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

Assessment of Coastal Water Resources and Watershed Conditions at Aniakchak National Monument and Preserve (Alaska)

Natural Resource Technical Report NPS/NRWRD/NRTR—2007/371

Cover photo
Vent mountain (cone) within Aniakchak Crater. Aniakchak Peak is the high point on the caldera rim. View toward south (Photo by R.G. McGimsey, 1997, in Neal et al. 2001)

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Acknowledgments

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Commonly used abbreviations

AC – Alaska Current
ACC – Alaska Coastal Current
ADEC – Alaska Department of Environmental Conservation
ADFG – Alaska Department of Fish and Game
ALAG – Alagnak Wild River
ANIA – Aniakchak National Monument and Preserve (National Park Service Designation)
ANILCA – Alaska National Interest Land Conservation Act
AWC – Anadromous Waters Catalog
EMAP – Environmental Monitoring and Assessment Program (of the US Environmental Protection Agency)
ENSO – El Niño Southern Oscillation
EPA – US Environmental Protection Agency
EVOS – Exxon Valdez Oil Spill
GEM – Gulf Ecosystem Monitoring (Exxon Valdez Oil Spill Trustee Council)
GOA – Gulf of Alaska
GRS – Geographic Response Strategies
HAB – Harmful Algal Bloom
I&M - Inventory and Monitoring Program
KATM – Katmai National Park and Preserve (National Park Service Designation)
KEFJ – Kenai Fjords National Park (National Park Service Designation)
LACL – Lake Clark National Park and Preserve (National Park Service Designation)
LIA – Little Ice Age
MCL – Minimal Contaminant Level
NADP – National Atmospheric Deposition Program
NOAA – National Oceanic and Atmospheric Administration (US Department of Commerce)
NPDES – National Pollutant Discharge Elimination System (of the US Environmental Protection Agency)
NPS – National Park Service (US Department of Interior)
NS&T – National Status and Trends (NOAA)
NWI – National Wetlands Inventory (of the US Fish and Wildlife Service)
PAHs – Polycyclic aromatic hydrocarbons
PCBs – Polychlorinated biphenyls

PDO – Pacific Decadal Oscillation
POPs – Persistent Organic Pollutants
SQG – Sediment Quality Guidelines
SWAN – Southwest Alaska Network
UAS – University of Alaska Southeast
USDA – US Department of Agriculture
USFWS – US Fish and Wildlife Service (US Department of Interior)
USGS – US Geological Survey (US Department of Interior)
WACAP – Western Airborne Contaminants Assessment Project

I. Executive Summary

This assessment of coastal water resources and watershed conditions in Aniakchak National Monument and Preserve (ANIA) is provided in response to a U.S. Congressional authorization to assess the environmental conditions in coastal watersheds within National Park units. ANIA is part of the Southwest Alaska Network (SWAN), which also includes the Alagnak Wild River (ALAG), Katmai National Park and Preserve (KATM), Lake Clark National Park and Preserve (LACL), and Kenai Fjords National Park (KEFJ). Very little baseline information has been collected in ANIA in the past, and, although the SWAN is currently implementing a Vital Signs Monitoring Program, the Program expects to conduct less extensive monitoring in ANIA than in the other units.

Physical, Oceanographic, and Climatic Setting

ANIA is 243,936 hectares (602,779 acres) and located on the Alaska Peninsula approximately 260 km (162 mi) southwest of King Salmon, where its headquarters are located. Aniakchak National Monument, which includes the caldera and its immediate surroundings, was established in 1978. The Aniakchak National Preserve was added two years later with the passage of the Alaska National Interest Lands Conservation Act (ANILCA). The Aniakchak River was designated as a Wild River by Title VI, Section 601(27) of ANILCA.

ANIA's physical features have been shaped by recent glacial and volcanic events. The defining geographical feature of ANIA is the massive, volcanically-active Aniakchak caldera, which occupies 35 km^2 (14 mi^2) and has a rim relief of 609 to 1020 m (2000-3450 ft). The rugged coastline of ANIA is approximately 129 km (80 mi) long and is characterized by wide sediment flats, bedrock platforms, and rocky headlands. The ANIA coast borders the northern Gulf of Alaska (GOA) and roughly parallels the Aleutian trench (>7000 m, 23000 ft), where the Pacific plate is actively subducting under the North American plate.

There are no climate monitoring stations within ANIA. Anecdotal descriptions and some short-term measurements by NPS researchers working in ANIA indicate that the summer climate is typically wet, windy, and cool, and sometimes accompanied by violent windstorms in the caldera. The National Weather Service has an observation station in Chignik, which is a reasonable proxy for climate in coastal ANIA. Mean monthly temperature in Chignik ranges from -4 ˚C (25 ˚F) in January to 12 ˚C (54 ˚F) in August and annual precipitation averages approximately 211 cm (83 in).

Hydrologic Information

Surprise Lake, the largest surface water body in the crater, is fed primarily by numerous springs and snowmelt. Surprise Lake's only outlet is the Aniakchak River, which flows 43 km (27 mi) through glacially-carved and ash-filled valleys to the Gulf of Alaska at Aniakchak Bay, picking up additional flow from several tributaries; the largest of which are Albert Johnson Creek and North Fork Aniakchak River. Other Pacific coast rivers in ANIA include 2 unofficially named creeks -- "Iris Creek" or "Creek 100" and "Willow Creek" or "Creek 200". There are no streamflow gauges within or in close proximity of ANIA, although flow dynamics may be analogous to Russell Creek near Cold Bay. Despite the lack of continuous streamflow data within ANIA, some discrete discharge measurements were recorded by water resource investigators in 1987, 1989, and 2003.

Several baseline natural history investigations were undertaken by the NPS in the 1980's regarding vegetation, small mammals, water quality, and fisheries. Most studies were conducted in the caldera itself. The largest single project was a study of the water chemistry and hydrologic condition of water bodies within the caldera, and the sediment chemistry, bathymetry, and biological characterization (phytoplankton, periphyton, zooplankton, benthic invertebrates, and fish) of Surprise Lake during the summers of 1988 and 1989.

There are no known data concerning groundwater or wetland resources in ANIA. ANIA does not contain any glaciers. While permanent snowfields exist, there are no known studies on the aerial dimensions and/or chemical attributes of these water resources.

Only very basic geospatial data pertaining to water resources are available for inland coastal portions of ANIA – primarily stream and water body location/extents as well as basic fish distribution. Most other related data, such as geology, soils, landcover, are derived from coarse-scale, statewide sources or are lacking completely. Information for marine intertidal and subtidal areas, however, maybe readily available from the ShoreZone coastal mapping project. ShoreZone aerially surveyed intertidal and shallow subtidal areas of ANIA in the summer of 2003 for the purpose of identifying shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. This multi-agency funded mapping effort is accessible online through a database with interactive GIS layers, digital maps, georeferenced aerial images and video of the ANIA coastline.

Biological Resources

Several threatened or endangered species occur in ANIA, including Steller sea lions, northern sea otters, and Steller's eider. The U.S. western stock of Steller sea lions, including populations in the ANIA region, is federally-listed as endangered due to declining numbers throughout the western Gulf of Alaska and Bering-Sea regions. Harbor seals have suffered a similar decline to that of Steller sea lions during roughly the same time period. The Southwest Alaska stock of sea otters was federally listed as Threatened in 2005. Little quantitative information on sea otter abundance is available specifically for ANIA.

As part of the NPS Biological Inventory Program, species lists have been compiled for vascular plants, fish, birds, and mammals within each of the SWAN units. Forty mammal species have been documented in ANIA as part of the NPS I&M program efforts. Terrestrial mammals include moose, caribou, brown bear, arctic fox, coyote, gray wolf, red fox, lynx, wolverine, river otter, ermine, mink, and arctic shrew, snowshoe hare, two species of lemmings, hoary marmot, arctic ground squirrels, and tundra voles. According to the fish-species list developed by the SWAN I&M program, within ANIA there are 16 confirmed or likely species and 3 unconfirmed species. All 5 species of Pacific salmon are present, as are sticklebacks, lampreys, dolly varden, longnose sucker, coastrange sculpin, round whitefish, arctic grayling, and Alaska blackfish. The Aniakchak River has the highest species richness (9 species) and Surprise Lake had the lowest (2 species). The maintenance of healthy salmon stocks and movement patterns throughout coastal water bodies in southwest Alaska is important not only for fisheries resources but also because spawning salmonids have significant ecological impacts on both terrestrial and freshwater aquatic ecosystems. A single amphibian species, the wood frog, likely occurs in a variety of aquatic habitats in the park, but its presence has not been verified.

As discussed above, biological-resource information is also available through the ShoreZone coastal mapping project, which provides descriptions of both habitat classification and biota in intertidal and nearshore habitats of ANIA.

Two vegetative reconnaissance studies have focused on the Aniakchak caldera. The inventory of vascular plants performed in ANIA as a whole (not limited to the caldera) as part of the NPS I&M program identified 472 species in the unit. To the east and south of the Aleutian mountains, including the ANIA areas outside the crater, alpine tundra dominates the vegetative landscape. While the slopes of the volcano are mostly barren, forbes, grasses, and sedges grow near creek drainages, and willow and alder occur along lower sections of the Aniakchak River and other coastal streams.

Water Quality Assessment

Water, sediment, and biological quality in marine waters was surveyed in 2002 by the State of Alaska as part of the nationwide Environmental Monitoring and Assessment Program (EMAP). Results from this sampling effort represent the most comprehensive dataset available on the physical and biological conditions in the coastal waters of southcentral and southwestern Alaska. Overall, water and sediment-quality conditions in the region were shown to be dominated by natural influences and lacking impairments.

Some monitoring of freshwater resources is included in the SWAN Vital Signs Monitoring Plan, and they include: surface water hydrology, freshwater chemistry, and landscape processes. Results of an I&M water quality review found no 303(d) waters present within ANIA (or any other SWAN unit), and concluded that although water quality collection has been sporadic, conditions appear to be acceptable with low nutrient levels and little evidence of anthropogenic impacts. For future long-term monitoring of water quality, SWAN streams and lakes were categorized into 3 tiers using a ranking procedure that incorporated accessibility, level of use/management issues, and ecological and spatial cover. In the coastal ANIA area, no waterbodies were identified as Tier 1, and the Aniakchak River drainage, including Surprise Lake, was designated as Tier 2 (targeted for sampling every 2-5 years).

Almost all information on freshwater quality within ANIA comes from studies of Surprise Lake and the Aniakchak River. Water quality information is available on the inlet streams to Surprise Lake, tributaries to the Aniakchak River, and 2 other coastal streams. Surprise Lake inlet streams have geothermal influences, which generally result in relatively higher temperature, conductivity, total alkalinity, hardness, and trace element concentrations, and lower pH and dissolved oxygen values. The chemical characteristics of Surprise Lake indicate a fairly well-mixed lake, with some variations due to proximity to hydrothermal inputs. As for the Aniakchak River and its tributaries, nutrient concentrations were either below detection or at very low values for both the mainstem and tributaries; major and trace element concentrations were generally within normal range; and alkalinity and major ion concentrations declined in a downstream pattern away from the caldera. Water quality data for other coastal streams in ANIA is extremely limited. Most other water bodies in ANIA are both unnamed and have undocumented water quality conditions; however, due to their remoteness, lack of trails and human services, and near inaccessibility to humans, it is fair to assume that their water quality conditions are almost entirely naturally influenced. There is very little information on precipitation chemistry in ANIA, however the National Atmospheric Deposition Program has sites in Alaska that may provide useful information about regional trends in precipitation quality and atmospheric deposition.

Some water quality "degradations" exist in ANIA, but these are due to natural geothermal influences and are therefore not subject to the same regulatory criteria as impairments caused by human activities. Several park streams have been documented to have temperatures that technically exceed state standards for aquatic life. In addition, pH criteria for aquatic life were exceeded in several ANIA streams including the warm spring complex in the caldera and at an Albert Johnson Creek slough, where 83 silver salmon were captured nonetheless. Two high Al concentrations found in Turbid Creek and Aniakchak below North Fork (based on single, one-time samples) exceeded the chronic and maximum EPA water quality criteria, although it is important to note that these streams also have no anthropogenic influence.

Water supplies in the Aniakchak caldera, the resource in ANIA most used by visitors and NPS researchers, may carry some health risks due to the naturally high concentrations of some dissolved minerals, and/or the high suspended particle load and relatively high temperatures that may favor pathogenic microbial growth. None of the water sources in the caldera have been adequately examined for human health risks, and visitors are recommended to collect drinking water only from cold inlets.

Past and potential future threats to water quality: oil spills, atmospheric and biologically-transported pollutants, and climate change

The grounding of the Exxon *Valdez* oil tanker on Bligh Reef in Prince William Sound in March, 1989 released 10.8 million gal (35,500 metric tons) of crude oil, which was transported through Prince William Sound, resulting in the oiling of much of the Alaska Peninsula, including two-thirds of ANIA's coastline. Fourteen years after, many species and communities show limited signs of recovery, and the lingering effects of the Exxon Valdez Oil Spill (EVOS) in ANIA are now considered part of the baseline.

The release of petroleum in marine waters continues to pose a great environmental threat to the ANIA coast, whether as catastrophic spills or chronic discharges. The Valdez Marine Terminal in Prince William Sound, and the Drift River Marine Terminal and Nikiski Oil Terminal and Refinery, both in Cook Inlet, store, process and transport many billions of barrels of crude oil in the vicinity of ANIA. Swift currents can quickly transport released petroleum great distances, as evidenced by the EVOS. In addition to physical impacts of large spills, the toxicity of many of the individual compounds contained in petroleum is significant, and even small releases can kill or damage organisms. Few large commercial vessels and cruise ships travel in the immediate vicinity of ANIA, but fishing vessels of all sizes are abundant in the Gulf of Alaska in general. No analyses of marine vessel impacts have been conducted for the ANIA coast, but marine vessels have the potential to degrade water quality by the accidental release of petroleum products, the release of wastewater or other discharges, or by resuspension of sediments. Currently, Geographic Response Strategies (GRS) are not developed in the vicinity of ANIA.

The ShoreZone mapping program computed an “Oil Residence Index” along coastal ANIA based on wave exposure levels and substrate types.

Global atmospheric pollutants such as mercury (*Hg*) and persistent organic pollutants (POPs) may enter ANIA via transport and deposition by spawning salmon that accumulate these toxins in the marine environment and by atmospheric deposition. Studies in nearby Bristol Bay watersheds showed that salmon may be major transporters of marine-derived Hg into freshwater environments, and that strong correlations exist between the density of salmon runs and PCB concentrations in lake sediments. Hg and most POPs are carried to Alaska via long-range atmospheric pathways, and upon deposition (wet or dry) these pollutants can biomagnify as they are transferred to higher trophic levels. Mercury and POPs in northern latitudes show significant concentration increases over the last few decades, and although *Hg* and POPs have not been studied in ANIA specifically, several studies in southern coastal Alaska (focusing on seabird eggs and lake sediments) indicate the region is being impacted by these contaminants and deserves further evaluation and monitoring.

Climate is an important natural resource issue for national parks in Alaska, and recent research suggests that changes in climate may dramatically impact water resources in Alaskan parks. Alaska’s climate has warmed by approximately 2.2 ˚C (4 ˚F) since the 1950s and is projected to rise an additional 2.8-10 ˚C (5-18 ˚F) by 2100. The most obvious effects of climate change on hydrologic resources in Alaska are changes in the extent of snow cover, glaciers, and sea and lake ice cover. In ANIA, climate warming has the potential to alter patterns of snow accumulation and incidence of rain events during winter. This could result in a shift toward higher streamflows in winter and lower streamflows during snowmelt runoff in the spring and summer. Climate warming also has the potential to affect the occurrence of lakes and ponds within ANIA because recent research from the Seward and Kenai Peninsulas has demonstrated a substantial landscape-level trend in the reduction of surface water area as well as in the number of closed-basin ponds since the 1950s.

Natural geologic disturbances

Natural geologic hazards such as volcanic eruptions, earthquakes, and tsunamis are common in ANIA, and present persistent threats to hydrologic and biological resources. Although not in a current state of unrest, the Aniakchak volcano is still active, as are many of the volcanoes along the Aleutian arc. Aniakchak has erupted at least 40 times in the last 10,000 years—more than any other volcano in the Aleutians—and the warm springs within the crater hint at persistent activity. The USGS has identified the major hazards associated with an eruption at Aniakchak as: ash clouds, ash fallout, ballistics (projectiles of rock and pumice), pyroclastic flows and surges, lava flows and domes, and lahars and floods. The Aleutian seismic zone, which follows the southern border of the Alaska Peninsula and the Aleutian islands, is one of the most active seismic zones in the world and is predicted to trigger a major earthquake in the next few decades. Such an earthquake may generate major extensive tsunamis along the southern coast of the Alaska Peninsula and Aleutian Islands. Tsunamis striking coastal ANIA may originate from tectonic movement almost anywhere along the Pacific plate boundary and beyond, or from submarine landslides and/or volcanic eruptions that release pyroclastic flows or other materials from a volcanic collapse into the ocean. In contrast to the relatively slow process of ongoing isostatic rebound from deglaciation, uplift or subsidence of the land due to tectonic activity may be extremely sudden. These types of geologic events may be destructive in their own right and they may also trigger secondary hazardous conditions by damaging human infrastructure (such as petrochemical industrial infrastructure) that in turn could lead to pollution of park resources.

Visitor Activities with Potential for Resource Impacts

Visitor use of coastal ANIA is concentrated in the caldera, on the Aniakchak River, and on hunting within the preserve. The main visitor activities with potential impacts within ANIA include: aircraft landings in the caldera and on the coast, rafting on the Aniakchak River and associated issues with campsite development and human waste, all-terrain/off-road vehicle use, and erosion/destruction of soils by hikers. Other possible impacts include dissemination of exotic species, disturbance of wildlife, and sport fishing, although these activities are currently considered to have negligible effects. Nonetheless, given the remoteness of ANIA, it is difficult for the NPS to monitor human disturbances and their potential impacts on ANIA's resources.

Exotic/Invasive Species and Disease

The presence and scale of exotic species in ANIA's coastal watersheds is not known or documented, and no studies have focused on this issue. However, the continued northward migration of escaped farmed Atlantic salmon and other non-native migrating species, and the expansion of the range of the Northern pike, pose large potential threats to indigenous salmon and trout and their stream communities. Disease concerns include the potential arrival of the avian influenza (H5N1) virus in Alaska. More information is needed in order to evaluate if harmful algal blooms (HABs) are an issue of concern in ANIA. Chytridiomycosis, a waterborne infectious disease contributing to amphibian declines globally, has been detected in southcentral and southeast Alaska and is likely an emerging threat to any ANIA wood frog populations, although chytrid prevalence in ANIA is currently unknown. Coastal debris and garbage is also thought to be a serious issue in the SWAN, however there have been no studies evaluating the scale of this phenomena along ANIA's coast.

Specific recommendations for management and monitoring of both freshwater and marine water resources in ANIA are provided in Table 1 below and detailed in *VI.B.. Recommendations*.

Table 1. Existing, intermittent, and potential stressors of ANIA water resources.

Indicator	Freshwater	Intertidal, Bays & Estuaries	Coastal waters
Water Quality			
Nutrients/ Eutrophication	OK	OK	OK
Contaminants	PP	PP	PP
Hypoxia	PP	OK	OK
Temperature	PP	OK	OK
Pathogens	PP	OK	OK
Turbidity	OK	OK	OK
Habitat Disruption			
Coastal development	OK	OK	OK
Water quantity/ withdrawals	OK	OK	OK
Coastal erosion/shoreline modification by humans	OK	OK	OK
Natural geologic hazards	IP	IP	IP
Recreational, subsistence usage			
Rafting, hiking, camping	PP	PP	NA
Fishing and hunting	OK	OK	OK
Off-road vehicle use	PP	PP	NA
Other Indicators			
Oil spills	NA	EP	PP
Harmful algal blooms	NA	PP	PP
Aquatic invasive species	PP	PP	PP
Climate change	PP	PP	PP
Coastal debris and garbage	NA	PP	PP

Definitions: EP= existing problem, IP= Intermittent Problem, PP = potential problem, OK= no detectable problem,
shaded =limited data, NA= not applicable.

II. Purpose and Scope

This assessment of coastal water resources and watershed conditions in Aniakchak National Monument and Preserve (ANIA) in Southwest Alaska (Figure 1) is provided in response to a 2003 U.S. Congressional authorization to assess the environmental conditions in watersheds of National Park Service (NPS) units. Of particular interest are the threats posed by point source and non-point source pollutants, the spread of exotic species, nutrient enrichment, coastal development and tourism, and extractive resource use. The NPS Watershed Assessment Program has been tasked with synthesizing existing data and providing recommendations to guide management actions that reduce the factors that currently stress, or threaten to stress, the health of NPS watershed resources. This report is provided as the Phase I assessment of coastal and watershed resources in ANIA, providing a synopsis of the existing state of knowledge about conditions in ANIA coastal watersheds. This report specifically focuses on watersheds that drain into the Gulf of Alaska. Watersheds such as the Meshik River and Cinder River drainages, which lie partially within ANIA boundaries but exit the unit and drain north toward the Bering Sea (Figure 2), are not within the scope of this report.

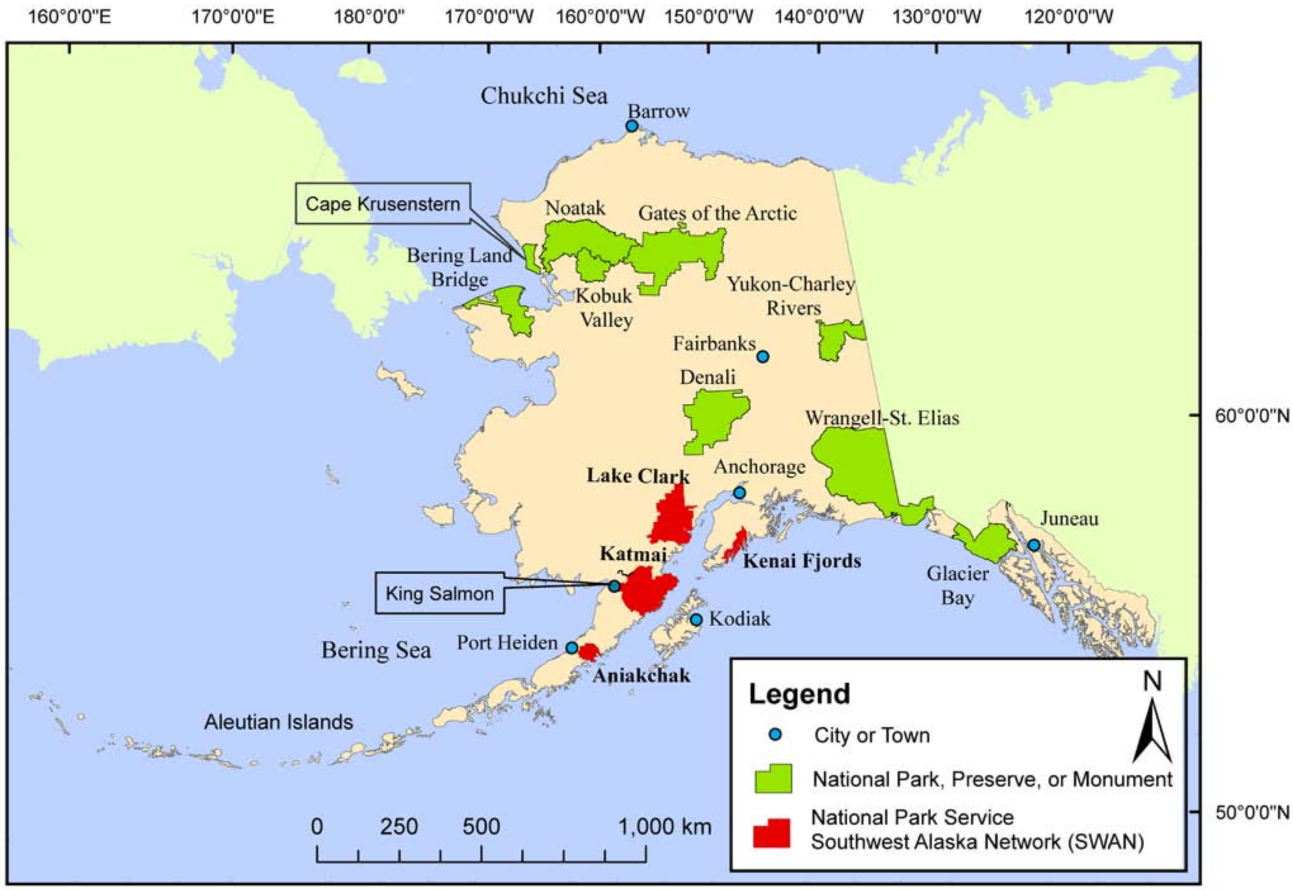

Figure 1: Location of Aniakchak National Monument and Preserve and other NPS units in Alaska.

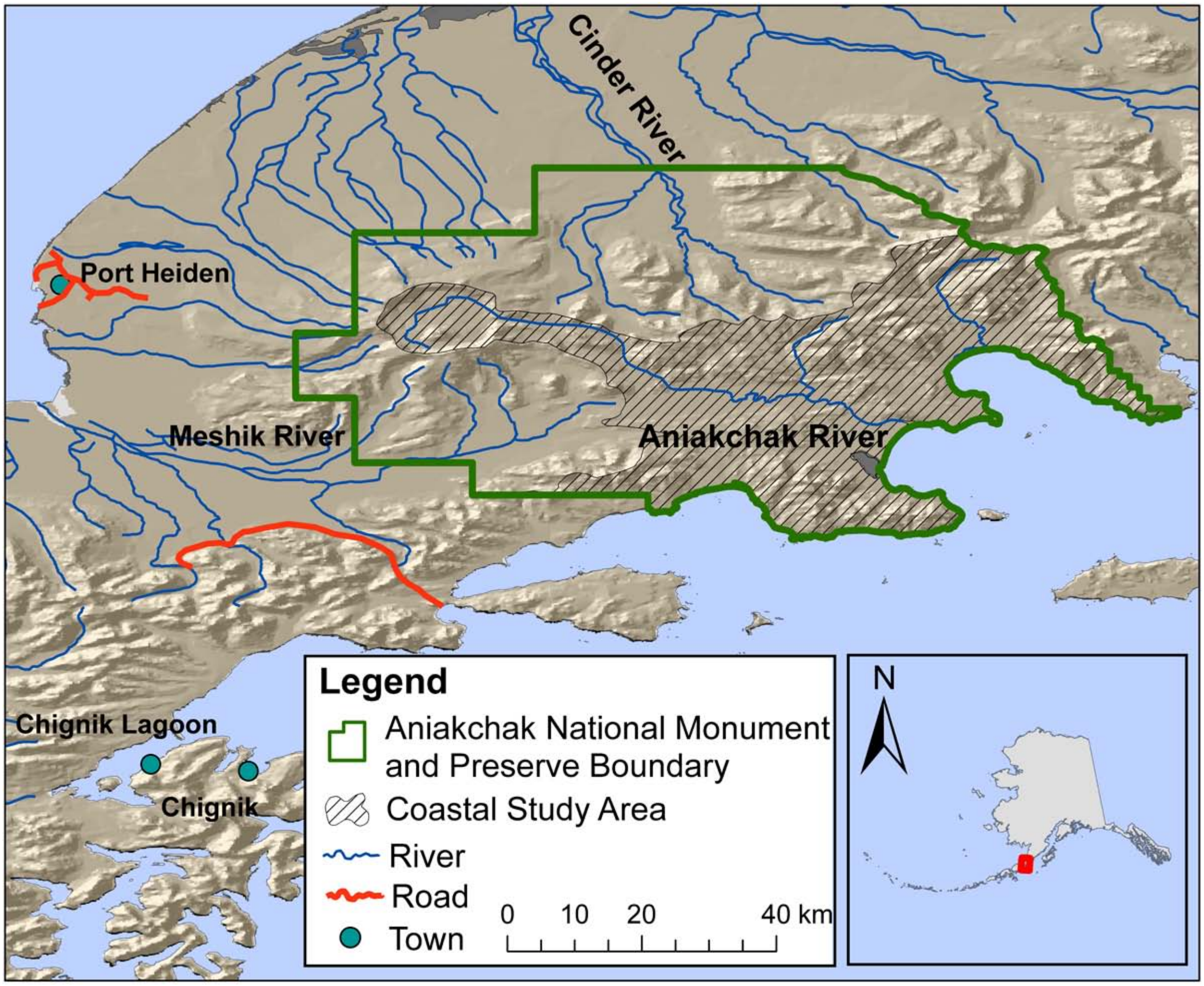

Figure 2. ANIA boundary, coastal watershed study area, and major rivers, including those adjacent to, but outside of, the study area.

ANIA is part of the Southwest Alaska Network (SWAN), which also includes the Alagnak Wild River (ALAG), Katmai National Park and Preserve (KATM), Lake Clark National Park and Preserve (LACL), and Kenai Fjords National Park (KEFJ) (Figure 1). These parks are currently part of the NPS Inventory and Monitoring (I&M) Program, in which baseline inventories and long term monitoring have recently been designed or are being implemented for biological and geophysical parameters that are "vital signs", or key indicators of environmental conditions, within park units. Many products of the ongoing SWAN I&M Program are relevant to this Watershed Assessment effort. Information, bibliographies, and other resources regarding the SWAM I&M Program can be found at http://www1.nature.nps.gov/im/units/swan/.

III. Park Description and History

A. Setting

A1. Geographic setting

Aniakchak National Monument and Preserve (ANIA) is located on the Alaska Peninsula approximately 670 km (416 mi) southwest of Anchorage, and 260 km (162 mi) south of King Salmon, where its headquarters are located in conjunction with those for Katmai National Park and Preserve (KATM) (Figure 1). The Alaska Peninsula separates the Bering Sea from the Gulf of Alaska, and its backbone is formed by the volcanically active Aleutian Mountains. The Aleutians arc westward into the Aleutian Islands archipelago, which extends nearly 2000 km (1240 mi), tracking the subduction zone of the Pacific Plate under the North American Plate. The Aniakchak crater is among the largest in the Aleutian Range and in the world, spanning 9.5 km (5.9 mi) at an elevation of 1341 m (4400 ft). The caldera is situated approximately midway across the Alaskan Peninsula, about 26 km (16 mi) from Bristol Bay at Meshik/Port Heiden, and 29 km (18 mi) from the shores of the Gulf of Alaska. The closest town is Port Heiden, 16 km (10 mi) to the northwest. The Monument and Preserve together encompass 243,936 hectares (602,779 acres): 55,515 ha (137,176 acres) in the national monument and 188,430 ha (465,603 acres) in the national preserve (Norris, 1996) (Figure 3). With the exception of one 24- hectare (60-acre) native allotment, the monument is entirely federally owned, and 95% of the Preserve is under federal jurisdiction.

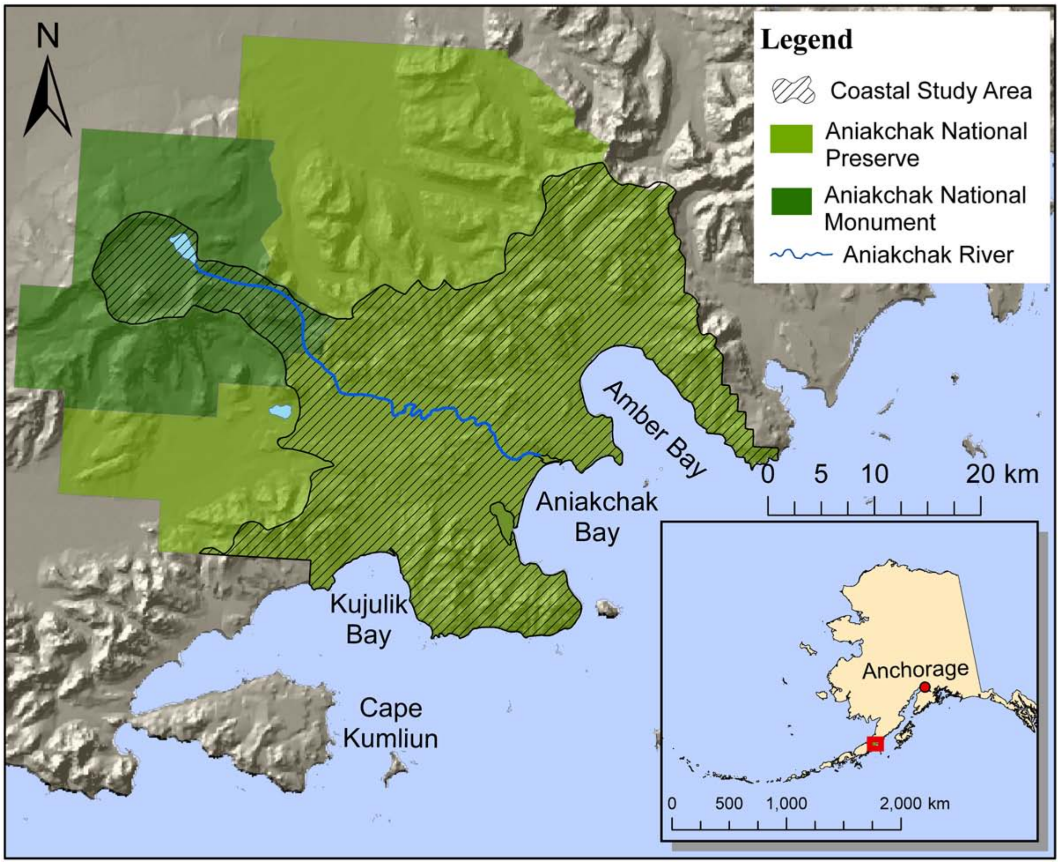

Figure 3: Boundaries delineating Aniakchak National Monument, Aniakchak National Preserve, and the coastal watershed study area that is the subject of this report.

The park unit is divided into four physiographic zones: the volcanic zone in the caldera; the upland zone, made up of other Aleutian Mountain peaks; the river valley zone on both sides of the mountain peaks; and the ocean-coastal zone along the Pacific (Norris, 1996). The Pacific coastal zone of ANIA is shaped by three bays: Kujulik, Aniakchak, and Amber Bays (Figure 4). The westernmost coastal area of ANIA is Cape Kumlik; the central coastal region contains Aniakchak Lagoon and Aniakchak Bay (Figures 4, 5); and the eastern edge of the park is Cape Kunmik. Aniakchak and Amber Bays have wide, cinder-covered beaches and are more exposed than the narrower, more protected Kujulik Bay, which harbors sandy, cinder beaches. The rugged coastline of ANIA is approximately 129 km (80 mi) long and is characterized by wide sediment flats, bedrock platforms, rocky headlands, and numerous small islands that are adjacent to, but outside, the zone of NPS jurisdiction, which is demarcated by the mean high tide line.

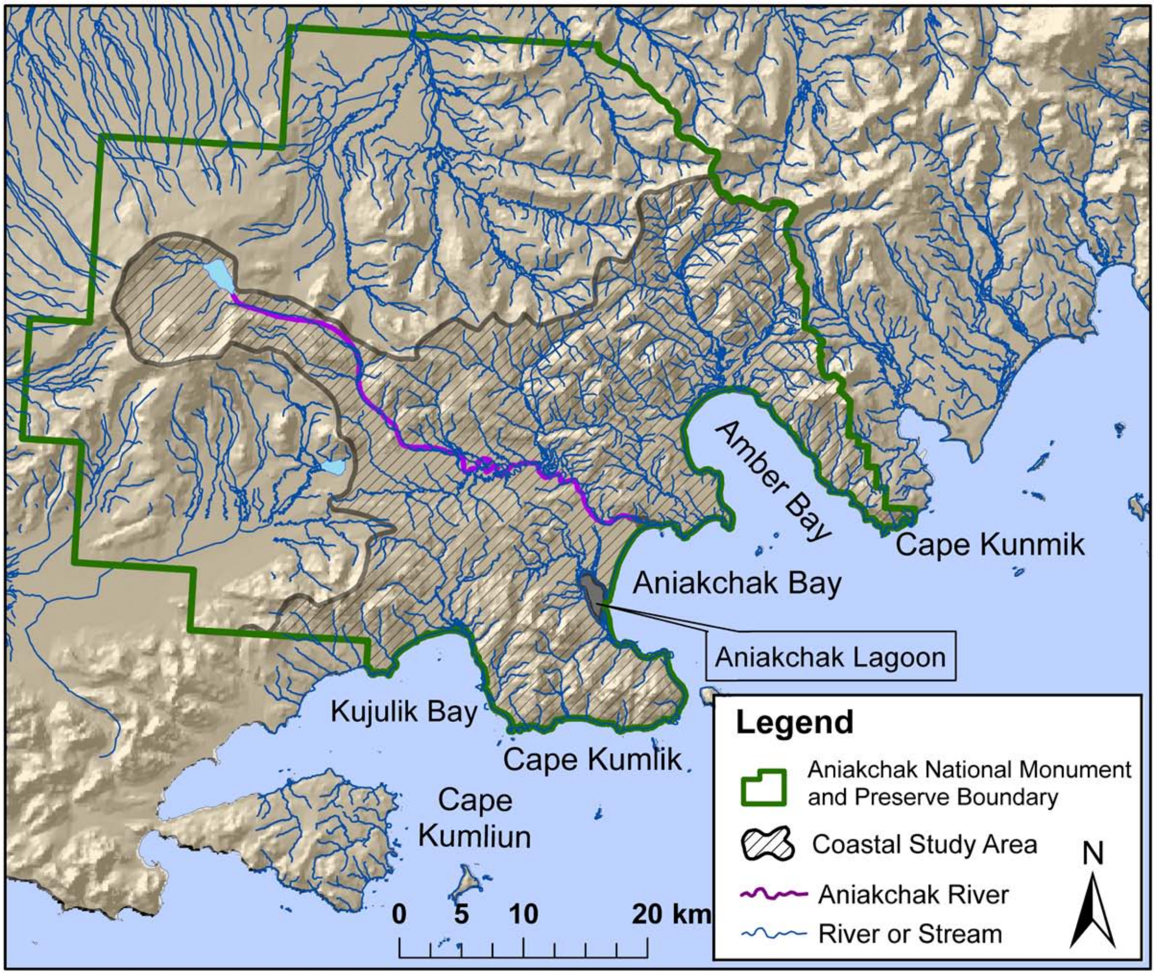

Figure 4: Bays and streams in and around ANIA.

The defining geographical feature of ANIA is the massive Aniakchak caldera. The caldera occupies 35 km^2 (14 mi^2) and has a rim relief of 609-1020 m (2000-3350 ft) (Waythomas et al., 1996). The lowest point on the caldera floor, at bottom of Surprise Lake is ~300 m (~980 ft) a.s.l., and the highest peak on the caldera rim is Aniakchak Peak at 1341 m (4398 ft) a.s.l. The caldera was formed by a cataclysmic eruption ca. 3400 yr B.P., in which a 2100 m volcanic cone collapsed, ejecting more than 50 km^3 (12 mi^3) of pyroclastic debris and tephra and creating extensive ash-flow deposits in the surrounding region (Miller and Smith, 1987). Since its initial formation, smaller eruptions have formed numerous volcanic features such as cinder cones (e.g. Vent Mountain, which stands 410 m (1340 ft) above the southcentral portion of the caldera floor), maars, and lava flows that are evident across the caldera floor. Many of the explosion features show evidence of underwater formation, which together with wave-cut terraces visible along the margins of the caldera, suggest that the crater may have been filled with a deep lake similar to that of Crater Lake, Oregon (Mahoney and Sonnevil, 1991). Major eruptions in the Aniakchak caldera occurred about 500 years ago (McGimsey et al., 1994) and again as recently as 1931 (Jaggar, 1932). Warm springs and ground temperatures reaching 80 ˚C (176 ˚F) indicate that Aniakakchak caldera is still volcanically active (Mahoney and Sonnevil, 1991).

Figure 5: Aniakchak River Mouth. NPS photo (http://www.nps.gov/ania/pphtml/photogallery.html).

The rather odd shape of the 43 km^2 (16 mi^2) Aniakchak River watershed boundary is controlled by the circular shape of the caldera and the fact that all other streams draining its external slopes flow north to the Bering Sea. Only the Aniakchak River claims the entire caldera interior within its watershed boundary (Figure 6). This headwater area of the river is wider than the first ~10 km (6 mi) of the River's drainage valley, defying the typical geomorphic configuration of watershed boundaries.

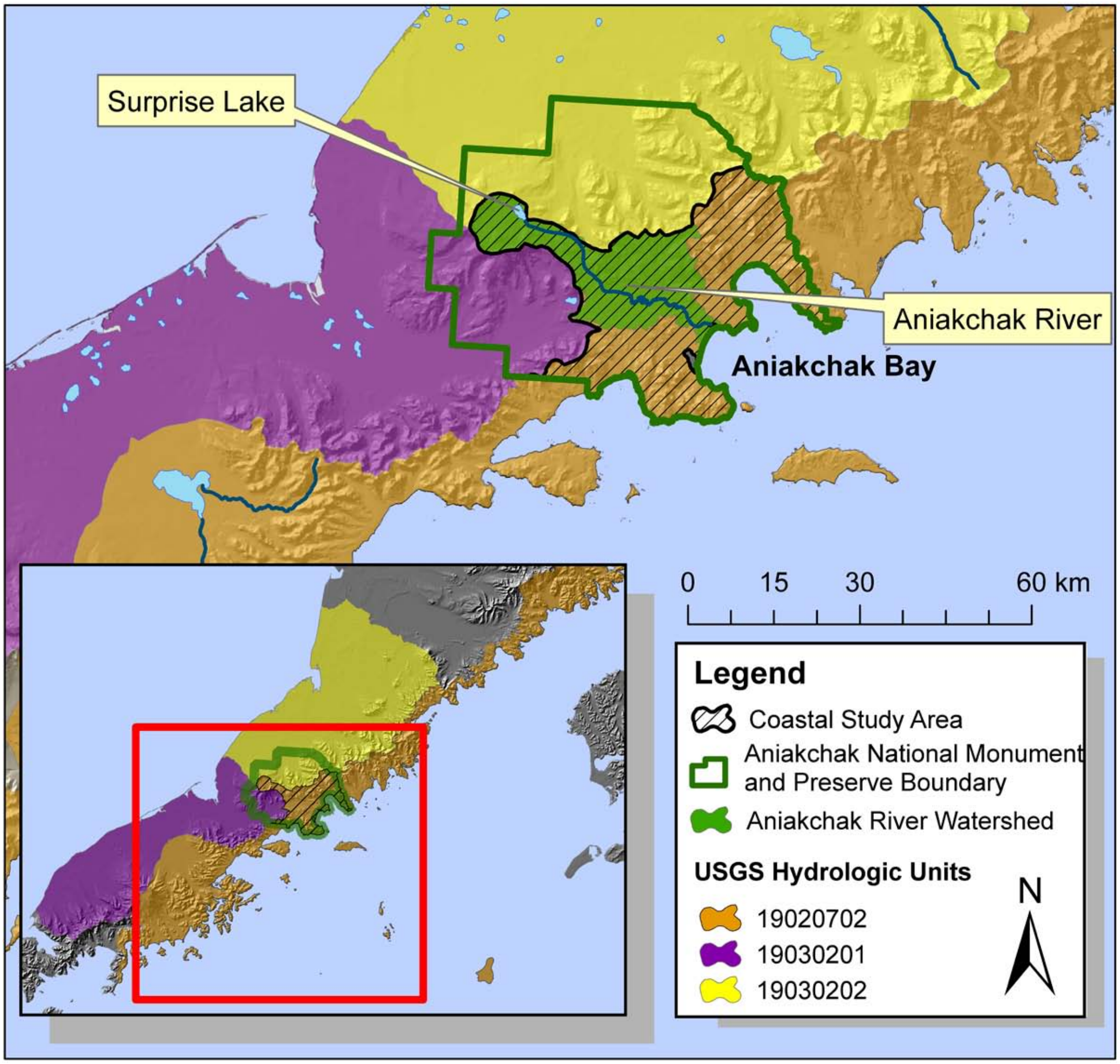

Figure 6: Location of the three USGS Hydrologic Units contained within ANIA boundaries. Hydrologic Unit Code #19020702 is Shelikof Strait, Hydrologic Unit Code #19030201 is Port Heiden and Hydrologic Unit Code #19030202 is Ugashik Bay.

A2. Human utilization

Very little is known about the pre-European anthropological history of the ANIA region. The NPS conducted several archaeological surveys of the area in 1990's to better understand the cultural history of the region (VanderHoek, 1999, 2000). Archaeological finds on the Umnak Island in Nikolski Bay indicate that the Aleutian Archipelago has been populated by humans for at least 8000 years (NPS, 2006a). The region's inhabitants have been identified as "Peninsular Eskimos" (Oswalt, 1967), or "Pacific Eskimos"; speakers of the Alutiiq dialect of Yup'ik. The Aniakchak area appears to have been a transition area between the cultural areas of the Aleutians and the Alaska Peninsula (NPS, 2006a). The linguistic boundary between the Eskimos and Aleuts is located in the Port Moller area, 200 km (125 mi) to the southwest of ANIA (Dumond, 1981; Dumond et al., 1975; Krauss, 1982). West of Port Moller there is evidence of Aleutian occupation, however less than 160 km (100 mi) east of ANIA (within KATM) lie archeological sites that are regarded as belonging to the Alaska Peninsula culture (NPS, 2006a).

Russian fur-seekers began exploring the Aleutians and coastal mainland Alaska in the mid-1700's, following the voyages of Vitus Bering in 1725 and Alexei Chirikoff in 1741 (NPS, 2006a). In 1784 G.I. Shelikov established the first European settlement in Alaska (on Kodiak Island) and several fur-trading centers developed in the KATM area, however there is no known record of Russian use of the ANIA area until the 1800's, when stores opened on Sutwick Island near ANIA and at a small village called Mitrofania south of the Chignik villages (ca. 100 km [62 mi] southwest of ANIA) (NPS, 2006a). It is likely that Native hunters, who either freely traded with or were enslaved by the Russians, used the ANIA coast during the fur trade period, but their specific camp locations remain unknown (Norris, 1996). Following the acquisition of Alaska by the United States in 1867, fur trappers overexploited sea otters and other fur-bearing animals to the brink of extinction, and as a result of the fur trade crashing, the salmon packing industry was born on the Alaska Peninsula ca. 1880 (NPS, 2006a).

Remains of a bunkhouse built by the Alaska Packers Association, a fishing venture established in 1917 at the mouth of the Aniakchak River are still visible today (Figure 7). Several different fish trap stations along the ANIA coast operated during 1917-1949 (Norris, 1996). Other known uses of the ANIA area in the 1920's included fur trapping in the ANIA interior area, and oil exploration by American geologists (Norris, 1996). Oil-seekers from the U.S. Geological Survey explored the ANIA area in 1922 and 1925; and it was on the 1922 trip that they "discovered" the Aniakchak Crater, whose cloud-shrouded peaks had previously eluded non-native explorers, fishermen, local residents, and governmental officials for decades (Smith, 1925). On a more academic mission, American explorer Father Bernard Hubbard, a Jesuit priest from Santa Clara University in California, visited the ANIA area just before and after the 1931 Aniakchak eruption. His works provided written documentation of the devastation to wildlife and plant life in the caldera and photo documentation of the tremendous landscape alterations caused by the blast (Hubbard, 1931).

Figure 7: Bunkhouse on Aniakchak Bay that was part of the Alaska Packers Association fishing venture begun in 1917. It is on the List of Classified Structures and has been nominated to the National Register of Historic Places. Photo: NPS (from http://www.nps.gov/ania/pphtml/photogallery.html).

In the summer of 1932 a razor-clam cannery operated at the southwestern end of Aniakchak Bay (Norris, 1996). From the 1940's to the 1960's, the ANIA area was used intermittently by subsistence hunters, by a few trappers, and by occasional oil explorers (Norris, 1996). Other than these records, there is little documentation of white visitors to ANIA before the 1970's, when several National Park Service planners and river runners explored the area.

ANIA is currently one of the most remote units in the National Park Service (NPS) and is the least visited NPS unit in the nation. In recent years, there were an estimated 200-300 recreational visitor days (e.g. 20-30 visitors for 10 days each) in ANIA annually; however the lack of an entrance station and backcountry permitting process does not allow for exact numbers to be known (NPS, 2006a). According to these estimates, even the next least visited park in Alaska—Lake Clark National Park and Preserve (LACL)—received 18 times more visitors than ANIA. With no resident or even seasonally-resident NPS rangers or other staff, no inhabited inholdings, no roads or trails leading into or within it, it is one of the most inaccessible NPS units and U.S. destinations in general. The caldera, into which planes and helicopters may land, is often shrouded in stormy, dense clouds, and has its own microclimate of harsh winds and cold temperatures that make conditions for access and visitation exceptionally challenging for both visitors and NPS staff.

A3. History of park designation

In 1967, the Aniakchak caldera was designated as a National Natural Landmark. Aniakchak National Monument, which includes the caldera and its immediate surroundings, was established on December 1, 1978, and two years later, with the passage of the Alaska National Interest

Lands Conservation Act (ANILCA), the Aniakchak National Preserve was added to create the Aniakchak National Monument and Preserve. The ANILCA mandate was "to maintain the caldera and its associated volcanic features and landscapes, including the Aniakchak River and other lakes and streams, in their natural state; to study, interpret, and assure continuation of the natural processes of biological succession; to protect habitat for, and populations of, fish and wildlife, including, but not limited to, brown/grizzly bears, moose, caribou, sea lions, seals, and other marine mammals, geese, swans, and other waterfowl." The Aniakchak River was designated as a Wild River by Title VI, Section 601(27) of ANILCA, which preserves the river, its surroundings, and its free-flowing condition for the benefit of present and future generations.

B. Hydrologic information

B1. Oceanographic setting

The Alaska Peninsula, including the ANIA coast, borders the northern Gulf of Alaska (GOA), which extends southeast to the Canadian mainland at Queen Charlotte Sound (Figure 8). Dominant habitats include continental shelf, slope and abyssal plain. Within the GOA, the continental shelf area represents more then 12 % of the continental shelf holdings of the U.S. (Hood and Zimmerman, 1986). The width of the continental shelf ranges from 5 km (3.1 mi) in the southeast to nearly 200 km (124 mi) around Kodiak Island (Weingartner et al., 2005). Abyssal depths (>7000 m [22966 ft]) occur in the northwest portion of the GOA within the Aleutian Trench. Slope and plain environments are dotted with subsurface banks, ridges, and seamounts which rise from over 1 km (.6 mi) in depth to within a few hundred m of the surface. Fjords, convoluted shorelines, underwater canyons and ridges, and multiple islands create a mosaic of geological features that contribute to a complex oceanographic domain. The oceanography of the GOA is composed of gyres, surface currents, predominant downwellings, and punctuated localized upwellings. Offshore circulation is dominated by a cyclonic subarctic gyre. The sluggish, easterly-flowing North Pacific Current bifurcates near 52° N and becomes the Alaska Current (AC) northward (Figure 8) and the California Current southward. The Alaska Coastal Current (ACC), inshore of the AC, is a low-salinity, cyclonic (counter-clockwise), fast-moving (13–133 cm/s [5-52 in/s]) current driven by winds and density gradients established through freshwater input (Hood and Zimmerman, 1986). Precipitation within the GOA ranges from 2–6 m (7-20 ft) per year (Weingartner et al., 2005). The region is affected by intense winter storms that frequently become trapped or stalled by the surrounding rugged coastal topography (Royer, 1998; Wilson and Overland, 1986). Persistent cyclonic winds, coupled with onshore surface Ekman transport promote downwelling favorable conditions for much of the GOA, however episodic and local upwelling may be generated by eddies or other local geography.

Despite predominant downwelling, the Gulf of Alaska is a productive ecosystem. Nutrients are supplied from small-scale upwelling, eddies, shear, Ekman transport, resuspension of shelf sediments and river discharge (Stabeno et al., 2004). Eddies are frequently generated off the British Columbia coast (Crawford et al., 2002). Eddies have also been generated west of Shelikof Strait (Crawford et al., 2000). Eddies in the GOA range from 10-50 km (6-30 mi) and normally persist for 1 to 4 weeks (Bograd et al., 1994). The arrival of eddies to the shore may increase larval recruitment via entrainment of fish and shellfish larvae within water conditions favorable to survival (Incze et al., 1989; Schumacher et al., 1993), whereas the generation of eddies may decrease larval recruitment via advection (Sinclair and Crawford, 2005).

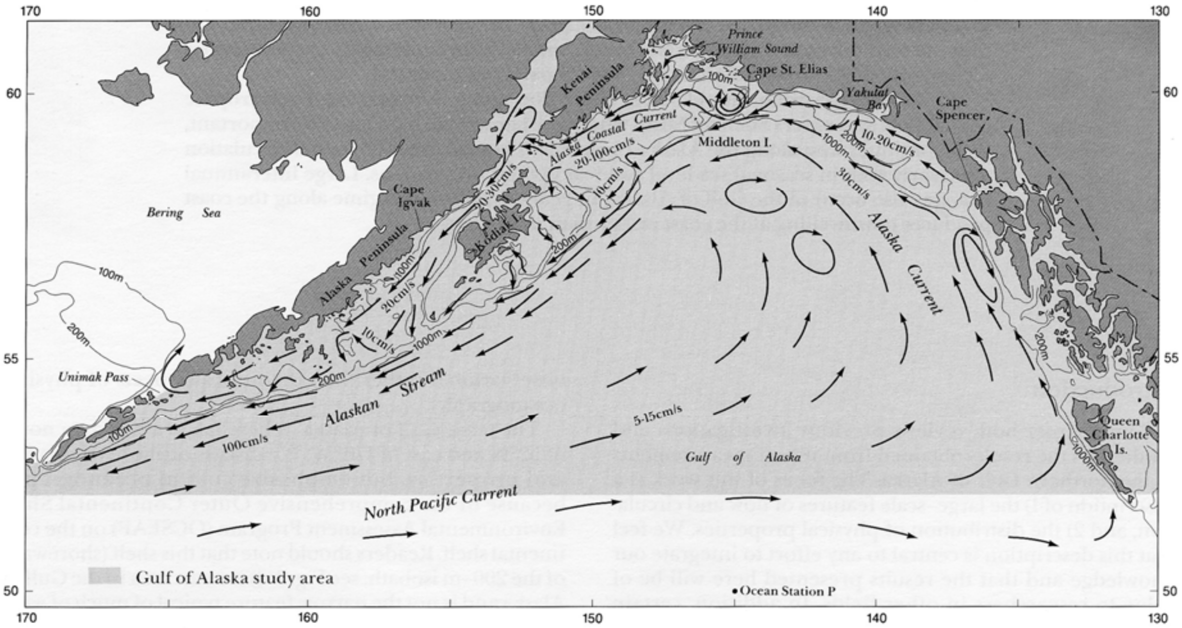

Figure 8: Predominant currents in the GOA (Reed & Schumacher 1986).

The GOA is meteorologically active and dominated by a persistently-located area of low pressure known as the Aleutian Low (Mundy and Olsson, 2005). Winter storms, characterized by low sea-level pressures, can routinely produce >15 m (49 ft) waves and gale strength winds (Wilson and Overland, 1986). The Low oscillates in strength and location throughout the year but maintains its influence on the regional climate (Mundy and Olsson, 2005; Wilson and Overland, 1986). The Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) are global-scale atmospheric and oceanic conditions that influence climate, weather events, circulation, and ultimately, the biology of the GOA. The PDO is characterized by descriptive weather indices that track anomalies of sea surface temperature, wind stress, and sea level atmospheric pressure (Hare et al., 1999). Wintertime location of the Aleutian Low creates a proxy for which regime the PDO is characterized. A negative PDO occurs when the Aleutian Low is centered in the southwestern GOA, over the Aleutians and southern Bering Sea. A positive PDO occurs when the Aleutian Low has a northeastern GOA locus, and the climate of the GOA is characterized by warmer sea surface temperatures, higher precipitation, and windier conditions (Hare et al., 1999). Opposite patterns for the Gulf are observed during negative phases of the PDO. Winters with strong Aleutian Lows tend to be associated with ENSO warming events (Niebauer, 1988), but warming in the equatorial Pacific is not always associated with intensification of the Aleutian Low and vice-versa.

Storms, wind mixing, and terrestrial inputs result in high productivity and a dramatic marine environment along the ANIA coast. Within Shelikof Strait, the ACC travels southwestward at the surface (Figure 9) at speeds ranging from 20 cm/sec (8 in/sec) in early summer to 100 cm/sec (39 in/sec) in the fall (Reed and Schumacher, 1986). This high-speed current transports freshwater, nutrients, contaminants and sediments from the eastern GOA and Prince William

Sound to the Shelikof Strait and Alaska Peninsula region. About half of the bottom sediments in Shelikof Strait are from the Copper River in the eastern GOA (Prentki, 1997). The high amount of freshwater input in the region results in estuarine flow in Shelikof Strait, with a southwestward flow of surface waters and a northeastward inflow of deep water (Reed et al., 1987).

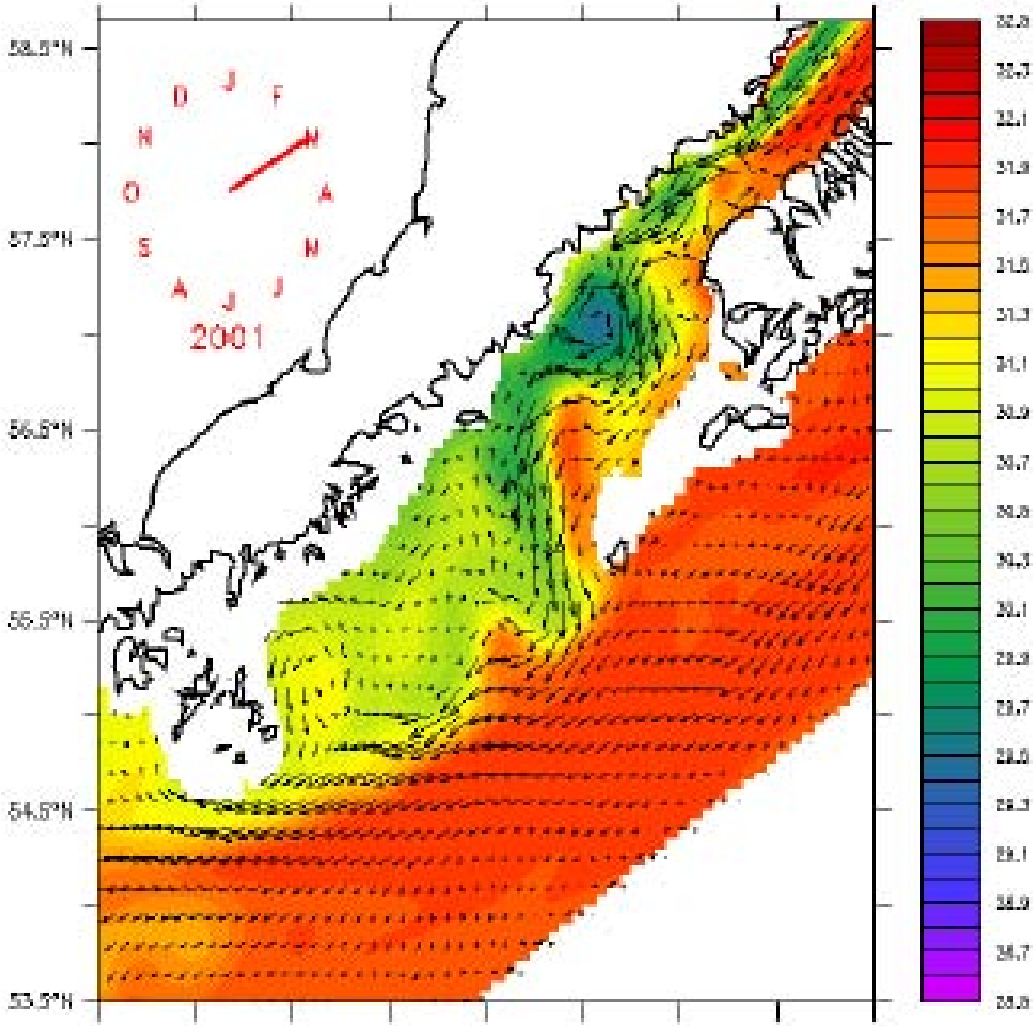

Figure 9: Results from a NOAA circulation model of the Alaska Peninsula for March 2001. Water salinity is indicated by the colors and arrows indicate water movement (NOAA model presented in Harper and Morris 2005).

Temperature and salinity in Shelikof Strait and along the Alaska Peninsula were surveyed in the summer of 2002 by the Environmental Monitoring and Assessment Program (EMAP) (Saupe et al., 2005). In this survey of southcentral and southwest Alaska, surface seawater temperature ranged from 5.1 to 16.5 ˚C (41 - 62 ˚F), averaging 11.1 ± 2.6 ˚C (52.0 ± 4.7 ˚F), and bottom temperatures ranged from 4.3 to 14.6 ˚C (40 – 58 ˚F), averaging 7.0 ± 2.7 ˚C (45 ± 4.9 ˚F) (Figure 10). Surface salinity ranged from 13 to 32 and bottom salinity ranged from 17.6 to 32.2 in this same region, and salinities in the ANIA region were in the high end of this range (Figure 11).

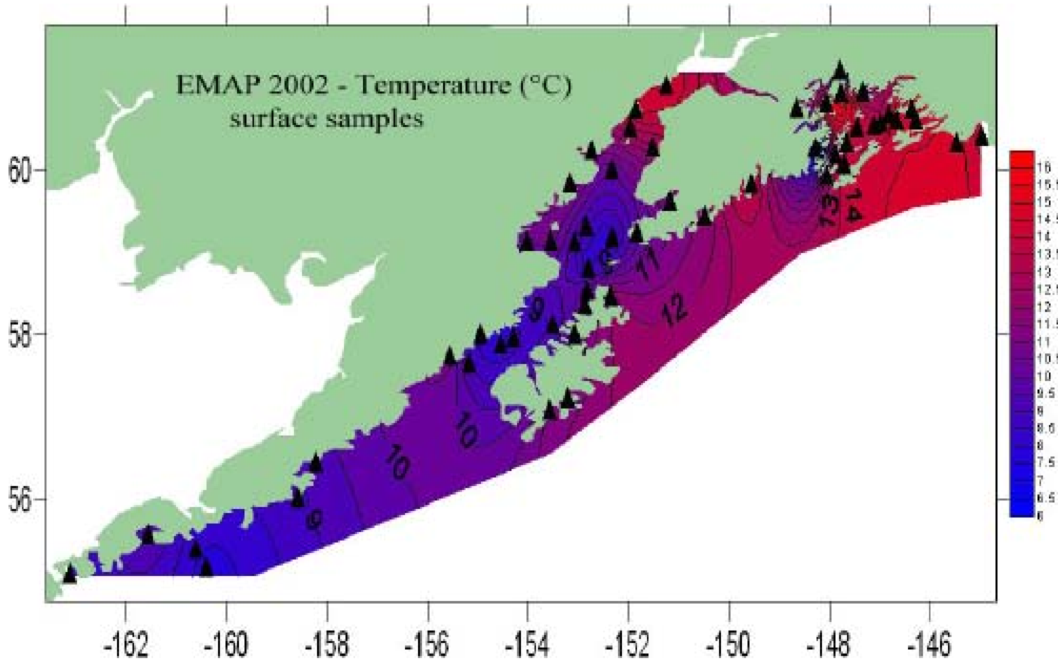

Figure 10: Surface temperature contours estimated from the 54 stations (triangles) sampled as part of the EMAP program (see section IV.A.1). Sampling occurred between June-August 2002 (Saupe et al., 2005).

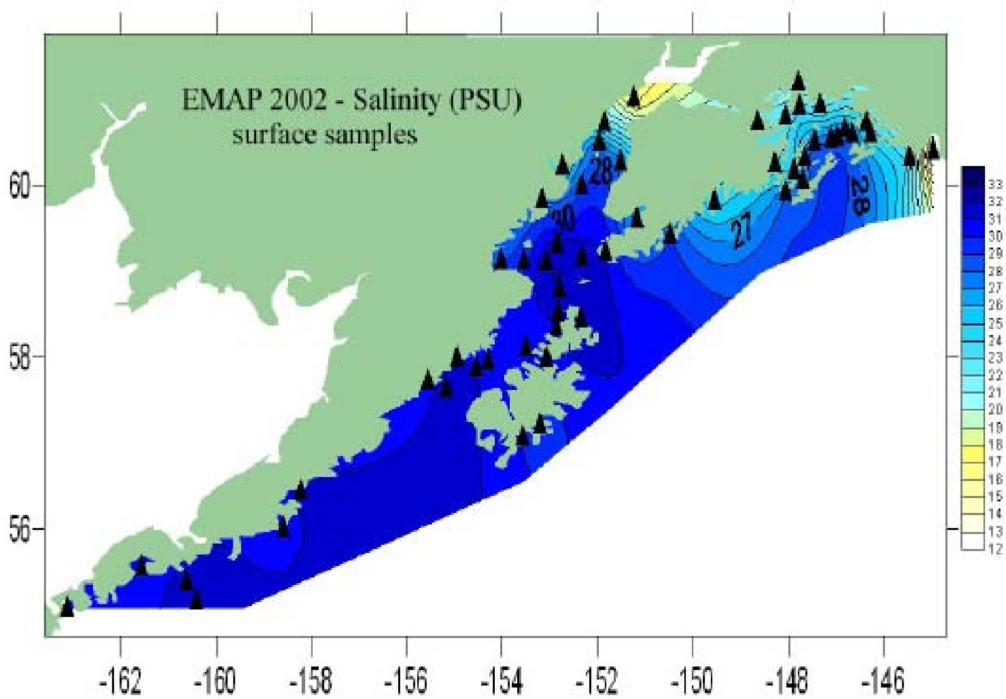

Figure 11: Surface salinity contours estimated from the 54 sampled stations (triangles), showing the lowest salinities occur relative to the major inputs of the principal rivers (Saupe et al., 2005).

B2. Climatic setting

There are no climate monitoring stations within ANIA or nearby KATM. However, the National Weather Service (NWS) has an observation station in Chignik, southwest of ANIA and on the Pacific coast, that is the best available proxy for climate in coastal ANIA. However, the current climate station at the airport in Chignik has only been operating since 2005, and historic climate data for Chignik are available from a NWS cooperative observer station that operated from 1967-1978 (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ak1716). These data indicate that the mean monthly temperature in Chignik ranges from -4 ˚C (25 ˚F) in January to 12 ˚C (54 ˚F) in August and annual precipitation averages approximately 211 cm (83 in). The closest station to ANIA in the Gulf of Alaska with a long term climate record is Kodiak. Kodiak's mean monthly temperature ranges from -1 to 13 ˚C (30 to 55 ˚F) and annual precipitation averages 190 cm (75 in), with peaks in the fall and winter (Figure 12). Norris (1996) has previously estimated that annual precipitation in the coastal area of ANIA averages at least 250 cm (100 in).

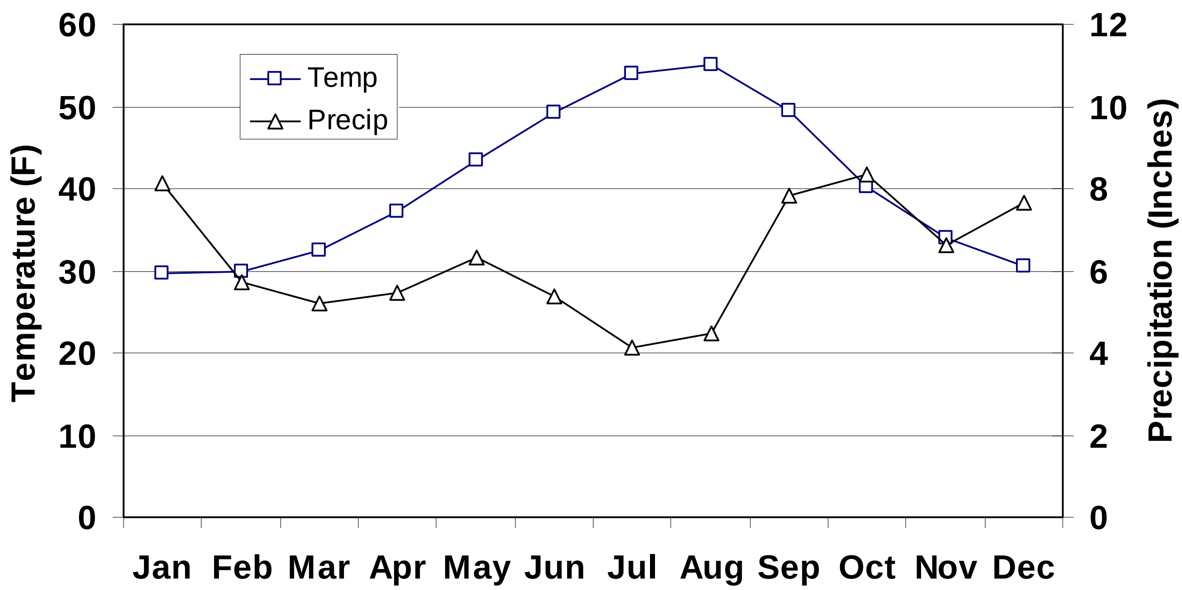

Figure 12: Mean monthly temperature and precipitation in Kodiak, Alaska for the period 1971-2000. Data from NOAA National Climatic Data Center (http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl)

The Aleutian Mountains function as a weak physical barrier between the Pacific coastal climatic zone, characterized by moderate temperatures and high precipitation rates, and the drier Bristol Bay Coast (Cameron and Larson, 1992). Straddling both these climate regimes, the Aniakchak caldera is affected by the shifting air currents that move between the two climate zones (Hasselbach, 1995). Eastward moving Aleutian low pressure zones deliver strong storms to the area, particularly in the fall and winter months. Orographic effects have a strong influence on climate and, in general, the higher the elevation in the Aleutians, the higher the precipitation and the cooler the temperatures (Cameron and Larson, 1992).

Based on anecdotal descriptions and some short-term measurements by various NPS researchers working in ANIA, the climate is typically wet, windy, and cool. Cloud cover is usually thick and sunshine rare, even in the summer, when fog and drizzle are the norm (Mahoney and Sonnevil, 1991). However, under certain conditions the crater rim may create a moderate rainshadow effect within the crater itself (Cameron and Larson, 1992; Norris, 1996). The crater rim also shields the crater floor from light external winds (<25 kph [16 mph]), but during stronger wind events, swirling gusts can concentrate and become trapped inside the caldera, creating a sometimes violently windy microclimate (Cameron and Larson, 1992; Mahoney and Sonnevil, 1991). Bosworth (1987) describes these winds as highly dessicating to plants due to their suspension of light, sharp, volcanic sand and ash that becomes very abrasive in under windy conditions. Meteorological conditions at Surprise Lake were collected between July and September, 1988 by Cameron and Larson (1992), who report warm air conditions (17-22 ˚C, 63-72 ˚F) and mostly clear skies for July; temperatures in the 9-12 ˚C (48-54 ˚F) range, overcast skies, and frequent precipitation in early August, and cooler temperatures 6-9 ˚C (43-48 ˚F), frequent rainstorms and high winds in late August. Meteorological data for the caldera was recorded during a 32-day vegetative study in the caldera in the summer of 1993 (Hasselbach, 1995). Average daily maximum and minimum temperatures were 15 ˚C (59 ˚F) and 9.4 ˚C (49 ˚F) respectively, cumulative precipitation was 29.4 cm (11.6 in), and maximum recorded wind speed was 100+ km/hr (59 mi/hr).

B3. Streams and Streamflow

B3a. Description and lists of streams

The highly porous volcanic material that comprises the caldera allows for almost no surface flow of water. Surprise Lake, in the northeast corner of the caldera floor, is the largest surface water body in the crater. It covers a relatively small portion of the caldera surface: 275.2 hectares (680 acres), and it has a maximum depth of 19.5 m (62 ft) (Mahoney and Sonnevil, 1991). It is fed primarily by numerous warm springs, snow, and cold springs. Only three permanent streams flow into the west end of Surprise Lake and two flow into the Aniakchak River (Bosworth, 1987). Cameron and Larson (1992) referred to one of these tributaries as “Turbid Creek” (name is unofficial), as it flows out of a particularly turbid pond in the southeast section of the caldera, unofficially named “Turbid Lake”. Bosworth (1987) described the inlet streams to Surprise Lake as running clear at the time of her research but hypothesized that during snowmelt, they are choked with ash and sediment and constantly shift across their alluvial plains as they deposit their sediment loads. The longest inlet stream [unofficially named “Sandpiper Creek” by Bosworth (1987)] is ca. 2.5 km (1.5 mi) long and is visibly fed by iron-rich, orange-colored warm springs, and the second longest stream is “Sedge Creek” [also unofficially named by Bosworth (1987)], which is ca. 1 km (0.6 mi) long. The two other lakes, “Turbid Lake” and an unnamed blue-green lake, are in the caldera, much smaller in size than Surprise Lake, and are located along the southeast wall (Cameron and Larson, 1992).

Surprise Lake’s only outlet is the Aniakchak River, which cascades out of the caldera through “The Gates,” a 457 m (1,500 ft) V-shaped notch in the east caldera wall that was likely created when the ancestral caldera lake breached the crater’s holding capacity (Waythomas et al., 1996). The Aniakchak River flows 43 km (27 mi) through glacially-carved and ash-filled valleys to the Gulf of Alaska at Aniakchak Bay, picking up additional flow from several tributaries along the way; the largest of which are Albert Johnson Creek and North Fork Aniakchak River. The other major rivers partially within ANIA boundaries are the Meshik River, which flows northwest into the Bering Sea south of the caldera, and the Cinder River, which also empties into the Bering Sea and flows north from areas east of the caldera. Neither river falls within Pacific coastal watersheds of ANIA, the study area of this report.

Major tributaries to the Aniakchak River are Albert Johnson Creek and North Fork Aniakchak River. Other Pacific coast rivers in ANIA include “Iris Creek” and “Willow Creek”, which are unofficial names given by Bennett (2004), although Miller and Markis (2004) called these same streams “Creek 100” and “Creek 200”, respectively. “Iris Creek” is the largest stream between the Aniakchak River and Cape Ayutka, and “Willow Creek” drains into south side of Amber Bay. Streams draining Cape Kumlik, in the western portion of coastal ANIA, are mostly short (< 5 km [3 mi]) and unnamed. West, Main, Northeast Creeks, and several smaller streams flowing from Cape Kunmik terminate in Amber Bay. Streams in the ANIA region that drain to the Pacific Ocean are generally short and steep, as opposed to the lower gradient, often braided streams draining north and west into the Bering Sea (Tande and Michaelson, 2001). Major watershed boundaries within ANIA are shown in Figure 13, and their watershed areas are listed in Table 2.

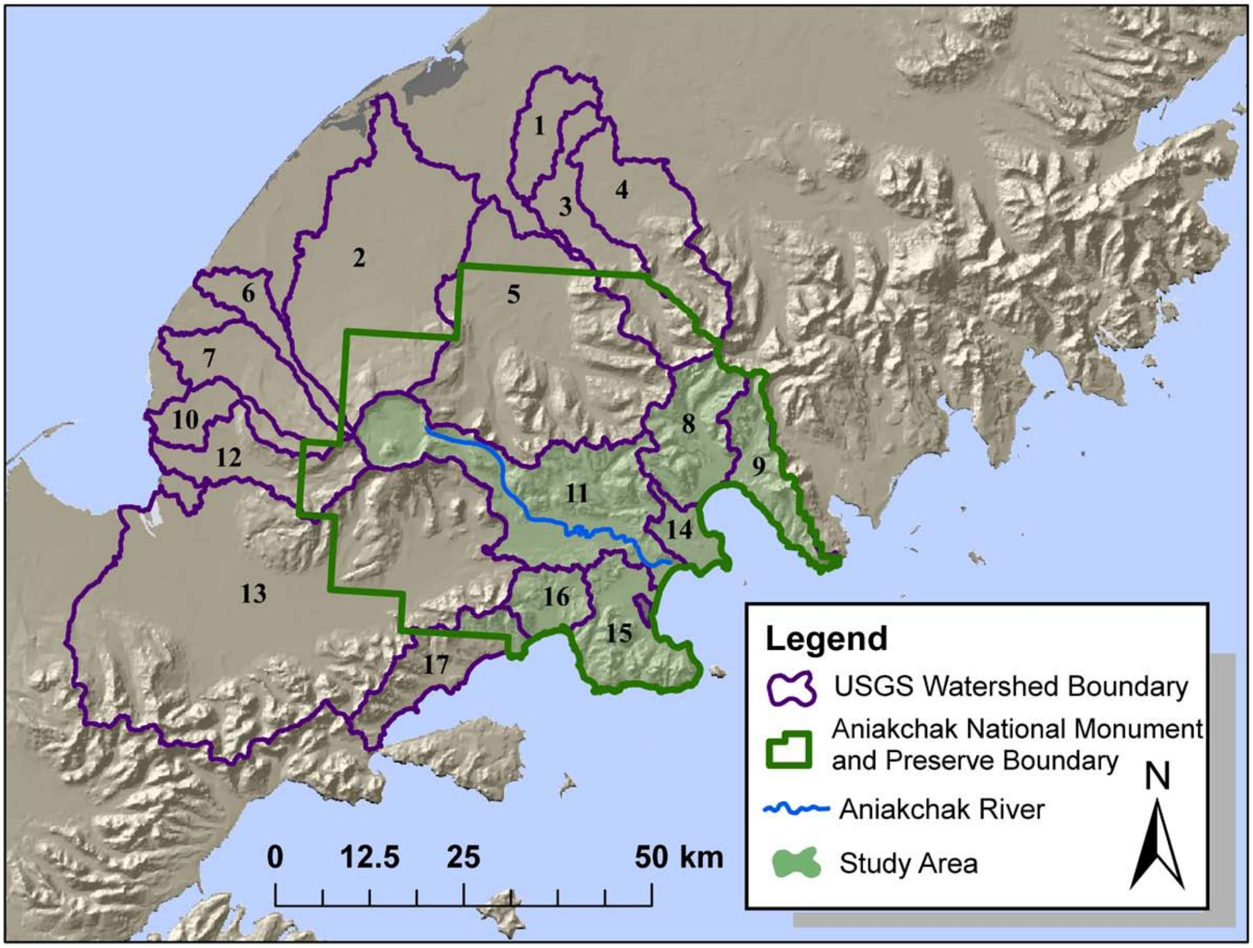

Figure 13: Map of watershed boundaries within and adjacent to ANIA (coastal study area shaded). See Table 2 below for watershed names that correspond with numerical codes in the figure.

Table 2. Watersheds entirely or partially within ANIA, and their surface areas. Watershed numbers correspond with coding on Figure 13.

Watershed #	Watershed Name	Area (km^2)	Area (mi^2)
1	Unknown	9.5	3.7
2	Mud (Hook) Creek	60.2	23.2
3	Pumice Creek	20.2	7.8
4	Old Creek	23.5	9.1
5	Cinder (Shagon) River	66.1	25.5
6	Reindeer Creek	8.0	3.1
7	Reindeer Creek (North Pass)	15.6	6.0
8	West Creek/ Main Creek	17.1	6.6
9	Northeast Creek (only named creek)	12.2	4.7
10	Barabara (Squlish) Creek	8.8	3.4
11	Aniakchak River	42.8	16.7
12	Birthday (Tananapuk) Creek	16.8	6.5
13	Meshik River	143.5	55.4
14	Iris Creek	5.4	2.1
15	Cape Kumlik	17.2	6.6
16	North Fork	7.8	3.0
17	Rudy Creek	14.9	5.8

B3b. Streamflow and physical habitat information

There are no streamflow gauges within or in close proximity of the ANIA unit. To the east and northeast, the closest actively gauged rivers are the Terror River near Kodiak and 6 streams in the Iliamna area (Figure 14; Table 3). However, these streams are 260- 420 km (162-261 mi) from ANIA and drain environments considerably different than those found in ANIA. In addition, most of these gauging stations only have records beginning in 2004. Approximately 325 km (202 mi) away, the nearest gauged stream to the southwest of ANIA is Russell Creek near Cold Bay (Table 3). Russell Creek is probably representative of streams in ANIA because it is a non-glacial, coastal watershed located on the Gulf side of the Alaska Peninsula. Russell Creek drains an area of 80 km^2 (31 mi^2), and the hydrologic record shows that the stream does not exhibit strong seasonal variations, reflecting the year-round cold climate, the consistency of storm events throughout the year, and the lack of glacial inputs during summer (Figure 15). Two gauging stations (USGS station #s 15297602 and 15297603) somewhat closer to ANIA, in Sand Point, AK, on an island approximately 200 km (124 mi) southwest of ANIA, operated for only 7 months in 1983-1984. The short period of operation and the long distance from ANIA renders these data of insignificant value for characterizing and interpreting streamflow dynamics within ANIA.

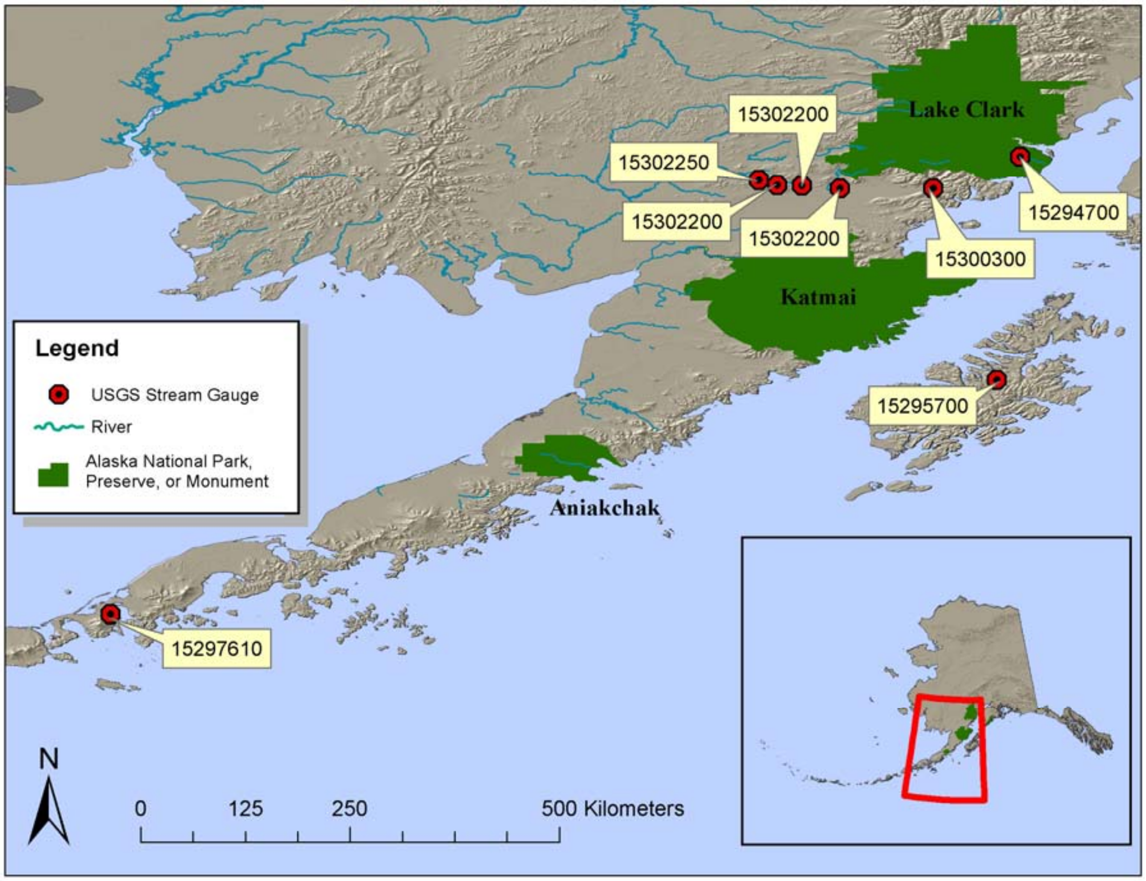

Figure 14: USGS stream gauges near ANIA.

Table 3. USGS streamflow gages near ANIA. Gauge numbers correspond with the stations shown in Figure 14. Coordinates are in NAD83. Data from USGS streamflow database for Alaska (http://waterdata.usgs.gov/ak/nwis/sw).

Station Name	Gauge #	Lat.	Long.	Km From ANIA (mi)	Period of Record
Terror R	15295700	57.694	-153.1639	262 (163)	1964-present
Johnson River	15294700	60.094	-152.9128	431 (267)	1995-2004
Iliamna R	15300300	59.758	-153.8469	370 (230)	1996-present
Koktuli R	15302200	59.793	-155.5247	325 (202)	2004-present
Koktuli R	15302250	59.843	-155.7186	324 (202)	2004-present
Roadhouse Ck	15300200	59.757	-154.8491	340 (211)	2005-present
Upper Talarik Ck	15300250	59.786	-155.2552	330 (205)	2004-present
Russell Creek	15297610	55.1769	-162.69	324 (201)	1981-present

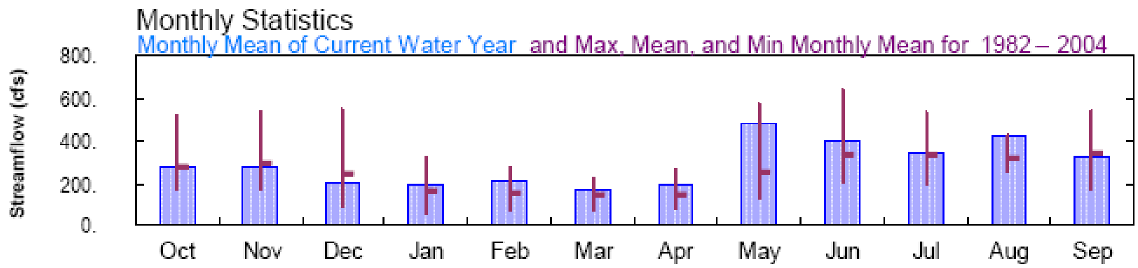

Figure 15: Monthly maximum, mean, and minimum streamflow for Russell Creek near Cold Bay, at the western end of the Alaska Peninsula, approximately 300 km (186 mi) west of ANIA. Data from USGS available at website: http://pubs.usgs.gov/wdr/2004/wdr-ak-04-1/regions/southwest/15297610.php.

Overall, the absence of current and historic streamflow gauging stations in or near ANIA prohibits any interpretation of temporal and spatial hydrological dynamics of streams within ANIA. Despite the lack of streamflow monitoring data within ANIA, some discrete discharge measurements have been recorded by water resource investigators. In a July, 1987 investigation of the Aniakchak River watershed (Mahoney and Sonnevil, 1991) documented that discharge on four Surprise Lake inlets ranged from 0.25-2.54 m^3/s (8.8 to 90 cfs), and that the discharge of the Aniakchak River in the caldera was 6.71 m^3/s (240 cfs) (Table 4). In 1989, additional discharge data was collected as part of a limnological research project on Surprise Lake (Cameron and Larson, 1993). The investigators measured the discharge of inlet stream to Surprise Lake and of the Aniakchak River and found them to range from 0.007-4.78 m^3/s (0.08-51 cfs).

Table 4. Stream discharge, velocity, width, and depth measurements for 4 tributaries to Surprise Lake and to the Aniakchak River in the caldera on July 24-26, 1987. From Mahoney and Sonnevil (1991)

Stream site	Discharge *m^3/s*	Stream width *m*	Mean velocity *m/s*	Max. depth *m*	Min. depth *m*
Trib. 1					
Site 1	*unable to measure because of channel braiding*				
Site 2	2.54	8.5	1.01	0.9	0.03
Site 3	1.95	17.3	0.50	0.5	0.1
Trib. 2 (Warm springs)	0.38	5.7	0.22	0.3	0.1
Trib. 3	0.25	4.5	0.16	0.2	0.1
Trib. 4 (Waterfall Cr.)	2.48	7.3	1.41	0.5	0.2
Aniakchak River	6.71	19.9	1.85	1.2	0.1

Mahoney and Sonnevil (1991) provide information on the stream width, stream depth, and mean velocity of the tributaries to Surprise Lake and of the Aniakchak River (Table 4). Physical habitat descriptions for streams other than Aniakchak River are provided in two fisheries investigations. As part of the sockeye salmon (*Oncorhynchus nerka*) investigation by Hamon (2000), Albert Johnson Creek was sampled for habitat parameters (habitat type, Wolman pebble counts, stream width, and depth) in 1999. In the lowest reach where fish were sampled, average stream depth and width were 46.6 cm (18.3 in) and 9.4 m (30 ft), respectively. Substrate composition was also sampled at this site and on two Surprise Lake beaches. Results of Wolman pebble counts show generally similar sizes at all sites, with average particle sizes falling into the fine to coarse gravel classification ranges. General habitat descriptions for "Creek 100/Iris Creek" and "Creek 200/Willow Creek" are provided by Miller and Markis (2004). Creek 100/Iris Creek is described to have a bank-full channel width of ~15 m (49 ft) and an average depth of 0.5 m (1.6 ft), and commonly has riffle and pool habitats in lower reaches (Miller and Markis, 2004). In contrast, Creek 200/Willow Creek is a continuous glide and has a highly sinuous incised channel that is ~2 m (6.6 ft) at bank-full stage and 1 m deep (Miller and Markis, 2004).

More recent discharge data are provided by Bennett (2004), who collected hydrological data in ANIA from May-July, 2003 (Table 5). In this baseline water quality inventory of ANIA, investigators measured 3 of the same tributaries to Surprise Creek as were measured by Cameron and Larson (1993); however, Bennett (2004) accounted for subsurface flow to Surprise Lake by comparing the tributary discharge to the Aniakchak River discharge. As a result, Bennett (2004) found that the tributaries contributed only 5.7%, 22%, and 6.8% of all surface flow to Surprise Lake, in contrast to the 14.4%, 65.6%, and 14.9% found by Cameron and Larson (1993), who did not account for subsurface flow. Bennett (2004) also documented that along the Aniakchak River, streamflow increased from 6.29 m^3/s (222 cfs) at the lake to 34.6 m^3/s (1223 cfs) below the confluence with the North Fork Aniakchak River (Bennett, 2004). Turbid Creek's flow was 0.67 m^3/s (23.8 cfs), Albert Johnson Creek's was 2.13 m^3/s (75.2 cfs), and the North Fork's was 6.54 m^3/s (231 cfs), accounting for 1.9%, 6.1%, and 18.9% of the Aniakchak mainstem flow, respectively (Bennett, 2004). However, discharge measurements at the various sites took place over a 4-day period (June 5-9, 2003) during which a rain event occurred, thereby preventing meaningful correlations of discharge data among sites. This report also has the only known discharge measurements of tributary streams to the Aniakchak River, as well as for 3 smaller coastal streams (Table 5).

Table 5. Discharge measurements (in cfs) along the Aniakchak River drainage in June-July 2003 (Bennett, 2004). Please refer to Bennett (2004) for specific site location.

Site	Date	Discharge (cfs)
Aniakchak at Surprise Lake	6/5/2003	222
Aniakchak bl North Fork	6/9/2003	1225
Turbid Creek	6/5/2003	23.8
Albert Johnson Cr_0	6/6/2003	75.2
Albert Johnson Cr_headwaters	6/21/2003	3.0
Albert Johnson Cr headwaters lake system	6/21/2003	4.4
North Fork, channel B	6/9/2003	23.1
North Fork, channel A	6/9/2003	202.7
First trib downstream of North Fork	6/9/2003	194.5
Second trib downstream of North Fork	6/9/2003	207.4
Lower Aniakchak R trib	7/20/2003	< 10 cfs
Iris Creek	7/18/2003	est. 10-15 cfs
Willow Cr	7/18/2003	est. 40 cfs
Pack cabin creek	7/20/2003	< 1 cfs

B4. Lakes and Ponds

The major lake within the study area is Surprise Lake within Aniakchak Crater and is the most intensely studied resource in ANIA. This lake lies at an elevation of 322 m (1056 ft) and covers 275 ha (680 ac), only 4% of the crater floor surface area (Mahoney and Sonnevil, 1991). However, according to (Waythomas et al., 1996), the Aniakchak Crater used to be entirely filled with a massive lake, which drained catastrophically at an unknown time in the last 3400 years. Within the crater are 2 other lakes ("Turbid Lake" and a blue-green lake in an eruption pit) and one "Snowmelt Pond", each of which is located on the eastern edge of the crater and are of far smaller dimensions than Surprise Lake (Cameron and Larson, 1993). Cameron and Larson (1992) sampled these waterbodies in 1989 for water chemistry, zooplankton, and phytoplankton.

Surprise Lake captures ca. 80% of the runoff in the caldera; the remaining 20% enters the Aniakchak River directly (Cameron and Larson, 1993). Eleven surface inlets and numerous warm and cold water springs drain into Surprise Lake, and three of the inlets account for ca. 95% of the surface water entering the lake (Figures 16 and 17) (Cameron and Larson, 1993; Mahoney and Sonnevil, 1991). Mahoney and Sonnevil (1991) provide bathymetric measurements of the lake, discharge data for the lake's tributaries, lake water quality data, and lake fish survey results. Cameron and Larson's (1993) limnological study of Surprise Lake provides additional water chemistry and physical attribute data, plus sediment chemistry, and biological characterization (phytoplankton, periphyton, zooplankton, benthic invertebrates, and fish).

Figure 16: View of Surprise Lake. Photo from (Tande and Michaelson, 2001)

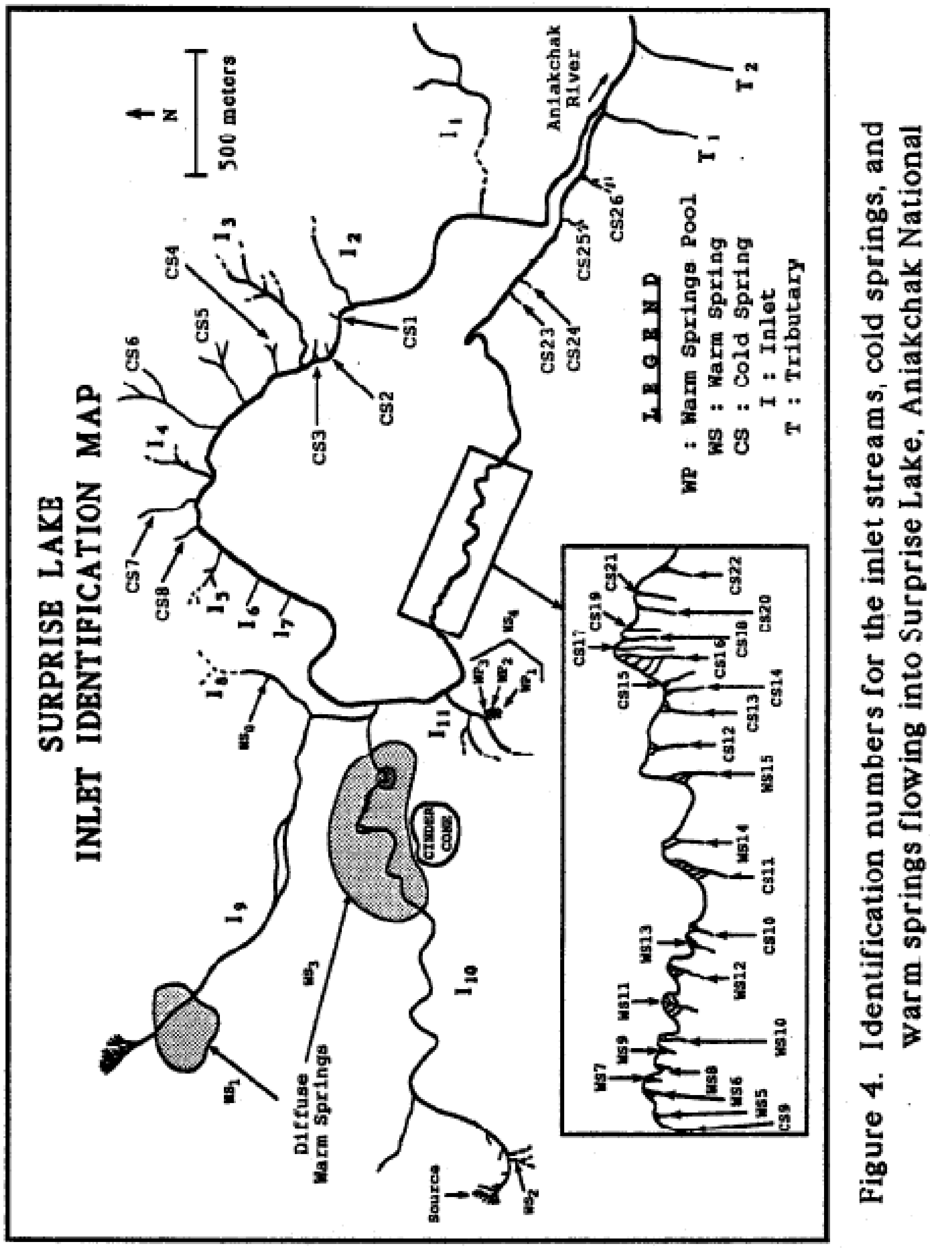

Figure 17: Map of Surprise Lake and its inlet streams (Cameron and Larson, 1993).

Mean and maximum depths of Surprise Lake were determed to be 13.7 m (44.9 ft) and 19.5 m (64.0 ft), respectively (Mahoney and Sonnevil, 1991). These and other morphological data for Surprise Lake are provided in Table 6 below.

Table 6. Morphological characteristics of Surprise Lake. From Mahoney and Sonnevil (1991).

Characteristic	**Value**
Surface area (ha)	275.2
Maximum length (m)	2595.1
Maximum bredth (m)	1363.9
Maximum depth (m)	19.5
Mean depth (m)	13.7
Volume (m^3)	37,585,665
Shoreline length	7,728.6
Littoral area (%)*	17

*Area that extends from the shore to a depth where light penetrates to the bottom

No other lakes in the study area are known to have been studied in any amount of detail approaching the investigations on Surprise Lake. As discussed in section *III.C.4c Aquatic invertebrates, chlorophyll, phytoplankton, and zooplankton,* Cameron and Larson (1992 and 1993) conducted extensive studies on the macroinvertebrates, plankton, and chlorophyll in Surprise Lake and its inlet streams. Most other lakes in the study area are significantly smaller and are unnamed.

B5. Groundwater

There are no known data available concerning groundwater resources in ANIA.

B6. Wetlands

It is not possible to estimate the wetland area in ANIA because the wetlands in the park have not been studied or comprehensively mapped. ANIA is one of several national parks in Alaska that have not been mapped through the U.S. Fish and Wildlife Service National Wetlands Inventory mapping program (http://wetlandsfws.er.usgs.gov/). Assuming that ANIA is similar to coastal KATM to the north, the majority of wetlands in the park are estuarine wetlands as well as palustrine and riverine wetlands located along valley bottoms. Coastal wetlands provide valuable habitat for fish, waterfowl and bears. Flora within these wetlands typically exhibit a high degree of spatial variability based on changes in topography and salt water exposure. Estuarine and marine wetlands in ANIA below the mean high tide line are primarily under the jurisdiction of the State of Alaska.

B7. Snow, Ice, and Glaciers

Deglaciation in ANIA likely began about 12,000 years before present (BP) and was likely complete by 10,000 yr BP (Black, 1983). ANIA does not presently contain any glaciers. While permanent snowfields exist, there are no known studies on the aerial dimensions and/or chemical attributes of these water resources. All water resource investigations in ANIA have concerned surface water resources only. For a discussion of the potential impacts of climate change on snowfields within ANIA, see section *V.B Climate Change.*

C. Biological Resources

C1. Current biological research and monitoring projects

C1a. Ecological subsections

A component of the SWAN I&M program is mapping and delineation of ecological subsections of each park unit for the purpose of evaluating land resources and refining research and management strategies for specific areas ((Tande and Michaelson, 2001). This mapping project noted the extreme scarcity of landform and land cover map information for the Aniakchak region and relied mostly on USGS/EROS composite Landsat satellite images and geologic information. According to the report, Nowacki et al. (2000) divided the Alaska Peninsula Ecoregion into the Bristol Bay Lowlands Section to the north of ANIA, and the Aleutian Mountain Range Section, which extends south into Unimak Pass. Further subsections include the Meshik River Lowlands, Aleutian Range Mountains - South, Aleutian Range Mountains - North, and the Aniakchak Volcano Subsections (Tande and Michaelson, 2001). This ecological subsection delineation project provides general information and some photographic documentation of the geology and physiography of each subsection as well as basic information regarding vegetation and landcover.

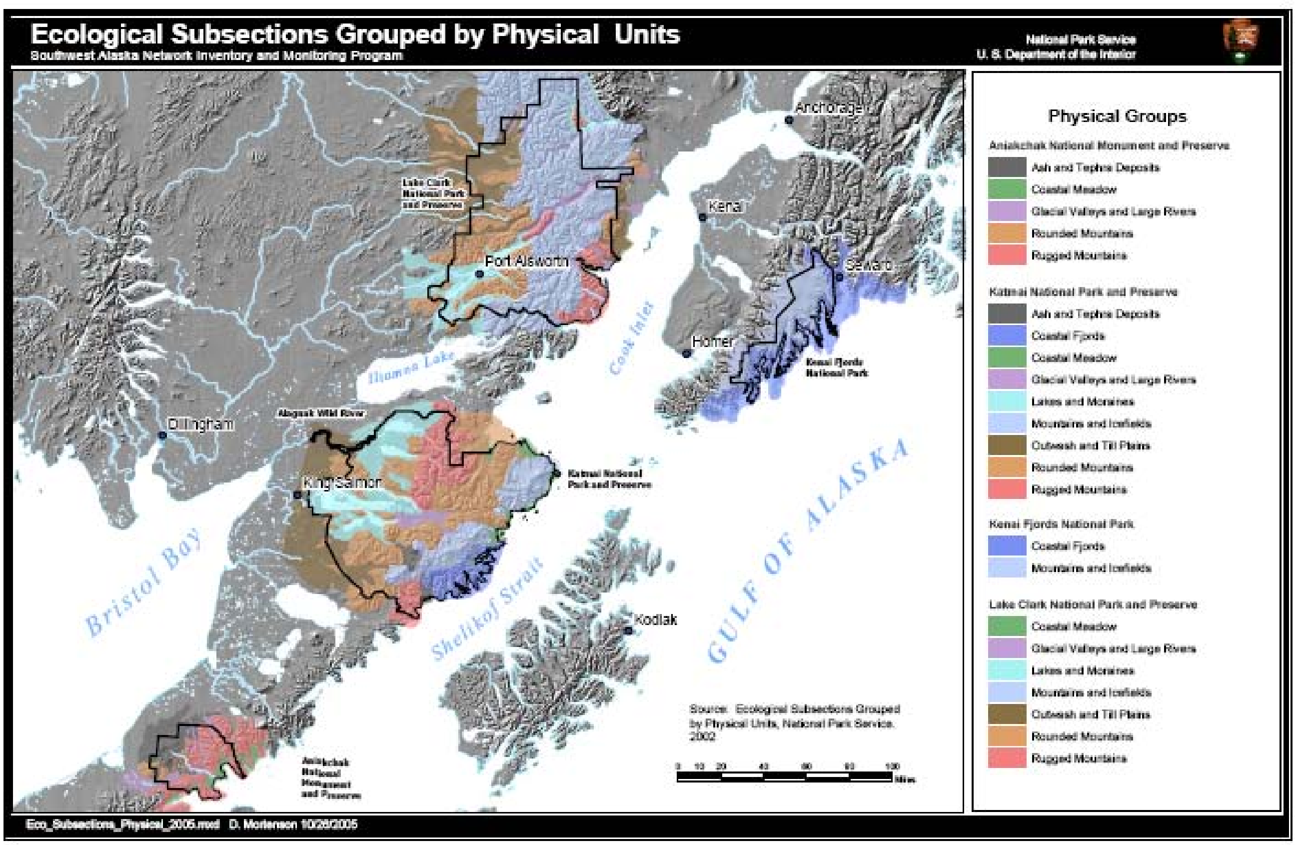

Figure 18. Ecological subsections as presented in SWAN Monitoring plan (Bennett et al., 2006)

C1b. Species lists from I&M Program

A 2003 survey of non-NPS research projects taking place within the SWAN region revealed no individual projects taking place exclusively within ANIA (Thompson, 2004). The NPS I&M program in ANIA is the most extensive effort to describe, catalog, and assess the condition of biological resources in ANIA. Information on the SWAN I&M program can be found at http://www.nature.nps.gov/im/units/swan/. As part of the NPS Biological Inventory Program, a component of the I&M Program, species lists were compiled for vascular plants, fish, birds, and mammals within each of the SWAN units (Lenz et al., 2002). As of September 30, 2001, there were 472 vascular plant species, 19 fish species, 145 bird species, and 40 mammal species reported to inhabit ANIA, although not all species were confirmed as present (Lenz et al., 2002). The full species list is given in Lenz et al. (2001).

C2. Marine Resources

C2a. Marine mammals

Steller Sea Lions

The U.S. western stock of Steller sea lions (*Eumetopias jubatus*), located westward of Cape Suckling, 144º W, and including the ANIA region, is federally-listed as endangered due to declining populations throughout the western Gulf of Alaska and Bering Sea regions (Figure 18) (Sease and Loughlin, 1997). The NOAA National Marine Mammal Laboratory (NMML) conducts aerial surveys of the western stock of Steller sea lions (Figure 19); however their data is not broken down to resolve abundances within ANIA. The designation of the western stock as endangered provides protection for Steller sea lion populations as well as "critical" habitats that support reproduction, foraging, rest, and refuge. The eastern stock of Steller sea lions (east of Cape Suckling, 144º W) in Southeast Alaska is currently stable (Calkins, 1999) but federally-listed as threatened (Gelatt et al., 2004).

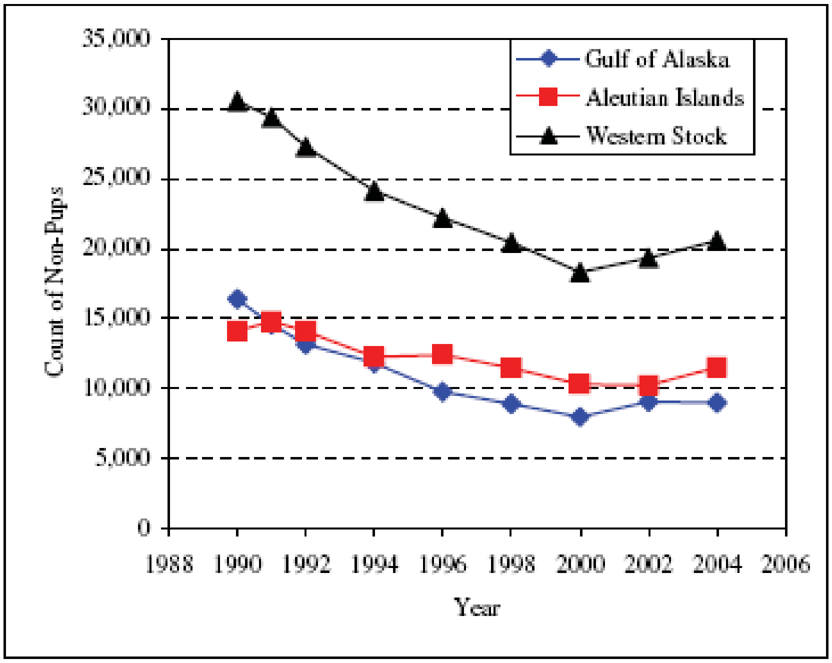

Figure 18: Counts of juvenile and adult Steller sea lions at rookery and trend sites throughout the range of the western U.S. stock (Fritz and Stinchcomb, 2005).

Harbor Seals
Harbor seals (*Phoca vitulina*) have suffered a similar decline to that of Steller sea lions, and this decline has occurred in roughly the same time period. The NMFS joined efforts with ADFG, the Alaska Sealife Center and the Alaska Native Harbor Seal Commission to produce a joint research plan (National Marine Fisheries Service et al., 2003) in which harbor seals in different regions of Alaska are surveyed every 5 years. Harbor seals in the Gulf of Alaska were most recently surveyed in 2006. However, stock status reports by NMFS have not been updated since December, 1998, because the geographic boundaries of Alaskan stocks are under consideration (Angliss and Outlaw, 2005). Harbor seals are a vital sign included in the SWAN Monitoring Plan with the plan for NPS to obtain NMFS data specific to NPS park units (Bennett et al., 2006).

Sea Otters
Northern sea otters (*Enhydris lutris kenyoni*) in Southwest Alaska, including the Aleutian Islands, Alaska Peninsula coast, and Kodiak Archipelago, were federally-listed as threatened in 2005 (USFS, 2007). Sea otters along the Alaska Peninsula have also experienced a decline, although populations in the eastern region of the Peninsula may be stable or increasing. Burn and Doroff (2005) repeated a sea otter survey along the Alaska Peninsula (Figure 19) to evaluate changes in the population from 1989 to 2001. Population estimates from 1989 to 2001 from Cape Douglas to Cape Aklek changed from 1.75 to 1.33 otters per km^2 (-24.2%), from Cape Kuyuyukak to Cape Aklek changed from 0.89 to 1.55 otters per km^2 (+72.9%), and from Cape Kuyuyukak to Castle Cape (region encompassing ANIA) changed from 3.94 to 4.06 otters per km^2 (+3.0%) (Figure 20; (Burn and Doroff, 2005). Little quantitative information on sea otter abundance is available specifically for ANIA. Otters were killed by the *Exxon Valdez* oil spill

(EVOS) (Garshelis, 1997), however the impacts on otter populations (Garshelis and Johnson, 2001) and specifically on otters in the ANIA region are uncertain.

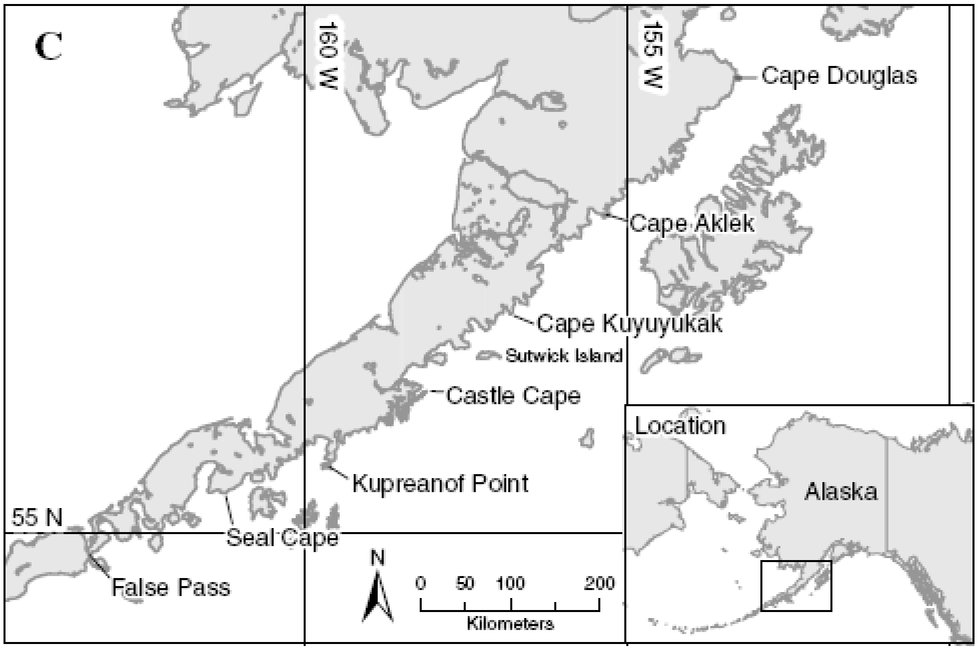

Figure 19. Sea otter survey areas along the Alaska Peninsula coastline (from Burn and Doroff, 2005).

Whales

Several whale species likely occur in waters off the ANIA coast but are not included in the NPSpecies list. The grey whale (*Eschrichtius robustus*) is the only whale present in ANIA according to the NPSpecies list (Lenz et al., 2001).

C2b. Marine fishes

Anadromous and freshwater fish species are extensively addressed in section *III.C.4 a. Freshwater Fishes*. Many species of marine fish likely occur in marine waters off the ANIA coast but are poorly documented. The NPSpecies list includes one species of marine fish that is present or probably present, the starry flounder (*Platichthys stellatus*) (Lenz et al., 2001).

C2c. Marine birds

Seventy-one shorebird species -- 1/3 of the known shorebird species in the world-- occur along coastal Alaska (Andres and Gill, 2000). Much of the marine bird research along the coastline from the past 1-2 decades has been motivated by the EVOS, in which an estimated 300,000 to 645,000 birds were killed (Ford et al., 1996) (see section *V.A.1.a. Oil spills*). Of particular concern, the Steller's Eider (*Polysticta stelleri*) is currently federally-listed as threatened (USFWS, 2007) and is present in ANIA (Lenz et al., 2001).

In an October 2003 pilot study along ANIA and nearby areas (Becharof National Wildlife Refuge (NWR), Alaska Peninsula NWR (Ugashik and park of Chignik Unit), researchers conducted aerial surveys of marine birds and sea mammals at 100 m (328 ft) above the ground and 400 m (1312 ft) from the shore (Savage, 2003). The majority of observed marine birds (for which scientific names, and sometimes common species names, were not given) were gulls (n= 5,109) and the second most abundant were scoters (n = 1,523). Gulls were widely distributed, but the majority was in Wide Bay (approx. 50 km [31 mi] east, up the coast from ANIA). Scoters were most abundant in the northern bays, including Wide Bay, Cape Unalishagvak to Cape Aklek, and Puale Bay. Cormorants (n = 351) were most frequent in Imuya Bay and Wide Bay. Murres (n = 137) were most common in Port Wrangle and Nakalilok Bay. Emperor geese (*Chen canagica*) were observed (n = 365) in Wide Bay and Imuya Bay. Other observed marine bird species were eiders (n = 8), long-tailed ducks (*Clangula hyemalis*; n = 6), loons (n = 23), red-necked grebe (*Podiceps grisegena*; n = 23), bald eagles (*Haliaeetus leucocephalus*; n = 12), and unidentified birds (n = 303). Savage (2003) also includes maps of the distribution of marine bird and sea otter observations.

Further information on marine birds in coastal ANIA and/or coastal areas that are proximal/adjacent to ANIA include: documentation of marine birds along the coastline between Amber and Kamishak Bays in KATM (Bailey and Faust, 1984); a marine bird survey of Becharof National Wildlife Refuge (NWR) (Kaler et al., 2003); specific information on bald eagle distributions along the Alaska Peninsula (Dewhurst, 1991; Savage and Hodges, 2000; Savage et al., 1993); breeding trends and population trends of Alaska marine birds (Dragoo et al., 2000); Harlequin duck (*Histrionicus histrionicus*) population genetics (Lanctot et al., 1999); distribution and abundance of Marbled Murrelets (*Brachyramphus marmoratus*) (Piatt and Ford, 1993); and population status of Kittlitz's Murrelets (*Brachyramphus brevirostris*), a candidate endangered species, along the southern coast of the Alaska Peninsula (Van Pelt and Piatt, 2005).

C2d. Marine intertidal resources

The best recent source of information on marine intertidal resources is derived from a coastal mapping project called ShoreZone, which provides descriptive overviews of the coastal habitat and classifications of the physical and biological attributes of the ANIA coastal environment (Harper, 2004; Morris, 2005). This project aerially surveyed intertidal and shallow subtidal areas of coastal ANIA in the summer of 2003 for the purpose of identifying shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. Eight ground stations in ANIA were visited in 2006 to ground-truth ShoreZone classification and generate a species list (NPS, 2007). This multi-agency funded mapping effort is accessible online through a database with interactive GIS layers, digital maps, aerial images and video of the ANIA coastline. At the Gulf of Alaska Imagery website (http://imf.geocortex.net/mapping/cori/launch.html), one can activate the Aniakchak layer of the map provided and take a virtual flight of coastal ANIA. One can generate maps of substrate types, as well as those of other many other coastal ecological and geological features (e.g. sediment type, splash zone, dune grasses, blue mussels, eelgrass) by turning on various layers available through the internet browser (Figure 20). The shoreline (as a percent of coast mapped) of ANIA is a mix of bedrock (5%), rock and sediment (56%), sediment (25%), and wetland (14%) (Harper, 2004). Supratidal vegetation common in the shoreline are sedges (6%) and dune grasses (67%); whereas subtidal vegetation includes eelgrass (16%) and bull kelp (50%) (Figure 21; (Morris, 2005). More information on the ShoreZone mapping program for coastal Alaska is available at www.coastalaska.net.

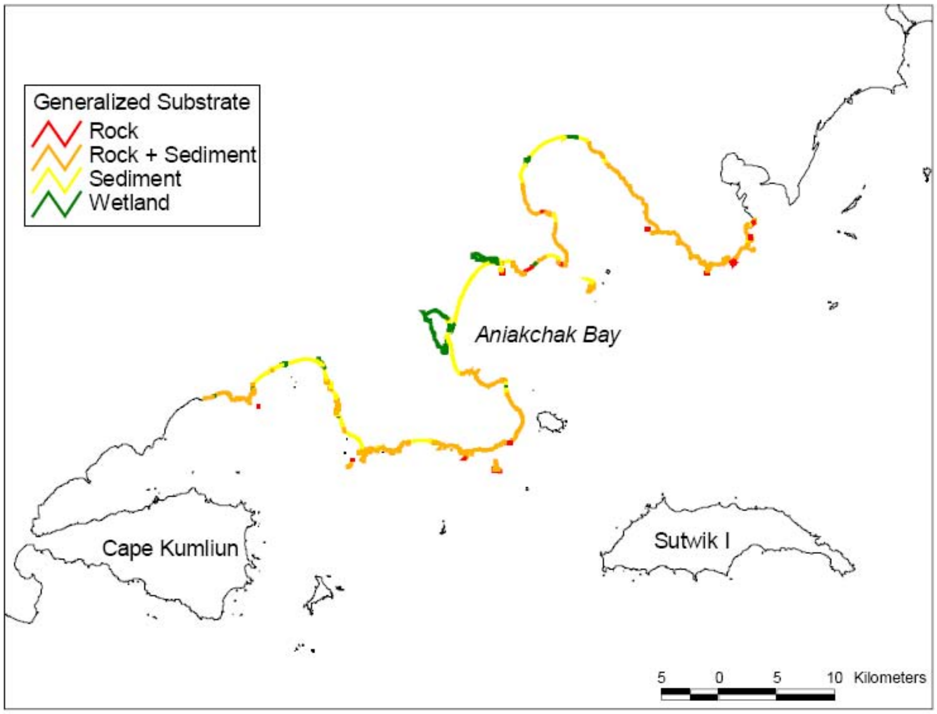

Figure 20: Distribution of general substrate types along the coast of ANIA (Harper, 2004).

Figure 21: Distribution of continuous bull kelp (red) and eelgrass (green) along the coast of ANIA. Figure generated from http://imf.geocortex.net/mapping/cori/launch.html interactive web browser. More information on the data source available at Harper (2004) and Morris (2005).

C3. Upland Resources

C3a. Plants and Forest Types

A 1987 vegetative reconnaissance study in the Aniakchak Caldera identified 138 species of vascular plants, collected 130 types of bryophytes and lichens, and catalogued 14 plant communities living in 11 habitat types within the caldera (Bosworth, 1987). A subsequent study yielded 348 vascular and nonvascular species and 7 vegetation groups within the caldera, as well as provided habitat reference information (Hasselbach, 1995). In all likelihood, the 1931 eruption of Aniakchak decimated all the vegetation within the caldera, and as a result, both the 1987 and 1995 surveys were partly a study of post-volcanic plant succession in the ash-filled caldera (Bosworth, 1987). The inventory of vascular plants performed in ANIA as a whole (not limited to the crater, as were the aforementioned studies) as part of the NPS I&M program identified 472 species in the unit. To the east and south of the Aleutian mountains, including the ANIA areas outside the crater, alpine tundra (including avens, low heath shrubs, prostrate willows, and dwarf herbs) dominates the vegetative landscape (Norris, 1996; NPS, 2006b) . While the slopes of the volcano are mostly barren; forbes, grasses, and sedges grow near creek drainages, and willow and alder occur along the Aniakchak River below its junction with Hidden Creek (NPS, 2006b).

Bosworth (1987) describes the caldera floor substrate as coarse sand or gravel-sized pieces of volcanic ejecta with some areas of larger "pavement" segments, which together make for difficult growing conditions for plants. In a later reconnaissance study of the caldera vegetation, Hasselbach (1995) emphasized the abundance of nitrogen-fixing taxa (representing 73% of the total lichen cover) that may highly facilitate primary succession. Although there are many species of plants in the caldera, vegetation cover there and on other ANIA peaks is generally sparse due to the dry and windy climate and the thick deposits of volcanic ash that blanket the landscape (Norris, 1996; Tande and Michaelson, 2001). There are no trees and relatively few tall shrubs in the caldera (Hasselbach, 1995). Within the caldera, vegetation is concentrated within 50 m (164 ft) of Surprise Lake and its tributaries, as well as the Aniakchak River (Bosworth, 1987; Cameron and Larson, 1992; Hasselbach, 1995). Hasselbach (1995) describes the vegetative communities and soil characteristics in the various portions of the caldera. She notes one ecologically noteworthy feature in the flat, open, apparently barren portions of the mid and upper caldera floor: cryptogamic crusts, which consist of mosses, liverworts, lichens, algae, and fungi and are believed to have important functions in soil development, moisture retention, erosion control, and nutrient enhancement (West, 1990).

Riparian vegetation at Creek 100/Iris Creek and Creek 200/Willow Creek is composed of willows, grasses, and forbes (Miller and Markis, 2004).

C3b. Animal communities

It is interesting to note that the first record of Cretaceous dinosaur tracks in southwest Alaska was recently made in ANIA (Fiorillo and Parrish, 2004). With regard to more recent fauna, a 1987 survey of small mammals in the Aniakchak caldera trapped or observed included artic ground squirrels (*Spermophilus parryii*), tundra voles (*Microtus oeconomus*; the most common mammal in the caldera), brown lemmings (*Lemmus sibiricus*), collared lemmings (*Dicrostonyz nelsoni*); later called a false report by Lenz et al. (2001), meadow jumping mouse (*Zaphus* *hudsonius*), four species of shrew (common shrew: *Sorex cinereus*, dusky shrew: *Sorex monticolus*, water shrew: *Sorex palustris*, and tundra shrew: *Sorex tundrensis*), and a porcupine (*Erethizon dorsatum*) (Jarrell, 1987). Jarrell (1987) notes that while there were no beavers (*Castor canadensis*) in the caldera, beaver lodges were evident in tundra ponds around the crater. Conspicuously absent were northern red-backed voles (*Clethrionomys rutilus*), which are the most ubiquitous rodent in Alaska, but a later survey found the species (Lenz et al., 2001). Jarrell (1987) explains that the small mammals present in the caldera were typical of early successional communities in Alaska, reflecting the recent disturbance by volcanic activity.

Lenz et al. (2001) provide a list of 40 mammal species documented in ANIA as part of the NPS I&M program efforts. Terrestrial mammals include moose (*Alces alces*), caribou (*Rangifer tarandus*), brown bear (*Ursus arctos*), arctic fox (*Alopex lagopus*), coyote (*Canius latrans*), gray wolf (*Canius lupus*), red fox (*Vulpes vulpes*), and lynx (*Lynx Canadensis*). Mustelids such as wolverine (*Gulo gulo*), river otter (*Enhydra lutris*), ermine (*Mustela erminea*), and mink (*Mustela vison*) are also listed. The small mammals identified by Jarrell (1987) are also listed as present or probably present, with addition of the arctic shrew (*Sorex arcticus*), snowshoe hare (*Lepus americanus*), Beringian hare (*Lepus othus*), 2 species of lemming (brown lemmings: *Lemmus sibiricus* and Greenland collared lemmings: *Dicrostonyz groenlandicus*), and the hoary marmot (*Marmota caligata*).

C4. Freshwater Resources

C4a. Fishes

The first major investigation of fisheries in ANIA was conducted in 1987 and 1988 (Mahoney and Sonnevil, 1991). Hamon (2000) conducted another fisheries study in the area, with a focus on sockeye salmon. As part of the SWAN I&M program, Lenz et al (2001) developed a fish species list for ANIA. Finally, the Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes (Johnson and Weiss, 2006) provides information on species presence in specific streams in ANIA. Each of these sources of information is described more in detail below.

The Mahoney and Sonnevil (1991) fisheries investigation included a major physical and hydrologic component and is referred to in several other sections in this report. In their investigations of Surprise Lake and its major tributaries, the Aniakchak River mainstem, Albert Johnson Creek, and the North Fork of the Aniakchak, Mahoney and Sonnevil (1991) documented the presence of a variety of freshwater and anadromous fish. In Surprise Lake and two of its main tributaries they found Dolly Varden (*Salvelinus malma*) and sockeye salmon. In Albert Johnson Creek and the North Fork Aniakchak River, they identified the presence of chum salmon (*Oncorhynchu keta*), coho salmon (*Oncorhynchu kisutch*), pink salmon (*Oncorhynchu gorbuscha*), sockeye salmon, Dolly Varden, and threespine stickleback (*Gasterosteus aculeatus*). They also noted that species diversity in these tributaries to the Aniakchak River was higher than within Surprise Lake. The authors also provide information on the ages and sizes of captured fishes.

Hamon (2000) studied the Aniakchak River watershed to document spawning populations and habitats, conduct morphological and habitat measurements, and obtain salmon genetic samples to compare with other southwest Alaska populations (Hamon, 2000). Of particular interest was the likelihood that ANIA's sockeye salmon population is one of the youngest on the Peninsula, where most runs are >10,000 years old. Hamon (2000) argued that the Surprise Lake/Aniakchak River's sockeye population cannot be more than ~3400 years old -- the earliest potential date of the formation of the Aniakchak River following the great outburst flood of the ancestral caldera lake (Waythomas et al., 1996). Furthermore, if the 1931 Aniakchak eruption completely wiped out the population in the watershed, the sockeye population may be only ~70 years old (Hamon, 2000). The discussion by Hamon (2000) emphasizes the importance of salmon colonization to biological succession within the watershed, because salmon contribute to the nutrient budgets of riparian ecosystems and serve as primary food sources for a wide variety of vertebrates.

Hamon (2000) focused on fish samples taken from the north shore of Surprise Lake, the outlet of Surprise Lake, and from Albert Johnson Creek. The report provides detailed information on the numbers, sex, spawning condition, body shape, body size, locations and habitat descriptions within the watershed (physical habitat is discussed in section *III A. 3. Streams and streamflow*.) Sockeye salmon generally avoid habitats with low or no dissolved oxygen, although for reasons that are not clear, they did not utilize putatively suitable habitat during the study period. Although the study focused on sockeye salmon, Hamon (2000) noted that other species captured included Dolly Varden in Surprise Lake and Albert Johnson Creek, and pink salmon, chum salmon and one king salmon (*Oncorhynchu tshawytscha*) in Albert Johnson Creek. The king salmon record was the first report of the species in the Aniakchak River drainage.

According to the fish species list developed by the SWAN I&M program, within ANIA there are 16 confirmed or probably present species and 3 unconfirmed species (*Alosa sapidissima, Rasbora heteromorpha, and Cottus aleuticus*) (Table 7) (Lenz et al., 2001). Two of the "probably present" and one of the "unconfirmed" fish listings in Lenz et al. (2001) were confirmed by Miller and Markis (2004). This most recently published study regarding fisheries in ANIA was undertaken with the goals of documenting fishes that were expected yet undocumented within ANIA, as well as provide descriptions of fish distributions, abundance, and biological characteristics. The study took place in August 2002 and July 2003 and included Surprise Lake, Aniakchak River, and Albert Johnson Creek, and two Pacific coastal streams ("Creek 100", called "Iris Creek" by some NPS researchers, and "Creek 200", also known as "Willow Creek"), Meshik Lake, and Meshik River. Of the eight expected yet undocumented species, three were captured: Alaska blackfish (*Dallia pectoralis*), coastrange sculpin (*Cottus aleuticus*), and ninespine stickleback (*Pungitius pungitius*). The single Alaska blackfish was found in the Meshik River (which drains to the Bering Sea); the coastrange sculpin were found in the Aniakchak River, Creek 100/Iris Creek, and Creek 200/Willow Creek; and the ninespine sticklebacks were found in Albert Johnson Creek, the Aniakchak River, Meshik Lake, and the Meshik River (Miller and Markis, 2004). The Aniakchak River had the highest relative species diversity, with 9 species, and Surprise Lake had the lowest, with only 2 species present. Miller and Markis (2004) provide information on relative abundance, length frequencies, and catch per unit of effort (CPUE) for all documented species in their sampling region.

Troy Hamon (NPS-King Salmon, personal communication, 2005) describes Albert Johnson Creek and the Northfork Aniakchak River as clearwater streams with abundant sockeye (Albert Johnson Cr.), chum, and pink salmon (Northfork), while other creeks in the area are generally turbid (Figure 22). Hidden Creek is another clearwater stream, but it contains no salmon, and Mystery Creek has chum salmon only at its mouth (Troy Hamon, NPS-King Salmon, personal communication, 2005).

Table 7. Anadromous and freshwater fishes that are present or probably present in ANIA from the NPSpecies list (Lenz et al., 2001) or confirmed by Miller and Markis (2004). Confirmed species are given a (*) following their common name. Alaska blackfish are confirmed, but only in the Meshik River drainage.

Family	Species Name	Common Name
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback*
Gasterosteidae	*Pungitius pungitius*	Ninespine stickleback*
Osmeridae	*Thaleichthys pacificus*	Eulachon
Petromyzontidae	*Lampetra japonica*	Arctic lamprey
Petromyzontidae	*Lampetra tridentata*	Pacific lamprey
Salmonidae	*Oncorhynchus gorbuscha*	Pink salmon*
Salmonidae	*Oncorhynchus keta*	Chum salmon*
Salmonidae	*Oncorhynchus kisutch*	Coho salmon*
Salmonidae	*Oncorhynchus nerka*	Sockeye salmon*
Salmonidae	*Oncorhynchus tshawytscha*	Chinook salmon*
Salmonidae	*Salvelinus malma*	Dolly varden*
Catostomidae	*Catostomus catostomus*	Longnose sucker
Cottidae	*Cottus aleuticus*	Coastrange sculpin*
Salmonidae	*Prosopium cylindraceum*	Round whitefish
Salmonidae	*Thymallus arcticus*	Arctic grayling
Umbridae	*Dallia pectoralis*	Alaska blackfish*

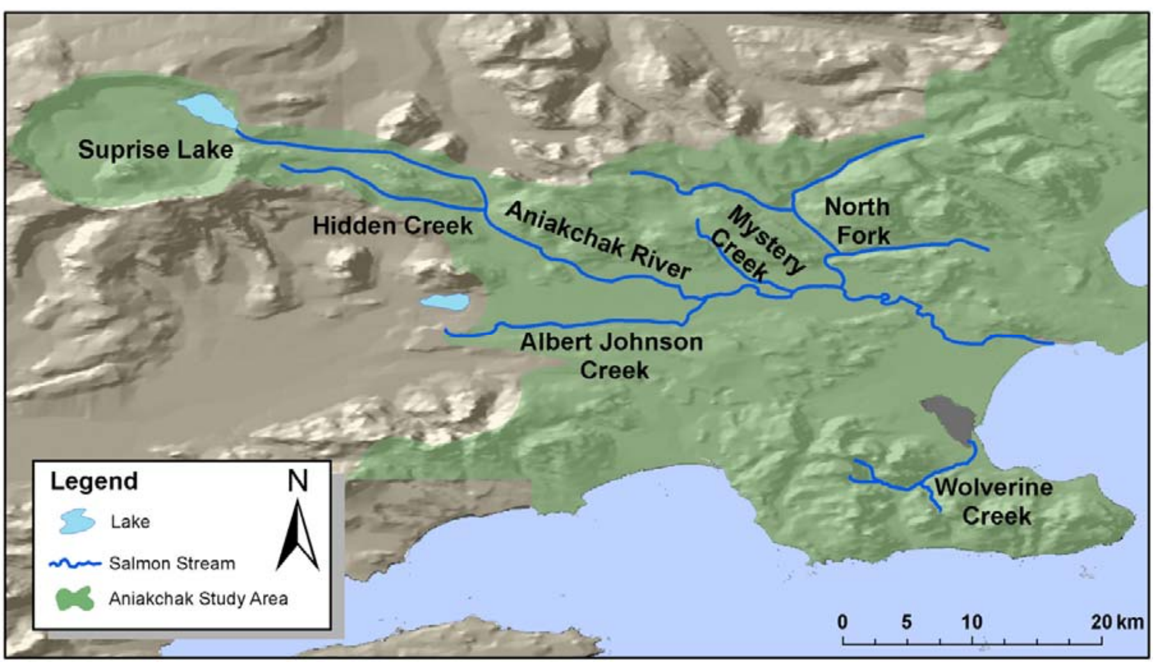

Figure 22: Main anadromous fish streams in ANIA coastal study area.

The Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes (Johnson and Weiss, 2006) is regularly updated by the Alaska Department of Fish and Game and provides information about the presence and types of anadromous fishes in streams of Alaska. According to this Anadromous Water Catalog (AWC), fish species that occur in the main coastal ANIA streams are:

- Albert Johnson Creek: sockeye and chum salmon
- Aniakchak River: sockeye, coho, pink, and chum salmon
- Mystery Creek: chum salmon
- Surprise Lake: sockeye salmon
- North Fork Aniakchak River: pink and chum salmon
- Wolverine Creek: coho, pink, and chum salmon

The AWC also provides information about the presence of non-anadromous species in numerous other streams in ANIA. Most streams are unnamed but are identified by way of a cataloged numbering system and by geographic location (latitude and longitude, USGS quad map name).

The maintenance of healthy salmon stocks and natural fish passage in coastal streams and rivers in ANIA is important not only for fisheries resources but also because spawning salmonids have significant impacts on biological resources in both terrestrial and freshwater aquatic ecosystems (see Gende et al., 2002 for a review). When salmon return to their natal streams to spawn, they transport nutrients from marine ecosystems and their carcasses release large quantities of these “marine-derived nutrients” to freshwater and terrestrial ecosystems (Cederholm et al., 1999; Johnston et al., 2004; Willson et al., 1998). Salmon affect the ecology of consumers at many trophic levels and have widespread effects on the food webs of coastal watersheds (Cederholm et al., 1999; Gende et al., 2002). The organic and inorganic nutrients (carbon, nitrogen, and phosphorus) released by spawning salmon are important to the overall health of these watersheds (Bryant and Everest, 1998) and can also strongly affect productivity in coastal streams (Chaloner and Wipfli, 2002; Wipfli et al., 1998). In particular, the seasonal pulse of salmon carcasses can dramatically elevate streamwater levels of limiting nutrients such as nitrogen and phosphorus (Mitchell and Lamberti, 2005) and thereby increase primary and secondary productivity in receiving streams. In addition, carcasses that end up in the terrestrial portions of riparian zones as a result of changes in stream discharge and transport by vertebrates provide a substantial input of nutrients, such as nitrogen and phosphorus, to riparian soils (Gende et al., 2002). These nutrients can be rapidly assimilated by microbial communities and vegetation in the riparian environment (Bilby et al., 1996) and putatively increase the growth rate of trees in the riparian forest (Helfield and Naiman, 2001). The ecological importance of salmon in coastal ecosystems suggests that fisheries management decisions related to salmon populations and salmon returns have the potential to affect biological resources within ANIA. To our knowledge, no research has been done within ANIA on the ecosystem function of salmon-derived nutrients. Although studies on this subject have been conducted elsewhere in southwestern Alaska, these studies may not be directly applicable to ANIA because the relative importance of salmon-derived nutrients to watershed nutrient stocks and productivity varies by location.

C4b. Amphibians

Although there are no published surveys of amphibians nor documented records of amphibians in ANIA, it is likely that the wood frog (*Rana sylvatica*) inhabits the park (S. Pyare, pers. comm., 2007). This freeze tolerant species, which is observed elsewhere on the Alaska peninsula and occurs as far as the north side of the Brooks Range, inhabits a wide variety of forest, muskeg, and tundra habitats, sometimes far from water (Hodge, 1976). An opportunistic, volunteer-based survey of amphibians in KATM and LACL, which are 155 and 350 km (96.3 and 218 mi) of ANIA, respectively, confirmed the presence of wood frogs at those NPS units (Anderson, 2004).

C4c. Aquatic invertebrates, chlorophyll, phytoplankton, and zooplankton

There are no known investigations of macroinvertebrates, plankton, or chlorophyll in any part of ANIA other than in the caldera, where Cameron and Larson (1992, 1993) conducted extensive studies. Cameron and Larson (1992) reported that 38 benthic invertebrate taxa were collected in August, 1988 from the inlet stream of Surprise Lake. The majority (30) were insect taxa (mainly chironomids, baetids, and trichopterans), and there were no reported gastropods (snails) or pelecypods (clams). Detailed classifications of the organisms, sample-site location information, and habitat descriptions of the source areas of the samples are provided in the report. All non-insect benthic invertebrate taxa found in the inlet streams were also present in Surprise Lake, although the lake also contained shaeriids (clams). In Surprise Lake, there was a lower diversity of benthic invertebrates, composed of 15 taxa (of which only five were insect taxa) (Cameron and Larson, 1992). Benthic invertebrate communities varied according to their proximity to cold or warm springs, offshore or nearshore location, and lake depth. Nearshore groups near warm springs were dominated by oligochaetes; those near cold springs were composed primarily of *Stictochironomus* and oligochaetes. Those at mid-depths were mainly sphaeriids and oligochaetes, while those in deep water were mostly sphaeriids and chironomid pupae.

Cameron and Larson (1992,1993) also surveyed pelagic phytoplankton, benthic algae (periphyton), and zooplankton communities in Surprise Lake during the summers of 1988 and 1989. They found that total chlorophyll concentrations (a proxy for phytoplankton biomass) increased with water clarity and with proximity to the sources of warm spring inflows. Twenty-two taxa (mainly cyanobacteria) dominated the phytoplankton community and are listed in Table 4 of (Cameron and Larson, 1993)). Periphyton communities also colonized and grew faster near sources of warm spring inflows. The authors provided thorough descriptions and classification of the twelve taxa of zooplankton present in Surprise Lake, of which *Polyarthra* sp. and *Bosmina* sp. were the most abundant (Cameron and Larson, 1993). Benthic macroinvertebrate surveys were conducted at various surficial locations as well as various depths of Surprise Lake, and as a result, the researchers described differences in organismal abundance and diversity with both spatial variation and with lake depth. Cameron and Larson (1992) also sampled “Turbid Lake” and “Snowmelt Pond” -- the two smaller lakes within the crater -- and made some comparisons with Surprise Lake and with lakes in nearby KATM. They found that poor light penetration into Turbid Lake accounted for the lack of any measurable growth of surface phytoplankton. Snowmelt Pond, with its high degree of clarity, contained a relatively high number of phytoplankton taxa compared with Surprise Lake and five lakes in KATM. Surprise Lake had relatively high density and numbers of zooplankton taxa, which is indicative of higher levels of pelagic productivity. In contrast, Turbid Lake and Snowmelt Pond had lower densities, probably due to their low total chlorophyll concentrations and associated harsh physical environments.

IV. Water Resources Assessment

A. Water Quality

A1. Intertidal and Marine

A1a. EMAP in southcentral and southwestern Alaska

Water, sediment, and biologic quality in marine waters were surveyed in 2002 by the Environmental Monitoring and Assessment Program (EMAP, information available at: http://www.dec.state.ak.us/water/wqamp/emap.htm). Under this program, administered by the Alaska Department of Environmental Conservation, samples were collected at 55 sites (3-352 m [10-1150 ft] depth) located throughout southcentral and southwest Alaska. Sites were located in Prince William Sound, Cook Inlet, Shelikof Strait, and Alaska Peninsula. The two closest sites (No. 70, 71) were located ~100-200 km (60-120 mi) west of the ANIA coast, and four more were located further west to the tip of the Alaska Peninsula (Figure 23). Sampled parameters, some of which were measured continuously and others discretely, included: water (nutrients, chlorophyll a, and total suspended solids), sediment (organic compounds, inorganic contaminants, total organic carbon, grain size, toxicity), and biota (benthos, fish contaminants, histopathy specimens). Ecological indicators of habitat included: dissolved oxygen concentration, salinity, water depth, pH, water temperature, total suspended solids, chlorophyll a concentration, transmittance, secchi depth, percent silt-clay of sediments, nutrient concentrations (nitrates, nitrites, ammonia, and phosphate), and percent total organic carbon in sediment. Benthic condition indicators included: infaunal species composition, infaunal abundance, infaunal species richness and diversity, fish species composition, fish abundance, fish species richness and diversity, and external pathological anomalies in fish. Exposure indicators were sediment and fish-tissue contaminants and sediment toxicity.

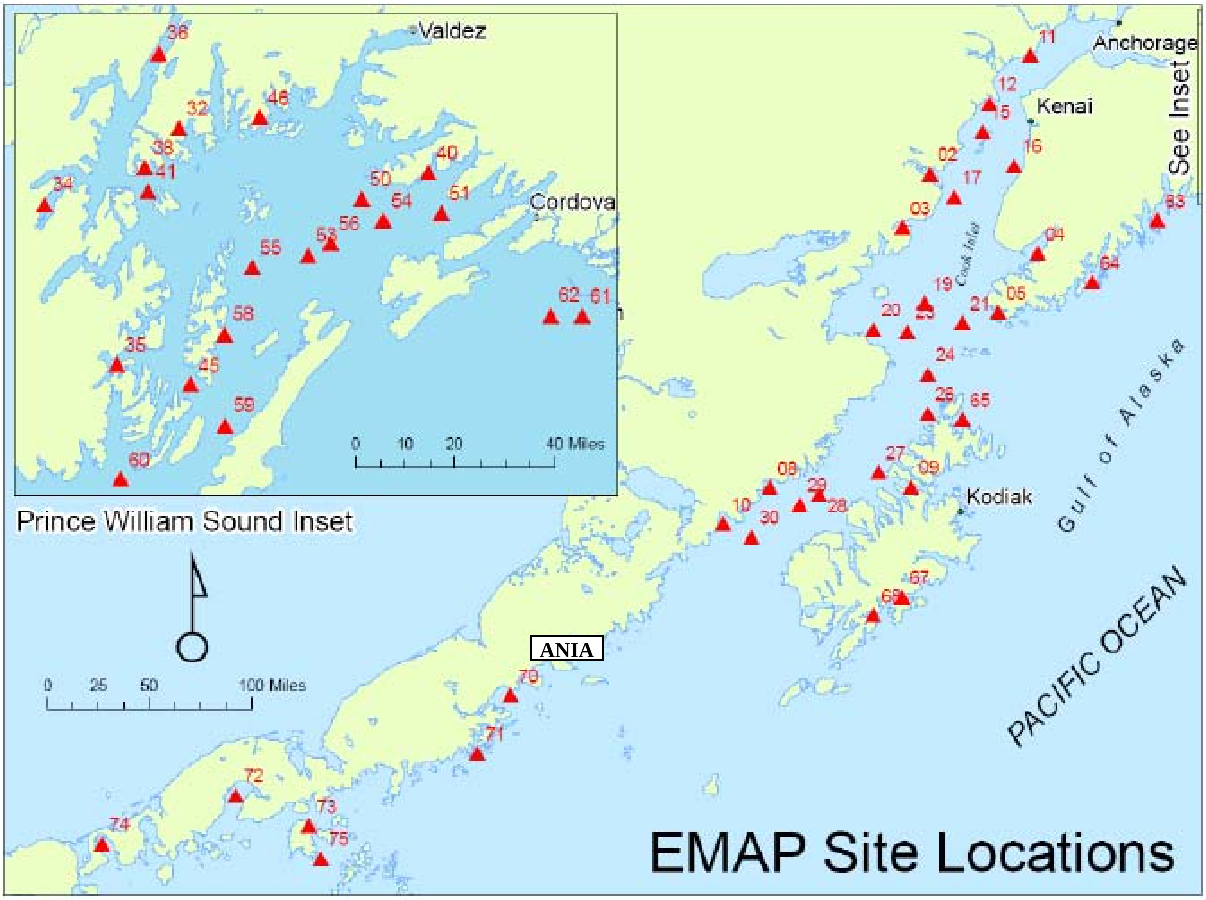

Figure 23: Sites sampled by EMAP in southcentral Alaska in 2002 (Saupe et al., 2005). The two-digit numbers reflect the last two numbers of each station. Prince William Sound is an inset.

Results from this sampling effort comprise the most comprehensive dataset available on the physical and biological conditions in the coastal waters of southcentral and southwestern Alaska (Saupe et al., 2005). Overall, water quality conditions in the region met were very good. For example, 100% of the study area met Alaska water quality standards for dissolved oxygen for all marine water uses. Water clarity (measured by Secchi depth and total suspended solids) indicated high light transmittance except for in areas near inputs of glacial rivers, which contribute massive volumes of glacial flour. Surface and bottom chlorophyll-a concentrations, which are useful indicators of eutrophication, were less than the NOAA threshold value (Bricker et al., 1999) of 5 μg/L (for low-eutrophication) at 100% of the study area. Although measured only once at each station, dissolved nitrogen nutrients (nitrate-N, nitrite-N, and ammonium), which may vary significantly over short time scales, were below the NOAA threshold value (Bricker et al., 1999) of 1.0 mg/L for nitrate-N and nitrite-N (no State of Alaska or national EPA standards exist for coastal waters for nitrate-N and nitrite-N), and far below both the acute and chronic Alaska water quality standards for ammonium at all sample sites. Except for one outlier, identified as likely due to contamination, all phosphate-P concentrations fell below the NOAA threshold value of 0.1 mg/L (Bricker et al., 1999). Ninety five percent of the study area had sediment total organic carbon concentrations that were between 0.5 and 3%; concentrations lower and higher than this range have been linked with adverse effects on benthic communities (Hyland et al., 2005).

In terms of contaminants, the EMAP project also found minimal evidence that levels were of concern (Saupe et al., 2005). The EMAP project tested for 25 polycyclic aromatic hydrocarbons (PAHs), 21 polychlorinated biphenyls (PCBs), DDTs and 13 other chlorinated pesticides, and 15 metals in fish and sediment tissues. Sediment data were compared to sediment quality guidelines (SQGs) developed by NOAA's National Status and Trends (NS&T) Program (Long et al., 1995) and to Washington State Sediment Quality Standards. The concentrations of metals (*Ag, Al, Cd, Cr, Cu, Hg, Fe, Pb, Mn, Ni, Se, Sb, Sn, Zn*) and arsenic in the sediments collected closest to the coast were all of acceptable quality, and almost all samples from the EMAP southcentral region were acceptable as well. Saupe et al. (2005) provide detailed graphical and tabular presentations of the metal concentrations in the samples distributed across the sampling area.

Sediment hydrocarbon concentrations were also generally low and within acceptable levels based on existing but relatively crude standards (Figure 24) (Saupe et al., 2005). High concentrations indicate natural sources (e.g. oil seeps, eroded source petroleum sedimentary rock, coal, terrestrial and marine plants and animals, peat, and forest fire deposits) and/or anthropogenic sources (e.g. petroleum industry discharges, municipal wastewater treatment discharges, non-point source runoff from urban zones, small spills from marine vessels, and large-scale spills such as the 1989 EVOS). Total PAH concentrations were below, and 90% were one order of magnitude below, the Effects Range Low (ERL) of 4020 ng/g for 100% of samples in the study region (Long et al., 1995). Not all PAH analyses have associated ERL and ERM (effects range median) values; however, for those with such standards, none exceeded the ERM's.

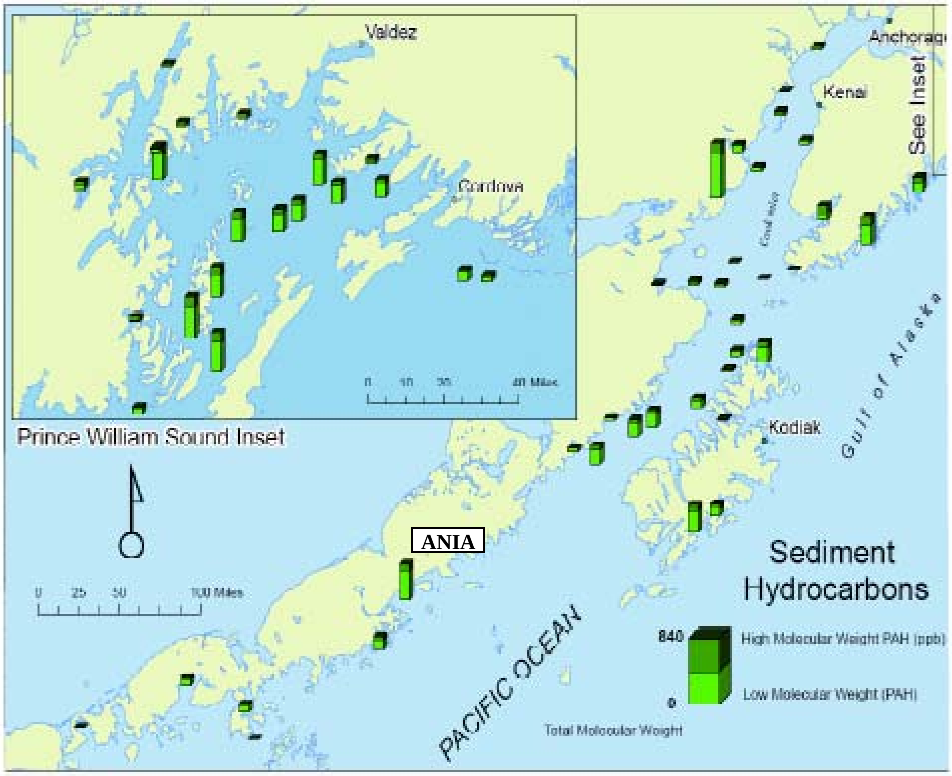

Figure 24: Sediment polynuclear aromatic hydrocarbon (PAH) concentrations (μg/g) at sampled stations across the EMAP study area, with low and high molecular weight PAH's shown as a fraction of total PAH. From Saupe et al. (2005).

No detections were found in sediments for the persistent organic pollutants analyzed in the EMAP study (Saupe et al., 2005). Sediment toxicity tests (bioassays based on a 10-day *Ampelisca abdita* amphipod survival test) showed only two stations (1.1% of the study area) with amphipod survival rates of < 80%, and these were not in the ANIA coastal vicinity. Additionally, Saupe et al. (2005) provide detailed data on benthic community taxa richness, diversity, and abundance. Fish tissue analyses (95 samples from the 55 stations) of metals and organic pollutants showed that 100% of samples fell below the U.S. EPA's Risk Guidelines for Recreational Fishermen and also below the U.S. Food and Drug Administration's "Action Limits" for commercial fish.

A1b. SWAN I&M nearshore marine monitoring

At the core of the I&M program is the selection of a suite of vital signs (Appendix A) that were chosen based on ecological significance and relevance to SWAN resource management issues(Bennett et al., 2006). According to Bennett et al. (2006), protocols for the monitoring of vital signs associated with the marine nearshore, which includes marine water chemistry, kelp and eelgrass, marine intertidal invertebrates, seabirds, and sea otters, are not planned for implementation at ANIA. More information on the vital signs monitoring plan is provided in

Bennett et al. (2006) and at the SWAN I&M website: http://www.nature.nps.gov/im/units/swan/index.cfm?theme=Overview.

A2. Streams and lakes

A2a. Overview of SWAN water quality component of I&M program

Several vital signs were selected for the SWAN I&M program that are directly related to freshwater resources, including: surface water hydrology, freshwater chemistry, and landscape processes such as snow cover, lake and coastal ice, and suspended sediments (Bennett et al., 2006). The design components of water-quality monitoring are fully integrated into the SWAN Vital Signs Monitoring Program (Bennett et al., 2006). To provide specialized guidance on the water-quality monitoring component, a cooperative project was established between the NPS, SWAN, and University of Washington School of Aquatic and Fishery Sciences (O'Keefe and Naiman, 2004). This collaborative effort resulted in an annotated bibliography of past and present freshwater research and monitoring in southwestern Alaska, as well as summarized existing knowledge and identified ongoing data collection efforts that are relevant to aquatic monitoring in SWAN (O'Keefe, 2005). Results of the water-quality monitoring project review found no 303(d) waters present within ANIA (or any other SWAN unit), and concluded that although water-quality collection has been sporadic, conditions appear to be generally good with low nutrient levels and little evidence of anthropogenic impacts (Bennett et al., 2006).

The project developed a strategy for long-term monitoring of freshwater aquatic resources within the SWAN units. Streams and lakes were categorized into 3 tiers using a ranking procedure that incorporated accessibility, level of use/management issues, and ecological and spatial cover(Bennett et al., 2006). Tier 1 lakes and streams are of the highest priority, have the easiest access, are heavily used by visitors, are of greatest management concern, and will be monitored annually. Tier 2 lakes and streams are of medium priority, less accessible, and will be randomly subsampled for less frequent monitoring (every 2-5 years). Finally, Tier 3 lakes and streams (low priority) will be sampled every ~10 years, if at all (depending on funding constraints), for the purpose of expanding the scale of inference of Tier 1 and 2 waterbodies. Vital sign metrics at Tier 2 and 3 waterbodies may also be collected by seasonal park staff on an opportunistic basis. The monitoring design for surface hydrology and freshwater chemistry calls for Tier 2 and 3 lakes and streams to be stratified by lake size, water type (clear, glacial, brown), and accessibility prior to selection using a GRTS design (Bennett et al., 2006; Stevens and Olsen, 2004). In the coastal ANIA area, no waterbodies were identified as Tier 1, and the Aniakchak River drainage, including Surprise Lake, was designated as Tier 2. No ANIA waterbodies were categorized as Tier 3 (Figure 25).

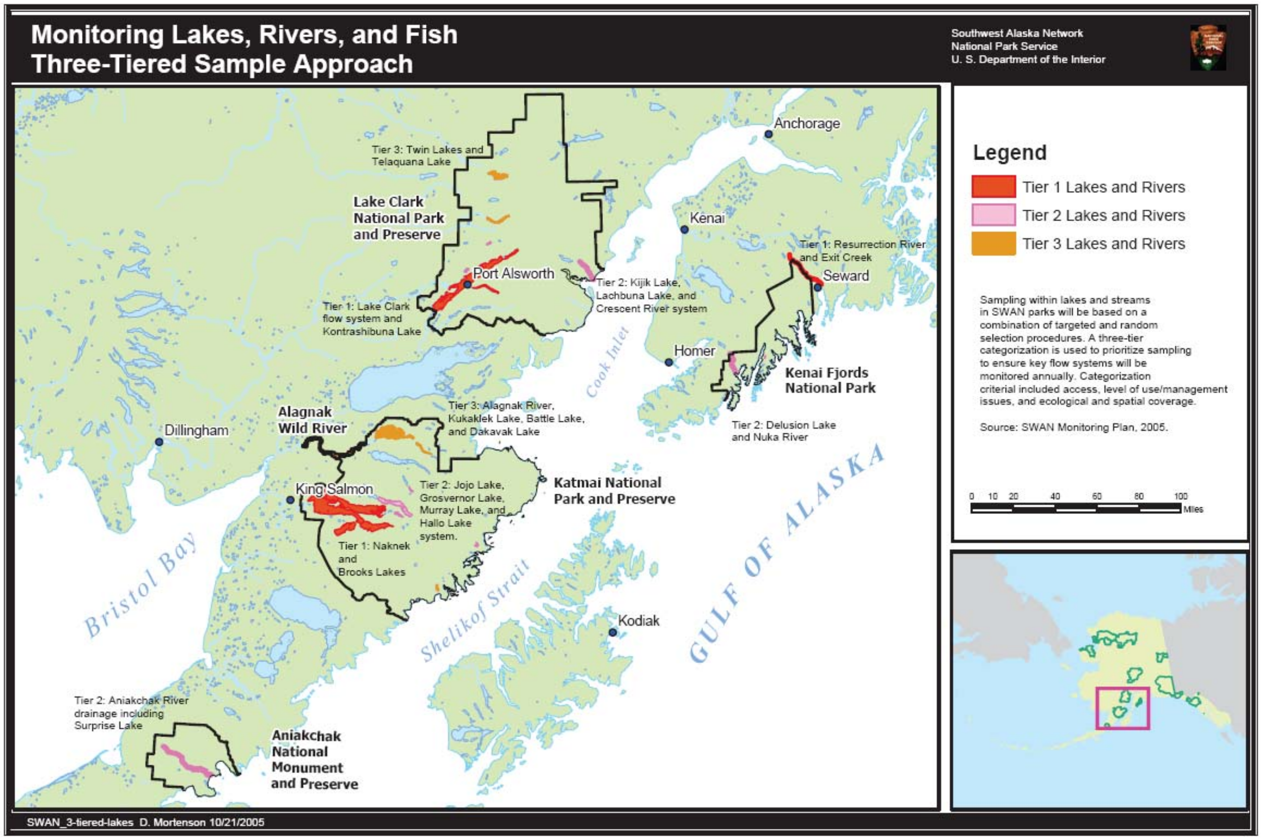

Figure 25: List and locations of proposed Tier 1, 2, and 3 lakes and rivers for monitoring aquatic resources in SWAN units. Along the ANIA coast, the Aniakchak River drainage, including Surprise Lake, is ranked as Tier 2 (Bennett et al., 2006).

A2b. Water quality of streams and lakes

Almost all information on freshwater quality within ANIA comes from studies of Surprise Lake and the Aniakchak River. Some information is available on the inlet streams to Surprise Lake, tributaries to the Aniakchak River, and 2 other coastal streams. Reports that include or focus on water quality in coastal ANIA are: Mahoney and Sonnevil (1991), Cameron and Larson (1993), Bennett (2004), O'Keefe and Naiman (2004), and O'Keefe (2005). Bennett (2004) provides the most recent water quality data for ANIA, with results for Surprise Lake, "Turbid Creek" (a tributary to Surprise Lake), the Aniakchak River, Albert Johnson Creek, Northfork Aniakchak River, and Meshik Lake.

A2b 1) Surprise Lake inlet streams

As part of their fisheries investigation of Surprise Lake and the Aniakchak River, Mahoney and Sonnevil (1991) sampled four inlet streams ("Tribuaries 1-4") to Surprise Lake in July 1987. It was observed that Tributary 2 originated from iron-soda springs, and as would be expected of a spring arising from active volcanic material that likely contains sulfuric acid, and it had warm temperatures, high conductivity, low dissolved oxygen, and slightly lower pH (Table 8).

Table 8. Water quality measurements of tributaries to Surprise Lake and Aniakchak River, July 1987 (Mahoney and Sonnevil, 1991)

Sampling site	Conductivity *(mS/cm)*	Dissolved oxygen *(mg/L)*	pH *(units)*	Temperature *(ºC)*
Trib. 1				
Site 1	101	10.8	6.8	11.4
Site 2	289	10.4	6.15	9.8
Site 3	288	10.5	6.20	8.9
Trib. 2 (Warm springs)	901	2.5	5.25	19.4
Trib. 3	58	12.7	7.9	4.4
Trib. 4 (Waterfall Cr.)	43	13.4	7.45	2.4

In a more detailed study one year later, Cameron and Larson (1993) provided major and trace-element concentration data in addition to standard water-quality parameters for Surprise Lake's 11 inlet streams and one warm spring. Specifically, their report provided data on pH, dissolved oxygen, hardness, alkalinity, conductance, temperature, nitrate + nitrite, ammonia + ammonium, total nitrogen, total filterable phosphorus, and total phosphorus, as well as concentrations of *Ca, Mg, K, Na, S, Si, Fe, Mn, B, Cu*, and *Sr* (Table 10). They found that hydrothermal inputs generally influenced the inlet streams by increasing temperature, conductivity, total alkalinity, hardness, and trace element concentrations, and by lowering pH and dissolved oxygen. Nutrient concentrations were not clearly associated with hydrothermal inputs, but dissolved nitrogen tended to be in the form of ammonia in the warm spring and inlet 11, which was clearly influenced by hydrothermal inputs, and in the form of nitrate in the cold inlets. Conductivity, temperature, pH, and dissolved oxygen generally matched those of Mahoney and Sonnevil (1991).

During the most recent published survey (June and July 2003) of water quality in ANIA, the highest water temperature (20.16-20.39 ˚C, 68.23-68.70 ˚F) and highest specific conductance (734-988 µs/cm) in the Aniakchak drainage was recorded in a warm springs tributary ("WS-4") to Surprise Lake (Bennett, 2004). This and another warm-springs influenced tributary to Surprise Lake were the only streams in coastal ANIA that had low dissolved oxygen levels [0.86 mg/L (9.6%) and 6 mg/L (55%)] and acidic pH values (5.83-6.69). Another tributary, named "Turbid Creek", which drains the southeast section of the Aniakchak caldera, had the lowest temperature in the water-quality survey, with a value of 2.96 ˚C (37.3 ˚F) (Bennett, 2004). Based on a single sample, it also had a slightly high *Al* concentration value (See Water Quality Stressors section below).

A2b 2) Surprise Lake

Three separate studies have evaluated the water chemistry of Surprise Lake: Mahoney and Sonnevil (1991), Cameron and Larson (1993), and Bennett (2004). Mahoney and Sonnevil (1991) sampled Surprise Lake at six locations of various depths during July 1987. Results indicated that conductivity was 369-489 µS/cm; dissolved oxygen was 8.5-10.4 mg/L; temperature was 9.4-12.6 ˚C (49-55 ˚F); and pH was near neutral at 6.2-6.8. Secchi disk readings indicated that visibility extended to 1.4-2.4 m (4.6-7.9 ft) below the water surface (Mahoney and Sonnevil, 1991).

Table 9. Water depth, depth of measurement, and water quality parameters for six sampling locations in Surprise Lake, 26 July 1987 (Mahoney and Sonnevil, 1991).

	Surprise Lake sampling location (A-F)					
Parameter	A	B	C	D	E	F
Total depth (m)	13.7	18.6	1.8	1.4	15.9	2.0
Depth of measurement (m)	10.0	16.0	1.4	0.9	10.0	1.8
Secchi disk (m)	2.6	2.9	1.7	1.4	2.3	2.0
Conductivity (μs/cm)	394	390	489	369	390	386
Dissolved oxygen (mg/l)	10.4	10.1	8.5	9.7	10.2	10.4
pH	6.8	6.8	6.2	6.7	6.8	6.7
Temperature (˚C)	10.0	9.4	12.6	10.1	9.6	11.4

On the same day as making the lake measurements presented in Table 9, Mahoney and Sonnevil (1991) also took a vertical-profile measurement (10 readings at approximately 2 m [7 ft] intervals to a max depth of 19.0 m [62.3 ft]) from the northeast section of Surprise Lake. Conductivity, dissolved oxygen, pH, and temperature measurements were generally within the same range of values as those from the six sites at various locations and depths of the lake and varied little with depth: conductivity was between 387-394 μS/cm; dissolved oxygen was 8.7-10.4 mg/L; pH values were between 6.9 and 7.2 units; and temperature declined only slightly with depth, from 11.1 ˚C (52.0 ˚F) at 0.2 m (0.7 ft) to 9.1 ˚C (48 ˚F) at 19.0 m (62.3 ft). These results indicate a fairly well-mixed lake at the time of sampling.

One year later (June-August 1988), additional water-quality depth profiles (up to 19 m [62 ft]) were conducted 5-7 times at four sites on Surprise Lake (Cameron and Larson, 1993). Results of the depth profiles at each station on each sampling date are graphically presented in Cameron and Larson (1993). Water-quality profiles varied slightly among stations, generally according to their proximity to hydrothermal inputs. Again, the water column did not develop an epilimnion, but there was typically a slight (1-5 ˚C, 2-9 ˚F) decrease in temperature with depth. Except for near the littoral zone, lake temperature was driven primarily by climate, and the frequent strong winds encouraged mixing of the lake and hampered the formation of a thermocline. pH was 6.0-6.7 at the surface and increased to 7.2 with depth. Conductivity also showed little variation with depth, although it was slightly elevated (to as much as 570 μS/cm) at the surface of one of the stations near a warm spring inlet. Dissolved oxygen levels decreased with depth on all sampling dates, with all values within a range of 85-110% saturation. One exception was again at the site near a warm spring inlet; here the dissolved oxygen level near the surface was relatively low, at about 80% saturation. Trace element concentrations in the lake were similar to those of the inlet streams moderately influenced by hydrothermal inputs (Table 10). Nutrients in the lake's near-surface waters were not associated with warm spring inputs, except for total phosphorus (TP) and total filterable phosphorus (TFP). TP was highest near a warm spring inlet, while TFP decreased with increasing proximity to warm spring inflows.

Table 10. Late July and August (1988-1989) concentrations of major and trace elements of inlet streams, warm spring 14 (at the point of entry to Surprise Lake), and at stations within Surprise Lake (Warm spring stations WS1 and WS2, reference station RS1, and mid-lake station (ML1). From tables 2 and 3 in Cameron and Larson (1993).

		Inlet streams-->					Warm spring
Parameter	Units	I1-I4	I8	I9	I10	I11	WS14
Ca	mg/l	2.67-3.54	6.9	7.87	17.23-38.18	42.22-54.48	100.55
Mg	mg/l	0.40-1.76	3.67	4.45	8.65-19.47	30.96-41.25	118.07
K	mg/l	BD-1.43	1.56	1.96	4.04-7.16	10.49-11.56	12.36
Na	mg/l	4.86-10.04	14.22	12.29	32.15-64.31	110.18-130.25	207.48
S	mg/l	0.94-1.94	0.75	1.41	3.26-7.48	7.67-10.20	65.05
Si	mg/l	3.35-12.83	10.6	13.8	10.92-27.66	8.61-15.80	25.74
Fe	μg/l	BD	BD	BD	BD	60-166	46
Mn	μg/l	BD	9	14	54-97	435-534	1249
B	mg/l	BD-0.04	0.06	0.19	0.86-1.87	4.25-5.4	2.58
Cu	mg/l	BD	BD	BD	BD	BD	BD
Sr	μg/l	BD-17	15	27	39-140	166-193	309
		Surprise Lake-->					
		WS1	WS2	ML1-1 m	ML1-14m	RS1	
Ca	mg/l	10.0-27.3	15.0-21.4	8.8-22.7	12.7-29.3	14.8-22.8	
Mg	mg/l	15.1-23.6	15.1-19.4	15.0-17.9	14.9-26.4	15.5-18.7	
K	mg/l	4.1-6.2	4.0-4.8	4.1-4.6	4.2-5.8	4.1-4.8	
Na	mg/l	42.0-67.1	41.0-52.0	41.3-48.2	41.0-65.8	42.9-49.7	
S	mg/l	7.6-10.7	8.0-9.2	8.0-9.1	7.9-14.1	6.1-9.8	
Si	mg/l	16.2-24.9	12.1-24.0	17.4-22.3	15.5-25.0	16.9-25.0	
Fe	μg/l	BD	BD	BD	BD	BD	
Mn	μg/l	16-146	33-76	Jun-71	16-74	26-101	
B	mg/l	1.0-1.8	0.9-1.3	0.9-1.1	0.89-1.5	0.9-1.3	
Cu	mg/l	BD	BD	BD	BD	BD	
Sr	μg/l	55-103	60-71	39-80	48-108	59-72	

Bennett (2004) provided another lake depth profile of Surprise Lake—taken at the same location as Cameron and Larson's ML-1 and Mahoney and Sonnevil's Site B, and results are largely consistent with the earlier studies. Specific conductance, temperature, dissolved oxygen, pH, and turbidity varied almost imperceptibly with depth, again indicating a well-mixed lake (Bennett, 2004).

Bennett (2004) also shows the influence of warm springs on the lake chemistry; for example, the pH of the lake offshore in the warm springs area was 5.91, whereas pH was neutral to alkaline in the vast majority of the watershed. Total nitrate/nitrite and Kjeldahl nitrogen (organic) concentrations were below detection (<0.095 mg/l and <0.33 mg/l, respectively) in Surprise Lake, and the lake was classified as oligotrophic (having low biological productivity) (Bennett, 2004). In terms of major cations, both Surprise Lake and the Aniakchak River were dominated by *Na*, followed by *Mg*, *Ca*, and *K*.

Water clarity in Surprise Lake varies according to season and is influenced by wind and wave action (Cameron and Larson, 1993). Cameron and Larson (1993) noted that bright orange precipitates deposited in the lake at the mouths of hydrothermal springs during the wintertime were distributed over the lake by easterly winds (>25 km/hr, 16 mi/hr) between ice-out and late July. This blanketing of the lake with precipitates changed the lake color from blue-green to olive green, which remained so until the precipitates slowly settled out during calm periods over the summer. Secchi disk clarity reached a maximum in mid-August, after the source of precipitates available for suspension had been depleted.

A2b 3) Aniakchak River and tributaries

Bennett (2004) provides the only known water quality data on the Aniakchak River (outside the caldera) and its tributaries (Garden Creek, Albert Johnson Creek, North Fork, a pond that flows into Albert Johnson Creek, and tributary in the lower watershed). She reports that during the water-quality survey in June 2003, water temperature in the mainstem Aniakchak River increased from 6.55 ˚C (43.8 ˚F) at the Surprise Lake outlet to 10.9 ˚C (51.6 ˚F) in the outwash section of the river, upstream of the confluence Albert Johnson Creek. Following three days of rain and heightened flows from the North Fork tributary, temperature readings in the lower Aniakchak River were 8.09 ˚C (46.6 ˚F). Specific conductance decreased downriver from ~390 µs/cm in Surprise Lake to 121 µs/cm at the lowest measurement before tidal influence; tributaries with much lower conductivities (63-95 µs/cm in Albert Johnson Creek; 53 µs/cm in the North Fork) diluted the mainstem values. Alkalinity and major ion concentrations also declined in a downstream pattern, reflecting the influence of more dilute chemical composition of the tributaries. pH values in the mainstem and tributaries was slightly alkaline (generally between 7.4 and 8.6). pH values in Albert Johnson Creek were 7.48-8.64, the most alkaline of the tributaries, and one of its sloughs had the record high pH of 9.68. Turbidity was low in the Aniakchak River, ranging from 2.7 NTU in the outwash section to 18.7 NTU in the tidally-influenced lower watershed. Nutrient concentrations were either below detection or at very low values for both the mainstem and tributaries (Bennett, 2004). Bennett (2004) also provided data of major and trace element concentrations in the watershed. Values were generally within normal range but one exception was an *Al* concentration exceedance in the Aniakchak River below the North Fork (see Section IV.B.). Tables containing georeferenced site locations and water quality results of all sample analyses are provided in Bennett (2004) and excerpted in Table 11 below.

Table 11. Water quality results from Bennett (2004) study in June-July 2003. Please refer to Bennett (2004) for more specific site location, specific date and time information. All below detection: total nitrate+nitrite, Cd, dissolved organic carbon. TKN= Total Kjeldahl Nitrogen. TP= Total Phosphorus.

Site	Aniakchak mainstem, trib; or other *	Temp ºC	Cond. (µS/cm)	D.O. (%)	pH	Turb. NTU	TDS mg/L	Alk. mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO_4^{2-} mg/L	Cl mg/L	TKN mg/L	TP mg/L	Al µg/L	As µg/L	Cd µg/L	Cu µg/
ANIA_DC																				
ANIA-rv_0	Mainstem	6.55	301	100.2	7.59	13.2														
ANIA_TUR	Mainstem		0				201	129	18	11	3.3	31	16.3	16	1.2	0.1	33	3.4	ND	ND
ANIA-rv_1	Mainstem	6.98	329	99	7.89	6														
ANIA-rv_2	Mainstem	6.99	329	98.3	7.91	5														
ANIA-rv_3	Mainstem	7.71	282	104.6	8.38	4.5														
ANIA-rv_4	Mainstem	10.9	262	107	8.38	2.7	153	99.9	15	8.6	2.7	24	12.5	13	1.1	0.1	45	2.5	ND	ND
ANIA-rv_5	Mainstem	10.9	246	106.1	8.44	2.7														
ANIA-rv_6	Mainstem	8.09	155	109.8	7.9	13.3	83.2	57.7	9.6	5	1.7	14	6.19	7.8	1.8	0.1	662	1.9	ND	1.3
ANIA-rv_7	Mainstem	9.07	100	123.5	7.68	16.8														
ANIA-rv_8	Mainstem	9.26	129	117.2	7.8	14.9														
ANIA-rv_9	Mainstem	9.39	124	118	7.81	16.3														
ANIA-rv_97	Mainstem	10.7	121	105.5	7.62	18														
ANIA-rv-98	Mainstem	10.7	121	106.1	7.62	18.7														
Turbid_0	Trib	2.98	66	101.3	7.83	1.9	41.8	22	6.2	1.6	0.7	4.3	4.52	2.9	ND	0.2	126	1.4	ND	0.6
Turbid_1	Trib	2.96	67	98	7.78	1.5														
Garden Cr	Trib	3.59	66	101.8	7.81	-0.7														
AJ Cr._0	Trib	11.5	93	118	8.64	33.6														
AJ Cr._1	Trib	11.5	95	117.6	8.64	0.5	72	33.8	6.2	2.5	1.3	8.4	2.54	6.5	ND	0.1	38	ND	ND	ND
AJ Cr._2	Trib	11.5	95	117.5	8.66	2.3														
AJ Cr._3	Trib	17.5	151	186	9.68	0.3														
AJ Cr._4	Trib	8.64	63	107.5	7.67	-0.2														
AJ Cr._5	Trib	8.64	63	107.4	7.67	0														
AJ Cr._6	Trib	10.1	60	112.3	7.48	-0.2														
AJ Cr._7	Trib	10.1	60	111.3	7.47	-0.2														
AJ Pond1_0	Trib	13.9	56	124.9	7.81	17														
AJ Pond1_1	Trib	13.9	56	124.6	7.81	11.9														
NF_0	Trib	7.35	53	109.3	7.45	21.8	21.6	15.2	5.6	1.1	0.4	3.5	2.7	3.1	ND	ND				
NF_1	Trib	7.25	53	107.4	7.42	15.9														

Site	Aniakchak mainstem, trib; or other *	Temp ºC	Cond. (µS/cm)	D.O. (%)	pH	Turb. NTU	TDS mg/L	Alk. mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO_4^{2-} mg/L	Cl mg/L	TKN mg/L	TP mg/L	Al µg/L	As µg/L	Cd µg/L	Cu g/
NF_2	Trib	8.06	53	116	7.43	17.2														
Below NF	Trib	8.43	54	113.4	7.36	18.7														
LANI_0	Trib	8.64	1252	87.4	6.83	-0.4														
LANI_1	Trib	8.65	1258	88.2	6.81	-0.5														
IRIS-CRK_0	Trib	20.1	83	123.9	8.03	0.8														
IRIS-CRK_1	Coastal stream	20.1	83	124.5	8.04	0.7														
IRIS-CRK_2	Coastal stream	21.5	91	130.7	8.03	2.6														
IRIS-CRK_3	Coastal stream	21.1	87	126.1	8.11	0.8														
IRIS-CRK_4	Coastal stream	10	65	223.8	7.47	39														
IRIS-CRK_5	Coastal stream	10	65	228.8	7.39	39.9														
IRIS-CRK_6	Coastal stream	13.1	76	772.9	6.94	11.4														
Willow Cr	Coastal stream	13.2	76	776	6.87	24.9														
PACK-CRK_0	Coastal stream	7.02	119	101.4	7.6	5.5														
PACK-CRK_1	Coastal stream	7.01	119	102.1	7.56	3.9														

A2b 4) Other Pacific coastal streams in ANIA

Water quality data for other coastal streams in ANIA is extremely limited. Only Bennett (2004) provided water quality results from Iris Creek Willow Creek and the small stream (flowing at <1 cfs) that is the water supply source for Packer's Cabin, during July 2003. The temperature in Iris Creek on July 15 was the highest recorded anywhere in ANIA in 2003, at 20.1 to 21.45 ˚C (68.2-70-6 ˚F), approximately 1 ˚C (2 ˚F) warmer than a warm-tributary in the caldera. Following a rain event 3 days later, the temperature in Iris Creek had dropped to 10.01 ˚C (50.02 ˚F). The creek waters were well oxygenated, with dissolved oxygen levels ranging from 10.15 mg/L (87.4%) to 11.55 mg/L (130.7%). pH values were near-neutral, between 6.87 and 8.11. Conductivity and total dissolved solids (TDS) were between 46-85 μs/cm and 0.042- 0.077 g/L, respectively. Turbidity was low in the Packer's cabin creek (0.9-5.5 NTU) and in Iris Creek (9.8-2.6 NTU), but increased in Iris Creek to 39 NTU after sustained rain. Willow Creek was measured only after a heavy rain event, with turbidity ranging between 11.4 and 24.9 NTU (Table 11).

A3. Precipitation

The only known information on precipitation chemistry in ANIA comes from the Cameron and Larson (1992) study of the Aniakchak caldera. Between June and August 1988, they collected samples of bulk deposition (rainwater and wind-blown particles) in order to get a "rough estimate" of precipitation chemistry. Because they did not separate wind-blown particles from the rain water samples, ionic concentrations were likely higher than pure rainwater, due to probable leaching of organic materials (plant matter and insects) and other particles into the collected water. Samples were collected 4 times, each over the course of an overnight period, and analyzed for trace elements, nutrients (nitrogen and phosphorus) and general water quality parameters. They report that all forms of nitrogen were undetectable on all but one event, when 15 small midges (*Chironomidiae*) were part of the sample, likely elevating the nitrogen concentration. On only 1 of the 4 events did they collect specific conductance, pH, alkalinity, and turbidity information; values were 10 μmhos/cm, 6.2 units, 7.0 mg/L, and 0.3 N.T.U., respectively.

Cameron and Larson (1992) also report the chemistry of a snow sample collected from depth of 10-30 cm (4-12 in) from the surface of a large snowbank approximately 100 m (328 ft) from Surprise Lake. The snow had lower concentrations of ions (*Si, Na, K, S,* and *P*) than the bulk deposition samples. Results of the bulk deposition and snow samples are reproduced in Table 12.

Although the chemistry of precipitation is not currently being monitored in ANIA, there are four National Atmospheric Deposition Program (NADP) monitoring sites in Alaska, two of which are administered by the National Park Service (Denali and Gates of the Arctic). The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) provides continuous measurement and assessment of the chemical constituents in precipitation at more than 225 sites throughout the United States. This long term, nationally consistent monitoring program provides critical information for evaluating the effectiveness of ongoing and future regulations aimed at reducing atmospheric emissions. The most representative NADP site for ANIA is located approximately 1500 km (94 mi) away in Juneau on the east coast of the Gulf of Alaska. Data from this site show a predominance of marine aerosols (chlorine, sulfate, and sodium) and very low levels of nitrogen (ammonium and nitrate) compared to sites in the contiguous United States. Data on precipitation chemistry in Alaska are available through the NADP website located at: http://nadp.sws.uiuc.edu/sites/ntnmap.asp.

Table 12. Bulk deposition (rainwater + wind-blown particles) and snowmelt chemistry for 4 collections made in the summer of 1988 near Surprise Lake (Cameron and Larson, 1992). "<D.L" = below the detection limit.

	Bulk Deposition				Snowmelt
	6/20/1988	7/13/1988	7/27/1988	8/2/1988	7/29/1988
ADF&G Lab Analysis:					
Specific conductance	-	-	-	10	-
pH	-	-	-	6.2	-
Alkalinity (mg/L)	-	-	-	7	-
Turbidity (NTU)	-	-	-	0.3	-
Reactive silicon (μg/L)	-	-	-	2613	-
Total iron (μg/L)	-	-	-	11	-
Total P (μg/L)	-	-	-	-	-
Total Filterable P (μg/L)	-	512	5.5	-	4.6
FRP (μg/L)	-	7.1	1.7	-	3.9
Total Kjeldahl N (μg/L)	-	< D.L.	< D.L.	< D.L.	< D.L.
NO_2+NO_3 (μg/L)	-	< D.L.	49.6	< D.L.	< D.L.
NH_3+NH_4 (μg/L)	-	< D.L.	< D.L.	< D.L.	
E.P.A. Lab analysis					
Na (μg/L)	413	643	218	409	110
S (μg/L)	141	530	161	210	< D.L.
K (μg/L)	< D.L.	2930	< D.L.	< D.L.	< D.L.
P (μg/L)	< D.L.	649	< D.L.	< D.L.	< D.L.

A4. List of water bodies with undocumented conditions/status

Most water bodies in ANIA are both unnamed and have undocumented water quality conditions, with the exception of those discussed above in the section on water quality in streams and rivers (section *IV.A.2. Streams and lakes*). However, due to their remoteness, lack of trails and human services, and near inaccessibility to humans it is fair to assume that their water quality conditions are entirely or almost entirely naturally influenced. Possible contamination by pollutants such as mercury and organic chemicals is discussed in section *V.A. Sources of past, current, and potential future pollutants*.

B. Water quality stressors and effects on biological resources

According to the findings of Bennett (2004), the water temperature at a warm-springs tributary to Surprise Lake (WS-4/I-11) was too high, and pH and dissolved oxygen levels too low, to support salmonids. Fisheries surveys corroborate this by noting the absence of sockeye, chum salmon, or Dolly Varden (Hamon, 2000; Mahoney and Sonnevil, 1991; Miller and Markis, 2004). Other streams with temperature values above aquatic life criteria (McCullough, 1999) were Albert

Johnson Creek (17.53 ˚C, 63.55 ˚F), Turbid Creek in the caldera (2.96 ˚C, 37.3 ˚F), lower Iris Creek (21.45 ˚C, 70.61 ˚F) in June, 2003. Despite the high temperature measured in Iris Creek, 38 juvenile silver salmon were caught in the vicinity, and rainbow/steelhead trout were found in the upper reaches of the stream. Bennett (2004) speculates that such high temperatures were either unusual and short-lived or that the fish species have adapted to greater temperature ranges. In a few locations, pH values were outside of the range of regulatory criteria for aquatic life (Environmental Protection Agency, 1986). Those locations were the warm-spring complex in the caldera (pH of 5.76-6.39, which is below the criterion of 6.5) and at an Albert Johnson Creek slough (pH of 9.68, which exceeds the criterion of 9.0) (Bennett, 2004). Furthermore, 83 silver salmon were captured in the Albert Johnson Creek slough (Miller and Markis, 2004). However, it is important to note that although these values technically exceed regulatory criteria, they are of natural origin and are not subject to the same regulatory actions as are streams that are degraded by human activities. The two high Al concentrations found in the Bennett (2004) study—in Turbid Creek and Aniakchak below North Fork—that exceeded the chronic and maximum EPA water quality criteria, deserve follow-up because these measurements are based on only a single sample from each site.

C. Water quality and human health issues

Based on the one-time sampling event of the creek that is the water supply source for Packer's cabin (the Alaska Packers Bunkhouse, a cabin on the coast that is a relict of the cannery era), water parameters measured indicated the creek was of good quality (Bennett, 2004). However, water supplies in the Aniakchak caldera, the resource in ANIA most used by visitors and NPS researchers, may carry some health risks (Cameron and Larson, 1992). According to Cameron and Larson (1992), none of the water sources (Surprise Lake, Surprise lake inlets, and Turbid Lake) in the caldera have been adequately examined to evaluate human health risks, and visitors are recommended to collect drinking water only from cold inlets. Warm springs-influenced inlet streams, Turbid Lake, and Surprise Lake may be hazardous due to the naturally high concentrations of some dissolved minerals, and/or the high suspended particle load and relatively high temperatures that may favor pathogenic microbial growth (Cameron and Larson, 1992). All samples were below the EPA drinking water standards for As, Cd, Cr, Pb, Ni, Zn and nitrate, but Fe concentrations were above the drinking water standard for warm spring inlets, Surprise Lake, and Turbid Lake, and Mn concentrations in the intermediate (cold-warm) inlets, warm inlets, and Surprise Lake also exceeded drinking water standards. Based on work by Bennett (2004), Fe concentrations in Surprise Lake and 2 sites along the Aniakchak River also were above the EPA's maximum contaminant level (MCL) of 300 μg/l. It is important to note that both Fe and Mn are classified as "secondary" contaminants, meaning that at the MCL concentration, they may have disagreeable aesthetic and/or cosmetic characteristics, but they do not pose a health risk to humans (Environmental Protection Agency, 1992). Concentrations of other measured parameters (sulfate, chloride, nutrients, Al, As, Cd, Cu, Pb, and Zn) at 6 sites in the Surprise Lake/Aniakchak River watershed were not out of range of EPA aquatic health or human drinking water standards (Bennett, 2004; Environmental Protection Agency, 1992, 1995).

D. Available GIS data pertaining to water resources.

Only basic geospatial data pertaining to water resources are available in ANIA – primarily stream and water body location/extents as well as fish composition (Table 13. Available GIS data in ANIA with relevance to water resources.). Some related data, such as geology and landcover data sets are available but these are generally coarse and derived from statewide initiatives. One important GIS data source currently lacking are mapped wetland (e.g. NWI) boundaries and classifications. For base data, USGS topographic DRG's are available at 1:63K and 1:250K scales, as are a 30-m Landsat scene and scanned and georeferenced aerial photos for select parts of ANIA.

Table 13. Available GIS data in ANIA with relevance to water resources.

Category	Data	Extent
Biological	Ecological Subsections	ANIA
Biological	Landcover	All of ANIA except NE section
Biological	Anadromous Waters Catalog	ANIA
Index	Coastal Atlas Index	ANIA
Physical	100 ft Contour	Aniakchak Caldera
Physical	Elevation	Aniakchak Caldera / ANIA
Physical	Surficial Geology	ANIA
Physical	Hydrological features	ANIA
Physical	Watershed boundaries (8-level code HUC)	ANIA
Physical	Coastline 1:63K	ANIA
Physical	Wisconsin glacial max and min extent	ANIA
Base	Satellite Imagery- Color IR	ANIA
Base	DRG Mosaic 1:250,000 & 63,360	ANIA
Base	Georeferenced aerial photos (AHAP)	Limited

V. Threats to Water Resources

A. Sources of past, current, and potential future pollutants

There are no identified point sources of contaminants within ANIA. However, non-point sources of pollutants can be categorized into oceanographic and atmospheric sources. Oceanographic sources include oil spill pollution, marine vessel pollution, oil development in the Gulf of Alaska, and biological delivery of marine-derived toxic chemicals. Atmospheric sources include airmasses that have the ability to deposit mercury (*Hg*) and persistent organic pollutants (POPs).

A1. Oceanographic sources

The release of petroleum in marine waters poses a great environmental threat to the ANIA coast, whether as catastrophic spills or chronic discharges. The Valdez Marine Terminal in Prince William Sound, and the Drift River Marine Terminal and the Nikiski Oil Terminal and Refinery, both in Cook Inlet, store, process, and transport many billions of barrels of crude oil in the vicinity of ANIA. Swift currents can quickly transport released petroleum great distances, as was observed by the EVOS in 1989 (discussed below in *VA1a1. Exxon Valdez Oil Spill*). In addition to physical impacts of large spills, the toxicity of many of the individual compounds contained in petroleum is significant, and even small releases can kill or damage organisms. The impact of a release of petroleum would depend on the size of the spill, the location of the spill, the type of petroleum product, and the effectiveness of the response to the spill. Currently, Geographic Response Strategies (GRS) are not developed in the vicinity of ANIA. The development of GRS sites is in the early stages and risk layers have been produced to identify candidate sites (Figure 26) (ADEC, 2006).

The ShoreZone mapping program computed an "Oil Residence Index" (ORI) along coastal ANIA based on wave exposure levels and substrate types (Harper and Morris, 2005). Coarse sediments, unlike rock or sheet piling, are highly permeable and can trap and retain large volumes of oil. The level of wave exposure also regulates oil residence because wave action is the most effective processes removing stranded oil from shore (Harper, 2004a). Using physical attributes of the ANIA coastline, Harper (2004a) identified areas particularly sensitive to oil spills, such as estuaries and wetlands, which have fine and organic sediment and have a low amount of wave exposure. In ANIA 55% of the coastline has an ORI of months to years (Figure 27).

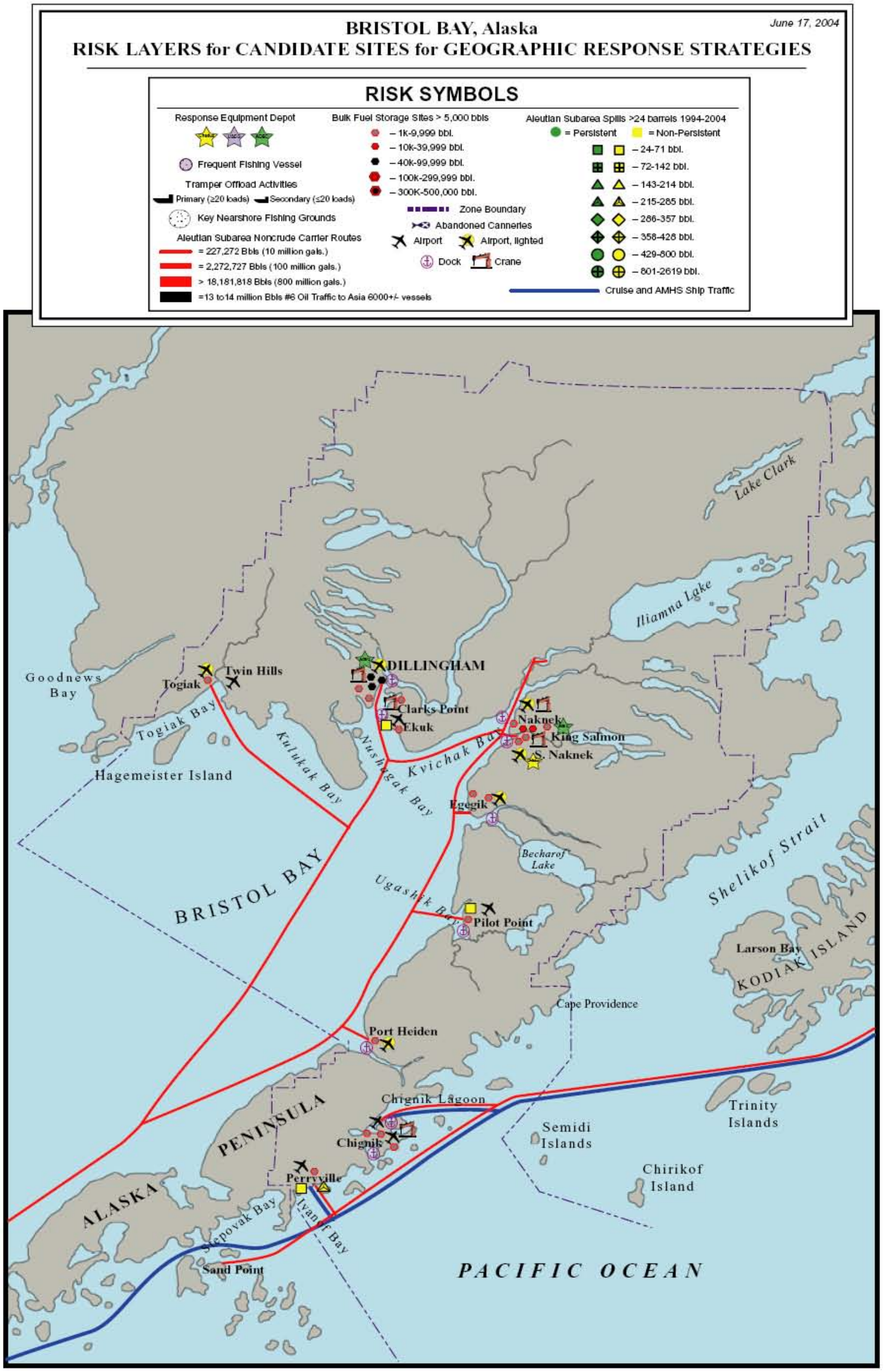

Figure 26: Risk layers for the identification of Geographic Response Strategies in the Bristol Bay region, encompassing ANIA (ADEC, 2006).

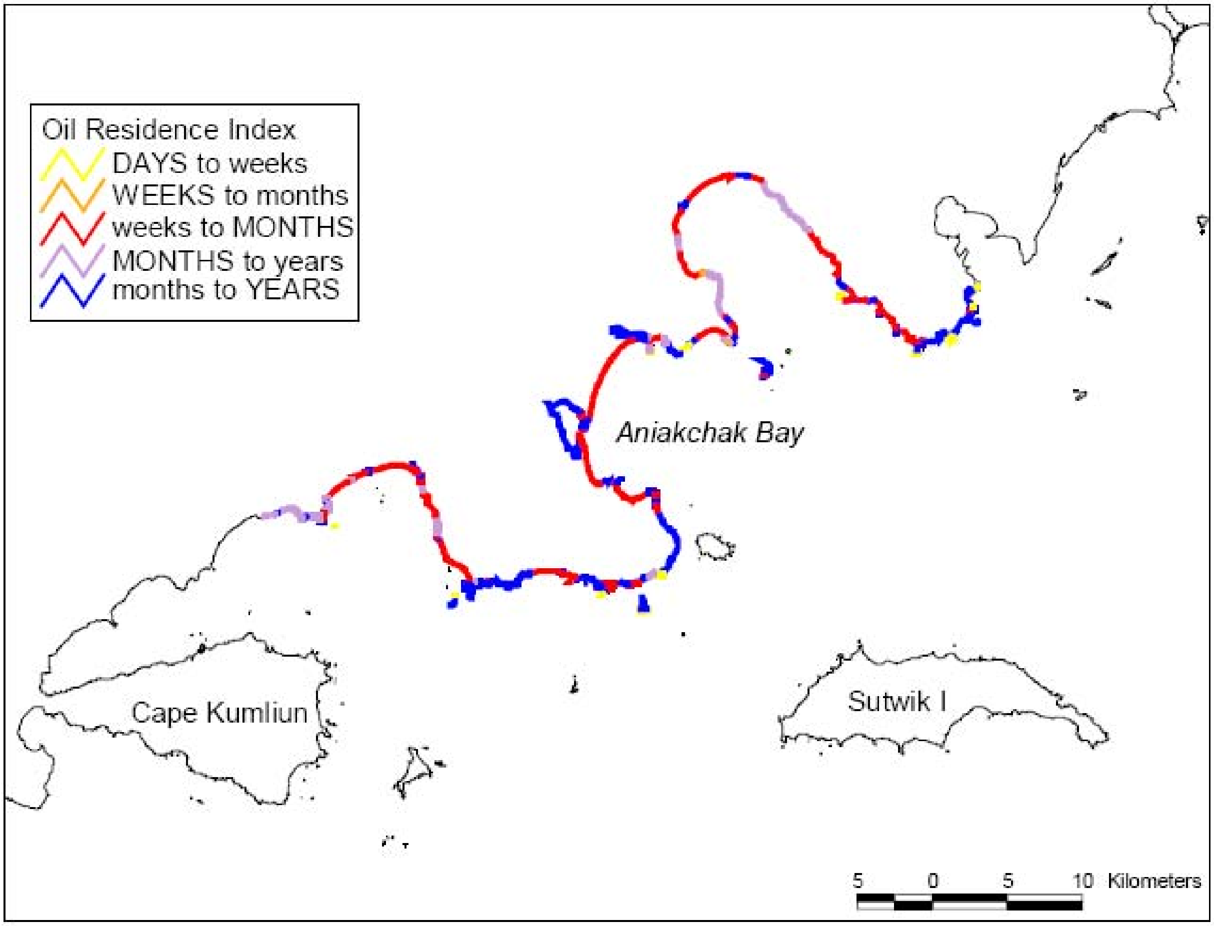

Figure 27: Distribution of oil residence index along the ANIA coastline from Harper (2004a).

A1a. *Exxon Valdez* Oil Spill (EVOS)

The grounding of the *Exxon Valdez* oil tanker on Bligh Reef in Prince William Sound in March, 1989 released 10.8 million gal (35,500 metric tons) of crude oil which was transported through Prince William Sound, along the northern Gulf of Alaska, and southwest into Shelikof Strait where it grounded on the Alaska Peninsula (Figure 28). The damage to ANIA was severe, with oiling on over two-thirds (109 km, 68 mi) of ANIA's coastline (Hanable, 1990). Two to four percent of the released oil came ashore on Shelikof Strait within KATM (Wolfe et al., 1994), resulting in the most extensive single human-caused disaster to strike a National Park (NPS, 1990). Cleanup and assessment efforts in ANIA were hindered by the inaccessibility of the ANIA coastline (Hanable, 1990). Much of the impact assessment and recovery work was conducted in more accessible areas of Shelikof Strait and Prince William Sound. Patches of unweathered oil mousse have persisted and retained their toxicity along exposed, rocky shorelines with boulder armored beaches in KATM (Irvine et al., 1999; Peterson et al., 2003). In addition, mussel beds have retained oil and have not yet returned to background levels (Irvine et al., 1999). Ecological communities in Prince William Sound (and likely Shelikof Strait) have been slow to recover from this catastrophic disturbance, and even fourteen years later, many species and communities show limited signs of recovery relative to baseline conditions (see review by Peterson et al. 2003). The lingering effects of EVOS in ANIA are now considered part of the baseline (Troy Hamon, NPS-King Salmon, personal communication, 2005). It is promising that the EMAP survey in 2002 (see *A1a. EMAP in southcentral and southwestern Alaska*) did not reveal any alarming levels of hydrocarbons in seawater or sediments; however intertidal areas that were most impacted by EVOS were not included in this survey.

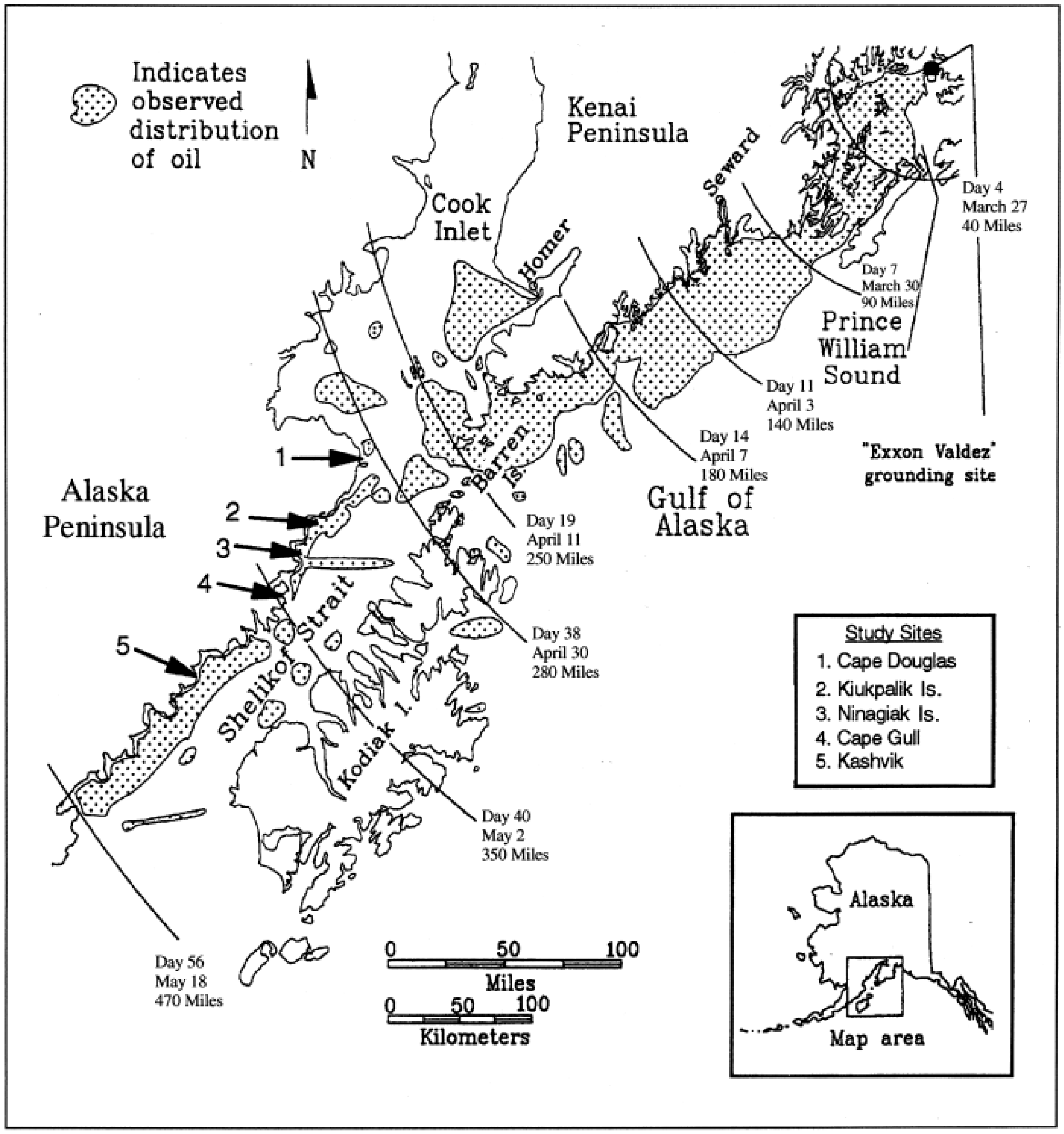

Figure 28: Geographical extent of the EVOS from 24 March, 1989 to 20 June, 1989. Study sites from Irvine et al. (1999) are included.

A1b. Marine vessel impacts

Few large commercial vessels and cruise ships travel in the immediate vicinity of ANIA (see Figure 26 for major shipping routes), but fishing vessels of all sizes are abundant in the Gulf of Alaska in general. No analyses of marine vessel impacts have been conducted for the ANIA coast, but marine vessels have the potential to degrade water quality by the accidental release of petroleum products, the release of wastewater or other discharges, or by resuspension of sediments. Wastewater generated by marine vessels that may serve as a source of marine pollution includes graywater (laundry, shower, and galley sink wastes), blackwater (treated sewage), hazardous waste, solid waste and marine debris. Private vessels may not be able to treat their wastewater before it is discharged; however because of the small volumes and large dilution factor, the effects of this wastewater may not be significant. An Alaska Department of Environmental Conservation report on the impact of marine vessels on Alaska water quality indicates that dilution levels for small marine vessels that treat and continuously discharge their wastewater are extremely high, and the only contaminant likely to be measured above ambient water levels would be fecal coliform bacteria (ADEC, 2002). Another potential pollution source is solid waste; however plastics and any garbage except dishwater, graywater, and fresh fish parts are not legally dumped within 5 km (3 mi) of the coast. Finally, vessels can affect water quality by resuspending sediments in marine waters through vessel movement, which can increase turbidity and interfere with filter feeding organisms as well as decrease water quality by reducing light penetration. The amount of sediment resuspension depends on the speed and size of the vessel, the sediment size, and the stability of the water column (NPS, 2003). The effects to water quality along coastal ANIA are most likely temporary and limited to the immediate area of vessel traffic.

A1c. Marine-derived biologic sources of pollutants

The benefits incurred by the contributions of salmon carcasses to the nutrient levels in aquatic systems (see section *IIICa Freshwater Fishes*) may be partially offset by another contribution of salmon: marine derived contaminants such as *Hg* and persistent organic pollutants (POPs). Mercury, a strongly toxic heavy metal, is emitted primarily by fossil fuel burning (Pacyna and Pacyna, 2002). POPs comprise a long list of highly toxic and very stable organic compounds such as polychlorinated biphenyls (PCB's), dichlorodiphenyltrichloroethane (DDT), dioxins, furans, and chlordane that are used as pesticides, industrial chemicals and industrial waste products (EPA, 2002). As salmon develop mass (95% in the pelagic environment), they incorporate marine contaminants such as the *Hg* and POPs and transport them into watersheds where they spawn (Ewald et al., 1998; Krümmel et al., 2003; Senkowsky, 2004; Zhang et al., 2001).

Krümmel et al. (2003) report strong correlations between the density of salmon runs with PCB concentrations in lake sediments in southwestern Alaska. Eight lakes in the Alaska Peninsula and on Kodiak Island were studied. Two of the lakes, Becharof and Ugashik Lakes, are only 50-100 km (30-60 mi) northeast of ANIA (**Figure 29**). The researchers found that the input of PCB's by spawning salmon can result in a 6-fold increase above atmospheric loading in these remote areas with high-density salmon returns.

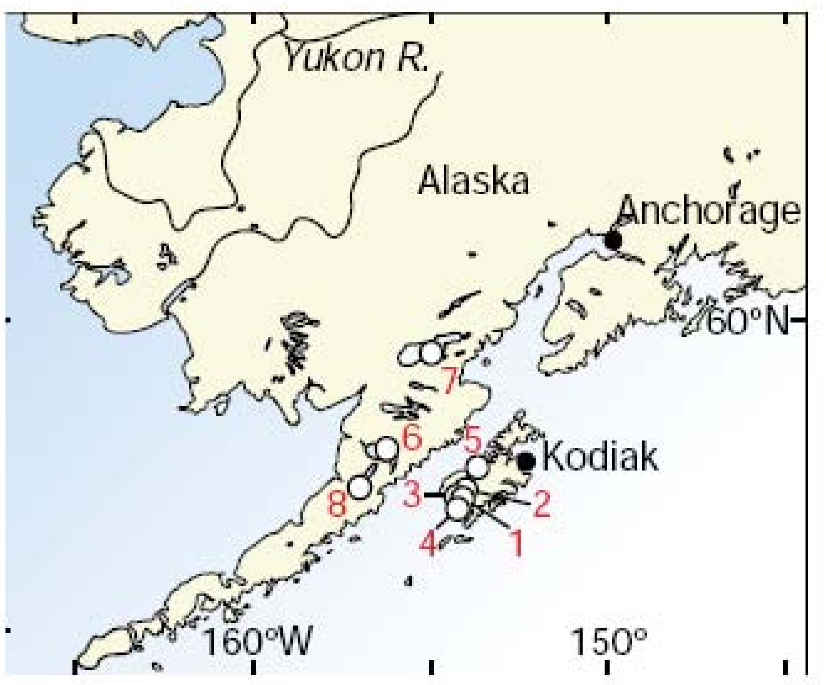

Figure 29: Sample locations of the 8 lakes surface sediments and sockeye salmon were collected for PCBs. Lake 1: Frazer; Lake 2: Karluk; Lake 3: Red; Lake 4: Olga; Lake 5: Spiridon; Lake 6: Becharof; Lake 7: Iliamna; Lake 8: Ugashik (Krümmel et al., 2003).

There is little published information on the direct contribution by spawning salmon to the *Hg* concentrations in streams, but a study of Bering Sea salmon returning to spawn in the Bristol Bay watersheds of southwestern Alaska (Kvichak, Naknek, Egegik, Ugashik, Wood, Igushik, Nushagak, and Togiak Rivers - ca. 200-300 km (120-190 mi) from ANIA) showed that salmon may be major transporters of marine-derived *Hg* into freshwater environments (Zhang et al., 2001). This research combined analyses of methylmercury concentrations in Bristol Bay salmon tissues with escapement data (ADF&G, 1999) to conclude that biotransport of methylmercury by the salmon may have accounted for as much as 21 kg (46 lb) of methylmercury transported into eight Bristol Bay watersheds over the past 20 years. A recent study more directly tested the effect of salmon carcasses on stream *Hg* concentrations in several tributary streams of Lake Ontario (Sarica et al., 2004). Comparing stream segments with variable salmon carcass densities, these researchers detected significantly higher concentrations of nutrients, total aqueous *Hg* and methylmercury, particulate *Hg*, and *Hg* in terrestrial invertebrates along stream segments with high salmon carcass densities compared to areas with low salmon carcass densities.

The available data indicate a strong likelihood that salmon are an important-- and possibly the dominant -- contributor to both the POPs and *Hg* budgets in streams where they spawn in areas such as ANIA in southwest Alaska. These contaminants are not only are released into the waters where they spawn, but they can enter the food chain. For example, a study on grizzly bears in British Columbia, Canada, found that salmon delivered 70% of the organochlorine pesticides, up to 85% of the lower brominated PBDE congeners, and 90% of PCB's measured in salmon-eating grizzly bears. These pollutant levels in the salmon-eating bears were significantly higher than in their non-salmon eating counterparts in inland areas (Christensen et al., 2005).

A2. Atmospheric sources of pollution

Mercury and POPs are the 2 major subjects of concern for much of Alaska in terms of atmospheric contaminants as well. They are global pollutants, crossing international borders and reaching remote areas that should otherwise be pristine (AMAP, 2004; Fitzgerald et al., 1998; Nriagu and Pacyna, 1988). Anthropogenic mercury deposition to Alaska appears to be similar in magnitude to that in temperate latitudes (Fitzgerald et al. 2005). *Hg* and most POPs are carried to Alaska via long-range atmospheric pathways (Garshelis, 1997; Schroeder and Munthe, 1998; Wania et al., 1999), and upon deposition can biomagnify as they pass up trophic levels (EPA 2002). Mercury and POPs in northern latitudes show significant concentration increases over the last few decades, and these trends are reflected in the extraordinarily high concentrations of some of these chemicals in the bodies of otters, whales, seals, bears, eagles, and indigenous peoples who rely on subsistence harvests (AMAP 2002, 2004). Few studies on contaminants in southwest Alaska exist; however, the evidence available indicates that the region is accumulating many potentially toxic chemicals imported atmospherically from afar.

Although there are no significant industrial sources of mercury (*Hg*) in southwest Alaska, *Hg* deposition to Alaska, as well as to virtually all remote places on the planet, has at least doubled since pre-industrial times (Engstrom and Swain, 1997; Fitzgerald et al., 1998). Mercury deposition (through dry or wet processes) is particularly favored in high altitude and high latitude regions due to cold condensation mechanisms and high rates of oxidation (Schindler, 1999). Recent revelations of large *Hg* pollution events during polar springtime (known as Atmospheric Mercury Depletion Events) in regions of northern Alaska, other high Arctic regions, and even some sub-arctic regions such as the Hudson Bay area of Canada (at the same latitude as southwest Alaska) have drawn scientific attention to the subject of *Hg* pollution in remote, high latitude, coastal environments (Lindberg et al., 2002; Lu et al., 2001; Schroeder et al., 1998). Recently, U.S. Geological Survey researchers have found similar high rates of mercury deposition along the coast of the Gulf of Mexico (D. Krabbenhoft, USGS, personal communication, 2005), suggesting this phenomenon extends far beyond the polar regions.

Although *Hg* and POPs have not been studied in ANIA specifically, several studies in southern coastal Alaska indicate the region is being impacted by these contaminants. One study on contaminants in seabird eggs showed that concentrations of POPs in common murre eggs from two islands in the Gulf of Alaska were significantly higher than in eggs from three colonies in the Bering Sea (Kucklick et al., 2002; Vander Pol et al., 2002a; Vander Pol et al., 2002b) (Figure 30). Eggs from St. Lazaria in Sitka Sound, southeast Alaska, had higher concentrations of SPCB's (sum of 46 congeners of PCBs) than eggs from any other Alaskan colonies (Kucklick et al., 2002; Vander Pol et al., 2002a; Vander Pol et al., 2002b). Geographic differences in POPs concentrations are not understood, but may be products of global wind and ocean current patterns that result from variable deposition characteristics within Alaska. Mercury was also evaluated in the seabird egg studies (Christopher et al., 2002; Davis et al., 2004; Day et al., 2006) which indicated that mercury pollution may also be more of a concern in Gulf of Alaska compared to the Bering Sea region. Thick-billed and common murre eggs collected from islands in the Gulf of Alaska had mercury concentrations that were significantly higher than in eggs from islands in the Bering Sea (Figure 31). The highest concentrations of mercury were again from St Lazaria Island (Christopher et al., 2002; Day et al., 2006). The authors of these studies speculate that higher mercury concentrations in the Gulf of Alaska sites may be due to the relatively warm temperatures, abundance of organic matter in forested areas and wetlands in Southeast Alaska, and presence of estuaries—all factors that stimulate mercury methylation processes—as well as strong freshwater discharge and high erosion rates.

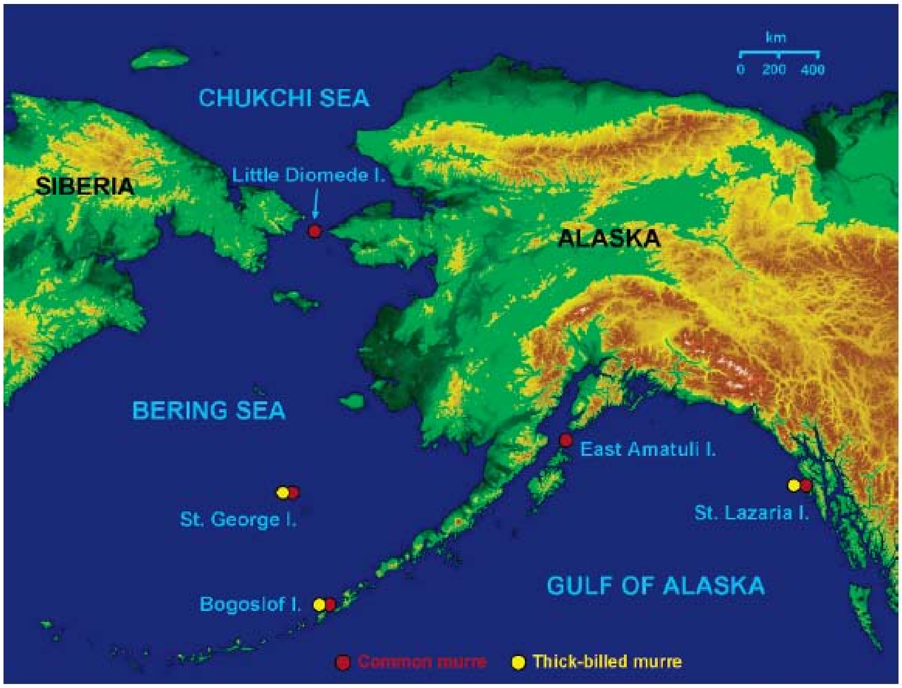

Figure 30: Map of the study area for Hg concentrations in eggs from five murre (Uria spp.) colonies (Day et al., 2006).

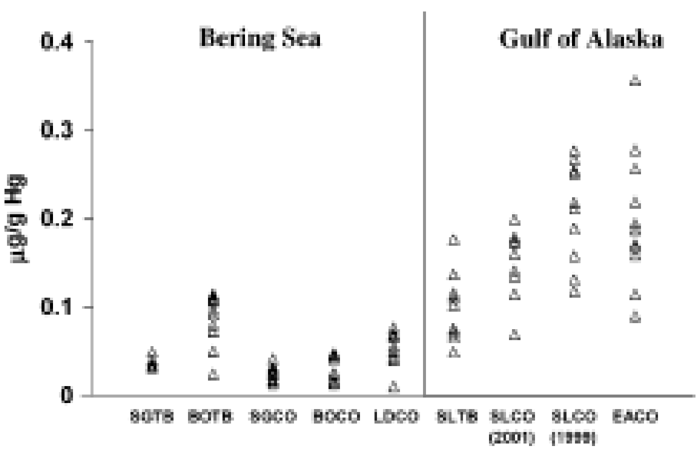

Figure 31: Total *Hg* concentrations (wet mass) for murre eggs for each collection event in the Day et al (2006) study. The first two letters of the four letter code indicate location (BO= Bogoslof, LD= Little Diomede, SG= St. George, EA= East Amatuli, SL= St. Lazaria) and the second two letters indicate species (CO= common murre, TB= thick-billed murre).

A study of dated sediment cores collected at three lakes in Glacier Bay National Park (GLBA) in southeast Alaska suggests that modern *Hg* accumulation rates in sediments are approximately double preindustrial accumulation rates (Engstrom and Swain 1997). Additionally, *Hg* deposition in GLBA did not show the recent declines observed at sites in the continental U.S., where regional mercury emissions have been reduced since the 1960's. These results suggest that southern Alaska is being affected by mercury emissions from remote sources (e.g. in Asia), that are steadily increasing their output (Pacyna and Pacyna, 2002).

While mercury emissions in the U.S. have decreased in recent decades, global emissions continue to increase, particularly in Asia, a major source region for prevailing weather patterns that feed the northwest coast of North America (Pacyna and Pacyna, 2002). As a result, Alaska is predicted to be impacted by rising mercury contributions for decades to come. As for POPs, the Stockholm Convention, a global initiative to phase out 12 of the most dangerous POPs should reduce the threat that these pollutants pose to ecosystems such as those within ANIA. However, numerous other forms of POPs are still being manufactured and released into the environment in large quantities with unknown consequences (Giles, 2004). In sum, the limited studies to date strongly suggest that the threats posed by mercury and POPs to ecosystems in Alaska are significant and deserve further evaluation and monitoring.

The NPS Air Resources Divison, in cooperation with the EPA, USGS, US Forest Service, and several universities, has recently begun to address these issues through a project called the Western Airborne Contaminants Assessment Project (WACAP) that aims to characterize the extent of airbone pollution to remote NPS units in the western US and Alaska (NPS, 2005c). Snow, fish tissue, water, lake sediment, lichen, vegetation, and subsistence native foods are being collected by WACAP at eight NPS units, including 3 in Alaska: Denali National Park and Preserve; Gates of the Arctic National Park and Preserve; and Noatak National Preserve. Samples are being analyzed for a group of semi-volative organic compounds, which include a variety of POPs, mercury and other trace metals. While no SWAN units were selected for this study, results from the 3 NPS units elsewhere in the state will provide important indications of the extent and magnitude of contaminant threats to park ecosystems. Analyses are expected to be completed in 2006 and results published in 2007.

Additionally, the state of Alaska Department of Environmental Conservation is planning on monitoring wet deposition of *Hg* to coastal southern Alaska by 2007 through establishment of two Mercury Deposition Network stations in Dutch Harbor and in Kodiak (Heidi Strader, Alaska DEC-Anchorage, personal communication, 2006). The data generated by these future studies will be instrumental in tracking *Hg* levels in southern Alaska. To date, wet deposition information is limited to one year of data collected by researchers in Glacier Bay National Park and Preserve, southeast Alaska, including *Hg* concentrations in precipitation (mean: 2.6 ng Hg/L) and estimated atmospheric wet deposition rates (mean: 4.6 μg m^{-2} y^{-1}) (Fitzgerald et al., 2006).

A3. Point sources of pollutants

There are no known point sources of pollutants along coastal ANIA.

B. Climate change

Climate change is an important natural resource issue for national parks in Alaska, and recent research suggests that changes in climate may dramatically impact water resources in Alaskan parks. On a global scale, mean surface air temperature has risen by about 0.6 ˚C (1.1 ˚F) in the last century and the best estimate of the International Panel on Climate Change is that temperatures will rise by another 1.7 to 4.0 ˚C (3.1 to 7.2 ˚F) by 2100 (IPCC, 2001). Recent climate change is dominated by human influences and there is now a relatively broad scientific consensus that the primary cause of climate change is human-induced changes in atmospheric composition (Karl and Trenberth., 2003). In particular, there have been rapid increases in the concentration of greenhouse gases such as carbon dioxide and methane, which absorb and re-radiate outgoing terrestrial long-wave radiation.

Models and recent observations both suggest that climate warming is amplified at higher latitudes (Hall, 1988; Serreze et al., 2000) and future changes in temperature are projected to be proportionally higher in high-latitude ecosystems (Roots, 1989). Over the past fifty years, Siberia, Alaska and northern Canada, and the Antarctic Peninsula have warmed more than any other regions on Earth, and the 20th century Arctic is the warmest of the past 400 years (Overpeck, 1997; Serreze et al., 2000). Alaska's climate has warmed by approximately 2.2 ˚C (4 ˚F) since the 1950's and is projected to rise an additional 1.6-5.6 ˚C (2.8-10 ˚F) by 2100 (Parson et al., 2000). The reasons for the larger temperature increases at high latitudes are not fully understood, but are thought to involve cryospheric (concerning snow and ice) effects such as the snow/ice albedo feedback effect (Sturm et al., 2005), coupled with changes in the atmospheric circulation, and possibly ocean currents. In addition, some analyses suggest that much of the recent warming was coincident with the most recent of the large-scale Arctic atmospheric and ocean-regime shifts occurring in the mid 1970's (Weller and Anderson, 1997).

Climate warming is already affecting the physical landscape in Alaska. The most obvious effects of climate change on hydrologic resources in Alaska are changes in the extent of permafrost, snow cover, glaciers, and sea and lake ice cover (Oswood et al., 1992). ANIA contains substantial area above treeline, and although ANIA does not contain glaciers, permanent and semi-permanent snowfields are common in north and northeast facing basins in the Aleutian mountains. These snowfields are an important source of summer stream flow in park watersheds. Data from the past half century suggest that the most dramatic climate warming in Alaska has occurred during winter months (Weller et al., 1997). In coastal ANIA winter temperatures are typically close to the freezing point of water (Figure 12), and climate warming has the potential to alter patterns of snow accumulation within ANIA. For example, as winter temperatures increase, the incidence of rain events during winter typically increases and the hydrologic storage of water in seasonal snowpacks decreases. The result of this trend is a shift toward higher streamflows in winter and lower streamflows during snowmelt runoff in the spring and summer.

At present, there are no long term hydrologic data available for ANIA to evaluate climate driven shifts in streamflow. However, discharge data collected since 1947 in the Kadushan River near Tenakee Springs, Alaska suggest that climate warming can have a pronounced impact on the timing of streamflow in watersheds with seasonal snowcovers (**Figure 32**). The Kadushan River may be an appropriate analog for ANIA because it is located at the same latitude (57˚N) and has a similar climate and elevation range to streams in the coastal portion of the park. A decrease in seasonal snowcover and associated lower summer streamflows may lead to increased streamwater temperatures in the late summer and fall. Changes in streamwater temperature may, in turn, influence the spawning success of salmon within ANIA (e.g. Hamon, 2000).

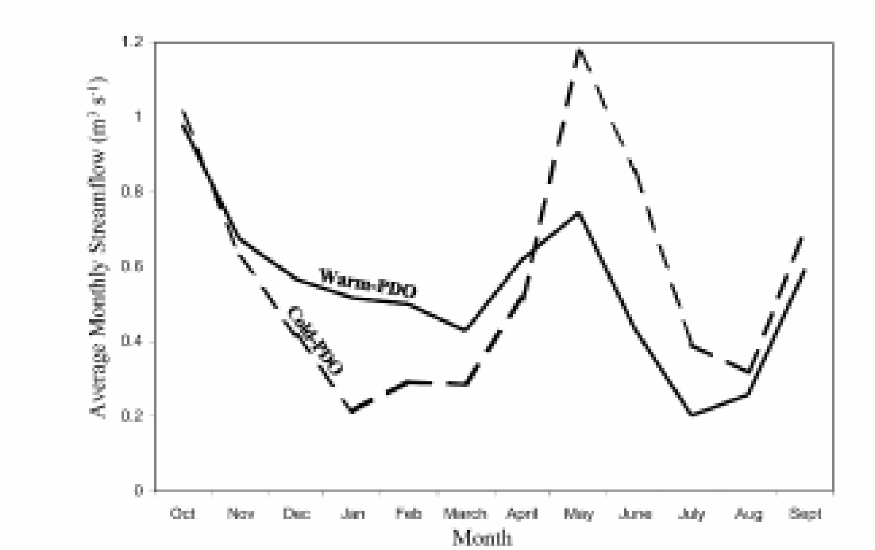

Figure 32: Annual streamflow patterns for the Kadushan River near Tenakee, Alaska during warm and cold periods of the Pacific Decadal Oscillation (from Neal et al., 2001). Climate warming results in an increase in winter streamflow and a decrease in summer streamflow.

Climate warming also has the potential to affect the occurrence of lakes and ponds within ANIA. Recent research from the Seward Peninsula and Kenai Peninsula, which are also along the southern coast of Alaska, has demonstrated a substantial landscape-level trend in the reduction of surface water area as well as the number of closed-basin ponds (Riordan et al., 2006). Since the 1950's the surface water area of closed-basin ponds in eight boreal regions in Alaska has decreased by 4-31% and the total number of closed-basin ponds has decreased by 5-54%. This loss and shrinkage of ponds is hypothesized to be due to increased drainage from warming permafrost and increased evapotranspiration during a warmer and extended growing season (Riordan et al., 2006). The loss of surface water bodies within ANIA has the potential to affect park fauna such as migratory waterfowl that depend on these resources. There is little, if any, permafrost within ANIA, so it is unclear how the hydrological changes noted by Riordan et al. (2006) may apply to ANIA (Alan Bennett, NPS-Anchorage, personal communication, 2007).

The effects of climate change on the chemistry of lakes and streams are unknown. Research on linkages between terrestrial and aquatic systems suggests that elevated temperatures and carbon dioxide levels will affect the distribution and productivity of plants, which will in turn affect the amount and quality of leaf litter entering streams and rivers (Meyer and Pulliam, 1992). Because soil microbial activity is linked to soil temperature and moisture, climate shifts will affect microbial processing of organic material in terrestrial systems, which will in turn affect the flow of nutrients from terrestrial to aquatic ecosystems. In addition, surface water quality could also be altered by predicted changes in the frequency of disturbances such as forest fires, wind storms, and coastal floods (Meyer and Pulliam, 1992; Parson et al., 2000). Ultimately, changes to the quality and quantity of runoff from terrestrial ecosystems will affect nearshore marine systems in ANIA because the productivity of these systems is partially controlled by the input of nutrients from coastal watersheds.

C. Natural geologic disturbances: volcanoes, earthquakes, and tsunamis

C1. Volcanic activity

Aniakchak crater is a large shield volcano that is a product of the massive volcanic forces powered by the subduction of the Pacific plate under the North American plate along the Aleutian trench (Alaska Volcano Observatory, 1998). The Aniakchak caldera, which formed 3,435 ± 10 years B.P. is one of a string of ~65 volcanic centers along the Aleutian chain that have been active in Quaternary time (last ~2 million years) (Beget et al., 1992; Miller and Smith, 1987) and is “perhaps the most spectacular caldera in the entire Aleutian arc” (Miller and Smith, 1987) (Figure 33). The Aniakchak caldera formed from the explosive collapse of a 2100 m (6900 ft) volcanic cone, which released >50 km^3 (19 mi^2) of pyroclastic debris and tephra (Miller and Smith, 1987). The ash flows produced by the formation of the caldera were massive, filling deeply glaciated valleys up to 75m near the caldera rim, as well as mobile, surmounting topographic barriers of several hundred meters (Miller and Smith, 1987).

The Aniakchak volcano is still active, as are many of the volcanoes along the Aleutian arc. Since 1990, one to two volcanoes in Alaska have erupted each year, including Novarupta (1912- the largest 20th century eruption in the world and the largest rhyolite eruption in recorded history), Redoubt (1989), Mount Spurr (1992), Pavlof (1996), Okmok (1997), and most recently, Augustine (2006) (Alaska Volcano Observatory, 1998, 2006). Aniakchak’s most recent large eruption was in 1931; and a much smaller event followed in 1942 (Alaska Volcano Observatory, 2006). The 1931 eruption is described as having been violent, with explosive and effusive phases that projected ash at least 600 km (1000 mi) north of Aniakchak (Neal et al., 2001). Homes in Port Heiden (known then as “Meshik”) were blanketed in pea-to egg-sized, frothy, black pumice; radio communications were hampered; and observations from Bristol Bay conditions of near-darkness due to the thickness of black ash (Neal et al., 2001). In the caldera, nearly all vegetation was buried and/or destroyed, three small lakes were completely filled with ash, Surprise Lake become cloudy with suspended ash, and there were many dead birds (Hasselbach, 1995; Hubbard, 1931). The eruption triggered earthquakes and rock avalanches, and fallout from the eruption affected several hundred thousand square kilometers of southwestern Alaska as well (Neal et al., 2001). Explorer Father Bernard Hubbard described losses of reindeer and caribou over 100 km (62 mi) from ANIA as “heavy”, and swans and geese were reportedly killed in nearby Ugashik (Hubbard, 1931; Neal et al., 2001).

Future volcanic activity similar to the 1931 eruption is likely for Aniakchak (Neal et al., 2001). Aniakchak has explosively erupted at least 40 times in the last 10,000 years—more than any other volcano in the Aleutian arc, and the warm springs within the crater hint at the activity

(Riehle et al., 1999). The USGS has identified the major hazards associated with an eruption at Aniakchak as: ash clouds, ash fallout, ballistics (projectiles of rock and pumice), pyroclastic flows and surges, lava flows and domes, and lahars and floods (Neal et al., 2001). The scale of the harm and destruction of wildlife, vegetation, and people varies widely. Each of these hazards is discussed in detail in (Neal et al., 2001)which also provides a detailed history of volcanic activity at Aniakchak. The Aniakchak Volcano is actively monitored by the Alaska Volcano Observatory in Anchorage.

The influence of volcanic activity on water resources in ANIA is most directly related to the water quality conditions of the warm springs within the caldera. Warm spring inlets are generally less supportive of fisheries due to their high temperatures and low dissolved oxygen concentrations. Changing volcanic conditions within the caldera may alter the scale and location of contributions from warm springs to the lakes and streams in the caldera.

C2. Earthquakes and tsunamis

The Aleutian seismic zone, which follows the southern border of the Alaska Peninsula and the Aleutian islands, is one of the most active seismic zones in the world (Stevens and Craw, 2004). The "Shumagin" segment of the volcanic zone, located along the southwestern Alaska Peninsula, has been predicted by (Nishenko and Jacob, 1990) to have a 74-84% chance of a magnitude 7.4 earthquake between 1988 and 2008, and many other scientists believe this zone is due for a major earthquake in the next few decades (Stevens and Craw, 2004). An earthquake in the Shumagin seismic gap may generate major extensive tsunamis along the southern coast of the Alaska Peninsula and Aleutian Islands (Kowalik and Murty, 1989). In 1964, the largest earthquake in North America- and the second largest earthquake ever recorded- occurred in northern Prince William Sound (Sokolowski, 2006). The earthquake raised some land areas up to 10 m, triggered landslides and avalanches, which in turn set off tsunamis that killed 115 people, and caused extensive structural damage in Anchorage and other Alaskan communities (Sokolowski, 2006).

Tsunamis striking coastal ANIA may originate from tectonic movement almost anywhere along the convergent Pacific plate boundary off Alaska's southern coast, from along the strike-slip boundary along southeast Alaska, or from far more distant sources along the massive Pacific plate. Submarine landslides and/or volcanic eruptions that release pyroclastic flows or other materials from a volcanic collapse into the ocean, may also initiate a tsunami in the Gulf of Alaska (Kowalik and Murty, 1989; Waythomas and Watts, 2003). For example, the volcanic eruption ~3,500 years ago that formed the Aniakchak Caldera resulted in the release of large-scale (>50 km^3) pyroclastic flows that set off major tsunamis (up to 7.8 m [26 ft] high) in Bristol Bay (Waythomas and Neal, 1998; Waythomas and Watts, 2003).

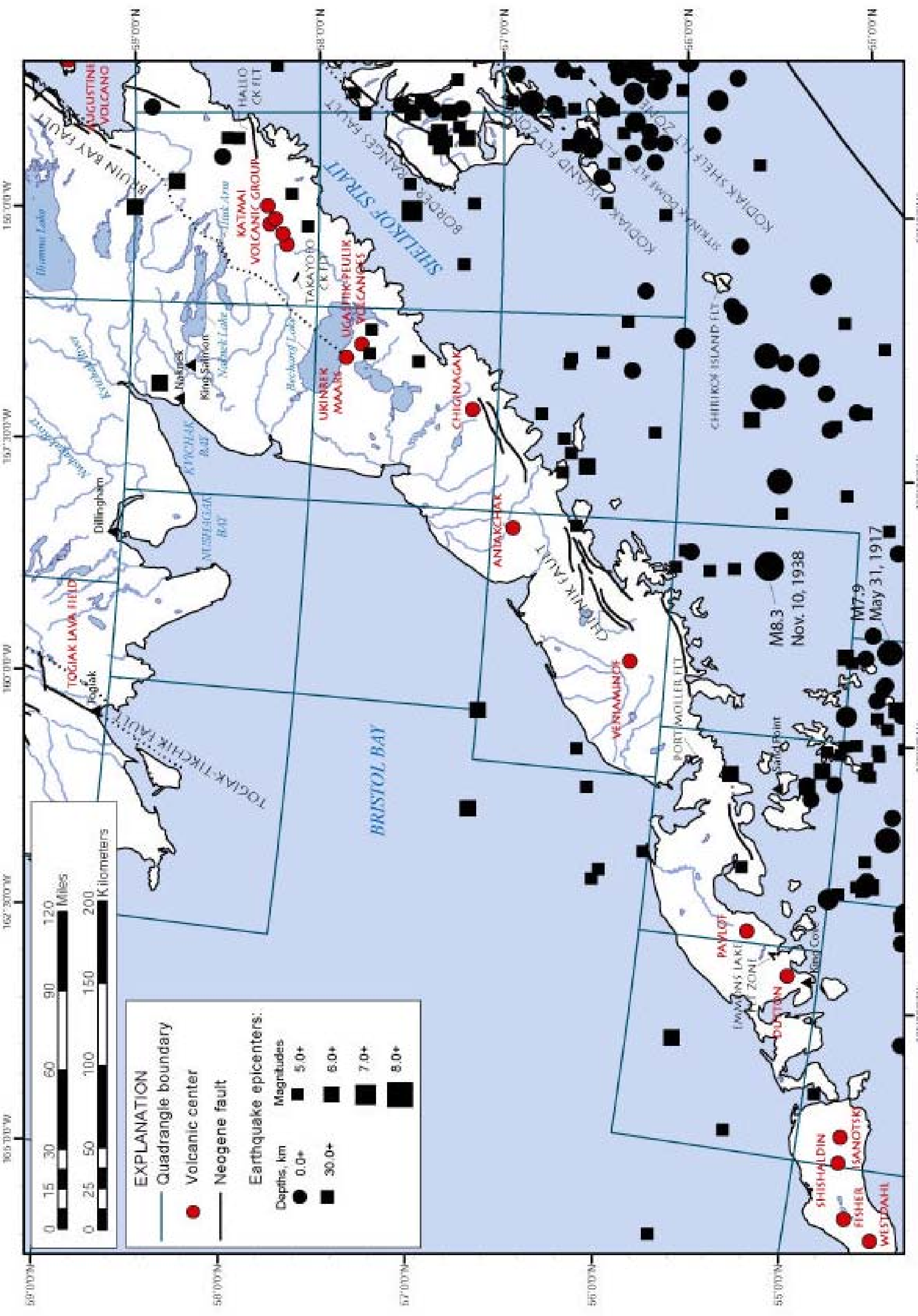

Figure 33: Volcanic centers, faults, and epicenters of earthquakes with magnitudes >5.0 in the Alaska Peninsula Region. Epicenters from the Alaska Earthquake Information Center. (Stevens and Craw, 2004)

Pacific tsunami warning systems are in place and are currently being enhanced due to efforts motivated by Indian Ocean tsunami that killed more than 200,000 people in Asia in December, 2004. Relevant tsunami warning centers are the West Coast and Alaska Tsunami Warning Center based in Palmer, Alaska, (http://wcatwc.arh.noaa.gov/) and the Pacific Tsunami Warning Center in Ewa Beach, Hawai'i (http://www.prh.noaa.gov/ptwc/).

C3. Uplift

The complex interplay of tectonic, isostatic, and global eustatic effects in the Gulf of Alaska results in highly spatially variable sea-level histories along the southcentral and southwestern Alaska coast. Earthquakes leading to sudden coastal uplift events are common along the tectonic setting of the Alaska Peninsula coast. The subduction of the Pacific plate under the North American plate tends to cause the continental plate to be uplifted, sometimes very suddenly as occurred during the 9.2 magnitude Good Friday earthquake in 1964. During this earthquake, for example, some portions of coastal southcentral Alaska were uplifted over 8m (26 ft0, while other areas subsided up to 2.25 m (7.38 ft) (Harper and Morris, 2005). Uplift of the land due to tectonic activity is superimposed by isostatic rebound from deglaciation, a process which raises the land and reshuffles successional processes on a much more gradual time scale (Bennett, 2004; Mann and Crowell, 1988). Changes in relative sea level have caused dramatic changes in fisheries and wildlife habitat in southeast Alaska's Wrangell-St. Elias National Park and Preserve (Mills and Firman, 1986). Uplift may also cause changes in the composition and location of key vegetative types, and in the distribution of birds and wildlife along the coastline. For example, in some areas of southeast Alaska, high marsh communities dominated by grasses have replaced the sedge-dominated low marsh communities (Armstrong et al., 2004). Migrating birds such as pipits and longspur favor high marsh communities, while low marsh communities are nutritionally crucial for waterfowl such as Vancouver Canada Geese (Armstrong et al., 2004). In addition to changes in habitat, these ongoing shifts in the elevation of the land surface also have implications for the hydrology of small coastal streams, many of which support salmon populations. As water tables drop in response to uplift events, it is possible that coastal streams fed by groundwater may experience reduced seasonal or perennial flows and become impassable for fish, limiting the range of certain anadromous stocks.

D. Potential impacts by recreation, hunting, and fishing

Most visitor use of coastal ANIA is concentrated in the caldera and on the Aniakchak River (NPS, 2005b). Raft trips are currently increasing in popularity with the recent invention of the packable raft, and weather permitting, trips can be reasonably affordable (Troy Hamon, NPS-King Salmon, personal communication, 2005). As advertised in an article in the *Anchorage Daily News*, visitors can fly into Port Heiden on Alaska Airlines, pack their raft, hike 35 km (22 miles) to the caldera rim, and paddle down the Aniakchak River "for a world class float" to the coast, and get picked up by a pre-arranged Beaver charter-- all for as little as $250 per person (Medred, 2005). As ANIA continues to become more "discovered" by outdoor enthusiasts, it is likely that visitor impact on the resources will rise accordingly. The lack of rangers in ANIA limits NPS regulation of human impact in the backcountry (e.g. human waste burial, campsite designation, food storage location; regulations are available in (NPS, 2005a) more difficult. However, at this date, the number of visitors is exceedingly low, and it is unlikely that wilderness users are having any measurable impact on the quality of park resources.

The main current visitor activities with potential resource impacts within coastal ANIA include: aircraft landings in the caldera and on the coast, rafting on the Aniakchak River, all-terrain/off-road vehicle use, and erosion/destruction of soils by hikers. Other possible impacts include distribution of exotic species, disturbance of wildlife, and sport fishing and hunting. Here we present the very limited amount of information regarding these activities within ANIA.

D1. Off-road vehicle use

According to (NPS, 2005a), there are no designated routes and no restrictions on load weight and size for off-road vehicles (ORVs) in ANIA. ORV use has been an ongoing issue for 8-10 years along part of coastal ANIA, and it is likely that the same persons are illegally driving ORVs through drainages and wetlands (Troy Hamon, NPS-King Salmon, personal communication, 2005). Without on-site rangers, it is difficult for the NPS to protect resources from ORVs. According to an NPS pilot who regularly visits the coast, two four-wheeler ATVs used the coastal area near the Aniakchak River outlet in 2003 (Alan Gilliland, NPS-King Salmon, personal communication, 2005). The ORV drivers claimed to be practicing their subsistence rights of hunting, and drove into the river at low tide, out to the point where the main ANIA archaeological site is, and into the grasslands for ca. 0.5 km (0.3 mi). By September 2003, a few months later, tracks in the beach grass and in the sand were gone, but the tracks in the tundra remained and were "very obvious" (Alan Gilliland, NPS-King Salmon, personal communication, 2005). In general, use of ANIA by ORVs is difficult because one needs to have a boat and the mechanical equipment to pull the machines in and out of the boat onto land; these technical complications probably account for the low incidence of ORV use. The threats that ORVs pose to water quality derive mainly from the disturbance of ANIA's abundant unconsolidated ash. An increase in the ash/sediment loads to streams can degrade the physical and chemical water quality attributes and can have cascading effects on stream macroinvertebrates and fishes (Cameron and Larson, 1992). Ash and soils within ANIA are generally held together delicately by seasonal snowcover and sparse vegetation and are easily susceptible to erosion by ORVs.

D2. Fishing and sport and subsistence hunting

Sport hunting is allowed in the Preserve portion of ANIA (not in the Monument) and subsistence hunting is allowed in both the Preserve and Monument (all of ANIA), although subsistence users have been lobbying to receive exclusive hunting rights to parts of the Preserve (Troy Hamon, NPS-King Salmon, personal communication, 2005). Beavers and wolves are the focus of these hunts, with some bear and moose hunting activity as well. However, given the small size and remoteness of ANIA, use of the resources by sport and subsistence hunters is relatively very small, and there are no major threats to ANIA's water resources identified based on these activities (Troy Hamon, NPS-King Salmon, personal communication, 2005). The only potential threat is the use of off-road vehicles by hunters and fishers (see section *IV.D.1. Off-road vehicle use* above).

Commercial, sport, and subsistence fishing along ANIA's coastline and in its streams is also relatively light (Troy Hamon, NPS-King Salmon, personal communication, 2005). The Aniakchak River supports only ca. 5,000-50,000 sockeye salmon, and many more pink salmon, which are of small commercial interest. Amber Bay on ANIA's coast has many shallow areas and reefs which make access by boat difficult; much better fishing opportunities exist in nearby Chignik Bay. No significant threat to ANIA's coastal water resources has been identified by these small-scale fishing activities.

D3. Hiking and camping

In her vegetative survey of the Aniakchak caldera, Hasselbach (1995) identified the presence of cryptogametic crusts in the caldera. She noted that they are typically present in high, barren areas that would be attractive foot traffic routes (Hasselbach, 1995 pg.24 and 46) and warned that the lack of designated trails may lead to the destruction of these delicate soils. Hasselbach (1995) also points out that visitor use of the caldera may impact the fragile plant communities in the caldera that are highest in density around Surprise Lake. Plant diversity in the caldera is also highest near the lake -- particularly in wind-protected areas that would be good candidates for campsites.

E. Exotic/invasive species and diseases

Nonindigenous aquatic exotic or invasive species that have been introduced or are moving into Alaskan waters include multiple species of fish, plants, and invertebrates (Appendix B). Water bodies of Alaska are likely to be invaded by nonindigenous species because the temperature ranges of oceans, rivers and lakes vary much less than terrestrial temperature ranges (ADFG, 2002a). The introduction of invasive species into Alaskan waters may be either accidental or due to negligence, and pathways of introduction include fish farms, aquaculture, transport on or in ballast water from ships or fishing vessels, live seafood trade, or sport fishing gear (ADFG, 2002a). In order to minimize the impact of invasive species in Alaska, the ADFG developed an Aquatic Nuisance Species Management Plan (ADFG, 2002a) with the purpose of focusing on preventing the invasion of those invasive species that are considered the highest threat (see the ADFG Invasive Species Website at http://www.adfg.state.ak.us/special/invasive/invasive.php.)

The presence and scale of invasive or exotic species in ANIA's coastal watersheds is not known or documented because no studies have focused on these issues (Troy Hamon, NPS-King Salmon, personal communication, 2005; Jim Larson, USFWS-King Salmon, personal communication, 2005). However, any increase in visitor use may result in the import of exotic species to the area in the near future, as may the continued northward migration of escaped farmed Atlantic salmon *(Salmo salar)* and other non-native migrating species. Northern pike (*Esox lucius*) pose a threat because they already occur in Interior Alaska, and they prey on small salmon and trout, potentially restructuring stream communities. Farmed Atlantic salmon in Washington State and British Columbia are accidentally released into the North Pacific Ocean each year and may affect native populations through disease, colonization, interbreeding, predation, habitat destruction, and competition (ADFG, 2002b). These farmed fish are thriving in the wild with recoveries in both British Columbia and Alaska and the first catches of Atlantic salmon in Southeast Alaska in 1991 (ADFG, 2002b). While ADFG has documented over 700 recoveries of Atlantic salmon in Alaskan waters, representing an estimated 3,000 immigrants per year, no Atlantic salmon have been documented in southcentral/southwestern Alaska or in the coastal ANIA area (Troy Hamon, NPS-King Salmon, personal communication, 2005). A possible invasive marine invertebrate species of concern is the green crab (*Carcinus maenas*) which is originally from northern Europe, became established in California in the 1990's, and has since become established in estuaries as far north as British Columbia. Bacteria, viruses, and parasites are also a threat to Alaskan waters because these can be easily introduced through nonindigenous species.

The avian flu virus has not been detected in North America; however, the potential exists for it to enter Alaska via migratory birds, particularly those coming from Asia. The Alaska Departments of Fish and Game, Health and Social Services, and Environmental Conservation are currently collaborating with the U.S. Fish and Wildlife Service to closely monitor wild birds, primarily in western Alaska, for the presence of the virus (State of Alaska, 2006). An outbreak of the virus has the potential to decimate bird populations in the ANIA region and elsewhere, and have cascading effects on the food web; however, it is difficult to foresee significant impacts on the quality and quantity of water resources if the virus remains limited to birds and does not spread to other species.

Chytridiomycosis is an emerging infectious disease caused by a waterborne fungus that, alone or in consort with other environmental stressors, has caused amphibian declines globally (Skerratt et al., 2007). This disease probably does pose a threat to resident wood frog populations in ANIA, but its prevalence in ANIA is currently unknown. It has, however, been detected on the Kenai National Wildlife Refuge and many other remote parts of Southeast Alaska (Reeves and Green, 2006)(S. Pyare, personal communication, 2007).

F. Harmful algal blooms

Harmful algal blooms (HAB) are caused by a few dozen marine phytoplankton that produce toxins. Although commonly called red tides, this term is misleading as with many HAB's, there is no discoloration to the water, and many seaweeds produce colored blooms. HAB's cause significant ecosystem, human health, and economic impacts (Anderson et al. 2000). HAB's have become a national and international research focus in the past decade. Most areas of the world have some form(s) of harmful algal bloom, although the frequency, severity and diversity vary greatly. One thing that is certain is that HAB's have been occurring more frequently and in more areas during the past few decades (Anderson, 1995; Burke et al., 2000). HABs have caused mass mortalities of marine bird, mammal, and fish populations, cause a variety of human illnesses that vary by type of toxic phytoplankton or diatom. Some cause respiratory problems among humans in certain geographic regions. Southwest Florida, for example, now issues health alerts and suggests that people with certain health problems stay inside and away from beaches during certain blooms. HAB's are known to cause a variety of shellfish poisoning (SP), including paralytic (PSP), diarrhetic (DSP), neurotoxic (NSP), and a fifth human illness, caused by finfish and not shellfish, is Ciguatera Fish Poisoning (CFP).

Harmful algal blooms have been documented for centuries. Early records from explorers and hunters describe outbreaks of illness after men ate local shellfish that are most likely the result of ingesting toxic dinoflagellates in shellfish tissues. The first recorded deaths due to PSP occurred during exploration of Puget Sound and the Strait of Georgia in 1791-1792 when several members of Capt. George Vancouver's crew died after eating shellfish from a cove near modern day Vancouver, BC. The earliest recorded event in Alaska was in 1799 when a party of Aleut hunters under the command of a Russian fur trading company ingested mussels. Within minutes, half the party experienced nausea and dry mouth, and two hours later, 100 hunters had died. Alaska has figured prominently in the discovery of HAB's and associated toxins, as the family of toxins responsible for PSP were named saxitoxins because they were extracted from the butter clam *Saxidomus giganteus* from Peril Strait, just northeast of Sitka.

The diversity of species that cause HAB's in Alaska is little studied. The largest problem caused by HAB's in Alaska is paralytic shellfish poisoning (PSP) from shellfish that have bioaccumulated the dinoflagellate *Alexandrium* sp. Alaska has one of the highest incidences of reported PSP in the world (Gessner and Schloss, 1996). Paralytic shellfish poisoning can cause paralysis, gastrointestinal problems, and respiratory arrest and can be fatal if prompt medical care and respiratory support is not available. There is no antidote. People have died in Alaska from PSP as recently as a decade ago, and there is at least one human health incident per year. Since 1973, there have been 176 incidences of PSP in Alaska from 66 outbreaks, with the majority in Southeast Alaska (Gessner, 1996).

Little is known about the distribution or abundance of HAB's in ANIA. The Alaska Department of Environmental Conservation is responsible for testing shellfish for PSP. Due to the geographic extent of Alaska (over 81,000 km (50,000 mi) of coastline) and the remote nature of many regions of the state, shellfish are only tested for PSP in association with a commercial harvest or mariculture facility. Non-commercial harvests are not tested, and people are advised not to eat shellfish that they collect. More information is needed in order to evaluate if HAB's are an issue of concern in ANIA. Any unusual incidences of mass mortalities of marine bird, mammal, and fish populations should be suspected as possible HAB-related events. NPS should advise against non-commercial harvests of shellfish because of the risks associated with PSP.

G. Coastal debris and garbage

No studies have been conducted to evaluate the magnitude and impacts of debris and garbage along ANIA's coastline, and there are no known efforts by the NPS to collect and rid the shores of such waste materials. However, coastal debris is thought to be a serious though largely unresearched issue in the SWAN (Alan Bennett, NPS-Anchorage, personal communication, 2005). A 1989 report from a coastal survey of the damage from EVOS on the coastal KATM area (northeast of the ANIA coast) described "the incredible amount of beach debris present at the high tide line among the driftwood… In many places you couldn't go 15 feet without seeing plastic of one kind or another—everything from pails, jerry cans, buoys, nets, floats, bottles, to very large items like rubber bumpers for boats"(Kavanagh, 1989). A marine debris and carcass survey several years later reported household garbage (probably cast-offs from ships), fish nets, crab and fish refuse, and timber industry refuse as the most frequently found items (NPS, 1994). Bottom trawl webbing was the most common fisheries refuse, followed closely by high-seas drift gillnets. Much of the garbage was of foreign origin, including Chile, Canada, the "U.S.S.R", and to the largest extent, Japan. By contrast, relatively little Cook Inlet off-shore petrochemical industry refuse was found. It is unknown whether the scale of the debris issue that exists in the Shelikof Strait and Lower Cook Inlet region is comparable to that along coastal ANIA, but it is very likely that at least some marine garbage ends up along the ANIA coast, particularly in its more protected bays where refuse may accumulate.

VI. Condition Overview and Recommendations

A. Condition overview

Based on our research of available data and our best professional judgment, we summarize the potential and existing stressors of ANIA water resources in the following table (Table 14).

Table 14. Existing, intermittent, and potential stressors of ANIA water resources.

Indicator	Freshwater	Intertidal, Bays & Estuaries	Coastal waters
Water Quality			
Nutrients/ Eutrophication	OK	OK	OK
Contaminants	PP	PP	PP
Hypoxia	PP	OK	OK
Temperature	PP	OK	OK
Pathogens	PP	OK	OK
Turbidity	OK	OK	OK
Habitat Disruption			
Coastal development	OK	OK	OK
Water quantity/ withdrawals	OK	OK	OK
Coastal erosion/shoreline modification by humans	OK	OK	OK
Natural geologic hazards	IP	IP	IP
Recreational, subsistence usage			
Rafting, hiking, camping	PP	PP	NA
Fishing and hunting	OK	OK	OK
Off-road vehicle use	PP	PP	NA
Other Indicators			
Oil spills	NA	EP	PP
Harmful algal blooms	NA	PP	PP
Aquatic invasive species	PP	PP	PP
Climate change	PP	PP	PP
Coastal debris and garbage	NA	PP	PP

Definitions: EP= existing problem, IP= Intermittent Problem, PP = potential problem, OK= no detectable problem,
shaded =limited data, NA= not applicable.

Overall, the freshwater and marine ecosystems in and adjacent to ANIA are dominated by natural influences with few potential problems of concern (Table 14). Although there are few data to directly support this assessment, we provide our rationale in more detail below.

Freshwater

ANIA is the least visited NPS unit in the nation; as such, human disturbance is extremely minimal. Water quality in freshwater areas is likely to be high and unaltered by humans due to the remoteness and inaccessibility of the unit. However, very few studies of stream, lake or groundwater water quality have been conducted. Most studies have focused on the caldera, and little research has been conducted in the Aniakchak River and other coastal stream watersheds. Existing studies have shown that some water-quality values (for temperature, pH, and aluminum) fell outside of the quality criteria allowed by federal and state water quality standards, although it is important to note that these "degradations" are of natural (volcanic) rather than anthropogenic origin and are therefore not subject to the same regulatory management. The samples from which such values were derived came from portions of the lakes, geothermal springs, streams within Aniakchak crater, and outside the caldera as well. Global contaminants such as Hg and POPs may pose a threat to freshwater water quality and biological health through 1) direct deposition and uptake into the food chain, and/or 2) via transport into watersheds by spawning salmon that accumulate these toxins in the marine environment. Habitat disruption is generally very limited, although the increasing popularity of fly-in rafting trips could lead to increased disturbance to fish and wildlife populations, as well as degradation of water due to garbage and human waste in or near streams and riparian areas. Additional threats to freshwater resources include trampling of cryptogametic soils and riparian vegetation by hikers and campers. There are no seasonal or permanent NPS rangers or other staff in ANIA and therefore, enforcement of recreational ethics codes is non-existent. There are no marked trails or designated camping areas. Large-scale freshwater habitat disruption may also occur due to natural geologic hazards such as volcanic eruptions, earthquakes, tsunamis, and uplift. In addition, no studies have been directed at aquatic invasive species. Finally, climate change has the potential to alter streamflow dynamics and decrease the number of lakes and streams within the park, both of which could affect fauna within ANIA.

Marine Coastal Waters and Bays & Estuaries

Water quality in marine and intertidal areas is high, but few studies of marine water quality have been conducted. The largest threat to intertidal and marine water quality is posed by oil spills from marine vessels (including oil tankers), accidents in proposed and ongoing oil drill platforms, oil refineries, storage areas, and transfer facilities in Cook Inlet, Shelikof Strait, and Prince William Sound. All of these are upstream from ANIA and could result in a human-caused error or be compromised from earthquakes, volcanic eruptions, and/or tsunamis. Lingering effects of the EVOS in 1989 persist along the ANIA coast and are now part of the baseline. Atmospheric deposition of global contaminants such as *Hg* and POPs poses a chronic threat to marine water quality. Habitat disruption along the coast is generally very limited, although off-road vehicle use could impair sensitive intertidal and or wetland habitat. Recreation and tourism usage is very low in the nearshore area, and these impacts are likely minimal. Sudden and massive disturbances that have occurred, or are likely to occur in the future due to natural physical hazards (volcanoes, earthquakes, tsunamis), may dramatically affect intertidal communities that are vulnerable to sudden, meter-scale uplift or subsidence events. No sampling has been conducted to evaluate the presence of harmful algal blooms, aquatic invasive species, or the extent of coastal debris on ANIA shores. The effects of climate change on the marine system are difficult to predict because of the unknown interplay between rising sea level and land surface uplift. However, it is clear that both of these processes have the potential to alter the coastal landscape and the ecology of intertidal and estuarine communities.

B. Recommendations

The SWAN is currently implementing their Vital Signs Monitoring Plan, which is based on a tremendous research and planning effort that is certain to greatly expand on the current level of understanding of water (and other) resources in the network. During the course of writing this report, we identified data gaps and areas in which further investigation or monitoring is warranted. These recommendations are numbered below (Table 15) and elaborated on in the following section.

Table 15. List of recommendations

Data access/management
1. Online archives of NPS publications and reports
2. Integration of water-resources information into centralized and web-accessible GIS

Water quality
1. Oil spill response planning
2. Establish baseline for marine contaminants
3. Assess threat from atmospheric and marine-derived contaminants
4. Expand on plans to establish baseline freshwater water quality and watershed condition
5. Evaluate and monitor impacts of tourism and recreation on water quality.

Biological resources and habitats
1. Continue to monitor recovery from EVOS
2. Invasive species survey
3. Planning for natural hazards
4. Wetlands inventory

Hydrology/Oceanography
1. Climate/weather stations
2. Streamflow gaging

B1. Data access/management

1. Online archives of NPS publications and reports

The SWAN has been making great progress at making park-related documents available in electronic format online. However, NatureBib is not yet publicly-accessible, and many important documents were referenced but not downloadable through NatureBib, an excellent searchable archive. At the time of our research (2005), the literature review in this report would not have been possible without a site visit to King Salmon, where we did manual searches through their filing cabinets. We have been informed that electronic archives are now (2007) available through the SWAN data manager.

2. Integration of information into centralized and web-accessible GIS

Data from surveys, monitoring activities, impairments, and inventories should be integrated into a centralized, publicly-available, web-accessible GIS, potentially the NPS Alaska Region GIS clearinghouse http://www.nps.gov/akso/gis/. In addition, several important GIS data sources are currently lacking. One example is wetland (e.g. NWI) boundary and classification data. This and other useful classified products for water resource monitoring could be derived through a combination of existing hydrological feature data sets, interpretation of existing aerial photos wherever these are available (e.g. AHAP products), and acquisition and classification of relatively inexpensive, moderate resolution, multispectral remote sensing imagery (e.g. 4-10 m IKONOS or SPOT) that encompasses all of ANIA. Imagery could be acquired by cooperating with other interested agencies (e.g. NOAA, AVO, DNR) with jurisdiction adjacent or near ANIA. In addition, this imagery could be useful for monitoring other hydrologic parameters within the park such as the extent of permanent snowfields and the number and aerial coverage of lakes and ponds. Finally, Shorezone GIS data and imagery could be an important source of baseline information for shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. This resource should be more fully explored to evaluate its potential applicability for monitoring structural and biological characteristics of coastal water resources in ANIA.

B2. Water quality

1. Oil spill response planning

The NPS should partner with other responsible agencies, Coast Guard, ADEC, etc., to develop an oil spill response plan, specifically Geographic Response Strategies, for the ANIA coast. Identification of critical habitats and areas of special concern in ANIA is a necessary first step to prioritize areas for oil spill response. NPS may want to partner with organizations developing circulation models for Cook Inlet and to predict potential oil trajectories. NPS may want to monitor future expansion of oil and gas facilities in Cook Inlet and Shelikof Strait.

2. Establish baseline for marine contaminants

Contaminant effects of the EVOS on ANIA shores are poorly documented. A contaminant survey could be conducted if residual effects are anticipated. Contaminants (from various sources) could be inventoried over a large spatial scale if the SWAN nearshore marine monitoring component of the I&M program were expanded to include contaminant analyses in mussels along ANIA. Alternatively, ANIA could adapt protocols developed by the NOAA Mussel Watch program. According to Mussel Watch, mussels are collected from the intertidal and then analyzed for over 70 polycyclic aromatic hydrocarbons (PAH's), polychlorinated biphenyls (PCB's), chlorinated pesticides, butyltins, and toxic trace elements, such as copper, cadmium and lead. Sediments at the test sites are also regularly analyzed for chemical contaminants, and shellfish from selected locations are analyzed for radionuclides. In addition, Mussel Watch monitors the health of mussel populations, including condition index, size frequency, stage of reproductive development, and prevalence and intensity of diseases, parasites and pathologies. ANIA could conduct this sampling once to establish a baseline. This activity would provide an opportunity to compare data to hundreds of others in the national program. The Marine Water Chemistry component of the SWAN Vital Signs Monitoring Plan does not include ANIA and only proposes to measure temperature and salinity (Bennett et al., 2006).

3. Assess threats from atmospheric and marine-derived contaminants

ANIA should partner with other agencies to assess the threat from global-scale pollutants such as mercury and POPs. Because these pollutants are not derived from localized sources, monitoring these pollutants in one park within the network would provide information that would be useful for assessing potential impacts in the other parks. The SWAN network could monitor future results from the ongoing WACAP project by the NPS Air Resources Division and the planned Mercury Deposition Network sites (to be funded by the Alaska DEC) in southcentral and southwestern Alaska. Studies on the influence of salmon carcasses on contaminants loads in ANIA streams, as well as studies on the role of wetlands in converting atmospheric mercury to methylmercury would greatly assist in evaluating the scale and magnitude of this potential problem. Direct atmospheric contaminant monitoring is not included in the SWAN Vital Signs Monitoring Plan (Bennett et al., 2006).

4. Expand on plans to establish baseline freshwater water quality and watershed condition

The SWAN Vital Signs Monitoring Plan (Bennett et al., 2006; Stevens and Olsen, 2004)will greatly enhance the understanding of baseline freshwater water quality in the network; however, no water bodies in ANIA are categorized as Tier 1, which would receive annual monitoring. The Aniakchak River drainage, including Surprise Lake, was designated as Tier 2 (sampling every 2-5 years). No ANIA waterbodies were categorized as Tier 3 (sampling every ~10 years, if at all). The Aniakchak River and its tributaries should be considered candidates for additional funding and support to increase the likelihood of monitoring over the long term. Physical, chemical, and biological parameters of interest could include: turbidity (streams), Secchi depth (lakes), temperature, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), pH, organic and inorganic nitrogen and phosphorus, sulfate, dissolved organic carbon (DOC), DOC quality, trace elements, organic pollutants, and pathogens (e.g. fecal coliform). Inventories of macroinvertebrate communities should also be conducted periodically.

5. Evaluate and monitor impacts of tourism and recreation on coastal water quality

Although visitor use in ANIA is exceedingly low, it appears to be on the rise. Visitors typically fly into the crater lake via float plane or access it by foot from Port Heiden, and raft down the Aniakchak River. There are no designated trails or campsites, no facilities, and no NPS rangers in the unit. There have not been any studies evaluating the impacts of visitor uses on the water and biological resources. We recommend that the NPS conduct studies to identify the location and density of visitors to the area (perhaps by requiring detailed permits), as well as investigate potential water-quality stressors due to disposal of garbage and human waste, ORV use, oil spills and leaks from boats and float planes, the use of unmaintained camping sites and trails, and the potential introduction of aquatic invasive species. We recommend that the NPS quantify and monitor the apparent rise in visitor use within ANIA and consider staffing a seasonal ranger in or near the caldera, if deemed appropriate.

B3. Biological resources and habitats

1. Continue to monitor recovery from EVOS

Coastal environments and biota impacted from the EVOS should continue to be monitored. Regular surveys of marine mammals should be continued by NMFS and USFWS, with the data for the park units archived by NPS. Nearshore marine monitoring is currently not included in the SWAN Vital Signs Monitoring Plan (Bennett et al., 2006).

2. Invasive species survey

Aquatic and marine environments should be surveyed for invasive species. Standard protocols, such as PVC settling plates as passive collectors in subtidal marine environments (Ruiz et al. 1997), could be used to survey invasive species. Freshwater streams should be monitored for the presence of potential invasive species such as Northern pike and Atlantic salmon. Only nonnative vascular plants are monitored by the SWAN Vital Signs Monitoring Plan (Bennett et al., 2006).

3. Planning for natural hazards

Future tectonic activity is inevitable in and around ANIA, and the likely effects of a large eruption, earthquake, tsunami, and/or catastrophic flood may have devastating short-term consequences to park resources. ANIA contains no human infrastructure within its boundaries or in its immediate vicinity and there is little that can be done to protect aquatic and biologic resources in ANIA from probable natural disasters such as a large volcanic eruption, earthquake, tsunami, or catastrophic flood. In the event of a disaster, it will be important to coordinate the rerouting of marine and air traffic away from the geologically active area, so that vessels and aircraft and any hazardous materials they may contain will not threaten ANIA resources in the event of their destruction. Further away from ANIA, petro-industrial infrastructure in the Cook Inlet region (e.g. Drift River facility, Valdez port) should be adequately maintained to withstand large-scale geologic events, which are inevitable in the entire southern Alaska region. Destruction of an oil storage facility hundreds of kilometers away could deleteriously impact the coastal region of ANIA, as was observed during the EVOS.

4. Wetlands inventory

The extent of wetlands resources in the park is not well documented. ANIA staff should work with the U.S. Fish and Wildlife Service to develop National Wetlands Inventory (NWI) for ANIA.

B4. Hydrology/Oceanography

1. Climate/weather stations

Climate change is one of the major threats to water resources in Alaskan parks. The surface water and to a lesser extent groundwater hydrology of coastal parks such as ANIA is particularly sensitive to climate change because the mean air temperature near sea level in southwestern Alaska during the winter is close to the freezing point of water. As a result, a relatively small increase in temperature can shift precipitation from snow to rain which, in turn, shifts the annual pattern of streamflow in coastal watersheds. Basic climate parameters in ANIA should be monitored, ideally at both a coastal and an interior location because of the strong climate gradient within the unit. Data collection should be automated, continuous, and archived with transmittal of information to national databases (i.e. NOAA, USGS). Physical parameters that should be monitored include: air temperature, relative humidity, precipitation, wind speed and direction, and incoming solar radiation. The SWAN Vital Signs Monitoring Plan includes provisions for monitoring climate in ANIA (Bennett et al., 2006).

2. Streamflow gauging

There are currently no gauging stations operating within ANIA, although streamflow is a key parameter in any water-quality monitoring effort. Information on seasonal discharge patterns as well as longer-term variations in streamflow would be highly useful for evaluating the effects of climate change on surface-water hydrology. In addition, streamflow data could provide information about flooding associated with volcanic activity. The Aniakchak River is the most appropriate candidate for a continuous stream gauge.

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Appendix A. Southwest Alaska Network vital signs in the context of the program-wide vital signs organization framework of the National Park Service. (Table 3-1 in SWAN Vital Signs Monitoring Plan, Bennett et al., 2006).

Level 1	Level 2	Level 3	SWAN Vital Sign	ALAG	ANIA	KATM	KEFJ	LACL
Air and Climate	Air Quality	Visibility and particulate matter	Visibility and particulate matter	-	●	-	-	●
	Weather and Climate	Weather and Climate	**Weather and Climate**	-	-	X	X	X
Geology and Soils	Geomorphology	Glacial features and processes	**Glacier Extent**	-	-	X	X	X
		Coastal / oceanographic features and processes	**Geomorphic coastal change**	-	-	X	X	X
	Subsurface Geologic Processes	Volcanic and Seismic Activity	Volcanic and Earthquake activity	●	●	●	●	●
Water	Hydrology	Surface water dynamics	**Surface hydrology**	X	X	X	X	X
	Water Quality	Water chemistry	Marine Water Chemistry			X	X	X
			Freshwater Chemistry	X	X	X	X	X
Biological Integrity	Invasive Species	Invasive/Exotic plants and animals	Invasive/Exotic plants	●	●	●	●	●
	Infestations and Disease	Insect pests	Insect outbreaks	-	-	●	●	●
	Focal Species or Communities	Marine communities	Kelp and eelgrass	-	-	X	X	X
		Marine invertebrates	Marine intertidal invertebrates	-	-	X	X	X
		Fishes	**ResidentLake Fish**	X	X	X	X	X
			Salmon	●	●	●	●	●
		Birds	**Black oystercatcher**	-	-	X	X	-
			Bald eagle	X	X	X	X	X
			Seabirds	-	-	X	X	X

Level 1	Level 2	Level 3	SWAN Vital Sign	ALAG	ANIA	KATM	KEFJ	LACL
			River otter (coastal)	-	-	X	X	X
			Brown bear	X	X	X	-	X
			Wolf	X	X	X	X	X
			Wolverine	X	X	X	X	X
			Moose	X	X	X	-	X
			Caribou	●	●	●	-	●
			Sea otter	-	-	X	X	X
			Harbor seal	-	-	●	●	●
		Vegetation complex	**Vegetation Composition and Structure**	X	X	X	X	X
			Sensitive Vegetation Communities	X	X	X	X	X
Human use	Consumptive Use	Consumptive use	Resource harvest for subsistence and sport	●	●	●	-	●
	Visitor and Recreation Use	Visitor usage	Visitor use	●	●	●	●	●
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land cover and use	**Land Cover/Land Use**	X	X	X	X	X
			Landscape Processes	X	X	X	X	X

X = Vital signs that the SWAN is working independently or jointly with a Network park, federal, state, or private partner to develop and implement monitoring protocols using funding from the vital signs or water quality monitoring programs

● Vital signs that are monitored independently of SWAN by a Network park, another NPS program, or another federal, state, or private agency. (category 2, information is obtained and used by SWAN)

- Vital sign will not be monitored in that park.

Appendix B. Non-indigenous invasive species that have invaded or could soon invade Alaska. The species listed are all highly invasive, have caused severe impact in areas they have spread to, and are capable of living in Alaska's climate. Many of these species have already spread to the Pacific Northwest and are a risk to Alaska. From ADFG (2002a).

Species	**Originally from…**	**Now located in…**	**Why it is a concern**
Fish:			
Northern Pike	Alaska	Spreading to other areas of Alaska	Highest priority threat to Southcentral Alaska. They eliminate or greatly reduce the native species. Cause damage to resident species (rainbow trout and grayling). Potential impact to coho salmon stocks.
Atlantic Salmon	Escape from Fish farms in BC and Washington	Cordova Ketchikan Yakutat Bering Sea	Serious threat to native species due to competition in stream habitat. Displace native fish by out-competing for food and spawning habitat.
Yellow perch		Kenai Peninsula	Compete with all resident fish species and salmon fry. This population has been eradicated.
Ornamental aquarium fish			Compete with and may feed on native species.
Invertebrates:			
Green crab	N. Europe	California to Vancouver Island	Out-competes resident species for shoreline habitat. Very aggressive.
New Zealand mud snail	New Zealand	Europe Asia Idaho Montana Wyoming California Arizona	May impact the food chain for native trout and the physical characteristics of streams themselves. A serious threat to Alaska's sport fisheries.
Chinese mitten crab	China	San Francisco Bay/delta Possible it is in Oregon's Columbia River	Similar life history to American eel and can move upriver hundreds of miles displacing native species. Feeds on salmonid eggs.
Zebra mussel	Europe	Great Lakes	Out-compete resident mussels, clog water intake lines, sequester nutrients for primary production.
Signal crayfish	W. Canada	Kodiak Island	Out-compete stream fauna, eat everything, can survive extended periods of drought and famine.
Spiny water flea	Europe	Great Lakes California	Displaces existing zooplankton communities, but is unpalatable to fish resulting in lower fish numbers.
Parasites:			
Whirling disease	Eurasian continent	Present in 22 states. Found in all western states except Arizona and Alaska.	Parasitic infection that attacks juvenile trout and salmon. Causes fish to swim erratically and in severe cases, to die.

Plants:

Hydrilla or water thyme	Originally from S. India and Korea.	Present in 15 states including California and Washington	Hydrilla is a noxious water weed that can quickly spread to become an impenetrable mat. Fills lakes and rivers completely until it “tops out” at the surface. Native plants are out-competed. Greatly slows water flow and clogs the area. Can alter water chemistry and oxygen levels. Hinders fish development.
Dotted duckweed	Australia and Southeast Asia	Present in 22 states including Oregon	This small floating plant grows rapidly into dense masses in still water covering the entire surface in a green “bloom”.
Purple loosestrife	Eurasia	Present in all states except Hawaii and Alaska. Also found in Canada.	Loosestrife is able to rapidly establish and replace native vegetation with a dense, homogeneous stand that reduces local biodiversity, endangers rare species and provides little value to wildlife.
Eurasian water-milfoil	Europe and North Africa	Present in 46 states including Alaska	Found in a variety of habits, becoming established in both impoundments and natural waters, sometimes brackish water or in clear, cool, spring-fed rivers. Problems include displacement of native vegetation, disruption of navigation and recreation by the formation of impenetrable mats, and decreased water flow.
Reed Canary grass	Eurasia	All but the southeastern portion of the US including Alaska. Also found in Canada.	Is invading freshwater wetlands and in some places choking channels of small streams. Its creeping rhizomes out-compete native grasses leading to less biodiversity.
Japanese knotweed	Great Britain	Sitka Juneau Other Southeast Alaska areas	Spreads rapidly, choking out native plants. Can spread along streambanks, shorelines, and estuaries. Loss of springtime cover and woody streamside vegetation causes destabilized stream banks and less woody debris in streams.
Foxtail barley	Western North America	Juneau Interior Alaska	Invades salt marsh habitats
Salt marsh cordgrass	Eastern seaboard of the US from Maine to Texas	Has spread to Canada and western US including Washington, Oregon, and California.	Able to trap sediment leading to higher deposition rates. Changes water circulation patterns. Competitive replacement of native plants and impacts native flora and fauna in intertidal zone. Also, decreases production of bottom-dwelling algae, changes bottom-dwelling invertebrate populations, and loss of shorebird foraging areas.
Dense-flowered cordgrass	Chile South America	California	Outcompetes native flora and impacts native fauna. Eliminates foraging habitat for shorebirds and waterfowl. Dense clusters slow the flow of water and increase sedimentation (raising the wetland).
Swollen	Southeastern US	Western	Grows in still or slow-moving water and

bladderwort	Washington	forms dense beds of floating plants. Impacts native plants and animals and water quality.

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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