_lbroo01_baro_20080930export

Dates are always formatted YYYYMMDD.

All file names must contain at a minimum: 4-letter park code, 5-letter waterbody code plus site number, date, and data format ID (raw, export, or qaqc).

Data Management, Analysis, and Reporting

SWAN freshwater flow system data management procedures support the fundamental goals of Southwest Alaska Network's Data Management Plan: to obtain data that are of high quality, readily available, easily interpreted, and are secure for the long term (Mortenson 2006). Though easily overlooked, following proper data management steps is vital throughout the entire data life cycle from data acquisition through reporting and archiving. Figure 12 provides a general schematic on the data life cycle for this protocol, see SOP 11: Water Quality and Hydrologic Data Management for a more detailed discussion on each step of the data life cycle.

Metadata Procedures

In the simplest sense, metadata are "data about data." That is, metadata provide answers to who, what, when, where, why, and especially how field data are collected. Metadata allow the users to evaluate the quality and usefulness of the data based on an understanding of the parameters involved with collecting the data. Many metadata pertaining to automated data logger deployments are produced at the time of deployment. Capturing the metadata at the appropriate time is critical to its usefulness, as, in this case, obtaining metadata after deployment makes metadata generation very difficult, if not impossible. Field forms (electronic or hard copy) provide a format for capturing much of the metadata associated with automated data loggers while data file headers often contain the remaining metadata needed for data documentation. Seemingly simple, yet critical, steps, such as ensuring that all field forms are filled out correctly and completely, may make the difference between properly acquiring all necessary metadata or not.

The vast majority of data collected for SWAN freshwater flow system project are tabular in nature; however, for geospatial data we will abide by Executive Order 12906, which mandates that every federal agency document all new geospatial data it collects or produces using the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM; www.fgdc.gov/metadata/contstan.html). All GIS data layers will be documented with applicable FGDC and NPS metadata standards. The Network will also generate FGDC-style metadata for non-spatial datasets that meet this standard, absent only the geospatial specific elements. For more details on the SWAN's overall strategy for metadata generation, management, and distribution see SWAN's Data Management Plan (Mortenson 2006).

Database Design

SWAN will be developing a relational SQL Server-based database that operates in conjunction with Aquarius Time Series software for data storage and retrieval. One advantage of designing a database to operate directly with Aquarius Time Series software is it allows for a more seamless flow in the data management process starting with post-collection processing and raw data archival through export of QA/QC data for analysis and reporting. The vast majority of monitoring data generated by monitoring freshwater flow systems will be continuous in nature. By continuous data we are referring to time series data that are collected frequently (e.g. hourly) through repeat measurements over the course of several weeks, months, or year round. Though the data generated are

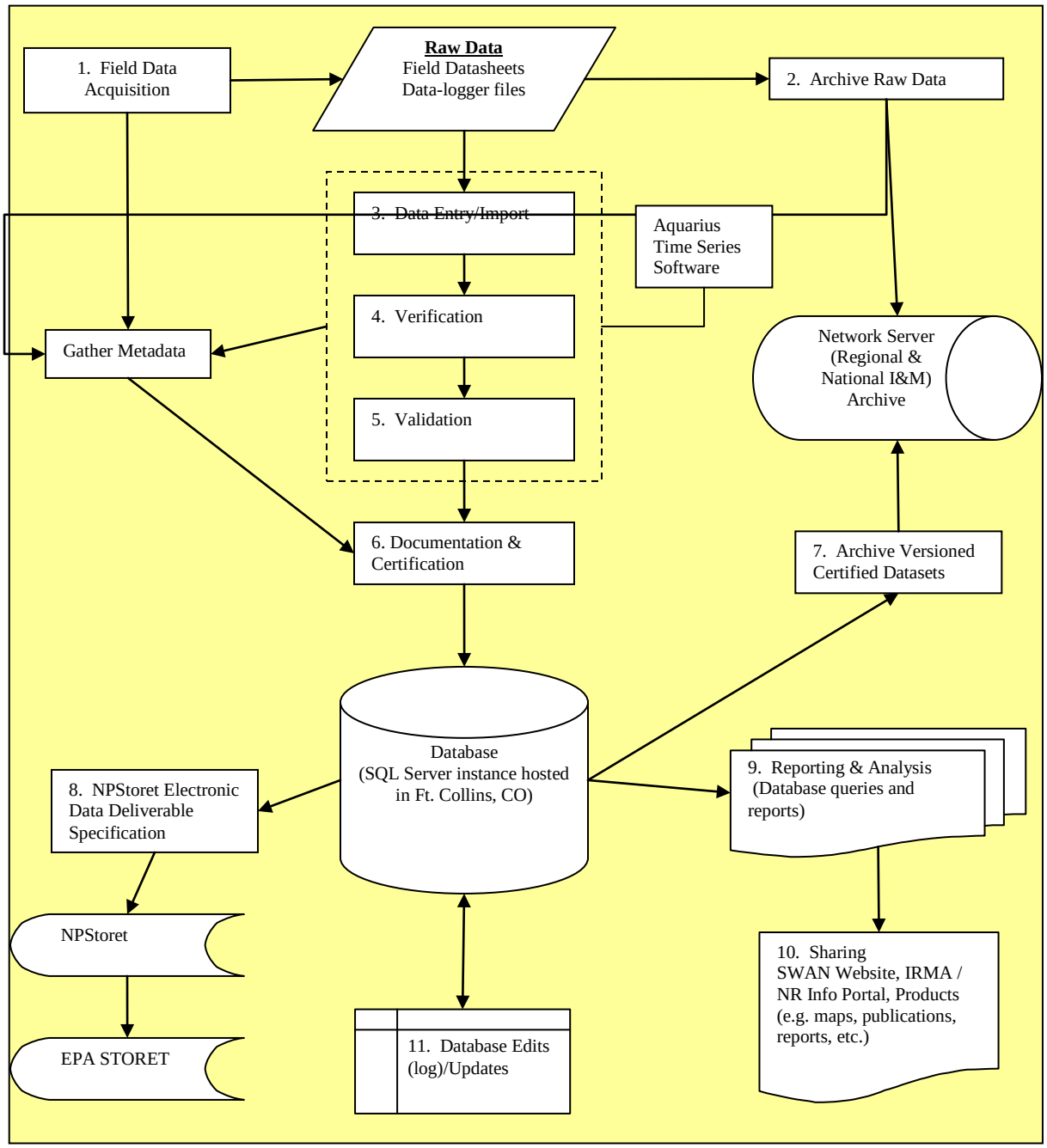

Figure 12. SWAN Water Quality Data Flowchart adapted from Heard (2007).

simple tabular data (i.e. date, time, and parameter of interest), the volume of data generated can be quite large. For example, one moored temperature array that monitors hourly water temperature year round from the surface to 100 m depth has the potential to generate nearly 193,000 data points in one year. Thus, a SQL Server-based database specifically designed to handle large sets of continuous data will provide us with greater data management flexibility than using other pre-existing databases, such as NPSTORET, that do not integrate time series datasets as easily. The schema for this database will

follow the hierarchical structure of Organization / Project / Location / Period of Operation / Sample (Figure 13).

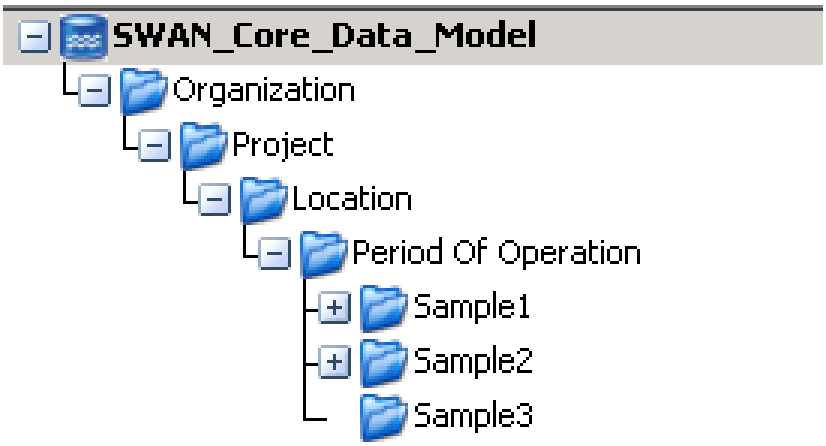

Figure 13. Simplified database schema for SWAN's continuous water quality database.

Data Analysis and Reporting

Analysis and reporting of monitoring data is a critical phase in the process of providing managers with useful information regarding park resources. A multitude of approaches and venues exist for presenting information to the intended audience from resource briefs and field season highlights to integrative resource condition assessments and multi-year trend syntheses. In an effort to synthesize the large amount of water quality and hydrologic monitoring data collected each year, we will, at a minimum, provide an annual data summary listing the mean, maximum, minimum, and degree of variation for each water quality parameter (see Table 9 for an example) across sample sites and lakes as well as provide a more in-depth trend analysis on a 5- to 10-yr basis. Additional measures, such as monthly degree days (for water temperature) or percent exceedance of water quality criteria, may also be of interest to report. We may synthesize results across depth strata, GRTS sites, or basins within a particular lake; however, the non-random selection of lakes sampled by SWAN precludes extrapolation of results to non-targeted waterbodies. Graphical displays are primarily meant to provide a visual characterization of the data being summarized. A variety of graphs may be presented depending on the data being displayed (see Figure 14A-14D for examples). Annual summary reports will include the following sections:

- Introduction briefly describing importance of the Vital Sign(s) being monitored.
- Study area description including maps of lakes and monitoring sites.
- Methods detailing field measurement techniques for vertical lake profiles, continuous water temperature, continuous water quality, and lake level / discharge monitoring.
- Results and Discussion categorized by monitoring method (e.g. continuous water quality, water level / discharge) including data summaries, graphical displays, and interpretation of results in relation to limnological variables.

- Conclusion and Recommendations discussing suggested changes to protocol(s), planned activities for the upcoming field season, and future monitoring
- Suggestions to incorporate into program activities to improve our understanding of park resources.

On a five to ten year basis, water quality and hydrologic data will be analyzed for trends. The objective of trend analysis is to detect changes (gradual or abrupt) in parameters over time. For water quality trend analysis, a Mann-Kendall Test and Seasonal Kendall Test are two common techniques used to examine trends among years and seasons (Helsel and Hirsch 1992). The Mann-Kendall is a rank-based test, which is a derivative of the Kendall's tau correlation coefficient where one variable is time (Jassby 1996). The Mann-Kendall Test does not assume data normality, is resistant to outliers, and is able to incorporate censored or flagged data since only ranks are used. The Seasonal Kendall Test is essentially a Mann-Kendall test conducted on each season or month separately then summed, thus only similar seasons or months are compared across time (Helsel and Hirsch 1992). The Seasonal Kendall Test has the advantage of removing short-term variability caused by seasonality in data that may otherwise mask trends across the entire time series if using the Mann Kendall Test. In a Seasonal Kendall Test, the 'season' can be defined by lake basins, depth strata, months, ice on / ice off periods, etc. As with annual data summaries, trend analysis can be complimented with graphic displays, such as bivariate plots, to illustrate trends (or lack thereof) over time. Status and trend reports and annual summary reports will be formatted following the NPS Natural Resource Technical Report series standards (http://www.nature.nps.gov/publications/NRPM/index.cfm).

Table 9. Example of descriptive data summary for water temperature from Lake Clark, Lake Clark National Park and Preserve.

Month	Max. Avg. Daily Temp[1] mean (1 SD[4]); °C			Min. Avg. Daily Temp[2] mean (1 SD[4]); °C			Monthly Degree Days[3]		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
January	0.7 (0.1)	2.7 (0.0)	1.1 (0.0)	< 0.1 (0.0)	0.1 (0.0)	0.3 (0.1)	8	22	27
February	1.9 (0.1)	1.1 (0.1)	1.2 (0.0)	0.7 (0.1)	0.1 (0.0)	0.6 (0.0)	38	14	28
March	2.4 (0.0)	1.5 (0.1)	1.1 (0.0)	1.4 (0.2)	0.6 (0.1)	0.8 (0.0)	65	37	28
April	3.4 (0.5)	2.3 (0.1)	2.0 (0.1)	2.0 (0.1)	1.2 (0.3)	0.8 (0.0)	83	56	34
May	4.3 (0.1)	3.7 (0.1)	3.6 (0.1)	3.0 (0.2)	1.8 (0.3)	2.1 (0.1)	108	92	89
June	9.9 (0.5)	8.4 (0.9)	8.5 (0.7)	4.0 (0.0)	3.6 (0.0)	3.6 (0.0)	204	155	160
July	15.0 (0.9)	11.0 (0.5)	14.1 (0.2)	8.9 (0.3)	7.2 (0.3)	5.9 (0.5)	395	285	321
August	15.9 (0.4)	13.5 (0.5)	12.1 (0.1)	10.3 (1.2)	10.5 (0.3)	8.1 (0.5)	403	378	320
September	13.5 (0.3)	10.2 (0.2)		7.9 (0.5)	6.4 (0.6)		292	236	
October	8.1 (0.1)	7.4 (0.1)		5.5 (0.0)	4.9 (0.0)		204	190	
November	5.6 (0.0)	4.9 (0.0)		4.5 (0.0)	3.2 (0.2		148	127	
December	4.4 (0.0)	3.6 (0.1)		2.5 (0.1)	0.5 (0.1)		116	76	

Year	Highest Avg. Daily Temp date	Highest Avg. Daily Temp 24-hr mean (1 SD); °C	Highest Avg. 7-Day Temp dates	Highest Avg. 7-Day Temp 7-day mean (1 SD); °C
2007	August 13th	15.9 (0.4)	Aug. 10th - 17th	14.7 (0.8)
2008	August 18th	13.5 (0.5)	Aug. 22nd - 29th	13.0 (0.5)
2009	July 18th	14.1 (0.4)	July 14th – July 20th	13.4 (0.6)

[1] Based on highest 24-hour average
[2] Based on lowest 24-hour average
[3] Difference between daily mean temperature and 0 °C summed for each month
[4] Standard deviations < 0.05 are reported as 0.0

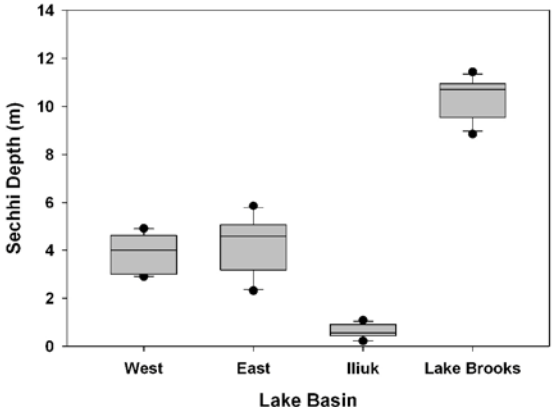

Figure 14A. Box and whisker plot displaying range of Secchi depths in three Naknek Lake basins and Lake Brooks.

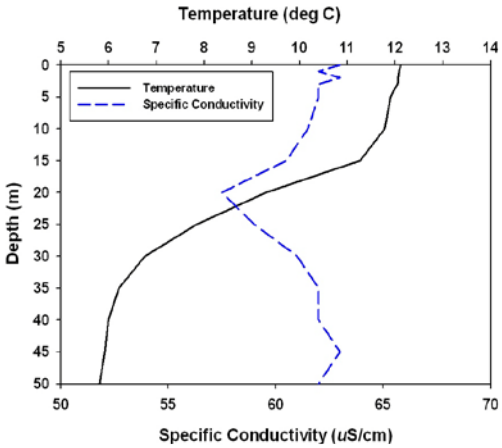

Figure 14B. Depth profile of water temperature and specific conductivity in upper Lake Clark.

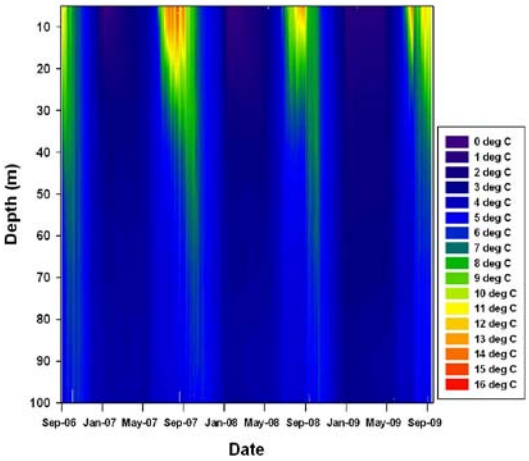

Figure 14C. Isotherm displaying water temperature stratification in Lake Clark.

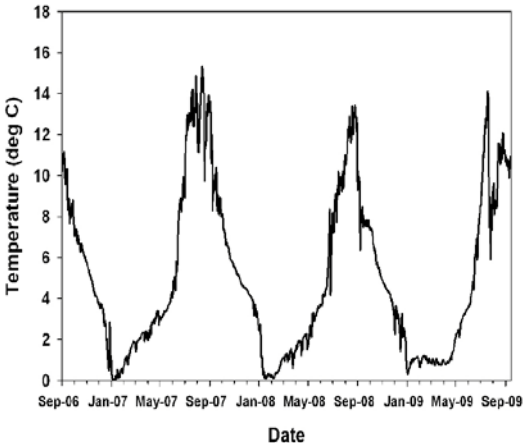

Figure 14D. Bivariate plot displaying near-surface water temperature in Lake Clark.

Personnel Requirements and Training

To fully implement this protocol, a part-time aquatic ecologist is required to work in collaboration with the network coordinator, data manager, and park-based resource staff. Implementation of the resident lake fish and salmon vital signs under the SWAN Vital Signs Monitoring Plan will require the remainder of the aquatic ecologist position.

Roles and Responsibilities

The SWAN aquatic ecologist will be the project leader for all monitoring aspects of freshwater chemistry and surface hydrology vital signs. The aquatic ecologist will work as part of a six member interdisciplinary team including project leaders in the climate/glaciers, landscape processes, terrestrial vegetation, terrestrial wildlife, and marine nearshore subject areas. The aquatic ecologist will be supervised by the network coordinator. The relationship of the aquatic ecologist to the SWAN is outlined in the organizational chart in Figure 15.

The aquatic ecologist will be based in Anchorage and will supervise an ecologist stationed at the King Salmon field office. The ecologist will serve as the park-based contact for field logistics and sampling. Field activities will be conducted by the network aquatic ecologist, network ecologist, and park-based ecologists/biologists/technicians (Table 10).

Qualifications and Training

The project leader will be responsible for ensuring that all personnel involved with data collection are familiar with instrument calibration, maintenance, operation, and data downloading. All personnel involved with field data collection efforts will review all aspects of data logger operation as a group prior to the start of each field season. Specific field data collection training aspects will include:

- Multi-parameter sonde calibration, maintenance, and operation
- Water temperature thermistor programming and downloading
- Acoustic Doppler current profiler calibration and operation
- GPS operation
- Electronic field form entry and archiving
- Basic limnology concepts and field sampling techniques

Additionally, several training / certification courses are required, such as motorboat operation certification and B-3 aviation safety, and others are strongly recommendation, such as wilderness first aid, for all staff involved with field activities. See SOP 1 for additional details on training and field season preparation.

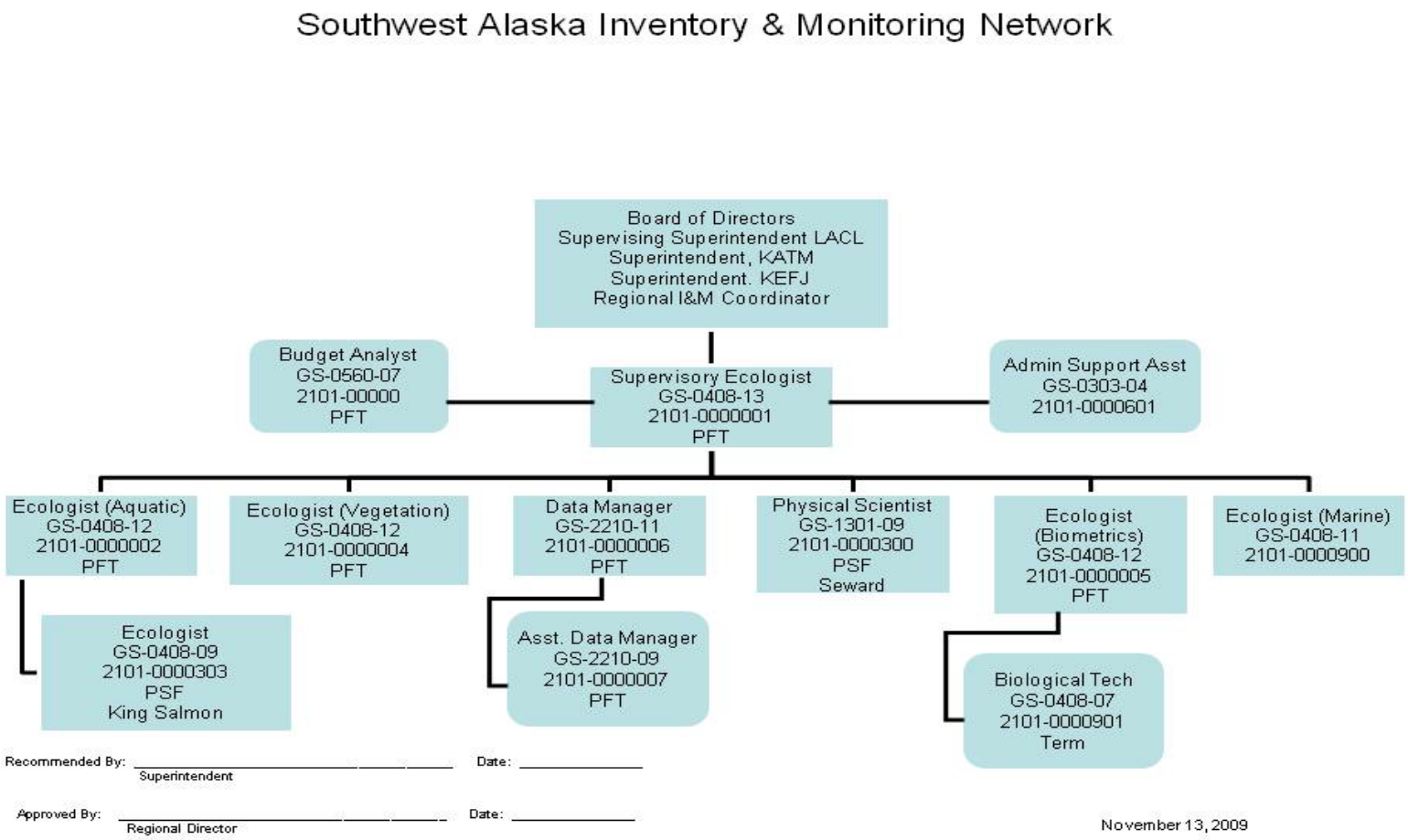

Figure 15. Southwest Alaska Network organizational chart.

Table 10. Network staff roles and responsibilities for freshwater flow systems monitoring.

Position	**Primary duties**
Aquatic Ecologist	Serves as project leader for freshwater monitoring in the Network. Responsible for developing and directing operational monitoring of water chemistry and surface hydrology.
KATM Fisheries Biologist LACL Fisheries Biologist KEFJ Resource Program Manager	Serve as the park-based support for freshwater monitoring. Are primary contacts regarding logistics and permitting for monitoring work in a given park. Assist with fieldwork, data collection, and supervision of technicians.
Ecologist (King Salmon based)	Under supervision of aquatic ecologist, assist with data collection, entry, summary, analysis and reporting. Assists with logistical coordination of field work.
Biometrician	Responsible for all aspects of sampling design and data analysis associated with freshwater chemistry and surface hydrology vital signs.
Data Manager	Serves as the primary person responsible for all aspects of data management for the Network. Works with the aquatic ecologist to design appropriate databases for data collection and for integration of data.
Network Coordinator	Serves as overall program administrator and supervisor. Provides consultation on all phases of protocol review and implementation. Reviews annual and status and trend reports.

Operational Requirements

Annual Workload and Field Schedule

The operational requirements to monitor freshwater flow systems within the SWAN must be considered within the context of other aquatic vital signs (resident lake fish and salmon) as well as staff scheduling, logistical considerations, and field crew safety – particularly in regards to weather and travel. The travel logistics of accessing most lakes within the SWAN and potential for weather delays require additional time to be built into all field work schedules. Additionally, the size of several Tier 1 lakes adds to the travel time between sample sites. For example, in order to complete all 50 vertical lake profile sites within the 5 basins of Naknek Lake, five full days with calm to minimal winds are required. Three full days are required to complete vertical lake profiles on Lake Clark, whereas most other lakes can each be completed in one full day. Given that four Tier 1 lakes plus two to three Tier 2 and 3 lakes will be sampled for vertical lake profiles each summer, this task alone requires 12 to 13 days of calm weather conditions (not including travel time between lakes and parks). All field activities will take place between mid-May and late September as ice / weather conditions are too uncertain outside these dates for reliable field activity planning. Table 11 provides a list of annual program activities including all aspects of field work, data management, and project administration.

Equipment Needs

The equipment and supply needs to carry out the freshwater flow system protocol safely and effectively are fairly extensive. Some equipment will require an initial one-time investment while other equipment will be recurring costs. Additionally, other equipment and supplies, such as boats, motors, and fuel, may be provided by parks as in-kind support. Given the heavy reliance on automated data loggers for data collection, a significant portion of the operational budget will go towards data logger purchase, maintenance, and replacement. The following list provides a summary of equipment / supplies needed to carry out the operational aspects of this protocol, this list is not meant to cover all equipment / supplies needed for extended field trips (such as personal gear, survival equipment, etc):

Water Quality Equipment / Supplies

<u>Capital Expenses:</u>
Multi-parameter sonde (YSI 600QS for lake profiles, YSI6600V2 for continuous monitoring)
Multi-parameter sonde control (YSI 650MDS) and field cable (8’ and 200’ cables)
Field-grade laptop computer (e.g. Panasonic Toughbook)
Secchi disc and cable
Digital camera and GPS
Multi-parameter sonde housing and security cable

<u>Expendable Supplies:</u>
Multi-parameter sonde calibration solutions (pH, specific conductivity, turbidity)
C cell batteries
Field notebook and clipboard
Hardcopy of field forms printed on waterproof or water-resistant paper

Table 11. Annual operational schedule for freshwater flow system monitoring.

Month	Project Administration	Field Activities	Data Management / Reporting
January			Analysis and synthesis of previous year's data
February	Research permit reporting and application		Analysis and synthesis of previous year's data
March	Field schedule planning, park float plane requests submitted; project supplies / equipment orders		Annual summary report / status and trends report due
April	Safety training / certification		
May	Field monitoring training / review; Safety training / certification	Deploy water level pressure transducers; discharge measurements	
June		Temperature array download / maintenance; deploy multi-parameter sondes	Begin current field season data review / entry
July		Multi-parameter sonde download / re-calibration; begin vertical lake profiles; discharge measurements	Data review / entry
August		Multi-parameter sonde download / re-calibration; finish vertical lake profiles	Data review / entry
September	Annual administrative review and work plan	Multi-parameter sonde download / retrieval; retrieve water level pressure transducers; temperature array download; discharge measurements	Data review / entry
October			Data review / entry
November			Complete data review / entry / certify all data
December			Data summarization, graphing, synthesis

Surface Hydrology Equipment / Supplies

Capital Expenses:

Water level pressure transducers
Barometric logger
Housing for loggers / rebar and clamps for attachment
Survey level, tripod, and stadia rod
Acoustic Doppler current profiler (RiverSurveyor M9) or Price AA current meter with mounting bracket
Marsh-McBurney flowmeter and wading rod
Survey reel tape (100 meter)
Field-grade laptop computer (e.g. Panasonic Toughbook)
Digital camera and GPS

Expendable Supplies:
Field notebook and clipboard
Hardcopy of field forms printed on waterproof or water-resistant paper
Benchmark caps and rebar

Budget

Table 12 provides the estimated annual operational budget to implement the freshwater flow system protocol (based on FY2010 dollars). Expenses not listed, such as boats, motors, and fuel, will be provided as in-kind support through KATM, KEFJ, and LACL. Staff salaries and travel expenses will be discussed below.

Table 12. Annual operational budget for water quality and surface hydrology monitoring. Expenses marked with an '*' indicate start-up costs, other expenses are expected annually or periodically.

Item	Quantity	Unit Cost	Total Cost
Multi-parameter sonde for continuous water quality monitoring*	3	$10,000	$30,000
Multi-parameter sonde for lake profiles and in situ monitoring*	2	$5,000	$10,000
Secchi disc*	2	$100	$200
Digital camera*	1	$400	$400
GPS*	1	$200	$200
Portable depth finder / chartplotter*	1	$600	$600
Field-grade laptop*	1	$1,800	$1,800
Water temperature thermistors	10	$120	$1,200
Water level pressure transducers	2	$1,200	$2,400
Barometric logger	1	$800	$800
Benchmarks	15	$10	$150
Chains and anchor material*			$1,000
		Subtotal:	$48,750
Consumables			
Line material and buoys for temperature arrays			$750
Multi-parameter sonde calibration solution			$1,500
Multi-parameter sonde replacement sensors and annual maintenance			$2,000
Misc. field equipment/supplies (waders, rain gear, batteries)			$1,000
Freight for equipment to and from parks			$1,000
		Subtotal:	$6,250
		Total:	$55,000

Staff Salaries and Travel Expenses

Staff Salaries:
The aquatic ecologist position will be funded by annual monitoring dollars provided to SWAN by the NPS Water Resources Discipline (NPS WRD). In FY2010, NPS WRD's

allocation to SWAN was $133,600. Note: $7,200 for rental of office space at the AK NPS Regional Office and 1% ($1,336) for a Regional Office Assessment are excised annually from this funding allocation. The FY2010 cost to fund a GS-12 aquatic ecologist position was $96,558 (including benefits and locality pay). The remainder of NPS WRD dollars will be used to fund the operational portion of the freshwater flow system protocol. Any discrepancies between NPS WRD dollars and operational budgetary needs will be reconciled with SWAN Vital Signs monitoring dollars. Other staff vital to implementing the freshwater flow system protocol, such as the King Salmon based ecologist and SWAN data manager, will be funded through SWAN Vital Signs monitoring dollars.

Travel Expenses:

With the exception of Exit Creek in KEFJ, all other SWAN lakes require the use of aircraft for at least a portion of the travel to access from SWAN's base in the NPS Regional Office in Anchorage, AK. This fact adds considerably to the operational costs of monitoring in southwest Alaska. Commercial air travel and park-based aircraft fees are difficult to estimate given constant changes in fuel costs, weather delays, and opportunistic travel as schedules remain flexible to accommodate other monitoring / park operational needs. Currently, commercial travel costs from Anchorage to Port Alsworth, AK (LACL field headquarters) are $400 / person roundtrip. Commercial travel costs from Anchorage to King Salmon, AK (KATM field headquarters) are $450 / person roundtrip. Commercial charter plane and park aircraft fees for access to remote lakes from Port Alsworth or King Salmon are too difficult to estimate on a per trip basis given all the factors influencing costs (e.g. aircraft type, flight time, number of flights required, aircraft waiting time, etc). However, total cost for accessing two or three remote lakes within LACL or KATM should be less than $2,500. Surprise Lake, a Tier 2 lake within ANIA, may be more expensive to access given the considerable travel time to reach this lake from King Salmon, AK.

Literature Cited

ACIA. 2004. Impacts of a warming Arctic. Arctic climate impact assessment. Cambridge University Press, Edinburgh, UK.

ADEC. 2008. Alaska's final 2008 integrated water quality monitoring and assessment report. Alaska Department of Environmental Conservation, Juneau, AK.

Adrian, R., C.M. O'Reilly, H. Zagarese, 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(6, part 2): 2283-2297.

Alaska National Interest Lands Claim Act. 1980. Public Law 96-487 – December 2, 1980. 94 Stat. 2371. 96th Congress. Washington, District of Columbia.

Anttila, S., T. Kairesalo, and P. Pellikka. 2008. A feasible method to assess inaccuracy caused by patchiness in water quality monitoring. Environmental Monitoring and Assessment 142: 11-22.

Arnold, S.M., and J.P. Middaugh. 2004. Use of traditional foods in a healthy diet in Alaska: risks in perspective. Second Edition, Volume 2 – Mercury. State of Alaska Epidemiology, Anchorage, Alaska.

Barrie, L., E. Falck, D. Gregor, T. Iverson, H. Loeng, R. Macdonald, S. Pfirman, T. Skotvold, and E. Wartena. 1998. The influence of physical and chemical processes on contaminant transport into and within the Arctic. Ambio. 30:410-415.

Barry, K.L., J.A. Grout, C.D. Levings, B.H. Nidle, and G.E. Piercy. 2000. Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 57:2032-2043.

Bartz, K.K., and R.J. Naiman. 2005. Effects of salmon-borne nutrients on riparian soils and vegetation in southwest Alaska. Ecosystems 8:1-18.

Bennett, L.A. 2004. Baseline water quality inventory for the Southwest Alaska Inventory and Monitoring Network, Aniakchak National Monument and Preserve. USDI National Park Service, Anchorage, AK.

Bennett, L.A. 2005. Baseline water quality inventory for the southwest Alaska inventory and monitoring network, Kenai Fjords National Park. Report Number: NPS/AKRSWAN/NRTR-2005/02.

Bennett, A.J., W.L. Thompson, and D.C. Mortenson. 2006. Vital signs monitoring plan, Southwest Alaska Network. National Park Service, Anchorage, AK.

Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic systems of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53:164-173.

Brabets, T.P. 2002. Water quality of the Tlikakila River and five major tributaries to Lake Clark, Lake Clark National Park and Preserve, Alaska 1999-2001. U.S. Geological Survey Water-Resources Investigation 2002-4127.

Brabets, T.P., and J. R. Riehle. 2004, Geochemistry of the Johnson River, Lake Clark National Park and Preserve, Alaska. U.S. Geological Survey Scientific Investigations Report 2003-4252.

Brabets, T.P., and R.T. Ourso. 2006a. Water quality, physical habitat, and biology of the Kijik River Basin, Lake Clark National Park and Preserve, Alaska, 2004-2005. U.S. Geological Survey Scientific Investigations Report 2006-5123.

Brabets, T.P., and R.T. Ourso. 2006b. Water quality of the Crescent River Basin, Lake Clark National Park and Preserve, Alaska, 2003-2004. U.S. Geological Survey Scientific Investigations Report 2006-5151.

Branson, J.B. 2007. The Canneries, Cabins, and Caches of Bristol Bay, Alaska. National Park Service Research / Resources Management Report 2007-63.

Buchanan T.J. and W.P. Somers. 1968. Stage measurement at gaging stations. U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A7.

Burgner, R.L., C.J. Di Constanzo, R.J. Ellis, G.Y. Harry, Jr., W.L. Hartman, O.E. Kerns, Jr., O.E. Mathisen, and W.F. Royce. 1969. Biological studies and estimates of optimum escapements of sockeye salmon in the major river systems in southwestern Alaska. Fishery Bulletin 67:405-459.

Buhl, K.J., and S.J. Hamilton. 1991. Relative sensitivity of early life stages of arctic grayling, coho salmon, and rainbow trout to nine inorganics. Ecotoxicology and Environmental Safety 2:184-197.

Cameron, W. and G. Larson. 1992. Baseline inventory of aquatic resources of Aniakchak National Monument, Alaska. Technical Report NPS/PNROSU/NRTR-92/03.

Cameron, W., and G. Larson. 1993. Limnology of a caldera lake influenced by hydrothermal processes. Archiv fur Hydrobiologie. Stuttgart [Arch. Hydrobiol.], 128:13-38.

Carter, R.W., and J. Davidian. 1968. General procedures for gaging streams: U.S. Geological Survey Techniques of Water- Resources Investigations, book 3, chap. A6.

Cederholm, C.J., M.D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24:6-15.

Chamberlain, D.M. 1989. Physical and biological characteristics and nutrients limiting primary productivity, Lake Clark, Alaska. M.S. Thesis, Michigan Technological University, Houghton, MI.

Chapin III, F.S., G.R. Shaver, A.E. Giblin, K.J. Nadelhoffer, and J.A. Laundre. 1995. Responses of Arctic Tundra to Experimental and Observed Changes in Climate. Ecology 76:694-711.

Cieutat, B. A., R. P. Goldfarb, J. C. Borden, J. McHugh and C. D. Taylor. Undated. Environmental Geochemistry of mesothermal gold deposits, Kenai Fjords National Park, South-central Alaska. KEFJ files.

Curran, J. 2003. Channel stability and water quality of the Alagnak River, Southwest Alaska. U.S Geological Survey Water Resources Investigations Report 02-4184.

Dale, B., and R. Stottlemyer. 1986. Chemical, physical and biological characteristics of Lake Clark and selected surface waters of Lake Clark National Park and Preserve, Alaska. GLARSU Report #17. Michigan Technological University, Department of Biological Sciences, Houghton, MI.

Dahlberg, M.L. 1976. Carrying capacity of nursery lakes for sockeye salmon, field operations report 1974. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Auke Bay Lab. Manuscript report MR-F No. 132.

de Fontaine, C. S., D. S. Kaufman, R. S. Anderson, A. Werner, C. F. Waythomas, J. R. Hancock, B. K Dennison, and K. L. Wallace. 2002. Late Quaternary volcanic ash in three lacustrine records, upper Cook Inlet, Alaska. Page 28 *in* Yesner, D. R., (ed.), Environmental change and human migrations in the North Pacific Basin, AMQUA 2002, 17, Program and Abstracts - American Quaternary Association, Anchorage, AK, Aug. 8-11, 2002.

Dorava, J. M., and A. M. Milner. 1999. Effects of recent volcanic eruptions on aquatic habitat in the Drift River, Alaska, USA: Implications at other Cook Inlet Region Volcanoes. Environmental Management 23:217-230.

Edmundson, J.A., and A. Mazumder. 2001. Linking growth of juvenile sockeye salmon to habitat temperature in Alaskan lakes. Transactions of the American Fisheries Society 130:644-662.

Ewald, G., P. Larsson, H. Linge, L. Okla, and N. Szarzi. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncorhynchus nerka*). Arctic 51:40-47.

Forbes, S.A. 1887. The lake as a microcosm. Bulletin of the Scientific Association (Peoria, IL), 1887:77-87.

Ford, J., and L. Hasselbach. 2001. Heavy metals in mosses and soils on six transects along the Red Dog Mine Haul Road, Alaska. NPS/AR/NRTR-2001/38. Western Arctic National Parklands, Kotzebue, Alaska.

Francis, J.A., D.M. White, J.J. Cassano, W.J. Gutowski Jr., L.D. Hinzman, M.M. Holland, M.A. Steele, and C.J. Vorosmarty. 2009. An arctic hydrologic system in transition: feedbacks and impacts on terrestrial, marine, and human life. Journal of Geophysical Research 114:1-30.

Freeman, C., C.D. Evans, D.T. Monteith, B. Reynolds, and N. Fenner. 2001. Export of organic carbon from peat soils. Nature 412:785.

Frenzel, S.A., and J.M. Dorava. 1999. Water quality data for the Talkeetna River and four streams in national parks, Cook Inlet Basin, Alaska. 1998. Prepared in cooperation with the National Park Service, Anchorage, Alaska. U.S. Department of the Interior, U.S. Geological Survey Open File Report 99-459. Denver, CO: Branch of Information Services.

Gende, S.M., R.T. Edwards, M.F. Willson, and M.S. Wipfli. 2002. Pacific salmon in aquatic and terrestrial ecosystems. BioScience 52:917-928.

Gibs, J., F.D. Wilde, and H.A. Heckathorn. 2007. Use of multiparameter instruments for routine field measurements (ver. 1.1): U.S. Geological Survey Techniques of Water Resources Investigations, book 9, chap. A6, section 6.8, August, available online only from http://pubs.water.usgs.gov/twri9A/.

Giffen, B., D.K. Hall, and J.Y.L. Chien. 2007. Glaciers of Kenai Fjords National Park and Katmai National Park and Preserve. Chapter 12 in GLIMS.

Goldman, C. R. 1960. Primary productivity and limiting factors in three lakes of the Alaska Peninsula. Ecological Monographs 30:207-230.

Goldstein, J.N., D.F. Woodward, and A.M. Farag. 1999. Movement of adult Chinook salmon during spawning migration in a metals-contaminated system, Coeur

d'Alene River, Idaho. Transactions of the American Fisheries Society 128:121-129.

Goransson, E., R.K. Johnson, and A. Wilander. 2004. Representativity of a mid-lake surface water chemistry sample. Environmental Monitoring and Assessment 95: 221-238.

Gregory-Eaves, I., B. P. Finney, M. S. V. Douglas, and J. P. Smol. 2004. Inferring sockeye salmon (*Oncorhynchus nerka*) population dynamics and water quality changes in a stained nursery lake over the past ~500 years. Canadian Journal of Fisheries and Aquatic Sciences 61:1235-1246.

Griffiths, L, L. Stromquist, J. Troutman with assistance from R. Falkman and P. Armato. 1999. Nuka mine site reconnaissance and characterization report. KEFJ files, incomplete copy.

Groisman, P.Y., and D.A.Easterling. 1994. Variability and trends of precipitation and snowfall over the United States and Canada. Journal of Climate 7:184-205.

Gunther. A. 1986. Report to the National Park Service on research performed under contract at Katmai National Park, Alaska during the summer of 1986. University of California-Berkeley, CA. Energy Resources Group and the Rocky Mountain Biological Laboratory, Crested Butte, CO.

Gunther, A. 1992. A chemical survey of remote lakes of the Alagnak and Naknek River systems, southwest Alaska, USA. Arctic and Alpine Research 24:64-68.

Harry, G.Y., C.L. DiCostanzo, W.L. Hartman, R.J. Ellis, W.F. Royce, R.L. Burgner, and O.A. Mathisen. 1964. Summary report of studies on the optimum escapement of sockeye salmon in southwestern Alaska, 1961-62. Unpublished. U. S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska and Fisheries Research Institute, U. of Washington, Seattle, Washington.

Hasselbach, L., J.M. Ver Hoef, J. Ford, P. Neitlich, E. Crecelius, S. Berryman, B. Wolk, and T. Bohle. 2005. Spatial patterns of cadmium and lead deposition on and adjacent to National Park Service lands in the vicinity of Red Dog Mine, Alaska. Science of the Total Environment 348:211-230.

Helfield, J.M., and R.J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology 82:2403-2409.

Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources: Techniques of water-resources investigations of the United States Geological Survey. Book 4: Hydrologic Analysis and Interpretation Chapter A3.

Hilderbrand, G.V., T.A. Hanley, and C.C. Schwartz. 1999. Role of brown bears (*Ursus arctos*) in the flow of marine nitrogen into a terrestrial ecosystem. Oecologia 121:546-550.

Hu, F.S., L.B. Brubaker, and P.M. Anderson. 1995. Postglacial vegetation and climate change in the Northern Bristol Bay Region, southwestern Alaska. Quaternary Research 43:382-392.

Hu, F.S., B.P. Finney, and L.B. Brubaker. 2001. Effects of holocene Alnus expansion on aquatic productivity, nitrogen cycling, and soil development in southwestern Alaska. Ecosystems 4:358-368.

Hynes, H.B.N. 1975. The stream and its valley. Verh. Internat. Verein. Limnol. 19:1-15.

Jassby, A.D. 1996. Methods for analysis of spatial and temporal patterns. RMP Contribution #18, San Francisco Estuary Regional Monitoring Program, Richmond, CA.

Jewett, S.C., and L.K. Duffy. 2007. Mercury in fishes of Alaska, with emphasis on subsistence species. Science of the Total Environment 2007:1-25.

Johnson, P., and C. Berg. 1999. Baseline hydrocarbon study: Katmai National Park and Preserve final report. U.S. Fish and Wildlife Service, Alaska Regional Office, Ecological Services Environmental Contaminants Program. Anchorage, AK.

Kaplan, L. A., and J. D. Newbold. 2000. Surface and subsurface dissolved organic carbon. Pages 237-258 *in* J. B. Jones and P. J. Mulholland (eds). Streams and Ground Waters. Academic Press, San Diego, California.

Keith, T.E.C., J.M. Thompson, R.A. Hutchinson, L.D. White, M. Nathenson. 1990. Geochemistry of streams and springs, Valley of Ten Thousand Smokes, Katmai National Park, Alaska. EOS, Transactions, American Geophysical Union 71:1691.

Keith, T.E.C., J.M. Thompson, R.A. Hutchinson, and L.D. White. 1992. Geochemistry of waters in the Valley of Ten Thousand Smokes region, Alaska. Journal of Volcanology and Geothermal Research 49:209-231.

Kennedy, E.J. 1990. Levels at streamflow-gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A.

Keyser,A.R., J.S.Kimball, R.R.Nemani, and S.W. Running. 2000. Simulating the effects of climate change on the carbon balance of North American high latitude forests. Global Change Biology 6:1-11.

Kline, T.C., J.J. Goering, O.A. Mathisen, P.H. Poe, and P.L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. $\delta^{15}N$ and $\delta^{13}C$ evidence in Sashin Creek, southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 47:136-144.

Kline, T.C., J.J. Goering, O.A. Mathisen, P.H. Poe, P.L. Parker, and R.S. Scalan. 1993. Recycling of elements transported upstream by runs of Pacific salmon: II. ^{15}N and ^{13}C evidence in the Kvichak River watershed, Bristol Bay, southwestern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 50:2350-2365.

Kozlowski, J. 2007. Water resources information and issues overview report, Katmai National Park and Preserve, Alagnak Wild River. Natural Resource Technical Report NPS/NRPC/WRD/NRTR-2007/057. National Park Service, Fort Collins, Colorado.

Krummel, E.M., R.W. Macdonald, L.E. Kimpe, I. Gregory-Eaves, M.J. Demers, J.P. Smol, B. Finney, and J.M. Blais. 2003. Delivery of pollutants by spawning salmon. Nature 425:255-256.

Kyle, R.E., and T.P. Brabets. 2001. Water temperature of streams in the Cook Inlet Basin, Alaska, and implications of climate change. U.S. Geological Survey, Water Resources Investigations Report 01-4109.

Landers, D.H., S.L. Simonich, D.A. Jaffe, L.H. Geiser, D.H. Campbell, A.R. Schwindt, C.B. Schreck, M.L. Kent, W.D. Hafner, H.E. Taylor, K.J. Hageman, S. Usenko, L.K. Ackerman, J.E. Schrlau, N.L. Rose, T.F. Blett, and M.M. Erway. 2008. The fate, transport, and ecological impacts of airborne contaminants in western national parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

LaPerriere, J.D. 1996. Water Quality Inventory and Monitoring – Katmai National Park and Preserve. University of Alaska, Alaska Cooperative Fish and Wildlife Research Unit, Fairbanks, AK.

LaPerriere, J.D. 1997. Limnology of two lake systems of Katmai National Park and Preserve, Alaska: physical and chemical profiles, major ions, and trace elements. Hydrobiologia 354:88-99.

LaPerriere, J.D., and J.R. Jones. 2002. Limnology of lakes in Katmai National Park and Preserve, Alaska: nutrients and plankton. Verh. Internat. Verein. Limnol. 28:1010-1016.

Latifovic, R. and D. Pouliot. 2007. Analysis of climate change impacts on lake ice phenology in Canada using the historical satellite data record. Remote Sensing of Environment 106:492-507.

Lawson, P.W., E.A. Logerwell, N.J. Mantua, R.C. Francis, and V.N. Agostini. 2004. Environmental factors influencing freshwater survival and smolt production in Pacific Northwest coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 61:360-373.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. Freeman Press, San Francisco.

Likens, G.E.. 1984. Beyond the shoreline: a watershed-ecosystem approach. Verh Int Verein Limnol 22:1-22.

Lohr, S. L. 1999. Sampling: design and analysis. Duxbury Press, Pacific Grove, California.

Magnuson, J.J., D.M. Robertson, B.J. Benson, R.H. Wynne, D.M. Livingstone, T. Arai, R.A. Assel, R.G. Barry, V. Card, E. Kuusisto, N.G. Granin, T.D. Prowse, K.M. Steward, and V.S. Vuglinski. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. Science 289:1743-1746.

Mahoney, B.A. and G.M. Sonnevil. 1991. Surprise Lake and Aniakchak River fishery investigation, Aniakchak National Monument and Preserve, Alaska, 1987 and 1988 final report. Fisheries Technical Report number 12. U.S. Fish and Wildlife Service, Alaska. King Salmon, AK.

Mathisen, O.A. and H.P. Poe. 1969. Studies of Lake Clark and its sockeye salmon runs, 1961-1968. University of Washington Fisheries Research Institute, Circular No. 69-5. Seattle, WA.

Mathisen, O.A., Parker P.L.,Goering J.J., Kline T.C., Poe P.H., Scalan R.S.. 1988. Recycling of marine elements transported into freshwater systems by anadromous salmon.Vereinigung für Theoretische und Angewandte Limnologie 23:2249–2258.

McDonald, M.E., A.E. Hershey, and M.C. Miller. 1996. Global warming impacts on lake trout in arctic lakes. Limnology and Oceanography 41:1102-1108.

Meyer, J. L., W. H. McDowell, T. L. Bott, J. W. Elwood, C. Ishizaki, J. M. Melack, B. L. Peckarsky, B. J. Peterson, and P. A. Rublee. 1988. Elemental dynamics in streams. Journal of the North American Benthological Society. 7:410–432.

Minshall, G.W., K.W. Cummins, R.C. Peterson, C.E. Cushing, D.A. Bruns, J.R. Sedell, and R.L. Vannote. 1985. Developments in stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Science 42:1045-1055.

Mortenson, D. 2006. Data management plan for the Inventory and Monitoring Program, Southwest Alaska Network. National Park Service. Anchorage, AK.

Naiman, R.J., R.E. Bilby, D.E. Schindler, and J.M. Helfield. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. Ecosystems 5:399-417.

National Research Council. 2002. Abrupt Climate Change: Inevitable Surprises, Committee on Abrupt Climate Change, National Research Council, Washington, DC.

National Park Service. 1997a. Baseline Water Quality Data, Inventory and Analysis, Katmai National Park and Preserve and Alagnak National Wild River. Water Resources Division and Servicewide Inventory and Monitoring Program. Technical Report NPS/NRWRD/NRTR-97/102. Fort Collins, CO.

National Park Service. 1997b. Baseline Water Quality Data, Inventory and Analysis, Lake Clark National Park and Preserve. Water Resources Division and Servicewide Inventory and Monitoring Program. Technical Report NPS/NRWRD/NRTR-2000/258. Fort Collins, CO.

National Park Service. 2002. Recommendations for core water quality monitoring parameters and other key elements of the NPS vital signs program. National Park Service Freshwater Workgroup Subcommittee, August 15, 2002, Fort Collins, Colorado. http://science.nature.nps.gov/im/monitor/protocols/COREparam.doc

National Park Service. 2004. Final Exit Glacier Area Plan, General Management Plan Amendment. Kenai Fjords National Park, Seward, AK.

Penoyer, P. 2003. Vital Signs Long-Term Aquatic Monitoring Projects, Part C: Draft Guidance on WRD Required and Other Field Parameter Measurements, General Monitoring Methods and Some Design Considerations in Preparation of a Detailed Study Plan. Water Resources Division, National Park Service, Fort Collins, CO.

Rantz, S.E. 1992. Measurement and computation of streamflow, Volume 1 Measurement of stage and discharge. U.S. Geological Survey Water-Supply Paper 2175.

Riera, J.L., J.J. Magnuson, T.K. Kratz, and K.E. Webster. 2000. A geomorphic template for the analysis of lake districts applied to the Northern Highland Lake District, Wisconsin, USA. Freshwater Biology 43:301-318.

Rognerud, S., T. Skotvold, E. Fjeld, S.A. Norton, and A. Hobaek. 1998. Concentrations of trace elements in recent and preindustrial sediments from Norwegian and Russian Arctic lakes. Canadian Journal of Fisheries and Aquatic Sciences 55:1512-1523.

Russell, R. 1980. A fisheries inventory of waters in the Lake Clark National Monument area. Alaska Department of Fish and Game, Division of Sport Fish, Juneau.

Saiki, M.K., D.T. Castleberry, T.W. May, B.A. Martin, and F.N. Bullard. 1995. Copper, cadmium, and zinc concentrations in aquatic food-chains from the upper Sacramento River (California) and selected tributaries. Archives of Environmental Contamination and Toxicology 29:484-491.

Sapiano, J.J.,W.D. Harrison, and K.A.Echelmeyer. 1998. Elevation, volume, and terminus changes of nine glaciers in North America, Journal of Glaciology, 44:119-135.

Schaefer, J.R., W.E. Scott, W.C. Evans, J. Jorgenson, R.G. McGimsey, B. Wang. 2008. The 2005 catastrophic acid crater lake drainage, lahar, and acid aerosol formation of Mount Chiginagak volcano, Alaska, USA: field observations and preliminary water and vegetation chemistry results. Geochemistry, Geophysics, and Geosystems 9:1-29.

Schindler, D.W., K.G. Beaty, E.J. Fee, D.J. Cruikshank, E.D. DeBruyn, D.L. Findlay, G.A. Linsey, J.A. Shearer, M.P. Stainton, and M.A. Turner. 1990. Effects of climatic warming on lakes of the central boreal forest. Science 250:967-970.

Schindler, D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. Canadian Journal of Fisheries and Aquatic Sciences 58:18-29.

Schindler, D.E., M.D. Scheuerell, J.W. Moore, S.M. Gende, T.B. Francis, and W.J. Palen. 2003. Pacific salmon and the ecology of coastal ecosystems. Frontiers in Ecology and the Environment 1:31-37.

Schindler, D.W., and J.P. Smol. 2006. Cumulative effects of climate warming and other human activities on freshwaters of the arctic and subarctic North America. Ambio 35:160-168.

Schindler, D.W. 2009. Lakes as sentinels and integrators for the effects of climate change on watersheds, airsheds, and landscapes. Limnology and Oceanography 54(6, part 2):2349-2358.

Shaw, G. E. 1982. Evidence for a central Eurasian source of Arctic haze in Alaska. Nature 28:815-818.

Shearer, J., and C. Moore. 2010. Water Quality and Surface Hydrology of Freshwater Flow Systems in Southwest Alaska: 2009 Annual Summary Report. Natural Resource Technical Report NPS/SWAN/NRTR—2010/304. National Park Service, Fort Collins, Colorado.

Smol, J.P., and M.S.V. Douglas. 2007. From controversy to consensus: making the case for recent climate change in the Arctic using lake sediments. Frontiers in Ecology and the Environment 5:466-474.

Soranno, P.A., K.E. Webster, J.L. Riera, T.K. Kratz, J.S. Baron, P.A. Bukaveckas, G.W. Kling, D.S. White, N. Caine, R.C. Lathrop, and P.R. Leavitt. 1999. Spatial variation among lakes within landscapes: ecological organization along lake chains. Ecosystems 2:395-410.

Stevens, D. L., Jr., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Stottlemyer, R. 1990. Preliminary assessment of change in limnology of Lake Clark following input of volcanic ash from Redoubt Volcano. Great Lakes Area Resource Studies Unit Report #45, Michigan Technological University, Houghton, MI.

Stottlemyer, R., and D. Chamberlain. 1987. Chemical, physical and biological characteristics of Lake Clark and selected surface waters of Lake Clark National Park and Preserve, Alaska. GLARSU Report #24. Dept. of Biological Sciences, Michigan Technological University, Houghton, MI.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organization for Economic and Cultural Development, DAS/CSI/68, 27:1-159.

Wagner, T.A. and S.H. Lanigan. 1988. Survey of fishery resources in the Meshik River drainage basin. Alaska Fisheries technical report number 1. U.S. Fish and Wildlife Service, King Salmon, AK.

Wagner, R.J., Boulger R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006. Guidelines and standard procedures for continuous water-quality monitors – station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1-D3.

Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.M. Fromentin, O.Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389-395.

Waythomas, C. F., T. P. Miller, and J. E. Begét. 2000. Record of late Holocene debris avalanches and lahars at Iliamna Volcano, Alaska. Journal of Volcanology and Geothermal Research 104:97-130.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, San Diego, CA.

Wilkens, A.X. 2002. The limnology of Lake Clark, Alaska. M.S. Thesis, University of Alaska, Fairbanks.

Williamson, G.E., W. Dodds, T.K. Kratz, and M.A. Palmer. 2008. Lakes and streams as sentinels of environmental change in terrestrial and atmospheric processes. Frontiers in Ecology and the Environment 6:247-254.

Williamson, C.E., D.P. Morris, M.L. Pace, and A.G. Olson. 1999. Dissolved organic carbon and nutrients as regulators of lake ecosystems: Resurrection of a more integrated paradigm. Limnology and Oceanography 44:795-803.

Wipfli, M.S., J.P. Hudon, J.P. Caouette, and D.T. Chaloner. 1999. Influence of salmon spawner densities on stream productivity in southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 56:1600-1611.

Witham, C. S., Oppenheimer, C. and Horwell, C. J, 2005. Volcanic ash leachates: a review and recommendations for analysis methods. Journal of Volcanology and Geothermal Research, 141:299-326.

Woo, M-k., K.L. Young, and L. Brown. 2006. High Arctic patchy wetlands: hydrologic variability and their sustainability. Physical Geography 27:297-307.

Wrona, F. J., T. D. Prowse, and J. D. Reist. 2005. Freshwater ecosystems and fisheries. Pages 353-452 *in* Arctic Climate Impact Assessment. Cambridge University Press, New York, NY.

York, G and Milner, A. 1999. Colonization and Community Development of Salmonids and benthic macroinvertebrates in a new stream within Kenai Fjords National Park, AK. ENRI. Final report to the National Park Service, Cooperative Agreement No. CA-9700-2-9021.

Zhang, X., A.S. Naidu, J.J. Kelley, S.C. Jewett, D. Dasher, and L.K. Duffy. 2001. Baseline concentrations of total mercury and methylmercury in salmon returning via the Bering Sea. Marine Pollution Bulletin 42:993-997.

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.

TIC Number: 953/101608, January 2011

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
1201 Oak Ridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA™