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Natural Resource Stewardship and Science

Monitoring Freshwater Systems in the Southwest Alaska Network

Protocol Narrative

Natural Resource Report NPS/SWAN/NRR—2015/925

ON THE COVER
Photograph of Kontrashibuna Lake in Lake Clark National Park and Preserve, Alaska.
Photograph courtesy of Jeff Shearer

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Protocol Narrative

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Executive Summary

The Southwest Alaska Network (SWAN) is one of 32 Inventory and Monitoring Networks covering 270 national park units within the National Park System. 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 park units.

The freshwater resources of these landscapes are impressive, ranging from countless small streams to five designated Wild Rivers to large, complex lake systems. This protocol narrative, and the accompanying standard operating procedures (SOPs; Shearer et al. 2015), provide 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 data and improve our methods. We will take a careful, conservative approach in modifying SOPs to ensure that the scientific credibility of the data 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.

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Background and Objectives

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.

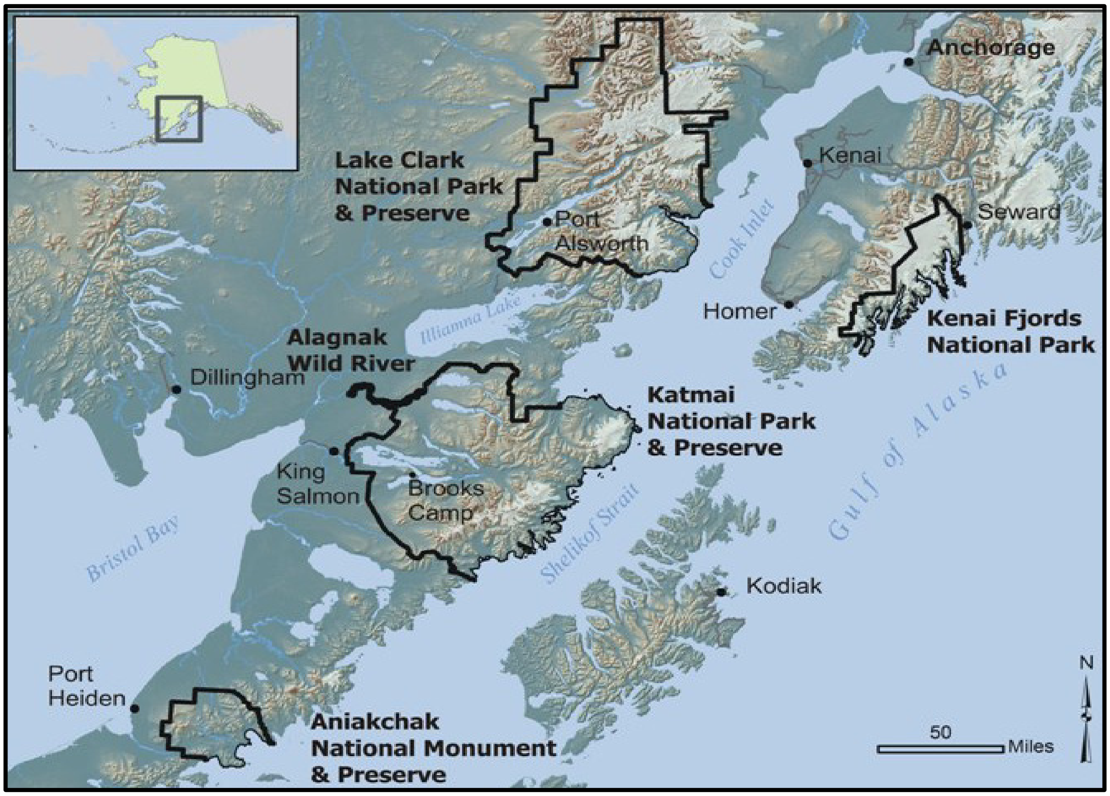

Figure 1. Map of park units included within the Southwest Alaska Network.

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 they 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 surface hydrology and freshwater chemistry as two resources of aquatic systems that warranted long-term monitoring in SWAN park units (Bennett et al. 2006).

This protocol narrative and the accompanying 14 Standard Operating Procedures (SOPs; Shearer et al. 2015) provide in-depth information on monitoring water quantity (surface hydrology) and water quality (freshwater chemistry) in aquatic systems within the 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 safety, instrument programming and use, data collection, data management, analyses, and reporting.

Rationale for Monitoring

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., outlet streams, 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 streamflow; (ii) water quality is, by national standards, unimpaired (i.e., no 303(d) surface waters exist within SWAN, ADEC 2013), 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 backdrop 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 synthesis report by 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). Air temperatures are increasing in Arctic areas at about twice the global average rate, with an expected 4–7 ºC 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. Associated 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 3 ºC 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 temperature changes $\geq$ 3 ºC, an increase considered significant for the incidence of fish diseases (Kyle and Brabets 2001). The water quantity and quality alterations resulting from changes in streamflow, 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 outflowing streams, inflowing tributaries, and contributing lakes, with the goal of achieving a spatially balanced coverage of the lake basin itself.

Parameters of Interest

The NPS Water Resources Division staff recommended that a set of core water quantity (discharge and water level) and water quality (temperature, specific conductivity, pH, and dissolved oxygen) parameters 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 the water quantity and quality parameters to be monitored is provided in Table 1.

Water Quantity (Surface Hydrology) Parameters

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 (cfs)). 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 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 discharge (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 streamflows, 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 streamflows 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.

Table 1. Water quantity and quality parameters monitored in SWAN park units. Ecological significance and stressors are synthesized from Wetzel 2001.

Parameters	Ecological Significance	Stressors
Water quantity		
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	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.
Water quality		
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.
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.
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.

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 streamflow 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.

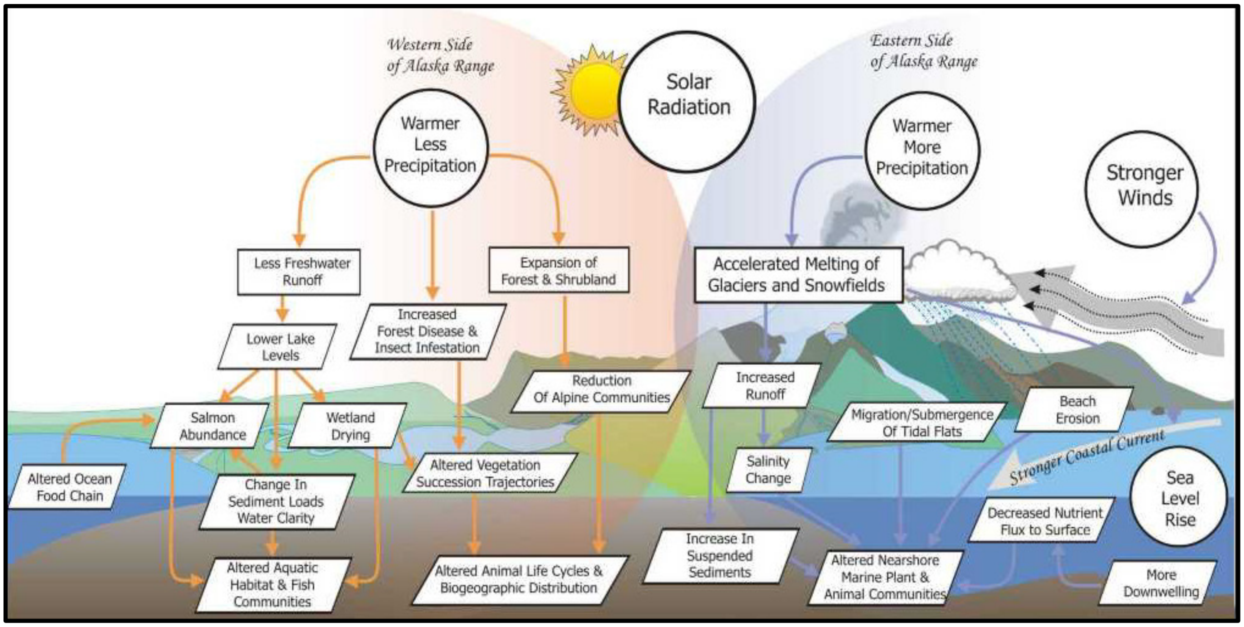

Figure 2. Conceptual model of projected landscape-level changes in SWAN parks due to climate change (Bennett et al. 2006).

Water Quality (Freshwater Chemistry) Parameters

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 2013). 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, volcanic activity, and inputs of contaminants from long-range and near-field sources (including biological conveyors such as salmon).

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 during 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 nutrient 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, 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).

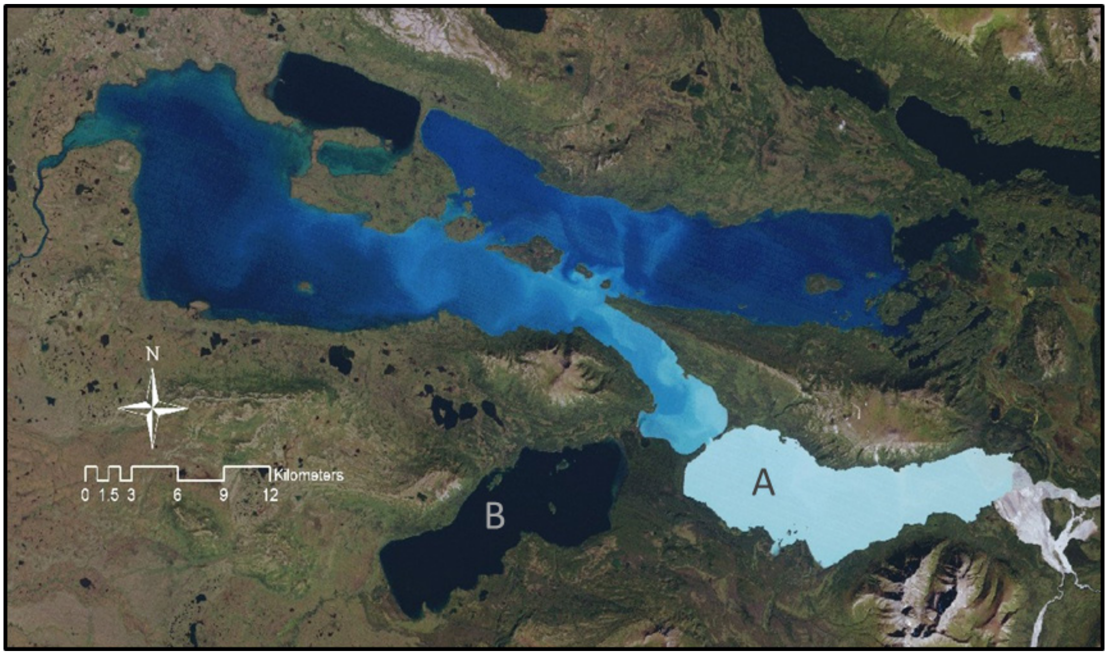

Figure 3. Satellite imagery of Naknek Lake and Lake Brooks, KATM. Note the stark contrast in water color between the Iliuk Arm of Naknek Lake (A) which receives surface runoff laden with volcanic ash and glacial silt, and Lake Brooks (B) which receives surface water free of volcanic or glacial inputs.

Given the integrated role aquatic systems have within the environment, we have chosen to monitor water quality and quantity 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 Quantity and Quality Data

Existing data to assess baseline streamflow relationships in SWAN park units are scant. Currently, no continuous stream gaging stations are maintained by the USGS Water Resource Division (USGS WRD) in SWAN watersheds. However, historical data are available at http://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 streamflow 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).

There have been several studies of baseline water quality conditions in SWAN park units (Table 2), 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 has focused on the Naknek and Lake Clark watersheds, primarily due to the expanse of these systems, their importance to fisheries, and management priorities at the park level.

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 U.S. Environmental Protection Agency (EPA) and NPS water quality criteria in summary reports for KATM (NPS 1997a) and LACL (NPS 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.

Measurable Objectives

The overall goal of SWAN's freshwater 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 quantity (surface hydrology) and quality (freshwater chemistry). 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 monitored continuously 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.

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 [a] (Waterbodies)
ALAG	Johnson and Berg 1999	1998	Aromatic compounds and hydrocarbons (Alagnak R.)
	Curran 2003	2003	Channel stability and water quality (Alagnak R.)
ANIA	Wagner and Lanigan 1988	1984	Core parameters (Meshik L.)
	Mahoney and Sonnevil 1991	1987–1988	Core parameters (Surprise L.)
	Cameron and Larsen 1992	1988–1989	Temperature, Secchi depth, major ions (Surprise L.)
	Bennett 2004	2003	Core parameters, major ions, DOC, Chl *a*, TN, TP, TSS, TDS, metals. Advanced suite of parameters only collected at 8 sites. (Surprise L. and tributaries, Meshik L., Aniakchak R., Willow Cr., Albert Johnson Cr., Iris Cr.)
KATM	Goldman 1960	1957	Algal plankton, nutrients, major ions (Naknek L.)
	Burgner et al. 1969	1961–1962	Temperature, DO, alkalinity, TDS, mineral analysis (Kukaklek, Nonvianuk, Colville, Grosvenor, and Naknek Lakes)
	Dahleberg 1976	1972–1976	Temperature, pH, alkalinity, conductivity, Secchi depth (Naknek L.)
	Gunther 1986 and 1992	1984–1986	Alkalinity, pH, major ions (various lakes including Battle, Kulik, Kukaklek, Iron Springs, Pirate, Nonvianuk, Murray, Hammersley, Coville, Idavain, Tony Malone, Pecker, and Brooks)
	Cameron 1993	1989	Water temperature, Secchi depth, major ions (Katmai and Kaguyak Crater Lakes, L. Brooks, and Naknek L.)
	LaPerriere 1996 and 1997	1990–1992	Major ions, nutrients, Secchi depth (various lakes including Brooks, Coville, Grosvenor, Hammersly, Idavain, Murray, Naknek, Battle, Kukaklek, Kulik, and Nonvianuk)
	Keith et al. 1992	1979–early 1990s	Physical and chemical water properties (Valley of Ten Thousand Smokes: R. 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 R.)
KEFJ	Edmundson and Mazumder 2001	1981, 1986–1987, 1997	Temperature, DO, irradiance, Secchi depth, major ions, nutrients (Delight and Desire Lakes)
	Cieutat et al. undated	1993	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	Core parameters, nutrients (Delusion L.)
	Bennett 2005	2004	Core parameters, turbidity (Resurrection R.; lakes and streams of Aialik Bay, Northwestern Fjord, Two Arm Bay, McCarty Fjord, and Nuka Bay)

Park	Source	Period of Record	Water Quality Parameters [a] (Waterbodies)
LACL	Mathisen and Poe 1969	1961	Secchi depth (L. Clark)
	Dale and Stottlemyer 1986	1985–1987	Core parameters, alkalinity, major ions, metals, nutrients (L. Clark, Twin, Telaquana, Turquoise, Lachbuna, Kijik, Upper and Lower Tazimina, Portage, Kontrashibuna, Two Lakes, Tlikakila, Kijik, Tanalian, Chulitna Rivers, Currant Creek, and L. Clark outlet)
	Stottlemyer and Chamberlain 1987	1985–1987	Core parameters, alkalinity, major ions, metals, nutrients (L. Clark, Twin, Telaquana, Turquoise, Lachbuna, Kijik, Upper and Lower Tazimina, Portage, Kontrashibuna, Two Lakes, Tlikakila, Kijik, Tanalian, Chulitna Rivers, Currant Crk., and L. Clark outlet)
	Chamberlain 1989	1985–1987	Core parameters, alkalinity, major ions, metals, nutrients (L. Clark, Twin, Telaquana, Turquoise, Lachbuna, Kijik, Upper and Lower Tazimina, Portage, Kontrashibuna, Two Lakes, Tlikakila, Kijik, Tanalian, Chulitna Rivers, Currant Crk., and L. Clark outlet)
	Deschu and LaPerriere 1998	1998	Core parameters, turbidity, major ions, nutrients (Tanalian, Kijik, Chulitna Rivers, Priest Rock Crk., 22-Crk.)
	Wilkens 2002	1999–2000	Core parameters, redox potential, Secchi depth, turbidity, suspended solids, total nutrients, total dissolved nutrients, true color (L. Clark)
	Brabets 2002	1999–2001	Core parameters, alkalinity, major ions, dissolved solids, nutrients, organic carbon, suspended sediment (L. Clark outlet, Currant Crk., and Tlikakila, Chokotonk, Chulitna, Kijik, and Tanalian Rivers)
	Brabets and Riehle 2003	2000	Core parameters, alkalinity, nutrients, organic carbon, suspended sediment (Johnson R.)
	Brabets and Ourso 2006a	2003–2004	Core parameters, alkalinity, nutrients, organic carbon, major ions, dissolved solids, iron, manganese, trace elements (Crescent R. and Crescent L.)
	Brabets and Ourso 2006b	2004–2005	Core parameters, alkalinity, nutrients, organic carbon, major ions, dissolved solids, iron, manganese, trace elements (Kijik and Portage L., Kijik and Little Kijik Rivers)

[a] Core parameters = water temperature, specific conductivity, pH, and dissolved oxygen (DO); DOC = dissolved organic carbon; TN = total nitrogen; TP = total phosphorus; TSS = total suspended solids; TDS = total dissolved solids; Chl a = chlorophyll a.

Water Quantity Objectives

Two objectives related to hydrological monitoring will be directed toward assessing changes in the timing, duration, and magnitude of river discharge and lake level in key SWAN systems. Objectives include answering the following questions:

1. What are the status and trend of the timing, duration, and magnitude of peak summer discharge at targeted sites (i.e., select tributaries and outlets) in the Lake Clark and Naknek Lake flow systems?

2. What are the status and trend of the timing, duration, and magnitude of peak summer lake levels at those targeted sites?

Water Quality Objectives

Three 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, specific conductivity, pH, and dissolved oxygen (DO) ─ drive chemical activity and influence the capacity of water to support life. Turbidity is an important indicator of light penetration, which affects productivity. Objectives include answering the following questions:

3. What are the status and trend of the core parameters during the mid-summer index period for priority lake systems within the SWAN? Status will be determined as summary statistics of central tendency (i.e., means, medians) and variability (i.e., standard deviations, coefficients of variation). Variability will reflect inter-annual variation, both vertically throughout the water column and spatially across the lake basin.
4. What are the status and trend of lake temperature, duration and depth of thermocline, stratification patterns, and warming and cooling patterns in priority lake systems? Status will be determined via summary statistics of central tendency and variability, as described above. Variability will reflect inter- and intra-annual variation throughout the water column.
5. What are the status and trend of the four core parameters and turbidity at select high-priority lake outlets during the ice-free period (approximately late May through September)? Status will be determined via summary statistics of central tendency and variability, as described above. Variability will reflect inter- and intra-annual variation.

Sampling Design

Rationale for Sampling Design

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 sampling designs: census, targeted, and probabilistic. Census sampling 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 sampling designs among state and federal programs. The USGS National Water Quality Assessment Program is an example of a targeted sampling 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 sampling design depending on the management question being addressed. However, census sampling designs are rare due to the level of sampling effort and costs involved.

Given the logistical challenges and costs associated with accessing most lakes in SWAN park units, monitoring primarily will follow a targeted sampling 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.

Initial Sampling Design

Three-Tiered Design and Waterbody Selection

In 2004 invited experts and SWAN park staff developed a three-tiered sampling design in which major lakes (and, in the case of KEFJ, major streams) were prioritized within SWAN park units (Table 3, Figures 4–7). This design was intended to ensure that key flow systems would be monitored annually even if I&M funding was greatly reduced. Prioritization criteria incorporated level of use, management issues, spatial coverage, ease of access, and physical/ecological attributes. Physical attributes included geologic source inputs (i.e., glacial and non-glacial sources), which are likely to respond differently to climate change. Ecological attributes included the presence/absence of anadromous salmon, which can be used to estimate the contribution of marine-derived nutrients and contaminants in freshwater systems.

Table 3. Characteristics of SWAN lakes and streams initially selected for water quantity and quality monitoring.

Tier	Waterbody	Park Unit	Size (ha)	Elevation (m)	Water Type	Anadromous Salmon?	Flow System
Tier 1	Naknek Lake	KATM	58,824	12	Glacial/Clear	Yes	Naknek
	Lake Brooks	KATM	7,557	22	Clear	Yes	Naknek
	Lake Clark	LACL	31,337	80	Glacial/Clear	Yes	Newhalen
	Kijik Lake	LACL	453	115	Clear	Yes	Newhalen
	Exit Creek	KEFJ		91−134	Glacial	No	Resurrection
Tier 2	Surprise Lake	ANIA	276	324	Clear	Yes	Coastal
	JoJo Lake	KATM	676	15	Clear	No	Naknek
	Grosvenor Lake	KATM	7,387	36	Clear	Yes	Naknek
	Murray Lake	KATM	263	506	Clear	Yes	Naknek
	Hallo Lake	KATM	306	43	Glacial	No	Coastal
	Delight Lake	KEFJ	16	320	Glacial	Yes	Coastal
	Nuka River	KEFJ		0−88	Glacial	Yes	Coastal
	Kontrashibuna Lake	LACL	2,009	148	Glacial	No	Newhalen
	Lachbuna Lake	LACL	333	409	Glacial	No	Newhalen
	Crescent Lake	LACL	3,958	143	Glacial	Yes	Coastal
Tier 3	Kukaklek Lake	KATM	17,372	249	Clear	Yes	Alagnak
	Battle Lake	KATM	1,300	257	Clear	Yes	Alagnak
	Dakavak Lake	KATM	409	90	Clear	Yes	Coastal
	Lower Twin Lake	LACL	838	605	Clear	Yes	Mulchatna
	Telaquana Lake	LACL	4,667	374	Glacial	Yes	Stony

Tier 1 (high priority) waterbodies offer relatively easy access and hence receive the heaviest use and are of greatest management concern. In KATM, Naknek Lake and Lake Brooks were selected as Tier 1 lakes. Tier 1 lakes in LACL included Lake Clark and Kijik Lake. All four Tier 1 lakes support anadromous salmon. Exit Creek, which originates from Exit Glacier in KEFJ, was identified as a Tier 1 stream due to high visitor use to the glacier (NPS 2004).

Tier 2 (medium priority) waterbodies are less accessible than their Tier 1 counterparts. Tier 2 lakes are important for expanding spatial coverage beyond Tier 1 lakes ─ that is, for comparing trends observed at Tier 1 sites with other flow systems in the parks. Tier 3 waterbodies are the lowest sampling priority based on the categorization criteria, but their inclusion further expands the spatial scale of park waters being monitored. Tier 2 and 3 lakes generally are smaller than Tier 1 lakes and will be sampled less frequently. However, given the vast volume of the Tier 1 lakes, subtle changes in water 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 lesser volumes. Note that describing lakes as “large” or “small” is a subjective task. All lakes monitored by SWAN, except Delight Lake in KEFJ, are larger than 250 hectares (ha) in area. As baseline data are collected from selected lakes within the SWAN and as natural variability is defined, smaller lakes that exhibit unusual patterns or trends will alert us to look more closely at all lakes for potential changes.

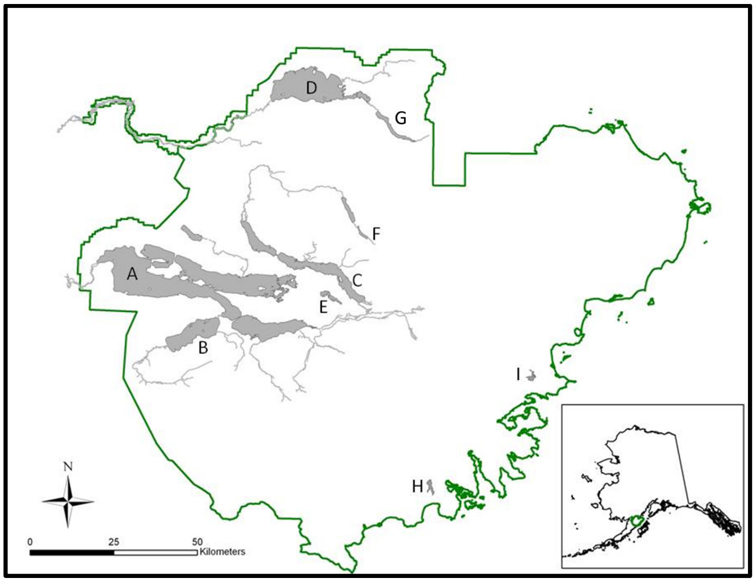

Figure 4. Lake systems within KATM selected for monitoring in the initial SWAN sampling design. Tier 1 lakes included Naknek Lake (A) and Lake Brooks (B). Tier 2 lakes included Grosvenor Lake (C), Jojo Lake (E), Murray Lake (F), and Hallo Lake (I). Tier 3 lakes included Kukaklek Lake (D), Battle Lake (G), and Dakavak Lake (H).

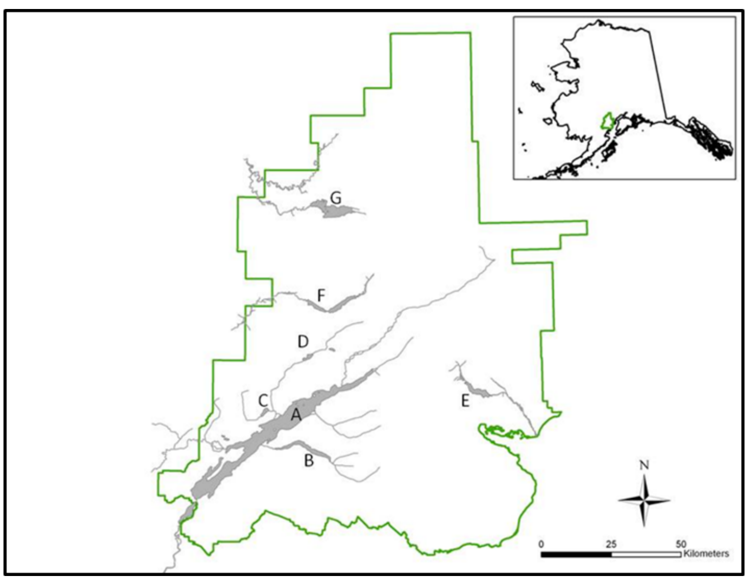

Figure 5. Lake systems within LACL selected for monitoring in the initial SWAN sampling design. Tier 1 lakes included Lake Clark (A) and Kijik Lake (C). Tier 2 lakes include Kontrashibuna Lake (B), Lachbuna Lake (D), and Crescent Lake (E). Tier 3 lakes included Lower Twin Lake (F) and Telaquana Lake (G).

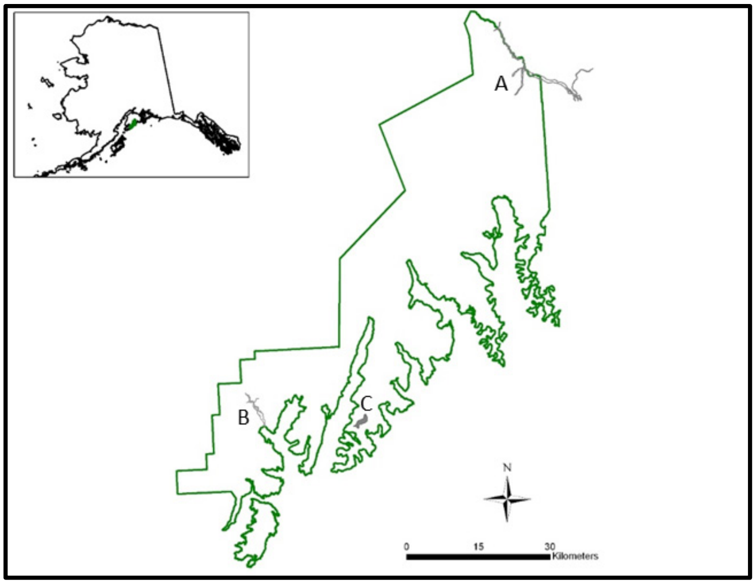

Figure 6. Lake and river systems within KEFJ selected for monitoring in the initial SWAN sampling design. Tier 1 systems included Exit Creek (A). Tier 2 systems included Nuka River (B) and Delight Lake (C).

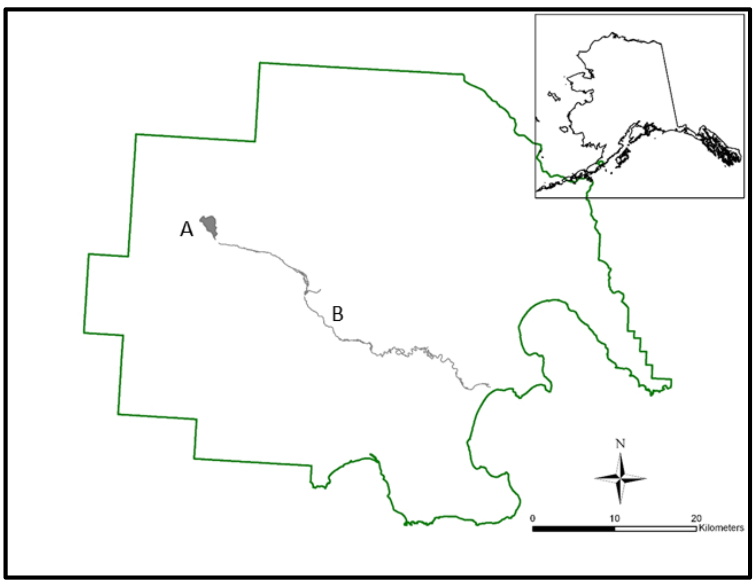

Figure 7. Lake and river systems within ANIA selected for monitoring in the initial SWAN sampling design. Tier 2 systems included Surprise Lake (A) and Aniakchak River (B).

Site Selection

Within individual waterbodies, a combination of targeted and randomly selected sites will be monitored. 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 will be selected through a generalized random tessellation stratified process (GRTS; Stevens and Olsen 2004). According to this process, each lake basin is overlaid with a grid system of 1-km2 or 0.25-km2 cells, depending on basin area, with a point assigned to the center of each cell in a Geographic Information System (Figure 8A). 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 8B). GRTS sites become fixed sample locations during sampling visits in subsequent years. **Note:** in order to maintain randomness, SWAN will assess the need to redo the GRTS draw occasionally (e.g., every 10–20 years). Finally, although we recognize the simplicity and utility of mid-lake sampling for lake monitoring programs (Goransson et al. 2004), 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.

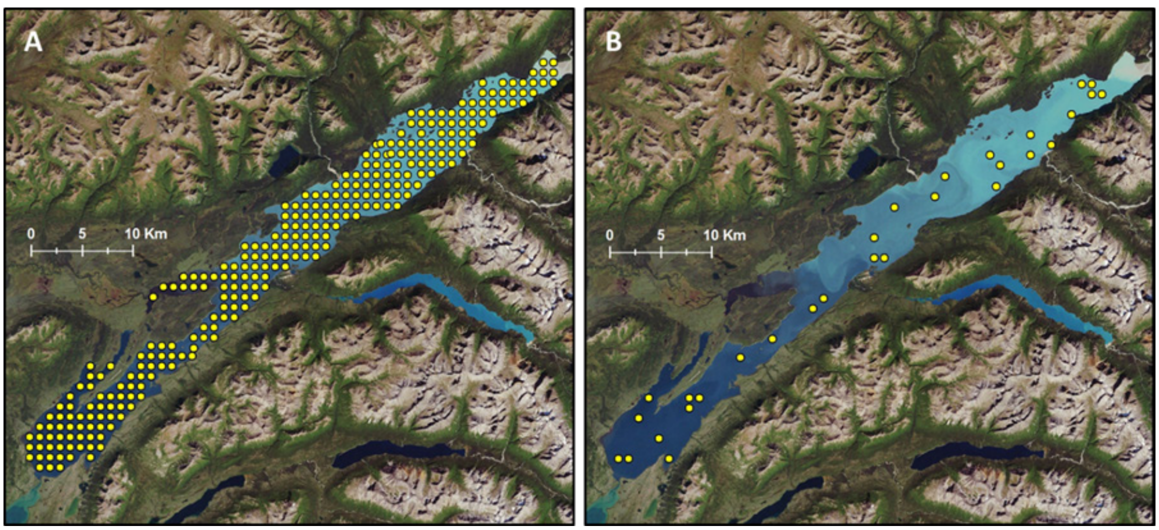

Figure 8. Potential GRTS sites generated (A) and final GRTS sites selected (B) using a 1-km^2 grid cell system developed for Lake Clark, LACL.

Targeted sites, such as lake outlets and tributaries, will be selected primarily based 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 and Savonoski Rivers, the largest tributaries in terms of discharge to Lake Clark and Naknek Lake, respectively, are examples of large glacial rivers with extensive deltas. Although single channel reaches of these river systems are accessible periodically, repeated access depends largely on streamflow conditions, making sample scheduling difficult ─ especially since neither river is 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 integrative but allows safe and 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). Details regarding this method are outlined in the accompanying SOP report (Shearer et al. 2015).

Sampling Frequency and Replication

Detecting long-term trends in water quality and quantity parameters is complicated by natural intra- and inter-annual 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 2002), 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 as late July through late August, to align with the dates when water temperatures typically exhibit the greatest vertical stratification.

Tier 1 systems will be sampled annually during this index period. Tier 2 systems will be sampled twice over a 10-year period, and Tier 3 lakes will be sampled once every 10 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 (n = 2 replicates) and at all discharge measurement sites (n = 7 replicates). 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.

Although index period sampling will satisfy objectives to monitor inter-annual variability in core parameters throughout the lake water column, objectives to monitor intra-annual (seasonal) variation in lake level, discharge, and temperature stratification will require more frequent sampling. Data recorders, such as water level pressure transducers and temperature thermistors, provide dependable, inexpensive methods for continuously monitoring lake stage and temperature (see the Monitoring Methods section, below). 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 streamflow 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 logistically unfeasible. 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.

Table 4. Sampling frequency initially envisioned for SWAN freshwater flow systems. Year 11 repeats the Year 1 sampling schedule.

Tier	Waterbody	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 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	Kontrashibuna Lake	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	
	Lower Twin Lake										X
	Telaquana Lake										X

To summarize, SWAN will address monitoring objectives through a combination of targeted and random sampling approaches in select 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 lake basins. Table 5 provides a summary of sample methods, locations, frequency, and timing for each monitoring objective. Methods are described in greater detail in the Monitoring Methods section (below) and the associated SOPs (Shearer et al. 2015).

Table 5. Summary of SWAN's sampling design for water quantity and quality vital signs. Objective numbering aligns with that listed in the Measurable Objectives section above.

Objective	Method	Location	Frequency	Timing	SOP
1	Pressure transducer, discharge measurement	Tier 1 outlets and select tributaries	Hourly	May – September	5, 6, 7
2	Pressure transducer	Tier 1 outlets	Hourly	May – September	7
3	Vertical lake profiles	All tiered lakes, GRTS sites	Synoptic; 1x/yr	Late July – late August	4
4	Moored temperature arrays	Tier 1 lakes	Hourly	Year-round	8
5	Unattended multiparameter sonde	Lake Clark and Naknek Lake outlets	Hourly	May – September	4

Revised Sampling Design

Between 2010 (when this narrative was drafted) and 2015 (when it was finalized), the sampling design underwent a series of revisions. For example, the three-tiered approach was replaced with a two-tiered approach characterized by different waterbodies and sampling frequencies (Table 6; Figures 9 and 10). As a result, while Tier 1 lakes are still sampled annually during the index period, Tier 2 and 3 lakes are pooled in a single group, and sampled three times every five years instead of once or twice every 10 years. This increase in sampling frequency was enabled by a study that evaluated the necessity of measuring 10 spatial replicates on Tier 2 lakes with uniform basins (Wilson and Moore 2013). Results indicated that water quality estimates in these lakes were well represented by a single vertical profile measurement, conducted near the lake center. Additional revisions to the vertical lake profile sampling design included omitting replicates at 10% of GRTS sites (from 2011 onward) and omitting sampling depths on the sonde ascent (from 2012 onward). Furthermore, inflowing tributaries have not been included in the sampling design since ~2011. The SOPs were revised in 2013 and 2014 to reflect these changes (Shearer et al. 2015). However, wording in this narrative was left mostly unchanged in order to document the original intent of the protocol and its evolving history ─ and also because many changes are currently being reconsidered.

Table 6. Revised two-tiered sampling design for water quality monitoring via vertical lake profiles.

Park	Tier	Location	2010	2011	2012	2013	2014	2015
LACL	1	Lake Clark	X	X	X	X	X	X
		Kijik Lake		X	X	X	X	X
	2	Little Lake Clark			X	X	X	
		Tazimina Lake (Lower)			X	X	X	
		Tazimina Lake (Upper)			X	X	X	
		Telaquana Lake			X	X	X	
		Twin Lake (Lower)			X	X	X	

Park	Tier	Location	2010	2011	2012	2013	2014	2015
		Twin Lake (Upper)			X	X	X	
		Two Lakes			X	X	X	
		Turquoise Lake				X	X	X
		Fishtrap Lake				X	X	X
		Snipe Lake				X	X	X
		Kontrashibuna Lake [a]		X		X	X	X
		Lachbuna Lake [a]	X	X		X	X	X
		Portage Lake				X	X	X
		Hickerson Lake – coastal				X	X	X
		Crescent Lake – coastal	X			X	X	X
KATM	1	Naknek Lake	X	X	X	X	X	X
		Lake Brooks	X	X	X	X	X	X
	2	Battle Lake			X	X	X	
		Hammersly Lake			X	X	X	
		Jojo Lake			X	X	X	
		Lake Coville			X	X	X	
		Lake Grosvenor			X	X	X	
		Murray Lake			X	X	X	
		Pirate Lake			X	X	X	
		Kulik Lake				X	X	X
		Mirror Lake				X	X	X
		Nonvianuk Lake				X	X	X
		Idavain Lake				X	X	X
		Spectacle Lake				X	X	X
		Kukaklek Lake				X	X	X
		Dakavak Lake – coastal					X	X
		Devil's Cove Lake – coastal					X	X
		Hallo Lake – coastal					X	X
KEFJ	2	Desire Lake – coastal					X	X
		Delight Lake – coastal					X	X

[a] The sampling design for these lakes differed enough in 2010 and 2011 that they will likely be re-sampled in 2015, even though it would be their fourth year of sampling in five years.

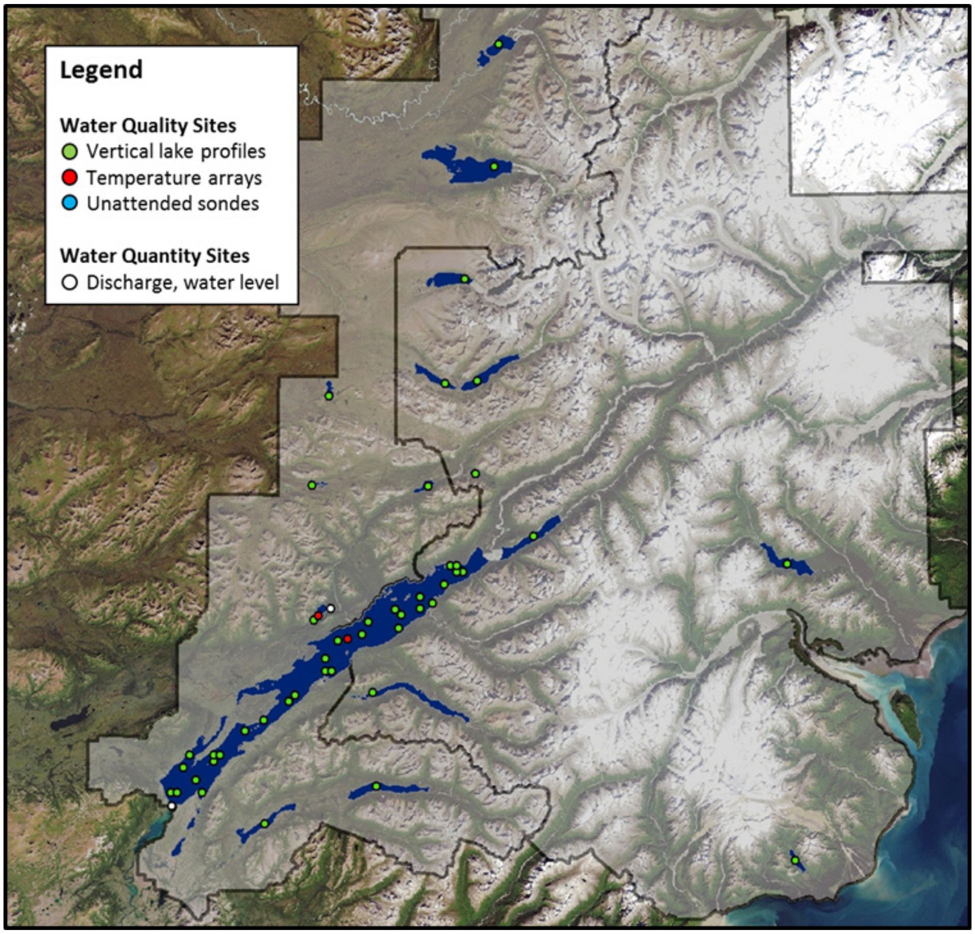

Figure 9. SWAN monitoring sites in LACL. Overlap between sites where discharge is measured and where an unattended sonde records core water quality parameters prevents visualization of both locations simultaneously on this map.

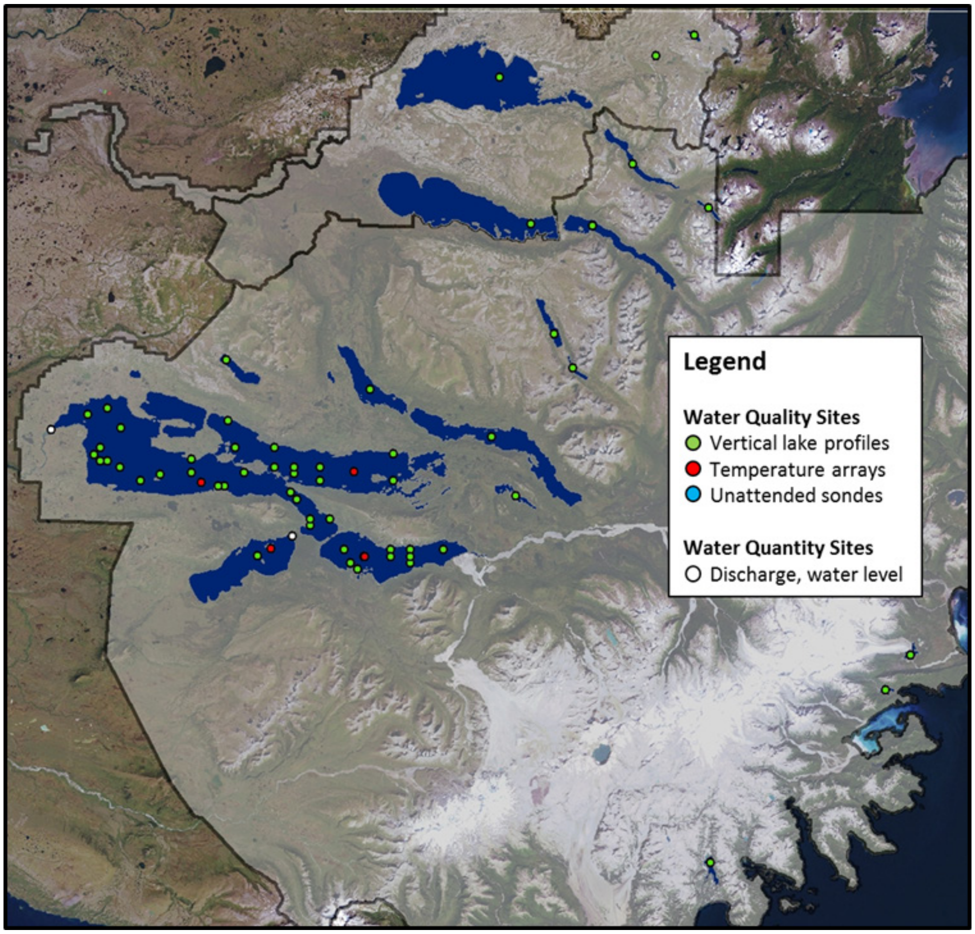

Figure 10. SWAN monitoring sites in KATM. Overlap between sites where discharge is measured and where an unattended sonde records core water quality parameters prevents visualization of both locations simultaneously on this map.

Monitoring Methods

Briefly, water quantity and quality and monitoring will rely on the following activities:

1. Continuous lake level monitoring during the open water period at the outlets of Tier 1 lakes using automated water level pressure transducers (e.g., In-Situ's Level TROLL 500 logger). 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 pressure logger.

2. Periodic discharge measurements during the open water period at the outlets of Tier 1 lakes. 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.

3. Vertical lake profiles during the mid-summer index period at each GRTS sampling point using a multiparameter water quality sonde (e.g., YSI's 600QS sonde), 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.

4. Continuous water quality monitoring during the open water period (approximately late May through September) at the outlets of Lake Clark and Naknek Lake with a sonde (e.g., YSI's 6600V2 sonde). Core parameters plus turbidity will be recorded hourly with monthly site visits for sonde maintenance and data downloads.

5. Continuous water temperature monitoring year-round at select locations in Tier 1 lakes. Automated water temperature thermistors (e.g., Onset's HOBO Water Temp Pro v2 logger), programmed for hourly measurements, will be positioned at fixed depth intervals from 5 m to 100 m on a moored temperature array. Automated light sensors (e.g., Onset's HOBO Pendant Temperature/Light logger) will be placed at fixed depths within the upper 15 m of the water column. An additional thermistor will be deployed near the water surface during the open water period only. Moored temperature arrays will be retrieved and downloaded once or twice per year.

In addition to these activities, other tasks must also be completed to facilitate freshwater monitoring. This section of the narrative summarizes the field-based activities and office-based tasks that are detailed in the accompanying SOPs (Shearer et al. 2015).

Field Season Preparation

Sampling remote lakes is expensive and requires extensive organization in order to be safe and successful. The field trip leader should review the entire protocol, including the SOPs, and resolve all questions concerning methods well in advance of the field season (Table 7). 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. Additional details regarding field season preparation can be found in SOP1 of the accompanying report (Shearer et al. 2015).

Table 7. Approximate timeline of tasks to prepare for field work related to SWAN freshwater monitoring.

Time Period	Task	Person Responsible for Task
Fall / Winter	Review SOPs and datasets, and revise SOPs as needed.	Project leader
February	Obtain Scientific Research and Collecting Permit(s) from each park unit where field work is planned.	Project leader
March	Create a preliminary schedule of field trips and training activities with approximate sampling dates.	Project leader
March	Order necessary supplies, such as water quality instrument calibration solutions.	Hydrologic technician
March / April	Check equipment for proper working order and make repairs as needed.	Hydrologic technician
April / May	Complete all required and recommended safety training.	Project leader and hydrologic technician
April / May	Confirm draft schedule of field activities with park staff and revise if necessary.	Project leader
April / May	Submit lodging and flight requests with each park unit where field work is planned.	Project leader and hydrologic technician
May	Assemble field folder containing maps, datasheets, site lists, copies of research permits, etc.	Hydrologic technician
Late May / Early June	Complete operational training for water quality and hydrology sampling.	Project leader and hydrologic technician
Fall	Inventory supplies and equipment and make a list of anticipated repairs.	Hydrologic technician

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 emails a float plan to dena_commcenter@nps.gov (if in LACL), katm_dispatch@nps.gov (if in KATM), the SWAN project and program leaders, and any other interested staff in the park where field activities will be conducted. Float plan details at minimum should 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 accompanies the field crew.

Due to the remote nature, expense of travel, and weather conditions within SWAN park units, field data will be collected primarily 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.

Water Quantity Data

The primary objective of surface hydrology monitoring is to track the timing, duration, and magnitude of summer inflows, outflows, and water levels 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 periodic measurement of 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 during 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. SOP5 in the accompanying report (Shearer et al. 2015) details SWAN's methodology for using a Marsh McBirney flow meter to measure discharge at wadeable stream sites. The steps described in SOP5 are based on the USGS two-point method (Buchanan and Somers 1968). However, most SWAN discharge monitoring sites are not wadeable during summer months, so boat-based discharge measurement techniques must be employed. SOP6 outlines the methodology for using an acoustic Doppler current profiler for estimating river discharge at unwadeable sites (Shearer et al. 2015).

Water surface elevations will be recorded with pressure transducers (or "level loggers") programmed to log hourly during the open water period. Level loggers will be non-vented, meaning level readings must be corrected for atmospheric pressure. Atmospheric pressure data will be recorded hourly with barometric pressure loggers (or "barologgers") placed near monitoring sites. Each level logger should be housed inside a metal pipe for protection and anchored to rebar driven into the substrate. The rebar should be placed in a location free from sediment deposition or lateral bank scouring.

Differential leveling ─ a procedure by which surveying instruments are used to determine the differences in altitude between points ─ will be employed to install the level loggers and to check them from time to time for vertical movement (Kennedy 1990). Specifically, a benchmark will be established at each monitoring site and the elevation of the level logger will be surveyed so that changes between annual deployments can be taken into account to maintain a consistent baseline elevation. The benchmark, reference points, and level logger will be surveyed periodically at each station for the purpose of determining if any datum changes have occurred (Rantz 1992). SOP7 provides further detail on water level measurements using pressure transducers (Shearer et al. 2015).

Water Quality Data

SWAN will make extensive use of multiparameter sondes to measure and record core water quality parameters at each sample location. 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. To this end, we will follow the procedures outlined in SOP3 (Shearer et al. 2015). Data will be collected through one of three methods: synoptic vertical lake profiles, continuous unattended sonde deployments, and periodic "in-situ" (discrete) measurements.

Synoptic vertical lake profiles will be collected during the mid-summer index period. Latitude/longitude coordinates of each lake profile site should be loaded into a handheld GPS unit and, if available, boat-mounted chart plotter. After navigating the boat or float plane 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. 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 or plane is navigated to the next lake profile site and the process is repeated. Hence, each site is measured once per year. Details regarding lake profile data collection are outlined in SOP4 (Shearer et al. 2015).

Continuous water quality monitoring with unattended sondes will take place at the outlets of Lake Clark and Naknek Lake. Sondes should meet criteria recommended in Penoyer 2003 (Table 8). They should be calibrated as described in SOP3 (Shearer et al 2015) and programed to record on a 1-hour interval. The length of deployment will vary depending on site conditions, the amount of fouling on sensors, battery life, and internal memory on the sonde. 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 is relatively low according to preliminary data collected during 2009 and 2010. After initial deployment, site visits will be used to check sonde operation, assess the degree of sensor fouling and drift, download data, and conduct routine sonde maintenance and re-calibration, if needed. SWAN's procedures for sonde deployment and subsequent site visits are outlined in SOP4 and follow guidelines discussed in Wagner et al. 2006.

Table 8. Stabilization criteria and recommended instrument specification criteria for recording field measurements, adopted from Wilde 2008 and Penoyer 2003, respectively.

Standard Direct Field Measurement	Measurement Stabilization Criteria [a]	Recommended Instrument Specifications		
		Range	**Resolution/ Sensitivity [b]**	**Accuracy [c]**
Temperature [d]		-5 to +45 °C	0.01 °C	± 0.15 °C
Thermistor thermometer	± 0.2 °C			
Liquid-in-glass thermometer	± 0.5 °C			
Specific conductivity [e]		0 to 10^5 µS/cm	1 to 100 µS/cm (range dependent)	± 0.5% of reading + 1 µS/cm
When ≤ 100 µS/cm	± 5 %			
When >100 µS/cm	± 3 %			
pH [f]		0 to 14 pH units	0.01 pH unit	± 0.2 pH unit
Meter displays to 0.01	± 0.1 pH unit			
Dissolved oxygen [f]		0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ± 2% of reading or 0.2 mg/L, whichever is greater
Amperometric method in mg/L	± 0.3 mg/L			
Turbidity [e]		0 to 1000 NTU	0.1 NTU	±5% of reading or 2 NTU, whichever is greater (depth limit of 200 ft)
Turbidometric method in NTU	± 10 %			

[a] Variability/repeatability should be within the value shown. Measurement stabilization criteria are not the same as the 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.

[b] These are manufacturer specifications for sensor resolution. As such, they are likely too narrow to be achieved in the field as a quality control check for sensitivity (i.e., AMS+), but they can be used as a starting point until more realistic AMS+ goals can be developed.

[c] 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 Irwin 2004 for details). Accuracy specifications reflect only the uncertainty in measurements of the instrument and sensor in combination, and not other factors that can affect accuracy, such as environmental factors or field personnel's ability to calibrate and operate using good measurement protocols.

[d] Recommended "calibration check" is quarterly. The sensor must be calibrated by the manufacturer.

[e] Recommended sensor calibration is daily.

[f] Recommended sensor calibration is at the beginning and end of sampling at each station (twice a day, minimum).

Periodic "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 SOP3. 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 obvious 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 SOP4 (Shearer et al. 2015).

Water temperature dynamics of Tier 1 lakes will be monitored continuously year-round using moored temperature arrays equipped with automated temperature thermistors. A moored temperature array consists of vertical anchor and instrument lines connected with a horizontal "bridle" 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 depth, and subsequently removed in early fall prior to lake freeze-up. 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 download 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. SOP8 details the steps needed for safely constructing, deploying, retrieving, and maintaining temperature arrays (Shearer et al. 2015).

Equipment Cleaning, Maintenance, and Storage

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. SOP9 lists potential aquatic invasive species to SWAN waters and provides details about cleaning field equipment (Shearer et al. 2015).

Once electronic equipment is removed from the field, it must be cleaned, maintained, and stored properly to assure reliable operation for the next field season. For multiparameter sondes, batteries should be removed, O-rings should be replaced and lubricated, and sensors should be cleaned 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 pressure transducers should be cleaned and checked to ensure 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.

Data Download, Export, and Processing

The use of electronic equipment, such as pressure transducers, temperature thermistors, and multiparameter 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 download, export, and processing are critical steps that must occur prior to data analysis and reporting.

The pre-use programming and post-use downloading of electronic equipment are carried out through the various types of proprietary software that accompany the equipment. The user must be familiar with the operation of software prior to programming any equipment to ensure that data are properly recorded, stored, and available for retrieval. SOP10 provides step-by-step instructions on the proper use of these types of software to download and export data, and SOP11 details the use of AQUARIUS Time-Series to process exported data (Shearer et al. 2015). The general workflow of post-collection data download, export, and processing will be as follows:

1. Retrieve equipment and download raw electronic data files.
2. Label raw data files according to proper file naming conventions (Table 9).
3. Place copies of all raw data files on the SWAN T Drive for archival.
4. Export raw data files from proprietary to non-proprietary (i.e., *.csv or *.txt) formats.
5. Import non-proprietary data files into AQUARIUS.
6. Correct data for erroneous readings, sensor fouling, and/or calibration drift.
7. Grade data based on calculations in Excel, and flag data based on identified threshold values.
8. Compute summary statistics, and then export corrected and/or summarized data sets.

Table 9. File naming conventions for aquatic monitoring data collected with electronic data loggers and other equipment. All file names must contain, at a minimum, the 4-letter park code, 5-letter waterbody code plus site number, date, and data format (e.g., raw, export, or qaqc).

Monitoring Technique	Parameter	File Naming Convention	File Name Example
Vertical lake profiles	Core parameters	park code_5-letter waterbody code + 1-letter basin ID + 3-digit site ID #_‘profile’_YYYYMMDD + format	KATM_naknle003_profile_20090814export
Continuous water quality	Core parameters	park code_5-letter waterbody code + ‘o’_‘continuous’_‘wq’_YYYYMMDD + format	KATM_naknlo_continuous_wq_20140904raw
Cross sectional water quality	Core parameters	park code_5-letter waterbody code_‘xsect’_‘wq’_YYYYMMDD + format	LACL_lclar_xsect_wq_20140913raw
In-situ water quality	Core parameters	park code_5-letter waterbody code_‘insitu’_YYYYMMDD + format	LACL_chulr_insitu_20090718qaqc
Acoustic Doppler profiler	Discharge	park code_5-letter waterbody code + ‘o’_‘Q’_YYYYMMDD + format	LACL_kijilo_Q_20140916export
Water / atmospheric pressure	Water level / barometric pressure	park code_5-letter waterbody code + ‘o’_‘lvl’ OR ‘baro’ OR ‘lvl_compensated’_YYYYMMDD + format	KATM_lbrooo_baro_20080930export
Temperature array	Water temperature	park code_5-letter waterbody code + 2-digit site ID #_3-digit depth + ‘m’ _‘temp’_YYYYMMDD + format	LACL_lclar01_020m_temp_20090613raw
Temperature array	Light intensity	park code_5-letter waterbody code + 2-digit site ID #_3-digit depth + ‘m’_‘light’_YYYYMMDD + format	LACL_lclar01_010m_light_20090613qaqc
Temperature array	Water level	park code_5-letter waterbody code + 2-digit site ID # _ ‘array’_‘lvl’_YYYYMMDD + format	LACL_lclar01_ array_lvl_20090613export

Data Management

Freshwater data management procedures support the fundamental goals of SWAN's Data Management Plan: to obtain high quality data that are readily available, easily interpretable, and secure for the long term (Mortenson 2006). Though easily overlooked, following proper data management steps is crucial throughout the entire data "life cycle," from data acquisition and metadata documentation, through reporting and archiving. Figure 11 provides a general schematic of the data life cycle for this protocol. See SOP12 in the accompanying report for a more detailed discussion of each step in the data life cycle (Shearer et al. 2015).

An integral part of the data life cycle is the use of AQUARIUS Time-Series software, created by Aquatic Informatics, Inc. AQUARIUS is the national standard for the storage and processing of aquatic time series data collected by the NPS I&M Program. This software platform keeps an unaltered raw copy of all data uploaded to it. Subsequent changes to the data are tracked in the database as a "change history." AQUARIUS also has the capacity to share data with the public through a web portal. Additional information on use of the software can be found in the user manual or training videos, which can be accessed online or through the help menu.

Quality Assurance / Quality Control

Quality assurance is the planned and systematic pattern of all actions necessary to guarantee that a project outcome optimally fulfills expectations. Quality control is the systematic evaluation of the various aspects of a project to ensure that the standards of quality are being met. Quality control (QC) includes quantifiable performance metrics like measurement precision, bias, and sensitivity; whereas, most quality assurance (QA) measures are qualitative aspects such as staff training and qualifications. SWAN uses various metrics for the QC of freshwater monitoring data ─ particularly water quality data collected using multiparameter sondes. All metrics are recorded in electronic worksheets, and then archived as metadata in AQUARIUS, as described in SOP13 (Shearer et al. 2015). Metrics include:

1. Method Detection Limit (MDL): for turbidity sensors on sondes deployed at lake outlets. MDL is determined in the lab/office each year using a low signal standard (e.g., near 0.1 NTU).
2. Minimum Level of Quantitation (ML): for turbidity sensors on sondes deployed at lake outlets. ML is calculated from MDL.
3. Alternative Measurement Sensitivity Plus (AMS+): for all core parameters except turbidity during unattended deployments. AMS+ is based on data recorded prior to cleaning monitor sensors during fouling assessments.
4. Relative Percent Difference (RPD) or precision: based on data collected following each calibration using standard solutions and calibrated sensors.
5. Percent Difference (PD) or bias: based on data collected during each calibration and error-check, before and after unattended sonde deployment and vertical lake profile measurements. Two PD values will be recorded for unattended sonde deployments: one to account for % fouling, and another to account for % drift.

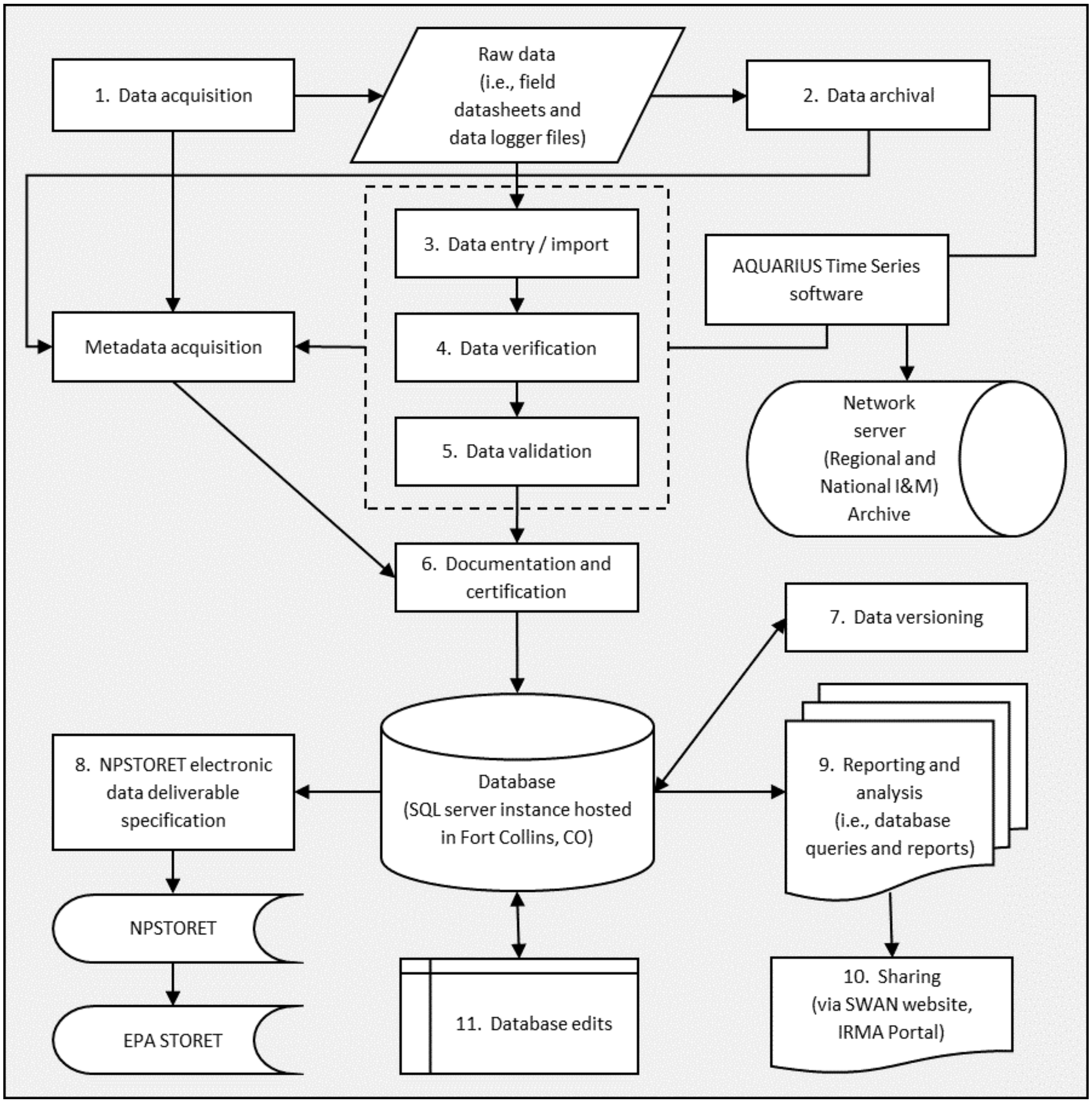

Figure 11. SWAN freshwater monitoring data flowchart, adapted from Heard 2007. Each numbered item within the flowchart has a corresponding description in SOP12 (Shearer et al. 2015).

Data Analysis and Reporting

Analysis and reporting of monitoring data is critical to the process of providing managers with useful information regarding park resources. Various approaches and venues exist for presenting information to the intended audiences, 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 quantity and quality data collected each year, we will, at a minimum, provide summary reports annually and more in-depth synthesis reports every five years, as described in SOP14 of the accompanying report (Shearer et al. 2015).

Annual Summary Reports

Annual reports will include summary statistics (e.g., mean, maximum, minimum, and degree of variation, as in Table 10) for each parameter, time period, and location of interest. Additional measures, such as monthly degree days (for water temperature) or percent exceedance of water quality criteria, may also be reported. Results may be synthesized 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 (e.g., Figure 12). Annual summary reports will include the following sections:

- Introduction—describing the 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—including data summaries, graphical displays, and interpretation of results, categorized by data type / monitoring method (e.g., vertical lake profiles).
- 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.

Five-Year Synthesis Reports

Every five years, water quantity and quality data will be analyzed for trends. The objective of trend analysis is to detect gradual or abrupt changes in parameters over time. Detecting cycles (i.e., oscillations, rather than one-way trends) will likely require longer time frames, since slow frequency patterns can take years to repeat.

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 analyses can be complemented with graphic displays, such as bivariate plots, to illustrate trends (or lack thereof) over time.

Table 10. Example summary of near-surface (5 m) water temperature data for Lake Clark between January 1, 2007 and September 1, 2009.

Month	Max. Avg. Daily Temperature [a] Mean (1 SD [d]); °C			Min. Avg. Daily Temperature [b] Mean (1 SD [d]); °C			Monthly Degree Days [c]		
	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	Warmest Day Date	Warmest Day 24-hr mean (1 SD); °C	Warmest 7-Day Period Dates	Warmest 7-Day Period 7-day mean (1 SD); °C
2007	August 13th	15.9 (0.4)	August 10th – 17th	14.7 (0.8)
2008	August 18th	13.5 (0.5)	August 22nd – 29th	13.0 (0.5)
2009	July 18th	14.1 (0.4)	July 14th – July 20th	13.4 (0.6)

[a] Based on highest 24-hour average.

[b] Based on lowest 24-hour average.

[c] Difference between daily mean temperature and 0 °C summed for each month.

[d] Standard deviations < 0.05 are reported as 0.0.

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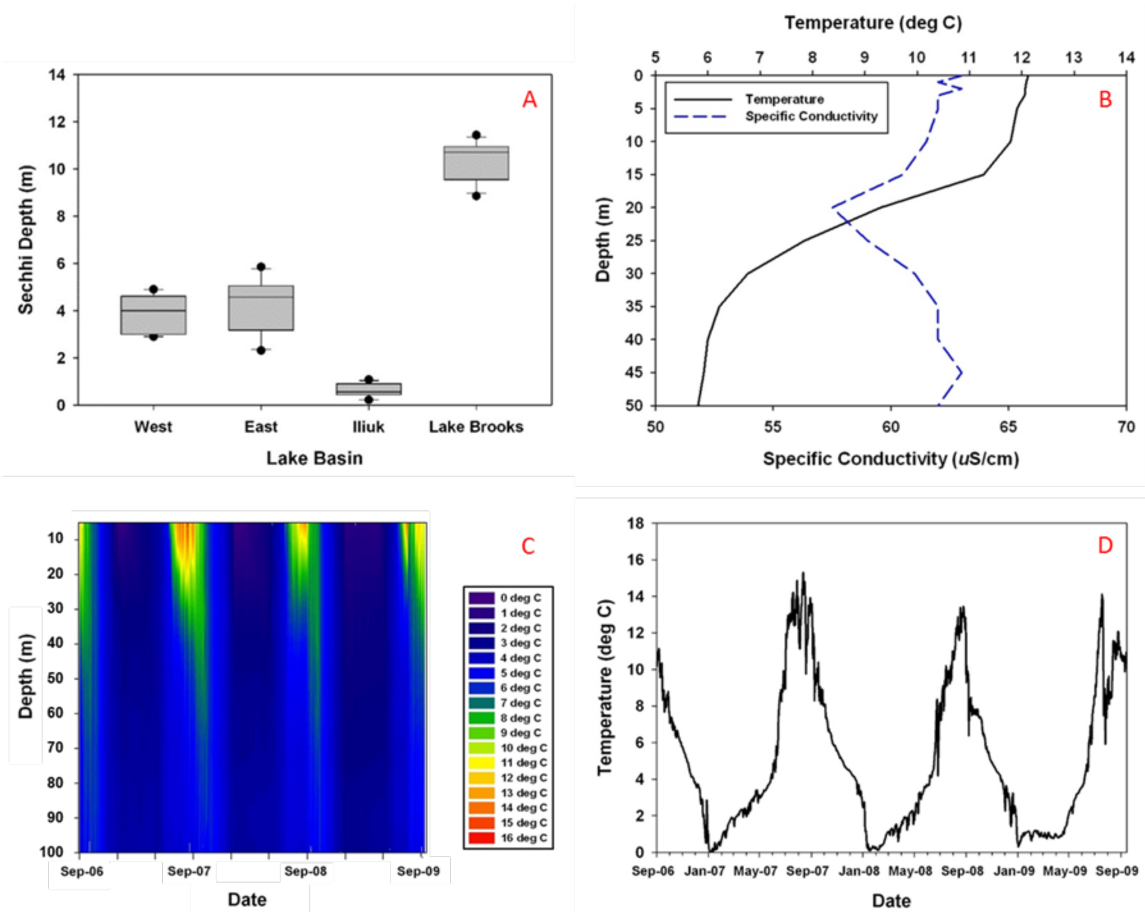

Figure 12. Examples of graphs often included in SWAN annual summary reports: boxplots (A), depth profiles (B), isotherms (C), and bivariate plots (D).

Personnel Requirements and Training

To fully implement this protocol, an aquatic ecologist is required to work in collaboration with the network coordinator, data manager, and park-based natural resource staff. The SWAN aquatic ecologist will be the project leader for all aspects of monitoring the freshwater chemistry and surface hydrology vital signs. Tracking the resident lake fish and salmon vital signs under the SWAN Vital Signs Monitoring Plan is also within the purview of the aquatic ecologist position. The aquatic ecologist will work as part of a five-member interdisciplinary team of project leaders in the climate/glaciers, landscape dynamics/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 13.

The aquatic ecologist will be based in Anchorage and will oversee a hydrologic technician stationed in King Salmon or Port Alsworth. The hydrologic technician will serve as the field crew leader and park-based contact for field logistics and sampling. Field activities will be conducted by the aquatic ecologist, hydrologic technician, seasonal field crew member(s), and park-based ecologists/biologists/technicians (Table 11).

Qualifications and Training

The aquatic ecologist 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:

- Multiparameter 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
- Review of the Job Hazard Analyses

Additionally, several training/certification courses are required, such as motorboat operation certification (MOCC) and aviation safety (B-3). Other courses (e.g., wilderness first aid) are strongly recommended for all staff involved with field activities. See SOP1 of the accompanying report (Shearer et al. 2015) for additional details on training and field season preparation.

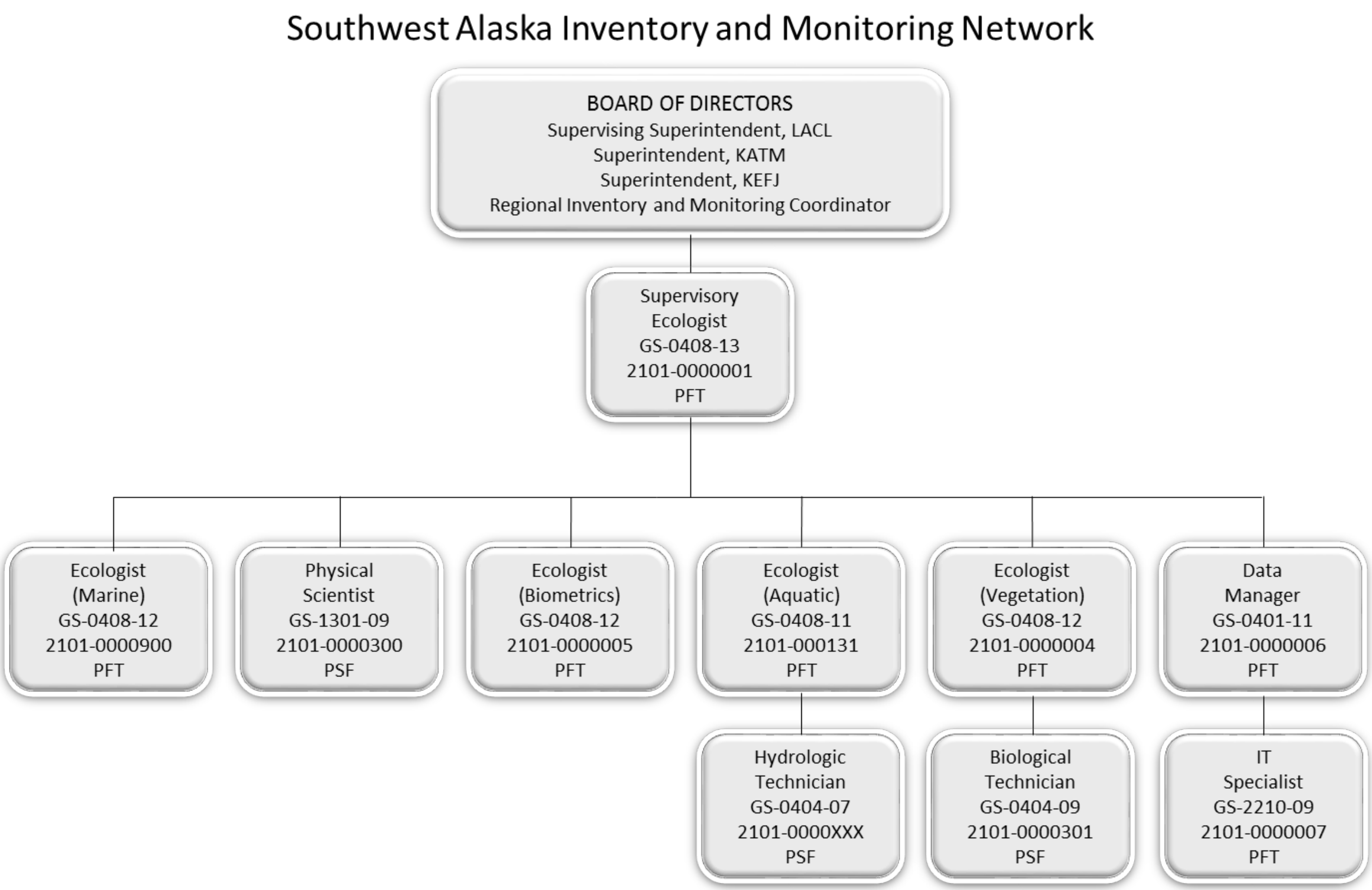

Figure 13. Southwest Alaska Network organizational chart.

Table 11. Network staff roles and responsibilities for freshwater 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 quantity and quality vital signs.
Hydrologic Technician	Assists with data collection, entry, summary, analysis, and reporting. Also assists with logistical coordination of field work.
Biometrician	Responsible for all aspects of sampling design and data analysis associated with water quantity and quality vital signs.
Data Manager	Responsible for all aspects of data management for the Network. Works with the aquatic ecologist to ensure that AQUARIUS meets SWAN needs.
Network Coordinator	Serves as overall program administrator and supervisor. Provides consultation on protocol review and implementation. Reviews annual and 5-year synthesis 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 hours required to access most sites and the potential for weather delays mean extra time needs to be built into field work schedules. All field activities will take place between mid-May and late September as weather conditions are too uncertain outside these dates for reliable planning (Table 12). Annual program activities also include project administration, data management, and reporting.

Table 12. Annual operational schedule for freshwater monitoring in the SWAN.

Month	Project Administration	Field Activities	Data Management and Reporting
January			Analysis and synthesis of previous year's data
February	Permit reporting and application		Analysis and synthesis of previous year's data
March	Field schedule planning; supplies and equipment purchasing; park float plane requests		Annual summary report or 5-year synthesis report due
April	Safety training and certification		
May	Field training or review; safety training and certification	Pressure transducer deployments; discharge measurements	
June		Temperature array download and maintenance; sonde deployment	Data review and entry
July		Discharge measurements; sonde download and re-calibration; vertical lake profiles	Data review and entry
August		Sonde download and re-calibration; vertical lake profiles	Data review and entry
September	Annual administrative review and work plan	Pressure transducer retrievals; discharge measurements; sonde download and retrieval; temperature array download	Data review and entry
October			Data review and entry
November			Data review, entry, certification
December			Data analysis and synthesis

Equipment Needs

The equipment and supply needs to carry out the freshwater monitoring 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 partial summary of equipment/supplies needed to carry out the operational aspects of this protocol. This list does not cover all equipment/supplies needed for extended field trips (such as personal gear, survival equipment, etc.), nor does it cover equipment/supplies needed for temperature arrays.

Water Quantity Equipment and Supplies

Capital Expenses

- Water level pressure transducers
- Barometric pressure loggers
- Housings for loggers, and rebar and clamps for anchoring
- Survey level, tripod, and stadia rod
- Acoustic Doppler current profiler (RiverSurveyor M9) and trimaran
- Marsh-McBirney flowmeter and wading rod
- Survey reel tape (100 m)
- 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

Water Quality Equipment and Supplies

Capital Expenses

- Multiparameter sondes (YSI 600QS or YSI6600V2)
- Multiparameter sonde display (YSI 650MDS) and field cables (8 ft and 200 ft)
- Field-grade laptop computer (e.g. Panasonic Toughbook)
- Secchi disc and cable

- Digital camera and GPS
- Multiparameter sonde housing and security cable

Expendable Supplies

- Multiparameter sonde calibration solutions (specific conductivity, pH, turbidity)
- C cell batteries
- Field notebook and clipboard
- Hardcopy of field forms printed on waterproof or water-resistant paper

Budget

Table 13 provides the estimated annual operational budget to implement the SWAN freshwater monitoring 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. Also not listed are unforeseen contingencies, which could add 5–10% to the total provided in Table 13. Staff salaries and travel expenses are discussed below.

Staff Salaries

The aquatic ecologist position will be funded by annual monitoring dollars provided to SWAN by the NPS Water Resources Division (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 monitoring protocol. Any discrepancies between NPS WRD dollars and operational budgetary needs will be reconciled with SWAN Vital Signs Monitoring Program dollars. Other staff vital to implementing the freshwater monitoring protocol, such as the hydrologic technician and data manager (Figure 13), will be funded through SWAN Vital Signs Monitoring Program dollars.

Travel Expenses

SWAN lakes require the use of aircraft for at least a portion of the travel 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. As of 2014, commercial travel costs from Anchorage to Port Alsworth, AK (LACL field headquarters) are $484 per person, round-trip. Commercial travel costs from Anchorage to King Salmon, AK (KATM field headquarters) are $532 per person, round-trip. 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.).

Table 13. Annual operational budget for water quantity and quality monitoring. Expenses marked with an asterisk (*) 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

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