LAKE CLARK NATIONAL PARK AND PRESERVE,

ALASKA

WATER RESOURCES SCOPING REPORT

Don P. Weeks

Technical Report NPS/NRWRD/NRTR-2001/292

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Don P. Weeks[1]

Technical Report NPS/NRWRD/NRTR-2003/???

Month, 2003

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United States Department of the Interior
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EXECUTIVE SUMMARY

Lake Clark National Park and Preserve (LACL) lies in a hydrologically complex environment in southwestern Alaska that has evolved around several volcanic and glacial events. This 4-million acre NPS unit includes over 6000 miles of rivers and streams that flow through marine, estuarine, palustrine, lacustrine, glacial, and volcanic environments. LACL includes the sixth largest lake in Alaska, Lake Clark, and three river segments designated as “Wild Rivers”: Chilikadrotna (11 miles), Mulchatna (24 miles), and Tlikakila (51 miles). The upper reaches of the Kvichak River watershed, which is the world’s most productive spawning and rearing habitat for sockeye salmon (*O. nerka*), extend into the park (National Park Service, 1999a).

Healthy water resources play an important role in the success of LACL’s diverse biota. The National Park Service (NPS) is aware of both widespread and local threats, which have the potential to degrade these pristine water resources. This, along with the lack of basic baseline water resource information, led the park to request assistance from the NPS Water Resources Division (WRD) to prepare this Water Resources Scoping Report (WRSR).

This report identifies and briefly describes the natural resources at LACL and the significant water-related issues that park management is challenged to address. The report also summarizes the park’s existing natural resources program to evaluate current staffing and natural resource management projects and to identify some of the park’s water resource management needs.

In certain cases, WRSRs meet the current water management needs for NPS units, where the number and complexity of issues are minimal. In such cases, park Resource Management Plan (RMP) project statements may be included in the report to provide NPS management with the necessary action plan(s) to address the high-priority issues.

For LACL, numerous water-related issues exist. Many of the issues presented in this report center around the lack of basic information (i.e., baseline data) that would better assist the NPS’s understanding of LACL’s water resources and appropriate management directions. Thus, the NPS may be unaware of significant and/or time-sensitive issues because the natural resource information is not available.

The contents of this report are limited to information made available to the author during the time this report was prepared. Where appropriate, issue-specific recommendation(s) previously proposed by NPS management via LACL planning documents (i.e., RMP) are included. As a result, descriptions of the natural resources and water resource issues vary in detail, and inclusion of issue-related recommendations are inconsistent.

A WRSR was recently completed (Weeks, 1999) for a neighboring NPS unit, Katmai National Park and Preserve (KATM). The descriptions for natural resources, legislation, watershed stakeholders, and water-related issues presented in this report duplicate some of the sections included in the KATM report. This is to be expected for parks located in the same geographic region. It is also important that "watershed stakeholders" are hearing consistent management objectives from neighboring NPS units. With both NPS units currently working toward a better understanding of their water resources, LACL and KATM can cost effectively address common issues through partnerships and coordinated projects.

As part of the effort by the NPS WRD to produce this report for LACL, WRD staff traveled to Anchorage and LACL in 1999. The purposes of this travel were to: 1) introduce elements of the WRSR effort to LACL, NPS-Alaska Support Office, and U.S. Geological Survey (USGS) staff, 2) become familiar with the water resources and high priority water-related issues at the park, 3) obtain pertinent information from park and other agency files, and 4) establish contacts with federal and state personnel and others with expertise on water resources in the region. The high-priority issues identified at LACL during this effort include:

- Baseline Inventory and Monitoring
- Climate Change and Influence on Water Resources
- Nutrient Cycling
- Coastal Management
- Minerals Extraction
- Crescent River Logging
- Private Lands
- Recreational Management
- Wetlands Management
- Spill Contingency Planning
- Water Rights
- Coordination

Each of these issues has aspects that affect the park's water resources, though some are not under NPS control; therefore, it is important to recognize that multi-agency communication and coordination are essential to successfully manage LACL's watershed. Based on the assessment of these issues, a recommendation and justification to produce a more comprehensive Water Resources Management Plan (WRMP) for LACL is presented at the end of this report. The WRMP process encourages other stakeholders to participate with the NPS during and after plan development. This process, if carried through, will encourage regional ownership of the WRMP, which is needed to effectively drive the plan's recommended actions.

INTRODUCTION

Lake Clark National Park and Preserve (LACL) encompasses approximately 4 million acres of public and private lands in southwestern Alaska and contains some of the most diverse water resources in the National Park system. The park and preserve include over 6000 miles of rivers and streams that flow through coastal, glacial, volcanic, and freshwater environments. The pristine headwaters for five major drainage basins are located within LACL's boundaries [the Kvichak River, Nushagak River, Kuskokwim River, Chakachatna River and Coastal basins]. The Kvichak River drainage basin is the world's most productive spawning and rearing habitat for sockeye salmon. LACL also includes the sixth largest lake in Alaska, Lake Clark, and three river segments designated as "Wild Rivers": Chilikadrotna (11 miles), Mulchatna (24 miles), and Tlikakila (51 miles) (National Park Service, 1999a).

It is important for the National Park Service (NPS) to differentiate between natural versus anthropogenic-impacted environments so that mandated management is appropriately implemented for LACL's water resources. This can be a challenge at LACL. For example, a stream void of biological diversity may be the result of natural volcanic influences and not a human-induced impact; thus, the NPS would seek to maintain this natural condition.

The objective of this report is to provide NPS management with a brief overview of LACL's diverse environments, existing water-related information and issues that pertain to LACL, while also identifying some of the "information needs" that will better assist NPS management in providing a greater level of water resource protection. At the end of the report, an evaluation of this information is presented to determine if a more comprehensive Water Resources Management Plan (WRMP) is warranted for this NPS unit.

The initial information-gathering effort for this report was a 10-day visit by the author to Anchorage and LACL in 1999. Information was derived from many sources, including interviews with park management and other Federal and State agencies (i.e., U.S. Geological Survey, Alaska Department of Environmental Conservation, etc.), and reviews of existing natural resources information with emphasis on water resources. The author was also fortunate to visit many of the remote sites in LACL (i.e., Port Alsworth, Lake Clark, Kontrashibuna Lake, Twin Lakes, Turquoise Lake, Cook Inlet coast), which provided a better appreciation of the diverse water resources and associated issues.

Location, Legislation, and Management

LACL is located approximately 150 miles southwest of Anchorage (Figure 1). This NPS unit is divided into a 2.6 million-acre park, located where the Aleutian and Alaska mountain ranges join together, and a preserve, which shares a common boundary with the park. The preserve lies immediately to the south and west of the park and includes less dramatic topographic relief than the park, with 1.4 million acres of foothills and tundra plains. Cook Inlet, which is a part of the Gulf of Alaska, is located along LACL's

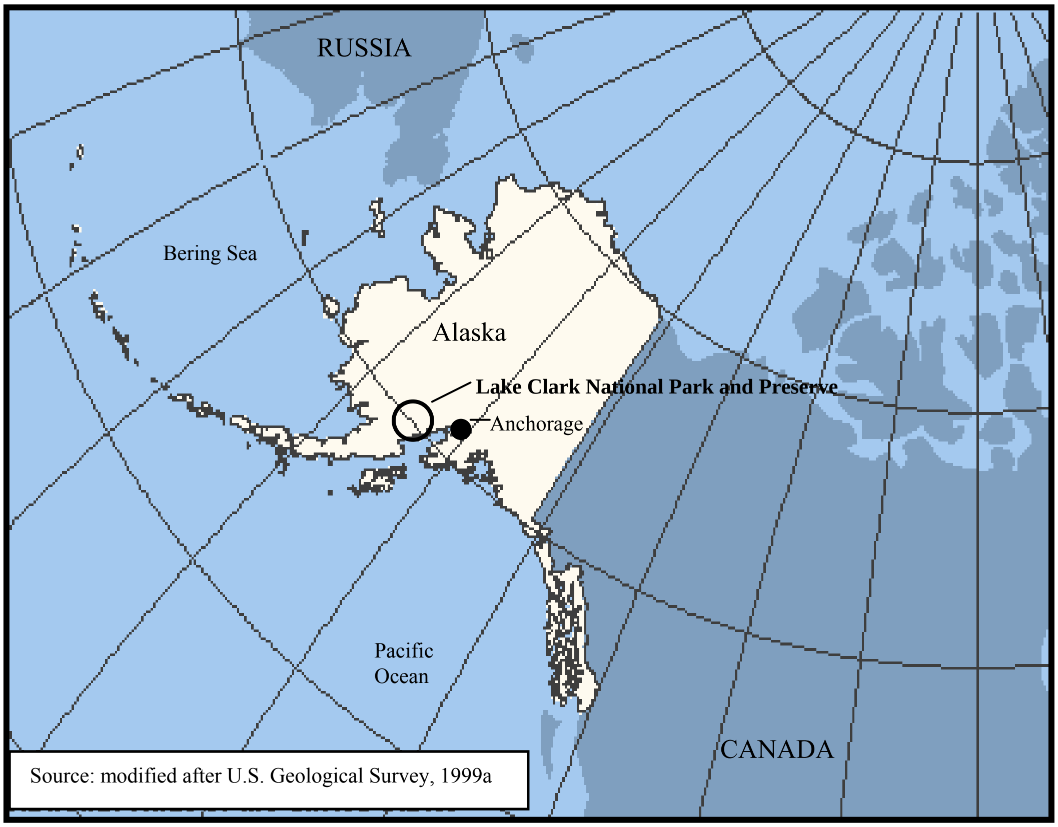

Figure 1. Regional Map, Lake Clark National Park and Preserve

southeastern boundary. The northern boundary cuts through the Alaska mountain range with the northeastern boundary cutting across the Chigmit Mountains. To the west, LACL's boundary cuts into interior lowlands that include the Kuskokwim, Kvichak, and Nushagak river basins. Iliamna Lake lies immediately south of LACL with the park's southern boundary separating Lake Clark and the Tazimina River from Six Mile Lake (Figure 2).

In 1978, President Carter designated 2.5 million acres as Lake Clark National Monument. In 1980, the park and preserve were established by the Alaska National Interest Lands Conservation Act (ANILCA) (P.L. 96-487). Congress specified in Section 201(7)(a) of ANILCA the purposes of LACL are to:

> Protect the watershed necessary for the perpetuation of the red salmon fishery in Bristol Bay; to maintain unimpaired the scenic beauty and quality of portions of the Alaska Range and the Aleutian Range, including active volcanoes, glaciers, wild rivers, lakes, waterfalls, and alpine meadows in their natural state; and to protect habitats for and populations of fish and wildlife including but not limited to caribou, Dall sheep, brown/grizzly bears, bald eagles, and peregrine falcons.

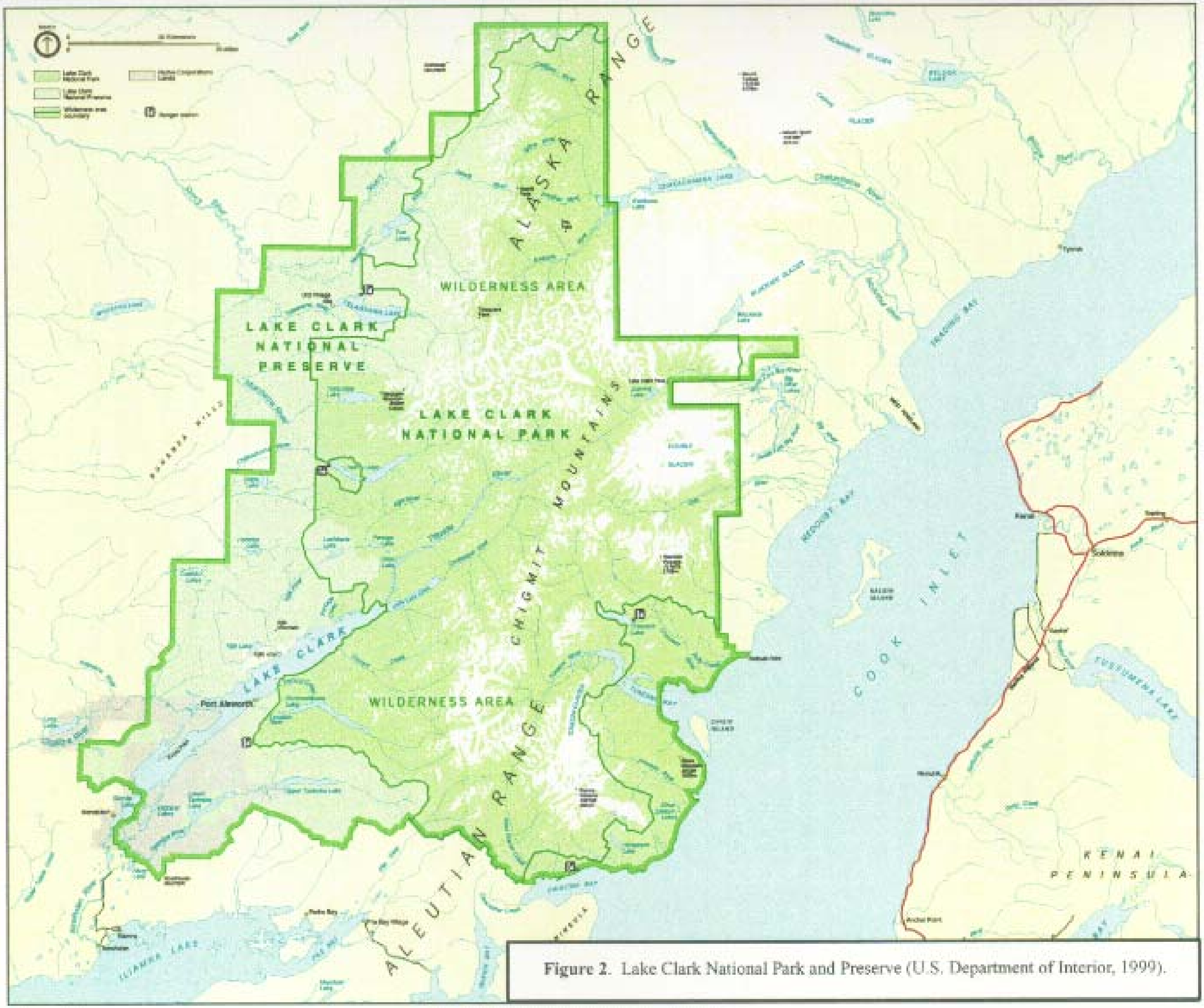

Figure 2. Lake Clark National Park and Preserve (U.S. Department of Interior, 1999).

Section 203 of ANILCA directed that LACL is to be administered pursuant to the NPS Organic Act. This act states that management of NPS units is committed to conserving the scenery and natural resources for the enjoyment of future generations (1916 NPS Organic Act, USC 1).

The Wild and Scenic River Act (16 USC 1271-1287) was approved in 1968. The Act establishes a National Wild and Scenic Rivers System and prescribes the methods and standards through which additional rivers may be identified and added to the system. Rivers are classified as wild, scenic, or recreational, and hunting and fishing are permitted in components of the system under applicable federal and state laws. Title VI, Part A, Section 601 of ANILCA provided for the addition of three river segments within LACL's boundary to the National Wild and Scenic Rivers System. The three rivers were the Chilikadrotna (11 miles), Mulchatna (24 miles), and Tlikakila (51 miles) rivers.

Section 701(b) of ANILCA established a Lake Clark Wilderness (2,470,000 acres) located mostly within the national park, but including some portions of the national preserve.

A significant percentage of lands within LACL's boundary, especially around Lake Clark and the LACL coast, are privately owned or selected for private ownership. While NPS regulations stemming from ANILCA and other authorities do not generally apply to private land in the park and preserve, there are numerous other federal, state and local laws that do apply. These include but are not limited to the Alaska Coastal Management Program, Alaska Anadromous Fish Act, Clean Water Act and Clean Air Act.

The National Parks Omnibus Management Act of 1998 provides clear direction for the NPS to obtain baseline resource information of high scientific caliber, and to manage park resources based on this information. LACL's Resources Management Program includes the following objectives to meet its legislative purposes (National Park Service, 1999a):

- Maintain and perpetuate the integrity of natural ecosystems and cultural resources.
- Protect habitat and populations of plants and animals for public enjoyment, scientific study, and compatible consumptive uses.
- Identify and protect all threatened and endangered species and their habitats.
- Collect baseline information on wildlife, plants, soils, water resources, fish, and air quality in cooperation with the state of Alaska, Native organizations and other agencies.
- Maintain natural processes to the greatest degree possible while protecting human life, private property, cultural sites, critical habitat, and endangered species. Minimize human-caused disturbances.
- Manage mining activities and sites to minimize damages to natural and historic resources and to protect historical values. Restore disturbed

landscapes that are not necessary for the interpretation of early 20th century settlement and the enjoyment of the visiting public.

- Identify and remove hazardous wastes that jeopardize human safety and adversely affect the environment.

DESCRIPTION OF NATURAL RESOURCES

Climate

In the park, the Chigmit Mountains divide the subpolar marine climate of Cook Inlet from the continental climate of interior Alaska. Local climatic conditions within these two regimes vary with elevation and the distance from mountains and large bodies of water (National Park Service, 1999a).

The climate on the east side of the mountains (coastal environment) is typically warmer and wetter than the west side. On the eastern side where the coastal lowlands form a wide transition between Cook Inlet and the mountains, the precipitation averages 15 to 20 inches annually. Precipitation increases dramatically, ranging between 40 to 80 inches per year, where the mountains immediately rise from Cook Inlet (LACL southeast coast). Mean coastal air temperature ranges from 10˚F to 32˚F during January, typically the coldest month. Mean temperature for the warmest month, July, ranges from 48˚F to 60˚F (National Park Service, 1983).

Port Alsworth, located west of the Chigmit Mountains, represents inland climate conditions. Annual precipitation at Port Alsworth is approximately 17 inches. Mean air temperature ranges from 12˚F in January to 56˚F in July. From 1960-1981, extreme air temperatures recorded at Port Alsworth were 86˚F and –55˚F (National Park Service, 1983).

Physiography

LACL's geographical setting and mountainous topography have resulted in several distinct physiographic regions. Racine and Young (1978) identified the following five physiographic regions within LACL's boundary: *Coastal* region, *Montane* region (Aleutian Range, Alaska Range), *Lake Clark–Kontrashibuna* region, *Foothill Lakes* region, and *Interior Lowlands* region (Figure 3).

The *Coastal* region is located in the southeastern part of the park and borders Cook Inlet. This region includes the lowlands between Cook Inlet and the upper elevations of the Aleutian Range (4000 - 5000 ft. msl). Large tidal fluctuations and glacial outwash along the coast have resulted in well-developed estuarine salt marshes. The *Montane* region includes the upper elevations of the Alaska and Aleutian ranges and represents a vast upland of alpine tundra, glaciers, permanent snow, ice and rock. Immediately west of the *Montane* region and penetrating these mountains in places along their west side are the *Lake Clark-Kontrashibuna* and *Foothill Lakes* regions. These regions are more closely related to interior and western Alaska than to the *Coastal* region to the east. The *Lake Clark-Kontrashibuna* region includes the Lake Clark watershed and constitutes low elevation valleys and mountain slopes bordering the several lakes. The *Foothill Lakes*

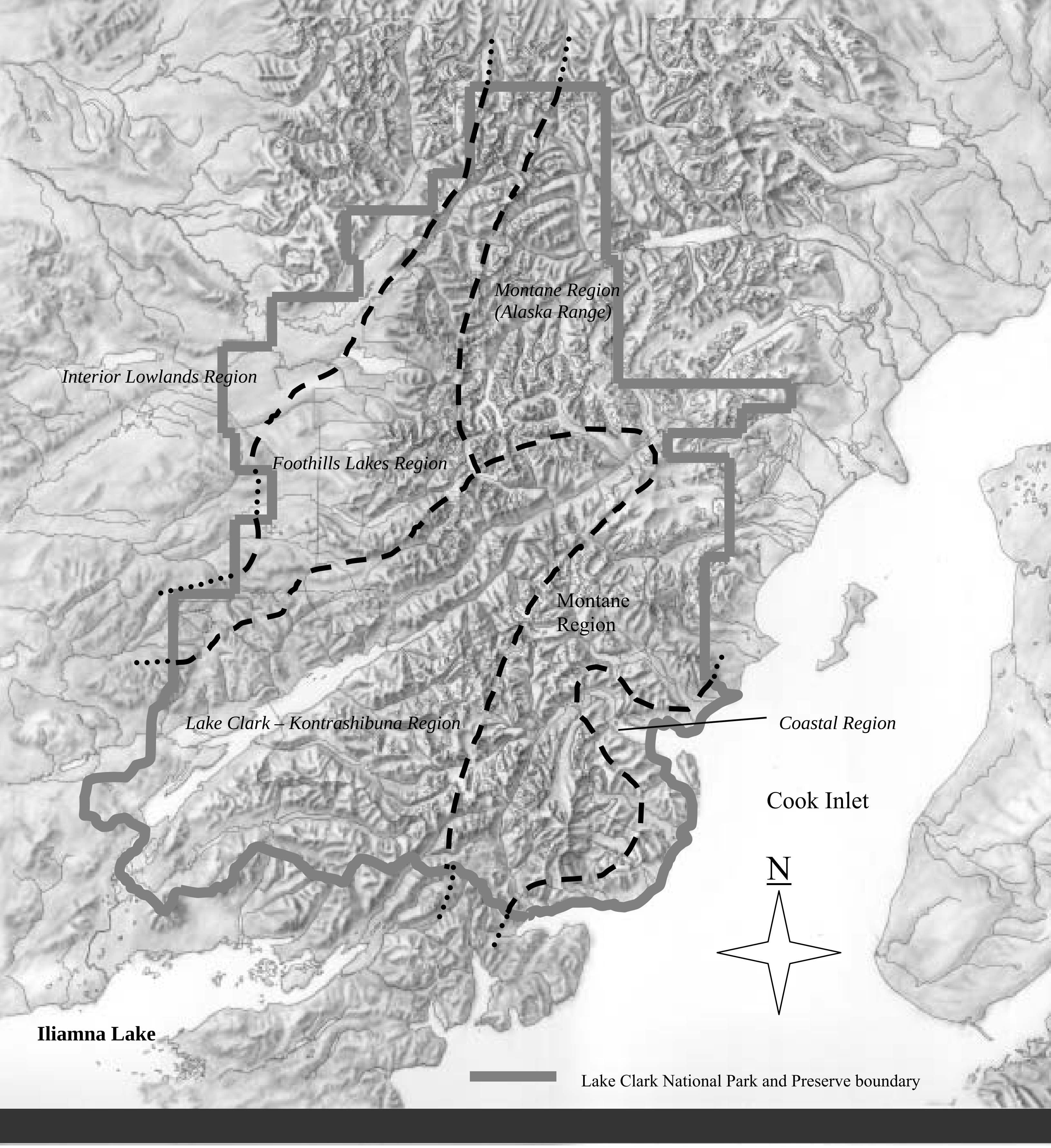

Figure 3. Physiographic regions within Lake Clark National Park and Preserve's boundary (modified after Racine and Young, 1978).

region occupies the high plains and plateaus of moraines just west of the mountains. The area is characterized by a series of large glacial lakes fed by meltwater from the *Montane* region. From south to north the main lakes are: Twin Lakes (1979 ft msl), Turquoise Lake (2504 ft msl), Lake Telaquana (1219 ft msl), and Two Lakes (1132 ft msl). The *Interior Lowlands* region occupies a small relatively flat area in the northwest corner of LACL. Drainages here include the Telaquana River and the Stony River, which flow west into the Kuskokwim River. Elevations of these broad flat valleys are low (around 1050 ft msl), and the climate is more typical of interior Alaska than the other four physiographic regions in LACL.

Geology

In geologic time, the region is not particularly old. Excluding a few greenstone deposits (395-440 million years old), rock outcrops formed between the earth's beginning (4.6 billion years ago) and 225 million years ago (end of the Paleozoic Era) are absent. This is because LACL is the scene of a dynamic, living geology. A young landscape shaped by uplift, intrusion, earthquakes, volcanism, and glaciation.

The Aleutian Range in LACL is a segment of the circum-pacific *Ring of Fire*, one of the most active volcanic belts in the world. Quaternary volcanism in the Aleutians is the result of plate convergence, approximately 7.0 cm/year, between the American and Pacific plates (Figure 4) (Kienle and Swanson, 1983). Modern tectonism is evident from the frequent strong earthquakes and four active volcanoes in the region (Redoubt, Illiamna, Augustine, and Douglas). Clusters of shallow and deep seismicity, with some magnitudes exceeding 6.0 on the Richter scale, have been recorded beneath Iliamna, Augustine, and Douglas volcanoes (Hampton, 1982). The most recent series of eruptions in the park was by Redoubt Volcano in 1989-90.

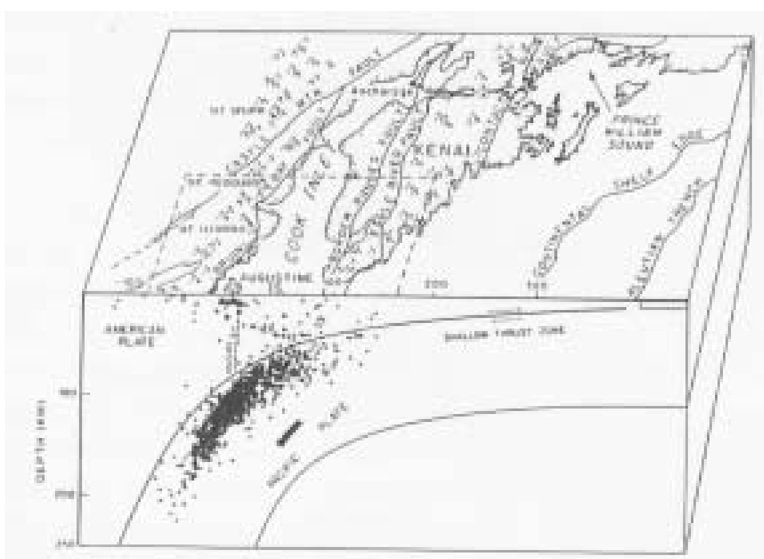

Figure 4. Subduction zone of Pacific Plate along the coast of Lake Clark National Park and Preserve illustrating locations "+" of individual earthquake hypocenters or initial rupture points (Stone, 1983).

Most of the southern portion of LACL, east of Lake Clark, consists of sedimentary and metamorphic rock of Mesozoic age. The geology in the northern half of the park is dominated by Tertiary and Mesozoic intrusive rocks (Dale and Stottlemyer, 1986). In detail, the geology and associated structure are very complex with igneous, metamorphic and sedimentary lithologies interacting at various scales.

Two major thrust faults are located within LACL (Figure 5). The Bruin Bay Fault can be traced 300 miles from Becharof Lake on the Alaska Peninsula to Mount Susitna, northwest of Anchorage, bisecting Chinitna and Tuxedni bays. The Lake Clark Fault, also referenced as the Castle Mountain Fault by Stone (1983) in Figure 4, runs approximately 80 miles to the northeast end of Lake Clark (Alaska Geographic Society,

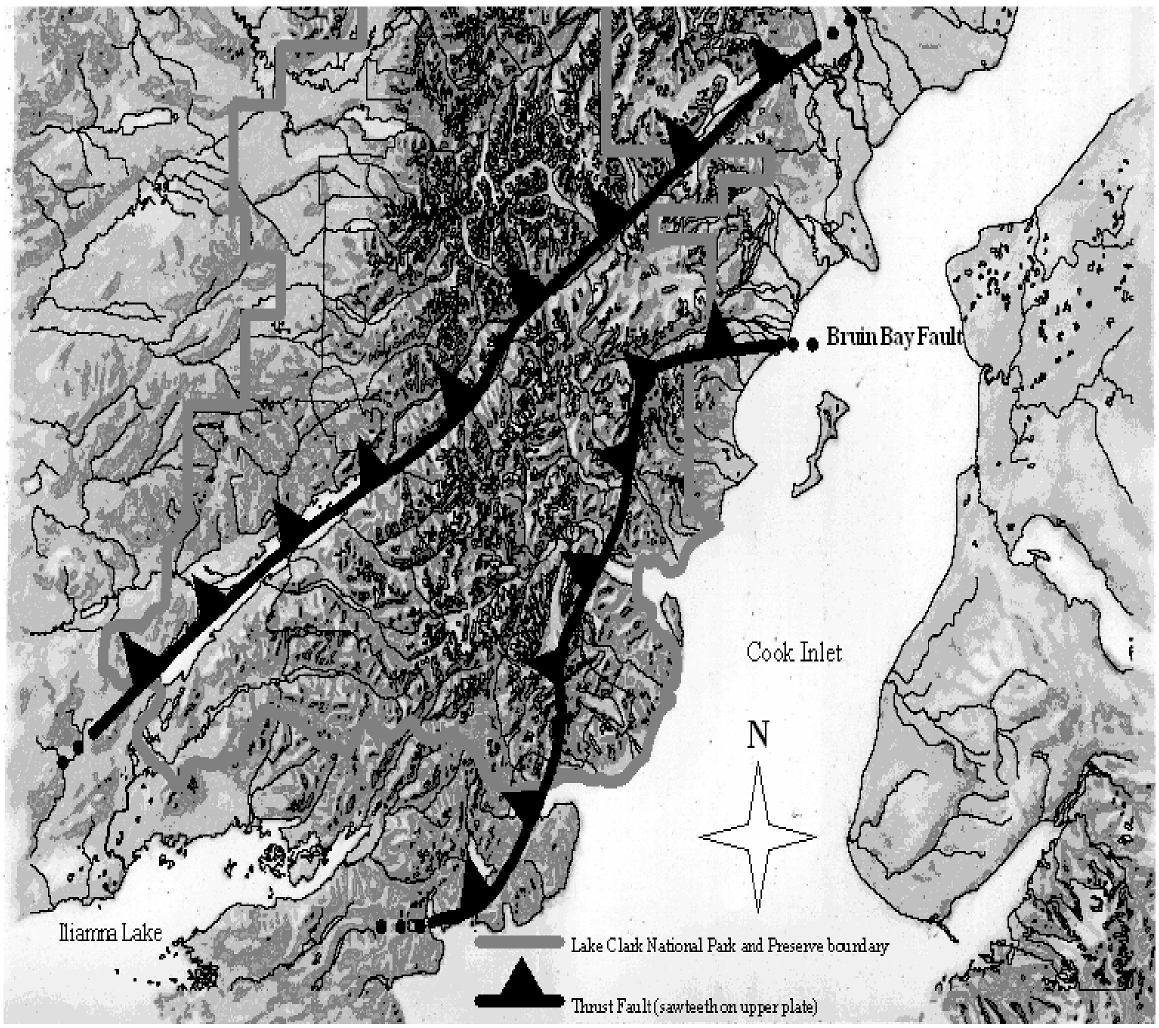

Figure 5. Location of Bruin Bay Fault and Lake Clark Fault in Lake Clark National Park and Preserve.

1986). The Lake Clark Fault underlies Lake Clark, structurally producing the lake's long linear geometric shape. The fault is characterized by a right lateral displacement of approximately 8 miles (Ivanhoe, 1962).

Soils

Currently, there have been no comprehensive soil surveys conducted in LACL (Natural Resources Conservation Service, 1998). In fact, minimal soil survey work has been conducted in Alaska. In general, soils in LACL are young, poorly developed, extremely variable and derived from glacial or volcanic processes (Racine and Young, 1978). The land surface below 1500-2000 ft. (msl) elevation has been scoured by Pleistocene glaciation. The topography above approximately 2000 ft. (msl) is either too steep to retain soils, covered by snow and ice, or at too great an elevation for soil-forming vegetation to grow. Soils west of the northern-most lakes (Twin Lakes, Turquoise Lake and Telaquana Lake) are better developed and support suitable rangeland for a healthy caribou herd (Chamberlain, 1989).

Hydrology

Watersheds

The Alaska and Aleutian mountain ranges form a continuous watershed divide separating the coast from the interior. LACL's most dominant interior drainage basin is the 3000 mi^2 Lake Clark drainage, which feeds Little Lake Clark, Lake Clark and Six Mile Lake (Brabets, pers. comm., 2000). The Lake Clark drainage is part of the *Kvichak River Basin* (see Figure 6), which drains Lake Clark (143 mi^2) and Lake Iliamna, the largest lake in Alaska (1226 mi^2). The 60-mile-wide basin extends northeastward from the northeast tip of Bristol Bay (Kvichak Bay) approximately 170 miles into the northwest slopes of the Aleutian Range. This basin also drains part of Katmai National Park and Preserve (Alagnak Wild River). The *Kuskokwim River Basin* drains the Stony, Necons, and Telaquana rivers, located in the northern portion of Lake Clark National Preserve, into Kuskokwin Bay. This large basin is approximately 500 miles long and averages 100 miles in width. The *Nushagak River Basin* drains the Mulchatna and Chilikadrotna rivers, located along the western portion of LACL, into Bristol Bay and is approximately 220 miles long and 100 miles wide. Along LACL's eastern boundary is the coastal drainage basin, which includes the *Chakachatna River Basin*. Streams along the coast drain the eastern mountain slopes to Cook Inlet (U.S. Department of the Interior, 1952). These coastal drainage basins include the following park drainages: Chilligan River, Igitna River, Neacola River, Drift River, Crescent River, Tuxedni River, Johnson River, and West Glacier Creek. The major drainage basins within LACL's boundary are presented in Figure 6.

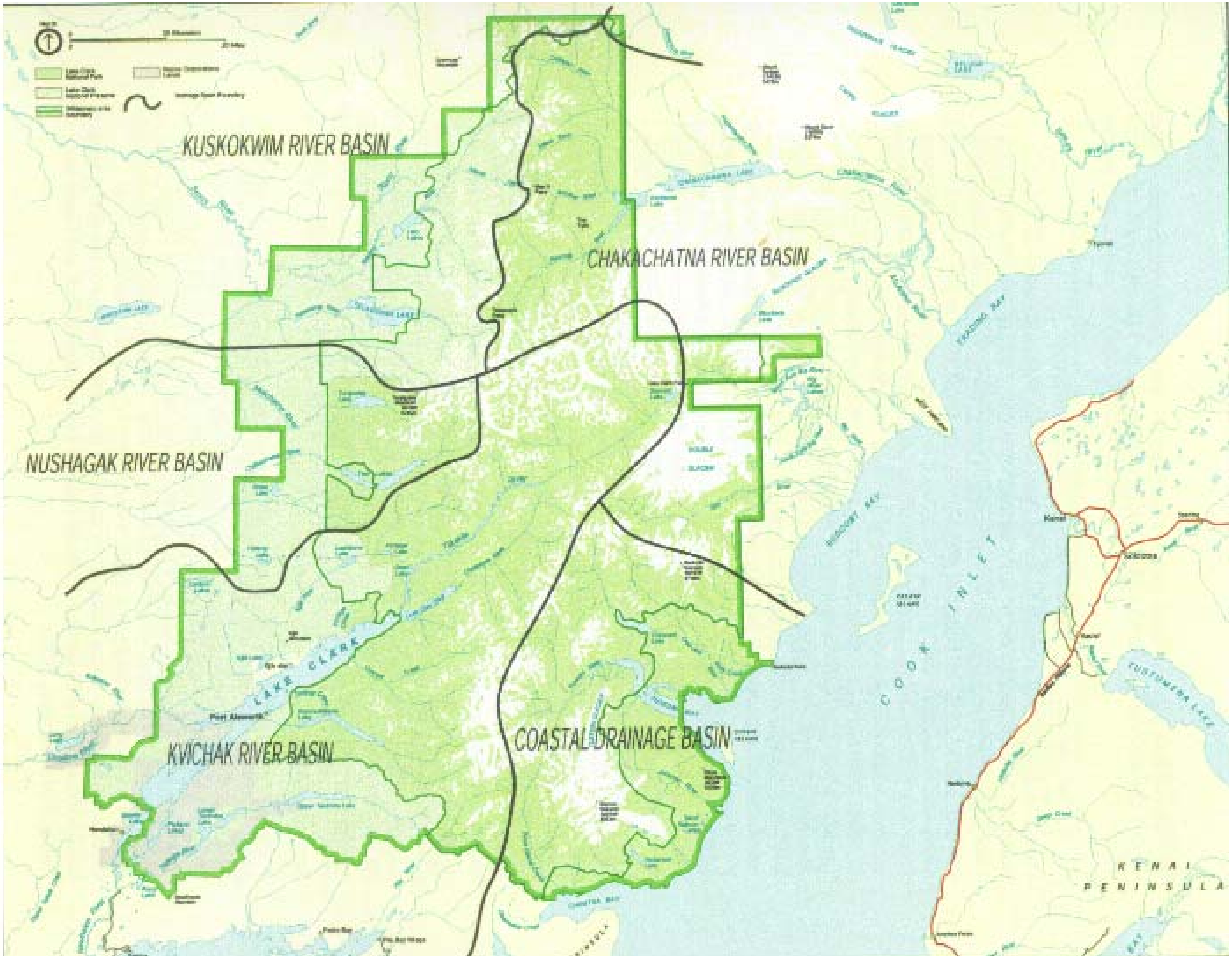

Figure 6. Major Drainage Basin Boundaries within Lake Clark National Park and Preserve (modified after U.S. Department of the Interior, 1999).

Surface Water

Freshwater Environments

Lakes

Over 20 major lakes of varying geometry (Table 1) and water chemistry dot LACL's landscape (see Figure 6). Major lakes located within the *Kvichak River Basin* include Lake Clark, the largest lake and most prominent geographic feature in the park, with a drainage area of 2942 mi^2 (Brabets, pers. comm., 2000). Discharge from Lake Clark varies seasonally from 1060 – 42,370 ft^3/s and is a major water source for the *Kvichak River Basin* (Demory et al., 1964). Lake Clark's discharge measured in 1999, using more accurate Acoustic Doppler equipment, ranged from 10,500 ft^3/s in November to 21,400 ft^3/s in August (Brabets, pers. comm., 2000). Kontrashibuna Lake feeds the Tanalian River, which discharges into Lake Clark immediately southwest of Port Alsworth. The lake is glacial in origin and fed directly from snowfields, small high gradient tributaries, and a major inlet stream at its east end. Portage Lake is a major water source for the Kijik River. This clear deep lake (maximum recorded depth = 170 feet) was the most alkaline (total alkalinity as $CaCO_3$ = 136 mg/L) of the lakes sampled within LACL in 1978 (Alaska Department of Fish and Game and National Park Service, 1980). Lachbuna Lake is also a major component of the Kijik River drainage, located approximately 18 river miles upstream of the Kijik River's outlet (Lake Clark). Kijik Lake is another major water source for the Kijik River. Although the lake bottom drops off sharply along the east and west sides of this deep lake (maximum recorded depth = 325 feet), significant littoral areas have established on the north and south ends. Several springs located at the south end of Kijik Lake contribute to the lake's recharge. Otter Lake, located on the western side of the Tlikakila River approximately seven miles upstream of the river mouth, is a shallow lake with no inlet streams. A small outlet connects the lake to the Tlikakila River. The upper and lower Tazimina Lakes feed the Tazimina River, where a hydroelectric facility was recently constructed in the preserve. The two lakes are the catch basins for a 350-mi^2 watershed. The Pickerel Lakes (Upper, Middle, Lower) empty into Sixmile Lake via a short outlet stream. Caribou Lake, located on the western preserve boundary, is one of several small lakes in the headwaters of the Koksetna River. This relatively small lake is primarily fed by snowmelt and springs from nearby alpine tundra hills (Alaska Department of Fish and Game and National Park Service, 1980).

Lakes located in the *Nushagak River Basin* include Turquoise Lake, the initial headwater source for the Mulchatna River. The main inlet stream, which originates from a glacier several miles away, enters the eastern end of the lake. Twin Lakes are the upper watershed source for the Chilikadrotna River. These two lakes occupy a glacial basin and are connected by approximately 0.3 miles of river. Fishtrap Lake, located along the preserve's western boundary is a major water source of the Little Mulchatna and Chilikadrotna rivers. Snipe Lake, also located on the western preserve boundary, feeds a small tributary to the Chilikadrotna River (Alaska Department of Fish and Game and National Park Service, 1980).

Table 1. Approximate length, width, and maximum-recorded depth for major lakes located within Lake Clark National Park and Preserve (source: Alaska Department of Game and Fish and National Park Service, 1980 unless otherwise noted).

Lake	Approximate length (miles)	Approximate width (miles)	Max recorded depth 1978-79 (feet)
Lake Clark	40[1]	3.7[1]	1056[2]
Kontrashibuna Lake	13	1.0	ns
Portage Lake	1.25	0.5	170
Lachbuna Lake	2.5	1.0	121
Kijik Lake	2.0	0.75	325
Otter Lake	0.75	ns	75.5
Upper Tazimina Lake	8.5	0.75	337
Lower Tazimina Lake	7.3	1.8	203
Upper Pickerel Lake	0.75	ns	62
Middle Pickerel Lake	1.5	ns	7
Lower Pickerel Lake	2.3	ns	8
Caribou Lake	0.7	ns	ns
Turquoise Lake	5.0	1.5	338
Upper Twin Lake	7.0	0.75	275.5
Lower Twin Lake	5	0.5	128
Fishtrap Lake	2.2	ns	78.5
Snipe Lake	2	0.8	52.5
Telaquana Lake	9.3	2.9	>426.5[3]
Two Lakes	4	1	>174[3]
Crescent Lake	6	2	ns
Hickerson Lake	2.3	ns	134.5

[1] data source (Donaldson, 1967), [2] data source (Wilkens, 2001), [3] depth exceeded length of survey equipment, ns = not surveyed

Lakes located in the *Kuskokwim River Basin* include Telaquana Lake, a 16-mi^2 lake that is the principal source of the Telaquana River. This deep lake (maximum-recorded depth > 425 feet) has an abundant littoral habitat in the western third of the lake, with a smaller littoral area in the extreme eastern end (inlet) of the lake. Two Lakes is actually one lake nearly bisected by a spit, and is a major source of the Necons River (Alaska Department of Fish and Game and National Park Service, 1980)

Two major lakes located within the *Coastal Drainage Basin*, immediately south of the *Chakachatna River Basin*, are Crescent and Hickerson lakes. Crescent Lake is the largest coastal lake in the park. The lake lies in a glacially cut valley that feeds the Crescent River. Hickerson Lake is located on the southeastern slope of Iliamna Volcano. This snow-fed lake does not have a surface outlet (Alaska Department of Fish and Game and National Park Service, 1980).

Streams

LACL contains over 6000 miles of streams. Streams located in the *Kvichak River Basin* include the tributaries for Lake Clark. The northeast section of Lake Clark is fed by three principal tributaries: the Tlikakila River [drainage area = 622 mi^2], Chokotonk River [drainage area = 158 mi^2], and Currant Creek [drainage area = 165 mi^2] (Brabets, pers. comm., 2000). These three streams issue from glaciers and constitute approximately 60% (estimated from summer flow data) of the major stream input to Lake Clark (Demory et al., 1964). Portage Creek is a small stream that enters Lake Clark from the north. There was a mining operation several miles upstream of the creek's mouth (Alaska Department of Fish and Game and National Park Service, 1980). The mining operation consisted of placer mining with evidence of hydraulic methods (Kucinski, pers. comm., 2000). In 1999, there was a request to startup the mining operation (Knuckles, pers. comm., 2000). The Kijik drainage consists of the Kijik River [drainage area = 298 mi^2 (Brabets, pers. comm., 2000)], a glacial (turbid) stream, and the Little Kijik River, a clearwater stream. The Little Kijik River feeds Kijik Lake before joining the Kijik River. Kijik Lake and the Little Kijik River compose the second largest red salmon spawning area in LACL. The Tanalian River [drainage area = 205 mi^2 (Brabets, pers. comm., 2000)], a glacial stream that passes through Kontrashibuna Lake, enters Lake Clark just southwest of Port Alsworth. Tanalian Falls, approximately 0.5 miles downstream from Kontrashibuna Lake, is an impressive barrier that prevents salmon from migrating further upstream. The Chulitna River [drainage area = 1157 mi^2 (Brabets, pers. comm., 2000)] drains tundra and lowlands and enters Lake Clark at Chulitna Bay, a large but shallow (10 – 65 ft.) bay. The river is a long (approximately 90 miles) slow flowing stream (1.5 - 2.0 ft/sec) that has a brownish color due to high organic content (Alaska Department of Fish and Game and National Park Service, 1980). In 1999, the U.S. Geological Survey recorded discharges at the mouth of the Chokotonk River, Tlikakila River, Currant Creek, Kijik River, Tanalian River, and Chulitna River. These data are presented in Table 2.

Table 2. Discharge data (ft^3/sec) recorded in 1999 using Acoustic Doppler equipment (Brabets, pers. comm., 2000).

Month 1999	Chokotonk River	Tlikakila River	Currant Creek	Kijik River	Tanalian River	Chulitna River
Mar	ns	25.3	ns	ns	ns	ns
May	ns	510	ns	ns	ns	ns
Jun	2190	ns	2670	1750	5920	4090
Jul	1200	ns	1590	857	1620	1400
Aug	1950	5850	1280	1130	1850	4060
Sep	ns	ns	885	758	650	3160
Oct	260	870	278	431	543	2200

Note: each value represents a single measurement collected at each stream mouth during the respective months.
ns = not sampled

The Tazimina River connects Upper and Lower Tazimina lakes and enters Sixmile Lake near its outlet, the Newhalen River. The U.S. Geological Survey monitored stream flows on the Newhalen River (Station 15300000) from 1951 to 1967, and from 1982 to 1986. Daily flow summaries for this period of record are graphically presented in Figure 7. As illustrated in this graph, peak discharge occurs during summer melting of the previous winter's snow and ice.

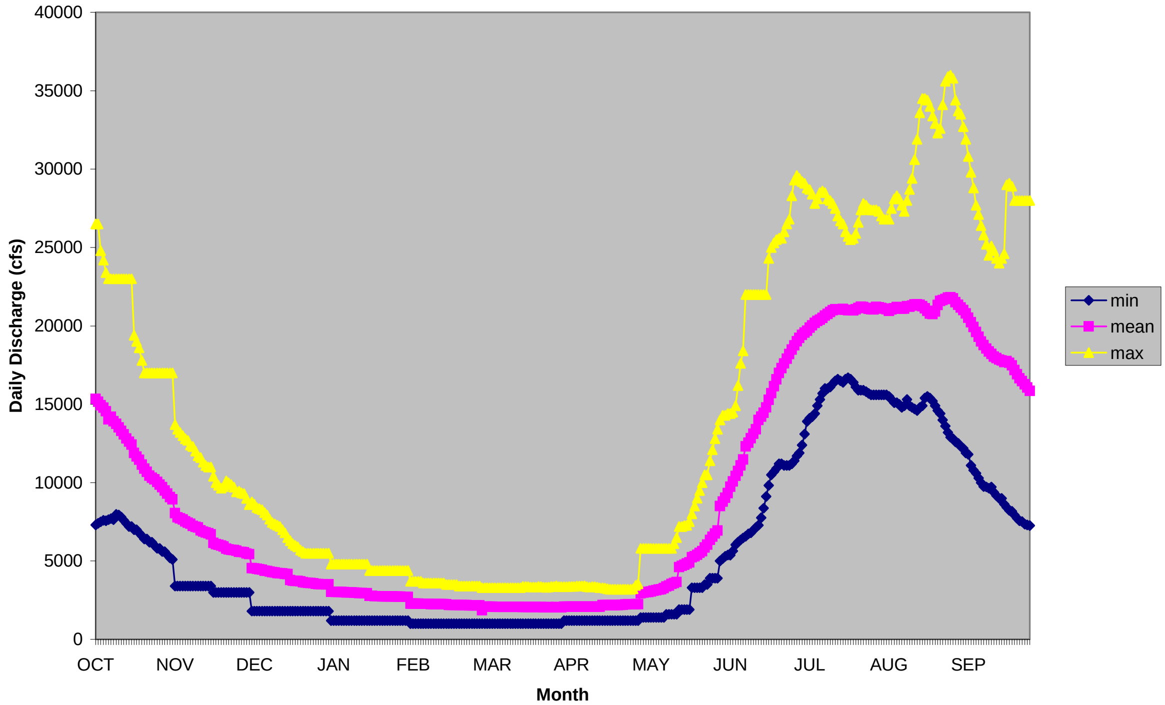

Figure 7. Newhalen River daily discharge summary (1951-67, 1982-86), Nondalton, AK - USGS Station 15300000.

The *Nushagak River Basin* includes the Chilikadrotna River that originates at Twin Lakes and flows southwesterly for approximately 60 miles before joining the Mulchatna River. Only the river's extreme upper section is included in LACL where mid-channel depths ranged from 3.3 – 8.2 feet and velocity averaged 3.3 ft/sec in 1978. The Mulchatna River originates at Turquoise Lake and flows southwesterly for approximately 217 miles to its confluence with the Nushagak River. In LACL, the river is approximately 50 meters wide with a recorded velocity of 3.3 ft/sec in 1978 as it meanders through a moraine deposit. The river increases in velocity through the Bonanza Hills as the gradient increases to 47 feet/mile (Alaska Department of Fish and Game and National Park Service, 1980).

The *Kuskokwim River Basin* includes the Necons River that flows out of Two Lakes and into the Stony River. The Telaquana River drains from Telaquana Lake before joining the Stony River.

The *Chakachatna River Basin* and the other LACL coastal drainages include all the streams that empty into Cook Inlet. The Neacola, Chilligan, Igitna, and Another rivers flow outside the park through Kenibuna Lake, located on the park's northeastern boundary, and into Chakachamna Lake. The outlet for Chakachamna Lake is the Chakachatna River that flows into Cook Inlet or joins the McArthur River before entering Cook Inlet. The Drift River is a braided system that drains the Chigmit Mountains, including Redoubt Volcano, before emptying into Cook Inlet. The Drift River Marine Terminal, located at the mouth of the river, presents several issues for the park that are discussed later in the report. The Crescent River empties into Cook Inlet just north of Tuxedni Bay, a sensitive salt marsh area. Currently, there are several issues related to timber harvesting that are discussed later in this report. The Johnson River drains the glaciers and snowfields on the southeastern slope of Iliamna Volcano. The U.S. Geological Survey, in cooperation with the NPS, has started monitoring the Johnson River for discharge and water chemistry in response to increased mining interests in the area. This issue is discussed in detail later in the report.

Wetlands

LACL contains extensive freshwater and saltwater wetlands, which exist in all five physiographic regions presented in Figure 3. Approximately 30-40 percent of LACL may be classified as wetlands (National Park Service, 1999a). At lower elevations (typically < 2500 ft msl), where there is periodic flooding or poor drainage, distinctive wetland ecosystems are common in the park (Racine and Young, 1978). A wetland must have one or more of the following three attributes: (1) at least periodically, the land supports predominately hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al., 1979).

The park's wetlands represent transitional environments, located between uplands and deepwater areas. Flora within these wetland systems exhibits extreme spatial variability, triggered by very slight changes in elevation. Temporal variability is also great because the surface water depth is highly influenced by changes in precipitation, evaporation and/or infiltration. Racine and Young (1978) described four different wetland ecosystems in LACL: 1) tidal salt marsh, 2) peat bogs, 3) fresh water marsh (bordering small ponds and river valleys), and 4) aquatic (shallow water in ponds and lakes that support aquatic vegetation). The U.S. Fish and Wildlife Service and NPS have established an interagency agreement to further develop wetland inventory maps (1:40,000 scale) for LACL (Knuckles, pers. comm., 2000). Details to this effort are discussed later in the report.

Glaciers, Lake Ice, and Snowpack

As evident in Figure 7, the hydrologic cycle in the park is influenced in part by extensive glaciers and snowfields that supply vast quantities of silty meltwater to the headwaters of drainage basins during the summer months. Glacial ice, much of it associated with Redoubt and Iliamna volcanoes, covers approximately 30% of the park. Most of the glaciers in the park have retreated dramatically in the last four decades, which indicates that melting is occurring faster than snow accumulation (National Park Service, 1999a).

Seasonal ice and snow cover affects the characteristics of aquatic ecosystems. They control the amount of light reaching the unfrozen water beneath the ice (Prowse and Stephenson, 1986). Ice can also prevent gas exchange between underlying waters and the atmosphere and may commonly lead to depletion of dissolved oxygen and the build up of reduced gasses such as CO_2, CH_4 and H_2S (Rouse et al., 1997). The processes accompanying ice formation during freeze-up and break-up have a wide range of effects on the bed, banks, and biota of lakes and rivers. These include frazil ice (aggregate of ice crystals formed in supercooled turbulent water) impact on fish and invertebrates, anchor ice growth, elevated water levels, channel blockage and increased scouring (Prowse, 1994.)

The snow line in LACL begins between 4000 – 5000 ft msl on the east side of the mountain ranges and approximately 8000 ft msl on the west side (Karlstrom, 1964). The overall absence of advanced forest at the higher elevations allows for little mitigation of runoff waters. Water quality from melt water in LACL is likely influenced by the bedrock (Dale and Stottlemyer, 1986).

Although permafrost is not prevalent in LACL, it is distributed sporadically at considerable depth in isolated areas of predominately fine soils where insulation is high (Chamberlain, 1989). Permafrost can influence the hydrologic cycle. For example, permafrost can impede precipitation from recharging aquifer systems. This could result in a greater surface runoff contribution to lake and stream recharge.

Coastal Environments

LACL's marine shoreline extends north from Chinitna Bay approximately 125 miles to Redoubt Point. According to an inventory of the physical and biological resources of LACL's coastline prepared by Bennett (1996), LACL's coastal environments are among the most important and biologically productive ecosystems in the Gulf of Alaska. The trophic relationship between shorebirds, seabirds, ducks and intertidal infauna may represent the most significant predator-prey relationships along the park's coastline (National Park Service, 1999a). Table 3 provides an inventory summary of the park's coastal environments. Salt marsh and mud flats make up most of LACL's coastline (22% of the total length each; and 42% and 24% of the total area, respectively). The management of lands along the LACL coastline can be complex since large blocks of land were conveyed to native corporations or are still being adjudicated under the Lands Act (Bennett, 1996).

Table 3. Approximate length and area of shoreline types along the coast of Lake Clark National Park (modified after Bennett, 1996).

Segment Type	Length (ft) [mi]	% Total Length	Area (acre^2)	% Total Area
salt marsh	101,957 [19.3]	22	1314	42
wide mud flat	98,637 [18.7]	22	736	24
wide sand flat	79,321 [15.0]	18	387	12
wide sand beach	68,087 [12.9]	15	97	3
wide sand and gravel flat	31,140 [5.9]	7	307	10
Cliffs w/ narrow sand & gravel	27,058 [5.1]	6	16	1
Narrow sand & gravel flat	12,117 [2.3]	3	21	1
Gravel alluvial fan	11,999 [2.3]	3	46	1
Cliffs w/ narrow gravel beach	9,193 [1.7]	2	7	<1
Cliffs w/ narrow sand beach	4,462 [0.8]	1	20	1
Ramp w/ narrow sand beach	6,585 [1.2]	1	3	<1
river channel			159	5
Total	**450,556 [85.3]**		**3113**	

Volcanic Environments

There are two active volcanoes within the boundaries of LACL; Redoubt and Iliamna. Extensive physical changes in riparian and aquatic habitats have resulted from volcanic-induced disturbances in the Cook Inlet region. Along with ash deposition, eruptions in the region have caused massive inputs of water and sediment into stream channels emanating from glaciers and snowfields on the volcanoes (Dorava and Milner, 1999).

Redoubt Volcano is drained on the north by the Drift River, on the east by Redoubt Creek, and on the south by the Crescent River, all of which flow into Cook Inlet. The volcano has produced at least 30 large tephra-forming eruptions during the past 10,000 years. Eruptions in 1902, 1966, 1968, and 1989-90 produced ash and generated floods in the Drift River by melting part of the volcano's extensive glacial cover (Till et al., 1992). The 1989-90 volcanic eruptions altered the hydrologic and geomorphic conditions of a 126-mi^2 area north and east of the volcano. Volcanic activities that affected the watershed include an ice and rock avalanche, pyroclastic surge and flow, and lahars (mudflows composed chiefly of volcaniclastic materials). The eruptions melted and eroded snow and glacial ice, destroyed riparian vegetation, filled the valley bottom with sediment, and altered stream channel geometry (Dorava et al., 1993)

In 1990, a study of Lake Clark (Stottlemyer, 1990) was conducted to repeat the basic limnological measurements recorded during a 1985-87 multiple lake study (Chamberlain, 1989) to determine how physical properties of Lake Clark and surrounding lakes may have been altered by ash inputs from the 1989-90 Redoubt eruption. According to Stottlemyer (1990), turbidity was considerably higher throughout Lake Clark after the eruption, decreasing light penetration and reducing the lake volume in which phytoplankton can photosynthesize by more than 70%.

Some impacts from volcanic eruptions are short-term (< 5 years), while others last much longer. In comparing macroinvertebrate community composition in the Drift River, after the 1989-90 Redoubt eruption with nearby undisturbed streams, Dorava and Milner (1999) found the Drift River macroinvertebrate communities still recovering after 5 years.

Hydroelectric Development

The Iliamna-Newhalen-Nondalton Electric Corporation provides electricity to the communities of Nondalton, Iliamna, and Newhalen located immediately south of LACL. In the past, residents in this area had to rely on diesel fuel for all power generation. To meet the current and future energy demands for the area, a hydroelectric facility was completed in 1997 on the Tazimina River in LACL (Knuckles, pers. comm., 2000). The 700 kW facility is located at river mile 9.5 on lands owned by the Iliamna Natives Limited and the Bristol Bay Corporation (HDR Engineering, Inc., 1992). The hydroelectric facility consists of an intake structure, penstock (430 ft. long, 60-inch diameter), powerhouse, and tailrace, with a buried transmission line (24.9 kV) that follows a 9-mile access road. The electricity generated from this facility eliminates the need to transport thousands of gallons of diesel fuel by barge to the area. The hydroelectric design uses natural "run-of-the-river" flows to power the turbines, which should create no noticeable effects in the Tazimina River flow regime, except between the intake and tailrace. At this location, approximately 4% to 10% of flows are diverted from the river between the months of June and October. During winter low flow months of November through May, between 10% to 100% of the river flow is diverted. The facility was designed to have minimal, if any, impact to river discharge, alkalinity, pH, free carbon dioxide, or dissolved oxygen downstream from the powerhouse [Williams (1995); HDR Engineering, Inc. (1995)].

Ground Water

There is minimal information available on LACL's ground water resources, but some basic hydrogeologic principles can be inferred from the park's geology and geomorphic features.

Glacial deposits typically present favorable conditions for ground water. Streams that issue from the edge of glaciers pick up large loads of unconsolidated sediments, dumping the coarser materials some distance downstream. These outwash gravels occur in the form of outwash fans and outwash terraces and constitute shallow but productive aquifer systems. Where moraines dam up melt water, fine-grained sediments can accumulate producing aquitards or confining beds (Mandel and Shiftan, 1981).

Hydrologic properties in volcanic terrain vary greatly, making predictions about ground water uncertain. Some lavas contain productive aquifers, while others are practically impermeable (i.e., good porosity caused by gas bubbles but poor permeability or interconnection of these pores). Loose pyroclastic rocks (pumice, ash, scoria) can be quite permeable when fresh, but the finer-grained varieties lose much of their permeability through compaction and weathering. Ground water quality can also be greatly influenced by volcanics. For example, noxious ions such as boron, arsenic and fluoride can be present at concentrations harmful for human consumption (Mandel and Shiftan, 1981).

LACL also contains coastal aquifers that are influenced by salt water, and aquifers contained in crystalline rocks (igneous units) that are influenced by faults and fractures. Based upon the variability in the park's hydrogeologic characteristics, ground water flow, depth, quantity, and quality can differ greatly over very short distances.

Water Quality

Some water quality data within LACL's watersheds are available. Early limnological studies of the aquatic systems that include LACL were of a broad or general nature [Burgner et al. (1969), Mathisen and Poe (1969), Alaska Department of Fish and Game and National Park Service (1980)]. A 3-year study of chemical, physical and biological characteristics of surface waters in the park, [Dale and Stottlemyer (1986), Stottlemyer and Chamberlain (1987), and Chamberlain (1989)], provided more specific water chemistry data on selected surface waters in LACL. Currently, there is an effort by the University of Alaska (Fairbanks) to better assess the limnology of Lake Clark (Wilkens, 2001).

Based on the limited data to date, surface water quality in the park appears to be of excellent quality. Highly mineralized areas, active volcanism, and large glaciers contribute to unique natural water quality in the park. For example, chloride and sulfate concentrations exceeded the secondary drinking water criterion of 250 milligrams per liter (mg/L) in the Drift River in April 1990 (870 mg/L and 980 mg/L, respectively) and in Crater Creek near the Redoubt Volcano in October 1991 (330 mg/L and 880 mg/L, respectively). In this case, water quality was found to exceed the drinking water criteria, but the fact that the relatively high chloride and sulfate concentrations resulted from natural, opposed to anthropogenic, influences eliminates the need for NPS interaction. This is likely the case for pH, too, where pH was measured 41 times at 12 monitoring stations from 1954-1991. Seven observations near Iliamna, the Tanalian River near Port Alsworth, and the Drift River near Kenai were outside the pH range of 6.5 – 9.0, which is EPA's chronic criteria for freshwater aquatic life. All 7 observations were less than or equal to pH 6.5. The lowest pH was reported in the Drift River (pH = 4.0) in April 1990, which was likely influenced by the 1989-90 Redoubt eruption (National Park Service, 1997).

A 3-year water quality study (1985-1987) by Michigan Technological University resulted in two reports [Dale and Stottlemyer (1986) and Stottlemyer and Chamberlain (1987)] and a master's thesis by Chamberlain (1989). The primary objective of the study was to acquire baseline data for LACL in order to establish a benchmark against which future change could be assessed. The following is a select summary of findings presented from this study, which included Lake Clark, Two Lakes, Telaquana Lake, Turquoise Lake, Twin Lake, Lachbuna Lake, Kijik Lake, Upper and Lower Tazimina Lake, Kontrashibuna Lake, Sixmile Lake, Tlikakila River, Chokotonk River, Currant Creek, and the Tazimina River. It should be noted that one limitation to this 3-year study is that water quality parameters were not measured past 40 meters, with most measurements limited to 25 meters, whereas Lake Clark is over 300 meters deep. The following water quality information was obtained from Chamberlain (1989), who evaluated the 1985 – 1987 study.

> Water temperature data collected from a mid-lake sampling site showed that Lake Clark was thermally uniform in June, but during the warmer summer months thermal stratification resulted (Figure 8). Dissolved oxygen was close to saturation, and never dropped below 10 mg/L. There were two distinct lake turnover periods, June and October, where dissolved oxygen profiles were uniform through the water column. Light penetration data for the summer indicated that sediment input has a dramatic affect on light attenuation. The euphotic zone (water layer in which sufficient sunlight is present such that photosynthesis prevails over respiration) was reduced at the northeastern lake stations in July. Comparing the 1985-86 light attenuation data, it appears that mid-July is the time of peak sediment input to Lake Clark, which originates from glacial meltwater. The sediment influence is largely confined to the upper northeastern half of the lake. By August, sediment distribution throughout the lake has occurred, and lake compensation depths (top of lake to bottom of euphotic zone) are reduced. The limited total suspended solids data indicate that the Tlikakila River contributes, by far, most of the sediment input to Lake Clark. Two other fluvial systems, Currant Creek and Kijik River, also contribute substantial amounts of suspended solids to the lake.
>
> The most obvious regional trend in lake chemistry when going north of Lake Clark is an increase in dissolved potassium relative to calcium (Telaquana Lake and Two Lakes). This increase is likely due to bedrock characteristics of the Alaska Range. Also, most lakes in LACL are very low in nitrate concentrations suggesting the basins feeding the lakes have little organic material and low aquatic productivity. The order of cation dominance in Lake Clark for each of the three study years was $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > H^{+}$. The order of anion dominance in Lake Clark during the study period was $HCO_3^- > SO_4^{2-} > Cl^- \geq NO_3^-$. The differences in ion dominance in LACL's surface waters reflect the geology of the region.
>
> In Lake Clark, seasonal decreases recorded for nitrate (NO_3^-) in 1986 and 1987 and the decrease in NO_3^- down lake were likely a result of biological impact. NO_3^- was found to be the most common nutrient limiting primary production in Lake Clark. [*LaPerriere (1999) identifies other nitrogen-limited lakes in Alaska.*] In Lake Clark, phosphate (PO_4^{2-}) also stimulated productivity, especially at the lower lake stations. Nutrient addition was found to stimulate during spring and early summer, but became less limiting, if not inhibitory during the late summer and

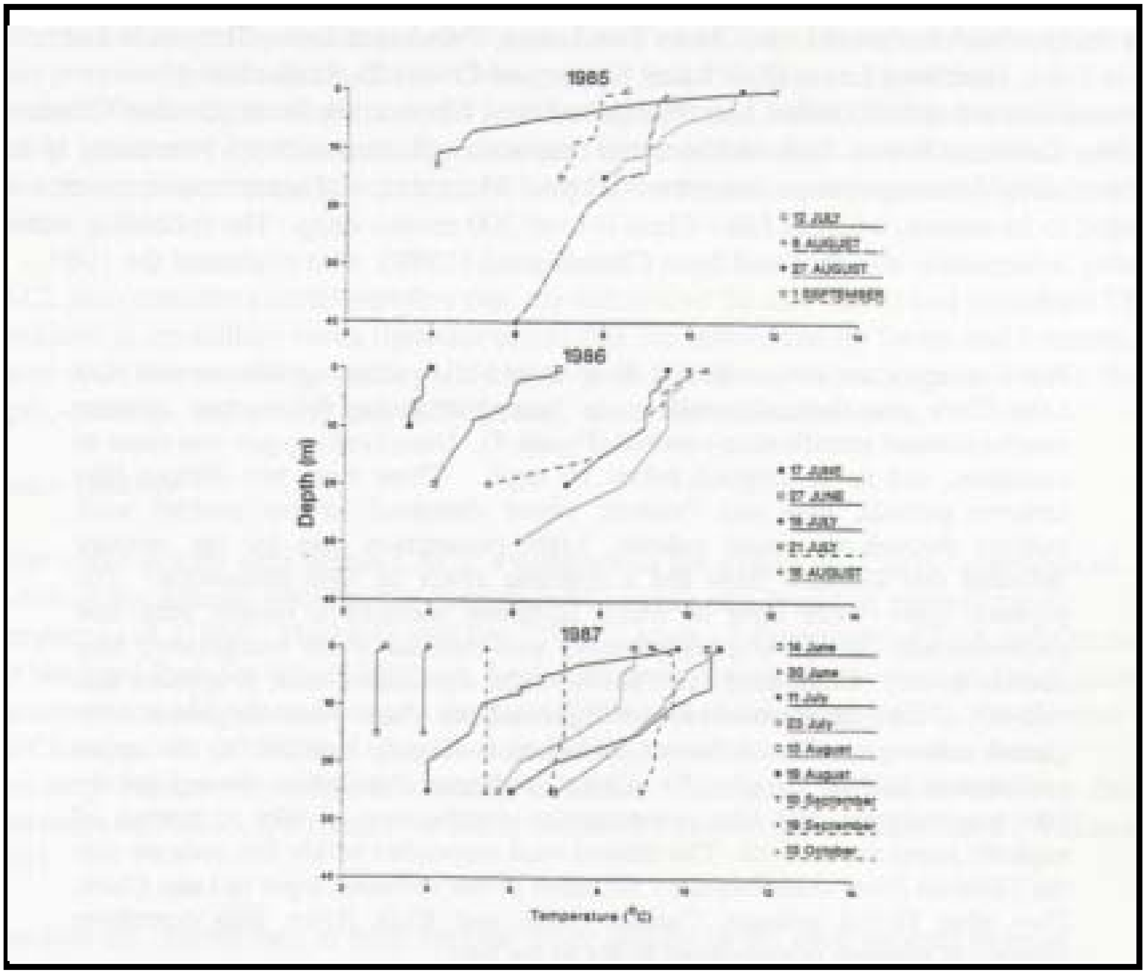

Figure 8. Water temperature profile data collected from Lake Clark, 1985 – 1987 (Chamberlain, 1989).

fall. These results point out that NO_3^- and PO_4^{2-} are important seasonally in controlling the productivity in Lake Clark. Natural factors that likely contribute to the variability in nutrient limitation include: sediment inputs, salmon decaying, and thermal stratification. [*Will the reduction of nitrogen from increased salmon harvests significantly impact phytoplankton species composition? Will anthropic contributions of nitrogen and phosphorus impact the natural integrity of the lake?*]

Four of the 8 Lake Clark stations sampled for fecal coliform and fecal streptococci bacteria had countable numbers. Fecal coliform ranged from 0 to 36 colonies/100 ml, and fecal streptococci ranged from 0 to 4 colonies/100 ml.

The water temperature and dissolved oxygen of all the smaller lakes studied in LACL were similar to those of Lake Clark. Each of the smaller lakes experienced uniform water temperatures through the water column in the spring and fall, and each was slightly stratified in summer. Dissolved oxygen was always at or near saturation. Light penetration varied widely between and within the smaller lakes studied (Table 4). Kontrashibuna, Kijik, and Upper and Lower

Tazimina lakes remained clear through the sample season, while the remainder of the lakes studied began the summer clear, becoming turbid later in the season. The 1987 light extinction coefficients recorded for Lake Clark were 0.30, 0.35, and 0.65 for June, July, and August, respectively.

Table 4. Light extinction coefficients for LACL lakes in 1987 (Chamberlain, 1989).

Lake	June	July	August
Upper Tazimina	0.056	0.077	0.099
Lower Tazimina	0.15	0.077	0.15
Lower Twin	0.072	0.042	0.17
Kijik (K13)	0.13	0.072	0.19
Kijik (K14)	0.10	0.11	0.19
Lachbuna	0.16	0.27	0.72
Telaquana	0.11	0.17	0.74
Turquoise	0.18	0.35	0.89
Upper Two	0.34	0.52	1.4

The ion concentration of Lake Clark tributaries varies widely with the Kijik River being the most concentrated and the Tazimina River being the most dilute (Table 5). The dominance in cation concentration was $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ except for the Tanalian and Tazimina Rivers where $Na^{+} > Mg^{2+}$. The dominance in anion concentration was $HCO_3^{-} > SO_4^{2-} > Cl^{-}$ and NO_3^{-}. The distribution and concentration of NO_3^{-} in Lake Clark suggest tributaries as the primary input source. The Tlikakila River mean NO_3^{-} concentration was greater than any of Lake Clark's other tributaries probably due to the presence of alder in the watershed.

According to Stottlemyer and Chamberlain (1987), after assessing the first and second year studies, the potential changes in land use, anthropic-altered atmospheric deposition, and increased recreation could pose threats to the pristine quality of LACL waters and the fisheries in the region.

In 1998, a 2-day water quality reconnaissance (Deschu and LaPerriere, 1998) was conducted on six of Lake Clark's tributaries (Tanalian River, Kijik River, Currant Creek, Chulitna River, 22-Creek, and Priest Rock Creek). Based on the preliminary tributary measurements, it is apparent that the major tributaries to Lake Clark are very diverse. Water volumes and temperatures, suspended sediment concentration and type, and chlorophyll *a* concentrations from the various tributaries differ. These tributaries flow

Table 5. Mean concentrations[1] of eight major ions and pH of affluents on Lake Clark and affluent and effluent of Kijik Lake, 1985-87, and precipitation, 1987 (Chamberlain, 1989).

Source	Ca^{+2}	$Mg+^{2}$	Na^{+}	K^{+}	NO_3^{-}	SO_4^{-2}	Cl^{-}	HCO_3^{-}	pH	N
Kijik River	565.2	106.5	65.9	9.0	12.4	153.2	13.3	410.0	7.41	8
Chulitna River	452.2	146.4	72.3	9.1	2.7	65.7	15.1	393.6	7.33	3
Kijik Outflow	375.1	67.8	57.2	8.0	23.7	105.4	14.0	296.7	7.16	11
Tlikakila River	365.0	50.3	38.5	27.6	12.1	80.5	11.8	303.4	7.22	9
Currant Creek	330.6	53.2	47.2	15.3	11.8	141.1	12.8	228.1	7.16	11
Tanalian River	325.8	68.3	72.4	9.3	10.1	139.4	38.8	191.3	7.40	3
Kijik Inflow	278.2	58.0	52.4	9.4	26.1	108.6	14.3	191.6	6.85	11
Tazimina River	182.8	40.2	48.9	4.6	10.7	76.2	18.2	140.2	6.89	10
Precipitation	94.2	4.4	7.8	2.1	0.47	8.2	13.3	92.9	6.56	3

[1] concentrations of ions = μeq L^{-1}, pH = pH units, N = number of samples.

into a large lake basin in a complex manner influenced by the differing water temperature and sediment densities. The morphometry and related mixing patterns have not yet been studied (Deschu and LaPerriere, 1998).

The University of Alaska at Fairbanks initiated a limnology study of Lake Clark in 1999. The purpose of the study was to study the physical and chemical characteristics of Lake Clark to its full depth, and examine the zooplankton species and biomass in cooperation with contemporaneous studies on the tributaries and the sockeye salmon in the lake. A summary of the study is presented below. The final version of this study will be available through the Alaska Cooperative Fish and Wildlife Research Unit at the University of Alaska at Fairbanks (Wilkens, 2001).

> Previous to this study, the water quality information available for Lake Clark concentrated on the top 25 meters of the water column, even though the lake has an average depth of 102 meters and a maximum depth of 322 meters. This on-going study is attempting to describe the current chemical/physical factors, zooplankton ecology and the seasonal temperature distribution of the lake.
>
> To date, samples were collected at five stations during June, July, and August of 1999 and 2000. Measurements of color, light, oxygen, pH, conductivity, oxidation/reduction potential, and temperature were taken directly with probes. Zooplankton, phytoplankton, and total suspended solid samples were collected through the entire water column, using nets and hoses, to create integrated samples. Temperature probes were arrayed on lines through the water column to depth at each station, and recorded continuous measurements for 1.5 years, starting in June 1999.
>
> Temperature profiles indicate the lake; (1) does not hard-stratify, and (2) mixes down to between 20 and 50 meters, deeper than was previously thought. Both the epilimnion (uppermost water layer) and hypolimnion (lowermost water layer) are fully oxygenated, probably year-round (Figure 9). Chlorophyll *a*

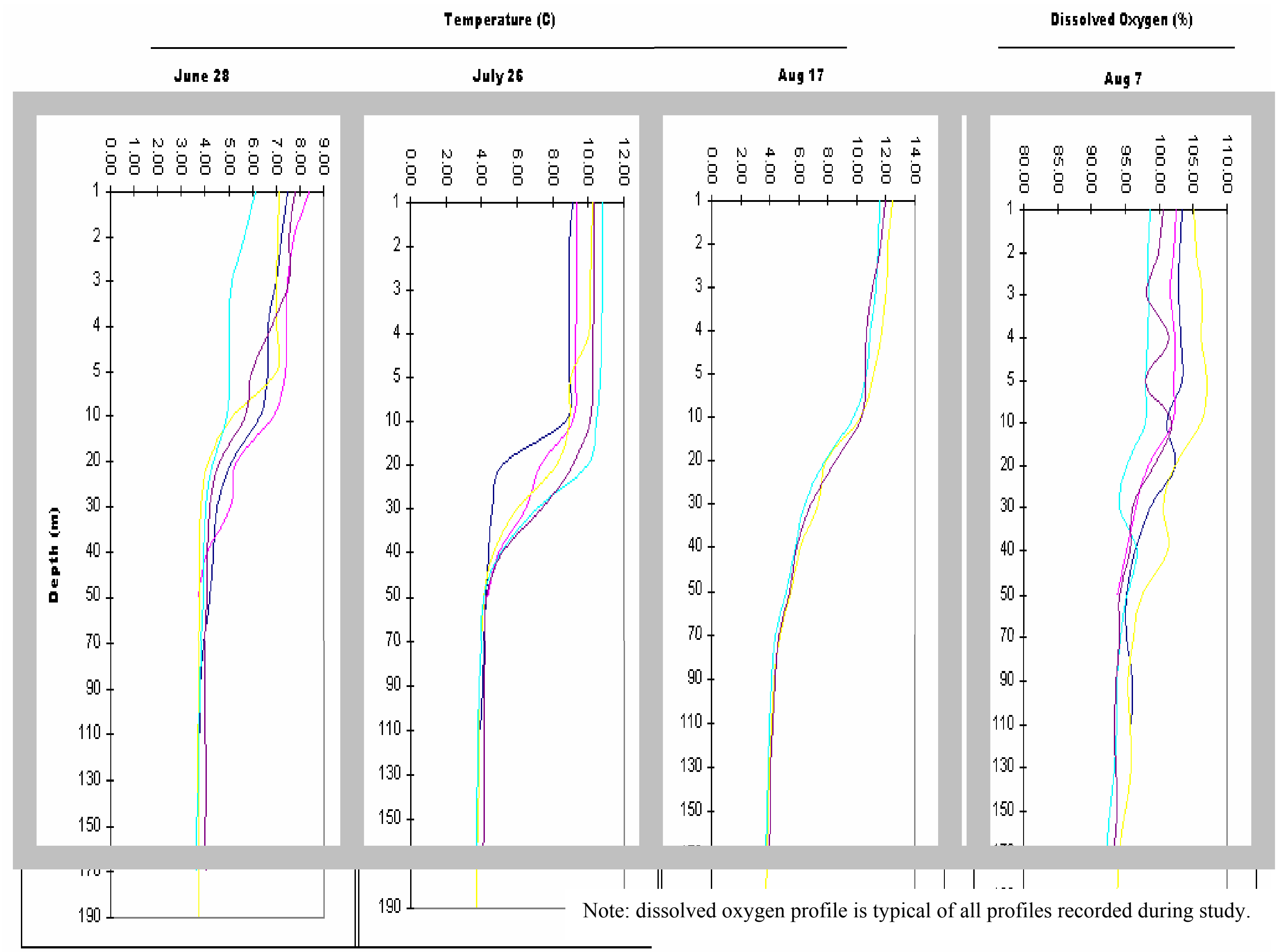

Figure 9. Preliminary temperature and dissolved oxygen profiles for Lake Clark, collected in 1999 (Wilkens, 2001).

concentration is most closely linked to euphotic depth, as opposed to integrated turbidity.

The fluctuation of total suspended solids is best explained by inorganic suspended solids, with organic solids remaining fairly constant throughout the growing season. A cursory look at the zooplankton data that is available to date indicates that the lake is dominated by cyclopoid Cladocerans, distributed throughout the top 50 meters of the water column.

Some preliminary conclusions are that Lake Clark mixes frequently and deeply, with wind events maintaining high oxygen levels. This would tend to increase the productivity of the lake and partially explains the abundance of sockeye salmon. Inorganic suspended solids have the largest effect on turbidity and euphotic volume, suggesting that; (1) phytoplankton is not self-shading in the lake and (2) the glacially-derived inlet rivers at the north end of the lake drive primary productivity, making the lake light-limited.

Navigable Waters

In 1980, the State of Alaska established a navigability program to respond to federal land conveyances and land management activities under the Alaska Statehood Act, the Alaska Native Claims Settlement Act, and ANILCA. The basic purpose of the state's program is to protect the public rights associated with navigable waters, including the state's title to submerged lands. Because state, federal and native land parcels blanket the state, navigability questions have arisen for Alaskan rivers, lakes and streams. While the navigability of many of these waterbodies for conveyance purposes has already been established, navigability for title has not been determined for most waterbodies.

A major goal of the state's navigability program is to identify the proper criteria for determining title navigability in Alaska and to gather sufficient information about the uses and physical characteristics of individual waterbodies so that accurate navigability determinations can be made. The greatest hurdle to overcome in identifying and managing navigable waters in Alaska has been the differences of opinion between the state and federal government regarding the criteria for determining title navigability. The criteria for navigability takes into account geography, economy, historical use, customary modes of water-based transportation, and the particular physical characteristics of the waterbody. Final court decisions in Alaska are still needed to provide legal guidance for accurate navigability determination (Alaska Department of Natural Resources, 1999a).

It is the position of the federal government that waters and submerged lands within the boundaries of NPS units created prior to Alaska statehood are federally owned (Gilbert, pers. comm., 1999).

Biological Resources

Water resources are especially important to the success of LACL's flora and fauna. Since a comprehensive evaluation of biological resources extends beyond this report, the following two sections concentrate on park biological resources that are federally-listed as threatened, endangered, or candidate species, and state-listed as endangered or species of special concern. Along with providing some basic background information, the purpose of this section is to begin exposing some of the biological concerns that might serve as indicators to water-related issues.

Flora

The National Park Service (1999) grouped LACL's vegetation into the following five regional categories, using a classification presented by Racine and Young (1978):

> **Forest:** The evergreen needleleaf forest is composed of Sitka spruce/alder in the coastal zone, white spruce/dwarf birch/lichen at Crescent Lake, and black spruce/Labrador tea around Lake Clark-Kontrashibuna and Two Lakes.
>
> The deciduous broadleaf forest occurs as balsam poplar/alder/horsetail on river floodplains; paper birch/alder/reedgrass mainly around Lake Clark in the Kontrashibuna region; aspen (very restricted distribution) in the Kontrashibuna region; and white spruce/paper birch/ feathermoss around Lake Clark, Kontrashibuna Lake, Crescent Lake, and the foothill lakes.
>
> The mixed evergreen-needle leaf and deciduous-broadleaf forest contains the following types: white spruce/balsam poplar/alder in a late succession stage on floodplains, and black spruce/paper birch/Labrador tea around Lake Clark-Kontrashibuna, Telaquana and Two Lakes. Distribution of the latter may be related to the natural wildland fire regime.
>
> **Shrub**: The shrub thicket occurs as subalpine shrub around treeline at Lake Clark-Kontrashibuna and the foothill lakes montane region; alder/reedgrass/cow parsnip on steep mountain slopes, particularly in the coastal zone; willow thickets bordering lakes, streams, and ponds; and dwarf birch/feathermoss on well-drained glacial plateaus both west of and with the foothill lakes region.
>
> **Tundra**: The alpine tundra includes dry tundra of dwarf shrubs, mats and cushionforming plants in snow accumulation zones on alpine mountain slopes, and in hollows and depressions; and tussock/dwarf shrub tundra and wet meadow on moist and wet poorly drained flats in the foothill lakes region.
>
> **Marsh**: The marsh consists of tidal salt marsh in the coastal zone; bogs, which occur sporadically at lower elevations in old pond basins in the Lake Clark-Kontrashibuna area and along the coastal zone; freshwater marsh on flat valley floors and upland plains; and small ponds throughout the foothill lakes region. Sedges dominate most of the freshwater wetlands.
>
> **Grassland**: The grassland is composed of reedgrass/fireweed/fern in the coastal zone and occasionally inland near the edge of rivers and lakes.

There are no threatened or endangered species of plants listed by the U.S. Fish and Wildlife Service (1999b) in LACL. The Alaska Natural Heritage Program Rare Vascular Plant Tracking List for April 2000 identifies 25 plant species that are classified by the State as critically imperiled (S1), imperiled (S2), or rare or uncommon (S3), see Appendix A.

Fauna

LACL contains a diverse assemblage of mammals, birds, and fish. The following information is based on a list of threatened or endangered species, as defined by the U.S. Fish and Wildlife Service (1999b) and endangered or species of special concern as defined by the Alaska Department of Fish and Game (1999). Since there are no listed fish within LACL, fisheries are not mentioned in this section. Water-relate issues associated with salmon are discussed in detail later in this report.

Mammals

The Steller sea lion (*Eumetopias jubatus*) is a federally-listed threatened species that inhabits the Cook Inlet coastline. The Steller sea lion is listed by the state as a species of special concern. Steller sea lions have declined dramatically throughout the Gulf of Alaska and Bering Sea during recent decades (National Park Service, 1994). Sease and Loughlin (1999) documented a 53% decline of adult and juvenile (non-pup) Steller sea lions for the central Gulf of Alaska during June and July aerial surveys from 1990 to 1998.

There are also seven whales federally-listed as endangered species that occupy Alaska waters. These are the northern right whale (*Balaena glacialis*), bowhead whale (*Balaena mysticetus*), sei whale (*Balaenoptera borealis*), blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*) and sperm whale (*Physeter macrocephalus*). Although the park's coastal waters are too shallow for some of the deep-water species (i.e., northern right and blue), fin whales frequent areas adjacent to LACL's coast and there were sightings of humpback whales off of Katmai National Park and Preserve's coast in 1998, which is approximately 100 miles southwest of LACL (Kavanagh, pers. comm., 1999). The humpback, northern right, and blue whales are also state-listed endangered species. The beluga whale (*Balaena mysticetus*), specifically the Cook Inlet population, is listed by the state as a species of special concern. The beluga whale has been sited at the mouth of Tuxedni River in LACL (Knuckles, pers. comm., 2000).

Birds

The Aleutian Canada goose (*Branta canadensis leucopareia*) is listed as a federally threatened species, and the short-tailed albatross (*Diomedea albartrus*) is listed as federal candidate species. The short-tailed albatross is a state-listed endangered species. Species of special concern listed by the state include the Aleutian Canada goose, American peregrine falcon (*Falco peregrinus anatum*), arctic peregrine falcon (*Falco peregrinus* *tundrius*), northern goshawk (*Accipiter gentilis laingi*), Steller's eider (*Polysticta stelleri*), and olive-sided flycatcher (*Contopus cooperi*).

It should be noted that more than seven thousand sea bird carcasses were recovered south of LACL from Katmai National Park's coast following the *Exxon Valdez* oil spill (National Park Service, 1994). This provides a graphic example of a water resource impact extending to biological communities in the region.

WATER RESOURCE ISSUES

The park's water-related issues presented in this section were identified during a 10-day information-gathering effort in LACL and Anchorage by the author, extending to numerous follow-up telephone calls after departing Alaska. Along with a technical literature review, information sources included interviews with NPS management and other federal and state agencies.

Baseline Inventory and Monitoring

To effectively manage natural resources, inventory and monitoring activities should integrate into the overall natural resources planning and management process. Information obtained from these activities better assists the NPS toward understanding how the various environments in a park unit function naturally, and help isolate anthropogenic changes.

With its large landmass, low population, and limited resource development, relatively little is known about Alaska's water resources, including LACL. The U.S. Geological Survey has calculated that Alaska in 1995 had an average of one stream gaging station per 8,395 square miles, compared to an average of one gage per 336 square miles in the lower 48 states (Bayha et al., 1997). This is particularly alarming because in 1998, only 45% of the Alaska stream gage sites met the U.S. Geological Survey's minimum 10-year record length, which is necessary to support a statistically reliable regional flow analysis (U.S. Department of the Interior, 1998).

In 1990, an Aquatic Resources Inventory and Monitoring Workshop was held in Chena Hot Springs, Alaska with resource managers from Alaskan parks. The following is a summary of suggestions presented during this meeting:

1. Goal for Inventory and Monitoring: to develop a meaningful database to assess the status and variation of representative aquatic resources in Alaskan parks.
2. Inventory: A synoptic survey of aquatic resources is required prior to implementing a monitoring program. Park units should be divided into sub-units based on common environments with surveys conducted for each sub-unit.
3. Monitoring: Project design should be based on regional objectives and specific park concerns, interests, and objectives. Quantitative sampling at several trophic levels is essential, unless there is a need to focus on a specific resource.
4. Methods: Standardization and documentation of methods is essential, especially for region-wide assessments of status and variation.

An inventory of water resources is needed at LACL. Methods should be designed to meet or exceed servicewide standards for Level I water resource and water quality inventories (National Park Service, 1999a). Baseline characteristics such as bathymetry and basic water chemistry profiles need to be collected on lakes. River discharge, length, gradient, and chemistry are needed on rivers. From this basic field information and supplemental GIS analysis, water resources could be stratified to building effective monitoring programs for park waters.

The NPS Water Resources Division prepared a comprehensive summary of existing surface-water quality data for LACL, *Baseline Water Quality Inventory and Analysis, Lake Clark National Park and Preserve* (National Park Service, 1997). The information contained in this 1997 report includes data, with some data analysis, from several EPA national databases (i.e., STORET).

Bennett (1996) prepared a comprehensive physical and biological inventory of LACL's coastline. Baseline data were collected on bird, mammal and invertebrate species composition, distribution, seasonal abundance, and annual productivity for bird and invertebrate species. Intertidal habitats were classified along the park's coast. Along with historical data, these new data were compiled into a single coastal resource database.

The U.S. Environmental Protection Agency (EPA) has endorsed the use of biological integrity as indicators of environmental condition and ecological health. It is unique among currently used indicators in that 1) they use information collected directly from the aquatic organisms and their surrounding biological community, 2) the biota are shaped by all environmental factors to which they are exposed over time, whether chemical, physical, or biological, and 3) they combine multiple, community-level, biological response characteristics into an indicate cumulative environmental impacts (Karr 1991, 1993). The Alaska Department of Environmental Conservation has initiated two pilot bioassessment projects in southeastern Alaska, Admiralty Island and Prince of Wales Island. The objective of these two projects is to evaluate EPA's Rapid Bioassessment Protocols for use in Alaska (Davis et al., 1996). The Rapid Bioassessment Protocols were designed as relatively inexpensive screening tools for determining if aquatic environments were supporting unimpaired biological communities (Plafkin et al., 1989). These protocols are essentially a synthesis of existing methods that have been employed by various state water resource agencies (Barbour et al., 1999). EPA has also developed a set of protocols for biological assessment of lakes and reservoirs relevant to issues of ecological integrity, which may be applicable for LACL (U.S. Environmental Protection Agency, 1998).

According to Chamberlain (1989), the Tazimina lakes and river systems are highly sensitive to anthropic change. This is due to the low HCO_3^- concentrations of Tazimina lakes, making the waters quite sensitive to many forms of atmospheric contamination and change in land use. The poor buffering and relatively low pH make the Tazimina Lakes susceptible to future change in pH, also a critical factor in salmon egg development. The hydrological system should be monitored in order to correct any water quality problems that might develop in the future (Chamberlain, 1989).

The NPS Water Resources Division traveled to Port Alsworth in 1988 to determine the 100-year floodplain of Lake Clark in relation to proposed NPS facilities. Long-term fluctuations are difficult to predict at Port Alsworth with the absence of long-term data relating to lake surface water elevation, precipitation, runoff, temperature, and groundwater movement. The best available information was provided through an interview with a 58-year resident, where the highest lake water level and approximate date were provided. Specific floodplains associated with the Tanalian River's 100- and 500-year recurrence interval floods can not be precisely mapped with the current information. Specifically, information required to calculate a reasonable flood peak for a specific recurrence interval and detailed topographical information to develop cross sections of the Tanalian River have not been developed (Rosenlieb, 1988). There are some limited flow data collected from the river, 1951 to 1956, by the U.S. Geological Survey, which is graphically presented in Figure 10.

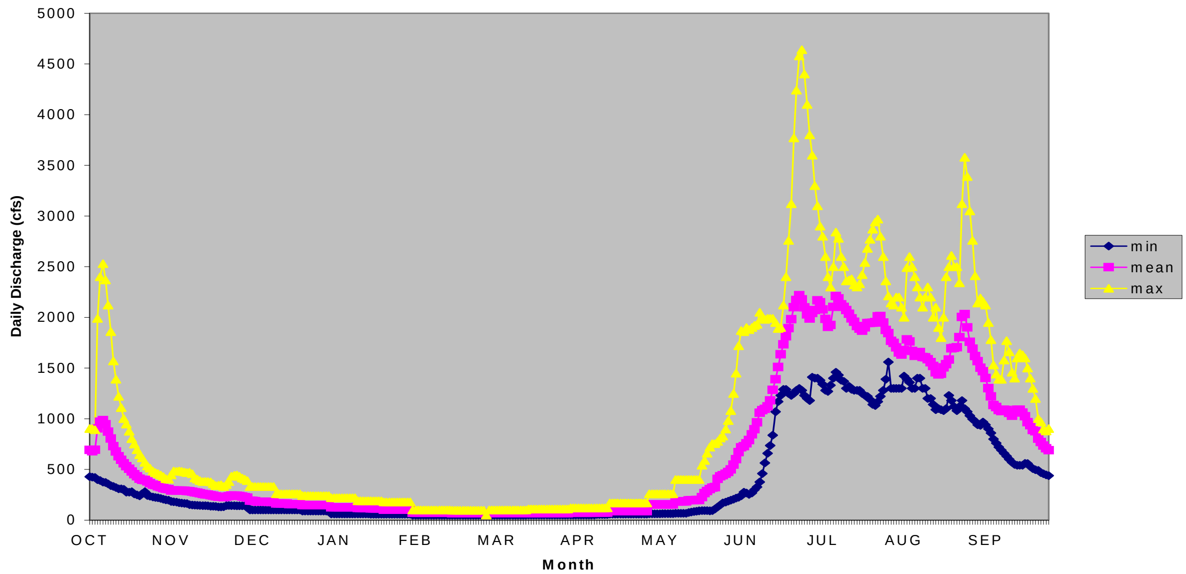

Figure 10. Tanalian River daily discharge summary (1951-56), Port Alsworth, AK - USGS Station 15298000.

Poor air quality can degrade water resources and aquatic communities. Quantitative air quality data are limited throughout Alaska and currently no baseline air quality data exist for LACL (National Park Service, 1999a). As previously discussed, the park includes environments extremely susceptible to contaminants because of poor buffering geology. Also, recent research has indicated that small increases in nitrogen can have significant impacts in nutrient-poor environments such as LACL (National Park Service, 1999a). Thus, airborne contaminants such as ammonium nitrate or nitric acid could significantly degrade water quality and alter aquatic communities in the park. Numerous sources for airborne contamination exist in the Lake Clark region including emissions from offshore oil/gas development in Cook Inlet and coal extraction at the Beluga coal fields northeast of the park. Without active air monitoring, LACL does not know what impact(s), if any, airborne contaminants contribute to the park's natural system, or how the current water quality correlates to air quality.

Baseline data on anthropogenic influences in LACL are needed to integrate into the park's management of natural resources. Currently, LACL lacks the information necessary to quantify land use. The park needs additional staff qualified to collect data and develop and implement a method to process this data that results in quantifying land use trends and anthropogenic pressures. This information would ultimately assist in evaluating land use effects on water resources and assure regulatory controls are in place to protect water quality and other environmental indicators (National Park Service, 1999a).

Inventory and monitoring programs for natural resources in the park assist both state and federal agencies with various management elements. This is especially important with subsistence management. Since 1990, the federal government has assumed responsibility for subsistence game management on federal lands. In 1999, the federal government also assumed management of subsistence fisheries on 243 million acres of federal land in Alaska, including LACL (Worl, 1999). Subsequently, LACL is now challenged with managing salmon fishery resources for rural subsistence priority within the park. The Federal Subsistence Management program involves the following five federal agencies; U.S. Fish and Wildlife Service (lead agency), National Park Service, Bureau of Land Management, Bureau of Indian Affairs, and USDA Forest Service. Ten Subsistence Regional Advisory Councils provide local subsistence information and relate concerns to the Federal Subsistence Board, which oversees the program. LACL is located in Region 4 (Bristol Bay), which has a seven member advisory board. Two major issues that concern subsistence management at LACL are the conservation of renewable resources and the opportunity for rural residents to participate in traditional subsistence harvests. Increasing numbers of recreational users in the backcountry as well as in developed areas of LACL has increased the potential for conflicts between consumptive and nonconsumptive users (National Park Service, 1999a). ANILCA identifies specific activities related to subsistence that require NPS participation. Specific subsistence management activities that need to be continued or implemented at LACL include population and harvest monitoring studies, determination of the eligibility dates of rural residents, administration of backcountry access permits, and limitations on subsistence activities, if necessary, and review of park programs for compliance [National Park Service (1994), National Park Service (1999a)].

Climate Change and Influence on Water Resources

One of the more significant natural resource issues in Alaska is climate change (Nelson, pers. comm., 1998). Paleoclimatologists have used proxy data (i.e., ice cores, tree rings, etc.) to reconstruct the earth's historical climate. These data have resulted in remarkable discoveries, including the fact that climate has fluctuated dramatically in the past and the global mean temperature has risen approximately 1 degree Fahrenheit on average the past 100 years [Trenberth (1997), Rouse et al. (1997)]. Northern hemisphere spring and summer snow cover, monitored by satellite imagery since 1973, has decreased by 10% since 1987 (Trenberth, 1997). Trying to define the source(s) for climate change has produced varied explanations from natural causes to human-induced impacts (i.e., burning fossil fuels, deforestation, etc.). Most of the scientific community believes the climate change we are currently experiencing is primarily human-induced. The burning of fossil fuels alters the balance of radiation on Earth through both visible particulate pollution (called aerosols) and gases that change the composition of the atmosphere. The latter are referred to as “greenhouse gases” because they are relatively transparent to incoming solar radiation, while they absorb and reemit outgoing infrared radiation, thus creating a blanketing effect that results in warming.

LACL’s environment is thought to be very susceptible to climate change. When Babe Alsworth first started flying through Lake Clark Pass in 1938, a glacial toe five miles wide filled the pass. At that time, planes had to fly 600 feet higher than today to clear the ice (Alaska Geographic Society, 1986). Today the glaciers in Lark Clark Pass have receded into the higher mountain valleys, suggesting the climate has warmed.

Pinney and Begét (1991) reported that rapid environmental changes and glacial fluctuations on the Alaska Peninsula might be in response to transient changes in the concentration of atmospheric greenhouse gases and solar intensity. Changes in moisture supply and thermal regime could alter topography and vegetation, which in turn could alter the water surfaces of northern peatlands and thus alter the natural delivery of CO_2 and CH_4 from surface waters to the atmosphere (Rouse et al., 1997). Increases in temperature can also extend ice-free seasons which will usually lead to increases in the ratio of evaporation + evapotranspiration to precipitation, resulting in less water found in the landscape (Schindler, 1997).

Because of the scarcity of real-time records, many regional climate summaries have relied heavily on modeled predictions, which are themselves of questionable validity (Schindler, 1997). Basic research and long-term monitoring are needed to compliment on-going regional and global efforts to better understand the causes and consequences of climate change. Research and monitoring needs presented by Rouse et al. (1997) include: 1) meteorological monitoring stations in remote areas, 2) accurate water balances for lakes and wetland systems, 3) better understanding of thermal behavior for wetland systems, and 4) better understanding the carbon budget of freshwater systems.

Nutrient Cycling

LACL’s aquatic ecology is heavily dependent upon the annual influx of nutrients with the upstream return of millions of adult salmon. Annual escapement estimates (tower counts) to the Newhalen-Lake Clark region since 1979 (Rogers et al., 1997) and aerial surveys of spawning populations since 1920 (Regnart, 1998) indicate significant numbers of sockeye salmon return to the Lake Clark region annually. The upper reaches of the Kvichak River drainage basin extend into the park. This watershed is the world’s most productive spawning and rearing habitat for sockeye salmon and constitutes about 50% of the sockeye salmon caught in Bristol Bay. This represents 33% of the entire U.S. catch, and 16% of the total world catch. The rivers and lakes of LACL contribute an estimated 20% of the salmon that are produced by the entire Kvichak system (National Park Service, 1999a). According to Demory et al. (1964), the Tazimina River is the largest salmon spawning area in LACL.

Annual salmon runs define the spatial distribution of LACL's fish and wildlife consumers, their nutritional status, and ultimately their reproductive success and abundance. Spawning runs of fish produce nutrients to streams and lakes by excretion, release of gametes, and their own mortality (Allan, 1995). An example is found in a report by Richey et al. (1975) who identified a phosphate peak following the die-off of kokanee salmon (*O. nerka*) in a small tributary in Lake Tahoe, California. In Sashin Creek, Alaska, isotope analysis showed that nitrogen and carbon derived from a spawning run of Pacific salmon (*Oncorhynchus spp.*) were incorporated into periphyton, macroinvertebrates and fish (Kline et al., 1990). Both phosphorus and nitrogen have been shown to stimulate the primary production of aquatic systems.

Anadromous and Resident Fisheries

Along with the issues previously identified regarding federal subsistence fisheries management, there are other numerous and complex fishery issues extending beyond the objectives of this report or a more comprehensive Water Resources Management Plan (WRMP). For example, estimated spawning salmon returns from 1979-1998 for the Newhalen-Lake Clark complex ranged from 9 million in 1979 to a low of 40,000 in 1996. The 1996 salmon run was the lowest on record since salmon counts began in 1976, representing only 2.3% of the previous 8-year average. Salmon are the keystone species in the region and provide a rich annual food source for many species. Declines in salmon abundance will likely have cascading effects through the entire ecosystem. Since 1990, the number of active eagle nests within the Lake Clark watershed has declined, possibly reflecting changes in annual salmon abundance [Rogers et al. (1999) and National Park Service (1999a)]. The USGS, in cooperation with the University of Washington, established a counting tower on the Newhalen River in FY00. The aerial surveys used to estimate salmon numbers result in gross estimations, especially in turbid waters. Ground surveys can be quite different from the aerial surveys (Deschu, pers. comm., 2000).

Available information regarding spawning adult salmon is limited to clear water portions of the watersheds. Water in approximately half of the park is turbid due to glacial influences and the extent of salmon use of these waters is unknown. Unidentified spawning congregations likely exist in LACL as sockeye salmon may spawn in turbid areas. Past research in Tustumena Lake on the Kenai Peninsula indicated 30% of the total sockeye salmon escapement spawned in glacially turbid water along the lake shore (Burger et al., 1995). In response to these information needs, a 5-year project was initiated in 1999 to better assess the degree of population structuring within LACL sockeye salmon (Woody and Ramstad, 1999). Carol Ann Woody (USGS-BRD) is leading the effort to radio tag up to 200 fish annually in order to identify their final spawning locations in the vast watershed. Tissue samples will be collected from sockeye salmon spawning aggregations identified through telemetry to determine genetic "fingerprints" for Lake Clark salmon. Telemetry will provide the ability to ascertain salmon run and peak spawning time, determine adult migration paths, locate major spawning groups and identify critical spawning habitats. To compliment this study, Troy Hamon (Katmai National Park and Preserve) will be working with the Alaska

Department of Fish and Game on an effort to estimate sport, subsistence, and commercial harvests affecting sockeye returning to Lake Clark and its tributaries.

North Carolina State University, supported by the NPS Alaska System Support Office and LACL field staff, conducted a 10-day pilot study on Lake Clark (Rand, 1999), *Hydroacoustic Survey of Fishes*, during the summer of 1999. The objectives of the study included: 1) determine the feasibility of quantitative population assessment of the fish population, specifically sockeye salmon and least cisco, during early summer, 2) evaluate the effectiveness of both side- and down-looking deployment of a transducer to determine differences in surface vs. deep water habitat use by resident fish, and 3) compare differences in target strength (a measure of fish size) that may be useful to help discriminate species. Major findings from the preliminary data include: 1) markedly higher density of targets in shallow vs. deep water habitats, 2) markedly higher mean target strength, which correlates to a larger fish size, from fish observed in the north basin, compared to targets measured elsewhere in the lake, and 3) markedly higher densities of fish near-shore vs. off-shore (Rand, 1999). This work is intended to lay the groundwork for a more comprehensive field sampling program at Lake Clark when the researchers area able to secure funding outside the NPS (Rand, pers. comm., 1999) (Deschu, pers. comm., 2000).

Coastal Management

The marine shoreline of the park extends north from Chinitna Bay approximately 125 miles to Redoubt Point. This segment of coastline and its near-shore islands are among the most important and biologically productive ecosystems in the Gulf of Alaska (Hood and Zimmerman, 1986). During 1994-96, surveys were conducted to obtain basic data on intertidal habitats, and distribution and abundance of marine and near-coastal vertebrates and invertebrates. The primary objective was to gain an understanding of LACL's coastal ecosystems and biotic processes (Bennett, 1996).

LACL's marine coastline is at constant risk from environmental threats associated with petroleum development, storage, and/or transportation. Cook Inlet currently supports Alaska's largest developed oil field outside of the Kuparuk and Prudhoe Bay field on the Beaufort Sea (National Park Service, 1999a). There are currently 15 production platforms operating in Cook Inlet. The Drift River Marine Terminal is a privately owned offshore oil loading platform in Cook Inlet with an onshore storage facility. The Nikiski oil terminal and refinery is located on the eastern shore of Cook Inlet. These two oil-loading facilities transfer over 3.3 billion gallons of oil per year (Potts et al., 1993). An exploratory well drilled in upper Cook Inlet in 1991 (Sunfish No. 1) was the first oil and gas discovery in Cook Inlet since 1965.

There are a variety of oil-industry-related activities that can result in permitted or fugitive discharges resulting in adverse effects on the biota of Cook Inlet. Such discharges include: accidental spills from tankers, pipelines, and well blowouts; permitted discharges of treated production water; permitted discharges of drilling muds and work-over fluids during drilling and servicing of wells; permitted discharges of waste water;

water discharge from storage tanks and ballast; and leakage from storage tanks and pipelines. It should be noted that natural oil seeps are also a potential source of petroleum hydrocarbons in Cook Inlet (Bennett, 1996).

Although LACL has a 3-mile wide buffer along the coast to preclude drilling in the area, the park's water resources are still threatened by exploration and potential development of oil and gas in Cook Inlet under the Outer Continental Shelf program. Because much of the LACL coast is characterized by embayed or protected shorelines, 52% has been classified as highly vulnerable to oil spill damage (Michel et al., 1978). Escalating oil and gas development activities in Cook Inlet resulting from lease sale 85A will result in increased hydrocarbon exploration and potential production in waters adjacent to LACL's coast. The Alaska Department of Natural Resources is currently offering lands for competitive oil and gas leasing in the Cook Inlet area (4.2 million acres) (Alaska Department of Natural Resources, 1999b).

The U.S. Department of the Interior has identified Tuxedni Bay as a possible onshore treatment site if a petroleum reserve is found in the area. The National Park Service has expressed opposition to the use of Tuxedni Bay as an onshore facility since there are existing facilities (Drift River marine terminal, Nikiski facilities) within the Cook Inlet region (National Park Service, 1999a). LACL's coastal environments support numerous summer resident and overwintering species that are vulnerable to oil spills. For example, the U.S. Geological Survey Biological Resources Division has identified Tuxedni Bay as an area of special biological sensitivity due to its importance for migrating shorebirds. Tuxedni Bay qualifies for hemispheric designation in the Western Hemisphere Shorebird Reserve Network based on its use by Rock Sandpipers, on of North America's least abundant species. It also supports internationally significant migratory populations of Western Sandpipers (Knuckles, pers. comm., 2000). These species are at high risk because they feed extensively in intertidal habitats or consume mussels and other invertebrates that are susceptible to petroleum contamination. Post-spill studies from the Exxon Valdez spill revealed that harlequin ducks, which use intertidal and shallow subtidal habitats, have exhibited population declines and reproductive failure throughout the spill area (Bennett, 1996).

The strong currents and a high tidal range in the Gulf of Alaska can transport spills great distances from their source. Extreme high tides in Cook Inlet can exceed 11 meters, making the tidal range among the largest in the world (Bennett, 1996). For example, a 1970 oil spill extended from the Katmai National Park and Preserve coast, southwest of LACL, to the Montague Islands, over 200 miles away. A report prepared by the U.S. Department of the Interior (1970) concluded that this spill was caused by deliberate discharges of slop oil and/or ballast from tankers.

A significant environmental concern for LACL's coast is the potential for future Redoubt volcanic eruptions (flooding, debris flows, etc.) impacting the Drift River Marine Terminal, which stores up to 84 million gallons of crude oil. The facility, located 15 miles north of the park's boundary, could directly affect LACL's coastal resources if the storage tanks failed and a petroleum spill occurred. The terminal is located on the floodplain of the Drift River. The braided river drains approximately 221 mi^2 of park land in the Chigmit Mountains to Cook Inlet, including Redoubt (Dorava et al., 1993). As previously discussed, Redoubt is an active volcano with eruptions as recent as 1990 and more expected. The explosivity of a volcanic eruption depends primarily on viscosity and volatile content of the magma or erupted material. For Redoubt, the equation for future explosive eruptions (high silica content) exists (Till et al., 1992). After the 1989-90 eruption, a new six meter high concete-lined dike was constructed around the perimeter of the oil terminal in an attempt to protect it from anticipated floods from the Drift River and Rust Slough (Dorava et al., 1993).

On March 24, 1989, the tanker vessel *Exxon Valdez* grounded in Prince William Sound, rupturing cargo tanks and spilling approximately 11 million gallons of crude oil into the sea. This accident resulted in the most extensive single human-caused disaster to ever strike National Parks (National Park Service, 1990). Coastal winds and currents transported the oil slick southwest along the north shore of the Gulf of Alaska. Fortunately, LACL's coast was just outside of the areas impacted by this large spill, but natural resource threats such as this will always exist for coastal parks in the region.

Along with petroleum-related issues, other issues along the park's coast are beginning to emerge or intensify. For example, gray water discharge is occurring where inholders (many of them operating small lodges for visitors) are dumping gray water/organic wastes into salt marshes. This practice attracts bears, which in turn attracts visitors to the lodges. The State of Alaska Department of Natural Resources (DNR) manages these tidally-influenced environments, but this has not been a priority issue for them (Knuckles, pers. comm., 1999). Other coastal issues (i.e., Minerals Extraction, Crescent River Logging) are discussed in this report separately.

Minerals Extraction

Under the Alaska Native Claims Settlement Act of 1976 (ANCSA), the Cook Inlet Region Corporation (CIRI) received title to approximately 21,000 acres of land known as the "Johnson River Tract" located on the west side of Cook Inlet in LACL. The Johnson River Tract is divided into two tracts. The northern tract is 9,600 acres of mineral estate; the southern tract is 11,342 acres of surface and subsurface estate. An ancillary camp and airstrip were constructed at the headwaters of the Johnson River in 1983. Since then, mineral exploration has been continuous. A high-grade deposit of copper, silver, lead, zinc, and gold has been delineated from a 1993 exploratory drilling program in the area. CIRI is investigating possible partnerships to extract the deposits, which includes exploratory engineering and economic feasibility of access routes from the deposits to Cook Inlet [Cook Inlet Region, Inc. and Westmin Resources Limited (1994), National Park Service (1999a)]. The Johnson River headwaters have the potential to become the largest commercial mining operation within an Alaskan park. Based on the current size estimate of the ore body, approximately 270,000 tons of ore would be mined and transported annually over a 3-year mine life (National Park Service, 1999a). Due to the proximity of the planned mine and support network of roads and ore stockpiles to the Johnson River, there is a high potential for contaminants to reach the Johnson River estuary and be transported along the coastline by prevailing tidal currents (Bennett, 1996).

CIRI maintains that conveyances and transportation easements granted under ANCSA are exempt from the requirements of NEPA, and a formal decision is pending. CIRI and Westmin Resources Ltd. prepared an environmental assessment in 1993, but it only addressed the selection of a transportation corridor across NPS land and a port site as granted by ANCSA. Fuel would be barged to the port site and pumped to upland storage facilities with a capacity of approximately 400,000 gallons. Fuel would be transported by truck from these storage tanks to the mine location (National Park Service, 1999a). Obvious environmental concerns related to accidental petroleum spills will exist during the life of the mining operation. Along with the threat of petroleum spills, contamination may leach from ore stockpiles into local streams (i.e., Johnson River, Bear Creek). Erosion problems (e.g., accelerated soil loss, increased stream turbidity) could also develop along access roads. To provide some baseline information for this high-profile area, the U.S. Geological Survey and NPS are collecting geochemical data from the Johnson River watershed and monitoring Johnson River discharge at a telemetered gaging station.

There are other potential mining activities in the region that also pose natural resource concerns for LACL. For example, Cominco, an international mining corporation, has filed state mining claims on the Pebble/Copper deposit north of Lake Iliamna. If developed, this open pit mine would be the largest in Alaska. Although development would occur 15 miles southwest of LACL, direct impacts on air and water quality may have substantial effects on park resources (National Park Service, 1999a).

Crescent River Logging

The Circle DE Pacific Corporation received approval to conduct timber harvesting activities on three cutting units (approximately 2,403 acres) along LACL's coast in Tuxedni Bay, within the Crescent River watershed. Timber in these units has been infested extensively by the spruce bark beetle, leaving large strands of dead trees. The timber is owned by Crescent River Timber Venture on lands owned by Ninilchik Native Association and Seldovia Native Association. Selective harvesting (partial cut) of white spruce will be employed. Access to the area involved construction of approximately three miles of primary roads and six miles of secondary roads (e.g., winter snow/ice roads, summer skid roads not involving fill) (Alaska Department of Game and Fish, 1997).

In 1998, a transfer facility for the logging operation, including a 550-foot causeway, was built in Tuxedni Bay. There is an environmental concern that this operation may result in significant impacts (e.g., long-term impacts) on the local flora and/or fauna. The salt marsh vegetation in the area is sensitive to alterations in marsh hydrology. Hydrological impacts can result in changes to the direction and rate of succession and community composition. The specific facility location, Squarehead Cove, is an intertidal mudflat that is important habitat for resident and migratory birds. Unfortunately, aerial photographs of the log transfer facility suggest that geomorphological processes and sediment deposition patterns in the cove are already affected by structures built in the intertidal zone (National Park Service, 1999a).

A survey conducted in 1980 revealed that Tuxedni Bay had the second highest bird density (332 birds/km^2) in Lower Cook Inlet (Arneson, 1980). Tidal marshes at the head of Tuxedni Bay are rated as critical spring habitat for brown bears (Hamilton et al., 1980). Harbor seals, a candidate for threatened status due to declining numbers, utilize upper Tuxedni Bay for pupping in June and as a haul out throughout the summer. Approximately 125 seals have been counted in this area [(National Park Service (1996) and Rappoport (1996)].

Between 1997 and 2002, 10 million board feet of lumber are proposed for removal from the forested areas (National Park Service, 1999a). The 5-year project area includes approximately 6 acres of state-owned tidal and submerged land. According to the tideland permit, Crescent River Timber Venture will restore the tidelands to their natural contour upon completion of the timber harvest contract (Alaska Department of Natural Resources, 1997).

Pursuant to 11 AAC 95.260(b), timber harvest operations within 100 feet of an anadromous or high-value resident fish stream must be located and designed primarily to protect fish habitat and surface water quality from significant adverse effects. In a 1997 Alaska Department of Fish and Game memorandum, several buffers where no timber activities would occur were recommended along selected streams to protect fish habitat (i.e., clean spawning gravels, stable channel morphology) within the Crescent River watershed. These streams include: 1) several tributaries to the Crescent River in the eastern portion of Unit CR103 that support anadromous and resident fish habitat; 2) an unnamed stream located approximately one mile north of the log transfer facility that supports coho salmon and has been nominated for inclusion in the Anadromous Waters Catalog and Atlas; and 3) an unnamed stream bordering the eastern edge of Unit CR102 that likely supports coho habitat. LACL, working with the Alaska Department of Game and Fish, U.S. Fish and Wildlife Service, and U.S. Army Corps of Engineers, should monitor local environments potentially impacted by the log transfer facility to ensure compliance of the approved project design and operations.

Private Lands

Residential subdivision and economic development on private lands within LACL's boundary can conflict with the park's enabling legislation and NPS management objectives. About 617,000 acres are in private or state ownership, or are being adjudicated. This includes approximately 75% of Lake Clark's shoreline and more than 90% of the park coastline along Cook Inlet. The exact land status is clouded by over-selection, selection by more than one entity, and the incomplete adjudication of many small tract entries and allotments (National Park Service, 1999a).

Native regional and village corporations selected some large tracts with the intention of extracting minerals and timber. These corporations own subsurface estates on their lands, which may be subject to mining activities. In the future, some selections will be relinquished as land entitlements are met elsewhere, and other selections will be conveyed to private ownership. Many private owners have purchased or settled on tracts to live seasonally or year-round, to pursue a subsistence lifestyle, to access hunting and fishing areas, or to own and manage lodges for visitors. ANILCA allows subsistence harvest of fish, wildlife, wood, and plants in the park, and sport hunting and trapping in the preserve. Some landowners have developed airstrips, small roads and all-terrain vehicle trails on their properties (National Park Service, 1999a).

At present, Port Alsworth and Hardenburg Bay support year-round human activity. The population of Port Alsworth has more than doubled over the past 10 years. Other locations such as Keyes Point and Hornberger's Heights support 25-50 residents seasonally (National Park Service, 1999a). Tanalian Incorporated owns 638 acres of land adjacent to Port Alsworth, Hardenburg Bay, and Tanalian Mountain (between the mountain and Lake Clark). Tanalian Incorporated owns an additional 3108 acres just south of the Tanalian River. The corporation has had longstanding plans to subdivide these parcels into residential lots (3-acre minimal size) (Knuckles, pers. comm., 2000).

In a 1994 report filed by LACL to the Alaska Department of Environmental Conservation, pollution sources associated with the Port Alsworth and Keys Point residential communities on Lake Clark were disclosed. Pollution included improper discharge of residential and commercial sewage; improper storage of hazardous materials (i.e., batteries, transformers, solvents); and fuel leaks/spills associated with storage and transport (Bennett, 1994). Since there are no community landfills or sewage treatment facilities at these remote communities, disposal of wastes is the responsibility of each private landowner, which results in a variety of techniques that are typically not acceptable from a regulatory or environmental perspective. Although the Alaska Department of Environmental Conservation regulates treatment and disposal of wastewater, and generally requires a permit for any system that generates more than 500 gallons per day, enforcement of this regulation is minimal to non-existent in rural Alaska. Additional private properties around Port Alsworth (i.e., Tanalian Inc. properties) are under consideration to subdivide and sell as individual building lots (National Park Service, 1999a).

Recreational Management

Tourism is the third most important industry in Alaska. The NPS estimates that about 1,600 sport hunting days, 3,500 angler days, and 30 to 35 river trips occur in LACL annually (National Park Service, 1999a). There are 39 commercial operators who currently offer "guided sportsfishing" activities in LACL. Along with guided sportsfishing, there are 15 other "guided commercial" services (e.g., air taxi service, photography guide, kayak touring, charter boat, etc.) offered in LACL. As of April 2000, LACL contained 72 commercial operators (Brock, pers. comm., 2000).

Sightseers, anglers, and hunters routinely fly or boat into LACL to take advantage of the park's pristine natural resources. With an increase in visitor use comes an increase in resource impacts. For example, the recreational demands by freshwater anglers in southwestern Alaska have more than doubled over the past decade. Today, jet-driven boats are becoming more popular in Alaska because of their shallow draft. Shallow headwaters are preferred by Pacific salmon (*Oncorhynchus*) and rainbow trout (*Salmo gairdneri*) as sites of egg deposition for reproduction. Based on a 1992-1993 study by the University of Alaska at Fairbanks, jet boat operation can lead to significant salmonid embryo mortality through mechanical shock, intrusion of fine sediments into the gravel affecting eggs that remain in redds, and the removal of gravel covering eggs in redds with subsequent washing away of eggs (Horton, 1994).

In response to increased visitation, LACL has prepared a *Long-Range Interpretive Plan* that identifies park themes, describes visitor experience goals, and recommends a wide array of interpretive services and outreach activities to communicate LACL's purpose, significance, and values (National Park Service, 1999b). It will be important to base interpretive management on sound scientific information, where appropriate. LACL should seek to educate the visitor on park-specific environmental issues through interpretive programs and literature (i.e., visitor brochures).

Wetlands Management

The NPS implements a "no net loss of wetlands" policy. Executive Order 11990 directs the NPS: 1) to provide leadership and to take action to minimize the destruction, loss, or degradation of wetlands; 2) to preserve and enhance the natural and beneficial values of wetlands; and 3) to avoid direct or indirect support of new construction in wetlands unless there are no practicable alternatives to such construction and the proposed action includes all practicable measures to minimize harm to wetlands (National Park Service, 1998). With approximately 617,000 acres of private or selected lands in LACL, development and resource extraction activities have a high probability of impacting wetlands (National Park Service, 1999a).

Director's Order 77-1: *Wetlands Protection* requires the NPS to conduct or obtain wetland inventories within each park unit. Presently, LACL does not have an adequate inventory of wetlands within its boundaries to assist proper NPS planning with respect to management and protection of wetland resources. LACL's coastal wetlands provide important habitat for arthropods, molluscs, echinoderms, fish, birds and mammals. It is important for the NPS to establish baseline wetland information to assist with separating anthropogenic impacts from natural processes.

Specific issues in LACL related to wetlands management include off-road vehicle (ORV) travel within LACL (e.g., all-terrain vehicles, airboats). ORV's are used for subsistence activities in the park and preserve, and by coastal landowners where incursions into tidally influenced wetlands occur. ORV's can damage fragile wetland habitats, unfortunately LACL currently does not have data to scientifically evaluate wetland impacts (Knuckles, pers. comm., 2000). Executive Order 11644 requires the designation of ORV trails and areas based on the protection of natural resources. Executive Order 11989 requires Federal agencies to close areas to ORV use when the activity is causing or will cause adverse affects on soils, vegetation, wildlife, wildlife habitat, cultural and historic resources.

Some wetlands mapping has occurred in LACL. During a 1994-96 park coastal survey, salt marshes (approximately 20 mi^2) were delineated and mapped at a scale of 1:12,000. Five attributes were interpreted for each of the 1,286 map polygons: physiographic location (4 classes); site moisture (2 classes); vegetation type (27 classes); growth form (8 classes); and landscape feature (13 classes). The U.S. Fish & Wildlife Service (USFWS) has developed National Wetlands Inventory (NWI) maps for portions of Alaska, including the coast and southern portions of LACL (U.S. Fish and Wildlife Service, 1999a). The USFWS and NPS have established an interagency agreement to further develop wetland inventory maps for LACL. The work is to be completed under a 50:50 cost share agreement. Under Phase I (FY00) of this project, 13 digitized maps are being produced using NWI conventions. Under Phase 2 (FY01), an additional 12 digitized maps will be completed. At the conclusion of Phase 2, 80% of the quads for LACL will be produced.

Spill Contingency Planning

The potential for petroleum spills along LACL's Cook Inlet coast will continue to threaten natural resources as long as mineral interests exist in the region. Threats exist from the Upper Cook Inlet Oil Platforms, pipelines, and tanker traffic in the inlet. The Drift River Oil Terminal near Redoubt Bay was nearly broached by a giant mudslide (lahar) resulting from the 1989-90 eruptions of the Mt. Redoubt Volcano. The NPS is severely limited in qualified personnel, spill response equipment, and baseline natural resource information to effectively respond to and evaluate impacts from petroleum spills in LACL. Emergency response to a major spill (i.e., *Exxon Valdez Oil Spill of 1989*) requires expertise and field equipment that extends beyond the capabilities of the NPS. As a result, a communication process (i.e., an updated Park Spill Prevention and Emergency Response Plan) should be completed so designated park staff can request assistance from qualified federal, state and/or private contractor personnel in a time-efficient manner. Furthermore, park staff should become aware of and familiar with *The Alaska Federal/State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Releases* (Unified Plan) and the Alaska Region sub-area plans covering parts of LACL. Sub-area plans addressing areas of the park are the Cook Inlet Sub-Area Contingency Plan, the Bristol Bay Sub-Area Contingency Plan, and the Western Alaska Sub-Area Contingency Plan (Rice, pers. comm., 2000).

In 1997, the U.S. EPA made a compliance visit (primary fuel and waste management) to Port Alsworth and cited numerous violations against several landowners in the area. LACL manages numerous fuel storage systems (i.e., heating oil, diesel, gasoline) to accommodate NPS operations. The park upgraded two NPS tank farms to meet state and federal requirements. Although this effort will greatly reduce the threat of accidental releases, the potential for petroleum contamination from NPS operations still exists. In response to the upgraded fuel facilities, LACL completed and obtained approval of the Lake Clark National Park and Preserve, Port Alsworth, Alaska, *Spill Prevention, Control and Countermeasure Plan* (SPCC Plan) in February 1999 (Mullens, pers. comm., 1999).

Water Rights

Alaska State law uses the Prior Appropriation Doctrine to administer most water uses. This doctrine recognizes a right to use water based upon actual use that began before July 1, 1966, and has been continued since, or upon completion of a permit process as established beginning July 1, 1966. Preference, or priority, among uses is given to the use that was established the earliest; this is sometimes referred to as the principle of "first in time, first in right". Alaska State law also recognizes rights for instream flow based upon completion of a permit process. Federal agencies are allowed to hold instream flow water rights. The U.S. Supreme Court has established in Federal case law a doctrine referred to as the Federal Reserved Water Rights Doctrine. This doctrine holds that, when the federal government reserves land for a specific purpose, it also reserves, often by implication rather than expressly, enough water, to the extent unappropriated water is available at the time, for the purpose of the reservation. Although the basis of the Federal right is entirely different from a Prior Appropriation right, the Court integrated the two systems by saying that the priority date of the Federal right is the date the land was reserved. Because the Federal right is created by the intent of the Congress, and interpreted by the Court, describing its exact contours of entitlement and quantification, and making them binding on all parties, must also be done accordingly. Generally, sovereign immunity prevents States and private parties from filing a court action that joins the U.S. in a suit to determine the entitlement and quantification of a federal reserved water right. However, the Congress provided a limited waiver of its sovereign immunity for this purpose in the McCarran Amendment. This gives rise to the general stream basin adjudication as an avenue to define Federal reserved water rights. There are presently no such actions occurring in the LACL area. State law also describes a procedure for addressing Federal reserved water rights but its effectiveness has not been tested.

The objectives of the Department of the Interior's water rights program in Alaska are to acquire and protect water rights for lands managed by the respective Department of the Interior Bureaus, including the NPS. All of the options under State and Federal law described above are available. At present, data is lacking to utilize either State or Federal law for protection of many water-related resources at LACL. Although, at least by NPS policy, Federal reserved rights were established with the creation of LACL and therefore, are already in place but not described, specific data demonstrating the amount of water available and the degree of reliance thereon of water-dependent resources is lacking. Similarly, State law requires a minimum of five years of stream flow gaging, as well as the biological, recreational, or water quality data to justify the need for instream flow protection.

Water quantity development is very light in the vicinity of LACL. This along with the fact that the park is located in the headwater portion of the area watersheds means that there are currently no significant threats to LACL water-related resources from water quantity development and the probability of future threats is low.

Coordination

Today, multi-agency coordination is essential in all Alaskan park units to effectively monitor and manage the natural resources. Unfortunately at LACL, it is difficult to establish long-term coordination relationships with other agencies. One reason is because Alaska is so large that attention cannot be directed to every watershed in the State due to limited resources. As previously stated, in 1995 Alaska had an average of one stream gaging station per 8,395 mi^2, compared to an average of one gage per 336 mi^2 in the lower 48 states (Bayha et al., 1997). Another reason is that LACL, along with other undeveloped areas in Alaska, lacks the time-sensitive water resource issues or human-induced impacts, which typically drive information-gathering projects.

The U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program has one study unit in Alaska, the Cook Inlet Basin Study Unit (Figure 11). Initiated in 1996, the Cook Inlet Study Basin includes LACL (U.S. Geological Survey, 1997). The U.S. Geological Survey's water quality concerns in the Cook Inlet Basin are related primarily to salmon spawning and documentation of conditions in relatively undeveloped environments.

In FY99, the U.S. Geological Survey and NPS implemented 35 partnership projects in national park units. The USGS – Water Resources Division is currently involved in two NPS/USGS partnership projects at LACL. One is a 3-year project. The first 2 years of this project will describe the geochemistry of the Johnson River headwaters and how that affects the river water quality, and the third year will be used to prepare a comprehensive report. The other is a 2-year project that will study the Tlikakila River. The primary objectives of this study are: (1) to determine the amount of water this river contributes to Lake Clark, and (2) to determine the river's basic water chemistry. LACL is requesting funds for five other Lake Clark tributaries (Tanalian River, Currant River, Chokotonk River, Kijik River, and Chulitna River), which are currently receiving only perfunctory attention (Knuckles, pers. comm., 2000).

The Alaska Watershed Monitoring and Assessment Project (AWMAP) is a statewide water quality monitoring project involving local, state, and federal agencies; industry; schools; University of Alaska; and other entities conducting water quality monitoring. The AWMAP objectives include (Alaska Department of Environmental Conservation, 1996):

1. Develop a network of individuals interested in and/or involved in the collection of environmental data.
2. Maintain current information on existing monitoring stations and programs in Alaska.

3. Develop a list of environmental indices (biological, chemical and physical) for short- and long-term monitoring that will allow for the assessment of water quality contaminants in Alaska.
4. Coordinate reporting of existing data and receipt of future data from existing monitoring stations in Alaska.
5. Develop a common set of criteria against which information will be evaluated.
6. Develop recommendations annually for locations and types of additional monitoring stations required to meet the overall objectives of monitoring water quality in Alaska's diverse environments.
7. Issue alternate year reports to the Section 305(b) reporting process on status of Alaska's Watershed Monitoring and Assessment Network.

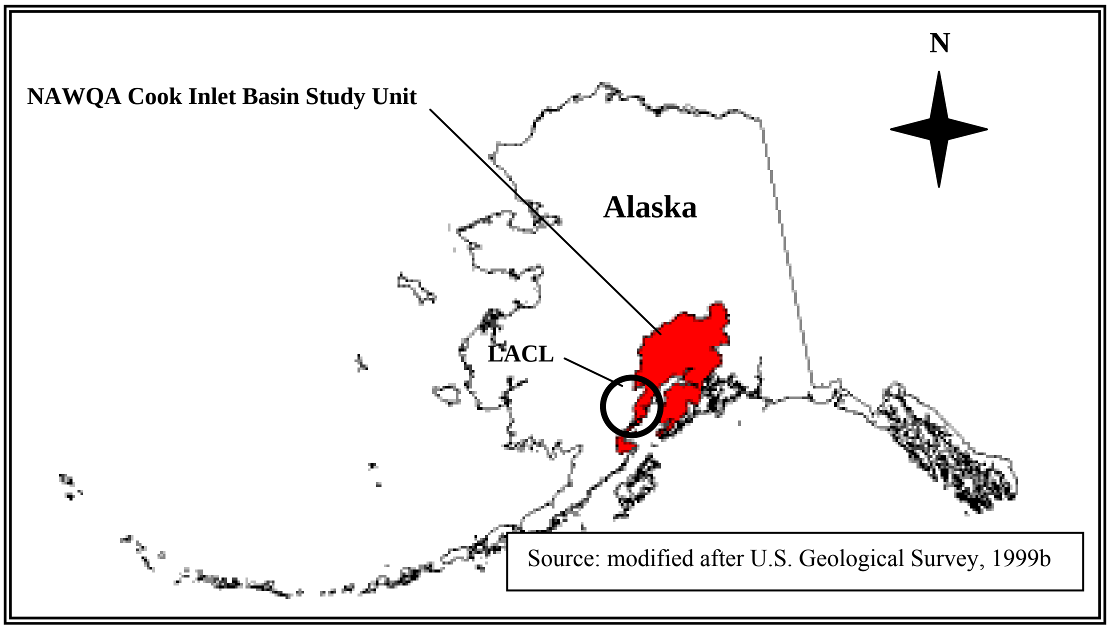

Figure 11. U.S. Geological Survey NAWQA Cook Inlet Basin Study Unit.

Since 1991, the U.S. Environmental Protection Agency has been promoting the Watershed Protection Approach as a framework for meeting the Nation's remaining water resource challenges (Barbour et. al., 1999). In 1995, the Alaska Department of Environmental Conservation and the U.S. Environmental Protection Agency sponsored the formation of a workgroup to develop a statewide approach for improved watershed management. The workgroup's objective is to create a process that could satisfy many of the regulatory requirements of the Federal Clean Water Act. These include producing Total Maximum Daily Loads (TMDLs) on a watershed basis, coordinating wastewater discharge permits within a watershed, and preparing a comprehensive list of impaired water bodies throughout the State (Alaska Department of Environmental Conservation, 1997). It is important for the NPS to be actively involved in these and other similar efforts to effectively voice their natural resource needs and contribute to the information databases. The Alaska Department of Environmental Conservation has expressed an interest in coordinating with NPS units in Alaska on water resource issues (Decker pers. comm., 1999).

A key element for the limited hydrologic data collected in Alaska is data coordination. The Interagency Hydrology Committee for Alaska (IHCA) comprises federal, state, and local agencies concerned with water resources. The IHCA coordinates interagency efforts so that data are collected in an efficient and effective manner, without duplication of efforts. A Geographic Information System (GIS) for Alaska lands and waters is currently being developed by the Alaska Geographic Data Committee, a joint Federal and State effort (U.S. Department of the Interior, 1998).

LACL has had some success in coordinating water-related projects with universities. For example the University of Alaska (Fairbanks) initiated a 2-year NPS Water Resources Division-funded project in 1999, *Water Quality and Zooplankton Assessment for Lake Clark*. The fieldwork includes lake profile readings for basic water quality parameters (water temperature, alkalinity, dissolved oxygen, chlorophyll-*a*, etc.), Secchi disc readings and zooplankton sampling. The study also includes continuous collection of water temperature, using a unique equipment design, throughout the year for five sites.

RESOURCES MANAGEMENT STAFFING AND PROGRAMS

LACL has a history of low staffing and funding levels for natural resources management. Throughout the 1980s and early 1990s, LACL's Chief Ranger, his/her staff (which included a Resource Management Specialist) and many volunteers carried out most of the resources management activities. Current base funding supports only one full-time Resource Management Specialist, assisted by one or two temporary technicians each year. One full-time person to manage the natural resources for a 4-million-acre park is seriously inadequate in meeting NPS mandates. The Natural Resources Management Assessment Program (NRMAP) has identified the need for 35 full-time natural resource positions at LACL based on park size, natural resources and complexity of issues. Critically needed positions include a wildlife biologist, wildlife technicians, hydrologist, fisheries biologist, fisheries technicians, and GIS/data manager (National Park Service, 1999a).

The Chief of Resource Management reports directly to the LACL Operations Chief and is responsible for the park's natural resource management program, geographic information system and environmental compliance. LACL and Katmai National Park and Preserve (KATM) were administratively linked in 1995 as part of the Servicewide reorganization initiative. The Operations Chief for LACL reports to the Superintendent who is also responsible for KATM and is based in Anchorage.

The main objectives for LACL's natural resource management program as defined in the Resources Management Plan (National Park Service, 1999a) are:

1. Gather baseline population and distribution data for key wildlife, fish and plant species through cooperative efforts with the state of Alaska, U.S. Fish and Wildlife Service, and other agencies;
2. Establish a data management system that uses appropriate state-of-the-art technology to manipulate, display, and analyze data;
3. Complete natural resource inventories and develop a long-term monitoring strategy for both biotic and abiotic ecosystem components;
4. Mitigate human impacts to maintain the visual and ecological integrity of the landscape;
5. Maintain ecosystem processes, such as a natural fire regime and natural predator-prey relationships, to the greatest extent possible; and
6. Develop scientifically sound information on which to base management decisions.

Meeting these broad objectives requires funding and human resources that greatly exceed LACL's current Natural Resources program. Partnerships have helped to alleviate some of the inadequate natural resource support. Projects in the park that directly or indirectly relate to water resources have already been summarized in the preceding sections of this report. These projects represent many hours of hard work by LACL's Chief of Resource Management and the NPS-Alaska System Support Office to forge partnerships with federal and state agencies and universities (i.e., USGS, NPS-WRD, UA-Fairbanks, NC State University).

RECOMMENDATIONS

The water-related issues and natural resource data presented in this report are supported through regional and local research and monitoring efforts. Identification of available water resource information (i.e., what has or has not been done at LACL?) has also contributed toward exposing the "data gaps", which translates to natural resource needs for LACL. The natural resource needs are summarized below:

- Baseline information on water resources.
  - Establish permanent gaging stations in the larger streams.
  - Establish permanent water quality monitoring stations in the streams and lakes representative of major drainage basins in LACL.
  - Bathymetrically map large lakes as needed to complement future studies and establish GPS-fixed stations in the deepest location of each lake to be monitored.
  - Define 100- and 500-year floodplains for Tanalian River and other streams, which may impact existing and future development (e.g., Port Alsworth) in LACL.
  - Correlate park's aquatic ecosystem structure with the annual nutrient loading from salmon. Build from existing and current information to better understand seasonal influences from nutrients on primary productivity in Lake Clark.
  - Establish meteorological monitoring stations in remote areas, in cooperation with the U.S. National Weather Service.
  - Assist the U.S. Fish and Wildlife Service with completion of National Wetlands Inventory (NWI) maps for LACL.
  - Accumulate appropriate data (i.e., stream flow, water quality, biological, recreational) to support instream water rights.
  - Monitor water quality and surrounding land-use for the Tazimina lake and river system due to highly sensitive water chemistry (i.e., poor buffering).
  - Establish continuous air monitoring at Port Alsworth and coast.
  - Continue efforts to assess population, migration, and harvest (sport, subsistence and commercial harvest) of sockeye salmon and other sportfish in LACL.
  - Develop models of glacial inputs to large watersheds.

- Internal Management
  - Maintain the current Spill Prevention Control and Countermeasure (SPCC) Plan, that meets the 1990 OPA standards, to properly address routine facilities operations (i.e., hazardous materials management) and spill response procedures. Provide annual staff "refresher" training to ensure efficient communication processes for emergency (i.e., spills) and compliance to regulatory requirements.
  - Evaluate current and new private developments, especially around Port Alsworth, Hardenburg Bay and coastal areas, such as Silver Salmon, for potential threats to water resources (e.g., improper sewage discharge, improper storage of hazardous materials). Work with the Alaska Department of Environmental Conservation to enforce compliance, as needed.

- Recreational Management
  - Better document recreational fishery activities and harvest data.
  - Conduct backcountry facility contamination assessments (phase I environmental audits), as needed.
  - Incorporate environmental education into LACL's interpretive program (e.g., provide educational brochures to visitors and local residents that communicate park management objectives, priority issues (including understandable data that supports the issues), and, if possible, alternatives for reducing environmental threats).
  - Better document ORV (all-terrain vehicles, airboats) use locations and intensity, and coordinate management with the state of Alaska.

- Coastal Management
  - Monitor expansion of oil and gas exploration in Cook Inlet and the Shelikof Strait.
  - Continue involvement with efforts seeking to approve Tuxedni Bay as a possible onshore petroleum treatment facility (e.g. encourage alternative sites such as using existing Cook Inlet facilities).
  - Evaluate visitor use impacts (e.g., gray water discharge into salt marshes) on coastal water resources.
  - Coordinate with State of Alaska concerning coastal planning.
  - Continue to support USGS/NPS partnership effort to collect geochemical and discharge data from Johnson River. These data will support management decisions regarding "Johnson River Tract" mining issues. Also evaluate efforts by CIRI to establish mining transportation easements, which are currently argued as being exempted from NEPA compliance.
  - Evaluate the Crescent River logging operations (e.g., log transfer facility) working with the Alaska Department of Game and Fish, U.S. Fish and Wildlife Service, and U.S. Army Corps of Engineers, to ensure compliance of the current project design and operations.

- Coordination
  - Continue to participate in the Alaska Department of Environmental Conservation and U.S. Environmental Protections Agency's state-wide effort, to improve watershed management.
  - Initiate cooperative efforts between LACL and the Alaska Department of Environmental Conservation, supported by Clean Water Act funding that address high priority water-related issues.
  - Maintain and develop new and existing partnerships, including the USGS - Water Resources Division (NAWQA – Cook Inlet study basin, Johnson River assessment), USGS – Biological Resources Division (salmon population and migration studies), University of Alaska – Fairbanks (Lake Clark water quality assessment), Katmai National Park (sockeye salmon harvest studies), and NC State University (quantitative fish population assessments).

The political and environmental complexity of the park's issues elevates the need to expand upon the information contained in this scoping report by producing a more comprehensive Water Resources Management Plan (WRMP) for the park. A WRMP will provide a more detailed description of the issues presented in this report, while including an overview of existing state and federal legislation that pertains to the park's water resources. The plan will also include recommended actions (project statements) for the park's Resource Management Plan that address these, and possibly other, high-priority issues. Project statement development should build from the natural resource needs outlined in this section. These project statements will define the specific problem(s) and recommended action(s), including a representative budget, that can compete for future internal and external funding calls.

The WRMP process will strengthen existing partnerships and encourage other stakeholders to participate with the NPS during and after plan development. Many of the issues presented in this report extend beyond NPS boundaries; thus, it is important to recognize the fact that multi-agency communication and coordination are essential to successfully manage LACL's water resources.

The park is encouraged to place a high priority in seeking funds, both internally and externally, to expand its resource management program, and to develop a WRMP. Expansion of the park's Resource Management Division with qualified staff is a critical component to a successful WRMP process. A WRMP will provide only minimal contributions to a park if there is minimal Resource Management staff and expertise to drive the recommendations. It is estimated that a WRMP for the park will take 2 years to complete and cost approximately $50,000. Until a WRMP is prepared for LACL, components of this scoping report should be used in the development of time-sensitive management strategies and project statements relating to water resource issues.

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Appendix A. Plants included in the Alaska Natural Heritage Program Rare Vascular Plant Tracking List, April 2000, that have been identified in Lake Clark National Park and Preserve (Caswell, pers. comm., 2000).

Species	State Ranking
Aphragmus eschscholtzianus	S3
Artemisia tilesii subsp. *Unalaschcensis*	S3
Carex lenticularis var. *dolia*	S3
Crassula aquatica	S3
Douglasia alaskana	S3
Draba incerta	S3
Draba stenopetala	S3
Geum aleppicum var. *strictum*	S1,S2
Isoetes occidentalis	S1,S2
Limosella aquatica	S3
Mertensia paniculata var. *eastwoodae*	S3
Minuartia biflora	S2
Papaver alboroseum	S3
Papaver nudicaule	S3
Plagiobothrys orientalis	S3
Potamogeton robbinsii	S1
Romanzoffia unalaschensis	S3
Rumex beringensis	S3,S2
Saxifraga adscendens subsp. *Oregonensis*	S2
Saxifraga nelsoniana subsp. *PorsildianaS3*	S3
Taraxacum careocoloratum	S3
Thlaspi arcticum	S3
Viola selkirkii	S3
Zannichellia palustris	S3

Note: S1 = Critically imperiled in state.
S2 = Imperiled in state.
S3 = Rare or uncommon in state.

Appendix B. List of Reviewers

The following individuals provided valuable input during the review process of this report.

Participant	Representing
Nancy Deschu	NPS-Alaska Support Office
Lee Fink	NPS-Lake Clark National Park and Preserve
Mark Flora	NPS-Water Resources Division
Troy Hamon	NPS-Katmai National Park and Preserve
Penny Knuckles	NPS-Lake Clark National Park and Preserve
Deb Liggett	NPS-Katmai National Park and Preserve, and Lake Clark National Park and Preserve
Barry Long	NPS-Water Resources Division
Chuck Pettee	NPS-Water Resources Division
Jim Tilmant	NPS-Water Resources Division
David Vana-Miller	NPS-Water Resources Division