National Park Service
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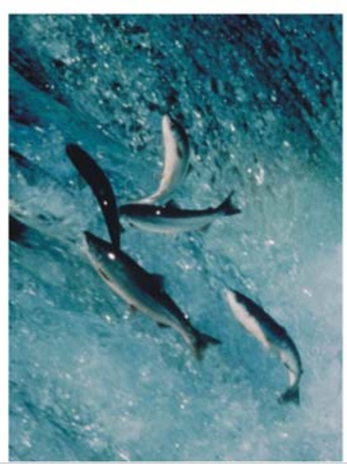
Natural Resource Program Center

Water Resources Information and Issues Overview Report
Katmai National Park and Preserve
Alagnak Wild River

Natural Resource Technical Report NPS/NRPC/WRD/NRTR—2007/057



ON THE COVER

Photographs: (top) Valley of Ten Thousand Smokes, Katmai National Park and Preserve (Jim Gavin); (lower left) Brooks River, Katmai National Park and Preserve; (lower middle) Brooks Falls, Katmai National Park and Preserve (Jim Gavin); (lower right) Alagnak Wild River (Jim Winn)

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October 2007

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

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The Natural Resources Technical Reports series is used to disseminate the peer-reviewed results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service's mission. The reports provide contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations. Current examples of such reports include the results of research that addresses natural resource management issues; natural resource inventory and monitoring activities; resource assessment reports; scientific literature reviews; and peer reviewed proceedings of technical workshops, conferences, or symposia.

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Please cite this publication as:

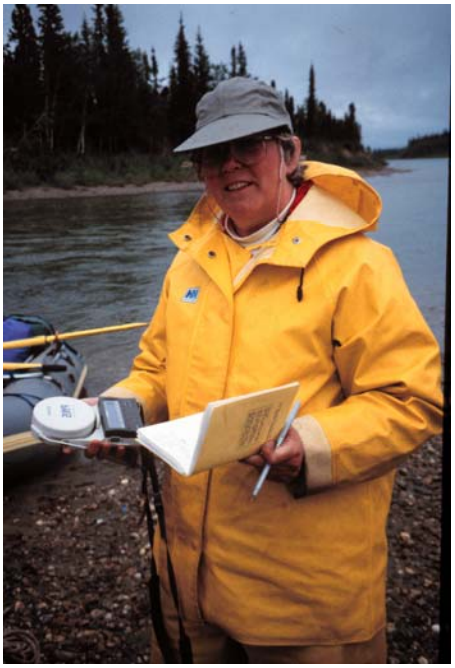
Kozlowski, J. 2007. Water Resources Information and Issues Overview Report, Katmai National Park and Preserve, Alagnak Wild River. Natural Resource Technical Report NPS/NRPC/WRD/NRTR—2007/057. National Park Service, Fort Collins, Colorado.

NPS D-112, October 2007

Dedication

Completion of this report was only possible through the diligent efforts of those who came before. There are many who contributed to our knowledge and expanded our appreciation for the value of water resources in Katmai, and we express our appreciation for their efforts. Above all, one scientist and her work will be remembered by many. Jacqueline LaPerriere was a gifted scientist and blessed with the ability to convey her enthusiasm for limnology to those she came in contact with. Without her contributions, dedication and love for science we wouldn't have the understanding and appreciation of water that we do.

It was with great sadness that we lost Jackie to cancer in 1997. But her smile, vivacious personality and dedication to her work will be remembered by all who met her. This report is intended to carry on her work and is dedicated to her memory.



Jacqueline D. LaPerriere

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Conversion Factors

To convert from:	**To:**	**Multiply by:**
Feet	Meters	0.3048
Miles	Kilometers	1.609344
Square miles	Square kilometers	2.5899881
Cubic feet/sec	Cubic meters/sec	0.02832

Executive Summary

Waters of Exceptional Value

Although Katmai National Park and Preserve (Katmai) is best known for its large populations of brown bears and fish and numerous volcanoes, its nearly 4.2 million acres encompass a vast land of extraordinary rivers, lakes, glaciers, alpine tundra, coastal fjords and bays, marshes, alder thickets and spruce forests, each supporting interdependent communities of species that have adapted well to live in Katmai's harsh climate. Katmai and the Alagnak Wild River contain some of the most spectacular waters in the nation, including the largest freshwater lake in the national park system and one of the longest contiguous coastlines (398 miles). These waters are remarkable for their color, clarity, size and number as well as their phenomenal ability to support large numbers of fish. Katmai's lakes and streams are truly a national treasure deserving of the highest level of protection that can be afforded.

The purposes and values for which Katmai National Park and Preserve was set aside recognize the exceptional water related resource values of the park. In the many proclamations and pieces of legislation setting aside lands that have now become Katmai National Park and Preserve, the President and Congress sought to protect nationally significant resources for the American public. Some of the resources they sought to protect were bears and fish and the aquatic habitats that these species are so dependent on.

Lands surrounding the west end of Naknek Lake were added to the park in 1969 (President, 1969) assuring that the entire lake and its shoreline were contained in the park. This addition was considered "necessary for the protection of the ecological and other scientific values of the lake and existing Monument." In later years scientists came to understand the importance of the Naknek drainage and how its waters represent the range of physical, chemical and biological variation found on the Alaska Peninsula. These waters provide an important area for studying fish productivity and the variables that influence it.

The 1.4-million-acre expansion in 1978 was made to protect brown bear habitat and watersheds vital to red salmon spawning. The added area included portions of the Alagnak drainage, which has since proven to be one of the more productive salmon drainages in the Kvichak system. The geological variation of this drainage provides an interesting comparison with other drainages in terms of water characteristics and salmon productivity.

Section 202 of the Alaska National Interests Lands Conservation Act (ANILCA) defines purposes and values for which Katmai was set aside:

> *To protect habitats for, and populations of, fish and wildlife…to maintain unimpaired the water habitat for significant salmon populations; and to protect scenic, geological, cultural and recreational features…*

In ANILCA, Congress specifically recognized the inestimable value of protecting water resources in the park.

Finally, Section 203 of ANILCA directs that Katmai be administered as an area of the national park system pursuant to the organic act of August 25, 1916, as amended and supplemented, and as appropriate to Section 1313 and other applicable provisions of ANILCA. The organic act states in part that:

> *The service…shall promote and regulate the use of…national parks…which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*

Challenges in Managing Water Resources in Katmai

The challenge NPS faces in managing water resources in Katmai is providing for public use and limited development of the park without degrading waters that are so important to the natural functioning of the ecosystem and the local economy. Compounding the issue is a recognized lack of information and understanding of the aquatic environment that the system is so dependent on. This conflict is no more apparent than at Brooks River, one of the foremost bear viewing areas in the world. For many years fuel spillage and groundwater contamination from overstressed utility systems and intense visitor and development pressure dominated this small area within the 4.2 million-acre wilderness reserve. Elsewhere at Katmai, increased recreational pressure from fishing, rafting and bear watching goes unchecked, development of inholdings in previously pristine areas increases and fish runs decline for unexplained reasons.

Functionally intact and biologically complex ecosystems, as are found in Katmai, provide food supply, flood control, purification of human pollutants, and an adaptive capacity to respond to unseen environmental conditions, such as climate change and habitat for plant and animal life. These benefits are costly, if not impossible, to replace. Long term maintenance of the processes and properties that support freshwater ecosystem integrity should, therefore, be a priority.

Although some important studies have been completed, our understanding of how Katmai's waters function, how natural processes function, what factors are most important in sustaining their viability and how they sustain high fish production remains poor. The majority of the park's waters appear to be pristine, but may face threats from sources far from Alaska, such as airborne contaminants. The actual impacts of these outside influences are unknown. In several areas surface and groundwaters suffer contamination from local sources and still others are faced with chronic low level inputs from increasing human use. For these reasons the National Park Service has developed this water resource report to establish a plan of action for protection of this important resource now and into the future.

Goals and Objectives for Management of Water Resources

The purpose of the Katmai Water Resource Information and Issues Overview is to provide a coordinated framework for monitoring, management and research of the aquatic resources in the park. The report provides a summary of past research conducted in the park and an evaluation of our current level of knowledge of the aquatic environment. It identifies threats to the aquatic environment and provides direction on prevention and/or mitigation of threats, and prescribes recommended actions, in the form of project statements, determined to address the key water resource issues of the park. Most importantly, the report provides a framework for working with our partners in management of water resources on these federal lands and adjacent areas that will allow development of a more comprehensive, cooperative, regionwide management strategy.

Consistent with general management planning goals for Katmai, the Water Resource Information and Issues Overview has three goals:

1. To protect ground and surface water quality and quantity;
2. Increase understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations; and
3. Participate in management on a watershed basis in close coordination with other agencies, universities, tribes and the private sector.

Long term objectives include a description of 1) watersheds, including natural and cultural features, 2) the distribution, type and relative importance of environmental processes and 3) the watershed's present condition relative to its associated values and uses.

Identifying and Prioritizing Water Resource Issues

Information for development of issue statements included in this report came 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.), onsite visits, and reviews of existing natural resources information with emphasis on water resources. The following high priority issues were identified at Katmai:

- Baseline Inventory and Monitoring
- Climate Change and Influences on Water Resources
- Nutrient Cycling
- American Creek Streambed Disturbance
- Alagnak Wild River Bank Erosion by Boat Traffic
- Water Resource Impacts from Backcountry Facilities
- *Exxon Valdez* 1989 Oil Spill
- Potential Oil/Gas Leasing in Lower Cook Inlet and Shelikof Strait
- Brooks Camp Petroleum Contamination
- Brooks Camp Wastewater Management
- Valley Road Management
- Wetlands Management

- Oil Spill Contingency Planning
- Water Rights
- Coordination

In early 2001 a water resource program management planning process was initiated for Katmai. More than 50 questionnaires were mailed to stakeholders in the region representing local, state and federal government agencies, tribal organizations and other interested groups. Respondents were asked to comment on and prioritize the existing list of water resource issues. In March of 2001 NPS held a public scoping meeting in Anchorage attended by a broad range of local, state and federal agency personnel, university professionals and tribal representatives. Meeting participants discussed and ranked the list of issues. From meeting discussions and survey results, the initial list of issues was expanded, some issues were consolidated and a final rank assigned. The resulting list of priorities forms the basis for establishing the direction of the water resource program at Katmai. Water resource issues identified as most pressing for Katmai, based on the scoping meeting, include:

- Lack of baseline information to determine if water quality is degrading and to understand the relationship between water quality and quantity
- Need to better understand the effects of increased visitor use and development on the aquatic environment
- Desire for long-term coordinating relationships with other agencies, universities, tribes and the private sector
- Inadequate data to adequately protect and enhance flow-dependent resource values
- Need for data on the impacts of global climate change on water resources
- Need to understand factors controlling the fertility and functioning of the system

Management recommendations, in the form of project statements, have been developed to address these water resource issues. Project statements are standard National Park Service programming documents that describe a problem or issue, discuss actions to deal with it and identify the additional manpower and/or funds needed to carry out the proposed actions. They are planning tools used to identify problems and needed studies and are programming documents used to compete with other projects and park units for monetary support.

The National Environmental Policy Act (NEPA) mandates that federal agencies prepare a study of the impacts of major federal actions having a significant effect on the human environment and provide alternatives to those actions. The adoption of formal plans may be considered a major federal action requiring NEPA analysis if such plans contain decisions affecting resource use, examine options, commit resources or preclude future choices. Lacking these elements, Katmai's Water Resource Information and Issues Overview report has no measurable impacts on the human environment and is categorically excluded from further NEPA analysis.

Implementation of water resource management project statements usually are covered by one of several NEPA categorical exclusions. These categorical exclusions require that formal records be completed (Section 3.2, DO-12 Handbook) and placed in park files. The park is responsible for proper completion of NEPA documentation under the applicable categorical exclusion(s) for each project during early planning stages.

Chapter 1: Goals and Objectives for Managing Water Resources in the Park

Katmai National Park and Preserve and the Alagnak Wild River contain some of the most spectacular waters in the nation, including the largest freshwater lake in the national park system and one of the longest contiguous coastlines (398 miles; see map following page 1-1). These waters are remarkable for their color, clarity, size and number, as well as their phenomenal ability to support large numbers of fish. Katmai's lakes and streams are truly a national treasure, deserving the highest level of affordable protection.

Aside from their natural aesthetic beauty, these waters provide many economically valuable services and long term benefits to society. Functionally intact and biologically complex ecosystems, as found in Katmai, provide food and habitat for plant and animal life, flood control, purification of human pollutants and an adaptive capacity to respond to future environmental conditions, such as climate change and habitat for plant and animal life. These benefits are costly, if not impossible to replace. Long term maintenance of the processes and properties that support freshwater ecosystem integrity should therefore be a priority.

The rivers, lakes and streams of Katmai also attract many park visitors. Recreational activities, including fishing, boating, rafting and kayaking depend on these waters. In many areas surface and ground water are used as a source of public drinking water. For centuries these waters have served as primary transportation routes for Alaska's Native peoples and continued to support rural residents' subsistence way of life. Today they provide the primary means of visitor access to the park and preserve. The local economy heavily depends on these waters to produce the salmon that is so vital to the subsistence, recreational and commercial fisheries. Fishing and tourism drive the economy in Bristol Bay, and much of that money can be directly attributed to these two industries.

Katmai's waters are critical to the structure and functioning of park ecosystems. Although the headwaters to all of Katmai's watersheds are encompassed within its boundaries, water quality can significantly affect the upstream migration of salmon into the park. For this reason it is vital that the park looks beyond its borders for partners in the management of water resources and the preservation of the aquatic ecosystem.

Although some important studies have been completed, our understanding of how Katmai's waters function, how natural processes function, what factors are most important in sustaining their viability and how they sustain high fish production remains poor. The majority of the park's waters appears to be pristine, but may face threats from sources far from Alaska, such as airborne contaminants. The actual impacts of these outside influences are unknown. In several areas surface and groundwaters suffer contamination from local sources, and still others are faced with chronic low level inputs from increasing human use. For these reasons the National Park Service has initiated the development of a water resource information and issues overview report to establish a plan of action for protection of this important resource now and into the future.

Initiating and developing this report can provide opportunities for development of allies, constituents and important partnerships to achieve common goals. While the report is ultimately the product of the planning process, the relationships built along the way may be the most important outcomes of the initiative. Local people and seasonal commercial operators are as concerned over protection of waters in Katmai as state and federal agencies are. Watershed management requires thoughtful stewardship that cannot be attained solely through government regulation and technical specialists. Only through coordination and cooperation with park users and regulatory agencies can we achieve the highest level of protection for these waters.

I. Purpose of the Water Resource Information and Issues Overview

The purpose of the Katmai Water Resources Information and Issues Overview is to provide a coordinated framework for monitoring, management and research of the aquatic resources in the park. The report provides a summary of past research conducted in the park and an evaluation of our current level of knowledge of the aquatic environment. It defines threats to the aquatic environment and provides direction on prevention and/or mitigation of threats and prescribes recommended actions, in the form of project statements, determined to address the key water resource issues of the park. Most importantly, the report provides a framework for working with our partners in management of water resources on these federal lands and adjacent areas that will allow a more comprehensive, cooperative, region-wide management strategy to be developed.

This report is designed to address specific water resource needs and actions during the next 10 to 15 years. It is consistent with the General Management Plan for the park (1987) and will complement future planning for the Alagnak Wild River Management Plan and the fisheries resource program. Water resource components of the park's Resource Management Plan (1999) are developed in greater detail in this report.

<u>Katmai's Water Resource Information and Issues Overview History</u>

It is important to understand the history of this report, since NPS water resources management plans are now a product of the past…a result of the 2004 *Park Planning Program Standards* replacing the NPS Director's Order #2, *Park Planning*.

In response to the park's technical assistance request, NPS Water Resources Division staff visited the park in 1998 to identify significant water resource issues facing park management.

The results from this trip are captured in the *Katmai National Park and Preserve Water Resources Scoping Report* (Weeks, 1999). Due to the political and environmental complexity of water-related issues elevated in this scoping report, a recommendation was presented to expand on the existing report information by seeking funding for the preparation of the more comprehensive *Water Resources Information and Issues Overview*.

Katmai was successful in competing for funding to prepare the overview report, with NPS Water Resources Division project funds released in 2001, scheduled for a two-year completion. Janis Kozlowski (NPS Alaska Regional Office) was selected as the project lead and primary author. The first big milestone was a project scoping workshop in Anchorage in 2001, organized by Ms. Kozlowski. The purpose of the workshop was to invite watershed stakeholders to discuss the water-related issues captured in the Weeks (1999) report and to identify other high-priority issues not captured in the scoping report for consideration in this report. The details of this very successful workshop are discussed later in this chapter under *Identifying Water Resource Issues and Research Needs*.

Taking the information obtained from the workshop, Ms. Kozlowski worked hard over the next two years assembling a very comprehensive draft product. The NPS Water Resources Division, along with regional agencies and Alaska NPS staff, provided a detailed review of the product, with most of these comments incorporated into the draft report. There were a few comments that created roadblocks for the report's completion, such as resource management issues and the park's coastal boundary.

Starting in 2005, a new direction for the NPS Water Resources Division's planning products was introduced in response to the 2004 *Park Planning Program Standards*. This report was caught in the transition, but was too far along to move it into the new format.

After two years of struggle to resolve some final comments, complicated by changes in staffing of key positions (e.g., the park's Superintendent and NPS Alaska Regional Director) and loss of the NPS Alaska Regional Water Resources Coordinator, the draft plan was turned over to Katmai National Park Planner/NEPA Coordinator, Helen Lons, in 2006 to finalize. With support of the new park Superintendent, Ralph Moore, a final review was completed to update the content for publication. With this final product, it is anticipated that others will gain a better understanding of Katmai water resource issues and participate in the preservation, monitoring and management of park water resources.

II. Environmental Compliance

The National Environmental Policy Act (NEPA) mandates that federal agencies prepare a study of the impacts of major federal actions having a significant effect on the human environment and alternatives to those actions. The adoption of formal plans may be considered a major federal action requiring NEPA analysis if such plans contain decisions affecting resource use, commit resources or preclude future choices. Lacking these elements, Katmai's Water Resource Information and Issues Overview has no measurable impacts on the human environment. Specific projects outlined in this report may require further environmental analysis and public involvement consistent with NEPA before a decision is made to implement the project.

III. The Challenge

The challenge NPS faces in managing water resources in Katmai is providing for public use and limited development of the park without degrading waters that are so important to the natural functioning of the ecosystem and the local economy. Compounding the issue is a recognized lack of information and understanding of the aquatic environment that the system is so dependent on. This conflict is no more apparent than at Brooks River, one of the foremost bear viewing areas in the world. For many years, fuel spillage and groundwater contamination from overstressed utility systems and intense visitor and development pressure dominated this small area within the 4.2 million acre wilderness reserve. Elsewhere, increased recreational pressure from fishing, rafting and bear watching go unmonitored and development of inholdings in previously pristine areas increases.

For these reasons, the focus of the Katmai and Alagnak Wild River corridor management programs must be on balancing human use with preservation and maintenance of a healthy aquatic system — a daunting challenge. Through identification of alternative actions and project proposals, this report will outline a program for management of the aquatic environment whose sole purpose is to protect the natural characteristics of these waters.

IV. Meeting the Challenge

Proclamations establishing and enlarging the park, as well as a number of federal laws provide the authorities for NPS management of water resources in Katmai (Chapter 2). The act that created the national park system, the Organic Act of 1916, mandates that the NPS preserve resources unimpaired for the enjoyment of future generations. To achieve that mandate, this report will help define the types of resource conditions, visitor uses and management actions that are desired to establish and maintain unimpaired conditions.

The Katmai General Management Plan (1986) serves as a guide for management of the park. The plan identifies a number of important goals for management of water resources. The water resource related management objectives it defines for Katmai include (page 47):

> *Aquatic habitats of the park and preserve will be protected to maintain natural, self sustaining aquatic populations.*
>
> *Salmon spawning habitat will be protected and maintained in its natural condition recognizing that Katmai contains major watersheds that provide salmon-spawning habitat vital to the commercial fishing industry, and therefore, the economy of the Bristol Bay region. Migrating salmon also represent an important upstream flow of nutrients into the park and are critical to the maintenance of healthy park ecosystems.*
>
> *Natural processes that are fundamental to the ecosystems of Katmai will be identified, and a monitoring program will be established to obtain baseline*

> *information and identify human-induced disturbances. Processes to be addressed include nutrient flow and the cycles and trends in air and water quality.*

The Government Performance and Results Act of 1993 (GPRA) is one of the most recent and comprehensive of a number of laws and executive orders directing federal agencies to join the "performance management revolution" already embraced by private industry and many local, state and national governments. Performance management ensures that daily actions and expenditures of resources are guided by long- and short-term goal setting in pursuit of accomplishing an organization's primary mission, followed by performance measurement and evaluation. The GPRA goals for Katmai that relate to water resource management include:

> *By September 30, 2005, all waters in Katmai National Park and Preserve and Alagnak Wild River will have unimpaired water quality.*

Elements of this report, as well as the Inventory and Monitoring Program funded by Congress, are working toward accomplishment of this important goal.

V. Goals for Management of Water Resources

Consistent with general management planning goals for Katmai, the water resources program at Katmai has three main goals:

1. to protect ground and surface water quality and quantity;
2. increase understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations; and
3. participate in management on a watershed basis in close coordination with other agencies, universities, tribes and the private sector.

Long term objectives include a description of:

1. watersheds including natural and cultural features;
2. the distribution, type and relative importance of environmental processes; and
3. the watershed's present condition relative to its associated values and uses.

Recognizing the contribution of past water resource studies conducted by fisheries biologists and university scientists, the intent of the majority of research recommended will focus on more process oriented questions that will aid in understanding changes in the aquatic ecosystem through time, as monitoring programs are established and implemented.

VI. Partnering in Watershed Management and Conservation

Today, multi-agency coordination is essential in park units to effectively monitor and manage the natural resources. Unfortunately, at Katmai it is difficult to establish long-term coordination relationships with other agencies. One reason is because Alaska is so large and resources so limited that attention cannot be directed to every watershed in the state. Another reason is that Katmai, along with other undeveloped areas in Alaska, lacks the time-sensitive water resource issues or impacts which typically drive funding for information-gathering projects. The one exception at Katmai is the *Exxon Valdez* 1989 oil spill where multi-agency monitoring projects supported by a monetary settlement are on-going along the Shelikof Strait coastline.

Despite its past track record, the park has made efforts to work more closely with its sister agencies, the State, inholders and neighbors; resulting in benefits for all entities. Many State and federal agency staff, commercial operators and concessionaires, borough natural resource managers, tribes and villages participated in development of the Water Resource Information and Issues Overview. They contributed their knowledge and ideas, shared their concerns and debated the issues. A list of participants in the planning process is in Appendix A.

The villages surrounding the park have a strong interest in protection of the park, as well as the area around the villages themselves. Some have developed comprehensive plans that address their natural resource goals for protection and maintenance of healthy ecosystems. The villages' goals are often directly in line with NPS goals and, therefore, serve as a basis for building a strong cooperative relationship for managing water resources.

The Village of Kokhanok, for example, developed a strategic comprehensive environmental plan in March 2001 (Andrew 2001). The plan proposes that a number of actions be initiated over the next five years that seek to understand and protect the natural environment in and around the village, mitigate existing problems and prevent known potential problems in the future. Education of school children and village residents on environmental issues was also defined as a high priority need. Many of the goals identified in the Kokhanok plan closely mirror the NPS goals for management of water identified in this report. These common goals provide opportunities for NPS and the village to cooperate on projects to resolve problems of mutual concern.

Kokhanok goals that overlap with NPS interests and concerns are to:

1. Educate school students and village residents in aspects of management of the environment using environmental experts in recycling, solid waste, fuel, water quality, waste water and natural resources;
2. Build tribal capacity in water quality monitoring, standards and assessments. Provide for training and technical assistance in the development of a monitoring program to identify pollution of water resources;
3. Procure funding to map, assess and determine environmental damage to wetlands and traditional lands. Design a plan to identify pollution sources and seek remediation through education, clean-up and restoration of lands;
4. Utilize local and professional organizational expertise in devising a local comprehensive resource and wetlands preservation plan in the village; and
5. Build tribal capacity in natural resource issues pertinent to the identification and preservation of natural resources in the village and region.

NPS and the region's tribal members also have a number of concerns and long range goals in common. The Bristol Bay Comprehensive Economic Development Strategy (2002), a product of the Bristol Bay Native Association, which represents over 10,000 tribal members in the region, identified concerns regarding protection of fishery habitat and has placed top priority on protecting salmon migratory routes and spawning grounds from environmental impacts (Bristol Bay Native Association 2002:58). The strategy also recognizes the importance of lands reserved in state parks, national park units and national wildlife refuges, encompassing nearly 14 million acres or nearly half of the region's 28.7 million acres of land (Bristol Bay Native Association 2002:2). Non-consumptive tourism opportunities, such as Native cultural and ecotourism activities, are favored by area villages.

VII. Relationship of this Report to Other Planning Efforts

Several other planning efforts have been completed or are underway that address issues closely related to those in the Water Resource Information and Issues Overview. As much as practicable, coordination between these planning efforts has been done. The following is a description of other known planning efforts or plans inside and outside the park that could have an effect on water resource management in Katmai.

<u>Katmai National Park and Preserve Fisheries Resources Information and Needs Assessment</u>

During the next several years, the NPS may prepare a Fisheries Resources Information and Needs Assessment for Katmai National Park and Preserve. The idea was borne out of concerns over the growth of fishing activity in the area and the perception of a need for a comprehensive coordinated fisheries resources assessment. The assessment will establish long-term management goals in cooperation with interested stakeholders who all could work to support the goals. "Stakeholders" are those people who are interested in, affected by or affecting water resources in the park.

Fisheries concerns centered on a number of issues including:

1. present and future growth of fishing activity;
2. lack of information on stock status and health;
3. crowding, fishermen experience and loss of wilderness values;
4. fishermen- wildlife interactions (particularly bear concerns);
5. associated resource impacts, including vegetation and water quality;
6. safety concerns; and
7. jurisdictional overlap and need to coordinate fisheries management efforts.

Toward this end, NPS will continue to compile information from all available sources on the status and growth of fishing in the park, status of fish stocks and resource impacts related to fishing activities. NPS will use this information as a basis of draft statements of desired resource and sociological conditions for park fisheries and for identifying fishery information needs.

In the past there has been an interest in constructing a road that might cross the Alagnak Wild River to provide access to a proposed mine site west of Lake Iliamna and continue on into Anchorage. In response to this and other anticipated natural resource impacts, Katmai staff prepared a proposal to develop an action plan for the Alagnak Wild River to implement informed decision-making for the wild river corridor. Baseline information collection was initiated and continues for development of an updated Alagnak Wild River Management Plan. The original plan, prepared in 1983, was required by the Wild and Scenic River Act [P.L. 90-542, as amended, §3(d)(1)]. The updated plan will address resource protection, development of lands and facilities, user capacities and other management practices necessary to achieve the purposes for which the Alagnak River was set aside. The goal of the plan is to protect and enhance the Alagnak's water quality and outstanding resource values. Analysis of baseline data from natural resource studies and visitor use surveys are needed to achieve this goal. A survey of users of the Alagnak was initiated in 2003 with results from the study currently under evaluation. These data will be used in the development of a new Management Plan.

VIII. Identifying Water Resource Issues and Research Needs

Katmai staff is aware of both widespread and local threats that have the potential to degrade Katmai's 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 to prepare a Water Resource Scoping Report (WRSR). The report, prepared by NPS hydrologist Don Weeks, was completed in 1999. The WRSR identifies and briefly describes the natural resources of Katmai and the significant water-related issues that challenge park management to address.

In certain cases, WRSRs meet the current water management needs for NPS units, where the number and complexity of issues are minimal. However, for Katmai, a number of water-related issues exist, including the extensive environmental damage that resulted from the 1989 *Exxon Valdez* oil spill. Many of the issues identified center around the lack of basic information (i.e., baseline data) that would better assist the NPS's understanding of Katmai's water resources and may lead to identification of additional issues.

In addition, each of the issues has aspects that affect the park's water resources, though some may not be under NPS control. The WRSR recognized that multi-agency communication and coordination are essential to successfully manage Katmai's watershed. Based on the assessment of these issues, a recommendation and justification was made to produce a more comprehensive Water Resource Information and Issues Overview report for Katmai.

Information for development of issue statements in the WRSR 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.), on-site visits and reviews of existing natural resources information with emphasis on water resources.

The following high priority issues were identified at Katmai:
- ♦ Baseline Inventory and Monitoring
- ♦ Climate Change and Influences on Water Resources
- ♦ Nutrient Cycling
- ♦ American Creek Streambed Disturbance
- ♦ Alagnak Wild River Bank Erosion by Boat Traffic
- ♦ Water Resource Impacts from Backcountry Facilities

- *Exxon Valdez* 1989 Oil Spill
- Potential Oil/Gas Leasing in Lower Cook Inlet and Shelikof Strait
- Brooks Camp Petroleum Contamination
- Brooks Camp Wastewater Management
- Valley Road Management
- Wetlands Management
- Oil Spill Contingency Planning
- Water Rights
- Coordination

In early 2001 the water resource management planning process for Katmai was initiated. In February more than 50 questionnaires were mailed to stakeholders in the region representing local, state and federal government agencies, tribal organizations and other interested groups. Respondents were asked to comment on and prioritize the existing list of water resource issues identified in the scoping report. In March 2001 NPS held a public scoping meeting in Anchorage attended by a broad range of local, state and federal agency personnel, university professionals and tribal representatives. Meeting participants discussed and ranked the list of issues. The initial list of issues expanded from meeting discussions and survey results. Some issues were consolidated and a final rank assigned. The resulting list of priorities forms the basis for establishing a direction for the water resource program at Katmai.

The top ranked issues were:

- Lack of baseline information to determine if water quality is degrading and to understand the relationship between water quality and quantity
- Need to better understand the effects of increased visitor use and development on the aquatic environment
- Desire for long-term coordination relationships with other agencies, universities, tribes and the private sector
- Inadequate data to protect and enhance flow dependent resource values
- Need for data on the impacts of global climate change on water resources
- Need to understand factors controlling the fertility/functioning of the system

Informal discussions on management of watersheds beyond park boundaries, the importance of acquiring data to support water rights applications, data dispersal and management, the need for integrated science studies and the lack of a water resource monitoring plan dominated. These discussions led to several specific recommendations that will be implemented during the planning process and are reflected in the report.

IX. Management Strategies

The NPS recognizes that to move forward on many of these issues a cooperative framework for management must be established. A commitment to open communication and cooperation is a critical first step. This report, therefore, proposes the establishment of a water resource management program that includes local, State and federal entities who manage water as well as tribes, private citizens, commercial operators and environmental groups who have a strong interest in maintaining pristine waters for fish production, recreation and other purposes.

Elements of the water resource management program include:

1. using the park as a classroom to involve the public in education, research and planning;
2. data management and distribution that improves accessibility of information regarding water resources; and
3. coordinating an integrated research program designed to increase knowledge of water resources and ecosystem processes in the park and along the Alagnak Wild River.

Chapter 2: Roles and Responsibilities for Management of Water Resources

I. Establishment of the Park

On June 6, 1912, one of the largest volcanic explosions ever recorded took place in the area surrounding Mt. Katmai on the Alaska Peninsula. A column of smoke billowed from Novarupta Volcano spewing seven cubic miles of incandescent ash and pumice over a wide area. The 30-square-mile Ukak River valley was buried by as much as 700 feet of hot ash that literally flowed from the volcano, turning the valley into a hellish plain where countless fumaroles emitted volcanic gases and vaporized the river and rainwater.

The mountain, scarcely known to the outside world before that time, thrust itself and the Bristol Bay area into prominence. While the eruption depopulated a large area and made a much larger area unattractive to live in, the National Geographic Society made its first attempt to explore the newly altered landscape surrounding the eruption site. It was largely due to the work of Robert Griggs on National Geographic Society expeditions and the popular features of his expeditions in National Geographic magazine that led to the designation of Katmai National Monument just six years after the eruption.

In 1918 Katmai National Monument was established by presidential proclamation under the authority of the Antiquities Act. Its purpose was to preserve, for their scientific and scenic values, the features associated with one of the most powerful volcanic explosions ever recorded.

In the years since the monument was established, Katmai has been expanded four times, but the rationale behind the expansions has borne no resemblance to that which created the original monument. Since the initial proclamation, multiple additions have been made to the original monument, reflecting the evolving perception of the area's purposes and values.

Robert Griggs made his fifth National Geographic sponsored visit to Katmai in 1930. Impressed with the bear population during his 1919 expedition Griggs lobbied for protection of brown bear habitat adjacent to the monument. He also recommended addition of the lake region – Brooks, Naknek, Coville and Grosvenor – which he considered an excellent breeding ground for waterfowl and the waterfalls at Brooks River, which he considered to be the "finest exhibition of leaping salmon to be found anywhere in the world." The NPS recognized the value of the brown bear habitat and expounded on the values of the "magnificent lakes and mountain scenery" in the surrounding region. In 1931, the monument boundaries were expanded by President Hoover to include areas along the Shelikof Strait coastline and in the interior lake system in recognition of the area’s historical and scientific value and for the protection of the brown bear, moose and other wild animals. The proclamation made Katmai the largest NPS unit in the system.

In 1942, all islands within five miles of the monument's coast were added to protect sea mammals and seabird nesting sites and to reduce poaching forays based from the islands. The expansion included about 20 offshore islands, totaling about 3,000 acres.

Lands surrounding the west end of Naknek Lake were added in 1969 "for the protection of the ecological and other scientific values of this lake and the existing monument…" This designation assured that the entire lake was protected within the monument boundaries.

Katmai was expanded to near its present size in 1978 by presidential proclamation to protect brown bear habitat and watersheds vital to red salmon spawning. With the passage of the Alaska National Interest Lands Conservation Act (ANILCA) in 1980, Congress redesignated the monument as a national park and preserve.

The Wild and Scenic Rivers Act was passed in 1968 and was amended in 1980 to preserve selected rivers or sections of rivers in their free flowing condition and to protect the water quality and fulfill other vital national conservation purposes. Under this act 25 river corridors or sections of rivers have been designated in Alaska. Sections 601(25) and 601(44) of ANILCA designated the Alagnak and its major tributary, the Nonvianuk River, as a wild river under the Wild and Scenic Rivers Act including the upper 56 miles of the Alagnak River (or commonly referred to by local people as the Branch River) and the 11- mile Nonvianuk River. The act [Title 6 §605(b)] specifies that the area be managed as a wild river pursuant to the Wild and Scenic Rivers Act, which states in Section 10(a) that:

> *Each component of the national wild and scenic rivers system shall be administered in such manner as to protect and enhance the values which caused it to be included in said system without, insofar as is consistent therewith, limiting other uses that do not substantially interfere with*

> *public use and enjoyment of these values. In such administration primary emphasis shall be given to protecting its aesthetic, scenic, historic, archeologic and scientific features.*

The Wild and Scenic Rivers Act was further amended [Section 10(c)] to say that in Alaska the lands designated as a wild river were subject to the provisions of other acts under which NPS units are administered. In case of conflict between provisions of these acts, the more restrictive provisions would apply. These other acts would include provisions of ANILCA, the Wilderness Act and the NPS Organic Act of 1916, as well as others.

Under ANILCA, Congress also established about three-quarters of the park and preserve as designated wilderness. The wilderness designation included waters, as well as lands, in the park.

Section 202(2) of ANILCA defines the purposes and values that Congress sought to protect in the park:

> *The monument addition and preserve shall be managed for the following purposes, among others: To protect habitats for, and populations of, fish and wildlife including, but not limited to, high concentrations of brown/grizzly bears and their denning areas; to maintain unimpaired the water habitat for significant salmon populations; and to protect scenic, geological, cultural and recreational features.*

In total, Katmai National Park and Preserve encompasses about 6,500 square miles of federal land near the north end of the Alaska Peninsula. It is bounded on the east by Shelikof Strait on the Gulf of Alaska. The north boundary follows the divide between the Nonvianuk/Alagnak drainage and the Kvichak/Iliamna drainage. The western boundary is the moraine on the west end of Naknek Lake and the Naknek drainage above this point is enclosed within the boundary. The southwest boundary encompasses the headwaters of the King Salmon River and Kejulik River drainages. The upper section of the Alagnak Wild River is included in Katmai National Preserve, but the lower portion is outside the boundary (see Appendix D maps).

II. Water Resource Related Purposes and Values

Although Katmai is often thought of as the land of bears, fish and volcanoes, its nearly 4.1 million acres encompass a vast land of rivers, lakes, glaciers, alpine tundra, coastal fjords and bays, marshes, alder thickets and spruce forests, each supporting interdependent communities of species that have adapted well to live in Katmai's harsh climate. The purposes and values for which Katmai National Park and Preserve was set aside recognize the exceptional water related resource values of the park. In the many proclamations and pieces of legislation setting aside lands that have now become Katmai National Park and Preserve, the President and Congress sought to protect nationally significant resources for the American public. Some of the resources they sought to protect were bears and fish and the aquatic habitats upon which these species are so dependent.

The original Katmai National Monument was established to "preserve an area that is of significant importance in the study of volcanism" (President 1918). The presidential proclamation specifically mentioned that the area offered excellent opportunities to study the causes of the catastrophe and its results and held lessons for park visitors on the forces that shaped America. It was thought that the area would become popular as a scenic destination in addition to its scientific value, affording an "inspiration to patriotism and to the study of nature."

Indeed, since the eruption the area has attracted numerous scientists and a large number of hardy backpackers as well. The deeply incised rivers draining the valley and its unique geologic features, such as fumaroles, and warm, cold and hot springs, have provided the setting for studying the 1912 eruption, as well as the processes that continue to shape landscapes and processes in the park.

Later additions to the monument that included significant portions of the Naknek drainage, Brooks Camp and islands off the coast, were set aside for their "features and objects of historical and scientific interest" and for the protection of brown bear, moose and other wild animals (President 1931, 1936 and 1942). Coinciding with these additions was the start of a long term study of fisheries in the Naknek drainage with its base at Brooks Lake. Having a great deal of foresight, these scientists collected some important information on the chemical, physical and biological characteristics of the waters they were interested in.

The lands surrounding the west end of Naknek Lake were added to the park in 1969 (President 1969) assuring that the entire lake and its shoreline were contained in the park. This addition was considered “necessary for the protection of the ecological and other scientific values of the lake and existing monument.” In later years scientists came to understand the importance of the Naknek drainage and how its waters represent the range of physical, chemical and biological variation found on the Alaska Peninsula. These waters provide an important area for studying fish productivity and the variables that influence it.

The 1.4 million acre expansion in 1978 was made to protect brown bear habitat and watersheds vital to red salmon spawning. The area added included portions of the Alagnak drainage, which has since proven to be one of the more productive salmon drainages in the Kvichak system. The geological variation of this drainage provides for an interesting comparison with other drainages in terms of water characteristics and salmon productivity.

Section 101 of ANILCA identifies the general purposes for Katmai National Park and Preserve as well as other conservation system units:

> *To preserve for the benefit, use, education, and inspiration of present and future generations certain lands and waters in the state of Alaska that contain nationally significant natural, scenic, historic, archeological, geological, scientific, wilderness, cultural, recreational and wildlife values . . . .*
>
> *To preserve unrivaled scenic and geological values associated with natural landscapes; to provide for the maintenance of sound populations of, and habitat for, wildlife species of inestimable value to the citizens of Alaska and the Nation, including those species dependent on vast, relatively undeveloped areas . . . and to preserve wilderness resource values and related recreational opportunities . . . within large arctic and subarctic wildlands and on free-flowing rivers; and to maintain opportunities for scientific research and undisturbed ecosystems . . . .*

Section 202 of ANILCA further defines purposes and values for which Katmai was set aside:

> *To protect habitats for, and populations of, fish and wildlife . . . to maintain unimpaired the water habitat for significant salmon populations; and to protect scenic, geological, cultural and recreational features . . . .*

In the act Congress specifically recognizes the inestimable value of protecting water resources in the park.

Finally, Section 203 of ANILCA directs that Katmai be administered as an area of the national park system pursuant to the Organic Act of August 25, 1916, as amended and supplemented, and as appropriate to Section 1313 and other applicable provisions of ANILCA. The Organic Act states in part that:

> *The service . . . shall promote and regulate the use of . . . national parks . . . which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*

Identifying the unique and invaluable features of a park does not assure their preservation. Although conserving park resources and values is the NPS's primary goal, it is often at odds with the park's fundamental purpose to provide for the enjoyment of park resources and values by the people of the United States. One of the challenges the NPS must face in developing a water resources program is to reconcile opposing pressures on the resource by identifying actions that will protect the superb quality and characteristics of the resource and associated values.

The primary responsibility of the NPS is to ensure that park resources and values will continue to exist in a condition that will allow the American people to have present and future opportunities for enjoyment of them. The NPS Management policies (2006) and Director's Order #55 use the terms "resources and values" to mean the full spectrum and intangible attributes for which the park is established and managed, including the Organic Act's fundamental purpose and any additional purposes as stated in the park's enabling legislation or Presidential proclamations. The impairment of park resources and values may not be allowed unless directly and specifically provided by statute. Thus, any action taken by the NPS must leave park resources and values unimpaired for the enjoyment of future generations.

The purposes and values for which Katmai National Park and Preserve was set aside recognize the exceptional water related resource values of the park. They include:

…the protection of the ecological and other scientific values of the [Naknek] lake and existing monument.

…to maintain unimpaired the water habitat for significant salmon populations…and to protect scenic…and recreational features…

The color, clarity and number of lakes and streams in Katmai are unique features of the park and make these waters of inestimable scenic value.

One of the many uses people enjoy in the park is the harvest of fish and wildlife. Before the passage of ANILCA, the NPS recognized that subsistence uses by local rural residents had been, and they are currently, a natural part of the ecosystem. Congress agreed and provided for subsistence use of resources in Katmai National Preserve and the Alagnak Wild River under the provisions of ANILCA. Under the act, sportfishing is also an allowable use of the park. Hunting, fishing and trapping are allowable uses in the preserve and along the Alagnak Wild River. ANILCA requires that such harvest activities remain consistent with the maintenance of natural and healthy populations of fish and wildlife in the preserve.

III. Boundaries and Jurisdiction

Water boundaries and jurisdiction over waters is one of the most controversial topics in the state of Alaska. State and federal managers differ markedly in their opinions on ownership and authority on federal lands. These battles have led to the public's confusion over where activities, such as hunting, can legally be conducted.

This section is intended to clarify the NPS position on water boundaries and jurisdiction to provide a basis and guide for management actions and to increase understanding of this complicated issue.

A. Navigable Waters in Pre-statehood Withdrawals

The federal government contends that the title to submerged lands in areas that were withdrawn or reserved by the federal government before statehood did not vest in the state. This dispute is an important one to the state since more than 95 million acres were enclosed within federal withdrawals and reservations by 1959 when Alaska became a state. In a 1986 decision (*Utah v. United States*, No. 85-1772) the Supreme Court held that intent to defeat a state's equal footing entitlement could not be inferred from the mere act of a reservation itself. To defeat a state's title, the United States would be required to establish that Congress clearly intended to include land under navigable waters in the federal reservation and would additionally have to establish that Congress affirmatively intended to defeat the future state's title to such land.

Proclamations establishing and enlarging Katmai are indicative of the intent of the President in withdrawing lands and waters for the purposes of the monument. The proclamations declare that the lands described are, "…reserved from all forms of appropriation under the public land laws …" (President 1918, 1942). The 1931 proclamation added additional lands to the monument implying a similar intent. The U.S. Senate Committee on Energy and Natural Resources' intentions in setting aside lands and waters as part of Katmai National Park and Preserve were recorded in Senate Report No. 96-413. With respect to waters in Katmai, the committee was clear that the "…existing monument *including waters and submerged lands is designated a part of the park"* (96th Congress, 1st Session 1979:165) [emphasis added].

Land withdrawals for the purpose of establishing Katmai National Monument made before statehood (1959) include the Valley of Ten Thousand Smokes, islands within five miles of the coast, the lake region including Brooks, Coville, Grosvenor and the eastern end of Naknek Lake. The title to submerged lands in these pre-statehood withdrawals for Katmai is clearly vested in the United States.

B. Navigable Waters Within ANILCA Conservation System Units

Under the Property Clause, Navigational Servitude and Commerce Clause, the U.S. Constitution gives Congress certain limited powers to control uses on state owned submerged land. ANILCA gives federal land managers authority to regulate navigable waters in conservation system units.

C. Title Navigability

The state of Alaska owns the beds of navigable waters within its boundaries unless the beds were reserved at the time of statehood. Unreserved submerged lands beneath navigable waters are granted to new states under the Equal Footing Doctrine. The Submerged Lands Act of 1953 confirms state title to beds of navigable waters. Congress expressly applied the Submerged Lands Act to Alaska in the Alaska Statehood Act of 1959, leaving little doubt about the ownership of unreserved submerged lands beneath 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 (ANCSA) 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 units blanket the state, navigability questions have arisen for Alaska rivers, lakes and streams. While the navigability of many of these water bodies for conveyance purposes has already been established, navigability for title has not been determined for most water bodies.

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 water bodies so that accurate navigability determinations can be made. The greatest hurdles to overcome in identifying and managing navigable waters in Alaska have been the differences of opinion between the state and federal governments regarding the criteria for determining title navigability. The criteria for navigability take into account geography, economy, customary modes of water-based transportation and the physical characteristics of the water body. Final court decisions in Alaska are still needed to provide legal guidance for accurate navigability determination (Alaska Department of Natural Resources 1999a).

Disputes between the state and federal governments have arisen over determining the proper criteria for title navigability and the survey and acreage accounting system used by the federal government for conveying land to the state and Native corporations. Because of these disagreements, the navigability of water bodies in the state has been an issue of contention since enactment of the Alaska Statehood Act and ANCSA. Part of the dispute was resolved with passage of the Alaska Submerged Lands Act in 1988 (94 Stat. 2430 amending Section 901 of ANILCA, codified at 43 USC 1631), which requires that the standard rules of survey in the BLM manual of Surveying Instructions be used for all federal surveys under the Statehood Act and ANCSA.

The judicial test for determining navigability was established more than 100 years ago. In the landmark decision of *Daniel Ball*, 77 U.S. 557, 563, (1870), the Supreme Court declared:

> *Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or are susceptible of being used, in their ordinary condition, as highways of commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water.*

Interpretation of the terms and phrases used in the *Ball* test are a source of disagreement between the state and federal governments. The federal government asserts the waterway must be used, or be capable of use, for transporting commerce to be considered navigable. Other, non-commercial transportation uses are not considered sufficient to establish navigability. The federal government's argument is that the type and purpose of the transportation required to establish navigability is critical to the decision. It also argues that when only recreation is involved, the waters are not being used as navigable highways but as an amusement park and are considered legally non-navigable.

In the Gulkana River case the courts found that to demonstrate navigability, it is only necessary to show that the water body is physically capable of "the most basic form of commercial use: the transportation of people or goods." (*Alaska v. United States*, 662 F. Supp. 455 (D. Alaska 1987). In *Alaska v. Ahtna, Inc*. the court of appeals affirmed the district court's finding that the modern use of the Gulkana River for guided hunting, fishing and sightseeing trips is a commercial use and provides conclusive evidence that the river was capable of commercial use at statehood. For the purposes of title navigability, the water body must have been navigable in 1959 when Alaska became a state. They also found that modern inflatable boats can be used to establish navigability.

Few navigability determinations have been made on waters in Katmai. However, in 1985 the Ninth Circuit declared the waters of the Alagnak River, Nonvianuk River, Kukaklek Lake and Nonvianuk Lake navigable and confirmed the state's title to their beds (*Alaska v. United States of America, Bristol Bay Native Corp, Levelock Natives Ltd. and Igiugig Native Corp.* A82-201 Civ, Feb. 4, 1985). In 1992 the state of Alaska notified Secretary of the Interior Lujan that it intended to file real property quiet title action as to the submerged lands underlying 185 water bodies. The water bodies listed in the Bristol Bay region were Kulik Lake and the mouth of the Naknek River to Naknek Lake (state of Alaska 1992).

D. Boundaries of Navigable Waters

The boundaries of navigable waters are determined in different ways, depending on if they are subject to the rise and fall of the tide. A non-tidal water boundary is the "ordinary high water mark." The boundary of tidal waters is the "mean high water line." This water boundary became fixed at the pre-1964 earthquake location whether uplift or submergence resulted.

In coastal areas, ANILCA Section 103(a) states that the boundary of the area added by ANILCA does not extend seaward beyond the mean high tide line to include lands owned by the state of Alaska unless the state agrees to the boundary extension. This statement indicates that coastal marshes and lagoons in the ANILCA additions, for example, fall within the boundary of Katmai National Park and Preserve, given that they do not lie seaward of the mean high tide.

E. Federal Powers and the Question of Regulating Subsistence on Navigable Waters

Congress has the authority to preempt state authority on federal lands and waters if it chooses to. The U.S. Constitution, under the Property Clause, Commerce Clause and Article 1 on "admiralty powers" provide extremely broad powers to Congress. Questions of federal power were clarified in *Kleppe v. New Mexico*, 426 U.S. 529, 539 (1976). The courts found that federal jurisdiction can extend beyond the boundaries of a conservation unit when necessary to protect the public lands in the conservation unit.

Similarly, Congress has broad power to regulate navigable waters under the Commerce Clause of the U.S. Constitution. *Kaiser Aetna v. United States*, 444 U.S. 164, 172 (1979) said, "It has long been settled that Congress has extensive authority over this Nation's waters under the Commerce Clause." In the case of a rural preference justified under the Interstate Commerce Clause, a reviewing court would ask "whether a rational basis existed for concluding that a regulated activity [substantially] affected interstate commerce." *United States v. Lopez*, 514 U.S. 549, 557 (1995). If so, then Congress would have authority to adopt a regulatory program governing the activity and to preempt any contrary state law.

Regulation of fish and game in Alaska affects interstate commerce. "It is generally accepted that taking fish from waters in the state of Alaska substantially affects interstate commerce. The activity supports a $1.2 billion annual industry that comprises nearly 55% of United States seafood production and accounts for approximately 40% of Alaska's international exports." [*Katie John v. United States*, 247 F.3d 1032, 1035 (9th Cir. 2001)]. Hunting activities also substantially affect interstate commerce as evidenced by the influx of sport-hunters from around the United States [*Alaska Professional Hunters Association, Inc. v. F.A.A.*, 177 F.3d 1030, 1031 (9th Cir. 1999)]. For these reasons it is clear that Congress could preempt state authority, for many purposes, on federal lands and navigable waters.

F. NPS Management of Activities on Waterways

In order to protect fish, wildlife and the other values and purposes of the national park system, the NPS developed general regulations intended to be applicable on waters located within park boundaries irrespective of ownership of submerged lands, tidelands, or lowlands and jurisdictional status. The United States does not hold title to all submerged lands under navigable waters in Katmai. However, federal authority to regulate within the ordinary reach of these waters is based on the commerce and property clauses of the U.S. Constitution, not on ownership. Under the authorities delegated in 16 U.S.C. § 3 in 1976, Congress amended the 1970 Act for Administration (or General Authorities Act) and authorized the NPS to "promulgate and enforce regulations concerning boating and other activities on or relating to waters located in areas of the national park system, including waters subject to the jurisdiction of the United States. (16 U.S.C. § 1a-2(h). Waters subject to the jurisdiction of the United States include navigable waters. [H. Rep. No. 1569, 94th Congress, 2nd Sess., 4292 (1976)]. Federal regulations in the 36 CFR Parts 1-5, 7 and 13 regulations (for Alaska parks) apply on navigable waters, regardless of jurisdictional status.

The general provisions of National Park Service regulations in 36 CFR Part 1 define the applicability and scope of the regulations. These regulations specifically state that the NPS regulations apply to all persons entering, visiting, or otherwise within (36 CFR § 1.2, Federal Register Vol. 61, No. 130, Friday, July 5, 1996):

- *(1) The boundaries of federally owned lands and waters administered by the National Park Service;*
- *(2) The boundaries of lands and waters administered by the National Park Service for public-use purposes pursuant to the terms of a written instrument;*
- *(3) Waters subject to the jurisdiction of the United States located within the boundaries of the National Park System, including navigable waters and*

areas within their ordinary reach (up to the mean high water line in places subject to the ebb and flow of the tide and up to the ordinary high water mark in other places) and without regard to the ownership of submerged lands, tidelands or lowlands; and

(4) Other lands and waters over which the United States holds a less-than-fee interest, to the extent necessary to fulfill the purpose of the National Park Service administered interest and compatible with the nonfederal interest.

36 CFR 1.2 (a)(2) indicates that NPS regulations would not apply on non-federally owned lands within park boundaries unless regulations containing a provision specifically applicable to such lands is promulgated. NPS regulations do not apply, for example, on Indian tribal trust lands in the park unless an agreement is reached with the benefiting tribe, nation or band.

IV. State and Federal Roles in the Management of Water Resources

A. State of Alaska Watershed Programs

The state of Alaska plays a primary role in watershed management. It has developed several programs to identify and resolve water resource issues and assist landowners in protecting waters they care for.

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 program recognizes that carrying out a comprehensive water quality monitoring program requires cooperation among many agencies and groups. The AWMAP framework was developed cooperatively between the Alaska Department of Environmental Conservation (DEC) and the U.S. Environmental Protection Agency (EPA).

The AWMAP objectives include (Alaska Department of Environmental Conservation 1996a):

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.

Alaska's Clean Water Action Program (ACWA) is a joint effort by state resource agencies (Departments of Environmental Conservation, Fish and Game and Natural Resources, including DNR's Office of Project Management and Permitting). The program is intended to unify efforts to protect and improve water quality, water quantity and fish habitat in the areas of greatest need. The state agencies are interested in working with federal agencies to design cooperative research and monitoring programs and explore collaborative ways to stretch both state and federal dollars.

Through this program the state agencies have agreed to

1. publish a report every two years on the health of Alaska's waters;
2. identify which waters need field monitoring to assess their health;
3. identify and prioritize waters "at risk" and "polluted" that are in need of protection or restoration;
4. provide technical and financial assistance to local and tribal governments, volunteers and nonprofit organizations committed to protecting and improving water quality and quantity and fish habitat; and
5. to join in cooperative agreements with federal agencies and private companies committed to protecting and improving water quality and quantity and fish habitat.

B. Federal Watershed Protection Programs

The Alaska National Interest Lands Conservation Act (ANILCA) of 1980, section 907 established the **Alaska Land Bank** program to provide legal and economic benefits to Native landowners and to provide for the protective maintenance of nonfederal lands, particularly where the lands relate to conservation system units. Land bank agreements may contain provisions, such as the landowner's responsibility to manage land in a manner compatible with the planned management of the unit. The superintendent's responsibility is also defined and may include technical or other assistance with or without compensation as agreed to by the parties. There are no Alaska Land Bank agreements in Katmai.

C. Summary of Federal Water Resource Laws, Regulations and Policy

Many federal, state and local agencies have an interest, mandated or otherwise, in the water resources in Katmai. The Alagnak Wild River, in particular, is a patchwork of land ownership that further complicates regulatory and management scenarios. Protection of water resources requires an understanding of the various policy, regulatory and management designations to facilitate coordination and cooperation among agencies and private landowners in Katmai.

All federal lands and waters within the park and preserve boundary are under proprietary jurisdiction of the NPS. Both federal and state agencies have authority for the enforcement of appropriate regulations.

Some of the water resource laws that are most relevant to Katmai National Park and Preserve are summarized in this section. For further information, many of these laws relating to water, water resources and wetlands can be accessed on worldwide web pages for the U.S. Environmental Protection Agency (http://www.epa.gov) and the U.S. Fish and Wildlife Service (http://www.fws.gov). State water quality laws and regulations may be found at: http://www.dec.state.ak.us/water/wqsar/wqs/wqs.htm.

Water laws at the state and local level are often patterned after federal laws, or serve in response to federal directives dealing with water pollution, wetlands and streamflow. For example, the federal Clean Water Act is the prime federal legislation. Its various subsections cover water pollution, wetlands, stream dredging, waste disposal and related topics, as described below. The state has enacted legislation that addresses parts of the Clean Water Act.

1. Federal Laws

The **National Park Service Organic Act** was passed in 1916 creating the National Park Service. The act states that the National Park Service has the responsibility to:

> *Promote and regulate the use of the Federal areas known as national parks, monuments, and reservations…conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations. (16 USC 1)*

The dual and sometimes conflicting mandates to preserve and protect resources while providing for their enjoyment by the public often complicate park management.

A 1970 amendment to the **General Authorities Act** states that all parklands are united by a common purpose, regardless of title or designation. NPS is required to manage these parks in accordance with the Organic Act and other applicable laws so as not to be "…in derogation of the values and purposes for which these various areas have been established…" Under this law, all water resources of the park are protected by the federal government. Only an act of Congress can change this fundamental responsibility of the National Park Service.

In 1978 an act expanding Redwood National Park (**Redwoods Amendment**) further amended the general authorities of the National Park Service to mandate that all park system units be managed and protected "in light of the high public value and integrity of the national park system." Furthermore, no activities should be undertaken "in derogation of the values and purposes for which these various areas have been established," except where specifically authorized by law or as may have been or shall be directly and specifically provided for by Congress. Thus, by amending the general

Authorities Act of 1970, this act reasserted systemwide the high standard of protection prescribed by Congress in the Organic Act.

The National Park Service Administrative Reform Act (1996) amends the Park System Resource Protection Act of 1990 to permit the NPS to recover costs from harm caused by oil or hazardous materials spills. Damages may include the costs of restoration or the lost values of a "park system resource" pending its restoration. A "park system resource" is any living or non-living resource within the park's boundary. Damage claims settlements may be used to restore resources that were the subject of a spill or other action and may be used to monitor and study resources.

Recognizing the ever increasing societal pressures being placed on America's unique natural and cultural resources contained in the national park system, the **National Parks Omnibus Management Act of 1998** attempts to improve the ability of the National Park Service to provide state-of-the-art management, protection and interpretation of and research on the resources of the national park system by:

- assuring that management of units of the national park system is enhanced by the availability and utilization of a broad program of the highest quality science and information;
- authorizing the establishment of cooperative agreements with colleges and universities, including but not limited to land grant schools, in partnership with other federal and state agencies, to establish cooperative study units to conduct multi-disciplinary research and develop integrated information products on the resources of the national park system, or the larger region of which parks are a part;
- undertaking a program of inventory and monitoring of national park system resources to establish baseline information and to provide information on the long-term trends in the condition of national park system resources; and
- taking such measures as are necessary to assure the full and proper utilization of the results of scientific study for park management decisions. In each case in which an action undertaken by the National Park Service may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered. The trend in the condition of resources of the national park system shall be a significant factor in the annual performance.

The **Wilderness Act** of 1964 established the National Wilderness Preservation System, composed of federal lands designated as wilderness areas. A wilderness, in contrast with those areas where man and his own works dominate the landscape, is … an area where the earth and its community of life are untrammeled by man… an area of undeveloped federal land retaining its primeval character and influence… which is protected and managed so as to preserve its natural conditions that:

- appear to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable;
- provide outstanding opportunities for solitude or a primitive and unconfined type of recreation; and
- have at least 5,000 acres of land or are of sufficient size as to make practicable their preservation and use in an unimpaired condition.

Generally, there are no permanent roads in any wilderness area. Except as needed for administrative purposes, there are to be no temporary roads or use of motorized vehicles or motorized equipment, no landing of aircraft, no other form of mechanical transport and no structure or installation in any wilderness area. However, ANILCA made certain exceptions to the Wilderness Act that applies to wilderness areas in Alaska. Section 1110(a) allows for the use of snowmachines, motorboats, airplane and non-motorized surface transportation for traditional uses and access to and from villages and homesites. Section 1303(a)(3) authorizes the use and occupancy of existing cabins and other structures by permit. New cabins and shelters are allowed if necessary for the protection of public health and safety (Section 1315) and temporary shelters and facilities may be allowed for subsistence purposes (as well as other uses) (Section 1316). Air and water navigation aids, communication sites and related facilities and facilities for weather, climate and fisheries research and monitoring may also be permitted in accordance with Section 1310 of the Act.

The **Wild and Scenic Rivers Act** (P.L. 90-542, as amended; 16 U.S.C. 1271-1287) of 1968 set aside selected rivers and their immediate environments that exemplify outstanding scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values. The act provides for the preservation of the selected rivers, or sections thereof, in their free-flowing condition to protect the water quality of these rivers and to fulfill other vital national conservation purposes. The act instituted a national wild and scenic rivers system, designated the initial components of the system and prescribed the methods by which and standards according to which additional components may be added to the system. In 1982 the secretary of the interior published final revised guidelines for eligibility, classification and management of river areas (Fed. Reg. Vol. 47, No. 173, Tuesday, September 7, 1982)

Wild Rivers, such as the Alagnak, are those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds and shoreline essentially primitive and waters unpolluted. These rivers are meant to represent vestiges of primitive America. Other classifications include Scenic River areas and Recreational River areas.

Components of the national wild and scenic rivers system are to be administered in such a manner as to protect and enhance the values that caused them to be included in the system. The idea of a Wild and Scenic River designation is not to halt development and use of a river; instead, the goal is to preserve the character of a river. Uses compatible with the management goals of a particular river are allowed. Development not damaging to the outstanding resources of a designated river, or curtailing its free flow, is also usually allowed. For rivers designated after January 1, 1986, as the Alagnak was, the managing federal agency is charged with developing a comprehensive management plan to address resource protection, development of lands and facilities, user capacities and other management practices necessary or desirable to achieve the purposes of the Wild and Scenic Rivers Act.

Water quality of a wild and scenic river is to be maintained or, if necessary, improved to levels meeting federal criteria or federally approved state standards for aesthetics and fish and wildlife propagation.

The **federal Water Pollution Control Act**, more commonly known as the Clean Water Act, was first promulgated in 1972 and amended several times since (e.g. 1977, 1987 and 1990). This law is designed to restore and maintain the chemical, physical and biological integrity of the nation's waters, including the waters of the national park system. To achieve this, the act called for a major grant program to assist in the construction of municipal sewage treatment facilities and a program of effluent limitations designed to limit the amount of pollutants that could be discharged. Effluent limitations are the basis for permits issued for all point source discharges, known as the National Pollutant Discharge Elimination System (NPDES).

As part of the act, Congress recognized the primary role of the states in managing and regulating the nation's water quality. Section 313 requires that all federal agencies comply with the requirements of state law for water quality management, regardless of other jurisdictional status or landownership. States implement the protection of water quality under the authority granted by the Clean Water Act through best management practices and through water quality standards. Standards are based on the designated uses of a water body or segment of water, the water quality criteria necessary to protect that use or uses and an anti-degradation provision to protect the existing water quality.

A state's antidegradation policy is a three-tiered approach to maintaining and protecting various levels of water quality. Minimally, the existing uses of a water segment and the quality level necessary to protect the uses must be maintained. The second level provides protection of existing water quality in segments where quality exceeds the fishable / swimmable goals of the Clean Water Act. The third level provides protection of the state's highest quality waters where ordinary use classifications may not suffice; these are classified as Outstanding National Resources Waters (ONRW).

ONRW status, in most cases, is a desirable designation to acquire for National Park Service units with significant water resource management responsibilities. For waters designated as ONRW, water quality must be maintained and protected and only short-term changes may be permitted. ONRW designations for waters outside the park boundaries, which parks can apply for, can also ensure the protection of water that flows into a park unit.

Some additional sections of the act relevant to Katmai include:

> **Section 303** of the act requires the promulgation of water quality standards by the states. Additionally, each state is required to review its water quality standards at least once every three years. This section also requires the listing of those waters where effluent limitations are not stringent enough to implement any water quality standard [so called 303(d) list]. Each state must establish, for each of the waters listed, total maximum daily loads for applicable pollutants.

Section 305(b) requires that each state prepare and submit to the U.S. Environmental Protection Agency a biennial report describing water quality conditions of lakes and streams. The report also lists any pollution problems occurring on certain stream reaches. Streams are then classified as supporting, not supporting, or only partially supporting their designated uses (for fishing, recreation, drinking, and so on).

Section 319 requires states to develop controls over non-point source pollution, such as erosion. Some sources of pollution, particularly industrial and municipal dischargers, fall under the National Pollutant Discharge Elimination System program (defined under Section 402 of the act).

Section 401 requires that any applicant for a federal license or permit to conduct an activity that will result in a discharge into waters of the U.S., shall provide the federal agency, from which a permit is sought, a certificate from the state water pollution control agency, stating that any such discharge will comply with applicable water quality standards. Federal permits that require Water Quality Certification from the state of Alaska include 404 permits from the U.S. Army Corps of Engineers for the discharge of dredged or fill material.

Section 402 requires that a National Pollutant Discharge Elimination System (NPDES) permit be obtained for the discharge of pollutants from any point source into the waters of the United States. Point source, waters of the Unites States and pollutants are all broadly defined under the act; but generally all discharges and storm water runoff from major industrial and transportation activities, municipalities and certain construction activities must be permitted by the NPDES program. The EPA usually delegates NPDES permitting authority to the state. The state, through the permitting process, establishes the effluent limitations and monitoring requirements for the types and quantities of pollutants that may be discharged into its waters. Under the anti-degradation policy, the state must ensure that the approval of a NPDES permit will not eliminate or otherwise impair any designated uses of the receiving waters.

Section 404 of the Clean Water Act further requires that a permit be issued for discharge of dredged or fill materials in waters of the U.S., including wetlands. The act includes other impacts to riverine systems, such as piping, filling, relocating, culverting and sand and gravel mining.

The U.S. Army Corps of Engineers administers the Section 404 permit program with oversight and veto powers held by the U.S. Environmental Protection Agency. The Corps must notify the EPA of intent to issue a permit in Katmai and solicit EPA comments regarding any potential impacts.

The **Clean Air Act** of 1970 (as amended) regulates airborne emissions of a variety of pollutants from area, stationary and mobile sources. The 1990 amendments to this act were intended primarily to fill the gaps in the earlier regulations, such as acid rain, ground level ozone, stratospheric ozone depletion and air toxics. The amendments identify a list of 189 hazardous air pollutants. The U.S. Environmental Protection Agency must study these chemicals, identify their sources, determine if emissions standards are warranted and promulgate appropriate regulations. That list includes PCBs; dioxins and furans; chlordane, mercury compounds; lead compounds; cadmium compounds; toxaphene; and trichlorobenzene, to name a few.

The **Coastal Zone Management Act (1972)** and its amendments (1990) enable coastal states to develop a coastal management program that would improve protection of sensitive shoreline resources, identify coastal areas appropriate for development, designate areas hazardous to development and improve public access to the coastline. The act requires that federal agencies conducting activities or undertaking development directly affecting the coastal zone shall ensure that the activities or developments are consistent with approved state management programs to the extent practicable.

Unlike other national environmental laws, participation in the federal Coastal Zone Management Program is voluntary. To encourage state participation, incentives include grant programs and expanded state powers in coastal areas. Since more than 60% of Alaska's land is in federal ownership, the opportunity to influence federal decision-making was a powerful incentive for the state.

Water Quality Improvement Act (1970). The act requires federally regulated activities to have state certification stating that the activity will not violate water quality standards.

The **Safe Drinking Water Act (1974)** and Amendments direct the U.S. Environmental Protection Agency to publish and enforce regulations on maximum allowable contaminant levels in drinking water. The act requires the Environmental Protection Agency to issue regulations establishing national primary drinking water standards. Primary enforcement responsibilities lie with the states. The act also protects underground sources of drinking water with primary enforcement responsibilities again resting with the states. Federal agencies having jurisdiction over public water systems must comply with all requirements to the same extent as any non-governmental entity.

The 1996 amendments to the Safe Drinking Water Act initiated a new era in cost-effective protection of drinking water quality, state flexibility and citizen involvement. Source water assessment and protection programs, provided under these amendments, offer tools and opportunities to build a prevention barrier to drinking water contamination. Source water protection means preventing contamination and reducing the need for treatment of drinking water supplies. Source water protection also means taking positive steps to manage potential sources of contaminants and contingency planning for the future by determining alternative sources of drinking water.

Congress passed the **National Environmental Policy Act (NEPA)** in 1969. Environmental compliance in the National Park Service encompasses the mandates of NEPA and all other federal environmental laws that require evaluation, documentation and disclosure and public involvement, including the Endangered Species Act, Clean Water Act, Executive Orders on Floodplains and Wetlands and others.

All natural resource management and scientific activities are subject to environmental analysis under NEPA. Parks are required to complete the environmental compliance process to the fullest extent possible when National Park Service resources may be affected, as set forth in the Council in Environmental Quality (CEQ) regulations. Participation by the National Park Service in the environmental compliance processes of other agencies and jurisdictions is an important management tool. It can provide the National Park Service with information that will allow the service to respond to possible external threats to a park well before they occur.

An environmental assessment is not included as part of this plan because the plan provides a general direction for the water resource program for KATM/ALAG. Specific actions may or may not be implemented depending on the availability of funding and staff. Compliance with NEPA will be undertaken for all actions, where appropriate, when it becomes apparent that an action is or actions are likely to be initiated. Individual project statements indicate the level of NEPA compliance anticipated before implementing the activity or action prescribed.

Section 10 of the Rivers and Harbors Act (1899), as amended was the first general legislation giving the U.S. Army Corps of Engineers jurisdiction and authority over the protection of navigable waters. Navigable waters of the United States are those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce. Army Corps of Engineers permits are required under Section 10 of the act for structures and/or work in or affecting navigable waters of the United States.

The U.S. Army Corps of Engineers began regulation of wetlands under this act and then received a much broader grant of jurisdictional authority under the Clean Water Act. Because of the broader geographic reach of “waters of the U.S.” jurisdiction under the Clean Water Act, Rivers and Harbors Act jurisdiction will usually not be of significance to wetlands regulation in current cases. There are, however, several situations in which Rivers and Harbors Act jurisdiction alone will apply. For instance, the mooring of a vessel in a bay may require a permit under the Rivers and Harbors Act, but would not under the Clean Water Act.

The **Fish and Wildlife Coordination Act** of 1965 requires federal agencies to consult with the U.S. Fish and Wildlife Service or the National Marine Fisheries Service and with parallel state agencies whenever water resource development plans result in alteration of a body of water. The Secretary of the Interior is authorized to assist and cooperate with federal agencies to “provide that wildlife conservation shall receive equal consideration and be coordinated with other features of water-resource development programs.”

The **Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)** commonly referred to as Superfund, was enacted in 1980. It created the federal Superfund to clean up uncontrolled or abandoned hazardous waste sites as well as accidents, spills and other emergency releases of pollutants. The act contains an extensive list of hazardous substances that are subject to release reporting regulations. The National Response Center must be notified immediately by the person in charge of a vessel or facility when there is a release of any environmental media of a designated hazardous substance exceeding the predefined reportable quantity within any 24-hour period. The reporting quantities are determined on the basis of aquatic toxicity, reactivity, chronic toxicity or carcinogenicity, with possible adjustments based on biodegradation, hydrolysis and photolysis.

The **Resource Conservation and Recovery Act (RCRA)** enacted in 1976, establishes a regulatory structure for handling, storage, treatment and disposal of solid and hazardous wastes. Many products and materials are regulated under this act, including commercial chemical products; manufactured chemical intermediates; contaminated soil, water or other debris resulting from the cleanup of a spill into water or on dry land; and containers and inner liners of the containers used to hold waste or residue.

The **Endangered Species Act of 1973** requires the NPS to identify and promote the conservation of all federally listed endangered, threatened or candidate species within park or preserve boundaries. While not required by legislation, it is the policy of the NPS to identify state locally listed species of concern and support the preservation and restoration of those species and their habitats.

2. Executive Orders

Executive Order 11988 (E.O. 11988 Floodplain Management) requires the NPS to manage the use and occupancy of floodplains in a manner that minimizes flood risk to humans and structures and minimizes impacts to floodplain resources and processes. The policy and procedures used by the NPS to implement EO 11988 are found in Director's Order (D.O.) 77-2. In brief, it is NPS policy to avoid the use of the regulatory floodplain whenever there is a practicable non-floodplain alternative and to restore, preserve and protect floodplain values. The regulatory floodplain is defined in the D.O. as the 100-year, 500-year or maximum floodplains, depending on the situation. When it is necessary to use the regulatory floodplain or cause impacts to the regulatory floodplain, a statement of findings is prepared describing: 1) why the floodplain must be used or impacted, 2) the level of risk to humans, structures and/or the environment that is being taken in association with the action and 3) how the risk will be mitigated. For the major rivers and numerous smaller tributaries located in the park and where park infrastructure is present or planned or an NPS-supported action occurs, floodplain delineations may be necessary in the future to ensure compliance with the floodplain Executive Order and Director's Order.

Executive Order 11990 (E.O. 11990), entitled "Protection of Wetlands," requires all federal agencies to "minimize the destruction, loss or degradation of wetlands and preserve and enhance the natural and beneficial values of wetlands." Unless no practical alternatives exist, federal agencies must avoid activities in wetlands that have the potential for adversely affecting the integrity of the ecosystem. National Park Service guidance for compliance with E.O. 11990 can be found in Director's Order #77-1 and Procedural Manual #77-1, "Wetlands Protection."

Particularly, it is the policy of the National Park Service to:

- avoid to the extent possible the long- and short-term adverse impacts associated with the destruction or modification of wetlands;
- preserve and enhance the natural and beneficial values of wetlands;
- avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative;
- adopt a goal of no net loss of wetlands and strive to achieve a longer-term goal of net gain of wetlands servicewide;
- conduct or obtain parkwide wetland inventories to help assure proper planning with respect to management and protection of wetland resources;
- use "Classification of Wetlands and Deepwater Habitats of the United States " (Cowardin et al. 1979) as the standard for defining, classifying and inventorying wetlands;
- employ a sequence of first avoiding adverse wetland impacts to the extent practicable; second, minimizing impacts that could not be avoided; and lastly, compensating for remaining unavoidable adverse wetland impacts at a minimum 1:1 ratio via restoration of degraded wetlands;
- prepare a statement of findings to document compliance with Director's Order #77-1 when the preferred alternative addressed in an environmental assessment or environmental impact statement will result in adverse impacts on wetlands; and,
- restore natural wetland characteristics or functions that have been degraded or lost due to previous or ongoing human activities, to the extent appropriate and practicable.

Executive Order 13423, entitled "Strengthening Federal Environmental, Energy, and Transportation Management", requires the National Park Service to conduct environmental, transportation and energy related activities in an environmentally, economically and fiscally sound, integrated, continuously improving, efficient and sustainable manner.

3. NPS Management Policies and Guidelines

The National Park Service Management Policies (2006) provide broad policy guidance for the management of units of the national park system. Topics include park planning, land protection, natural and cultural resource management, wilderness preservation and management, interpretation and education, special uses of the parks, park facilities design and commercial uses. These policies and guidelines broadly require the NPS to maintain, rehabilitate and perpetuate the inherent integrity of aquatic resources.

With respect to water resources, it is the policy of the National Park Service to determine the quality of park surface and groundwater resources and avoid, whenever possible, the pollution of park waters by human activities occurring inside and outside of parks. In particular the National Park Service will work with appropriate governmental bodies to obtain the highest possible standards available under the Clean Water Act for protection of park waters; take all necessary actions to maintain or restore the quality of surface and groundwaters in the parks consistent with the Clean Water Act and all applicable laws and regulations and; enter into agreements with other agencies and governing bodies, as appropriate, to secure their cooperation in maintaining or restoring the quality of park water resources.

The National Park Service will also manage watersheds as complete hydrologic systems and will minimize human disturbance to the natural upland processes that deliver water, sediment and woody debris to streams. The National Park Service will manage streams to protect stream processes that create habitat features such as floodplains, riparian systems, woody debris accumulations, terraces, gravel bars, riffles and pools.

The National Park Service will achieve the protection of watershed and stream features primarily by avoiding impacts to watershed and riparian vegetation and by allowing natural fluvial processes to proceed unimpeded. When conflicts between infrastructure (such as bridges) and stream processes are unavoidable, park managers will first consider relocating or redesigning facilities, rather than manipulating streams. Where stream manipulation is unavoidable, managers will use techniques that are visually non-obtrusive and that protect natural processes to the greatest extent practicable.

Additionally, natural shoreline processes (such as erosion, deposition, dune formation, shoreline migration) will be allowed to continue without interference. Where human activities or structures have altered the nature or rate of natural shoreline processes, the National Park Service will investigate alternatives for mitigating the effects of such activities or structures. The National Park Service will comply with the provisions of Executive Order 11988 and state coastal zone management plans prepared under the Coastal Zone Management Act.

Water for the preservation and management of the national park system will be obtained and used in accordance with legal authorities. Park waters – either surface waters or groundwater – will be withdrawn for consumptive use only when such withdrawal is absolutely necessary for the use and management of the park. The National Park Service will consider all available authorities on a case-by-case basis and will pursue those that are the most appropriate to protect water-related resources in parks. The National Park Service will work with state water administrators to protect park resources and will participate in negotiations to seek the resolution of conflicts among multiple water claimants.

Recommended procedures for implementing servicewide policy are described in the National Park Service guideline series. The guidelines most directly pertaining to actions affecting water resources include:

Director's Order #12: Conservation Planning, Environmental Impact Analysis and Decision-making;

Director's Order #77-1: Wetland Protection;
Director's Order #77-2: Floodplain Management (under review);
Director's Order #83: Public Health;
NPS-75: Natural Resource Inventory and Monitoring; and
Natural Resource Management Reference Manual #77.

D. Alaska State Statutes and Administrative Codes

Alaska Water Use Act (AS 46.15). The Department of Natural Resources shall determine and adjudicate rights in the water of the state and in its appropriation and distribution. Alaska is relatively young with respect to water laws. The state uses the Doctrine of Prior Appropriation to allocate water for consumptive uses and instream flows. AS 46.15.165 allows the state to initiate, by order, an administrative adjudication to quantify and determine the priority of all water rights and claims in a drainage basin, or other identifiable and distinct hydrologic system, including NPS state appropriative and federal reserved water rights. AS 46.15.166 authorizes the state to initiate a judicial adjudication, with the concurrence of the attorney general, if a federal reserved water right has been or might be asserted by an agency of the United States on its own behalf, if consistent with the McCarren Amendment (43 U.S.C. 666). The McCarren Amendment waives the United States' sovereign immunity and allows it to be sued as long as the state is pursuing a basinwide comprehensive adjudication of all water rights. AS 46.15.145 allows the state, an agency or a political subdivision of the state, an agency of the United States or a person to apply to the state to reserve sufficient water to maintain a specified instream flow or levels of water to protect natural resources and sanitary and water quality purposes.

Alaska Water Quality Standards (18 AAC 70). Section 303 of the federal Clean Water Act provides for state establishment of water quality standards. The NPS is required to comply with state water quality standards. Water quality standards are composed of three separate but interrelated components: 1) the designated beneficial uses of a water body such as contact recreation, drinking water supply or a cold water fishery; 2) numerical or narrative criteria that establish the limits of physical, chemical and biological characteristics of water that are sufficient to protect the beneficial uses; and 3) an antidegradation provision to protect the existing uses of water. The criteria generally have a quantitative and/or descriptive component. An example of both would be: not less than 5 parts per million of dissolved oxygen per 100 ml of water or surface waters must be free from floating debris, scum and other floating materials attributable to municipal or industrial discharges in an amount sufficient to be unsightly or deleterious. The criteria cover the spectrum of pollutants from conventional (i.e., fecal coliform and dissolved oxygen) to toxic pollutants. These standards are largely health and effects based.

The Clean Water Act provides a valuable tool to the NPS for protecting its water resources from the influences of external point and nonpoint sources of pollution. At the same time, Section 313 of the act requires the NPS to "…comply with all federal, state, interstate, and local requirements, administrative authority, and process and sanctions respecting the control and abatement of water pollution in the same manner and to the same extent as any non-government entity including the payment of reasonable service charges." (33 USC 1323).

The state of Alaska has established water quality standards for "interstate waters within the state of Alaska." (Appendix C: 18 AAC 70 Water Quality Standards as amended as of December 28, 2006). The standards apply to waters used for public water supplies, contact recreation, fish and wildlife habitat, shellfish, agriculture and industry. They specify the allowable levels of coliform bacteria, dissolved oxygen, pH, turbidity, temperature, dissolved organic substances, petroleum and solid residues, sediment, toxic substances, color, radioactivity and esthetic considerations.

The backbone of the Clean Water Act's effort to eliminate point sources of pollutants into the nation's waters is the National Pollutant Discharge Elimination System (NPDES) created by section 402 of the act. The NPDES program is itself an interesting regulatory conundrum in that it authorizes by permit what otherwise would be illegal under the act – the discharge of pollutants into the waters of the United States. However, by requiring industrial and municipal dischargers to meet stringent effluent standards, it has been successful in significantly improving the quality of the nation's surface waters. NPS facilities that include a discharge wastewater treatment plant must meet the requirements of the NPDES program. The State of Alaska applied for primacy on June 29, 2006 to administer a NPDES program.

Alaska's regulations have a classification for high quality waters or waters of "exceptional recreational or ecological significance" that are restrictive under anti-degradation policies (18 AAC 70.015). The regulation specifically states that, "if a high quality water constitutes an outstanding national resource such as a water of a national or state park or wildlife refuge or a water of exceptional recreational or ecological significance, the quality of that water must be maintained and protected." In other words, in areas such as state and national parks, the existing water uses and the level of water quality necessary to protect existing uses must be maintained and protected. No reduction in water quality is allowable from ambient conditions.

The state of Alaska also has a provision for designating waters as "Outstanding Natural Resource Waters" (ONRW), including waters of exceptional recreational and ecological significance but also unique waters such as hot springs (18 AAC 70.230). However, to date the state has not developed a process by which the program may be implemented, and there is no list of waters protected under this classification.

In reading the state's antidegradation policy along side the section on reclassification of waters (18 AAC 70.230) a reasonable interpretation would suggest that waters in National Park Service units are by default "outstanding natural resource waters." The regulation states that waters in areas administered under the National Wilderness Preservation System under 16 USC 1131-1136 (18 AAC 70.230(d)(1-3)), water in state and national parks, preserves and monuments and waters in wild and scenic rivers established under 16 USC 1271-1287 may not be reclassified. If waters in national parks, such as Katmai, are considered high quality waters constituting outstanding natural resources that are subject to provisions of the antidegradation policy and they may not be reclassified to a lower standard, then the waters in Katmai would be considered outstanding natural resource waters.

This interpretation of the regulations would not consider all waters within the boundaries of Katmai as outstanding natural resource waters. For example, state lands near Kamishak Bay inside Katmai are neither National Park Service lands nor fall under the several categories of state park, critical habitat area or marine or estuarine sanctuary that cannot be reclassified. In keeping with the goal of ecosystem management, NPS would support the inclusion of such lands in the Outstanding Natural Resource Waters program.

Coastal Zone Management Act (PL 92-583, as amended). The federal act establishes a national policy and develops a national program for the management, beneficial use, protection and development of the land and water resources of the nation's coastal zones. While the act establishes national goals for coastal zones, it also provides substantial state discretion in interpreting and achieving its goals.

Alaska Coastal Management Act (AS 46.40). The Alaska Coastal Management Program (ACMP) is voluntary. Rather than develop a separate permit process, Alaska developed a networked program that relies on the existing regulatory authority of state agencies and coastal districts. The coordinating office for this networked program is the Office of Project Management and Permitting in the Alaska Department of Natural Resources.

As incentives to participate, the state passes on federal grant funding, and the coastal districts participate in project reviews and state permit decisions. Each district develops coastal management policies to further define and protect resource values that are unique to its area. After approval by the state and federal government, the district policies become an enforceable component of the ACMP and have the same status as the statewide standards. Although the program gives the coastal district a voice in state and federal actions, it is also used to guide local land management and permit decisions.

Coastal zone management programs have been approved for the Bristol Bay, Lake and Peninsula, Kodiak and the Kenai Peninsula Boroughs. Each borough has an approved coastal management plan with a set of enforceable policies. Due to recent changes in the state coastal zone regulations, some borough programs are currently under state review with pending revisions.

Federal lands are specifically excluded from state coastal zones. Although federal lands are excluded from state coastal zones, federal activities affecting the state's coastal zone are to comply with the state program to the maximum extent practicable. Activities occurring on federal lands that directly affect state coastal resources are subject to federal consistency determinations.

Anadromous Fish Act (AS 16.05.870). The act provides protection for specific rivers, lakes and streams or sections of them that are important for the spawning, rearing, or migration of anadromous fish. Brooks River, the Alagnak River and the Nonvianuk River are designated anadromous fish streams specifically protected by this act. The act requires that any person or government agency that desires to construct a hydraulic project, or to use, divert, obstruct, pollute, or change the natural flow or bed of a river, lake, or stream, or to use wheeled, tracked, or excavating equipment or log-dragging equipment in the bed of a river, lake, or stream to notify the commissioner of the Department of Fish and Game of their intention and to receive approval before beginning the project.

Bristol Bay Area Plan (2005). The Bristol Bay Area Plan directs how the Alaska Department of Natural Resources will manage state shorelands, tidelands and submerged lands within the planning boundary.

Chapter 3: Factors Affecting the Formation and Evolution of Watersheds

I. Climate

General weather patterns and climatological conditions for the Katmai area can be ascertained from reviewing records from the National Weather Service's (NWS) stations at King Salmon and Kodiak Island, which have comprehensive records dating from 1949. Intermittent weather data from National Weather Service cooperative stations are also available for Brooks Lake and Brooks River from 1951 to 1990.

A. General Climatic Conditions for Katmai

Climate is a generalized statement of the prevailing weather conditions that exist at a given location based on a long statistical record of measurements. A number of climate classification systems have been devised to characterize different climates. One of the most popular systems is that devised by Vladimir Köppen (1846-1940), German climatologist and botanist, who used temperature and precipitation records to define areas that differentiated different vegetation types. According to Köppen's system, which uses a shorthand code to distinguish climates, Katmai's climate is classified as Cfc and Dfc (Strahler and Strahler 1992:156). The "C" and "D" designations denote temperate and snow climates, respectively. The "f" indicates sufficient precipitation throughout the year, and "c" indicates that less than four months have mean temperatures above 10^{o}C (50^{o}F).

A classification system specific to Alaska has been devised by Searby (1968). Searby's classification system divides Alaska into four climatic zones: maritime, transitional, continental and arctic. Katmai includes three of Searby's four classifications (or all four if mountain peaks are included). Katmai's eastern and southern coasts bordering Shelikof Strait have a maritime climate characterized by small temperature variations, high humidity, heavy precipitation, high occurrence of clouds and fog, temperatures generally above freezing, cool summers and warm winters. Maximum summer temperatures are generally in the 50s (10^{o}C-15^{o}C), and winter lows are in the 20s (-7^{o}C–1^{o}C) (Selkregg 1976). The Aleutian Range runs along Katmai's Shelikof coast, leading to precipitation that ranges between 50 centimeters (20 inches) and 180 centimeters (70 inches). Precipitation on the high eastern flank of the Aleutian Range may exceed 500 centimeters (200 inches) per year. Surface winds are strong and persist throughout the year.

On the leeward side of the Aleutian Range, Katmai's climate changes to a transitional and then to a continental climate. The latter occupies most of the northeast quadrant of Katmai and is characterized by large variability in diurnal and annual temperature and relatively low precipitation, humidity and cloudiness. Warm summers and cold winters exist, and precipitation is generally less than 50 centimeters (20 inches). Although surface winds are generally light, channeling effects through mountain passes can produce locally strong winds.

Much of Katmai's climate can be classified as transitional with conditions intermediate between maritime and continental. King Salmon, the closest NWS station, lies 10 kilometers (6 miles) west of the Katmai's western boundary. King Salmon's climate can be classified as transitional and, while data from this station may be representative of other transitional areas in Katmai, conditions for King Salmon should not be interpreted as representative of continental and maritime regions. Hence, weather conditions at King Salmon are a good approximation for those at Brooks Camp. Climatic conditions for the maritime region of Katmai are better characterized using data from the NWS station on Kodiak Island, rather than King Salmon. Additionally, local geographic conditions produce a variety of microclimates that are impossible to delineate due the lack of spatial and temporal historical weather data.

B. Historical Records

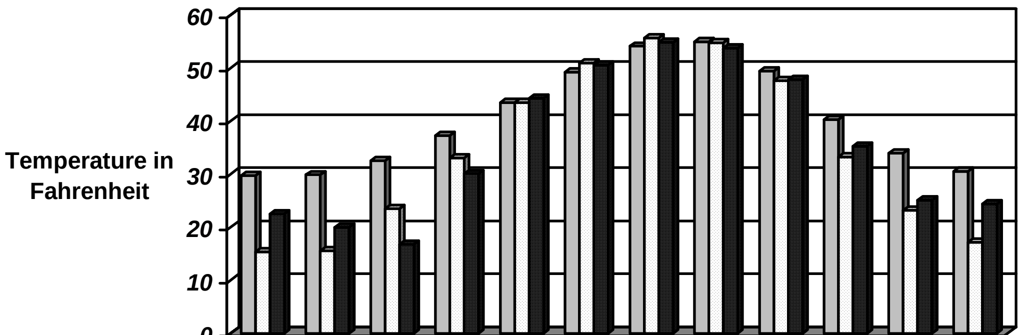
Historical records were gathered searching databases maintained by the NWS, Western Region Climate Center (WRCC) and Alaska Climate Center. Normal climatic conditions are defined with reference to average conditions gathered over a 30-year period. Thirty-year records for the period 1971-2000 were used where they existed to describe normal conditions. In general, NWS stations at King Salmon and Kodiak contained complete and comprehensive records. Some weather data are available for Brooks Lake from 1951 to 1972 and for Brooks River from 1967 to 1990. Because the availability of data from Brooks River is very sparse, it was not used in the analysis. Therefore, any data reported as Brooks comes from the 1951-1972 Brooks Lake data.

1. Temperature

Precipitation and air temperature vary in Katmai, depending on the geographic location. A maritime climate predominates along the Katmai coast with diurnal and seasonal temperature ranges normally confined to rather narrow limits (Young and Racine 1978). The climate is also typically warmer and wetter along the coast. At low elevations the average annual temperature is about 42^{o}F and this zone lacks prolonged periods of freezing weather (Searby 1968; Hartman and Johnson 1978).

The mean annual temperature at King Salmon ranges between 15.4^{o}F in January to 55.7^{o}F in July. Temperatures on Kodiak Island, which are more representative of Katmai’s maritime climate, range between 29.7^{o}F in January and 55.0^{o}F in August. (Figure 1, Western Region Climate Center Data 2002).

The mean monthly temperatures for Kodiak and King Salmon are 40.5^{o}F and 34.5^{o}F, respectively. While the temperature data clearly demonstrate the lower variability in monthly temperatures for Kodiak Island, data for King Salmon are more indicative of continental conditions; and data for Brooks Lake tend to reflect a transitional climate. The mean March monthly temperature for Brooks Lake reported as 16. 8^{o}F is questionable because this would make March the coldest month at this location; furthermore, the March temperature for Brooks Lake is inconsistent with the temperature patterns displayed at Kodiak and King Salmon.



	J	F	M	A	M	J	J	A	S	O	N	D
Kodiak	29.7	29.9	32.6	37.3	43.5	49.2	54.1	55.0	49.4	40.3	34.0	30.6
King Salmon	15.4	15.6	23.5	33.1	43.5	50.9	55.7	54.8	47.6	33.3	23.2	17.2
Brooks Lake	22.5	20.0	16.8	30.1	44.3	50.5	54.9	53.7	47.8	35.3	25.1	24.4

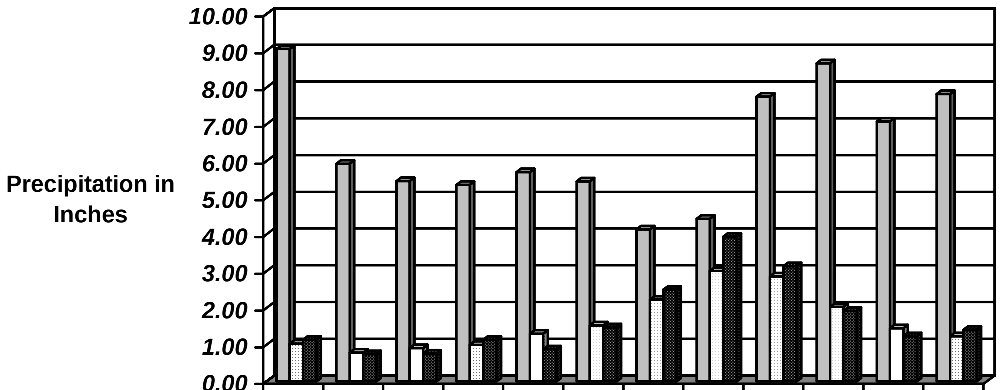
Figure 1. Monthly mean air temperature data, 1971-2000, for Kodiak Island and King Salmon. Data for Brooks Lake, 1951-1972 (Western Region Climate Center 2002).

2. Precipitation

Most precipitation (60%) falls as rain from May through September (National Park Service 1994). Precipitation for the Kodiak Island station ranges between 5.45 inches in July and 8.66 inches in October with an average annual precipitation 76.83 inches. (Figure 2, Western Region Climate Center 2003).

King Salmon's lowest precipitation is 0.79 inches in February, and the highest monthly precipitation is 3.01 inches in August with an average annual accumulation of 19.32 inches. Precipitation data for Brooks Lake are similar to data for King Salmon with a low value of 0.75 inch in February, a high value of 3.94 inches in August and an annual accumulation of 20.30 inches. Precipitation is high during all months for Kodiak Island. Precipitation levels at King Salmon and Brooks Camp show higher variability compared to Kodiak Island, where the lowest precipitation occurs during the late winter and early spring (February-April) and the highest precipitation occurs in late summer and early fall (July-October).

Precipitation levels at Kulik River in the northern portion of the park have only recently been recorded. Seasonal data for 2001 through 2003 for Kulik River indicate highest summer precipitation levels during August with reported levels closer to those for King Salmon than Kodiak, which is in the maritime zone.



	J	F	M	A	M	J	J	A	S	O	N	D
Kodiak	9.05	5.93	5.46	5.35	5.70	5.45	4.14	4.43	7.76	8.66	7.08	7.83
King Salmon	1.03	0.79	0.91	1.00	1.30	1.53	2.23	3.01	2.86	2.03	1.45	1.23
Brooks Lake	1.14	0.75	0.76	1.14	0.88	1.48	2.50	3.94	3.14	1.92	1.23	1.41

Figure 2. Monthly mean precipitation data, 1973-2003, for Kodiak Island, and 1955-2003 for King Salmon. Data for Brooks Lake, 1951-1972 (Western Region Climate Center 2003).

The Kulik River reporting station lies in the lee of the Aleutian Range in the transitional climatic zone, partially explaining the similarities in precipitation levels for the two areas. However, the August 2002 precipitation figures illustrate that weather conditions between the two areas may be quite different. In August 2002, the Kulik River station recorded 5.62 inches of rain, with 4 days measuring more than 0.5 inch of rainfall (Wehrman 2002; table 1 below). In fact, two days measured 0.9 and 1.06. In comparison, at the King Salmon weather station in the period of 1955-2000 the average number of days in August with rainfall exceeding 0.5 inch was just one day. Between June and August only two days measured more than 0.5 inch of rain at the King Salmon station (Western Region Climate Center 2003). With additional data over the years, weather anomalies and trends should be easier to differentiate.

Precipitation in the form of snow is prevalent from November to April for both Kodiak and King Salmon (table 2) (National Oceanic and Atmospheric Administration 1998).

Table 1: Average rainfall (in inches) by month from weather reporting stations in and around Katmai National Park and Preserve.

Month/Year	Kulik River	King Salmon	Kodiak	King Salmon 47 year Average
August 2001	2.27[a]	2.37	9.21	
September 2001	1.88	1.64	6.89	
June 2002	0.93	1.46	3.96	1.70
July 2002	1.46	2.51	8.38	2.15
August 2002	5.62[b]	3.51	3.04	2.89
September 2002	2.75	2.33	1.10	2.81
June 2003	0.84	2.30	6.63	
July 2003	1.59[c]	2.45	3.36	
August 2003	2.70[d]	4.53	7.82	
September 2003	0.32	1.57	8.31	

a = first 8 days of the month missing, b=The average number of days with precipitation levels measured above 0.5 inch for the King Salmon station from 1955 to 2003 was 1 day in August. The Kulik River station reported 4 days above 0.5 inch in 2002, including days with .9 and 1.06 inches of precipitation. c=last 2 days of the month missing, d=three days during the month were missing.
Source: Harry Wehrman, Kulik Lodge and Western Region Climate Center 2003 at www.wrcc.dri.edu/summary.climsmak.html

Table 2. Mean snowfall in inches for Kodiak and King Salmon (T =Trace)

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Kodiak	15.6	17.5	12.3	7.4	0.6	T	0.0	T	T	2.2	7.1	14.9	77.6
King Salmon	8.3	6.5	7.0	4.5	0.9	0. 0	0.0	T	T	3.2	6.4	9.0	45.8

Kodiak and King Salmon do not accumulate appreciable snow cover. The average snow depth in January for King Salmon is 4 inches. Mean snow depth recorded at Brooks Lake is greatest in December with a mean value of 10.7 inches, but for all other winter months the mean snow depth is less than 6 inches. Maximum snow depths for King Salmon and Brooks Lake for the winter months range between 5 inches and 20 inches.

3. Wind

Southeasterly and easterly winter winds predominate in the King Salmon area for the months from October to March (Waythomas 1994). Winter winds are associated with high pressure over northern Alaska and low pressure over the southern Bering Sea and Gulf of Alaska. Summer winds, present between June and September, are generally from the south or southeasterly direction. During the late winter and early spring, February to May, winds are from the north or northeast. The frequency of winds associated with specific direction and speed for King Salmon is displayed in figure 3 (Selkregg 1976). Strongest winds for King

Salmon come from the east. Average wind speeds for King Salmon display little monthly variability with a high of 11.5 mph in March and a low of 9.9 mph in July (National Oceanic and Atmospheric Administration 1998). Winds for Kodiak display greater seasonal variability with high winds in winter and lower winds in summer. The highest winter monthly average wind speed is 12.7 mph occurring in both December and January, while the lowest monthly average is 7.7 mph in July (National Oceanic and Atmospheric Administration 1998).

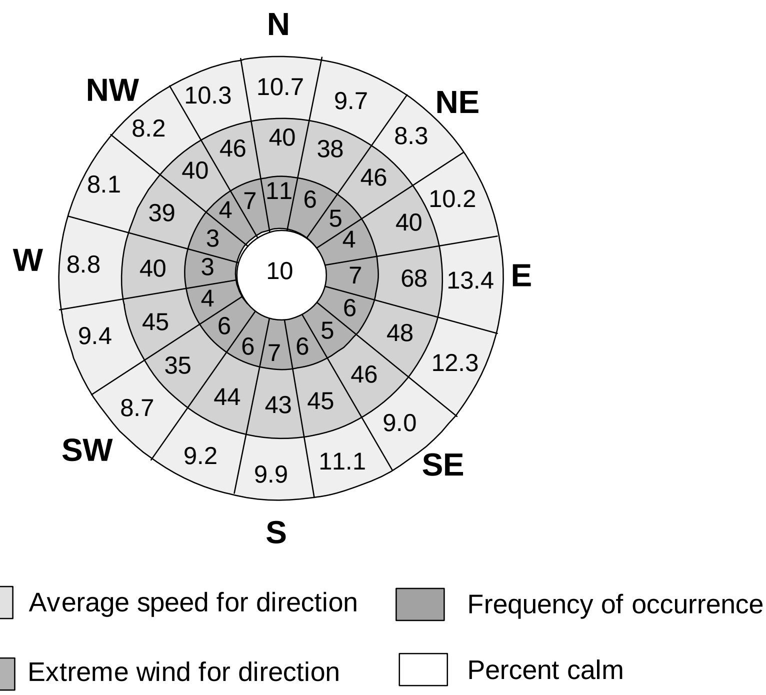


Figure 3. Summary of wind data for King Salmon. Wind speed values are in miles per hour (Selkregg 1976).

The climate of the Alaska Peninsula and Katmai is heavily influenced by storms originating in the North Pacific and moving into the area along a storm track that parallels the Aleutian chain. Storm frequency for the Katmai area is greatest during the late summer and early fall from August through October (Klein 1957). The strongest winds at Brooks Camp and the Valley of Ten Thousand Smokes come from the south or southeast. Sudden windstorms known as *williwaws* can arise swiftly, creating waves greater than 6 1/2 feet on Naknek Lake. Frequent storms passing through the area keep large lakes well mixed throughout the summer leading to straight-line profiles for water quality parameters (LaPerriere 1997).

4. Thermal Regime

Several variables based on temperature can be used to characterize the climate of an area. The number of heating degree-days is a value used to estimate the energy requirements for heating buildings. One heating degree-day is recorded for each degree that the daily mean temperature is below 65° F. The number of heating degree-days is an indirect measure of the mean monthly temperature; i.e., the lower the mean monthly temperature, the greater the number of heating degrees-days for a given month. Monthly heating degree-days for Kodiak and King Salmon are summarized in table 3.

Table 3. Average monthly heating degree-days for Kodiak and King Salmon.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Kodiak	1,096	983	989	833	667	474	339	310	468	766	931	1,067	8,923
King Salmon	1,538	1,384	1,286	957	667	425	290	317	521	984	1,254	1,481	11,104

The growing season can be defined in terms of length and period and is defined with respect to a surface index temperature. Typical index temperatures include 24, 28 and 32 degrees Fahrenheit. Values below freezing take into account that the growing season is defined as that part of the year when soil temperature at 19.7 inches below the soil surface are higher than biologic zero (41°F). The length of the growing season is the number of consecutive days in which the temperature is greater than the index temperature. The period is defined by the beginning date and ending date where the temperature has not fallen below the index temperature. The growing period is roughly equivalent to the freeze free period. The growing period for King Salmon using a 28°F index and a 50% probability extends from mid-May until mid September, lasting approximately 140 days (figures 4, 5 and 6) (Western Regional Climate Center 2002).

Freeze-free periods dictate when rivers and lakes freeze over in fall and breakup in spring. The average date of fall freeze for rivers in the Naknek area is November 17 and for spring breakup is April 9 (Hartman and Johnson 1978:39).

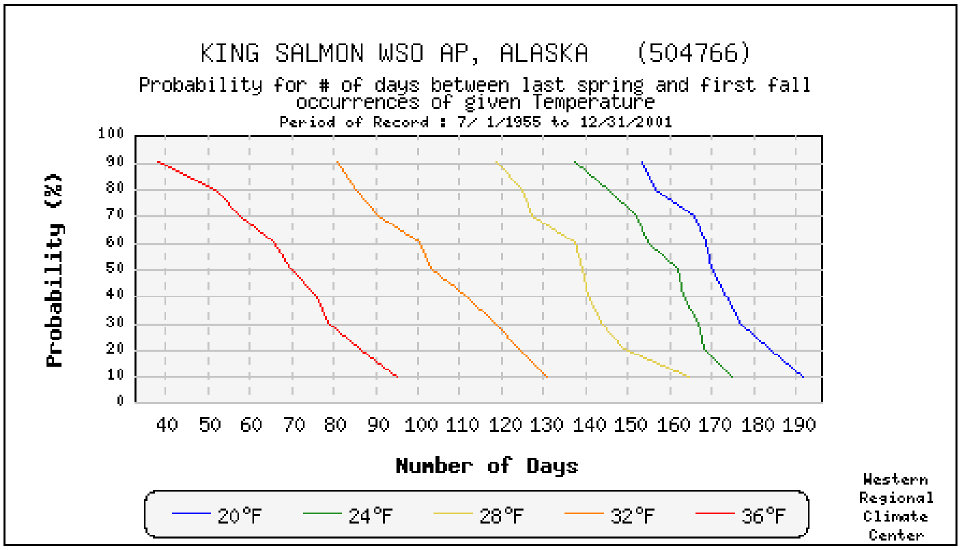


Figure 4. Freeze-free probabilities for King Salmon (Western Regional Climate Center 2002).

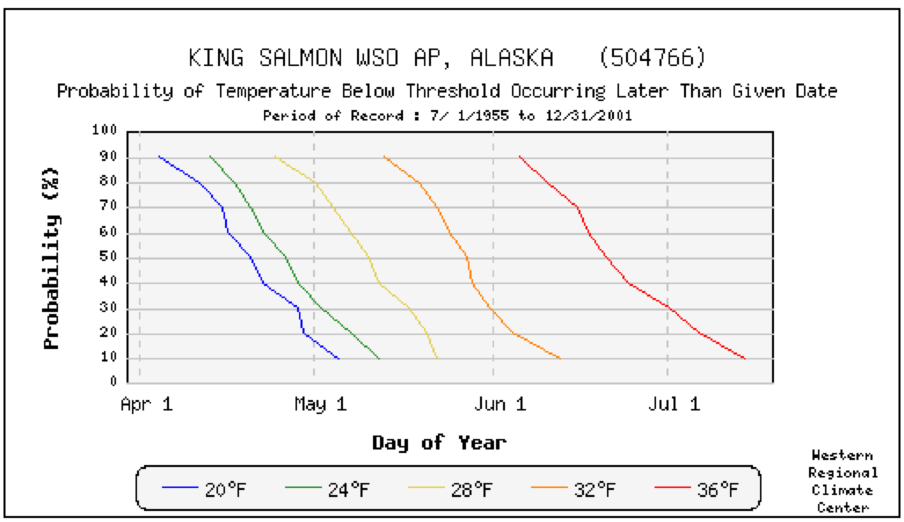


Figure 5. Spring freeze probabilities for King Salmon (Western Regional Climate Center 2002).

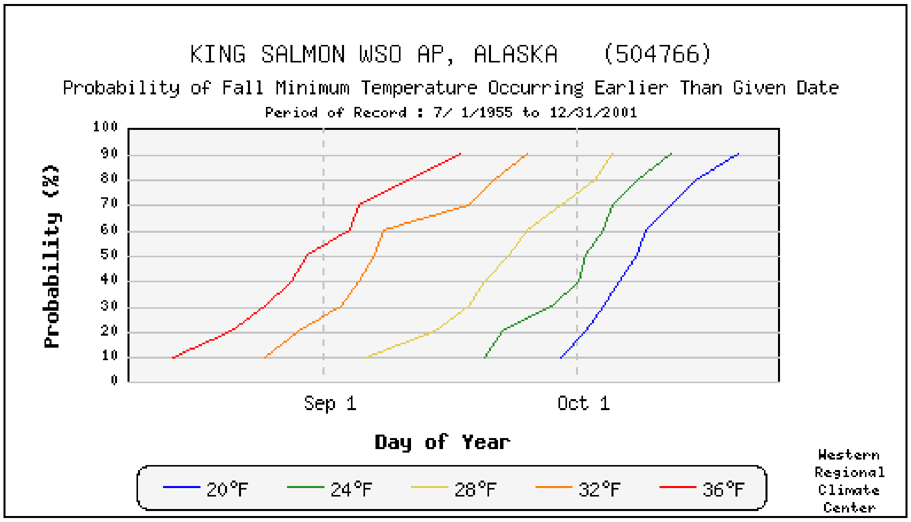


Figure 6. Fall freeze probabilities for King Salmon (Western Regional Climate Center 2002).

C. Climate Cycles

Most of the climatic data in this report are based on the 30-year normal period from 1971-2000. Both short- and long-term climatic cycles extending from several months to several decades can have significant impacts on annual averages determined using the 30-year normal period. In recent years, the impact of El Niño events has become more fully appreciated. Gravier (1999) compared climate data for El Niño and non-El Niño years for a number of stations in Western Alaska and found no statistical difference in annual temperatures for stations in Southwest Alaska (Cold Bay, King Salmon and Kodiak). Precipitation during El Niño years increased in the coastal stations of Cold Bay and Kodiak, but decreased slightly in King Salmon and stations located in continental weather regions.

El Niño events have durations spanning 6 to 18 months. Longer climatic cycles may mask or intensify El Niño events. The Pacific Decadal Oscillation (PDO) is a long-term El Niño-like cycle that produces warm and cool phase events lasting about 20 to 30 years (Hare and Francis 1995). The most recent PDO phase is a warm event that commenced in 1977 and has persisted through the 90s. Warm PDO events are associated with higher salmon productivity in Alaska, while low PDO events correlate with low salmon productivity (Hare et al. 1999). El Niño and PDO events may affect stream discharge, and the climatic phase would be important to consider when analyzing stream data.

II. Physiography

Katmai National Park and Preserve lies astride the Aleutian Range on the Alaska Peninsula between the first and second largest lakes in Alaska: Iliamna and Becharof. This dynamic land has been repeatedly raked by massive glaciations, buried in volcanic ash and beset by howling storms from the North Pacific. Its lakes and streams nurture, and are nurtured by, some of the largest salmon runs in the world. Migrating waterfowl nest in the gentle marshlands, huge bears fatten up for hibernation on the spawning salmon, seals and whales patrol the coastal lagoons and offshore waters and vegetation struggles to recolonize a barren, wind blasted ash-covered land.

Volcanic eruptions have occurred with some regularity on the Alaska Peninsula. The most notable eruptions occurring in Katmai in historic time are the 1912 eruption of Novarupta, followed by several eruptions of Mt. Trident between 1953 and 1968 (Hildreth and Fierstein 2000). Minor ash eruptions and outbursts have also occurred on Mount Mageik, Mount Martin, Novarupta and Mt. Katmai since the 1912 eruption (Wilcox 1959:419).

Land cover influences snow accumulation, soil moisture depletion, surface runoff, infiltration and erosion. These factors can affect the water quality of a stream or river. For example, some types of vegetation can reduce the amount of sediment entering a stream by preventing erosion. Some vegetation types actually affect the chemistry of the water.

Katmai Landscapes

Defining the scale of landscape units is primarily dependent on terrestrial parameters: climate, terrain, vegetation, lithology and soils (Oswood et al. 2000:405). But given the linkage between terrestrial and aquatic systems, these landscape units can serve as aquatic regions as well as terrestrial (Omernik 1995; Omernik and Griffith 1991 in Oswood et al. 2000:406). At Katmai, there are18 subsection level landscape units in four sections: Bristol Bay lowlands, Lakes and Hills, Shelikof Strait Coastland and the Aleutian Range (landscapes map following this page). Understanding the landscape contributes a great deal to our understanding of water processes and function in this complex system.

Landscape units are delineated at varying scales of ecosystems (Bailey 1980). Each level has a slightly different set of defining parameters, beginning with global climate patterns for the domain level, moving down to local weather, lithology and surficial geology processes and farther down to soils and vegetation patterns at the subsection level. Table 4 shows how the ecosystems in and around Katmai National Park and Preserve are broken out at the various levels. This discussion focuses on the section level of mapping, which describes large ecosystem units and how they relate to the flow of water throughout the region.

Katmai is composed of four major landscape units at the section level of ecosystem mapping (landscapes map following this page). These units run more or less north/south along the Alaska Peninsula. Long and meandering rivers running west to Bristol Bay break this north/south pattern, while short, braided streams flow east into Shelikof Strait. The controlling processes that define them are glaciation and major climatic patterns, with an overlay of volcanic activity. The western edge and the Alagnak River lowlands are part of a Bristol Bay lowlands unit that reaches from the moraines to Bristol Bay. A lakes and rolling hills unit encompasses the large lake and moraine systems eastward to the rugged Aleutian Range. The Aleutian Range unit covers the major mountain ranges. The Shelikof Coastlands are small units perched between the mountains and Shelikof Strait. Table 5 shows relative spatial coverage of each section for both Katmai and the Alagnak Wild River.

Table 4. Landscape units at multiple scales for Katmai.

Domain[1]	Division[1]	Ecoregion[1]	Section	Subsection[2]
Polar	Bering taiga	Bristol Bay lowlands	Bristol Bay lowlands	Alagnak River lowlands
				Bristol Bay lowlands
				Lowland outwash and drift deposits
Maritime	Aleutian meadows	Alaska Peninsula	Lakes and hills	Coville Lake deposits
				Iliamna drift deposits
				Kukaklek Lake moraines
				Lakes Region hills
				Lakes Region spruce covered moraine
				Lakes Region old lake bed deposits
			Aleutian Range	Barrier Range Mountains – North
				Barrier Range Mountains – South
				Kamishak River hills
				Savonoski River floodplain and terraces
				South Kejulik Mountains
				Valley of Ten Thousand Smokes
				Walatka Mountains
				Kejulik Mountains
			Shelikof Strait Coastlands	Shelikof Strait lowlands

[1] Nowacki et al. 2001
[2] Shephard M. E., 2000

Table 5. Ecosystem sections in Katmai.

Section	Percentage of Park Units	Acres
Bristol Bay lowlands	4.2%	171,500
Lakes and Hills	31.1%	1,281,400
Aleutian Range	61.6%	2,537,800
Shelikof Strait Coastlands	3.1%	130,400

The Bristol Bay lowlands are poorly drained, with low relief, rolling hills and meandering rivers. The Alagnak, Naknek and King Salmon Rivers are the major drainages out of the park to the west. The soils are primarily windblown loess and alluvial outwash from glacial advances. Aeolian and alluvial processes have muted the moraine and outwash features from older glaciations. The river valleys are active floodplains and old terraces through undifferentiated glacial drift and ground moraines. Figure 7 shows the active floodplain of the Alagnak River and an eroding bank of an old terrace of the previous floodplain. There is evidence of inter-glacial marine incursions into the area of the Bristol Bay lowlands. The fine-grained soils, permafrost and low relief provide poor drainage, resulting in a mosaic of wetlands and ponds with a matrix of white spruce woodlands and alder/grasslands or dry tundra in drier sites. Rivers in this unit are slow and meandering.

Katmai's lowlands are described by Young and Racine (1978) as a transition zone where the Interior Alaska white spruce (*Picea glauca*) forest gives way to tundra. This low-latitude forest-tundra ecotone occurs along much of the western coast of Alaska. Although located at a lower latitude, the tundra at Katmai is similar to that found in arctic Alaska and attributed to the maritime climatic influences.

Wetlands support communities dominated by sedges, mosses and dwarf shrubs (figure 8). Wetland and pond complexes provide nesting and rearing habitat for many species of waterfowl and shorebirds. Slight ridges are better drained and support “subforests” of white spruce and Kenai birch, with alder thickets and patches of *Calmagrostis* grasslands. The southernmost extent of white spruce on the Alaska Peninsula is just south of King Salmon. Several species of salmon migrate through the river systems of the lowlands enroute to spawning grounds higher in the watersheds. These rivers also support a number of resident fish populations.

Figure 7. The Alagnak River meanders through a broad floodplain carved below older floodplains.

Figure 8. A wetland of the Bristol Bay lowlands showing emergent vegetation, sedges and willows on slight rises. Old moraines form the rolling hills in the background.

The lakes and hills region represents the termini of late Wisconsin glaciations and the proglacial lakes that developed during the inter-stadial periods. At least three glacial advances pushed into this area from 25,000 to 10,000 years BP (before present) (Stilwell and Kaufman 1996), leaving a series of well-defined moraines at the western end of large lake basins and between some lakes such as Iliuk Arm and main Naknek Lake. Volcanic ash is mixed with till in some moraines and indicates that glaciations and volcanic eruptions have been concurrent in this land for a long time. Portions of the glacial basins are occupied by large lakes, ringed by zones of lacustrine deposits from older pro-glacial lakes. A few rounded hills were largely above the reach of glacial ice. Exposed and lightly covered bedrock supports deciduous forests and alder on the slopes, with heath tundra and rock on the tops.

Figure 9. Rolling moraines north of Naknek Lake showing mosaic of vegetation types and ponds formed by melting ice abandoned by retreating glaciers.

The moraines themselves are composed of undifferentiated and poorly sorted till, resulting in moderately well drained soils. The moraines support spruce and birch/balsam poplar forests with low and dwarf shrub communities in the understory and openings. Figure 9 illustrates this mosaic of spruce “islands” surrounded by low shrub with scattered ponds in the distance. Small ponds are left from buried ice melting in the moraines after glacial retreat. Short stretches of rivers flowing through these moraine ridges tend to be shallow, swift and rocky. Moraines around Kukaklek Lake (figure 10) are dominated by fruticose lichens and ericaceous shrub tundra, providing rich habitat for caribou and berries for bears, ptarmigan and voles.

The old lake bed deposits are remains of a system of large lakes that formed between the terminal moraines and retreating ice fronts. Consequently, the soils are fine-grained and well sorted, resulting in slow groundwater movement and moderate to poor drainage. The unit around Lake Coville (figure 11) supports wetlands and fairly dense spruce forests on the higher ground and side slopes. Lacustrine deposits and old lake terraces west of Brooks and Naknek Lakes are vegetated with sedge/low shrub tundra and open alder stands.

Figure 10. Rolling moraines and lakes on the north side of Kukaklek Lake. Dark green areas are alder patches, interspersed with lichen and dwarf shrub tundra and a myriad of ponds.

Today, large lakes with varying loads of silt and volcanic ash, depending on the headwater streams, cover much of the region. The landscapes map following page 11, a Landsat Thematic Mapper image of Katmai, shows the high silt load in Iliuk Arm (light blue), plumes of silty water in Naknek Lake and clear water (black) in Brooks and Nonvianuk Lakes. These lakes provide rearing habitat for large runs of salmon that spawn in the tributary streams.

The rugged, glaciated volcanic peaks of the Kejulik and Cape Douglas Mountains rising more than 7,000 feet above the sea, and the more gently rounded sedimentary and granitic Walatka and Kamishak Mountains form the **mountain region** of Katmai. The Cordilleran icesheet pushing out of Cook Inlet rode up into the Kamishak River valley and highlands, eventually contributing to the large glacial basins now occupied by Naknek and other lakes. The Kejulik Mountains were the source of the coalescing valley glaciers that pushed west during the late Wisconsin period. These mountains also host the volcanoes that periodically send ash falls and flows over the surrounding countryside (figure 12). The Aleutian Range is a meeting place of storm systems from the Gulf of Alaska and Bristol Bay, with fairly high precipitation and awesome winds through the valleys between Bristol Bay and Shelikof Strait. The mountains capture and store precipitation as snow and glaciers, releasing it into rivers off both sides of the ranges. Several large river systems reach deep into the mountains from the west, while those on the eastern slopes are short and steep. The Katmai River (figure 13) is a prime example of loose material from both glaciers and ash fall, resulting in wide, braided and unstable floodplains.

Figure 11. Wetlands cover the old lakebed of a Pleistocene lake north of Lake Coville. Lighter green areas are sedge wetlands, with tall shrubs growing in the slightly higher dark green areas. Spruce and alder cover the side slopes.

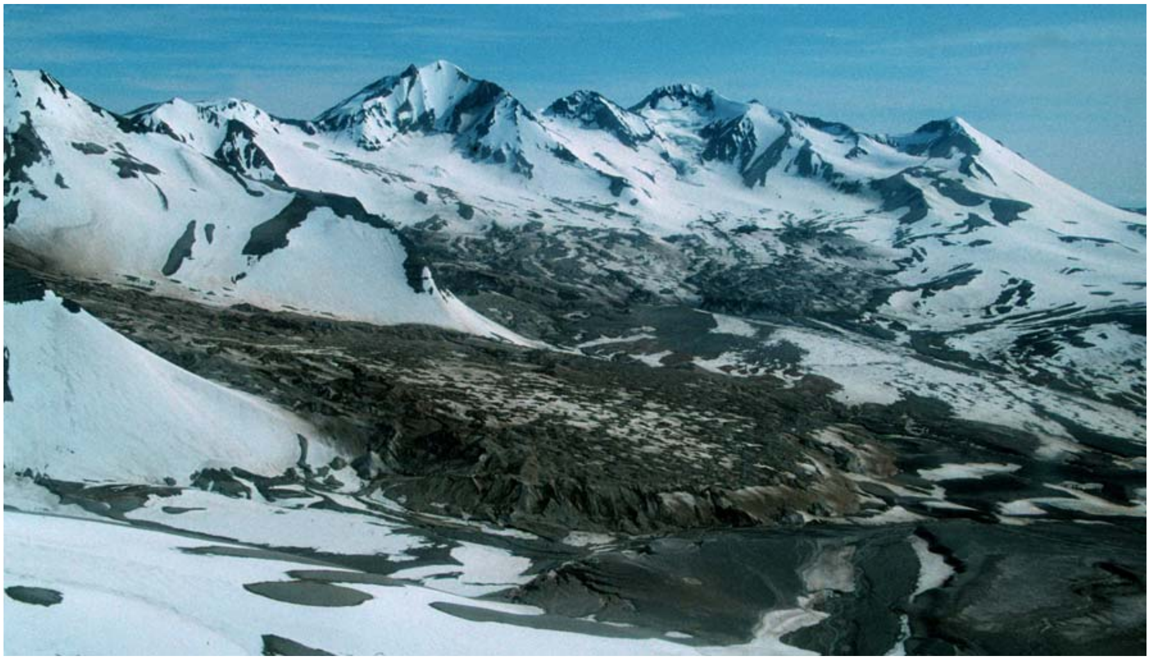


Figure 12. The Aleutian Range landscape is made up of rugged volcanic and sedimentary mountains, covered by repeated glaciations. Trident Volcano, at the eastern edge of the Valley of Ten Thousand Smokes, supports several glaciers. Volcanic ash was directly deposited during the 1912 eruption and redeposited by winds. These unstable and dry surfaces have not revegetated in nearly a century.

The incredibly harsh conditions and frequent major disturbances do not provide a stable habitat for plant communities or wildlife. The Kejulik and Cape Douglas Mountains shown in figure 14 are permanently glaciated, with valley glaciers nearly reaching the Shelikof coast. Below barren, exposed ridgetops and outcrops, patches of alpine tundra and low shrubs find footholds in sheltered niches and shallower patches of ash from the 1912 Katmai eruption. Lower slopes support dense alder stands, with a few Sitka spruce on the coastal headlands. Several valleys around Novarupta and Katmai, and slopes on the eastern side of the range, are still covered with deep ash deposits that remain unvegetated.

The Walatka Mountains and Kamishak highlands support dwarf shrub and alpine tundra at higher elevations, with dense alder on lower slopes and cottonwood stands along the streams in the lowest valleys. Beavers help shape floodplains of streams from sea level to the upper limits of alpine low willow. Portions of the large west-flowing river valleys are forested with white spruce, with balsam poplar along the floodplains. Figure 15 shows the upper reaches of the Savonoski River with a broad active floodplain below old terraces covered with alder, grassy meadows and scattered spruce. Moose and some waterfowl frequent the valleys, with bears passing through during salmon migration and blueberry seasons.

Figure 13. The lower reaches of the Katmai River show unvegetated and unstable volcanic ash deposits and the highly braided river channels. Griggs (1922) reported quicksand and large changes in the river's channels from year to year during his explorations immediately following the Katmai eruption of 1912.

Figure 14. Glaciers shroud Mount Douglas, flowing nearly to the coast of Shelikof Strait.

Figure 15. The Savonoski River flows from glaciers of the Kejulik Mountains westward into Naknek Lake.

The **Shelikof coastlands** are small units of floodplains and coastal lagoons along the eastern shore of Katmai. These units are at the mouths of major streams, where alluvial deposits and marine storms form beach ridges and lagoons and large braided floodplains. Most of the streams are silty from glacial materials and ash. They do not support the large sockeye runs of the western side, but do have smaller salmon runs of sockeye and chum that feed coastal bears.

Figure 16 shows the beach and estuary complex of Hallo Bay where flooding rivers and coastal storms mingle the freshwater and marine ecosystems. The silty water of Hallo Creek in the center of the photo flows into Shelikof Strait. Rich estuarine sedgelands are light green meadows to the right of the beach line.

These areas are generally unstable, but have adapted to repeated disturbances and support early successional communities of sedges, aquatic forbs and grasses. Alder and elderberry patches provide nitrogen for the soils, and sheltered sites support stands of Sitka spruce. These areas, though small, provide rich habitat for bears, with a diversity of food sources including shellfish, spring sedges, salmon, berries and seeds throughout the bear’s feeding season.

Figure 16. The coastal beaches and lagoons at Hallo Bay are typical of landscapes in the Shelikof coastlands. Bears forage for early season sedges in the estuarine marshes and shellfish in the tidal flats.

III. Geology

A. Geologic Setting

Katmai National Park and Preserve's geologic setting is one of the most tectonically active regions in the world. This setting has produced some of the most spectacular geologic features and unique events in recorded history.

The active volcanoes of the Aleutian Island arc represent the present day location of an actively subducting plate margin. Eruptions of these active volcanoes, most notably the 1912 eruption of Novarupta, have sparked numerous scientific studies and lead to the establishment of Katmai National Monument.

Geologic processes, beginning in early Jurassic time with the emplacement of the Alaska-Aleutian Range batholith and associated volcanic rocks, have created a complicated landscape where the Aleutian volcanic arc is superimposed on the older continental margin.

Regional uplift and rapid subsidence created a basin that allowed the continuous deposition of sediments into one of the thickest low grade metamorphic sedimentary sections found in the world, the Jurassic Naknek Formation.

At least two major glacial advances in the Pleistocene further shaped the landscape of the park, generating extensive glacial features, such as the hummocky topography associated with the Bristol Bay lowlands. The most recent glacial advances about 6,000 years ago altered the lake basins of several of Katmai's larger lakes with moraines that dam once-larger lakes into smaller lakes, notably Nonvianuk and Kulik Lakes.

B. Structure and Tectonics

The science of plate tectonics has resulted in the concept of geologic terranes. Geologic terranes are fault-bounded, regionally extensive bodies of rock, whose geologic history differs from adjacent terranes. They are foreign "rafts" of the earth’s crust, added to a land mass at an active convergent plate margin by the process of accretion. Katmai is situated on the Peninsular terrane, now defined as a subterrane of the Wrangellia composite terrane, a larger terrane extending to the west side of Cook Inlet. Paleomagnetic studies indicate the Wrangellia terrane formed near the equator during the Triassic period and drifted northward and docked to the Alaska mainland around 100 million years ago. It is believed to be one of the most extensively displaced terranes in the world.

The Bruin Bay fault is a major structural feature of the park (simplified geologic map of Katmai following this page). The fault trends southwest to northeast through the length of the park. It is a high angle reverse fault that has as much as 3 km of stratigraphic or vertical displacement and 65 km of left lateral offset. (Detterman and Reed 1980). In the Katmai area, the west side of the fault moved up in relation to the east side.

Several episodes of regional deformation of the Katmai area are indicated by the tight and possibly overturned folds in rocks of the Paleozoic Kakhonak Complex and in the Mesozoic, the Triassic Kamishak formation. During the Tertiary, gentle folding inclined the strata of the Naknek and the younger Cretaceous and Tertiary formations. These folds trend roughly parallel with the structural grain of the region (Riehle et al. 1993).

C. Bedrock Geology

The oldest rocks in the Katmai area are Paleozoic metamorphosed quartzites, schists, amphibolites and gneiss, of the Kakhonak Complex, which outcrop along the edges of the Alaska-Aleutian Range batholith (Riehle et al. 1993). Very limited exposures of these rocks are found in the park. Outcrops are located immediately north of Takayofo Creek and the Bruin Bay fault. A small island outcrop of the unit occurs in the North Arm of Naknek Lake. A ridge immediately northeast of Coville Lake has another exposure of the Kakhonak Complex.

Triassic age rocks are even more limited in Katmai. Slightly recrystallized basalt lava flows intercalated with limestone comprise the Kamishak formation; outcrops can be found north of Becharof Lake.

In the Lower Jurassic, an initial volcanic arc is represented by the Talkeetna formation, a brown, tuffaceous sandstone interbedded with lahar and tuff deposits. It is found in outcrops only to the northwest of the Bruin Bay fault.

Jurassic magmatic rocks associated with plate tectonics are represented by the plutons (large bodies of intrusive igneous rock), dikes (tabular bodies of igneous rock injected while molten into a fissure) and sills (tabular bodies of igneous rock injected while molten between sedimentary or volcanic beds or along foliation planes of metamorphic rocks) commonly referred to as the Alaska-Aleutian Range batholith. They are related to the volcanic island arc deposits of the Talkeetna formation. These magmatic rocks consist of crystalline quartz diorite, diorite and granodiorite composed mainly of varying proportions of hornblende, mica, quartz and feldspar. They outcrop throughout the park north of the Bruin Bay fault in a northeast trending band across the Alaska Peninsula. Erosion of these rocks was the source of the sediments deposited as members of the Naknek formation.

The most extensive geologic formation in the park is the Upper Jurassic Naknek formation. The Naknek is represented by a sequence of non-marine members, consisting of fine- to medium-grained sandstones, progressing to the dominantly marine members, which consist of very fossiliferous thin sandstone beds interbedded with thin siltstone beds. The Naknek formation was deposited in shallow seas as the Alaska-Aleutian Range batholith was being uplifted to the northwest, resulting in a thickening of the formation to the east. The Naknek underlies most of the southeastern part of park, including those areas now intruded and overlain by more recent volcanics.

In the Cretaceous period, repeated transgressive seas deposited shallow marine sandstones, conglomerates and limestones. In the park, the Upper Cretaceous Kaguyak Formation is the most extensive of these sedimentary sequences. Members of the formation consist of siltstone interbedded with thin fossiliferous limestone beds. Later members consist of sandstone and siltstones. Following deposition, the Kaguyak formation was uplifted and eroded extensively. Now it outcrops on top of basement highs of the Naknek formation. The Kaguyak formation extends from Katmai Bay north to the eastern portion of the Kamishak River drainage, in the eastern part of the park.

There are three major belts of Tertiary intrusives, as well as scattered dikes, sills and small plutons throughout the park. The oldest of these groups is on the northern side of the park near Lake Grosvenor and Battle Lake. These rocks are medium-grained quartz diorite to granodiorite. A second area of Tertiary intrusives is found from Yori Pass to the Rainbow River. Rocks from this group are altered igneous rocks with prominent phenocrysts (larger crystals). On the east side of the park, a large pluton can be found around Douglas and Fourpeaked Volcanoes. The pluton consists of fine- to medium-grained tonalite to granodiorite (Riehle 2002).

In late Tertiary, volcanic activity resulted in the breccias, lava flows, sills, pyroclastic flows and tuff deposits of the Barrier Range. These outcrop along the Katmai River to Kukak Bay. Alteration and oxidation of minerals in these deposits has resulted in extensive areas of orange and red iron staining.

Volcanic rocks include Pleistocene vent deposits, which consist of andesitic and dacitic lava flows, breccias, tuffs, domes and pyroclastic deposits that are observed in isolated localities. The greater degree of erosion of these older deposits distinguishes them from later Holocene pyroclastic deposits of similar origins.

Similar to the Tertiary deposits, the Quaternary volcanics are mainly andesitic and dacitic lava flows, tuffs, breccias and porphyritic lava flows of the active Aleutian volcanic arc.

The pyroclastic flow and ash from the eruption of Novarupta in 1912 created, among other features, the Valley of Ten Thousand Smokes. The 1912 eruption was a sequence of first a highly siliceous rhyolite, followed by a thick dacite component and last the dominantly near-vent andesite. The sources of the differing components of the magma and deposits continue to be the subject of geologic debate and study.

D. Geologic Processes Contributing to Water Quality

Geologic processes occurring over long periods of time, such as plate tectonics, regional uplift or deformation, fault plane movement and erosion affect water quality at relatively constant rates that, for most purposes, represent steady-state dynamics. When these processes occur in short geologic timeframes, water quality can be affected. Water movement along fracture planes, joints, and through brecciated zones can preferentially transport dissolved and suspended chemical constituents over long distances in a relatively short amount of time, impacting groundwater aquifers and surface water bodies. In addition to immediate impacts to water quality, these events may result in major geologic and topographic features that continue to impact water resources. Downward ground movement in an earthquake may drown a wetland area and change the ecology of the local environment.

Some of the greatest physical processes acting on the earth are erosion and weathering, the primary contributors to the chemical and physical components of water quality. Erosional rates are affected by many factors, such as slope, precipitation, climate, geology, vegetation, as well as depositional events such as volcanic activity, mass ground movement, or flooding.

Depositional geologic events such as glaciation, flooding, mass land movement or volcanic activity directly affect water quality. In addition to concurrent impacts to water quality during the activity, these events may result in major geologic and topographic features that continue to impact water resources. The following are physical processes affecting Katmai waters.

- Glaciers, moraines, glacial unconsolidated materials from several ice advances and retreats have resulted in deposition of terminal and lateral moraines, which have a significant effect on the morphology of the land surface and lake basins.

- Volcanic eruptive episodes have resulted in deposits, such as tephra, tuff, flows and breccia, and continue to fuel hydrothermal systems associated with magma bodies near cones, vents and calderas.

- Faults can allow water movement along fracture planes, joints and through brecciated zones, which can preferentially transport dissolved and suspended minerals over long distances.

E. Rock Composition and Its Influence on Water Chemistry

Rock compositions, and their rates of chemical weathering, are the principal determining factors of the characteristics of water chemistry. The chemical and physical decomposition of rock types produce the geochemical signature of surface waters and stream sediments. This geochemical signature can enhance the understanding of the chemical properties of waters, identify water source areas and refine interpretation of the geologic nature of the watershed.

In the Katmai area, integrated analysis of surface water data and rock composition yield a greater understanding of water quality characteristics. For example, volcanics in a watershed can contribute to high metals concentrations, low alkalinity and higher sulfates in surface waters. Hydrous aluminum sulfates from volcanic deposits form several minerals that decompose to release aluminum, sulfates and hydroxide ions. Although there are no recent volcanics in the Battle Lake and Iron Springs area, weathering of Jurassic and Tertiary volcanic deposits and associated mineral deposits in these drainages are likely contributing factors to the low alkalinity, high acidity and high aluminum and iron found in waters of that area.

Studies conducted by Miller (2002) documented the influence of rock composition on the geochemistry of stream and spring waters in non-mineralized and some mineralized areas in western Colorado and Nevada. Miller’s studies established a range of baseline geochemistry for surface waters associated with the dominant rock composition types of the drainage basins.

For the purpose of assessing mineral resources in the Katmai area as part of the Alaska Mineral Resource Assessment Program (AMRAP), geochemical signatures were tied to bedrock lithologies and stream sediments by Church, et al. in 1994. These data in conjunction with water quality data, as reported by LaPerriere (1996) appear to correlate with the baseline water quality characteristics and associated lithologies observed by Miller.

Excerpts and data from these studies are described below.

F. Geochemical Signatures of Selected Drainages

1. Naknek Drainage Basin

The Naknek drainage is the largest drainage basin in the park and containing the park’s largest lakes. Naknek, Brooks and Coville Lake reside in basins that are predominately Quaternary unconsolidated surficial deposits. These deposits consist primarily of gravels, sands and silts of an alluvial, colluvial, glacial, marine, lacustrine and eolian nature and include locally reworked pumice and ash from Quaternary volcanic eruptions. A band of Jurassic Talkeetna Formation outcrops in this area, including Dumpling Mountain. On the northwest side of Dumpling Mountain and Lake Coville, Upper Tertiary volcanics are in contact with the Jurassic Talkeetna Formation. The Iliuk Arm of Naknek Lake is bounded on the north shore by outcrops of the Jurassic age Alaska-Aleutian Range batholith. Paleozoic Kakhonak Complex outcrops on an island in the North Arm of Naknek Lake.

Samples taken by Church et al. (1994), in bedrock and stream sediments associated with the Tertiary volcanics north of Naknek Lake exhibited iron, manganese and arsenic anomalies. Iron oxide coatings were observed throughout lava flows as thin, red hematite coatings along fractures in the flows. The Tertiary andesitic and dacitic lava flows and breccias contribute to alkaline pH values, moderate conductivity and few trace element anomalies in waters in contact with this rock type. The fine-grain size of the rock minerals with a high surface area available for chemical reactions, favors dissolution of silicate minerals, resulting in higher silica concentrations in the water.

Samples taken from the Talkeetna Formation south of Naknek Lake near Dumpling Mountain showed anomalous concentrations of metals – copper, molybdenum, silver, lead, zinc, tungsten, gold, bismuth and cadmium. Waters in contact with this volcanic-related lithology have slightly alkaline pH values and moderate to low alkalinity values. Higher concentrations of sulfate are associated with this type of deposit.

The Brooks River flows through Quaternary glacial and volcanic deposits, with occasional outcrops of Jurassic intrusives of the Alaska-Aleutian Range batholith and volcaniclastic Talkeetna Formation. These two lithologies most likely contribute to the high concentrations of iron observed in water samples taken in the river. The geochemical data from samples taken from the batholith show widely disseminated pyrite (Church et al. 1994). Oxidation of this pyrite allows transport of the metal to dissolving waters. No consistent anomalies were noted in the Alaska-Aleutian Range batholith indicating mineralization associated solely with this unit, although most samples had high values of manganese.

In the American Creek drainage, upper reaches of the drainage have outcrops of Tertiary volcanics consisting of andesitic and dacitic lava flows and breccias, which are intruded by Tertiary hypabyssal rocks. These lithologies contribute to alkaline pH values and moderate conductivity to the geochemistry of waters in residence. The larger surface area due to the fine grain size results in more rapid chemical weathering and dissolution of silica. The contact between the rock types has resulted in mineralization (a gold placer claim once existed on the creek).

At Margot Creek, LaPerriere (1996), reported titanium and surmised an igneous source. Church (1994) observed thin veins of chalcopyrite and molybdenite in the zone of alteration surrounding the contact between a Tertiary granitic pluton and the Naknek Formation. Anomalous concentrations of copper, molybdenum, silver, gold and arsenic were in all samples taken at the site. Some samples reported anomalous concentrations of nickel, cobalt, bismuth, cadmium, boron, manganese, chromium, lead or tin. On the basis of the geology and geochemistry, Church indicated a probable undiscovered porphyry copper-molybdenum deposit at this location.

In the Valley of Ten Thousand Smokes, the Ukak River drains the 1912 ashflow deposit of Novarupta. Samples taken of the ashflow deposit indicate anomalous concentrations of molybdenum, lead, arsenic, aluminum, cobalt, nickel, bismuth and cadmium in hematite-rich siliceous sinter. These types of deposits are highest in total dissolved solids; and Keith et al.

(1992) documented an enrichment of dissolved constituents in Knife Creek and River Lethe, two major streams draining the 1912 ashflow deposit. In a similar deposit in his Colorado study area, Miller (2002) described most waters associated with this rock type as calcium-sulfate type waters. They are acidic to slightly alkaline, and conductivity is moderately low. This observation correlates well with the sample results obtained by Keith.

2. Alagnak Drainage Basin

The Alagnak drainage is the most geologically diverse of the drainages in the park. The major lakes of interest in this basin are Kukaklek, Kulik, Battle and Nonvianuk.

Kukaklek and Nonvianuk Lake basins are primarily bounded by unconsolidated glacial deposits on their western shores, while the northeastern end of these lakes and the entire basins of Kulik and Battle Lakes are underlain by the Jurassic Talkeetna Formation, Tertiary volcanics and intrusives and the Jurassic Alaska-Aleutian batholith.

The major rivers in this drainage include the Alagnak River, the major portion of which falls within the Quaternary unconsolidated sediments of glacial, glaciofluvial and fluvial origin. Upper reaches drain areas of bedrock consisting primarily of Tertiary volcanics.

Kulik Lake basin is underlain by Tertiary plutons intruded into the Talkeetna Formation and in contact with the Jurassic Alaska-Aleutian Range batholith. A great deal of mineralization is associated with the contact between the Tertiary intrusives and the Talkeetna Formation, suggesting that polymetallic veins formed when plutons intruded the rocks of the Talkeetna Formation. It is weathered to reddish brown and exhibits anomalous concentrations of copper, gold and lead at some of these contacts. Geochemical data in this area show a consistent suite of arsenic, copper, molybdenum, lead, silver and zinc at anomalous concentrations adjacent to outcrops of the Tertiary intrusive rocks. Samples taken in drainages at the western end of the lake showed anomalous concentrations of copper, molybdenum, silver and lead. Copper and manganese were found to be very high throughout the area. Zinc was reported at anomalous concentrations in most samples taken from the Talkeetna Formation. Waters in contact with intrusive crystalline rocks generally have average silica concentrations due to slow chemical weathering, however weathering of the silica-rich lavas and tuff of the Talkeetna Formation would elevate the silica concentrations. Mineralization associated with the intrusive contact would elevate sulfate values, due to weathering of pyrite and other sulfide metals, resulting in waters of low alkalinity.

Battle Lake has similar geology to Kulik Lake. Waters of this lake exhibit the geochemical signature of weathering of a volcanic rock type and more pronounced effects of the mineralization that occurs at the contact between Tertiary intrusives and the Talkeetna Formation. This accounts for the high sulfate waters of this drainage and the lake, which was found to be 15 mg/l (LaPerriere 1996). Sample results from the tributaries to Battle Lake revealed that those tributaries that directly drained areas of this contact exhibited slightly acidic to slightly alkaline pH values, low alkalinity, high sulfate and elevated values of copper, aluminum, iron and zinc. This is consistent with weathering of the lithologies involved and the mineral occurrences at the contact between the rock types. In general, the pH levels of tributaries draining the Talkeetna Formation are slightly acidic, indicating weathering of the volcanic source.

Iron Springs Lake, much talked about for its “striking rust” color, actually straddles the contact between the Tertiary intrusives and the Talkeetna Formation. As documented in the geochemical sampling by Church et al. (1994), this contact displayed much pyrite oxidation and sulfide mineralization. Chalcopyrite, a copper-iron-sulfide was reported in veins. Anomalies of aluminum, iron and zinc at this location are again associated with this contact between formations. The long residence time of water in this contact zone results in leaching of these properties to the lake water. Samples taken at the lake reported a pH value of 3. 65. Sulfate concentrations in the water were 10 times that of Battle Lake (LaPerriere 1996).

3. Coastal River Basins

The Coastal River Basin consists of waters primarily originating in the mountains of the Aleutian Range and escaping to Shelikof Strait and Cook Inlet. Among these rivers are the Kamishak, Little Kamishak and Strike Creek, sharing similar geologic basins that originate in Jurassic Naknek Formation and lower reaches, consisting primarily of Quaternary alluvial deposition of these formation-derived sediments.

Weathering of the Naknek Formation would likely contribute water quality characteristics of moderately high conductivity and alkaline pH values. Silica levels of sandstone-derived waters are low due to coarse grain size and well-crystallized minerals in the sandstone. The Naknek Formation had widespread disseminated pyrite in all samples. A variety of pyrite hosts trace metals in its structure; and, therefore, the decomposition products of pyrite would result in higher sulfate and trace metal values. The alkalinity of the formation would buffer most acidity as a result of this weathering.

Mineral occurrences were indicated by anomalous concentrations of elements (Church et al. 1994) at the following locations along the Katmai coast. The localized contribution of mineralized zones to water quality characteristics would be of the nature previously described. Geochemical signatures of the waters will vary slightly according to the base metal enrichment associated with a particular site.

Ikagluik Creek

Mineralized samples in this area contained anomalous concentrations of copper, silver, lead, manganese, arsenic, molybdenum, zinc, chromium, nickel, gold and cadmium. Mineralized areas occurred where Tertiary porphyritic plutons intrude the Naknek Formation. Rocks in the zone around the intrusion were altered to chlorite and calcite. There was evidence of multiple phases of quartz veins containing pyrite, molybdenite and chrysocolla. Chrysocolla is an important surface indicator in the presence of porphyry copper deposits.

Fourpeaked Mountain Area

The area is mapped as Quaternary volcanic deposits, but is underlain by Jurassic and Cretaceous sedimentary units. These formations are in contact with Tertiary intrusive rocks and exhibit base metal anomalies near the contact. Unique anomalous concentrations of arsenic were reported in samples; field observations recorded abundant pyrite. In addition to arsenic, sample results showed anomalous concentrations of antimony, gold and silver. Some localities showed additional anomalies of bismuth, manganese, cadmium, cobalt, copper or molybdenum. The Big River area had the most prominent anomalies.

Ninagiak River Area
This area is similar to the Fourpeaked area in geology, underlain by the Naknek Formation, with Quaternary volcanics on the peaks. Anomalous concentrations of metals are found in the Naknek Formation at some locations where there is evidence of pyrite veins. Red-brown color anomalies are developed in these locations due to oxidation of pyrite in the fractures. Tertiary dikes intruded into the Naknek Formation were another source of reported anomalies of silver, bismuth, antimony, copper and zinc.

Kukak Bay to Mount Dennison Area
In this location, exposures of Cretaceous sedimentary rocks, Jurassic Naknek Formation and Tertiary volcanic rocks show color anomalies around zones of Tertiary intrusives. Sampling revealed anomalies of copper, gold, silver, mercury, boron and cadmium. Near the Kukak Bay pluton, at the head of Kukak Bay, one sample taken at the terminus of a glacier had 150 ppm gold, the highest concentration in any of the samples taken in the Katmai area.

Katmai River Area
Five drainages in this area underlain by the Naknek Formation, altered to hornfels where it is intruded by Tertiary dikes and sills. The contacts between these intrusives, in conjunction with the widely disseminated pyrite of the Naknek Formation, have resulted in similar localized metal anomalies as reported above. Anomalous concentrations of molybdenum, arsenic, antimony, bismuth and mercury occur near these intrusive bodies.

In summary, Church et al. (1994), found evidence of six different types of mineral deposits in the Katmai area. A distinctive geochemical pattern of anomalies was identified for each of these deposit types. All of these mineral occurrences appeared to be associated with plutonic rocks of Tertiary age.

G. Volcanic Environments

Quaternary igneous areas of the size mapped in Katmai are rare in the state and country. A compilation of observations of volcanic eruptions since 1870 and ash stratigraphy shows that Katmai has had a long history of volcanic activity (Ward and Matumoto 1967). In 1912, Novarupta violently erupted. The 60-hour eruptive sequence yielded about 35 km^3 of tephra (pyroclastic material ejected during a volcanic eruption), the most voluminous outburst of the twentieth century (Hildreth 1987).

In addition to Novarupta, six other volcanoes in the vicinity have been intermittently active since the withdrawal of Pleistocene glaciers from the landscape: Mount Katmai, Mount Martin, Mount Mageik, Trident Volcano, Snowy Mountain and Mount Griggs (Fierstein and Hildreth 2001:24). Six more volcanoes, which have had no activity recorded in the last 200 years, are considered active: Mount Dension, Alagogshak, Mount Steller, Kukak Volcano, Kaguyak Volcano, Four-Peaked Mountain and Mount Douglas (National Park Service 1994). The Katmai volcanoes represent the highest density of young volcanic centers in Alaska and are also in one of the most seismically active volcanic areas in Alaska where additional eruptions producing ash clouds and lava flows are likely (Neal 2001).

The eastern Aleutian volcanic arc consists of 40 major Quaternary volcanic centers spanning 1,500 km with at least 12 of these centers containing calderas (Miller and Smith 1987:435). Radiocarbon dating indicates that 10 of these calderas were formed during the Holocene when deglaciation of the Alaska Peninsula was occurring. Approximately 12% of the world's 714 Holocene-age volcanoes (85) have volcanic lakes (Simkin and Siebert 1994). The other two were formed during the early to late Wisconsin time (Pleistocene) (Miller and Smith 1987:435). Of these 12 craters, Kaguyak Crater (1.6 miles in diameter) lies in Katmai National Park and is dated to about 1630 BP (Beget 1994).

Historic caldera forming processes created four other calderas in Katmai National Park: Katmai, Mt. Martin, Mt. Mageik and Douglas. Each crater in the park contains water but none has an outlet stream. Mount Martin, Mageik and Katmai pose the greatest potential hazard of lake water and magma violently mixing to generate an explosive phreatomagmatic eruption (Fierstein and Hildreth 2001:2). This is but one example of the hazards of volcanic activity on humans as well as ecosystems.

The effects of very large volcanic eruptions (Novarupta was the world's largest eruption in 120 years) appear to have influenced the world's climate. A dust veil was reported as far east as Greece and Algeria, leading to pioneering work on atmospheric turbidity and the effect of aerosols on climate (Fierstein and Hildreth 2001:9). High acidity levels attributed to the eruption of Novarupta were observed in the Greenland Ice Cap (Hammer et al. 1981) and Rampino and Self (1984 in Miller and Smith 1987:437) estimated a worldwide temperature drop of 0.2°C following the eruption.

Localized effects of volcanic activity on water chemistry and stream morphology are common. Extensive physical changes in riparian and aquatic habitats have been observed from other volcanic-induced

The Griggs expedition of 1917 hiked up to see Katmai Crater Lake firsthand. Many found the site to be more beautiful than the Valley of Ten Thousand Smokes itself. They agreed that photographs did not adequately portray the vastness of the lake or its features. Griggs felt the crater needed to be seen to be appreciated much like the Grand Canyon. The colors of the crater walls, the water and deposits; the steepness of the walls and the depth of the crater were more than could be described or shown in photographs.

Griggs survey of the crater lake indicated its size as 3 miles long and 2.75 miles wide. It is 3,700 feet from the bottom to the highest point on the rim. In comparison Kilauea in Hawaii has a maximum depth of 500 feet. (Griggs, 1918, Nature)

Only two craters surpass Katmai in size: Crater Lake in Oregon and Haleakala in Hawaii. But Griggs declared Katmai Crater to be "far grander a spectacle to look upon" for the crater walls surrounding the larger crater lakes were much lower in comparison to Katmai Crater and therefore were less spectacular in appearance. Furthermore, Griggs saw the view overall as having no equal in the world:

> …if one recalls the fact that the beautiful blue of the Katmai lakes and the wonderful canyon of Katmai River, which is almost as deep as the Grand Canyon lie in full view from the crater rim, he will recognize that for sublimity of scenery this place has no equal in the whole world (Griggs 1918:167)

disturbances in the Cook Inlet region. Along with ash deposition, lahars, or mudflows, are of particular concern in Alaska where even small volcanic eruptions can cause rapid melting of snow and ice on many volcanoes. The 1989-90 eruption of Mt. Redoubt north of Katmai demonstrated the risk from lahars in valleys that drain an ice-and-snow-covered volcano. Massive inputs of water and sediment entered the Drift River channel emanating from glaciers and snowfields on the volcanoes (Dorava and Milner 1999). Katmai's volcanic summits are extensively ice covered and may be expected to produce similar catastrophic lahars and flooding with volcanic activity as they have done in the past. Volcanic activity in Katmai is often not observed first hand. However, the evidence left behind is obvious well after the fact, as described in the accounts that follow, and attests to the extent of physical alteration that may be expected from volcanic activity in this actively evolving region.

Following the 1912 eruption Griggs saw extensive physical changes in the morphology of streams. During the summer of 1912 the Katmai River was dammed by a landslide triggered by 1912 siesmicity. The river remained dammed for three years until heavy snowmelt in 1915 breached the dam and an enormous flood broke out through Katmai Canyon (Fierstein and Hildreth 2001:38). During his visit in 1915 Griggs saw evidence of the great flood that had snapped off trees and filled the 10 km wide Katmai River valley with debris, pumice and ash several feet deep (Griggs 1917). In places the high water mark was 25 feet above the bed of the stream. The church at Katmai Village was awash in a sea of liquid mud up to 5½ feet and some of the houses were filled to the eaves with pumice (Griggs 1917). The river, although subsided in 1915, remained several feet above its former channel and was described as "five miles wide and five inches deep" (Griggs 1917).

The origin of a catastrophic lahar, some three years following the eruption, was a vast, dammed lake in the valley between Katmai Volcano and the neighboring mountain (Fierstein and Hildreth 2001:2). The mixture of water and volcanic debris moved rapidly down Knife Creek in the Valley of Ten Thousand Smokes, flowing in the opposite direction of the Katmai River flood, impacting areas 10-20 km from the source.

Years later, five andesitic lava flows erupted from a newly formed satellitic vent in the southwest flank of the Trident Volcano cluster between 1953 and 1960 (Ray 1967). The first flows moved southwestward into Katmai Pass and displaced the headwaters of Mageik Creek slightly to the west (Keith et al. 1992). Later flows moved southward over the 1912 tephra but did not reach the creek.

Some impacts from volcanic eruptions are short-term (< 5 years), while others last much longer. Data suggest significant fertilization of watersheds by ashfall in the region. Griggs (1920) reported that the ash from the 1912 eruption included 0.36% phosphorus, 0.47% magnesium and 3.8 % calcium. Although vegetation was greatly reduced during the first two years following the eruption, Griggs (1920) found plant growth to accelerate above normal after the second year. A similar correlation was observed in examining the growth history (1855 – 1951) of five spruce trees (*Picea spp*.) around Brooks Lake. As shown in figure 17, an abrupt and rapid increase in annual growth rates occurred in 1914, peaking in 1918 (Eicher and Rounsefell 1957).

No invertebrate collections were made following the 1912 eruption, but studies from other areas indicate what might be expected in community composition following a volcanic event. For example, Dorava and Milner (1999) compared macroinvertebrate community composition in the Drift River (approximately 100 miles northeast of Katmai), which was impacted by the 1989-1990 Redoubt volcanic eruption, with nearby undisturbed streams. They found the Drift River macroinvertebrate communities still recovering five years after the event.

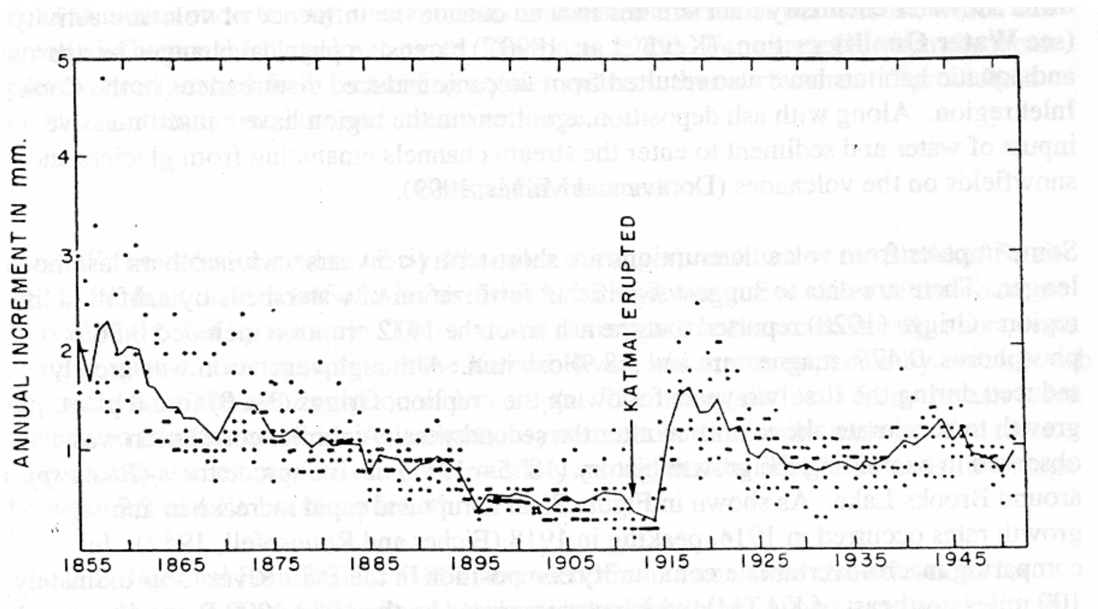


Figure 17. Annual growth increments of five spruce trees from Brooks Lake, 1855-1951, illustrating the marked long term effects of ashfall on increased soil fertility (Eicher and Rounsefell 1957).

IV. Soils

Factors affecting soil development most dominant in the region are the type of parent material available, climate and relief. The type of soil formed can affect water quality as precipitation reacts with chemical constituents in the soil and mobilize them into local waterways. The level of soil erosion is also dependent on the type and distribution of soils as well as relief.

No comprehensive soil surveys have been conducted in Katmai (Natural Resources Conservation Service 1998). In fact, minimal soil survey work has been conducted in Alaska. One limited study in the park evaluated soil properties in the Valley of the Ten Thousand Smokes (Cameron 1970). According to this study, volcanic ash produced from the 1912 eruption of Novarupta is largely siliceous material. These soils are low or without typical clays; thus, conditions are not favorable for organisms. Not surprising, the valley is nearly void of visible vegetation except in localized patches, and biological soil crusts are still an important group of microflora in this ash-impacted area.

In conjunction with soil surveys, Cameron (1970) identified soil microflora found surrounding dying fumaroles in the Valley of Ten Thousand Smokes. The biological soil crusts, or cryptogamic soil crusts, that he found are communities of highly specialized organisms composed of cyanobacteria, green algae, lichens, mosses, microfungi and other bacteria (Belnap et al. 2001). These communities serve as the “glue” in otherwise barren ash deposits in the Valley of Ten Thousand Smokes stabilizing the surface where they occur from the erosive forces of wind and water. These unique communities are prevalent in the Valley of Ten Thousand Smokes but are probably not limited to that area of the park.

Dominant soils in the Bristol Bay lowlands are Typic Haplocryands, Typic Fluvaquentic Cryofibrists, Histic Pergelic Cryaquepts, Pergelic Cryaquepts and Typic Cryochrepts. Most soils are formed in volcanic ash deposits of various thicknesses underlain by gravelly glacial till, outwash deposits or silty alluvium.

In the mountainous areas many soils are formed in deposits of volcanic ash and cinder over glacial deposits and are highly erodible. This area is generally free of permafrost. Dominant soil types are Typic Haplocryands and Typic Vitricryands. Glacial deposits cover all but the highest parts of ridges. Mountain peaks, rock escarpments and talus slopes have little or no soil cover. Some depressions are filled with fibrous peat.

V. Glaciers, Lake Ice and Snowpack

The Katmai region has a history of multiple glaciations by a piedmont glacier system, which at its maximum, extended nearly 100 miles west of the Aleutian Range across Kvichak Bay (Muller and Ward 1966). Deglaciation of the Alaska Peninsula occurred about 9,000-10,000 years BP or shortly before (Detterman 1986). Today, because the line of volcanic summits reaches 6,000 feet to 7,100 feet elevation and lies in a region of high precipitation, all the range crest centers are extensively ice covered (Hildreth et al. 2000:88).

Glaciers account for 35% of the total runoff in Alaska (Mayo 1986). Where glacial runoff contributes 50% or more to streamflow, seasonality may be strongly influenced; even with as little as 5% of the basin glacierized (Milner, Irons and Oswood 1997).

Currently, glaciers make up 216,000 acres (6%) of Katmai (National Park Service 1994). 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.

Glaciers of the Aleutian Range are classified as temperate due to a year round ice temperature close to 32^{o}F. Since glaciers store an enormous amount of water in the form of ice, drainages that are fed from glaciers can be highly complex. Solar radiation and air temperature dictate how much water is released and may be highly variable from year to year. Seasonal variability of flow causes temporal variability in water quality, making it important to understand the ecological dynamics of a watershed.

Katmai glaciers provide a unique opportunity to study climatic and volcanic effects on glaciers. The 1912 ash layer blanketing many of the glaciers in the park to varying degrees provides a datum from which to evaluate the changes in their form over time. Furthermore, the glacier formed in Katmai Crater is of known date having been formed following the 1912 eruption of Novarupta.

Lakes at lower elevations in the Naknek drainage usually become ice free in early May (Bureau of Commercial Fisheries et al. 1964:17 and Crawford and Cross 1995). However, in 1999 an aircraft was able to land on the ice of Nonvianuk Lake on May 25 (Sonny Petersen, pers. comm 2003) and local pilots reported breakup for Naknek Lake as late as May 22-25 for three different years between 1981 and 1991 (Crawford and Cross 1995). Also in 1999, Naknek Lake ice remained through May (Jim Gavin, pers. comm. 2003). Higher elevation lakes, such as Murray and Hammersly, may remain under ice for several weeks longer. In fact, local reports indicate solid lake ice as late as mid-June in 2001 at Hammersly and Murray Lakes, and ice was still visible on Little Kamishak Lake until early July of 2000 (Sonny Petersen, pers. comm., July 2001).

The lower Naknek River is generally open between mid-March and late April with an average breakup date of April 9 (U.S. Dept of Commerce 1964).

Lakes freeze for the winter in early December (Buck et al. 1978:66) while the lower Naknek River becomes frozen on average as of November 17 (U.S. Dept. of Commerce 1964). Observations of Naknek Lake ice-up from local pilots indicate an average date for ice cover on the lake is January 22 (Crawford and Cross 1995). Higher elevation lakes, such as Murray and Hammersly, freezeup several weeks in advance of lower elevation lakes. Warmer winter temperatures during 2002-2003 resulted in open water conditions on Naknek Lake until the week of March 10 when a thin blanket of ice formed across the lake (Jim Gavin, pers. comm. 2003). This is the latest freezeup date of Naknek Lake recorded. Records from 1970-1995 by local observers indicate that February 16 was the latest Naknek Lake freezeup date remembered occurring during the winter of 1993-94 (Crawford and Cross 1995).

Naknek Lake freezes earlier in winter than Lake Iliamna because it is more sheltered from prevailing winds (Hartman et al. 1967). However, Goldman (1960), Merrell (1958b) and others report open water on Iliuk Arm in mid-winter when air temperatures were below 0^{o}C; and Bureau of Commercial Fisheries et al. (1964:17) report that Iliuk Arm seldom freezes over completely. Early explorers witnessed this phenomenon and attributed it to the presence of hot springs in the area. Later scientists attributed the open ice conditions to Iliuk Arm's depth (Goldman 1960:225).

Bay of Islands is generally the last area of Naknek Lake to freeze over and may remain open many years (Jim Gavin, pers. comm. 2003). NASA satellite photos of the Alaska Peninsula show open water at the west end of Grosvenor Lake as well as all of Iliuk Arm (http://rapidfire.sci.gsfc.nasa.gov/gallery/?2002090-0331/Alaska. A2002090. 2140.1km. jpg). On first impression it may seem like a wind phenomenon. However, at the same time the east end of Becharof Lake and Lower Ugashik Lake were ice free.

Mean annual frozen precipitation totals for King Salmon, which represent Katmai's interior, and Kodiak, which represent Katmai's coast, vary from 46.1 inches to 77.4 inches, respectively (National Oceanic and Atmospheric Administration 1998). Seasonal ice and snow cover affects the characteristics of aquatic ecosystems. It controls 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 gases, such as CO_2, CH_4 and H_2S (Rouse et al. 1997). The processes accompanying ice formation during freezeup and breakup 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).

Katmai is underlain by discontinuous or isolated masses of relatively shallow permafrost (3-100 meters), which can greatly influence the hydrology, erosion, vegetation and human activities of the area (Dearborn 1979). For example, permafrost can prevent precipitation from recharging aquifer systems, thus surface runoff provides a greater contribution to lake and stream recharge.

VI. Flow Regimes

Water flow throughout most of the park is primarily influenced by snowmelt, glacial melt and precipitation. Peaks in discharge, lake levels, sediment transport and other factors are influenced by the source, mode of transport and timing of water into lakes and streams.

Glacial fed streams rise gradually during snowmelt and glacial melt, resulting in peak discharge in mid to late summer. In their synthesis of data from eight glacial streams statewide, Milner et al. (1997) reported that during May, flows begin to rise with increasing solar radiation reaching a maximum peak rate about mid summer. From that time, flows gradually decline until November/December when freezeup occurs. The timing of the peak is influenced by climate, watershed size and the extent of winter precipitation.

Glaciers in the Aleutian Range supply water to the Naknek and coastal drainages. Smaller glaciers and snowfields exist in the headwaters of the Alagnak drainage. Runoff from glaciers rises as temperature increases over the summer causing stage peaks later in the summer than waters influenced primarily by snowmelt and precipitation.

Spring thaw generally occurs from mid-April through May with peak discharge occurring (Eskimo Creek hydrograph data in NPS 2001:48) in snowmelt dominated regimes. In contrast to glacial fed streams these waters show little daily flow variations. However, as the summer progresses, lesser peaks of discharge occur during rain storms. In mid-October to November another peak occurs as fall rains contribute to runoff. Following freezeup in late October to early November, rivers and streams exhibit very low flows throughout the winter months (Buck et al. 1978:63).

In lowland areas of the western portion of the park, such as around Brooks Lake, gradual melting of groundwater frozen over the winter months and precipitation are the major contributors to water flow. No significant snow accumulation occurs in those areas.

The Alagnak River is snowmelt dominated, rising in stage before late May and early June and peaking in mid-June to early July (Curran 2003). Following the snowmelt peak, flows decrease through the summer and early fall with the exception of short rainfall-induced peaks.

Streams in the Valley of Ten Thousand Smokes drain the mountains surrounding the valley. The three major streams draining the valley are Knife Creek, River Lethe and Windy Creek. These streams join together to form the Ukak River within 100 m of each other at Three Forks Overlook. The Ukak River flows through Naknek Formation and glacial and fluvial deposits through the distal end of the ashflow sheet (Keith et al. 1992:214). These streams are composed largely of meltwater from seasonal snow. Summer rains produce daily, even hourly variations in stream flow (Keith et al. 1992:213). Seeps and springs, in the mid-valley region issuing from vertical joints in the ash sheet, also contribute to these streams. Discharge decreases in the fall and freezing temperatures stop the flow in much of this region although upper Knife Creek has been observed flowing along its entire length by mid-March (Keith et al. 1992:214).

Rapid snowmelt in the spring and early summer during years of high snowfall produce dramatic changes in water levels. High water levels have occurred at fairly frequent intervals over the past 25 years. The most recent occurrence of this phenomenon was in 2001. High snowfall in the mountains over the winter accompanied by unseasonably high temperatures in May and particularly June resulted in high water throughout the summer. Terry Keith (pers. comm. October 2001) indicated that in June of that year the water of the River Lethe was the highest she had seen it.

Naknek Lake levels normally fluctuate as much as seven feet between spring and late summer (U.S. Geological Survey 1951, National Park Service 1997:26). The highest stage observed in the Brooks River area occurred in the mid-1970s. Local flooding around the mouth of Brooks River peaked at the 38-foot contour line on the lake side of the Camp and up to about 37 feet elevation (fish cleaning building) on the river side (Sonny Petersen pers. comm. July 2001 or National Park Service 1997:26). Unusually high snowfall in the winter of 1976-77 resulted in water levels several feet higher than previously recorded observations (Ostermick 1977). Local resident Mike Shapsnikoff had lived in Naknek since 1936 and remarked that the water was higher than he had ever seen it. By mid-August NPS staff reported water 19 inches above the dock on Brooks River. Water lapped at the foundation of the fish house and up against Wein employee housing areas at Brooks Camp. High east winds coupled with high water resulted in severe erosion of the riverbank, pulling the dock free of its footings, and eliminated the trail to the river and campground. Pumice jammed the beaches and the mouth of the River. Before this event, pumice had been observed just below the falls (Sonny Petersen pers. comm. 2001) indicating that similar, but more severe, high water conditions had previously occurred, depositing beach pumice nearly a half mile from the shore of the lake.

Milner et al. (1997) developed temperature curves for four hydrologic units in the state. The southcentral region includes the coastal areas of Katmai east of the Range. There were no data for comparison in the southwest portion of the state. They reported low winter flows in non-glacial streams in southcentral Alaska. The streams generally experience a peak during the spring at the height of snowmelt and another in the fall from precipitation events. Inland streams are generally frozen five to five and a half months, while closer to the ocean the period of freezeup is reduced to four to four and a half months (Milner et al. 1997). In some years rivers may not freeze. Accumulated degree days are about 1,400 to 1,500 for streams near the coast (Milner et al. 1997).

There are no continuous stream flow data in Katmai. The closest USGS stream gaging stations are located outside the park at Eskimo Creek (Naknek River basin - King Salmon, Alaska) and Kvichak River (Kvichak River basin - Igiugig, Alaska). The Eskimo Creek gauge collected partial crest stage data from 1965-67 and again from 1969-73. Continuous streamflow information was also recorded from 1973-1984 as well as some chemical and water temperature data for some years between 1964 and 1972 (U.S. Geological Survey 1998).

Continuous streamflow records for the Kvichak River at Igiugig are available from 1967-87. Limited chemical and sediment data were recorded for some years between 1956 and 1972 (U.S. Geological Survey 1998).

Scattered discharge records exist for various drainages. Early data are limited to Brooks Lake tributaries (Hartman 1958:148-149, Hartman 1959:72, Hartman et al. 1964, Hoopes 1972, McAfee 1960, Eicher 1971). Between 1990 and 1992, discharge was recorded on 19 streams in the park across the Naknek and Alagnak drainages. The reported discharges ranged from 2 cubic feet/second (cfs) in a tributary that feeds Brooks Lake to 530 cfs in American Creek (LaPerriere 1996).

Summer discharge rates for Knife Creek exceed $7x10^5$ L/min (412 cfs) and $5x10^5$ L/min (294 cfs) for the River Lethe near Three Forks. Mid-winter discharges are unknown (Keith et al. 1992:213). Windy Creek measured discharge in June 1991 was 2. $84x10^5$ L/min. Flow is generally higher in early summer because of snowmelt at the headwaters; and discharge may double at any time during heavy rain in the headwaters region, making these waters particularly dangerous to hikers (Keith et al. 1992:214).

Stream gradients were reported by Hoopes (1962) for Hidden Creek, One Shot Creek and Up-a-Tree Creek on Brooks Lake. The highest gradient reported was 257.1 feet per mile on a section of One Shot Creek. The average for this stream over a 2.4 mile reach was far less at 63 feet per mile. The steepest gradients in the park occur along coastal drainages. For example, mapped streams feeding and draining Dakavak Lake on the coast measure an average gradient of 15%.

VII. Groundwater

A petroleum contamination assessment at Brooks Camp identified a shallow (3 - 15 feet below ground surface) water table aquifer and a deeper artesian aquifer in the underlying igneous bedrock (National Park Service 1997). Outside of a few independent site characterizations such as this, there is minimal information available on Katmai’s groundwater resources. However, some basic hydrogeologic principles can be inferred from the park's geology and geomorphic features.

Glacial deposits typically present favorable conditions for groundwater. 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 dammed up meltwater, such as the western edge of Naknek Lake, fine-grained sediments can accumulate, producing aquitards or confining beds (Mandel and Shiftan 1981). Glacial-fluvial sand and gravel deposits that underlie King Salmon are the primary aquifer(s) in the area (Waythomas 1994).

Hydrologic properties in volcanic terrain vary greatly, making predictions about groundwater uncertain. Some lava contains productive aquifers, while other lava is 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).

Katmai 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 on the variability in the park's hydrogeologic characteristics, groundwater flow, depth, quantity and quality can differ greatly over very short distances.

Petroleum products constitute the primary threat of contamination to groundwater. Approximately 90% of the contaminated groundwater sites in the state are polluted from petroleum. Nitrates and fecal coliform may also be of concern in areas where septic systems are in use.

VIII. Hydrothermal Systems

Thermal springs, fumaroles and heated ground are the surface manifestations of subsurface hydrothermal systems. Because of their increased temperatures and chemical composition these features and any associated gaseous discharges can have a profound effect on local surface waters. In Katmai, hydrothermal features are commonly found on the flanks of volcanoes or in the Valley of Ten Thousand Smokes. Waters flowing through and within the 1912 ashflow are most affected by these systems.

A. Fumaroles

After the region was blanketed with pumiceous fallout from the 1912 Novarupta eruption, fumaroles (vents, usually volcanic, from which vapors and gases are emitted) discharged from the ashflow sheet and were vigorously active when discovered in 1916 (Griggs 1922). During his first visit to the Valley of Ten Thousand Smokes, Griggs (1917) wrote:

> I can never forget my sensations at the sight which met my eyes as I surmounted the hillock and looked down the valley; for there, stretching as far as the eye could reach, till the valley turned behind a blue mountain in the distance, were hundreds - no, thousands - of little volcanoes…

Dr. Shipley, who accompanied Griggs on the 1917 National Geographic Katmai expedition, reported a variety of odors (i.e., hydrogen sulfide and hydrochloric acid) coming from active vents in the Valley of Ten Thousand Smokes (Griggs 1918). Fumarole temperatures up to 645º C were measured in 1919 (Allen and Zies 1923). High temperature fumaroles were vigorously active in the ashflow sheet for about 15 years following the eruption (Fierstein and Hildreth 2001:9). Cooling of the ashflow sheet and the influx of surface waters caused the fumaroles to gradually cool and die out (Allen and Zies 1923, Fenner 1923, Zies 1924). No subsequent studies were done until 1979 after the fumaroles had become cold, except for a few in the near-vent region (Keith 1984, 1991a).

While still active the fumaroles leached chemical constituents from the volcanic deposits. As the hot fluids traveled upward, they cooled and decompressed rapidly, became oversaturated, subsequently depositing various minerals and cementing the ejecta, forming encrustations (Hogeweg 2002:10). Although most of the fumaroles died out in the 1930s they are still evident today as bright dark purple and red to yellow and white color on the lighter pinkish gray ashflow. Because many fossil fumaroles are more weather resistant than the surrounding ash they rise several centimeters above the surface of the ashflow and overlying fallout deposits.

The chemical composition of waters draining the 1912 eruptive deposits in the valley has been continuously affected by cold surface water leaching of metastable and unstable minerals and glass from the 1912 tephra and from fumarolic alteration (Keith et al. 1992:225). During high-temperature fumarolic alteration, hot gases transported chemical constituents leached from within the ashflow sheet to the surface where they were deposited as incrustation minerals (Keith 1991a). Many of these minerals were water soluble and easily eroded by extreme wind and precipitation conditions in the valley (Keith 1991a). Waters draining the 1912 deposit carried a substantial load of dissolved constituents from these deposits (Keith et al. 1992:225). As fumaroles cooled and incrustations diminished, the concentrations of dissolved constituents in the stream waters also decreased. In fact, Keith et al. (1992:225) predicts that reactions between waters and tephra should be approaching a steady state of dissolution.

While dissolution and erosion of metastable and unstable minerals in the fumarolic encrustations by wind and rain continue to influence water chemistry in the Valley of Ten Thousand Smokes, inputs from thermal waters are probably contributing much higher concentrations of constituents to surface waters in the valley today (Keith et al. 1992:226). Waters upvalley from the thermal springs carry similar concentrations of major constituents, except that waters are higher in sulfate and fluorine, probably from fumarolic deposits (Keith et al. 1992:225). Lower Knife Creek and lower River Lethe contain greater concentrations of all constituents relative to their concentrations in the upper valley (Keith et al. 1992:220).

Apart from the fumaroles in the Valley of Ten Thousand Smokes, Motyka et al. (1993:Sheet 4 of 4) report active fumaroles occurring in the crater or on the flanks of Mt. Martin, Mt. Mageik, Mt. Trident, Mt. Griggs, Kukak and Mt. Douglas. Steaming ground was also reported on Snowy Mountain and Mt. Trident (Motyka et al. 1993:Sheets 3 and 4 of 4).

B. Thermal Springs

Hydrothermally active areas as hot as 90°C have been mapped as discontinuous, elongate, clay-altered layers concentrated along some of the concentric fractures outlining the Novarupta caldera, as well as along systems of crossfractures (Keith 1986). Keith et al. (1990) reported that thermal springs in the Valley of Ten Thousand Smokes, discharge about 20 meters below the surface of the ashflow sheet through vertical cooling cracks in the tuff. In 1990, the maximum measured temperature of the springs was 29.8° C in early summer when waters in the upper valley were still frozen. Later in the summer, the temperatures decreased to approximately 17° C, most likely because of increased mixing with cooler surface meltwater from the upper valley.

In the mid-valley region of the Valley of Ten Thousand Smokes, hundreds of thermal springs issue from near the bottom of a 15 m deep erosional gorge of the southwest fork of Knife Creek over a 300 meter reach (Keith et al. 1992:214, water sample stations inset B in chapter 4 following page 10). Green algae surround these spring orifices. The major orifices discharge at a rate of more than approximately 100 L/min. Just downstream of the springs, stream discharge was measured at approximately 35,000 L/min and temperatures ranged from 15^{o}C to 29.2^{o}C (Keith et al. 1992:214).

The springs exhibit similar chemical composition over time regardless of temperature (Keith et al. 1992:220), and concentrations of all constituents are higher in the mid-valley thermal springs than waters above or draining the 1912 deposits. In particular, concentrations of chloride, sodium, potassium, lithium, boron and sulfate, indicators of hydrothermal fluids, are higher (Keith et al. 1992:220).

Thermal springs were reported by Keith et al. (1992:215) in two areas south of Katmai Pass. These springs were not reported in this area until the Trident eruptions (1953-60) but may have been present earlier. Bacterially concentrated iron oxide gives these springs a distinct, brick red appearance. Total discharge was measured at about 100-300 L/min.

Well established hot springs having temperatures as high as 42^{o}C occur along the north side of Mageik Creek (Keith et al. 1992:214, water sample stations inset B in chapter 4 following page 10). These are the highest recorded temperatures, in recent time, for thermal springs in the park. Their properties reflect the hydrothermal system beneath Trident Volcano (Keith et al. 1990). Hot springs were first reported in this area in 1898 (Spurr 1900) and later were mapped by Griggs and others (Griggs 1922; Allen and Zies, 1923). Discharge rates at these springs range from about 5 L/min. to 30 L/min.

The Katmai Pass and Mageik Creek thermal spring waters are chemically distinct groups based on chemical and isotopic data (Keith et al. 1992:222). The springs south of Katmai

Pass are lower temperature and waters are more dilute in most constituents relative to the Mageik Creek spring waters. Mageik Creek spring waters contain the highest concentrations of arsenic, strontium, cesium and rubidium as other major constituents relative to other thermal waters in the Valley of Ten Thousand Smokes (Keith et al. 1992:222).

No other thermal springs have been described in the park although the presence of additional springs is likely. LaPerriere (1996) documented elevated stream temperatures in an inlet stream on Kulik Lake, indicating the possible presence of warm springs in that area. The source of the thermal waters was not located.

C. Cold Springs

The hill at Three Forks Overlook at the northwest end of the Valley of Ten Thousand Smokes is the site of several small cold springs. Discharge rates are approximately 2 L/min in late June, but are commonly dry by August (Keith et al. 1992:213). The discharge rate appears to be related to the amount of precipitation and consequently the waters have a short residence time in the rocks (Keith et al. 1992:213). These springs are in contact with the Naknek Formation, glacial deposits and a mantle of dacitic fallout covering the hill.

Cold springs along the River Lethe gorge discharge from vertical joints 2-3 meters above the base of the ashflow sheet. Discharge has been measured at 60 L/min from three major springs, but overall discharge is less than that from the mid-valley thermal springs (Keith et al. 1992:214). Most of the springs are inaccessible due to steep, unstable walls and the fast flowing river. However, measurements at the upper end of the system recorded a temperature of 8.8^{o}C, indicating there may be some source of thermal input into the spring. Other springs sampled along the Lethe were estimated to discharge at a rate of about 40-60 L/min and are submerged during the summer when the river is flowing (Keith et al. 1992:215).

Lethe spring waters have compositions similar to cold springs above the 1912 deposits except that River Lethe spring waters are significantly higher in chloride, lithium and sodium (Keith et. al. 1992:220). Data from these springs suggest there may be a thermal water component here as well.

A cold spring above Juhle Fork has a discharge rate of approximately 20 L/min. It issues from an altered Tertiary dioritic sill (J. Riehle, oral comm. 1990 in Keith et al. 1992:213) in the Naknek Formation.

IX. Air Resources

While it is assumed that Katmai’s air is pristine because of its remote location, this assumption cannot be validated due to the dearth of air quality data collected in the park. Atmospheric deposition of toxic pollutants is a concern at Katmai. It is currently unknown what the risk to the park is from these pollutants, or the extent of current distribution or impacts of these toxics in the food web. Pollutants of concern are persistent organic pollutants (POPs) such as DDT, PCBs and furans and metals such as mercury. These pollutants can travel long distances (in some cases from Europe and Asia), persist in the environment for a long time and tend to accumulate at higher levels of the food chain, causing toxic effects in fish, mammals and in humans who consume them.

NPS initiated a project in 2002, "Western Airborne Contaminants Assessment Project," to determine the risk to ecosystems and food webs in western national parks from the long-range transport of airborne contaminants. It has been designed and implemented by the National Park Service's Air Resource Division in cooperation with national parks, the Environmental Protection Agency, the U.S. Geological Survey, the U.S. Forest Service and several universities (National Park Service 2002a). The contaminants of concern are compounds and elements known as Persistent Bioaccumulative Toxics (PBTs). This group contains a variety of persistent organic pollutants (POPs) such as PCB, DDT and HCH, as well as elements such as mercury (Hg). These materials are direct or indirect products of human industrial activity and can be transported thousands of miles in the atmosphere. The project includes three national parks in Alaska; Noatak, Denali and Gates of the Arctic. Snow, water, lichen and fish were sampled at each of these parks during 2004. A subset of secondary vegetation samples were collected from western parks including Katmai, Glacier Bay and Wrangell-St. Elias in Alaska. These samples will help determine the contaminant load at Katmai compared to other western parks. A final WACAP report will be available in late 2007 (Blett pers. comm. 2007).

Naturally occurring events are also responsible for local and long range changes in air quality. Volcanic vents are a frequent and perhaps constant source of chemical emissions producing a distinct odor and affecting local air quality, while eruptions have more long reaching effects. The eruption of Novarupta provides an example of these long range effects. Following the 1912 eruption, Griggs (1917:13) noted what he considered to be effects of the 1912 eruption,

> Great quantities of very fine dust were thrown into the higher regions of the atmosphere and quickly distributed over the whole world, so as to have a profound effect on the weather, being responsible for the notoriously cold, wet summer of that year.

The effects of volcanoes on the earth's atmosphere continue to be studied and will not be discussed here. However, local effects of volcanic emissions can be considerable and should not be underestimated. Air monitoring equipment to detect specific constituents would be necessary to establish the level of background emissions attributable to Katmai's many volcanoes. Suffice it to say, not all sources of airborne "contamination" can be attributed to human sources.

A. Air Quality Issues

Katmai is designated as a Class II floor attainment area for air quality protection. This designation allows for moderate increases in some pollutants, but prevention of significant deterioration (PSD) requirements remains in effect. Maintaining air quality is critical to preserve the park's scenic value, as well as its wildlife and water quality. The Resource Management Plan for Katmai National Park identified several threats to air quality in the park (National Park Service 1994:150). These included:

- automobile and air traffic from King Salmon and Naknek
- smoke from incinerators, dumps, fireplaces, wood-burning stoves, and furnaces in the local area
- power generation from King Salmon, Naknek and local communities
- regional pollution from Dillingham and Kodiak
- campfires at Brooks Camp and backcountry sites
- long distance transport from industrial areas

The global dispersion and deposition of pollutants has subjected many remote areas to pollutants, e.g., Barrow, Alaska. Additionally, problems associated with global warming, arctic haze, ozone depletion and acid precipitation extend beyond regional airshed boundaries to affect the entire planet. There is currently no air quality monitoring in Katmai. Data from monitors in Denali National Park may give an indication of trends in Katmai. From 1995-2004, air quality (ozone pollutants) in precipitation and visibility-reducing particles) was relatively stable in Denali Park. However, researchers noted an increase in nitrate and ammonium particles in precipitation (Blett pers. comm. 2007).

Several high altitude lakes in Katmai have low alkalinity and are acid sensitive (LaPerriere 1996). Naturally, acidic lakes are often located in volcanic areas; and high aluminum concentration has been reported for several creeks in Katmai (Gunther 1992, LaPerriere 1996). These streams appear to be devoid of fish. Areas with low alkalinity may be particularly sensitive to acid precipitation. The average pH for 16 precipitation events measured in 1985 and 1986 was 5.0. Although this pH is more acidic than pure rainfall in equilibrium with CO_2 (pH = 5.6), it corresponds to the value given for remote areas uncontaminated by industrial emissions or calcareous dust (Schindler 1988:149). The pH values found for fresh snow and snowmelt on the Kenai Peninsula in 1981 was 5.2 (Alaska Department of Environmental Conservation 1981).

1. Impacts from Developed Areas

One potential threat to air quality in Katmai is power generation from surrounding communities and Brooks Camp. Several areas were identified as potential contributors of pollutants to Katmai’s airshed. These include King Salmon, Naknek, Dillingham, Illiamna and Kodiak. The Naknek Electric Association operates a plant along the Naknek River approximate six miles west of the park boundary. The Nushagak Electric Cooperative supplies power for Dillingham, located 75 miles west of the park. Kodiak has two generating stations, the Nyman Power Plant and the Kodiak generating station. The latter is used as an emergency backup and is not in regular use. Power for Illiamna is supplied by a hydroelectric generation station and backup power comes from a generation station in Newhalen.

Localized impairment may occur at Brooks Camp in the form of generator and incinerator emissions, vehicle, boat and aircraft emissions. Emissions from these sources have not been quantified and no visual changes in the viewshed have been reported.

Title V air permits issued by the Alaska Department of Environmental Conservation (2002) for generating plants report potential emissions from generating units (table 6).

While the majority of emissions come from the generators, fugitive emissions from fuel storage tanks also contribute to the overall emissions from the generating facilities.

Another community impact results from transportation usage in surrounding communities, particularly King Salmon and Naknek. King Salmon's population is 442 with 196 occupied housing units, and the population in Naknek is 678 with 247 occupied housing units (Alaska Department of Community and Economic Development 2000, http://www.dved.state.ak.us. cdb/commdb/CF_COMDB.htm). No data are available for transportation emissions from these populations, but emission factors from EPA AP-42 (2000) (a compilation of emission factors for both stationary and mobile sources) could be used to estimate the contribution of transportation sources to the airshed.

Table 6. Potential emissions from power generation in Katmai region (in tons per year)

Plant	Pollutant				
	NO_x	CO	SO_2	PM-10	VOC
Naknek	578	150	82	58	unreported
Dillingham	326	97. 3	63. 3	7. 1	10. 4
Nyman (Kodiak)	249	19	160	0	11

VOC=volatile organic compounds

2. Arctic Haze and Visibility

A distinct haze was occasionally noted during monitoring in 1986 by Katmai staff. Haze problems have been noted for Tuxedni, a remote area to the northwest of Katmai on the shores of Lake Clark National Park and Preserve (Alaska Department of Environmental Conservation 1991). Arctic haze was first observed over Alaska and reported during the mid-1950s in connection with weather reconnaissance flights over the state. Arctic haze has been heavily researched since the early 1970s by scientists from the United States, Canada, Europe and Russia. Arctic haze is an episodic seasonal phenomenon that is most prevalent in winter and early spring when concentrations of pollutants associated with arctic haze increase by an order of magnitude (Arctic Monitoring and Assessment Programme 1997). Approximately 90% of arctic haze is attributed to sulfate particles. Air masses associated with arctic haze may transport pollutants for as long as a month before final deposition occurs. Studies on sources of arctic haze have demonstrated that most of the haze in Alaska originates in northern central Russia and western Europe (Rahn and Lowenthal 1986; Ratz 1991).

In contrast to arctic haze, local and regional haze may be generated in close proximity to where it is observed. Local nitrous oxide emissions may be responsible for haze conditions. Given the relatively large emissions of NO_x from power generation (table 6), local emissions coupled with the right meteorological and atmospheric conditions (stable atmospheric inversions) may lead to haze in Katmai.

Long-range aerosol transport occurs via numerous pathways from Eurasia to Alaska. Particulate matter, such as sulfate, is directly transported, while gaseous pollutants may make several hops from one location to another, as they are deposited and then re-volatized. Persistent organic pollutants (PCBs, dioxins, furans) follow pathways similar to arctic haze. Heavy metals can be transported as particulate matter; but it is important to note that in remote areas, natural sources are often the primary source of heavy metals (Arctic Monitoring and Assessment Programme 1997). This may be especially important in volcanic areas, such as Katmai, where windblown dust may be the major source of heavy metal.

In the decade from 1986-1995 air samples were collected at seven national parks in Alaska and subsequently analyzed to determine the sources of aerosols (Polissar et al. 1998). The seven parks were Northwest Alaska Areas, Gates of the Arctic, Bering Land Bridge, Yukon Charley Rivers, Denali, Wrangell-St. Elias and Katmai. Air sample filters were analyzed for elements and factor analysis used to characterize aerosol sources for the different parks. By measuring the concentration of different elements in aerosol samples, which act as chemical tracers, sources of the aerosols can be identified. Data for Katmai were the least comprehensive and had several temporal gaps during the collection period (Sisler and Cahill 1993).

Analysis of filters showed that long-range anthropogenic sulfate transport was not as important at Katmai compared to the other parks. Furthermore, when annual data were divided to examine seasonal differences, Katmai had low seasonal variability. The authors attributed the lack of strong seasonal variability at Katmai to the greater importance of local sources as opposed to long-range sources from the Arctic. This would make sense because Katmai is the most southerly of the seven national parks tested. The other park that had low seasonal variability was Wrangell-St Elias. Conversely, during the winter in Gates of the Arctic and Northwest Alaska Areas, long-range transported aerosols comprised the majority of the mass collected on the filters. In winter, the polar front that defines the southern boundary of the cold stable arctic air mass extends southward into Interior Alaska. Arctic haze is transported in this arctic air mass from Eurasia to Alaska. In summer, the polar front retreats northward, and changes in weather patterns reduce flow into Interior Alaska over the polar route. During this period, air masses from the North Pacific have a much greater influence on Alaska weather.

The lack of seasonal variability in Katmai aerosol samples can be attributed to a North Pacific influence throughout the year. Katmai's southern location lies south of the polar front in winter; and, therefore, the arctic air mass and associated arctic haze does not impact Katmai to the extent associated with more northerly locales in Interior Alaska. Primary aerosol sources for filters collected at Katmai were attributed to sea salt, motor vehicles, windblown dust and soil, coal combustion and incineration. Local forest fires were the major source of aerosols at all national parks except Katmai. The authors of the national park aerosol study noted that even though a source from forest fires was not observed at Katmai, sulfur, sodium and carbon emissions were associated with local sources.

While the importance of local sources for several factors was noted at Katmai, high concentrations of black carbon, sulfur and sodium indicated long-range transport from northwest of Katmai was present in the aerosol samples. Sources from the northwest include sea salt and pollution from Siberia. In summary, it appears that the aerosols at Katmai are influenced more by local sources than long-range transport, but some long-range aerosols can be measured at Katmai. Regional aerosol is influenced heavily by transport from the North Pacific. Due to the limited data and analyses available for Katmai (as compared to other national parks), the exact apportionment of the aerosol mass between local and long-range sources is difficult to determine.

3. Greenhouse Gases

Greenhouse gas impacts on Katmai's resources are based on an assessment of how the climate may be impacted by rising global concentrations of CO_2 and CH_4. Most scenarios show a steady global warming during the twenty-first century with temperature changes more drastic at higher latitudes. This translates into a longer growing season, greater precipitation in coastal areas and greater snow cover, but for a shorter period (McBeath 1984). The growing season is predicted to be approximately three weeks longer by the middle of the twenty-first century. Winter temperatures would increase by 7^{o}F and summer temperatures by 4^{o}F. Higher temperatures would be expected to increase decomposition rates and enhance nutrient cycling, possibly leading to greater productivity in aquatic systems. Additionally, a longer ice free period would allow productivity over a longer period.

B. Air Quality Monitoring Recommendations

Katmai's resource management plan made several recommendations in 1994 regarding air quality impacts. These recommendations primarily involved collecting data to assess baseline conditions in Katmai:

- establishment of a full IMPROVE sample site and monitoring sulfur dioxide
- ozone monitoring
- air quality monitoring in the park
- visibility photo documentation on a 5 to 10 year schedule
- study of acid precipitation on a 5 to 10 year schedule
- biomonitoring of sensitive plant species

The first recommendation is to establish an IMPROVE (Interagency Monitoring of Protected Visual Environments) sampling site to measure visibility-reducing pollutants within Katmai boundaries. Currently in Alaska, IMPROVE monitoring is taking place at Tuxedni Bay, located approximately 150 miles northeast of Brooks Camp; Simeonof, approximately 140 miles south of Katmai; and Denali Park, approximately 300 miles northeast of Katmai. The IMPROVE station at Denali has been operating since 1988. The IMPROVE stations at

Tuxedni and Simeonof were established in 2001. Data for all three sites are available from the VIEWS website (http://vista.cira/colostate.edu/views) and may be indicative of general regional trends in air quality. As noted above, at Denali, visibility has been relatively stable from 1995-2004. As of August 2006, there was not a long enough data record at Tuxedni or Simeonof to detect trends.

In addition to collecting IMPROVE data, an attempt could be made to identify the impact of local sources on Katmai's air quality. Polissar's paper noted the importance of local sources in Katmai's aerosol samples. The impact of local emissions on Katmai's air would require a more comprehensive analysis of climatology and emissions in the vicinity of Katmai. Park staff could consider documenting visibility impairment events (e.g., pollutant plumes, layered haze) with a camera.

Sulfur and chloride rich gases from Mt. Trident, Mt. Griggs, Mt. Mageik and Mt. Douglas contribute an unquantified amount of gases into the air each year. Separating local, natural sources of airborne constituents, such as these from long range, human caused emission, has not been attempted and poses some significant challenges.

Chapter 4: Watershed Characteristics

I. Katmai – One of the Largest Outdoor Laboratories in the World

Katmai has always provided fertile ground for explorers and scientists. The eruption of Novarupta first led National Geographic Society sponsored investigations in the Valley of Ten Thousand Smokes beginning in 1915 with Robert Griggs. Others later followed with the primary focus of their studies being the eruption site and ashflow. These early scientists contributed a great deal to our knowledge of this unique and wonderous environment newly created by the 1912 eruption and opened the door for others to follow. The earliest of the studies focused on water resources centered on the newly created ashflow sheet.

Thermal features in the Valley of Ten Thousand Smokes have held the interest of scientists since their discovery. Shipley (1919a) recorded some of the first temperature readings of fumarolic gases in 1917. Sayre and Hagelbarger (1920) in 1918 continued the measurements, and in 1919 Allen and Zies (1923) expanded the study to include the temperature and composition of the gases emitted from the fumaroles in the valley. They also estimated the volume of water given off as steam from the ash layer, located some hot springs in the lower valley that had not been previously observed and recorded the unusual flow characteristics of streams draining the valley. Later, Zies (1924) published interpretations of his own and other early explorers' measurements of fumarolic characteristics. He concluded that fumarolic activity would diminish eventually and that hot springs would be all that remained. Zies' predictions proved, largely, to be true. But many years would pass before interest in fumarolic activity was renewed.

By 1940 the NPS scientists had begun to recognize that they knew little about the resources of Katmai. Victor Cahalane, a biologist from Mt. McKinley National Monument, was sent to Katmai to make an inventory of the diversity of biological resources in the monument (Cahalane 1959). Later, in 1953-54 with a grant from the Office of Naval Research, studies known as the "Katmai Project" were initiated. A team of scientists including geologists, biologists, volcanologists, geomorphologists, archaeologists, a geographer, mammologist, parasitologist and an entomologist were included in the group. Among other findings, the group concluded that the primary vent of the 1912 eruption had been Novarupta and not Mount Katmai, as had been originally thought. As a result of these studies, research into other aspects of Katmai's natural history was initiated in later years although the focus of a great deal of research funding would continue to be on the Valley of Ten Thousand Smokes.

"Salmon limnology" became popular in the 1920s, and Bristol Bay streams may have benefited from this increased interest had the area been more accessible. Study sites in those early years were selected based on ease of access and to a large degree still are today. Brooks Lake, in particular, had captured the interest of scientists early on, but it wasn't as readily accessible as other areas. Consequently, new theories, equipment and methods were often tested elsewhere before being attempted at Brooks Lake.

The first "salmon limnology" project was conducted on Karluk Lake on Kodiak Island (Birge and Rich 1927, Juday et al. 1932). Assessment of the value of this lake as habitat for salmon was the primary focus of the research. Organic matter and nitrogen input from decaying salmon carcasses, bathymetry, temperatures and plankton studies were conducted (Hobbie 1997:48). Similar studies began in the Brooks River area in the 1940s.

Experimental limnology in Alaska began 20 years later at Bare Lake on Kodiak Island. A theory that declining runs of salmon and resultant lower phosphorus loading would decrease primary productivity was tested. Eventually it was believed that lower productivity would affect the size of the salmon smolt leaving the lake for the sea, affecting their ability to survive to adult stages (Hobbie 1997:48). Whole lake fertilization was used to test the theory: the first of its kind of study anywhere. It would be another 20 years before similar experiments were conducted in the Brooks River area.

Afognak Island was the site of another scientific first in limnology when nitrogen and phosphate sources to lakes were reported. Dugdale and Dugdale (1961) suggested that alder was the source of nitrogen to steep watersheds. Twenty-five years would pass before a similar study was conducted in the Brooks Lake drainage.

The first limnological studies were conducted in the Naknek drainage incidental to projects focused on fish. It was widely believed that the abundance of salmon was determined by conditions juvenile salmon encountered in their early life in freshwater environments. Although their growth in freshwater is only a fraction of what is achieved at sea, it is of great importance to their ability to survive to become a sexually mature adult (Foerster 1954). This focus on the spawning and rearing grounds for salmon led to numerous studies over the years of the factors that affect fish production. In fact, the desire to conduct research in the Naknek drainage led to the establishment of a research station on Brooks Lake in 1940. The Naknek drainage has been one of the primary producers of sockeye salmon in Bristol Bay, and Brooks Lake and Brooks River were considered one of the more highly productive areas in the drainage.

The U.S. Bureau of Commercial Fisheries, Auke Bay Lab (later to become the National Marine Fisheries Service) began studies in the Brooks River area, primarily on salmon, in the late 1940s. Following statehood (1959), the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game conducted additional work. In the spring of 1961 the Secretary of the Interior requested an increase of $1.5 million for an intensified salmon research program in Alaska (Burgner et al. 1969:407). Money was given to the Bureau of Commercial Fisheries Auke Bay Biological Laboratory. The Fisheries Research Institute at University of Washington was given about half the money; and between the two institutions, salmon research was conducted in the Nushagak, Kvichak, Chignik, Naknek, and Karluk watersheds.

University studies and other agencies initiated short projects eventually, primarily at the request of the National Park Service that resulted in some of the most focused limnological studies to date. These early fishery studies in the Naknek system focused on the four lowest altitude lakes: Coville, Grosvenor, Naknek and Brooks. These studies yielded a variety of limnological information scattered among agency reports.

Fisheries biologists in the late 1940s and 1950s recognized that the physical, chemical and biological characteristics of the lake and stream environments were intimately associated with the growth and survival of juvenile sockeye salmon. Their studies were designed to understand the effects of various components of the watershed on fish and consequently devised a more integrated approach to the question that included a broader range of scientific inquiry than was typically observed in such studies. The first integrated science studies were initiated on Brooks and Naknek Lakes in the 1950s under Merrell (1957) but were conducted by a consortium of professional expertise and PhD candidates from universities across the country. These investigations resulted in some of the first, and in some respects, the only, data on climate, fish, the physical, chemical and biological properties of lakes and streams, properties of substrate, aquatic invertebrates and aquatic vegetation. This early work was some of the first information gathered on biological communities in these lakes, which largely has gone unrepeated since. Some of the water chemistry data would later come into question as methodologies improved, but most of the basic findings of these studies have gone unchallenged since the late 1950s.

In 1957 Eicher and Rounsefell looked at the effects of lake fertilization from volcanic activity on the abundance of salmon (1957). They cited tree growth increases, chemical composition of waters, plankton volumes and size of young salmon migrating seaward as evidence of the effects of volcanic ashfall on the environment. They concluded that sporadic eruptions may play an important role in determining the abundance of sockeye salmon. Data supporting their conclusions were taken from fish studies on Kodiak and Afognak by Ball (1914), Evermann (1914) and Rich and Ball (1928); from vegetation studies by Griggs (1920) and Eicher and Rounsefell (1957); and data Eicher and Rounsefell collected on soil (nitrogen only) and water chemical composition. Plankton volume, total hardness, fixed CO_2, silica and nitrate nitrogen analyses were done on surface samples from Brooks and Naknek Lakes in 1947 and reported in the paper published in 1957.

Goldman (1960) studied plankton algae of Brooks Lake and completed some limited work on algal plankton of Naknek Lake and Becharof Lake in 1957 for a PhD thesis reporting nitrogen limitation on growth of planktonic algae. Later studies ultimately proved his conclusions to be false (LaPerriere 1993). He also discovered Naknek Lake had less planktonic primary production per unit area than Brooks Lake due to reduced light penetration. Samples were also collected for analysis of major anions and cations.

A detailed report on stream gradients, bottom composition, flow and changes in morphology from beaver activity in tributaries of Brooks Lake was made by Hoopes (1962). The ecology of the stream drainages and size of the drainage area are presented, as well, constituting the first descriptive survey of any Katmai drainages.

In 1962-63 limnetic zooplankton in four lakes in the Naknek drainage were sampled: Naknek, Grosvenor, Coville and Brooks. The study by K.E. Biesinger (1984) of the EPA office in Duluth Minnesota was the first of its kind in the park. Study results over the two year period indicated that species composition and relative abundance varied considerably among the four lakes sampled as well as between basins in the lakes.

Burgner et al. (1969) published the first limnologic data on two headwater lakes in the Alagnak drainage: Kukaklek and Nonvianuk Lakes. They conducted plankton algal and limnologic studies focused on the factors affecting productivity of sockeye salmon. Sample sites included six river systems on the Alaska Peninsula and five other systems in the vicinity.

Other sockeye salmon fishery investigations by Hartman et al. (1967 and 1972) provided additional data on water temperature and light penetration and some lake water chemistry. Wallace (1969) looked at food preferences of five species of fish, collecting both stomach contents of fish and samples of zooplankton for comparison.

At the request of the NPS, U.S. Geological Survey scientist Chester Zenone conducted an investigation of surface and groundwaters near developed sites and potential sites for future development. Brooks Camp, Bay of Islands, Three Forks Overlook and Margot Creek along the Valley Road were sampled. The test well samples collected along Brooks River are the first groundwater data collected in the park. He found adequate supplies in the areas visited, but iron concentrations exceeding public health standards at Brooks Camp and Bay of Islands.

Studies initiated in the early 1970s by fisheries biologist Michael Dahlberg produced some limited limnological information on Naknek Lake. The focus of Dahlberg's work was the feasibility of large scale hatchery production of sockeye salmon fry on several Alaska Lakes, including Naknek. Studies began in 1972 and ran through 1976, consisting of one sample site per lake.

In 1973 and 1975-76 temperature profiles, alkalinity, conductivity and pH measurements and water transparency by Secchi disk were taken biweekly from June to September at all samples sites. Solar radiation was measured in the spring, summer and fall. Samples were also collected and analyzed for phytoplankton standing crop as estimated by mg of chlorophyll *a* per m^3.

Surface water samples were analyzed for 14 elements in 1973. The number of spawning sockeye salmon was estimated from aerial counts throughout the Naknek River drainage. That year was one of the lowest returns of sockeye with only 2.5 million fish returning to all districts. Escapement into the Naknek River was estimated at 357,000 fish (Dahlberg 1972).

In 1975 and 1976, no chemical analysis of waters was done except for alkalinity, conductivity and pH. Zooplankton standing crop was measured, and a more intensive analysis of species collected was presented for Naknek River system lakes.

Savonoski Crater was the focus of geological and geophysical studies in 1964 (Muller and Ward 1966) and five years later by French, Muller and Ward (1972). The crater, partially filled by a circular lake, was first mapped in 1951. Geologists were primarily interested in the crater's origin and not in the lake itself. However, a topographic survey of the lake's bottom was constructed by Muller and Ward during their 1964 visit to the site.

Katmai Crater Lake provides a unique opportunity to study glacier/volcano interactions. Mount Katmai, which collapsed following the eruption of Novarupta in 1912, was the source of several large glaciers. Partial melting of the glaciers and consequent flooding of still hot ashflows produced unusual land forms and alterations of the ash. Post-eruption recovery of the glaciers provides the opportunity to study the dynamics of glacial mass balance.

The three glaciers that formed inside the crater following the collapse of Mount Katmai are also of scientific interest. Although the hydrologic budget and thermal state of the crater are poorly understood, they have a major effect on the dynamics of the lake and glaciers in the crater. Changes in the rate at which the lake is rising could indicate a surge in volcanic activity.

Rising lake levels and glacier development in the crater became the focus of research by Muller and Coulter (1957). Their report on field observations made in 1953 and 1954 includes inferred climatic conditions in the crater, a description of glacier growth and development and circumstantial evidence of lake level rise and temperatures.

During the first expedition to Katmai Crater in 1953, Muller and Coulter (1957) of the U.S. Geological Survey studied the Knife Creek Glaciers formed on the western slopes of Trident and Katmai volcanoes. They sought information on glacier activity following and produced by the 1912 eruption of Novarupta. Five ablation stakes were emplaced on Fourth Glacier in early July and rechecked in early September. Photographs and maps of the glaciers are included in the report.

In 1974-75, Roman Motyka (1977) resurveyed Katmai Crater Lake's surface elevation, collected water samples for geochemical analysis, took lake temperature measurements and observed the growth of the lake and glacier.

At the request of NPS, the Arctic Environmental and Data Center in Anchorage compiled information on the aquatic resources of the Naknek River drainage in 1978. NPS was interested in understanding the structure and functioning of the system to evaluate the potential effects of salmon enhancement projects proposed at the time, as well as other human induced manipulations of the aquatic system. The report by Buck et al. (1978) addressed NPS needs by: 1) conducting a thorough review of the literature available, which resulted in an annotated bibliography, 2) providing a narrative summary of knowledge about the Naknek River drainage, 3) developing graphic models designed to show the structure and processes of the ecosystem and, 4) identifying management options for assessing impacts to the ecosystem, as well as filling gaps in knowledge of the aquatic ecosystem.

State hydrologists Clay, Inghram and Carrick (1983) floated the Alagnak River in 1982, recording their observations as they moved along. They recorded, by reach, their observations of channel pattern, bed and bank material, width, depth at the deepest point, surface flow velocity and bank and channel stability. Some river discharge measurements were also taken. Their report on the trip included a travel diary and log of observations and a synthesis of information on the physical and climatic characteristics of the Alagnak River focusing on factors that affect the hydrological characteristics of the river. They provide an overview of what little hydrologic information there was available at the time and a mean annual and monthly range of steamflow using linear regression analysis.

From 1984 to 1986, A.J. Gunther, a PhD candidate lichenologist from the University of California at Berkeley, developed a preliminary nitrogen budget for Brooks Lake. Goldman (1960) had already concluded that Brooks Lake was nitrogen limited and Gunther assumed that any additional reduction in nitrogen input to the lake would adversely affect juvenile salmon growth and survival. Therefore, the study was directed toward quantifying the nitrogen inputs to the lake from all sources. At Brooks Lake rates of nitrogen fixation were estimated using the acetylene reduction technique and the biomass of nitrogen fixing lichens and alder in the Brooks Lake drainage determined using Landsat imagery and field reconnaissance. Stream discharge in Brooks Lake tributaries, the relative contribution of decaying salmon to the system and soil mineralization rates in the Brooks Lake drainage were also measured.

In addition to the Brooks Lake study, Gunther sampled other lakes in the Naknek and Alagnak drainages. The results were published in "A chemical survey of remote lakes of the Alagnak and Naknek River Systems, Southwest Alaska, USA" (Gunther 1992 and 1986). The paper reported on the chemical characteristics of Battle, Kulik, Kukaklek, Iron Springs, Pirate and Nonvianuk in the Alagnak drainage and Murray, Hammersly, Coville, Idavain, Tony Malone and Pecker in the Naknek drainage. His objectives were to sample as many of the lakes as possible where no previous analysis had been done. Of particular interest were the upper lakes of the Alagnak drainage, which he believed to be particularly vulnerable to the effects of acid deposition due to the area's granitic parent material. Analysis consisted of measurements of alkalinity and pH, major anions and cations and trace metals.

During the summers of 1988 and 1989, Will Cameron collected baseline information on physical, chemical and biological characteristics of Surprise Lake, a caldera lake, in Aniakchak National Monument (Cameron 1993). Objectives of the study were to describe the nature and magnitude of perturbations associated with warm springs entering Surprise Lake and inlet streams. To better understand the influences these warm springs had on Surprise Lake, Cameron sampled four lakes in Katmai National Park in 1989 for comparison: Katmai and Kaguyak Crater Lakes and Brooks and Naknek Lakes. Data was of a limited nature with samples being collected over the course of three weeks. Cameron measured temperature and Secchi disk depth and collected samples down to 98 ft (30 m) for analysis of plankton communities at all four lakes. Surface water chemistry at one meter was analyzed at the two crater lakes as well.

Horton (1994) studied jet boat effects on egg mortality and spawning behavior of adult fish on American Creek in 1992 and 1993. Both field and laboratory analysis were conducted. Pressure, water depth and substrate movement were the variables selected for evaluating jet boat effects. In the field, known numbers and developmental stages of embryos were held in artificial redds while boats of various sizes, hull configurations and engines were passed over the top. The study evaluated the mechanisms by which mortality may occur under the conditions available on American Creek.

In 1990, LaPerriere (1996) initiated a study of water quality in the 10 largest lakes of Katmai. Some limited sampling of major inlets and outlets of the lakes was conducted as well with an emphasis on the inlets of Brooks Lake, which were sampled each year between 1990 and 1992. A profile of conditions in the lakes was taken for water chemistry analysis, algal biomass and net hauls for zooplankton samples. Nutrient bioassay experiments were conducted on five lakes in 1992 and 1993, resulting in a new theory on limiting factors in Katmai lakes. LaPerriere also refuted some of the findings of earlier studies on nitrogen limitation (Goldman 1960) and acid vulnerable lakes (Gunther 1992).

In the course of studying fumarolic alteration in the Valley of Ten Thousand Smokes, Terry E.C. Keith initiated a water sampling program to collect and analyze waters entering and draining the 1912 deposits. Her purpose initially was to collect background geochemical data on cold water leaching of the 1912 deposits (Keith et al. 1992:209). However, soon after the effort began, thermal springs were discovered and the emphasis of the study turned to identifying the source and significance of the springs. Before Keith's work, no chemical data on waters from the Valley of Ten Thousand Smokes region had been reported.

Keith's data on waters in the Valley of Ten Thousand Smokes date back to 1979. Physical and chemical properties of the waters of River Lethe, Knife and Windy Creek, as well as the cold and thermal springs, constitute one of the longest standing water resource databases in the park. While a number of other data sets have been generated from past studies of park lakes and streams, Keith's work provides a unique look at an area where no generalities from other places in the park will apply. These data contribute to our understanding of a young igneous environment as well as to our knowledge and understanding of aquatic ecosystems in Katmai.

A synoptic investigation in the Cook Inlet watershed, as part of the National Water Quality Assessment Program (NAWQA), was conducted in 1998 by the U.S. Geological Survey, including the Kamishak River in Katmai (Frenzel and Dorava 1999). Samples of stream water, streambed sediments and fish tissue (Slimy Sculpin) were collected for chemical analysis. Field pH, conductivity and dissolved oxygen measurements were made on site. Biological (algae and benthic macroinvertebrates) and geomorphic information were also collected at each site. Subsequent analysis of samples collected from the Kamishak River in 1998 resulted in a Cook Inlet regionwide description of the levels of organic compounds and trace elements in streambed sediments and fish tissues (Frenzel 2000).

In 1996 the NPS and U.S. Fish and Wildlife Service entered into an interagency agreement specifically to conduct a baseline study of potential petroleum hydrocarbon contamination in six sites in the park. In 1996 and 1997 Kulik Lodge, Grosvenor Lake Lodge and the Alagnak Wild River were sampled. In 1997 additional samples were collected from Naknek Lake and Brooks Lake near Brooks Camp and Lake Camp. Water samples were analyzed for purgeable aromatic compounds, including benzene, toluene, ethyl benzene and xylene. Sediment samples were analyzed for nC_{10} – nC_{34} aliphatic hydrocarbons and for 44 polynuclear aromatic hydrocarbons. Results of the study are reported by Johnson and Berg (1999) of the U.S. Fish and Wildlife Service Environmental Contaminants Program in Anchorage.

With a desire to quantify the controls on river incision rates, Whipple, Snyder and Dollenmayer (2000) from Massachusetts Institute of Technology looked at the rates of incision of the Ukak River in 1997. The 1912 eruption of Novarupta filled the valley with ash, forcing the Ukak River to carve a new bedrock channel. This provided a unique opportunity for scientists to measure the precise rate of incision over a known time period without the vagaries of long term geologic uncertainties such as climate change and exact timing of events.

Concerned about increased rates of erosion on the Alagnak River, the NPS funded a study of channel stability and water quality. In the report Curran (2003) concluded that measurements of bank erosion processes, particularly the development of a wave-generated shelf, and visual observations suggest that boat wakes increase bank erosion rates, especially at high, exposed banks. Analysis of aerial photography and other assessments of bank erosion processes indicate that this increase in erosion rates has not altered the mechanisms of channel change, which in the past 50 years have included complex, compound channel changes and meander migration.

A majority of the research to date has been conducted in the Naknek and Alagnak drainages. Little research has occurred along the coast, and virtually no data points exist for waters in the Egegik River drainage inside the park.

Katmai remains one of the finest natural laboratories in the world, providing outstanding examples of intact ecosystems relatively undisturbed by humans. But it is interesting to note that although the methods for freshwater research have changed through time, the difficult logistical problems and increased funding requirements inherent in Alaska research have not. Modes of transportation have improved, but access is as difficult and costly as it was almost 100 years ago when the first freshwater research was conducted in Alaska.

The sections that follow summarize the information so diligently collected in these projects through time. Although not comprehensive, these descriptions will highlight the characteristics and features of Katmai waters that make them both unique and valuable.

II. Surface Water Resources

A. Watershed Descriptions

Katmai lies entirely within the Naknek, Kvichak and Egegik watersheds and two coastal river basins that primarily drain the Aleutian Range mountains to the Shelikof Strait and Cook Inlet (a set of three water sample station maps follow this page). In these watersheds is a great diversity of river and lake types, which will be described in sections to follow.

The Naknek River drainage is the largest drainage basin in Katmai. Seventy-three percent, 2,660 mi^2 (6,889 $km^{2)}$ of the 3,640 mi^2 (9,428 km^2) drainage is located in Katmai's boundary (National Park Service 1997:26). The Naknek River flows approximately 35 miles (956 km) from its outlet in Naknek Lake to Bristol Bay and drains seven major lakes: Naknek, Brooks, Coville, Grosvenor, Idavain, Murray and Hammersly in the park. The Naknek River is a major producer of sockeye salmon with total runs averaging 5.0 million from 1983-1992 (Crawford and Cross 1995). Fish are harvested in a commercial gill net fishery in Bristol Bay by sport and subsistence fishers in Naknek River and sport fishers in Katmai National Park and Preserve.

The Kvichak River basin is 60 miles (97 km) wide and extends 170 miles (274 km) northeastward from the northeast tip of Bristol Bay to the northwest slopes of the Aleutian Range (U.S. Department of the Interior 1952). This basin contains two large lakes located outside of the park's boundary: Lake Clark (143 mi^2 / 370 km^2) and Lake Iliamna (1,115 mi^2 / 2,888 km^2), the largest lake in Alaska. Katmai occupies only a small portion of this larger watershed, which includes the Alagnak River.

The headwaters of the Egegik River basis are located in the southwestern area of the park and drain west into Bristol Bay. Four headwater creeks contribute flow to the King Salmon River and Kejulik River, which drain into the Egegik River outside of the park boundary. The Egegik River basin extends from within five miles of the Shelikof Strait coast to Bristol Bay and is approximately 40 miles (64 km) long (U.S. Department of the Interior 1952).

The Katmai coast extends more than 400 miles (644 km) from Kamishak Bay to Cape Kubugakli following the rugged coastline of Shelikof Strait. The park encompasses the entire watersheds of its coastal streams, with the exceptions of Little Kamishak River and Strike Creek. With its narrow fjords, island dotted bays, sandy beaches, and rocky headlands; the coast is a complex ecosystem that includes river systems, marshes, beaches, intertidal zones, estuaries and coastal uplands. The park includes all islands within five miles of its shore.

The coast has two distinct watersheds: the North and South Coastal Basins. The North Coastal Basin includes a crater lake on Mount Douglas and the Kamishak and Douglas Rivers. Rivers drain to the north into Kamishak Bay.

The South Coastal Basin drains into Shelikof Strait. It contains several crater lakes and Dakavak Lake along with numerous rivers and streams.

The Gulf of Alaska coastline is located at the contact between the Pacific and North American tectonic plates. It is a geologically unstable zone affected by frequent earthquakes, crustal movements and volcanic eruptions. Glacial advances and retreats contribute to the physical dynamics of the region as well. As a result of these processes, sea levels change continuously at time scales ranging from the instantaneous during earthquakes to the gradual changes that accompany isostatic rebound following deglaciation (Mann et al. 1998:119).

As a result of these physical processes the trend along the Katmai coast has been toward uplift. This trend is evidenced by the number of archaeological sites in positions away from the shoreline. Crowell and Mann (1996:26) investigated sea level history along the Katmai coast, looking at terrestrial peat deposits in what is now the intertidal zone and archaeological sites on raised storm berms. Data suggest that relative sea level was at least 4 ft (1.25 m) lower than present 10,000 years ago, followed by higher than present levels that peaked about 7000 BP. Sea level then declined to somewhat lower than present, then remained stable until rising slightly in the last 200-300 years (Crowell and Mann 1996:26). Peat deposits up to 4,000 years old are now about 1.5 ft (0.46 m) below sea level due to the recent rise.

Crustal deformation associated with the 1964 earthquake was more extensive than any known deformation related to other quakes. Notable tectonic changes in land level occurred over an area of between 70,000 mi^2 (181,299 km^2) and 110,000 mi^2 (284,899 km^2). The amount of subsidence averaged 2.5 ft (0.76 m), with a maximum subsidence of 7.5 ft (2.3 m) measured along the southwest coast of the Kenai Peninsula.

Measurements of sea level indicators in the vicinity of Shelikof Strait and Kodiak Island right after the earthquake suggest that there was slight land uplift in the vicinity of Cape Douglas, but no measurable uplift or subsidence along the Katmai coast south of the cape (Plafker 1969). However, analysis of peat deposits by Crowell and Mann (1996:26) suggest that the slight rise in sea level in the last 200-300 years may be partially attributed to subsidence in the 1964 earthquake. Because of the complex interplay of tectonic, isostatic, and global eustatic effects in the Gulf of Alaska, sea level histories must be developed for fairly localized areas to be useful. In fact, Mann et al. (1998:112) found that sea level often varies markedly between sites only 150-300 ft (46 – 91 m) apart due to tectonism and the isostatic effects of glacier fluctuations.

B. Lakes

Katmai contains the largest freshwater lake in the national park system - Naknek Lake - and some of the largest lakes in Alaska. Only Iliamna and Becharof (437 mi^2 /1,132 km^2) in Alaska are larger than Naknek Lake (235 mi^2 / 609 km^2). Large lakes in Katmai make up approximately 8% of the park's surface area, and most are found at low elevations (< 1000 ft msl) along the northern slope of the Aleutian Range.

Igneous rocks intrude older sedimentary formations in the park, creating lake basins of heterogeneous parent materials (Gunther 1992). The lake basins in the region were deeply carved by glaciers during several advances between 8,000 and 25,000 years ago. The deepest recorded lake depth is 530 ft (162 m) in the Iliuk Arm of Naknek Lake. Lakes become much shallower toward the west as a result of glacial deposition, and terminal moraines enclose the western ends of many large lakes in the park.

Katmai's lakes are of several types:
1) small lake complexes on morainal and old marine sediment landscapes occupying areas west of the range,
2) moderate to large glacial dam lakes,
3) very large morainal depression lakes serving as headwaters to floodplain rivers in the Bristol Bay lowlands,
4) isolated caldera/crater lakes, and
5) small, isolated lakes in flat, poorly drained morainal landscapes.
Many lakes, such as the Naknek, are fed by glacial meltwater often through an extensive river system while isolated, flat, morainal lakes are recharged through snowmelt.

The variety of basin forms and drainage patterns make the watershed and lake characteristics of the Naknek system particularly interesting. The spectrum of nursery lake types – both physical and chemical – found along the Alaska Peninsula is present in one river system. The spectrum of biological types is also nearly complete in this drainage (Bureau of Commercial Fisheries et al. 1964:18).

The Naknek drainage is the largest in Katmai. The upper 2,660 square miles (6,889 km^2) 73%) of the 3,640 mi^2 (9,428 km^2) drainage are encompassed in the park. Major lakes contained in the Naknek River drainage are presented in Table 1 and shown on the physiography map in Appendix D.

Table 1. Major lakes in the Naknek River drainage of Katmai National Park and Preserve (Bureau of Commercial Fisheries et al. 1964:16 and Burgner et al. 1969:409).

Lake Name	Area (km^2)	Maximum Depth (m)	Altitude (m)	Lake Name	Area (km^2)	Maximum Depth (m)
Naknek	609	173	10	Idavain	11	69
Brooks	75	79	19	Hammersly	9	No data
Grosvenor	73	107	31	Jo-Jo	7	No data
Coville	31	53	33	Murray	2.6	No data

Lakes Coville and Grosvenor and Naknek Lake form a chain of lakes that drains into the Naknek River. Coville has the shallowest basin at a depth of 62 ft (19 m), receiving its water from snowmelt and runoff via the 50-mile (80 km) American Creek. It serves as a settling basin for the deep glacier-scoured Grosvenor Lake, downstream of Coville. The Iliuk Arm of Naknek Lake is also a deep, glacier scoured basin receiving waters from Grosvenor Lake, the glacier fields in the Savonoski River drainage and ashflows of the Valley of Ten Thousand Smokes via the Ukak River.

As a result of the heavy load of allochthonous materials from the Ukak River water quality and transparency in the Iliuk Arm of Naknek Lake, are profoundly different than other basins in the drainage (physiography map following this page). In contrast, Brooks Lake is a glacier scoured basin affected only by snowmelt and runoff from low mountains and extensive tundra. The water in Brooks Lake is extremely clear. Snowmelt and runoff from wet tundra supply water to the North Arm of Naknek Lake. The west end of the lake is relatively shallow and separated from the North Arm by a moraine (Table 2).

Table 2. Basins of Naknek Lake (Burgner et al. 1969).

Basin	**Area (km^2)**	**Depth (m)**		**Volume (km^3)**	**Shoreline Development**
		Maximum	**Mean**		
North Arm	182	167	63	11.52	2.07
Iliuk Arm	94	173	96	9.00	1.71
South Bay	32	71	27	.86	1.41
West End	302	80	13	3.77	1.82
Total	610			25.15	

These lakes range from 33 to 1,699 ft in elevation (10 to 518 m) (Murray Lake) and from 1 mi^2 to 235 mi^2 (2.6 km^2 to 609 km^2) in area, totaling almost 309 mi^2 (800 km^2). Maximum depths in the lakes that have been mapped range from 174 ft to 568 ft (53 m to 173 m) (Bureau of Commercial Fisheries et al. 1964:16, Burgner et al. 1969:409).

The Alagnak River drains an area of 1,390 mi^2 (3,600 km^2). Lakes and ponds cover 12% of the basin's area. Major lakes contained in the Alagnak drainage are presented in Table 3. Lakes in the drainage lie between 630 ft and 833 ft (192 m - 254 m) in elevation and vary in size from 5 mi^2 to 68 mi^2 (13 km^2 to 177 km^2).

In the Aleutian Range lie one caldera (Katmai) and four crater lakes: Kaguyak, Martin, Mageik and Douglas. Katmai is technically a caldera lake but was named a crater lake since it was formed as a result of the 1912 eruption of Novarupta. Kaguyak Crater Lake was formed in recent prehistoric times. Katmai and Kaguyak are the two largest crater lakes in the park. Mt. Douglas and Mt. Mageik were formed during the Holocene, and Mt. Martin is undated. Another apparent crater lake - Savonoski Crater Lake - lies on a lower ridge west of the range near the confluence of the Rainbow and Savonoski Rivers. All but Savonoski and Kaguyak have some form of thermal manifestation associated with the lake. None of the crater lakes has outlet streams.

Table 3. Major lakes in the Alagnak River drainage of Katmai National Park and Preserve (National Park Service 1994 and Burgner et al. 1969:409).

Lake Name	Area (mi^2)	Elevation (ft)	Lake Name	Area (mi^2)	Elevation (ft)
Kukaklek	67.5	802	Pirate	0.8	1148
Nonvianuk	51.5	626	Spectacle	0.8	1000
Kulik	10.7	659	Mirror	0.6	1400
Battle	5.0	833	Iron Springs	0.3	1900

There are fewer lakes located along the Shelikof Strait coast. These coastal lakes are much smaller than those found in the park north of the Aleutian Range. Heard et al. (1969) believes that most lakes along Katmai's coast are glacial in origin and are relatively deep for their size. Dakavak Lake is the largest coastal lake, approximately 2.8 miles (4.8 km) long and 0.6 miles (1.0 km) wide for an area of 1.7 mi^2 (4.4 km^2) with a depth greater than 69 ft (21 m).

There are no large lakes in the Egegik River drainage in the park.

C. Rivers and Streams

The largest streams in the Naknek drainage are the Naknek, Grosvenor, Savonoski, Rainbow, Ukak and Brooks Rivers and American, Hardscrabble, Ikagluik, Margot, Idavain and Headwaters Creeks. A six-foot-high falls is located about mid-river on the Brooks River where water flows over a fault. The falls does not provide an effective barrier to fish passage. A higher waterfall, about nine miles up Idavain Creek, effectively isolates Idavain Lake from the Naknek system. A high waterfall on Margot Creek also isolates this creek's upper reaches to fish migration.

The Ukak River drains the Valley of Ten Thousand Smokes and is fed by the River Lethe, and Knife and Windy Creeks. Both the River Lethe and Knife Creek flow through the 1912 ashflow through an incised gorge of up to 82 ft (25 m) deep, accumulating a high volume of

water and sediment by the time they reach the Ukak River. Mid-valley springs issue from vertical joints in the ash sheet, approximately 7 – 10 ft (2 - 3 m) above the rivers, providing another source of water to these streams. The relatively clear Windy Creek is in contact with the edge of ashflow for only a short stretch before meeting the Ukak and therefore contributes little sediment. The Ukak downstream of the confluence of the three streams is heavily laden with ash by the time it empties into the Iliuk Arm of Naknek Lake.
The largest streams located in the Alagnak River drainage in Katmai are the Alagnak (Branch), Nonvianuk, Kulik and Battle rivers and Nanuktuk, Moraine, and Funnel creeks.

The Alagnak River is a designated Wild River and one of the major tributaries in the Bristol Bay region. It originates at Kukaklek Lake and its main tributary, the Nonvianuk River, at Nonvianuk Lake. Headwater elevations range from 984 ft to 5,151 ft (300 m to 1,570 m) along the eastern edge of the basin. Snowfields and glaciers comprise less than 1% of the basin. Long, narrow lakes entrap much of the upland generated sediment load, resulting in a clear water flow in the Alagnak. The Alagnak River flows westward to the Kvichak River along its 74 mile (119 km) course, draining an area of 1,390 mi^2 (3,600 km^2), meeting the Kvichak about 10 miles (16 km) upstream of Kvichak Bay.

The first 20 miles (32 km) of the river are steepest, falling roughly 17.8 ft/mi (3.4 m/km). After the confluence of the Nonvianuk and Alagnak Rivers the remaining 54 miles (87 km) are more gradually sloping, averaging 7.8 ft/mi (1.5 m/km) (Clay, Inghram, and Carrick 1983:3). The Nonvianuk River measures 11.5 miles (18.5 km) long from the lake to the confluence with the main stem of the Alagnak. The average gradient is 15.2 ft/mi (2.9 m/km) (Clay, Inghram, and Carrick 1983:3).

Contact, Angle and Takayofo Creeks are the largest streams in the Egegik drainage. They flow west into the King Salmon River. The headwaters of the Kejulik River lie in the park's southeastern end. The river drains into Becharof Lake in the Becharof National Wildlife Refuge.

Along Katmai's coast in the North Coastal Basin, the Kamishak River, Little Kamishak River, Strike Creek and Douglas River flow into Kamishak Bay located in Cook Inlet. Numerous named (e.g., Katmai River, Alagogshak Creek and Big River) and unnamed streams flow down the characteristically short, steep drainage along the Shelikof Strait coastline in the South Coastal Basin (National Park Service 1994). The only major lake along the coast is Dakavak Lake at 1.9 mi^2 (4.9 km^2) (National Park Service 1994:39).

A number of the coastal streams flow from massive glaciers of the Aleutian Range and can carry a load of glacial flour. Several streams are also heavily laden with volcanic ash. One example of this latter stream type is the Katmai River, which was impacted by volcanic ash deposited from the 1912 eruption of Novarupta. The heavy silt loads from the ash-laden watershed transformed this single channel system into a three-mile-wide braided river. Its channels run through soft ash laden mud, terminating at the sea where a mixture of ash and pumice sit 2-5 ft (0.6 – 1.5 m) deep. The streams that empty into the numerous bays along the Shelikof Strait coastline range from 2.9-19.3 miles (5 – 31 km) long.

D. Wetlands

Alaska contains approximately 175 million acres (70.8 million ha) of wetlands or 63% of the total wetland acreage in the United States (Hall 1994). Wetlands cover 43.3% of Alaska's surface area in comparison to only 5.2% in the contiguous 48 states. U.S. Fish and Wildlife Service (USFWS) estimates that Alaska has lost 200,000 acres (80,937 ha) of wetlands, or less than one tenth of one percent of the state's original wetland acreage. In Alaska, the majority of wetland areas lost have been around urban areas, in farming zones and where surface mining has occurred. This suggests that almost all of the wetlands in Katmai are undisturbed. In comparison, the contiguous 48 states have lost an estimated 53% of their original wetland acreage. In California, Illinois, Indiana, Iowa, Kentucky, Missouri and Ohio more than 80% of wetlands have disappeared (Hall 1991).

The highest concentration of wetlands on the Alaska Peninsula occur on the Bristol Bay side where in places more than 45% of the land surface is classified as wetland (Hall and Frayer 1994). Wetlands in this region are maintained by permafrost, heavy rainfall, glacial melt water, river flooding, beaver activity, snowmelt, impermeable soils and bedrock. The physiography map in Appendix D shows just how prevalent small lakes and ponds are west of the Aleutian Range.

Katmai contains extensive wetlands that include marine, estuarine, riverine, palustrine and lacustrine environments (estimates exceed one million acres). The park's wetlands represent transitional environments, located between uplands and deepwater areas. Flora in 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, infiltration and thermokarst activity.

The NPS uses the Classification of Wetlands and Deepwater Habitats of the U.S. (Cowardin et al. 1979) in identifying and delineating wetlands. According to the Cowardin classification system, 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).

However, all suspect wetlands on NPS properties are delineated using the U.S. Army Corps of Engineers 1987 Wetlands Delineation Manual. By using the Cowardin classification system to define wetlands on NPS property, parks can have wetlands that would not be typically defined according to the 1987 manual. Where chemical factors such as hypersalinity or physical factors do not allow plants/soils to establish is an example of a single-attribute wetland. Thus, if an inland site is naturally devoid of plants and soils due to extreme salinity, the wetland is delineated using only one of the hydrology criterion.

There are a number of tundra ponds, beaver ponds, and small tundra lakes along the park's western boundary. These bodies of water (or lacustrine wetlands if they are shallower than 2 meters in depth) are shallow, frequently contain submerged and emergent aquatic vegetation and occasionally have no surface connections with major stream systems (Heard et al. 1969). The Savonoski River/Bay of Islands area and the Margot Creek drainage, also located in the park's interior, contain extensive marshes and ponds.

Tidal wetlands are areas of very high habitat value for fisheries, waterfowl and bears. Along the park's coast, marine and estuarine wetlands are common and often contiguous with riverine, palustrine and lacustrine wetland systems (National Park Service 1994).

E. The Coastal Margin

Katmai's boundary includes nearly 400 miles (644 km) of rugged coastline of the Shelikof Strait and Cook Inlet on the Gulf of Alaska. Islands located within five miles of the coast are also administered by the park. The coast contains portions of two drainage areas: the North Coastal Basin draining into Kamishak Bay and the South Coastal Basin flowing toward Shelikof Strait.

The Katmai coast is a geomorphically diverse coastline with large tracts of rocky exposed shoreline backed by mountains. Strong currents combined with large tides and directionally variable high winds create a rapidly changing, storm-wave environment. The Alaska coastal current travels southwestward down the Shelikof Strait (Royer et al. 1990) at speeds ranging from 0.66 ft/s (20 cm/s) in early summer to 3.3 ft/s (100 cm/s) in the fall (Reed and Schumacher 1986). Maximum daily high tide ranges from 7 – 20 ft (2-6 m) in Shelikof Strait (Brower et al. 1977). Although maximum wave heights reach 23 – 30 ft (7 - 9 m), the mean between October and March lies between 10 and 13 ft (3 - 4 m) and 3 and 7 ft (1 - 2 m) during summer months (Wilson and Overland 1986).

Cook Inlet receives immense quantities of glacial sediment from the Knik, Matanuska, Susitna, Kenai, Beluga, McArthur, Drift and other rivers. This sediment is redistributed by intense tidal currents. Most of this sediment is deposited on the extensive tidal flats or is carried offshore through Shelikof Strait and eventually deposited in the Aleutian trench beyond Kodiak (Arctic Environmental Information and Data Center 1974:109). Powered by the Alaska Coastal Current, sediments of the Copper River drainage drift into lower Cook Inlet and Shelikof Strait where they eventually settle to the bottom. Recent survey results of the Minerals Management Service (MMS) indicate that about half of the bottom sediments in Shelikof Strait are from the Copper River in Eastern Alaska (Prentki 1997). Longshore transport of sediment in Cook Inlet is generally up the inlet, although Kamishak, Tuxedni and Kachemak Bays are areas where this trend is reversed.

In National Park Service (1994) identified 11 coastline classifications for Katmai:
1) exposed rocky headland,
2) sheltered rocky shore,
3) wave-cut platform,
4) gravel beach,
5) mixed sand and gravel beach,
6) coarse-grained sand beach,
7) fine/medium-grained sand beach,
8) exposed tidal flat,
9) exposed tidal flat / moderate biomass,
10) sheltered tidal flat, and
11) marsh.

The Katmai coastline was mapped in 2003 as part of the larger Shore Zone project (Harper and Morris 2005), and includes 31 of the 34 possible shore type categories. Many factors contribute to the complexity of the coastline including major substrate type and wave exposure. Within these major substrate types, the Katmai coastline is classified as rock - 8%, rock and sediment -37%, sediment -34%, wetland/estuary - 19%, and current dominated - 2%. Wave exposure influences both physical and biological processes along the coastline. The majority (60%) of the coastline is characterized as low energy (semi-protected, protected and very protected). Only 2% of the coastline is classified as exposed with the remaining 37% classified as semi-exposed (Harper and Morris 2005).

Shoreline modification has been documented at two shorelines areas at Kukak in Kukak Bay within the park. One area contains landfill on 42.7 ft (12.7 m) of shoreline and the other area contains rip-rap representing 52.2 ft (15.6 m) of shoreline. Together these modifications represent less than 1% of the Katmai coastline.

Through detailed analysis of aerial photos and site visits, biotic assemblages were mapped based on the physical and biological attributes of the coastline. These biotic assemblages are described using BioBand distribution (Harper and Morris 2005). Biobands are easily recognized distinct visual signatures consisting of assemblages of attached epibenthic biotic. Biobands may be characterized by a single species or by co-occurring species. Due to its geomorphic complexity, 17 Biobands have been identified along the Katmai coast. *Alaria* and splash zone/*Verrucaria* Biobands are associated with the greatest length of shoreline, 271.3 mi (436.6 km) and 262.8 ft (422.9 km), respectively. Dragon kelp is the least frequently occurring Bioband, only distributed along 4.7 mi (7.6 km) of shoreline.
A variety of aquatic biota (i.e., arthropods, mollusks, echinoderms, fish, etc.) are associated with these different coastal environments, which support both aquatic communities and terrestrial species along Katmai's coast, including one of the park's biggest visitor attractions, the brown bear (*Ursus arctos*).

III. Characteristics of Katmai Waters

Brooks Lake has been the subject of numerous fisheries investigations and is consequently one of the most studied lakes in the park. Data for the Naknek drainage are far greater in time, diversity of data collected and number of sample sites than other drainages in the park. In fact, there are no data for that portion of the Egegik drainage in the southern portion of the park and very little for the coastal drainages.

Maps in Appendix D graphically show where water sampling has occurred and the source of data reported. An inventory and limited evaluation of water data for Katmai was published by the National Park Service Water Resources Division (National Park Service 2001a) and serves as a good starting point for those interested in water resources of the park. In the sections to follow is a synopsis of what has been learned about freshwater environments in Katmai primarily in the past 50 years.

A. Physical Properties

1. Lakes

a. Morphometry. The shape of a lake basin affects many characteristics of the lake itself. Shelves or bays can essentially create a lake composed of many smaller lakes whose characteristics differ. Therefore, it is important to have bathymetry for all lakes that are subject to study. In Katmai only Lakes Grosvenor and Coville and Naknek, Brooks, Katmai Crater and Idavain Lakes have been bathymetrically mapped (LaPerriere 1997:90, Burgner et al. 1969:411). These lakes all are in the Naknek drainage.

Katmai Crater Lake was mapped and the lake elevation determined during Griggs's second expedition in 1917. It was the first bathymetric map available for a park lake.

Brooks Lake was mapped in 1957 by Merrell and Hartman as part of a comprehensive scientific study of fish populations and factors affecting their growth and survival (Merrell 1957:113-116 and 1964:49). A portable fathometer was used to chart bottom contours across multiple transects using a USGS 1:62,500 quadrangle as the base map. In 2002 the map was georeferenced and digitized for use in GIS applications.

The North and Iliuk Arms of Naknek Lake and Lakes Coville and Grosvenor were mapped by staff of the Auke Bay Lab in the 1960s (Bureau of Commercial Fisheries et al. 1964:15) and were published in the PhD thesis of Wallace (1969:9). The 1958 depth soundings in portions of Naknek Lake produced the first look at the basin characteristics of this large lake (Hartman 1958:93). Depths exceeding 405 ft (652 m) were recorded in Iliuk Arm.

b. Trophic Status and Thermal Stratification. The larger lakes in Katmai are oligotrophic (low in nutrients). Typical of an oligotrophic lake, dissolved oxygen profiles are orthograde, meaning the percent of oxygen saturation is more or less 100 percent with increasing depth (Merrell 1957:126, LaPerriere 1996 and 1997:92). The main influence on dissolved oxygen levels is temperature, and with the small temperature gradient in Katmai lakes waters are saturated at depth.

LaPerriere (1997:92) classified these lakes as discontinuous, cold polymictic or able to circulate during the ice-free season due to frequent winds from coastal storms. The result is thermal instability that allows summer heat to mix deep into these lakes. The mixing conditions and heat allow these lakes to be important producers of fish, particularly juvenile sockeye salmon.

Generally lakes in the temperate zone stratify into distinct layers that are resistant to vertical mixing. Upper lake levels generate the most photosynthetic activity and are the most productive biologically while lower levels accumulate nutrients and are generally colder and less oxygen rich. In areas outside the temperate zone (such as arctic and subarctic regions of Alaska), lakes are generally only weakly stratified (Perry and Vanderklein 1996:232), and high wind situations can cause a lake to mix vertically. Mixing of the highly productive surface waters of a lake with the nutrient rich lower layers allows surface waters to remain productive. Because of the high wind and weak-to-nonexistent stratification of large lakes in Katmai, vertical mixing of waters is common.

Although temperatures varied from year to year, temperature profiles from 1990-92 illustrate the lack of persistent summer stratification in the large lakes (LaPerriere 1996:22). During the warmer summer months, Buck et al. (1978:66, 71) reasoned that thermal stratification seldom develops due to winds, which actively mix these lakes. LaPerriere (1996:34) went further to say that stable summer stratification of Katmai lakes is probably an occasional but rare occurrence. This theory was first forwarded by Ellis (1974:3). Based on research from 1961-64, he concluded that thermoclines occasionally occur but last only a few days. During the course of a three year limnologic study, LaPerriere (1997:92) found evidence of only one thermocline (defined as the plane of maximum rate of decrease of temperature with respect to depth – generally a change of >1^{o}C per meter [Wetzel 2001]) in Lake Coville in July 1992. However, a thermocline was not observed at a different station in the lake on the same day. Such thermally unstable lakes contain more summer heat than similar lakes that stratify. Stratified lakes at a similar latitude would maintain a cold temperature ~39 ^{o}F (4^{o}C) hypolimnion even during the warm summer months. Temperatures at the bottom of Battle Lake measured 49 ^{o}F (9.5^{o}C) in 1990, and the depths of Nonvianuk Lake measured 55 ^{o}F (11^{o}C) that year (LaPerriere 1996 and 1997:92). Higher heat loads and mixing could be responsible for higher growth of aquatic organisms and fish in the Katmai lakes.

Synoptic temperature surveys of Brooks Lake were conducted by Hartman in 1958 and an annual heat budget of 26,580 g-cal/cm^2 was calculated (1958:96). Later Dahlberg (1972) and others recorded temperatures from several basins in Naknek Lake and Brooks Lake. Highest surface temperatures were reached in mid-August.

<u>c. Seiches</u>. Periodicity and nodality of seiches in Brooks Lake were investigated in 1958. A seiche is a surface wave which is commonly caused by wind-induced tilting of the waters surface (Wetzel 2001). The amplitude of three seiches measured was quite low - between 0.03 and 0.06 ft (0.09 – 0.06 m) (Hartman 1958:107). In contrast, lake level rise due to wind action was measured at 0.4 ft (0.12 m).

The type of seiche observed on Brooks Lake probably occurs on most large lakes in the park and would be most likely characterized as a surface seiche. Except for the example above, observations of a seiche in Katmai lakes have not been recorded.

d. Optical Properties. Large lakes are primarily clear water with the exception of the upper end of Naknek and Kulik Lakes where glacial flour and ash (in the case of Naknek Lake) enter from upper inlets. The depth of the euphotic zone (where light is sufficient for photosynthesis to occur or approximately the depth of 1% light) is important in terms of lake productivity and reduced in glacial or ash laden waters and in stained lakes. Salmon smolt production has been shown to be highly correlated with the euphotic volume of Alaska lakes (Koenings and Burkett 1987).

The Iliuk Arm of Naknek Lake receives turbid, glacial and pumice/ash laden waters from the Savonoski and Ukak Rivers. LaPerriere (1996:71) measured turbidity in Savonoski and Ukak Rivers in 1990 at 123(+/- 47) and 210 (+/-412) NTU (nephelometric turbidity unit) respectively. In comparison the closest value for other streams measured in Katmai was 2.4 (+/-2.9) NTU. As a result of increased turbidity and consequent reduced light penetration in Naknek Lake, Goldman (1960:226) found less planktonic primary production per unit of surface area in Naknek Lake than in Brooks Lake. However, photosynthetic rates per unit volume basis were three times higher for Naknek than Brooks Lake (Goldman 1960:226).

At first glance, LaPerriere's (1996) data appear to present a different picture (table 4). Naknek and Brooks Lake data show comparable turbidity and phytoplankton productivity values. However, LaPerriere's sample site in Naknek Lake was in an area outside of the influence of the highly turbid waters of Iliuk Arm. Table 4 shows the depth of the euphotic zone (approximated by the depth of 1% light) and turbidity levels of similar value for both Brooks and Naknek Lake sample sites allowing for a closer comparison of productivity per unit volume.

Table 4. Mean optical and related water quality characteristics of large lakes in Katmai. Values are means calculated over a three year period (n=3) unless otherwise indicated.

Lake	Secchi Depth (m)	Phytoplankton (mg/m^3 chl a)	Turbidity (NTU)	Depth of 1% Light (m)
Battle	17	0.13	0.83	67
Brooks	9.7	0.47	1.1	24
Coville	5.7	1.16	1.2	16
Grosvenor	10	0.52	0.87	23
Hammersly	14[a]	0.55[b]	1.6[a]	30[a]
Idavain	4.4[b]	1.02[b]	0.77[b]	11[b]
Kukaklek	13	0.63	0.68	34
Kulik	10	0.46	0.89	32
Murray	13	0.34	0.66	31
Naknek	5.3	0.69	1.3	23
Nonvianuk	11	0.49	0.84	30

Source: LaPerriere 1996:56-57. [a]n=2, [b]n=1

Likewise, total dissolved solids were generally higher in Naknek Lake due to glacial and volcanic inputs with the mean total value reported as approximately 110-142 ppm and the highest values being in the Iliuk Arm (Hartman 1958:118 and Burgner et al. 1969:413).

Brooks Lake and Lakes Coville and Grosvenor values were about half of Naknek Lake values ranging from 51–75 ppm (Hartman 1958:118 and Burgner et al. 1969:413).

The transparency of Naknek Lake progressively increases westward (physiography map in Appendix D). Iliuk Arm is the most turbid and has Secchi disk readings of less than 1.6 to 3.3 ft (0.49 – 1.0 m) (Hartman 1958:108, Hartman 1959:51 and Heard et al. 1969) although Goldman (1960:218) recorded a reading of 8.1 ft (2.5 m). Farther westward, the south bay of Naknek Lake (near Brooks Camp) had readings of 9.8 ft to 13.5 ft (3.0 – 4.1 m) (Hartman 1958:108, Hartman 1959:51, and Dahlberg 1972). The North Arm of Naknek Lake Secchi disk readings measured 23.5 to 26 ft (7.2 – 7.9 m) (Dahlberg 1972) comparable to Coville and Grosvenor Lakes at 17.6 and 27.4 ft (5.4 – 8.4 m), respectively (Burgner et al. 1969:417). Mid-lake readings by LaPerriere (1996:57) over a three year period showed Secchi disk readings averaging 17.4 ft (5.3 m) in Naknek Lake during the month of August.

In contrast, transparency readings were recorded for Brooks Lake that ranged from 31.3 ft (9.54 m) in July to 55.1 ft (16.8 m) in August (Dahlberg 1972, Merrell 1957:121 and 1964:56 and Hartman 1958:108). Secchi disk readings in Brooks Lake indicate a pattern of increasing transparency throughout the summer months, peaking in August, followed by a decrease in transparency in September (Dahlberg 1972, Merrell 1964:56) as shown in table 5. However, Hartman (1959:51) recorded decreasing Secchi depths for Brooks Lake in 1959 from 50 ft (15 m) in May to 33 ft (10 m) in October with a peak in July of 49 ft (15 m). LaPerriere's (1996:46) three year August average for Lake Brooks was 31.8 ft (9.7 m).

Table 5. Brooks Lake secchi disk transparency

	July	August	September
Transparency (ft)	34 – 37.5	41 – 54.5	42 - 44
Transparency (m)	10.5-11.5	12.5-16.7	13-13.5

Source: Dahlberg 1972 and Merrell 1964:56

Battle Lake, with its clear cobalt blue waters, mirrors Crater Lake in Oregon, one of the clearest lakes in the United States (Larson et al. 1996), in light penetration at 0.060 and 0.070 respectively (LaPerriere 1996:60 and Cole 1994). However, Secchi depth transparency for Crater Lake is often about 131 ft (40 m) in depth (Cole 1994) while Battle Lake's three year average in August measured less than half that depth at 56 ft (17 m) (LaPerriere 1996:60). LaPerriere (1996:60) reasoned that bacteria or ultraplankton of about 1 micrometer in size may be of a concentration and refractive index to participate in light scattering. Light penetration to great depth in this lake is not very affected by the scattering that seems to occlude the Secchi disk.

LaPerriere (1996:2) found that water clarity in Katmai lakes was directly related to total phosphorus concentrations and phytoplankton biomass. This relationship offers an easy measurement for eutrophication using time series measurements of Secchi transparency, and the method was recommended for long term monitoring at Katmai. The large volume of the 11 largest lakes in Katmai will provide some resistance to impacts from human development and land practices. However, local temporary effects of poor waste disposal practices and land clearing activities could have local temporary effects on water transparency.

e. Water Levels. Observations of the formation and alteration of crater lakes is seldom seen first hand, but Katmai Crater is an exception. Many accounts of this young volcanic lake's characteristics since inception have become part of a permanent record. The 1.9 by 2.5 mile (3 by 4 km) crater and lake were first observed in July 1916 by Griggs and his expedition party (Griggs 1922). Steep, nearly vertical walls rising 1,969 to 3,281 ft (600 to 1,000 m) above the milky turquoise blue lake met them. The lake was described by Griggs (1917) as

> *…a wonderful blue and green vitreolic lake with a crescent shaped remains of an ash cone near the middle. In the larger end was a circle of lighter colored water which was in continual ebullation. Around the margin were a thousand jets of steam of all sizes, issuing from every crevasse with a roar like a great locomotive when the safety valve lets go. On the far side, close to the water, were two large, bright yellow spots of sulphur, while in two angles less activity there were snowfields.*

Fenner and Yori (1930) reported that Katmai Crater Lake seen in 1916-1919 expeditions was not present in 1923. Instead vigorous fumaroles were active on the floor of the caldera and on lower side walls. A spectacular 98 ft (30 m) diameter mud geyser was also observed on the northeast floor of the caldera. Sometime between Fenner's observations in 1923 and Hubbard's visit in the late 1920s or early 1930s, the lake again formed. Hubbard (1935) also reported the growth of permanent snowfields on the northern and southern slump masses.

By 1951 the elevation of the lake had raised to 3,898 ft (1,188 m) (USGS topographic map, Mt. Katmai B-3, Alaska) an increase of 597 ft (182 m) in 28 years. By 1953 the snowfields on the slump masses had developed into glaciers with the southern one reaching to lake level (Muller and Coulter 1957). A third glacier had formed in the northwestern side of the caldera. By 1975 the lake had risen to an elevation of approximately 4,052 ft (1,235 m) with a lake depth of 755 ft (230 m) (Motyka 1977). The lake had been rising at a rate of approximately 6.5 ft/yr (2.0 m/yr) between 1953 and 1974, but by 1975 the rate appeared to be decreasing (Motyka 1977) (table 6). The lake, now 820 ft (250 m) deep, has apparently reached a steady state and is no longer rising (Fierstein and Hildreth 2001:9).

Table 6. Summary of lake level changes, Mt. Katmai Crater Lake (Motyka 1977:20)

Year	Approximate lake depth (m)	Estimated annual change (m)
1917	10-15	2-3
1923	0	?
1951	182	6.6
1953	--	5[#]
1974	229	2
1975	230	1.2*

[#] Estimated photo comparison (Muller and Coulter 1957)
* Measured in field survey

Luntey (1954:65) and later Muller and Coulter (1957) reported that the lake seemed to remain unfrozen all winter, indicating a heat source under the water surface. Extrapolations of average temperatures from King Salmon and Kodiak along with the presence of three glaciers indicate the lake should freeze by early winter, but Electrical Resistance Tomography (ERTS) imagery from 1975 show the lake surface ice free while a 1967 photo shows the lake almost completely frozen over (Motyka 1977:20). The winter of 1974-75 was reportedly especially cold, which may indicate that the lake is in a state of thermal fluctuation or is beginning to warm up (Motyka 1977:20).

A zone of upwelling, characterized by the presence of small sulphur particles, sampled by Motyka in 1975 (1977:20), coincided with the location of the mud volcano observed by Fenner (1930). The aerial extent, appearance and location of discoloration were noted to vary and sometimes disappear completely for several minutes or more (Motyka 1977:20). The next recorded visit to the caldera was in 1986 by Keith et al. (1992:215) who observed in place of the upwelling zone a visible yellowish plume, which persisted as of 1990. She also reported several weak fumaroles active on the caldera walls near the lake level.

Samples collected from a depth of 197 ft (60 m) in the largest of several upwelling plumes and near the plume indicate high levels of sodium, chloride, potassium, boron, sulfate and lithium (Na, Cl, K, SO_4, B and Li) concentrations (Motyka 1977:20). These data suggest that there is a large input of concentrated thermal waters and/or volcanic gases entering the lake from below the floor of the caldera (Table 7).

Since the end of the Pleistocene, there has been a decline in Naknek Lake's water level, with a rapid drop within a few years after the 1912 Novarupta eruption. Possible causes for the change include:

1) a long-term change in the regional precipitation regime,
2) a change in the mass balance of the glaciers at the headwaters of the Naknek drainage,
3) downcutting of the Naknek River through the terminal moraine that dams Naknek Lake, or
4) a seismically induced shift in the elevation of the Naknek River bed (National Park Service 1994).

Lake level data are not routinely recorded in the park.

Table 7. Katmai Crater Lake analytical data for water samples collected in 1975. Numbers clearly indicate input into the lake from thermal sources or volcanic gases.

Sample Site	Temp ^oC	PH	Cl mg/L	Na mg/L	K mg/L	Li mg/L	B mg/L	SO_4 mg/L	SiO_2 mg/L	Cond. µS
Near Plume	5.5	2.05	1350	760	90	0.92	12	1250	120	6580
At 60m- at the largest of upwelling plumes	5.5	1.94	1750	590	110	1.2	14	1200	140	7580

Source: Motyka 1977:20

2. Streams

Katmai has an extensive and diverse array of stream types, from steep, glacial fed rivers to small, intermittent streams varying in gradient, rate of flow and geology. Streams draining the eastern side of the range are typically short, high gradient on bedrock. In contrast, on the western side of the range, rivers flowing toward Bristol Bay consist of large, low gradient rivers and small, low gradient stream complexes. Generally only low gradient streams are used by anadromous fish.

Much of the main stem of the Alagnak River below its confluence with the Nonvianuk River is a multi channeled or anabranching course (Nanson and Knighton 1996). Unlike a true braided river with rapidly shifting channels, the anabranching channels of the Alagnak remain stable for tens of years separated by vegetated islands.

The Naknek and Alagnak Rivers are subject to tidal influence. At the mouth of the Naknek tidal range is 22.8 ft (6.95 m) (U.S. Army Corp of Engineers 1954). Tidal height can fluctuate by several feet as far upriver as King Salmon (18 miles) with strong, southwest winds (Straty and Jaenicke 1971). The Alagnak is influenced by tidal fluctuations to at least 13 miles (21 km) from its mouth (Curran 2003).

Large rivers in the park receive clear water tributaries, but some are frequently dominated by glacial runoff and carry large silt loads, such as the Savonoski River. They take on the characteristics of their upstream tributaries and generally show a great deal of similarity along their course. These rivers are resistant to small scale perturbations due to their size and the volume of water flowing through the system. Large rivers act as corridors for fish to migrate to clearwater streams and side channels and sloughs that provide important rearing habitat for salmonids.

In contrast to large rivers, smaller rivers and streams can be highly individual and are far less resistant to even small perturbations. Biotic modifications of streams result from several sources, such as beaver activity, salmon spawning and human activity. In these small streams a run of spawning salmon may constitute a substantial portion of marine derived nutrients to the system. Likewise, beavers can cause significant changes in local hydrology, nutrient cycling and biota. Beaver dam building modifies a stream by impounding water, increasing sediment load and retention, altering fish spawning and rearing habitat, altering riparian vegetation and changing the processing and export of carbon and nutrients (Naiman, Johnston and Kelley 1988). Beaver trapping in Katmai is low; and beaver numbers, given the number of lodges observed, appear to be high.

Water temperatures near a glacial source, such as the streams and small rivers close to the glacier, are generally less than 50 ^{o}F (10^{o}C) (Milner et al. 1997). Larger, slower rivers farther from the source may rise substantially above that temperature. Peak temperature is usually reached in southcentral streams in August or September.

B. Water Chemistry

1. Lakes

Chemical composition of the large lakes in the park varies. LaPerriere (1996) found the larger lakes in Katmai to be oligotrophic or low in nutrients.

The lakes generally are reflective of the inputs they receive from inlet streams showing chemical concentrations in the middle range of inlet concentrations (LaPerriere 1996). However, in the case of Battle Lake (Table 8) unusual inlet characteristics may have an influence locally on the receiving lake. Mid-lake concentrations did not always mimic mid-range values for inlet streams. In lakes, except Battle, conductivity decreased with depth. In Battle Lake conductivity increased near the bottom of the lake, which LaPerriere (1996 and 1997:93) speculated was a result of higher density and higher concentrations of major and trace metal ions from inlet waters plunging to depth in the lake, resulting in a "salty" layer. Because some inlets have a stronger influence on lake chemistry than others, some lakes, such as Battle, may be difficult to characterize from one sampling station even if the lake has only one basin (LaPerriere 1996:73).

Conductivity of the large lakes is moderate and usually decreases with depth, except in Battle Lake as noted above (LaPerriere 1997:93). Naknek Lake, however, exhibited conductivity values more than twice as high as nearby lakes (LaPerriere 1997:93)

<u>a. pH</u>. The pH in large lakes in Katmai is usually near neutral but in more productive lakes surface pH varied by time of day and on clear days, indicating that photosynthesis was responsible for the shift. Although the planktonic algal crop was low for Battle Lake, photosynthesis appeared to be of sufficient intensity to shift pH about one unit over the upper 5 m on a sunny day as compared to a cloudy day (LaPerriere 1997:96).

Table 8. High natural concentrations of constituents in inlet streams are responsible for the unusual characteristics of Battle Lake.

	HCO_3^- (mg/L as $CaCO_3$)	**Chloride (mg/L)**	**Sulphate (mg/L)**	**Aluminum (mg/L)**
Battle Lake	2.9	4.3	15.0	0.18+/-0.03[#]
Inlet 1 (Iron Springs)	0*	9.4	18.3	3.84
Inlet 2	0*	7.4	6.0	0.20
Inlet 3	0*	7.6	3.7	0.10
Inlet 4	5.5	7.5	4.7	0.05
Inlet 5	0.6	8.0	17.7	0.16
Battle River (outlet)	5.4	8.2	6.7	0.08
Mid-range concentration	3.1	8.0	10.1	0.87

Data after LaPerriere (1996). Stream and lake data are from 1990 unless otherwise indicated.
[#] Data from 1992. *No titrable alkalinity.

Measurements of pH in Naknek and Brooks Lake and Brooks Lake tributaries showed a consistent value between 7.1 and 7.5 for all depths and dates sampled during the summer months (Merrell 1957:126, Hartman 1958:113, Hartman 1959:52, Hartman and Conkle1960:45, Merrell 1964:56, Burgner et al. 1969:413). However, winter pH levels were reportedly lower at 6.2 (Merrell 1958b).

The natural acidity of the upper Alagnak basin is evident from pH levels in tributaries to Battle Lake resulting in lower pH values for Battle Lake and other upper lakes in the drainage. Of particular influence on the acidity of Battle Lake are the inputs from Iron Springs Lake where pH has been reported as 3.65 (Gunther 1986:8). Mine Creek, with a recorded pH of 7.18 (Table 9) has little effect in neutralizing Iron Springs Lake, due to its low flow. By the time waters from Iron Springs Lake reach Battle Lake via “Tributary 1,” the pH has increased only slightly to 4.16 (Gunther 1986:appendix and Gunther 1992:66).

Both arms of the Alagnak drainage have significantly higher sulfate concentrations than those found in the Naknek drainage, indicating a local source of sulfate (Table 9). The bedrock geology in this area explains the unusual characteristics of these waters (Geology in chapter 3). Acidity in this drainage may be attributed to oxidation of iron sulphide ores (or pyrite of rocks), clearly evident along the shores of Battle and Iron Springs Lakes as an orange or rust color, resulting in sulfuric acid drainage into the lake (Wetzel 2001). The entire streambed of Iron Springs Creek exhibits this unique coloration as well. Venting of sulfide gases from active volcanoes in the Aleutian Range could also contribute to acidity (Gunther 1992:67).

The only mining claim in the park, Pfaff mining claim, was in this area where pyrite was mined. Pyrite on oxidation yields sulfuric acid, which would explain the low pH of the lake and stream. The mine is no longer active.

Table 9. Characteristics of Alagnak drainage waters.

Lake or Stream	PH	Alkalinity (mg/L $CaCo^3$)	Sulfate (mg/L)	pH	Alkalinity (μeq/L	Sulfate (μeq/L)
	LaPerriere 1996			Gunther 1986 and 1992		
Alagnak Drainage						
Battle Lake		2.43	16	6.6	52 (2.3)	166 (35.7)
Tributary 1		--	--	4.16	--	1034.5
Tributary 2		--	--	6.13	35.50	59.20
Tributary 3		--	--	6.65	80.50	34.45
Tributary 4		--	--	6.65	90.00	14.2
Tributary 5		--	--	7.05	175.00	546.70
Kukaklek Lake		8.87	0.77	7.0	149 (2.0)	--
Kulik Lake		5.10	0.11	7.2	155	227
Nonvianuk Lake		11.9	1.1	7.0	203 (2.0)	120 (1.13)
Iron Springs Lake		--	--	3.65	--	1516 (5.76)
Iron Springs Creek		--	--	3.68	--	1514.80
Mine Creek				7.18	177.50	69.45
Pirate Lake		--	--	6.7	86 (5)	--
Naknek Drainage		36.9	0.6			
Murray Lake		10.20	0	7.1	186	--
Hammersly Lake		11.4	0	7.1	204	--
Coville Lake		30.4	0	7.6	502 (0.7)	41 (0.1)
Grosvenor Lake		29.8	0	--	--	--
Brooks Lake		35	0	--	--	--
Naknek Lake		31 ±1	30 ±3	--	--	--
Pecker Lake		--	--	7.0	107 (0.4)	25 (0.07)
Idavain Lake		25.6	1.6	7.5	417 (10.7)	17 (0.3)
Tony Malone		--	--	9.3	797	--

Source: Streams from Gunther 1986 and lakes from Gunther 1992. Numbers in parenthesis are standard error of the mean, n=number of samples. --=no sample data. LaPerriere 1993:295 –Data are averages over three years 1990-1992.

Studies indicate that Iron Springs Lake may be unique, at least in the western United States, due to its acidity and size. Only 0.1% of lakes in the west have pH <5 (Eilers et al. 1993). In addition, many of the naturally acidic lakes reported in the literature are ponds, springs or small lakes (Gunther 1992:67).

Many of the naturally acidic lakes in the world can be found in volcanic regions, such as the Taupo Volcanic Zone of New Zealand where oxidation of sulphides from underwater gas vents and springs produce acidity (Yoshimura 1933, Brock 1973, McColl and Forsyth 1973, Forsyth 1977, Forsyth and MacKenzie 1981, Eilers et al. 1988 in Gunther 1992:66-67). Despite the low pH of these lakes, many organisms are still able to survive these harsh conditions. In Lake Kata-numa in Japan the diatom *Pinnularia sp*. was found to be very abundant in this crater lake of pH 1.4 (Yoshimura 1933:201). Species diversity increased at pH 3.2 to 3.4 pH when higher plants, benthic flora and fauna and fish reappeared (Yoshimura 1933:201). Lakes with pH of 3.4 to 4.5 are known to contain many types of algae (particularly desmids and diatoms), crustaceans and some aquatic insects (Patrick et al. 1981:446).

Crater lakes on Katmai, Mount Martin, Mount Mageik and Mount Douglas are acid "volcanic" waters. These waters are formed when volcanic crater lakes absorb high temperature, sulfur- and chlorite-rich volcanic gases (Motyka et al. 1993:5). Each of these crater lakes continues to be fed by geothermal activity under or near the surface of the lake. Mt. Mageik is a bluish-yellow to yellow-green, acid lake (pH~1), 300 m in diameter and 100 m deep (Motyka et al. 1993:Sheet 3 of 4). Its temperature has been measured at 72^{o}C fueled by superheated fumaroles as hot as 172^{o}C. The lake is in a continual state of roiling agitation fringed by a yellow sulfurous froth along the shoreline (Fierstein and Hildreth 2001:16). Mt. Douglas crater lake is blue-green, 160 m x 200 m, acidic (pH~1) and covered in a black scum of sulfide minerals (Motyka et al. 1993:Sheet 3 of 4). Subaqueous fumaroles cause surface turbulence in the lake, giving it the visual appearance of a virtual witch's brew.

b. Major Ions. The large lakes in Katmai resemble average temperate lakes of the world with respect to major cation concentrations. Major ions tend to exist in the proportions of Ca>Mg≥Na>K and CO_3 – HCO_3 >SO_4>Cl, except in coastal regions where Na and Cl tend to exist in greater proportions (Wetzel 2001). Katmai lakes exhibited what might be considered a coastal pattern in proportions with higher concentrations of Na and Cl probably due to the close proximity of Bristol Bay and the Gulf of Alaska with: Ca (53-68%)> Na (19-28%)>Mg (11-23%)>K (≤1%) (Burgner et al. 1969:413 and LaPerriere 1997:94). A strong correlation between chloride and distance from the coast has been observed in lakes on the Kenai Peninsula (Eilers et al. 1993) and the North Slope of Alaska (Kling et al. 1992). Sodium concentrations were also highly correlated with those of chloride and decreased with distance from the coast in a pattern similar to that observed for chloride in western Canadian lakes (Pienitz et al. 1997:337).

Further characterization of lakes is possible by proportion of dominant ions. LaPerriere grouped 11 large lakes in Katmai by the proportion of ions measured, resulting in five categories. Most lakes were characterized as calcium-bicarbonate although Naknek, Kukaklek, Kulik and Battle Lakes exhibited different characteristics. Lake types are shown in Table 10.

Altitude was shown to be strongly inversely correlated with major ion concentrations, alkalinity and conductivity over a three-year period with the exception of sulfate and chloride levels, which were not related to altitude (LaPerriere 1997:94). Murray Lake, the highest elevation lake studied, had the lowest major ion concentration at 0.55meq/l and a conductivity of 39 μS/cm compared to Naknek, the lowest elevation lake studied, at 3.06 meq/l major ions and conductivity of about 139 μS/cm (LaPerriere 1997:94). Water tends to accumulate salts as it flows down the drainage in contact with lithology and soils, explaining the relationship of ion concentrations and altitude. Low overall concentrations of ions in

Katmai waters is a function of the cold climate reducing weathering processes and relatively high precipitation causing a high dilution factor as well.

Table 10. Lake types in Alaska as characterized by Jackie LaPerriere (1996).

Lake type by Ion Proportions	Lakes fitting the profile
Calcium-bicarbonate	Naknek Drainage: Brooks Coville Grosvenor Hammersly Idavain Murray Alagnak Drainage Nonvianuk
Calcium chloride-bicarbonate	Alagnak Drainage Kukaklek
Calcium sulfate-bicarbonate	Naknek Drainage Naknek
"Triple water" (having roughly equal proportions of the three major anions)	Alagnak Drainage Kulik
Calcium sulfate	Alagnak Drainage Battle

c. Nitrogen and Phosphorus. In early studies of the Naknek drainage, Goldman (1960:227) found Brooks, Naknek and Becharof Lakes to be nitrogen limited. Buck et al. (1978) took the nitrogen limitation conclusion further and applied it to the entire Naknek drainage, where it had not been tested. Studies in the 1990s by LaPerriere (1993:294 and 1996) confirmed that Brooks and Naknek Lakes and Lake Coville are indeed nitrogen limited (<13 TN:TP ratio), but nutrient stimulation bioassay experiments found Lake Grosvenor and Kulik Lake to be phosphorus limited (ratio >60 TN:TP) (LaPerriere and Jones 2002:1013). In an attempt to compare lake data over time, LaPerriere found early data from Brooks Lake to be suspect. Merrell (1957:122, 1958a, 1964:52) and Hartman (1958:113-114, 1959:56) reported soluble phosphorus data that were below the detection limits of even today's more modern methodology (LaPerriere 1993:295). Such findings raise questions as to the validity of the data collected during these early studies and make it impossible to render any conclusions about environmental changes over time.

Questions remain concerning why some lakes in Katmai are nitrogen limited while others, in the same drainage, are phosphorus limited. This question warrants additional study.

Nitrite nitrogen measurements were made in a number of early studies by Merrell (1957:123-124 and 1964:52), Hartman (1958:108,112, 1959:55) and Hartman and Conkle (1960:46-47). Investigators found that nitrogen levels were consistent throughout the summer and throughout the water column; and they, therefore, concluded that fish carcasses contributed little to nitrogen loading in Brooks and Naknek Lakes. Hartman (1958:108) hypothesized that the source of nitrogen to these lakes was from the atmosphere, soil or vegetation.

Analysis of rainwater samples revealed undetectable amounts of nitrite, discounting one of the theories presented (Gunther 1986).

Modern theories of nitrogen loading in lakes would consider the atmosphere, soil and vegetation as sources, but might place primary importance on the contribution made by decaying fish carcasses. The nitrogen analysis conducted more that 40 years ago was done using the best methods available at the time, the Klett-Summerson photoelectric colorimeter; but the measurements made were very close to the method detection limits, which may have led Merrell and Hartman to erroneous conclusions on nitrogen sources in these lakes. Later, Finney et al. (2000) found that Kodiak Island lakes seem to have a built-in dependence on nutrients from decaying salmon, which can be greatly affected by low salmon returns whereas Bristol Bay lakes (Ugashik, Becharof and Tazimina) continued to produce large numbers of salmon despite high commercial harvest. Bristol Bay lakes appear to be less affected by the boost of nutrients from decomposing salmon perhaps because the boost is small compared to nutrients coming from other sources (Finney et al. 2000:797).

Nitrogen content of the soil is estimated at 43.0 ppm, while volcanic ash from Novarupta contained less than 1% of the nitrogen found in cultivated soil (Shipley 1919a). Goldman suggests the most important source of nitrogen to Brooks Lake comes from Headwaters Creek, whose source is in the tundra, and nitrogen-fixing alder thickets, which could contribute a substantial proportion of nitrogen to the water (Goldman 1960:225). He found nitrite nitrogen levels more than twice the average of two other stations in Brooks Lake the day following a rain storm. He concluded that rain soaking through the nitrogen-rich tundra before entering streams could account for a significant proportion of nitrogen to the lake. He further reasoned that the rate of replenishment of nutrients determined the productivity of the system, rather than the concentration of nutrients at any given time (Goldman 1960:225). From the Brooks Lake studies Goldman concluded that productivity of the lake is dependent far more on replenishment of nutrients from tributary streams than depth of the euphotic zone (Goldman 1960:224).

Shipley (1919b) found very low levels of ammonia in rainfall of Southwest Alaska. He found a maximum value of 0.016 ppm NH_3 compared to 0.44 ppm observed in Scotland at about the same latitude. Rainfall along the Shelikof Strait averaged only 0.0018 ppm (Shipley 1919b).

Nitrogen fixing in Brooks Lake itself does not provide a significant source of nitrogen. Gunther (1986:8-9) found no acetylene reduction activity in samples of lake water collected in the mid-1980s. Goldman (1960:219) found cyanobacteria (blue-green algae) but of a genera that are not known as nitrogen fixers (*Microcystis* and *Lyngbya*).

Gunther's study did not focus solely on lake systems. He found that lichen-shrub-tundra per hectare has the greatest nitrogen fixing capacity per lichen biomass at 2.76 kgN/ha-yr in conifer forest habitat, 1.8 kgN/ha-yr in lichen shrub tundra to as low as 0.18 kgN/ha-yr in graminoid shrub tundra (1986:9, appendix). He also reported that soil mineralization studies indicate that net mineralization of nitrogen occurs in the alder stands much more than in any other habitat analyzed (1986:9).

In Gunther's study (1992:66) the Alagnak lakes exhibited higher concentrations of nitrate and lower concentrations of sodium than lakes of the Naknek drainage. The higher nitrate concentrations in the Alagnak drainage, he concluded, are probably due to lower productivity (Table 11). Burgner (1969:417-418) surveyed 10 lakes in the region and reported the lowest primary productivity and the second lowest standing crop of phytoplankton in the Alagnak drainage. The Naknek drainage ranked much higher in comparison.

The reasons for the differing concentrations of sodium are unclear.

Table 11. Lakes in the Alagnak drainage have higher concentrations of nitrate and lower sodium than lakes of the Naknek drainage.

Lake	PH	Alkalinity µeq/L	Al µeq/L	SO_4 µeq/L	NO_3 µeq/L	Na µeq/L
Alagnak Drainage						
Battle (n=2)	6.6	52	9	166	8	61
Iron Springs (n=3)	3.65	--	742	1516	<2	87
Pirate (n=2)	6.7	86	--	--	--	--
Kulik (n=1)	7.2	155	--	227	17	--
Nonvianuk (n=3)	7.0	203	0.8	120	2.6	71
Kukaklek (n=3)	7.0	149	--	--	--	--
Naknek Drainage						
Hammersly (n=1)	7.1	204	--	--	--	--
Murray (n=1)	7.1	186	--	--	--	--
Idavain (n=2)	7.5	417	<0.4	17	<.05	129
Coville (n=2)	7.6	502	2.0	41	<.05	140
Pecker (n=2)	7.0	107	3.3	25	<.05	123
Brooks #	7.6	602	--	96	<.1	--
Tony Malone (n=1)	9.3	797	--	--	--	--

Brooks Lake data from Gunther 1986, samples taken in 1984 and 1986.
Remainder of table from Gunther 1992:66-67. -- = no data

d. Alkalinity. Gunther reported that lakes in the Alagnak system exhibited lower surface water alkalinity than those of the Naknek system (Gunther 1992:65). Later LaPerriere (1996) confirmed Gunther's findings, reporting that the high-altitude lakes were acid sensitive as shown by the ratio of alkalinity to calcium plus magnesium. Of these, Battle Lake had the lowest alkalinity along with elevated concentrations of aluminum.

The low ratio of alkalinity to calcium plus magnesium observed in Katmai lakes while natural is quite unusual. Schindler (1988) reported that ratios of 0.8 to 1.1 in acidic areas not susceptible to acid deposition are the norm. He further said that ratios below 0.6 in pristine areas are seldom seen even in areas where weathering of high sulfur minerals occurs. LaPerriere (1997:97) documented ratios for some Katmai lakes that fell far below the norm. High altitude lakes (Murray and Hammersly) in the Naknek drainage had a ratio of 0.8 just within the normal range while Nonvianuk (0.7), Kukaklek (0.6), Kulik (0.5) and Battle (0.2) in the Alagnak drainage fell below the normal range.

Alkalinity ranged from a low of 58µeq/L at Battle Lake to moderate levels in Kulik, Murray and Hammersly, and high levels at Brooks and Tony Malone Lakes (Gunther 1986:7) (table 11). The low alkalinity of Battle Lake was attributed in part to the inflow from an acidic tributary, Iron Springs Creek (pH = 4.1) (Gunther 1986:6) and the granitic parent materials in the Alagnak drainage. The U.S. Fish and Wildlife Service (King Salmon, AK) conducted surveys in this acidic tributary and found virtually no traces of aquatic invertebrates or fish. However, a joint National Park Service/Alaska Pacific University collection of macroinvertebrates during July of 2001 (Kozlowski, forthcoming) resulted in a well populated sample in the same tributary.

Landers et al. (1988 in Gunther 1992:67) concluded that waters exhibiting alkalinity of less than 200 µeq/l may be susceptible to acid deposition and waters with alkalinity less than 50 µeq/l were extremely acid sensitive (Schindler 1988:149). Thus, the Alagnak drainage, and the upper lakes of Battle, Pirate and Kulik particularly, would be a high priority for monitoring for effects of acid deposition.

e. Sulfate. Gunther (1992) attributed the acid sensitivity of lakes to high sulfur concentrations observed (Table 11), but LaPerriere disagreed. LaPerriere's findings showed that high sulfate concentrations have no influence on alkalinity and in fact make these lakes less acid sensitive. Microbial reduction of sulfate to an elemental form actually increases the acid neutralizing capacity of these waters, rather than rendering them acid vulnerable (LaPerriere 1997:98).

LaPerriere (1996) also criticized Gunther's conclusion (1992) that lakes in the Alagnak drainage may be more susceptible to acid deposition than lakes in the Naknek drainage due to naturally occurring sulfate in the Alagnak drainage. Gunther did not sample Naknek Lake, the largest lake in the Naknek drainage, which LaPerriere (1993:295) found to have the highest concentration of sulfate of all the 10 lakes sampled in the two drainages. In Naknek Lake she found high sulfur concentrations coupled with high alkalinity further discounting his theory. LaPerriere concluded that vulnerability to acid deposition would be greatest in lakes with both low sulfate and alkalinity, such as that observed in Kukaklek, Hammersly and Murray lakes.

Higher concentrations of sulfate in Kulik, Battle and Naknek Lakes probably result from reduced sulfur sources in the lithology (Table 11) (LaPerriere 1997:97). In the case of Kulik there also appears to be a possible geothermal source evidenced by elevated temperatures and sulfur concentrations in a tributary to the lake.

LaPerriere observed a strong inverse relationship between altitude and alkalinity among the ten lakes (r^2=0.57, p=0.01) indicating that higher altitude lakes, such as Hammersly and Murray, in both the Naknek and Alagnak drainages may be susceptible to acid deposition as well (LaPerriere 1993:295).

f. Trace Elements. Most trace elements were below detection limits in the large lakes of Katmai (LaPerriere 1997:94). Those of measurable levels were strontium, barium, boron and aluminum. Strontium exhibited a strong inverse relationship with altitude indicating a geologic source. Boron was measurable in Naknek Lake, about twice the detection limit of

0.02 mg/L (LaPerriere 1996:84), and high (0.17 mg/L) in the Ukak River (Keith et al. 1992). The source was probably the ashflow from the Valley of Ten Thousand Smokes (Keith et al. 1992). Other measurable levels of elements attributable to the ashflow and/or igneous rocks were copper, lithium and titanium in the Savonoski and Ukak Rivers (LaPerriere 1996:84). Titanium was also measurable in American, Headwaters and Margot Creeks.

g. Aluminum. Aluminum at levels that may be chronically or acutely toxic to aquatic organisms were found in several streams and in Iron Springs Lake (Gunther 1992 and LaPerriere 1996), while it was below the detection limit in other large lakes. Iron Springs Creek on Battle Lake and Up-a-Tree and Headwaters Creeks on Brooks Lake indicated levels chronically toxic. Lethal levels of aluminum were measured in Savonoski and Ukak Rivers (Table 12). Total aluminum levels at 6.7 mg/L in Iron Springs Lake are comparable to levels observed in other acidified waters of a similar pH range (Havas and Hutchinson 1983, Wehr and Whitton 1983 and Rask et al. 1986 in Gunther 1992:66). Analysis using an existing model predicts that about 66% of the aluminum in the lake exists in a free ion state (Al^{3+}), resulting in concentrations of 4.4 mg/L, which is well above the level of 0.2 mg/L known to be toxic to trout (Cronan and Schofield 1979 in Gunther 1992:66 and Dietrich and Schlatter 1989:210).

Aluminum was measured at two to three times the detection limit in surface waters of Battle Lake (0.03 mg/L) (LaPerriere 1997:94). Values were elevated in Battle Lake throughout the water column. Measurable levels of aluminum were detected, at least once, in American Creek, Battle Lake inlets and in Headwaters and Up-a-Tree Creeks on Brooks Lake. High concentrations were measured in the Savonoski and Ukak Rivers, where even the acute freshwater criterion for the protection of aquatic life was exceeded, as it was in Iron Springs Creek (Table 12)(LaPerriere 1996:84).

Table 12. Levels of aluminum in Katmai waters and its chronic and acute toxicity levels. Data from LaPerriere (1996), except where otherwise noted.

	Aluminum (mg/L)	**Toxicity Levels**	
		Chronic	**Acute**
Iron Springs Creek	3.84/1.03	Alaska's freshwater aquatic life criteria*: 87 µg/L	Alaska's freshwater aquatic life criteria*: 750 µg/L
Up-a-Tree Creek	0.06/1.03		
Headwaters Creek	0.2/0.38		
Savonoski River	7.44	EPA Secondary Drinking Water Regulations (2002): 0.05 to 0.2 mg/L	
Ukak River	7.67		
Iron Springs Lake#	6.7		

Source: Gunther 1992:66-67.
* From: www.state.ak.us/dec/dawq/wqs/documents/freshwateraquaticlifecriteria.htm

High levels of aluminum and other toxic metals raise a concern for humans as well as aquatic biota. Visitors and park staff should not drink waters in the Battle Lake watershed and in the Ukak and Savonoski Rivers due to high concentrations of toxic metals. During periods of high runoff increased concentrations of dissolved aluminum may be observed. Naturally occurring aluminum becomes more mobile particularly in acidic waters such as those found in the Battle Lake area.

Although there may be no adverse effects to biota at either the acute or chronic levels (Table 12), high chronic levels of dissolved aluminum are toxic to fish, benthic invertebrates and some single-celled plants (http://www.bae.ncsu.edu/programs/extension/wqg/). LaPerriere (1996:2) speculated that because of the low algal and zooplankton concentrations in Battle Lake and probably toxic levels of aluminum, sockeye that spawn in the inlets of Battle Lake rear in Kukaklek Lake, the next lake down where conditions are more favorable. The Savonoski River is a known migration route for salmon, indicating that aluminum and other trace element concentrations in the waters must be at tolerable levels.

h. Iron. Potential water sources were sampled in 1968-69 by the U.S. Geological Survey to determine the quality of the ground and surface waters near developed or potential development sites in the park. Samples collected on both the north and south sides of Brooks River had iron concentrations exceeding the 0.3 mg/L recommended upper limit for drinking water indicated in the 1962 U.S. Public Health Service regulations (Zenone 1970:12). LaPerriere (1996) found much lower levels of iron in the river in the early 1990s, at 0.075 mg/L. Several other lakes and streams sampled contained levels of iron that exceed the Environmental Protection Agency's National Drinking Water Secondary Regulations (section on "Water Quality Standards" in this chapter). Alaska has not adopted a drinking water standard for this constituent.

i. Silica. Silica is the primary component of diatom skeletal structure. Diatoms are the principal food source for zooplankton in oligotrophic lakes such as those found at Katmai. Weathering bedrock and surficial deposits are the primary source of silica to Katmai waters. Silica values for Katmai waters are consistent with readings of other similarly situated lakes residing in volcanic watersheds but far greater than most North American lakes.

Three distinctive magmas (rhyolite, dacite, and andesite) were mechanically and complexly intermingled during the 1912 eruption, producing tephra deposits with a range of bulk composition. The main ashflow is compositionally zoned with the earliest (lower) half nearly all rhyolite and the later half progressively more dacitic and andesitic (Hildreth 1983). The central dome is rhyolite, contaminated with a minor amount of interbanded dacite lava. The bulk SiO_2 content is 77% for the rhyolite, 66-64.5% for the dacite, and 61.5-58.5% for the andesite (Hildreth 1983).

Waters draining the ashflow sheet or that are heavily ash laden from the 1912 eruption have much higher measurable levels of soluble silica. Soluble silica measured in the Savonoski River was 22.3 ppm (Hartman 1958:134). The river drains a sizable area covered in ash deposits from the 1912 eruption of Novarupta. At the same time, the Ukak River, a mixture of waters flowing through and on the periphery of the flow, measured 7.4 ppm (Hartman 1958:134).

In studies conducted between 1947 and 1960, Merrell and others (1957:125 and 1964:54, Hartman 1958:108,111, Hartman 1959:54, Hartman and Conkle 1960:46, Goldman 1960:218) reported silica values ranging from 7 ppm to 16.2 ppm for Brooks Lake and a survey of the literature revealed fairly consistent measurements throughout waters sampled in the Naknek drainage, ranging from 7.7 ppm to 12 ppm (Merrell 1964:55). Becharof Lake, just south of the park, did not receive a large amount of ash from the eruption of Novarupta, and consequently the silica levels in that lake provide a sharp contrast to Brooks and Naknek. Goldman (1960:224) recorded a low 1.04 ppm for Becharof Lake.

While Brooks Lake values were reportedly low, tributaries to the lake were contributing from 6.1 ppm to 19.1 ppm soluble silica to the lake (Hartman 1958:131,133, Hartman 1959:61, and Hartman and Conkle 1960:49). In 1958 West Creek exhibited the lowest levels (between 5.5 and 8.2 ppm) while the other four tributaries measured much higher (between 14.3 and 19.1 ppm). This phenomenon was not repeated in 1959 but was evident again in 1960 (Hartman and Conkle 1960:49). Hartman attributed the reduction in lake silica levels to settling and biogenic activity.

Soluble silica measurements varied considerably from year to year although Merrell (1964) found little difference between depths, seasons or locations on Brooks Lake. Table 13 shows the values recorded and their sources.

Table 13. Soluble silica concentrations for waters in the Naknek drainage.

Basin	Silica concentration (ppm)	Source
Grosvenor Lake	7.7	Hartman 1958, Burgner et al. 1969, Merrell 1964, Wallace 1969, Goldman 1960, Eicher and Rounsefell 1957
Coville Lake	9.9	
South Bay – Naknek Lake	9.3	
Iliuk Arm – Naknek Lake	11.0-11.6	
Naknek Lake	8.1-11.6	
Brooks Lake	9.1-12.0	

j. Other constituents. Elevated levels of sulphate, arsenic, cadmium, copper, selenium and chloride were measured at hot springs in the Valley of Ten Thousand Smokes and in Katmai Crater Lake. Values exceeded the acute freshwater criterion and drinking water standards for freshwater sources. These elevated levels were generally only observed in waters influenced by thermal features. However, cadmium levels were high in a tributary of Battle Lake, measuring 9 μg/L (National Park Service 2001a:vii).

Several other constituents were elevated as well in specific areas. Beryllium in One-Shot-Creek, tributary to Brooks Lake, measured 5 μg/L, and lead concentrations in Battle, Brooks, Grosvenor, Kukaklek and Coville lakes and a tributary to Kulik Lake were high (>15μg/L) (National Park Service 2001a:vii). Zinc ranging from 126-317 μg/L was reported at Iron Springs Lake, Katmai Crater Lake and Up-A-Tree Creek with the highest concentration being at Iron Springs Lake. Lastly, boron was found in measurable amounts only in Naknek Lake (0.05 mg/L) (LaPerriere 1996:45).

2. Streams

The influence of tributary water on lakes is evident in Katmai studies. Goldman (1960 and 1964:371) found a consistent increase in productivity in the direction of major tributaries during a period of nitrogen deficiency. Later, LaPerriere (1996) showed the effects of a few tributary inputs on the chemistry of Battle Lake.

Terry Keith's study of waters in the Valley of Ten Thousand Smokes (Keith 1984, 1986, 1991a, 1991b and Keith et al. 1990, 1992) is the most extensive for park waters. Water samples have been collected in the Valley of Ten Thousand Smokes since 1979 to determine the extent to which the 1912 tephra deposits are still being leached by surface waters. Aside from this study only a very few efforts have been focused on stream characteristics.

Streams in the Valley of Ten Thousand Smokes vary considerably from the general description of river systems outside the 1912 ashflow. Weathering of the 1912 ashflow and input from thermal and cold springs result in very different physical and chemical properties of these waters (Water Sample Stations Inset B following this page). Fish do not spawn up these streams, although they may be expected any time (Keith pers. comm. 2003), and very few wildlife observations are made in the mostly barren ashflow. Vegetation plays little role in the cycling of nutrients. Knife Creek and the River Lethe, the two major streams draining the deposit, are enriched in dissolved constituents (SiO_2, Ca, Na, K, Mg, Li, Cl, F, SO_4) compared to streams and springs that have not had contact with the ashflow (Keith et al. 1990:1691). They also have greater concentrations of these constituents the longer they flow through the ash, meaning that lower reaches of the rivers have higher concentrations than those 20 km upvalley (Keith et al. 1992). Downstream increases in dissolved constituents are thought to be, in part, caused by the entry of thermal waters mid-valley and in part by dissolution of unstable or metastable fumarolic minerals.

Upper reaches of Knife Creek and the River Lethe are more concentrated in dissolved constituents than waters flowing outside the ashflow sheet, and upper waters of Knife Creek contain higher concentrations of almost all constituents compared to upper River Lethe (Keith et al. 1992:219). Field pH has been recorded as low as 4.2 in the upper Knife Creek, and waters are more acidic than other waters in the valley. Keith et al. (1992:219) reasoned that the higher acidity may be due to a thin layer of ashflow tuff blanketing the five glaciers at the head of Knife Creek. Sources such as leakage from Katmai Crater Lake or from a hydrothermal system below Novarupta caldera have been all but ruled out. All constituents in lower Knife Creek are more concentrated than in the lower River Lethe. Constituents in Windy Creek, flowing mostly outside the ashflow sheet, are very dilute. When the three streams meet and blend to form the Ukak River, the result is that chemical constituents of these waters are higher than waters above the 1912 deposits and are an average of lower Knife Creek and the lower River Lethe. The Ukak is slightly more dilute in Na and HCO_3 because of inflow from Windy Creek (Keith et al. 1992:220).

C. Sediment

Little attention has been devoted to sediment loading in waters or sediment quality in Katmai. However, recent studies by Curran (2003:19) reported concentrations of calcium, sodium, aluminum, iron, manganese, scandium, titanium and vanadium in Alagnak River bed sediments that equaled or exceeded mean concentrations of unsieved Alaska stream and lake sediment reported by Gough et al. (1988).

The Canadian Council of Ministers of the Environment (2001) established guidelines for some trace elements in unsieved streambed sediments. A lower assessment value called the interim freshwater sediment quality guideline (ISQG) and an upper value called the probable effect level (PEL) were established. The ISQG indicates concentrations below which adverse biological effects are not expected to occur. PEL is the concentration above which adverse biological effects are expected to occur frequently. Constituent concentrations in sieved samples are generally higher than concentrations in unsieved samples.
Arsenic and chromium concentrations in Alagnak River sieved sediment fell between the ISQG and PEL assessment values (Curran 2003:19). Arsenic levels are commonly elevated in Alaska stream and lake sediments with mean values higher than the PEL (Gough et al. 1988).

Some limited observations of sedimentation and bottom materials were undertaken during early fishery investigations in the Naknek drainage. Goldman (1960) characterized bottom sediments of Brooks Lake and sedimentation in beaver ponds on Brooks Lake tributaries. He found that the fine bottom sediments could be easily mechanically resuspended and thereby increase metabolism of the lake. Sediment extract measured .062 ppm phosphorus compared to the lake's .0057 ppm, 0.023 ppm nitrite compared to the lake's .0012 ppm and 6 ppm more silica than lake water (Goldman 1960:223).

Stream bottom composition and compaction were studied by McAfee (1960) and Hoopes (1962, 1972) at salmon spawning areas in Brooks Lake tributaries. These studies were attempts to relate spawning behavior and site selection to gravel size and compaction. Gravels were least compacted in Brooks River and most compacted in Up-A-Tree Creek (McAfee 1960). Bottom substrate varied between streams from 37% of the particles greater than 3 inches (7.6 cm) in diameter to 78% of the particles smaller than 0.5 inches (1.3 cm) in diameter (Hoopes 1962:137,226).

D. Biota.

1. Phytoplankton

A look at ranking of lake systems in Southwest Alaska provides an interesting comparison of primary productivity versus fish production (Table 14). In surface area productivity the Alagnak lakes rank last and Naknek sixth. On the basis of productivity in the euphotic zone, Alagnak lakes again ranked last while Naknek ranked third overall. In standing crop of phytoplankton, as measured by chlorophyll *a*, Alagnak lakes ranked ninth, outdone only by Nuyakuk lakes, while Naknek ranked fifth (Burgner et al. 1969:418).

Table 14. Ranking of southwest Alaska lake systems comparing primary productivity and fish production.

Lake System	Escapement per km²		Primary Productivity		Standing Crop Phytoplankton (chlorophyll *a* per liter)	Total dissolved solids (ppm)
	Rank	No.	Per m² surface area	Per m³ euphotic zone		
Karluk	1	8350	2	2	2	3
Chignik	2	8070	1	1	1	2
Igushik[1]	3	4360	3	4	7	10
Wood	4	2340	4	5	3	6
Alagnak	**5**	**1441**	**10**	**10**	**9**	**5**
Ugashik	6	1338	9	9	6	8
Kvichak	7	1330	7	7	4	7
Naknek	**8**	**1122**	**6**	**3**	**5**	**1**
Snake[1]	9	290	5	8	8	9
Nuyakuk[1]	10	280	8	6	10	4

1 – Only a few determinations were made. Source: Burgner et al. 1969:418

Burgner et al. (1969:416) report that Kukaklek and Nonvianuk Lakes in the Alagnak drainage ranked near the bottom in productivity compared to other lakes on the Alaska Peninsula and mainland areas, such as the Wood and Tikchik Lakes near Dillingham. Only Lake Clark ranked lower in productivity on a lake surface area basis (Burgner et al. 1969:417). Alagnak Lakes also had low standing crops of phytoplankton.

Burgner was quick to point out that productivity varies considerably from year to year. His studies were based on two years of data from 1961-62. Theories on growth of juvenile salmon abound and most suggest density dependent factors affecting growth and survival of salmon. However, Burgner et al. (1969:454) reported that primary productivity was greater in 1962 than in 1961. At the same time the abundance of juvenile salmon was greater in 1962, and rate or growth of juvenile salmon was greater in 1962 as well.

Over the years a number of nutrient bioassays were conducted to determine the response of primary producers to selected trace nutrients. The results were variable probably due to different methods and techniques employed (Buck et al. 1978:75). Goldman (1960:225) first found that magnesium stimulated growth of phytoplankton cultures, but later concluded (1964) that a mixture of trace elements was responsible for growth. He also found that additions of vitamin B12, thiamine or biotin also served the same purpose.

Later a complex study of nutrient enrichment and trace element limitation, conducted by Biesinger (1967), resulted in inconclusive findings. In waters from the Naknek River drainage, Biesinger (1967) learned that cobalt, vanadium, lithium, boron, iron, magnesium or molybdenum increased productivity of phytoplankton. By comparison Brooks Lake phytoplankton samples were stimulated by vanadium, lithium, and molybdenum. A great deal of seasonal variation was observed. However, the study was inconclusive because different cultures reacted differently from each other and from natural communities of phytoplankton.

Carbon 14 productivity experiments were conducted by Goldman (1960) as part of the integrated study of fish production in the Naknek drainage. Results indicate that Naknek Lake is more productive in the top 32.5 ft (10 m) than clear Brooks Lake. However, below 32.5 ft (10 m) Brooks Lake is more productive due to deeper light penetration (Merrell 1964:60).

Highly turbid Iliuk Arm shows a rapid decline in photosynthesis below 23 feet (7m) probably due to light limitations (Goldman 1960:218). Not surprisingly the waters in front of Brooks Camp show a higher rate of photosynthesis than waters in Iliuk Arm (Goldman 1960:227). The depth of the euphotic zone in Brooks Lake ranged from 82 ft (25 m) to more than 164 ft (50 m) with an average of 151 ft (46 m), while Naknek Lake averaged only 53 ft (16 m) with considerable variation in light and turbidity (Goldman 1960:226-227).

One of the most remarkable conclusions to date is the much higher rate of productivity per unit volume (as measured by carbon uptake) in Naknek Lake, as compared to Becharof or Brooks Lake. Carbon fixation in Naknek Lake (range of 8.71 to 14.05 mg C/m^3/day) is three times that of Brooks Lake (range of 1.96 to 4.87 mg C/m^3/day) and 17 times that of Becharof (0.63 mg C/m^3/day in one observation), but the difference in productivity per meter squared of surface area between Brooks and Naknek Lake is not great. Naknek Lake averaged 173.04 mg C/m^2/day, while Brooks averaged 158.32 mg C/m^2/day (Goldman 1960:215-216).

Chlorophyll *a* measurements of Naknek and Brooks Lakes and Lake Coville (Table 15) by Dahlberg (1972:Table 10,1975) and Burgner et al. (1969:417) indicated the highest average standing crop for Lake Coville and Naknek Lake measured 0.9-1.0 mg/m^3, followed by Grosvenor at 0.7 mg/m^3 (Burgner et al. 1969:417) and Brooks Lake at 0.4-0.6 mg/m^3 (Dahlberg 1972:table 10, Dahlberg 1975, Burgner et al. 1969:417). Chlorophyll *a* concentrations peaked at about 66 ft (20 m) in depth on Brooks and Naknek Lakes throughout the summer (Dahlberg 1976:Fig 27-29).

Biesinger (1967) also conducted a series of measurements of primary productivity indicating highest productivity in Coville Lake followed by Naknek and Brooks Lakes and Lake Grosvenor in descending order. Although his methodology did not allow for a simple comparison, his measurements of relative productivity levels seemed to confirm the findings of other investigators on lake productivity. Goldman (1960:226) conducted additional measurements of primary productivity showing little difference between Naknek and Brooks Lake waters when comparing integrated productivity for the entire water column.

Further studies by Biesinger (1967) indicate the relative importance of nannoplankton with cell sizes smaller than 64 microns to productivity of Katmai lakes. From 64%-69% of the total carbon uptake for Brooks Lake was attributed to nannoplankton while in Naknek Lake it measured as much as 86% (Biesinger 1967).

Table 15. Comparison of productivity in Naknek and Alagnak Lake systems.

Drainage Basin and Lakes	Primary Productivity			Chlorophyll *a*		Transparency	
	Number of Samples	Mean C fixaton/4 hour period/ m^2 lake surface area (mg)	Mean C fixation/ 4 hour period/ m^3 euphotic zone (mg)	Number of Samples	Mean concentrations mg/L)	Number of Samples	Mean Secchi disk reading (m)
Alagnak Basin							
Kukaklek	18	22	1.1	4	.6	3	10.2
Nonvianuk	20	24	1.2	4	.5	4	13.2
Naknek Basin							
Coville	411	99	5.9	80	1.0	72	5.4
Grosvenor	553	61	2.9	85	.7	84	8.4
Naknek[1]	810	59	3.4	86	.9	135	4.4
Iliuk Arm	--	--	--	--	--	--	.9
Brooks	832	47	1.7	73	.5	154	10.8

Source: Burgner et al. 1969:417, 1-excluding Iliuk Arm

The primary species of phytoplankton in the Naknek drainage were identified by Goldman (1960:219), Hartman (1958:127) and Merrell (1957:111 and 1964:48). Chrysophyta were most abundant in Goldman's studies, second in abundance were green algae. In Brooks Lake, Merrell (1957:111 and 1964:48) found diatoms consistently most abundant at all depths while green algae were observed to pulse during the summer months. The following year Hartman (1958:126) observed an early July and mid-August pulse, the first being dominated by green algae and the second dominated by diatoms.

Green algae, blue-green algae and diatoms were uniformly distributed throughout the season and at varying depths in Brooks Lake, Naknek Lake and Iliuk Arm (Hartman 1958:126). Diatoms dominated at every depth all summer long in Naknek Lake and Iliuk Arm, and blue-green algae and protozoa were virtually absent from the highly turbid waters of Iliuk Arm (Hartman 1958:126). Brooks Lake exhibited a very different pattern that year with green algae dominant the first half of the summer when diatoms became more abundant and dominated the rest of the season (Hartman 1958:129). In subsequent studies by Merrell (1964:48) diatoms dominated all summer while green algae exhibited a late June-early July and early August pulse.

Although most oligotrophic lakes are deficient in blue-green algae, in Katmai lakes they are relatively abundant (Rawson 1955 in Wetzel 2001). Melosira was generally the most dominant diatom throughout the summer. This species is usually found in eutrophic lakes but has been identified at Brooks and Great Slave Lake in Canada. Other generally eutrophic lake species were found in Brooks as well: Synedra, Fragillaria and Asterionella (Merrell 1964:48).

2. Zooplankton

Merrell (1957 and 1964) first identified the feeding patterns of juvenile sockeye in studies at Brooks, Naknek and Karluk Lakes. It was commonly believed at the time that red salmon were primarily plankton feeders, but his research revealed that insects were far more common than plankton in observations of stomach contents (1957:87, 1958b:85, 1964:36-39). A seasonal shift from insects to plankton was noted as the summer progressed. Merrell concluded that insect production may be more important to the growth and, ultimately, survival of young salmon than plankton (1957:87, 92 and 1964:36). Migration along lakeshores in the littoral zone was explained by the high consumption of insects that could not be captured as readily from deeper waters.

Merrell's conclusions were supported by studies in Kamchatka (Krogius and Krokhin 1956), but refuted by Ricker in studies of Cultus Lake where insects became the most important food item in the diet in spring and fall but was otherwise dominated by *Daphnia spp*. (Ricker 1937 in Wallace 1969:97).

Young salmon in nursery lakes are pelagic zooplankton feeders (Johnson 1961 and Hoag 1972 in Biesinger 1984:2), but little was known about the Alaska sockeye salmon nursery lakes. Wallace (1969:105) reported that genera of zooplankton are differentially selected by limnetic fish in the Naknek system. The composition of limnetic fish varied as well, and he concluded that an understanding of the relationships between limnetic fish and zooplankton selective foraging behavior must include each nursery area in the system.

Wallace (1969:83) found that the ratio of various species in the stomachs of fish varied considerably from one lake to the next and his results did not agree with Merrell's findings. In Lake Coville, for example, stomach contents were 70% cladocerans, 28% copepods and <1% insects. In the south bay of Naknek Lake nearly 70% of stomach contents were copepods, 20% cladocerans and 10% insects (Wallace 1969:86). Insects were relatively more important in the diet, constituting about 20% of the food, of these fish than in other areas, but still not the dominant food in their diet as Merrell had indicated. Wallace (1969:94) also did not find a seasonal variation in the diet of sockeye or pond smelt.

Differential selection of zooplankton species was observed in Naknek and Brooks Lakes and in Lakes Coville and Grosvenor (Wallace 1969:105).

These studies of the stomach contents of fish provide the first list of zooplankton species existing in park waters. Although not exhaustive, the list provides an idea of the species assemblage for Brooks Lake and the relative abundance by species.

Over the course of the summer of 1957, Merrell also collected zooplankton from Brooks Lake using a vertical tow net. He observed a decline in zooplankton abundance throughout the season and large vertical fluctuations due to diurnal migration, which were later confirmed in a second season of fieldwork (Merrell 1957:106, 1964:45, Hartman 1958:120 and Goldman 1964). Merrell (1964:45) proposed two alternative hypotheses on seasonal abundance of zooplankton: progressively less favorable conditions for plankton production or cropping by fish. But observing that fish stomach contents contained a higher proportion of insects in early summer when zooplankton is abundant led to the conclusion that insects are preferred over zooplankton. He further surmised that if fish were the cause of depressed populations of zooplankton, then under conditions of high densities of sockeye salmon, zooplankton could be the factor limiting production. At the conclusion of the Brooks Lake studies Merrell was convinced that zooplankton were not limiting sockeye production in Brooks Lake.

Later studies of 36 Alaska lakes showed that zooplankton biomass was the strongest predictor of smolt size, accounting for 52% of the variation in mean age-1 smolt fork length and weight (Edmundson and Mazumder 2001:644). They also found that smolt density accounted for only 10% of the variance in age-1 smolt size while temperature explained 24% of the variation in fork length and 19% of the variation in weight. Risk of predation in freshwater environments and salmon survival at sea are dependent on smolt size (Henderson and Cass 1991 and Koenings et al. 1993).

In contrast to Brooks Lake, the standing crop of zooplankton is much less dense in Naknek Lake and Iliuk Arm than compared to Brooks Lake, where densities remained at about the same low level all summer. The diversity in limnological conditions in Naknek Lake was reflected in differences in zooplankton populations. As might be expected, the turbid Iliuk Arm had the lowest standing crop of zooplankton, but species diversity was similar to other sample stations (Biesinger 1984:10). Just outside Iliuk Arm where clear waters from Brooks Lake mix with turbid waters from the Iliuk Arm zooplankton are two to three times more abundant than in the Iliuk Arm, but still lower than any other sample stations in the drainage. In Brooks Lake the standing crop of zooplankton was similar across stations, but species composition varied (Biesinger 1984:10).

Goldman (1960) found that zooplankton densities were highest in Coville Lake. Later Dahlberg (1976) recorded zooplankton densities three times greater in Idavain Lake than other basins in the Naknek drainage.

Zooplankton standing crop and species dominance exhibited seasonal variation in Brooks and Naknek Lakes. Two pulses occurred in both lakes with the episodes less pronounced in Naknek Lake. The highest density of zooplankton occurred in July in both lakes, followed by a depression in mid-August. Finally a late summer pulse peaked about the first of September, and a rapid decline followed (Biesinger 1984:11). Pulses were not dominated by the same species.

Annual variation in standing crop was also noted by Biesinger (1984:12). He found zooplankton numbers to be higher in 1963 than in 1962, which he attributed to higher incident solar radiation and primary productivity, which translated into larger populations of plankton (Biesinger 1984:13). The timing of species dominance also varied between years.

Substantial diel vertical migration occurred in the cladocerans and rotifers in Brooks and Naknek Lakes and copepods in Naknek Lake (Biesinger 1984:14-15). Vertical distribution of zooplankton was consistent throughout the water column in Brooks Lake, reflecting the lack of thermal or chemical stratification. Naknek Lake exhibited a much more distinct pattern with the highest density of zooplankton concentrated at about 33 ft (Hartman 1958:122). The density decreased substantially above or below that depth. The least numbers of zooplankton were found at the surface during mid-day.

Copepods were consistently the most abundant zooplankton found in both 1957 and 1958 studies of Brooks Lake. However, Naknek Lake populations were dominated by rotifers while the Iliuk Arm had the highest density of copepods and rotifers were rare (Hartman 1958:122). In a comparison between Karluk Lake on Kodiak Island, a lake of comparable size and in a similar geographic setting, and Brooks Lake Merrell (1964:46-47) found similar composition of zooplankton except for rotifers. In Karluk Lake rotifers were the most abundant zooplankton species (Juday et al. 1932 in Merrell 1964:46), while at Brooks Lake rotifers were only observed in stomach contents of fish and were never captured in net tows.

Eighteen species of zooplankton from the Naknek drainage were identified in a study by Hartman et al. (1963) constituting the first species list for Katmai. Fifteen stations were sampled in that study and including Brooks and Naknek Lakes and Lakes Grosvenor and Coville. He reported no significant difference in species composition between lakes or basins. No information on the relative abundance of each species was indicated.

Biesinger (1984:8) found five species of Copepoda, five of Cladocera and 10 of Rotifera in limnetic samples of Grosvenor, Coville, Naknek and Brooks Lake. *Diaptomus* sp, *Cyclops* sp., *Daphnia longiremis*, *Bosmina coregoni*, *Kellicotia longispina*, and *Conochilus unicornis* were the dominant limnetic forms (Biesinger 1984:8). The distribution of species between lakes varied somewhat.

Most of the cladocerans and rotifers in the Naknek system are widely distributed and abundant in Northern United States, Canada and Alaska while species of copepods found tend to be more restricted to Northern Canada and Alaska (Biesinger 1984:8). *Cyclops strenuus* and *Cyclops capillatus* are generally relatively rare in North America but were numerically the most abundant zooplankers in the Naknek River system (Biesinger 1984:8).

Relative abundance of species also varied between lakes. Rotifers were most abundant in Coville Lake in July where they equaled nearly half the zooplankton in the sample while cladocerans were most abundant in Grosvenor in July and August (Biesinger 1984:9). In Naknek and Brooks Lakes copepods dominated the zooplankton (Biesinger 1984:9).

Pennak (1957) reported that two zooplankton species of the same genus present at the same time as dominants in a lake is unusual. Biesinger’s (1984:9) observations confirmed this theory as dominance of one species of copepod, cladoceran, or rotifer was evident in almost all samples.

3. Aquatic Invertebrates

Alexander (1920) and Merrell (1964) made the only early collections of invertebrates from stream bottoms. Other studies focused on the collection of aquatic insects from stomach contents of sockeye salmon and other fishes and provide a listing of species known to occur (Merrell 1964:40). Merrell (1964) reported that Diptera were the most abundant in shallow waters and decreased considerably with depth. Alexander (1920) collected craneflies in the

Naknek drainage, but did not present information on their habitat preferences. Heard and Hartman (1965) collected stonefly, caddisfly and Diptera from the stomachs of pygmy whitefish and amphipods, ostracods, the pelecypod Pididiu, and nematodes from other species of fish.

Even today, little is known about aquatic insects in Katmai or elsewhere on the Alaska Peninsula. A pilot project conducted by National Park Service staff in 2001 looked at the variability of stream macroinvertebrates by habitat type across the park. Results of the project include species lists by stream and habitat type (Kozlowski, forthcoming).

During the summer of 1958 Branson and Heard (1959:14) found a large population of the snail *Lymnaea emarginata* in Brooks Lake along with smaller numbers of *Menetus cooperi planospirus* and *Valvata helicoidea*. These species were largely restricted to the north side of the lake, 10-25 ft (3 – 7.6 m) below the surface where plant growth occurs. The snails were found in large number in the stomach contents of whitefish and Dolly Varden. Slugs were also collected on this lake. Unidentified species of snails were also observed by Greenbank (1954:6) in Idavain Lake.

The worm *Polycelies borealis* was found to be abundant in the gravels of Brooks River where Merrell (1958b) and Hartman (1958:151) reported finding numerous planaria associated with sockeye salmon eggs and fry during winter.

4. Aquatic Vegetation

Hartman (1958:144) used SCUBA gear to conduct a study of ecological profiles of Brooks Lake. These profiles resulted in maps of vegetation type, percent cover, bottom substrate and fish abundance by depth. He found the shallow water limit of vegetation to be about 11 feet and the deep water limit at 55 ft (17 m) (Hartman 1958:144). *Miriophyllum* was the most abundant in shallow waters, but beyond 15 ft (4.6 m) of depth *Chara* and *Nitella* were more abundant (Hartman 1958:147, Merrell 1958a, Branson and Heard 1959, Hartman, Heard and Strickland 1962, Heard et al. 1969, Heard 1962). Also observed in Brooks Lake were *Ranunculus* sp., *Potomageton praelongus* and some unidentified filamentous algae (Hartman 1958:147, Heard and Hartman 1965).

In Coville Lake, Ellis (1974) and Wallace (1969) described large areas of submerged *Potomogeton*, and Greenbank (1954:6) reported abundant aquatic vegetation (*Potomogeton*, *Scripus*, *Sparganium* and *Equisetum*) in Muriel Lake.

IV. Biological Indicator of Contamination

Scientists have learned that the presence, condition and numbers of certain species can provide information about the health of a waterbody. They can serve as an early warning system for pollution or degradation in a watershed. These plants and animals are known as biological indicators. In freshwater ecosystems these indicators may be fish, invertebrates, periphyton or macrophytes.

Lake trout are sensitive to water flow, sedimentation, and contaminants such as PCBs and organochlorine pesticides. Water flow is necessary to carry away ammonia that fish excrete and which is toxic in high concentrations. Sedimentation also is detrimental to spawning, like other salmonid species. Lake trout also bioaccumulate concentrations of contaminants in their tissues, resulting in fish that may be harmful for consumption. Wilson et al. (1995) sampled trout, as well as grayling, and found a wide variety of organochlorine pesticides and PCBs that were highly concentrated in their muscle and liver tissues. Concentrations of contaminants biomagnified up the food chain. The lake he sampled, Schrader Lake, is a remote lake situated at the foothills of the Brooks Range in the Alaska National Wildlife Refuge, and human use of the lake is very limited. Wilson stated that contamination was due to long-range atmospheric transport. Organochlorine pesticides are entirely man-made organic chemicals used in agriculture and are known to disrupt endocrine and nervous system function in fish, birds and mammals, including humans (U.S. Geological Survey 1996; Colborn et al. 1993). To date, no studies have tested the concentrations of contaminants in lake trout or other resident freshwater species in ecosystems in Katmai.

The slimy sculpin is also a good biological indicator of contamination, particularly organochlorines, semi-volatile organic compound (SVOCs) and trace elements because these contaminants bioaccumulate in their tissues relative to water. The USGS sampled stream sediments and fish tissues to investigate contamination throughout the Cook Inlet region. They found concentrations of contaminants above normal in some areas in Cook Inlet. However, in remote areas, such as the Kamishak River along the Shelikof Strait in Katmai, no contamination was found (U.S. Geological Survey 2000b).

V. Water Quality Standards

State water quality standards designate specific uses for which water quality must be protected and specify the pollutant limits, or criteria, necessary to protect these uses. Seven designated uses for freshwater and seven for marine water are specified in state standards. The seven freshwater uses are: drinking water, agriculture, aquaculture, industrial, contact recreation, non-contact recreation and growth and propogation of fish, shellfish, other aquatic life and wildlife. The seven marine water uses are: aquaculture, seafood processing, industrial, contact recreation, non-contact recreation, and growth and propogation of fish, shellfish, other aquatic life and wildlife, and harvesting raw mollusks and other raw aquatic life for consumption. A copy of Alaska's water quality standards can be found on the state of Alaska web site at: http://www.dec.state.ak.us/water/wqsar/wqs/wqs.htm.

For each of the freshwater and marine uses, the state standards specify criteria for a variety of parameters and pollutants. The criteria are numeric and descriptive. These criteria are used in the 303(d) assessment process to determine if water quality violations have occurred.

Water quality standards also contain provisions for antidegradation, which mimic federal law. The regulation requires protection of high quality waters of a national or state park, wildlife refuge or a water of exceptional recreational or ecological significance.

There are no impaired waters in Katmai, but several sites just outside the park in the community of King Salmon are on the state's 303(d) list of impaired waters. A discussion of these contaminated waters can be found in chapter 6, under "Environmental Risk Factors."

The Environmental Protection Agency (EPA) has developed a set of National Secondary Drinking Water Regulations that are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor or color) in drinking water. EPA recommends secondary standards to water systems, but does not require systems to comply. However, states may choose to adopt them as enforceable standards. Aluminum levels in some park waters exceed these standards. This topic is discussed earlier in chapter 4 in the section on water chemistry.

Some waters in Katmai exceed the recommended levels for some constituents. Although the levels observed are above freshwater criteria, these levels are not the result of human influences, but due to natural sources, such as weathering of bedrock or surficial deposits. Waterbodies exceeding freshwater standards are shown in Table 16. In addition, hot springs in the Valley of Ten Thousand Smokes and Katmai Crater Lake exceed a number of criteria including: sulphate, chloride, arsenic, cadmium, copper, selenium, and zinc (National Park Service 2001a:vi-vii) and LaPerriere (1996:45) observed levels of aluminum in waters of Battle Lake that appeared to exceed the freshwater chronic criterion for the protection of aquatic life.

Table 16. Waterbodies in Katmai that exceed freshwater criterion.

Constituent	Acute Freshwater Criterion	Drinking Water Criterion	Waterbody	Waterbody Level
Beryllium		4 µg/L	One-Shot Creek	5 µg/L
Cadmium	3.9 µg/L	5 µg/L	Battle Lake	9 µg/L
Copper	18 µg/L		Ukak River	34 µg/L
Lead	82 µg/L	15 µg/L	Battle Lake, Brooks Lake, Lake Coville, Lake Grosvenor, Kukaklek Lake and a tributary to Kulik Lake	20 – 90 µg/L
Zinc	120 µg/L		Iron Springs Lake, Up-a-Tree Creek	126-317 µg/L

Source: National Park Service 2001a. Water quality criteria were based on the Environmental Protection Agency's Quality Criteria for Water 1995 Final Draft (Silver Book).

VI. Terrestrial Biota of the Watershed

The biological resources at Katmai are incredible. The park is home to the largest protected population of brown bears in North America and prime spawning habitat for salmon, which is the foundation of the Bristol Bay commercial fishing industry – the largest in the world. During 1972-91, the annual run of sockeye salmon bound for the Naknek and Kvichak drainages averaged 15.3 million fish, 53% of the total Bristol Bay run. From 1985-91, the sockeye escapement into the Naknek drainage averaged 1.8 million, and 5.4 million into the Kvichak drainage (National Park Service 1994).

Diverse floral communities also exist in the park, in part because of the dynamic landscapes (i.e., glaciers, coast, lakes, rivers, etc.) and variation in topography, from sea level to 7600 ft. above mean sea level (msl) (National Park Service 1994). Buck et al. (1978) prepared a comprehensive summary of natural resource information on the Naknek River drainage some of which are reported here.

Water resources are especially important to the perpetuation of Katmai's flora and fauna. The following sections concentrate on the park's biological resources that are federally-listed as threatened or endangered and/or state-listed as endangered or species of special concern, to begin exposing some of the biological concerns that might serve as indicators to water-related issues.

A. Flora

Landcover types for Katmai were defined and mapped by the National Park Service (2002d). Table 17 shows the relative percentages of each cover type in the park, and the landcover map in Appendix D shows where each occurs.

Table 17. Katmai landcover types and relative proportions.

Landcover Types*	Percentage	Total Acreage
Water	8.03	328,420
Shadow/Unclassified	0.06	2,289
Snow/glacier	6.17	252,197
Barren	16.90	691,357
Sparse vegetation	5.15	210,499
Lichen	0.07	2,969
Wet herbaceous	2.66	108,755
Mesic herbaceous	6.44	263,211
Dwarf/shrub/mesic herbaceous	4.96	202,782
Dwarf shrub/moss	0.91	37,137
Dwarf shrub	10.18	416,330
Mixed low/dwarf shrub	2.33	95,323
Low willow shrub	4.11	168,125
Tall willow shrub	3.40	139,121
Tall alder shrub	18.62	761,600
Spruce woodland	1.24	50,801
Mixed broadleaf/needleleaf forest	1.64	67,217
Birch forest	3.16	129,056
Cottonwood/poplar forest	1.64	67,172
Open spruce forest	2.30	94,037
Closed spruce forest	0.04	1,456
	100%	4,089,854

*National Park Service 2002d.

The farthest southwest stand of white spruce occurs in Katmai near Brooks Lake. The largest stands of white spruce occur in the region between Brooks and Nonvianuk Lakes. Large bands of spruce occur on moraine, till and colluvial deposits. Lacustrine deposits of an old lake bed also support islands of white spruce just north of Lake Coville. Large, young stands of white spruce are also common on well drained surfaces in the Savonoski River floodplain.

Along the mountainous slopes surrounding the Valley of Ten Thousand Smokes, willow and alder stands are common. Nitrogen fixing alder are also prominent in the lowland regions of the Walatka Mountains, on steep slopes of the low rounded hills sections of the park east of the Aleutian Range, are interspersed in the open white spruce woodlands, the lower slopes of the Kamishak River drainage and among the Kejulik Mountains.

Coastal communities contribute substantially to the diversity of Katmai. Located southwest of the Aleutian Range, the climate is significantly warmer and wetter than in the Bristol Bay drainages east of the range. Associated with the variety of shoreline types are a variety of biotic communities. Terrestrial communities are closely intertwined with the aquatic communities, some of which are outside the park boundary. The dynamics, productivity, and species diversity of estuaries may be of particular importance to the integrity of the adjacent upland and marine communities.

For a more thorough description of vegetation patterns in Katmai, the reader is referred to “Ecological Subsections of Katmai National Park and Preserve, Alaska” (Shephard 2000).

There are no threatened or endangered species of plants listed by the U.S. Fish and Wildlife Service (2000a, 2001e) in Katmai. Alien flora species reported in the park include: shepherd’s purse *(Capsella bursa-pastoris*), clover (*Trifolium repens*) and pineapple weed (*Matricaria matricarioides*), occurring at disturbed sites within the Brooks River developed area; and bluegrass (*Poa pratensis*) and knotweed (*Polygonum aviculare*) have been collected in Katmai’s backcountry, away from significant visitor use areas (National Park Service 1994).

B. Marine Mammals

Katmai is home to marine and terrestrial mammals and fish, as well as sea and land birds. The species described in the section that follows spend some time in Katmai's aquatic environments. Obviously, fish are more than partial inhabitants of aquatic environments and because of the diversity of species found in Katmai as well as their importance as a component of aquatic habitats they will be discussed separately in chapter 5.

Marine mammals, including Steller (northern) sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina richardsi*), and sea otters (*Enhydra lutris*), are found in the waters and on haulouts along the Katmai coast in the Shelikof Strait. These animals are particularly important and interesting because of their role in the ecosystem and their abilities that enable them to live in a marine environment.

1. Steller Sea Lions

A decline in Steller sea lions (*Eumetopias jubatus*) has been noticed principally in the Gulf of Alaska and Prince William Sound (National Marine Fisheries Service 2000), but a dramatic decline of this species has also been observed along the Shelikof Strait coast of Katmai

(National Park Service 1994). Prasil (1970) observed an average of 627 sea lions (n = 3 surveys) between Capes Gull and Ilktugitak during aerial surveys in June and July from 1968 to 1970. Sea lions were concentrated at two haulout areas at Kuliak rocks and at the islets off Cape Ilktugitak. Peak counts at these two sites in the summer of 1991 totaled less than 40 sea lions (Starr and Starr 1991). At Shakun Reef Rock more than 200 animals regularly have been observed in recent years, but this contrasts sharply with counts of more than 1,000 that were seen during the 1970s (National Park Service 1994).

Because of the decline in Steller sea lions, this species and parts of its habitat are now protected federally and by the state of Alaska. The Steller sea lions in Alaska are protected based on a designation of two separate stocks, separated by a line of 144 degrees longitude. The western stock, two federally protected critical habitat areas, and one unprotected habitat area occur in waters off the coast of Katmai along the Shelikof Strait (National Marine Fisheries Service 2000).

2. Harbor Seals

Harbor seals (*Phoca vitulina richardsi*) have suffered a similar decline to that of Steller sea lions and this decline has occurred in roughly the same time period (Lowry 1989, National Marine Fisheries Service and Alaska Department of Fish and Game 2000). Although they are not a federally protected species under the Endangered Species Act, this species is listed by the state of Alaska as a Species of Special Concern (Alaska Department of Fish and Game 2001f).

Along the Katmai coast, counts by Prasil (1970) from 1968 to 1970 resulted in an expanded average count of 719 harbor seals (n = 6 aerial surveys) from Douglas River to Cape Kubugakli. No recent quantitative data is available about the abundance of this species along the coast of Katmai (National Park Service 2001b).

In areas in the Prince William Sound and the Gulf of Alaska, harbor seals have declined by 80 % over the last 20 years (*Exxon Valdez* Oil Spill Trustee Council 2001). The cause of the decline has been disputed, but many researchers think that effects of the *Exxon Valdez* Oil Spill, which occurred in 1989, are to blame for the recent declines. Also, some biologists believe that populations along the coast are not recovering. The National Marine Fisheries Service and the Alaska Department of Fish and Game have research programs underway to document population trends and important aspects of their life history, habitat, behavior, and factors that may impact their survival, including human disturbance at haulouts (National Marine Fisheries Service and Alaska Department of Fish and Game 2000; Alaska Department of Fish and Game 2000a).

3. Sea Otters

Sea otters (*Enhydris lutris*) are commonly observed on the Katmai coast although no current quantitative information is available about the abundance and residency of these animals near Katmai (National Park Service 2001b). Prasil (1970) reported counts averaging about 150 individuals on the Katmai coast from 1969 to 1970. Moderate densities of otters occur in Kamishak Bay, Cape Douglas, and around the Shakun Islets. Over 500 otters were observed in the Hallo Bay - Shakun Islets area days before oil from the *Exxon Valdez* struck the coast. Impacts of the *Exxon Valdez* oil spill on sea otters along the Katmai coast are not known.

Sea otters are considered to be keystone species, meaning they have an integral role in the ecosystem. They influence the kelp forest ecology by preying mainly on marine invertebrates that graze the kelp. Without this species, kelp forests diminish and the fish that inhabit these ecosystems vacate the area (Estes and Duggins 1995).

Commercial hunting between 1742 and 1911 for pelts almost made the sea otter extinct throughout its range (U.S. Fish and Wildlife Service 2000b). Following this decline and the continued decline that was noticed into the 1990s among the Aleutian Islands population (U.S. Fish and Wildlife Service 2000b), the sea otter was designated as a candidate species. This means that it is being studied to determine if it should be proposed for the listing of threatened or endangered species.

C. Terrestrial Mammals

Terrestrial mammals that are directly associated with freshwater aquatic environments in Katmai National Park and Preserve include the brown bear (*Ursus arctos*), beaver (*Castor canadensis*), and river otter (*Lutra canadensis*). Terrestrial mammals are vehicles for distributing marine-derived nutrients and energy from salmon into the terrestrial ecosystem. Other terrestrial mammals may be indirectly associated with aquatic ecosystems, but only those species that have a direct effect will be considered in this section.

1. Brown Bears

The bears in Katmai are part of the largest protected population in North America, with about 1,500-2,000 individuals. They are not only an important part of the parks ecosystem, but they are also a major attraction for visitors to the park and the surrounding area (National Park Service 1994).

Brown bears are an important component of the park’s ecosystem because of the role they play in facilitating the addition of essential nutrients and energy to the food and energy web in the terrestrial ecosystem. They consume large quantities of salmon, which incorporate marine-derived nitrogen and carbon into their tissues. Through carcass dispersal, elimination and eventually their mortality, bears play a critical role in transport of marine derived nitrogen through the system.

Throughout Katmai, bears congregate at numerous salmon spawning streams to feed. The Brooks River is the most popular bear feeding and viewing area in the park, and through the years the numbers of bears seen at the river has increased. The number of independent bears that can be seen foraging for salmon at Brooks River during the salmon spawning season has steadily increased from about five individuals in the 1970s to more than 50 by 2003 and more than 70 by 2006 (pers. comm. Olson 2007).

Bears in Katmai participate in various activities that depend on the availability of food resources and the climate during the year. Bears hibernate from late fall through mid-May to cope with cold winter temperatures and a lack of food. After hibernating, they descend from their dens to the coastal plain where food is more abundant. Here they disperse and feed on carcasses of marine mammals that have washed ashore, moose calves and adults, plants such as sedges and forbs and a variety if marine intertidal organisms. By mid-July when salmon arrive, bears congregate along streams. During the summer months the distribution of bears largely reflects the distribution of salmon. Following salmon spawning, some bears begin to move away from streams and supplement their diet with berries. Berries may be available near spawning streams, but some bears move away from streams to higher elevations to feed. Increasingly, bears use the coastal plain to feed.

Of all the salmon streams in the park, the Brooks River is particularly important because it is the first place where a significant number of salmon become available to bears. Salmon arrive in late June, peaking in late July. Then, bear numbers in the Brooks River area begin to increase steadily. The fish, which are not yet ready to spawn, are still healthy and are difficult for all but the most skilled bears to catch, making an entertaining and alluring spectacle for tourists.

Bears disperse from the Brooks River as salmon runs diminish and the fish move upstream to spawning grounds. Once spawning occurs in September and October, bears congregate along streams, and there is a second peak in bear activity at the Brooks River and other salmon streams.

The solitary nature and wide-ranging movements of bears make monitoring their populations difficult. Consequently, other than estimates of population density and counts of bears in isolated aerial surveys, there is a lack of information about bear population trends. In the Katmai coastal region, the bear population density is estimated at 550 per 1000 $km^{2,}$ which is the highest recorded density for the species (Sellers et al. 1991). Spring time brown bear population estimates for Katmai Preserve are 131-184, based on 1993 surveys (Sellers et al. 1994). An additional 50 bears are thought to inhabit the Alagnak Wild River corridor. During 1974-80, Will Troyer monitored the numbers and composition of bears aggregated along salmon spawning streams and identified the periods of peak concentration of bears. Monitoring was continued by park staff, beginning in 1983, but was disrupted by the oil spill of 1989. Limited spawning stream bear survey work was reinstated in 1992. Surveys have been carried out in other areas of the Alaska Peninsula by Alaska Department of Fish and Game and U.S. Fish and Wildlife Service staff.

Even though the population density of brown bears in Katmai is the highest recorded for the species, impacts from human activities such as hunting and fishing potentially influence Katmai bear population dynamics. This pulse has continued through progressive age classes and has now resulted in an increase in the number of single, older bears. High salmon escapement levels may have contributed to increased bear survival rates during recent times (Sellers and McNay 1984).

2. Furbearers

The group of terrestrial mammals known as "furbearers" that have a direct effect on the aquatic ecosystem in Katmai includes the beaver (*Castor canadensis*) and the river otter (*Lutra canadensis*). They are subject to harvest in the preserve and in areas adjacent to the park. No information is available on the distribution and abundance of furbearing animal populations in Katmai National Preserve (National Park Service 2001b).

Human harvest of beavers is the main threat to this species. Historically, unlimited numbers of beavers were commercially harvested. Today, beavers are still harvested for their pelts, but the use of this resource is regulated (Alaska Department of Fish and Game 1994g).

Threats to river otters are mostly related to human activities. River otters have no natural predators except humans. Fishing is considered a threat to the river otter. They are prone to entanglement in fish nets and crab pots. Otter are also subject to harvest.

D. Birds

There are 167 species of birds known to be present in Katmai National Park and Preserve (National Park Service 2001c). Species that may occur seasonally in Katmai, although they have not been documented, include the Aleutian Canada goose, American peregrine falcon and bristle-thighed curlew. Birds protected federally under the Endangered Species Act or by the state of Alaska are discussed in another section. Seabirds and individual species with known threats have been summarized below. Information on these species was taken from the 1994 Katmai National Park and Preserve Natural Resource Management Plan.

1. Seabirds

Seabirds spend most of the year feeding at sea and only come on shore to breed. While at sea they must endure powerful ocean storms, demonstrating their remarkable strength in surviving harsh conditions. However, seabird populations are vulnerable to especially adverse human disturbances because they typically have long life spans and low birth rates.

Surveys of seabirds nesting along the coast of Katmai were carried out in 1973 and 1981. These surveys documented the following approximate populations: 9,000 glaucous-winged gulls; 8,000 tufted puffins; 2,800 horned puffins; 2,000 cormorants; 1,000 pigeon guillemots; 900 black-legged kittiwakes; 200 black oystercatchers; 60 harlequin ducks; 25 common eiders; and 20 parakeet auklets.

After the 1989 *Exxon Valdez* Oil Spill, more than 7,000 sea bird carcasses were recovered from the Katmai coast. Restoration needs for coastal birds are still being assessed and long term impacts and recovery may not be known for many years.

Information on the locations of sizes of seabird nesting colonies was obtained in the surveys of 1973 and 1981. Twenty four sites with colonies of nesting seabirds have been identified. These water-oriented species are of particular interest because of their potential vulnerability to oil contamination.

2. Peale's Peregrine Falcons

The Peale's peregrine falcon (*Falco peregrinus pealei*), while reported to be fairly common historically on the Katmai coast, has been rarely seen since the 1989 oil spill. The population of this non-migratory subspecies is not threatened with extinction, but information about the abundance of this species is limited. It is difficult to assess the trends of this species because it is difficult to distinguish from the endangered American peregrine falcon. Few systematic surveys of peregrine falcons have been conducted. No recent, systematic survey information is available concerning the status or trend in the population of peregrine falcons in Katmai.

Occasional sightings of peregrine falcons are reported in the interior of the park. These may have been either Peale’s peregrine falcons or the endangered American peregrine falcon.

3. Bald Eagles

Nesting bald eagles (*Haliaeetus leucocephalus*) are common in Katmai, primarily along the coast and along inland rivers and lakes. The "Protection of Bald and Golden Eagles Act" (16 USC 668-668d) provides special protection for eagles and reflects the public interest in them. Golden eagles may possibly nest in Katmai, but this has not been confirmed. Individuals are occasionally seen in mountainous areas of the park.

Bald eagle nesting surveys were conducted throughout the park by Will Troyer during 1974-80. Surveys have been carried out along specific inland lakes and streams where eagles are most likely to be subject to human disturbance since 1983. The objective of the surveys was to identify trends in the numbers of nesting bald eagles. Extensive coastal bald eagle population and productivity surveys were conducted between 1989 and 1992 in response to the *Exxon Valdez* oil spill.

E. Rare, Threatened and Endangered Species

In an effort to preserve the diversity of all life and prevent the degradation of natural ecosystems, of which people are a part, the United States government under the Endangered Species Act of 1973 identifies and protects wild species and their habitats, which are in decline. Declining species and at least parts of their habitats that occur in Katmai National Park and Preserve are under this protection. Most listed species are marine and occur along coastal areas of the Shelikof Strait side of the park. Federally protected species that are endangered, threatened, or delisted in Alaska include the Steller sea lion, short-tailed albatross, Steller's eider and the Aleutian Canada goose (U.S. Fish and Wildlife Service 2001e).

The state of Alaska cooperates with the federal government in identifying, monitoring and managing wild species that appear to be declining. State listed species include those that have been identified by the federal government in addition to other species. In Katmai, the additional state-listed species are mostly marine and occur along the Shelikof Strait coast. All state listed species are considered endangered or species of special concern. Included in the state's list of species are the short-tailed albatross, Aleutian Canada goose, gray-cheeked thrush, blackpoll warbler, Steller sea lion, harbor seal and the Steller's eider (Alaska Department of Fish and Game 2001f).

Table 18 lists species that may occur in Katmai National Park and Preserve and that are listed either federally or by the state of Alaska.

Table 18. Listed species of birds and mammals and their federal and state status.

SPECIES Scientific Name	Common Name	Population	Federal Status	State Status
Branta canadensis leucopareia	Aleutian Canada Goose	No info.	D	SSC
Catharus minimus	Gray-cheeked thrush	No info.	No rank	SSC
Dendroica striata	Blackpoll warbler	No info.	No rank	SSC
Diomedea albartrus	Short-tailed albatross	Entire species' range	E	E
Eumetopias jubatus	Steller Sea Lion	Western stock: west of 144 degrees longitude	E	SSC
Phoca vitulina	Harbor seal	No info.	No rank	SSC
Polysticta stelleri	Steller's Eider	Alaska breeding population	T	SSC
***Endangered=E**	***Threatened=T**	***Delisted=D**	***Species of Special Concern=SSC**	

Steller sea lions (*Eumetopias jubatas*) have declined throughout the Gulf of Alaska and the Bering Sea during recent decades (Lowry 1989). Thus, the populations, as well as all habitat that are considered "critical" or "essential to the species' conservation, [which are] those that support reproduction, foraging, rest, and refuge," are now protected under the Endangered Species Act (National Marine Fisheries Service 2000). The Steller sea lion was first federally listed in 1990 as threatened under the Endangered Species Act. Then in 1997, the population was split into two stocks to the east and west of 144 degrees longitude and, consequently, their status is considered separately. The western stock is present along Katmai's Shelikof Strait coast and it is listed as endangered. The eastern stock is still listed as threatened (National Marine Fisheries Service 2000). This species is also listed as a species of special concern under the state of Alaska.

Habitat areas protected for Steller sea lions in Alaska include all major Steller sea lion rookeries, haulouts and associated terrestrial, air and aquatic zones around these places. They are protected under the established rule on critical habitat for Steller sea lions (58 FR 45269) (National Marine Fisheries Service 2000).

Along the Katmai coast, major haulouts are included in the established "critical habitat" areas. One critical habitat area is Shakun Rock, located at 58 33.0 degrees N latitude and 153 41.5 degrees W longitude (T. Smith pers. comm. 2001). Another haulout considered "critical habitat" is Cape Kuliak or Kuliak Rocks, located at 58 08.0 degrees N latitude and 154 12.5 degrees W longitude (T. Smith pers. comm. 2001). Cape Ilktugitak, monitored in 1991 by National Park Service staff (Starr and Starr 1991), is not included as an established critical habitat area. The guidelines or limitations of the use of established critical habitat areas are explained in 50 CFR Part 227.12.

Another listed species is the short-tailed albatross (*Diomeda albartrus*), which is federally and state listed as endangered. This is a large sea bird that lives in the North Pacific Ocean. Its range extends from Hawaii to the central Bering Sea, breeding only in Japan (U.S. Fish and Wildlife Service 2000c). Its decline has been attributed to harvesting individuals in Japan from breeding colonies, breeding habitat loss and degradation, longline fishing, plastics pollution, and oil spills (U.S. Fish and Wildlife Service 2000c). The world population dwindled to less than 50 individuals at one point, but there are now about 1,200 (U.S. Fish and Wildlife Service 2000c).

In response to the decline of this species, the short-tailed albatross has been listed federally as endangered since 1973. However, due to an administrative error, its protected range has only recently included areas in the United States. This bird has also been listed by the state of Alaska as endangered. Although individuals are protected, no critical habitat areas have been defined for this species.

In Katmai, this species occurs along the Shelikof Strait coast (Cahalane 1944). Few birds may use coastal areas of Katmai during the winter months, preferring to spend their time in the sea at this time of year (Balogh 2001).

The Steller's eider (*Polysticta stelleri*) is on the federal list of threatened species. The state of Alaska lists this species as a species of special concern. Like the short-tailed albatross, it occurs along the Shelikof Strait coast of Katmai. This species is also a seabird, but it nests in northern Alaska and migrates to wintering and feeding areas in western and southwestern Alaska (U.S. Fish and Wildlife Service 2001c and 2001d). Katmai does not contain any established critical habitat areas for this species.

Another species being monitored is the Aleutian Canada goose (*Branta canadensis leucopareia*). This species is considered a success because of its long and successful recovery program started in 1973 (U.S. Fish and Wildlife Service 2001a). The species was federally delisted on March 20, 2001; but it will be monitored for a five-year period until March 20, 2006. At that point, the U.S. Fish and Wildlife Service will decide if the species requires continued monitoring. The state of Alaska ranks the Aleutian Canada goose as a species of special concern.

Katmai lies within the migratory path of the Aleutian Canada goose between nesting areas in the Aleutian Islands and wintering areas along the western United States coast (U.S. Fish and Wildlife Service 2001a). No information is available about abundance or residency of this species in the park (National Park Service 2001c).

Other species of animals listed as special species of concern under the state of Alaska include the harbor seal (*Phoca vitulina*), gray-cheeked thrush *(Catharus minimus*) and the blackpoll warbler (*Dendroica striata*). While it is known that the harbor seals have suffered a decline similar to the Steller sea lion (National Park Service 1994), little is known about the other species. No studies have been conducted on the gray-cheeked thrush and the blackpoll warbler in Katmai, and only sporadic observations document their presence in the park (Gibson 1970, National Park Service 1970, Boyd 1997).

The Kittlitz Murrelets, while not listed, are of interest because of their habit of nesting in remote areas of Alaska and the Russian Far East, their low nesting density and the extreme difficulty in finding their nests. Only 17 nests of this species had been located by 1983 (Day 1997:271). Since that time only three additional nests have been reported, two of which are located in Katmai National Park and one on the Kamchatka Peninsula (Day 1997:271). Nest sites at Mt. Griggs and Broken Mountain are far from salt water (39 and 32 km, respectively) where the murrelets might be expected to feed (Day 1997:271-2).

Chapter 5: Fisheries

I. Bridging the Gap Between the Sciences of Hydrology, Limnology and Fisheries Management

Pacific salmon, and especially sockeye salmon, play an important and complex role in the dynamics of lakes and streams in Katmai - a role that isn't completely understood despite years of intensive research. Sockeye salmon populations navigate from the high seas to distinct freshwater spawning areas. Fry emerge in the winter or early spring and migrate into a nursery lake where they reside for one or more years. Fry and eggs serve as prey for several species in the nursery lakes, and young sockeye must compete for insects and zooplankton both among themselves and with other species of fish and are in fact prey themselves for larger, resident fish. Eventually the fry transform to smolts and migrate to the sea where they will increase their body weight anywhere from 10-100 times before returning to spawn and die in their natal streams (Hartman and Burgner 1972). Decomposing carcasses contribute substantial amounts of biogenic nutrients to the ecosystem that allow these oligotrophic lakes to be important producers of young salmon.

Given this one example, it isn't difficult to understand that the sciences of hydrology and fisheries must be inextricably linked. Considerations in managing water must take into account the fish populations, as well as other aquatic organisms living in the waters. Heede and Rinne (1989) urge scientists and managers to bridge the gap between the disciplines of hydrology, fluvial morphology and fisheries management. They cite the need for fisheries managers to understand hydrodynamic influences and fluvial morphology effects on fish habitat quality to be better able to predict and understand both detrimental and beneficial effects on stream habitat as a result of natural or human induced changes. Likewise, limnologists and hydrologists must consider the dynamics of fish populations, life history and habits in their understanding of water chemistry and biological factors observed.

Numerous and complex fishery issues extend beyond the objectives of this report. For example, there is escalating sportfishing pressure on the Alagnak River drainage with associated mortality and mutilation of rainbow trout, questions about the origin of some fish populations and parasites such as Salmincola affecting rainbow trout in the Alagnak River. In response to fishery issues such as this, Katmai may initiate the preparation of a fisheries information compilation and needs assessment. This Katmai assessment would have a comprehensive focus that prioritizes the park's information needs to address high-priority fishery issues. It would integrate NPS and state policies and appropriate legislative mandates into park-specific resource management actions.

The scope of this water resource information and issues overview report includes understanding the role of fish in ecosystem functions, documenting and protecting the characteristics of the aquatic environment that sustain their populations, and protecting fish habitat from degradation. Having an understanding of the fish populations in the park is important to understanding the characteristics of its waters. This chapter intends to provide the reader with a basic understanding of fish populations and issues in Katmai that will be, at least partially, addressed in this report.

II. The Importance of Fish to Local People and Katmai's Ecosystem

The average American probably knows fish by the name listed above the sticker price at the local fish market, the type of fish listed on a box of fish sticks or an advertisement for cheddar fish snacks. But in Katmai and the larger Bristol Bay region, fish are extremely important to people for consumption, business and recreation. The local as well as state economies are largely dependent on fish. To Native Alaskans fish are not only a commodity from which some derive cash support, but a part of a way of life that they have depended on for many generations. The subsistence harvest of salmon and other freshwater fish provides the mainstay of the diet for many local people.

The drainages in Katmai support one of the largest sockeye salmon fisheries in the world and a world class rainbow trout fishery. Sportfishermen from around the world spend thousands of dollars to stay at local lodges, using fishing guides to locate the best places to fish in

Katmai and surrounding waters. Salmon, rainbow trout, arctic char and other fish are the focus of their efforts.

Fish are important for the contribution they make to the local economy, for maintenance of the subsistence way of life as well as their importance in aquatic and riparian ecosystems and their unique scientific values. Proclamations establishing Katmai describe these purposes and values in greater detail. Additions to the original Katmai National Monument legislated "…the protection of populations of brown bear, moose and other wildlife and habitats for brown bear and *spawning red salmon*." The Alaska National Interest Lands Conservation Act (ANILCA) redesignated Katmai as a park and preserve and stated purposes for this land, including "…to preserve for the use, benefit, education, and inspiration of present and future generations certain lands and *waters*…that contain…geological, scientific, wilderness…and wildlife values… ." Other purposes, as stated in ANILCA are "…to provide for the maintenance of sound populations of, and habitat for, wildlife species…including those species dependent on vast, relatively undeveloped areas; to protect the resources needed for subsistence needs; and to maintain opportunities for scientific research and undisturbed ecosystems;…*to maintain unimpaired the water habitat for significant salmon populations… ."*

Protecting these water-resource-related park purposes and values provides managers with a significant challenge. Managers are challenged with recognizing the importance of salmon as a commercial commodity harvested by humans, as a subsistence resource harvested by Alaskans for food, as well as for the crucial role salmon play in supporting ecosystem health.

Although salmon and trout are the best known of the fish inhabiting Katmai waters, fish, in general, are an important part of the aquatic ecosystem in Katmai. Twenty-four species of fish are known to occur in the park (Jones et al. 2005). Some of these species are discussed in later sections, relative to their role in the food chain and their contribution to ecosystem function.

The Role of Salmon in Sustaining the Ecosystem

Fish, especially anadromous salmon, provide an important function in the aquatic and riparian ecosystem as facilitators of nutrient cycling. Most of the world's store of nitrogen is found in the world's ocean floor; and salmon, while growing in the ocean, accumulate marine-derived nitrogen in their tissues. When salmon return to their natal streams to spawn and die, their eggs and carcasses are consumed by a variety of different organisms of all trophic levels in the aquatic and riparian ecosystem. Nitrogen, that would otherwise not enter these ecosystems, is used to build amino acids and proteins, which form essential structures for functional biological molecules such as muscle, DNA and enzymes.

In addition to nitrogen, spawning salmon also provide a source of carbon and phosphorus essential to maintaining the production of juvenile salmon and other trophic levels of a stream through excretion and decomposition (Juday et al. 1932, Barnaby 1944, Donaldson 1967, Krohkin 1975, Mathisen 1972, Koenings and Burkett 1987). Kline et al. (1990) evaluated the contribution of ocean-derived nutrients to each trophic level in three sections of

Sashin Creek, Alaska, which is separated by two waterfalls. He found that in the spawning section of the stream, primary producers, macroinvertebrates, and resident fishes contain high concentrations of the marine-derived nitrogen and the marine organic carbon. He observed caddis fly larvae feeding directly on the surface of salmon carcasses. The caddis fly, among other aquatic insects, is a food source for juvenile salmon and other fish. Donaldson (1967) and Mathisen (1972) reported that benthic algae rapidly take up marine-derived nutrients, including nitrogen, carbon and phosphorus, from decomposing carcasses and make them available to higher trophic levels. Salmon carcasses, eggs and newly hatched fry are also sources of nutrients for birds, mammals and fish; and, therefore, these nutrients quickly become distributed throughout aquatic and terrestrial ecosystems. The seasonal abundance of salmon also affects the summer and fall distribution of consumers, such as resident fish, birds and mammals.

Recent research in Alaska has shown that upland as well as aquatic ecosystems depend on the seasonal, marine-derived nutrients from anadromous salmon (Bartz 2002, Naiman 2002, Helfield 2001, Helfield and Naiman 2001, 2002). In fact, the link between salmon and terrestrial/riparian communities is accumulating and building the case for ***salmon as a keystone species*** (Naiman 2002). As a keystone species the population and abundance of salmon affect the integrity and persistence of the entire community (Wilson and Halupka 1995 in Cederholm et al. 2000:65). In fact, Cederholm (et al. 2000) found in Washington and Oregon that 138 species were predators or scavengers of salmon at one or more stages of a salmon’s life. Salmon directly affect the ecology of many aquatic and terrestrial consumers and indirectly affect the entire food web.

An argument may also be made that the lakes of Katmai should be considered keystone habitat based on their ability to produce such large numbers of salmon. These habitats are critical to ecological processes and the health and maintenance of numerous terrestrial and aquatic organisms.

There is abundant evidence that salmon availability influences population dynamics of consumers via the consumption pathway. More carcasses generally mean higher densities and growth of invertebrates. Juvenile salmon may grow faster feeding on salmon tissue and consuming invertebrates (Bilby et al. 1996, Wipfli et al. 1998, 1999, Chaloner and Wipfli 2002). Studies suggest that spawners may elevate stream productivity through stimulating lower trophic levels that support juvenile salmon and other fishes (Wiplfi et al. 1999:1606, Bilby et al. 1996 and Wipfli et al. 1998). More spawners mean higher nutrient inputs and more energy rich detritus for scavengers and detritivores potentially providing more prey for fish. Larger smolts have been shown to have an advantage in survival in the ocean than their smaller counterparts (Bilton et al. 1982, Ward and Slaney 1988 and Holtby et al. 1990 in Bilby 2001:7). The influence spawning salmon have on the growth of juvenile salmon in freshwater may be reflected in an increased rate of survival through their entire life history (Bilby et al. 2001:7).

The influence of returning sockeye salmon on the productivity of lake ecosystems has been well documented (Juday et al. 1932, Kline et al. 1990, Mathison 1972). For example, chronically low salmon returns for several years in Lake Dalnee, Kamchatka, Russia, resulted in: 1) a 20% decrease in annual primary productivity, 2) a 30% decrease in total annual production of zooplankton and 3) a 45% decrease in total annual production of plankton eating fish (including juvenile sockeye) (Krohkin 1975 in Cederholm 2000:62).

Salmon play a critical role in background water quality levels in healthy watersheds. Waters supported by salmon runs may be very different from waters in other ecoregions. Learning more about the range of historic nutrient loadings to freshwater systems is important to our understanding of how declines in salmon runs and disruptions in sub-ecosystems of salmon may be altering biotic communities in Katmai waters.

Although research has been conducted in the cycling of nitrogen, particularly with respect to fish, terrestrial vegetation, lithology and atmospheric inputs, we still lack understanding of the contribution of each to Katmai watersheds. Questions remain regarding what makes some lakes more important producers of sockeye, why nursery lakes, such as Naknek are so important, what factors are the key to their productivity and what effect higher escapements of salmon have on lake and fish productivity. Furthermore, in Alaska streams biotic and abiotic mechanisms exist that capture and retain seasonally available salmon carcasses. What nutrient inputs are required to sustain such a self-enhancing system? How should biogeochemical cycling be incorporated into fisheries management decisions on the number of spawners and carcasses needed to sustain highly productive rearing habitat? Because Katmai is one of the largest spawning and rearing habitats for Bristol Bay salmon, understanding the relationship between salmon and terrestrial and aquatic environments they sustain is critical.

To understand how humans affect aquatic ecosystems, it is essential to understand the role of salmon-derived nutrients in the freshwater ecosystem and the processes of nutrient loading, spiraling, and cycling in streams and lakes. Aquatic systems have metabolisms that function based on physical processes, loading rates of materials, energy and nutrients, rates of primary and secondary production and resulting changes in standing stocks of fishes (Cederholm et al. 2000). Disruptions or altering of the system may have effects that are yet to be fully appreciated.

III. Management of Fish Stocks

A. Management Authority

Fish have always been an important resource for people in the Katmai region. Based on archaeological work in the area, it is evident that early Natives made extensive use of fish. When commercial salmon and the cannery system began soon after the United States purchased Alaska from Russia in 1867, the local subsistence fishery in the region changed. Salmon then became a commodity, and the commercial sale of salmon escalated as markets for salmon opened nationwide. Consequently, harvest of salmon increased throughout Bristol Bay and active management of fish stocks became necessary.

During the early days of commercial fishing on Bristol Bay, only sockeye salmon possessed value. Any fish believed to detract from the all important sockeye runs was considered worthy of eradication, rainbow trout were no exception. During 1920-1925, the U.S. Bureau of Fisheries undertook annual "fish eradication" programs in the Naknek watershed. After a two-year lapse, the eradication program was revived in 1928 in the form of a bounty for each "predator" fish removed from the watershed; the program continued until 1941 (Montague 1974).

Fisheries in Alaska were under Federal jurisdiction from 1867 until 1959 when Alaska became a state. The Bristol Bay commercial salmon fishery was first regulated in 1889 when Congress passed a law prohibiting barricades across rivers and the Secretary of Treasury was authorized to regulate traps (Unrau 1992). The White Act of 1924 established fishing districts and the goal of 50% escapement for the annual run, and outlawed all salmon traps. This law became the basic fishery law of Alaska until statehood in 1959. With statehood, management of fisheries fell largely under the jurisdiction of the new state government. In 1980, when approximately 97 million acres of Alaska were designated as federal conservation units, federal agencies recognized the role of the state in management of fisheries on federal lands. In 1982 the Alaska Department of Fish and Game (ADF&G) and the NPS developed a Master Memorandum of Understanding (MOU). This MOU recognized that Alaska Department of Fish and Game and the boards were mandated the authority and responsibility to manage, control and regulate subsistence, commercial and recreational uses of fish in Katmai, in a manner consistent with ANILCA (Alaska Department of Fish and Game and National Park Service 1982).

However, on October 1, 1999, management of subsistence harvest of fish on federal public lands reverted to the federal government, following the court's ruling on State of Alaska v. Babbitt, 72F.3d 698 (9th Cir. 1995) cert denied 517 U.S. 1187 (1996). The final rule expanded the federal subsistence program to include all waters within and all inland waters adjacent to the exterior boundaries of 34 identified federal conservation units, including waters passing through in-holdings in these areas. The federal subsistence management program expanded significantly with the assumption of fisheries responsibilities. Today, federal and state fisheries and wildlife managers meet together under the terms of an interim memorandum of understanding that was signed in 2000.

In Katmai National Preserve, subsistence harvest of resources, including fish, is permitted by ANILCA (§ 203). ANILCA did not provide a provision to allow subsistence harvest of resources in Katmai National Park. Therefore, subsistence harvest of fish was only allowed in Katmai National Preserve under federal subsistence regulations made by the Federal Subsistence Board. The Code of Federal Regulations was modified (36 CFR 13.66) to allow local residents who are descendants of Katmai residents (lived in the Naknek Lake and River drainage) authorization, in accordance with State fishing regulations or conditions established by the Superintendent, to continue their traditional fishery for red fish (spawned-out sockeye salmon that have no significant commercial value) within Katmai National Park.

Commercial fishing and sport fishing (including areas within Katmai National Park and Preserve and along the Alagnak Wild River) continue to be regulated by the state of Alaska. The Kodiak office of Commercial Fisheries monitors salmon populations spawning in drainages on the Shelikof Strait coast of Katmai from Cape Douglas south to Cape

Kubugakli. The Homer office of Commercial Fisheries monitors populations spawning in the Kamishak and Douglas drainages in Kamishak Bay. The King Salmon office of Commercial Fisheries currently monitors populations spawning in the Naknek and Alagnak drainages. Decisions regarding escapement goals and fishery openings and closings are made in these offices.

B. Effects of Salmon Run Timing and Strength on Park Waters

Humans intercept and harvest many returning salmon and other fish in commercial, subsistence and recreational fisheries. Harvesting of salmon, especially in the commercial fishery, represents the greatest threat to salmon stocks in Katmai. Over-harvest would not only affect salmon populations, but also other fish and wildlife populations and ecosystems which depend on returning salmon for food and nutrients (National Park Service 1999).

Bristol Bay and Katmai, specifically, support one of the largest concentrations of spawning sockeye salmon in the world. From 1972-91, the annual run of sockeye salmon bound for the Naknek, Alagnak and Kvichak drainages averaged 15.3 million fish, 53% of the total Bristol Bay run (National Park Service 1999). On average, approximately 96% of all salmon species harvested in the Naknek/Kvichak Commercial Salmon Fishing District are sockeye salmon (Westing et al. 2006). The other 4% are incidentally harvested salmon including chinook, chum, pink and coho.

The Alaska Department of Fish and Game manages the commercial salmon fishery in the Naknek/Kvichak District for a sockeye salmon escapement of 0.8 to 1.4 million in the Naknek River, 0.32 million in the Alagnak River, and 2.0 to 10.0 million fish in the Kvichak River (Baker et al. 2006). These escapement goals are based on historical spawner-return data and limited smolt data. These numbers represent a Sustainable Escapement Goal (SEG), a level of escapement that is known to provide for sustained yield over a five to ten year period (Baker et al. 2006). In 1991 a record of almost 3.6 million fish escaped the fishery and entered Naknek River to spawn (Table 1). The number was 40% higher than the previous recorded high of 2.6 million in 1980. In 2004, the Alagnak River had a record escapement of almost 5.4 million sockeye, more than 16 times the current escapement goal.

Commercial harvest openings can have a large effect on run strength and ultimately on wildlife and other species, dependent on the run. The commercial drift net harvest of salmon in the Naknek/Kvichak District occurs in Bristol Bay near the mouth of the Naknek River or in the river itself. Since 2001, most of the harvest has occurred in-river in the Naknek River Special Harvest Area (NRSHA). Movement of the fishery into the NRSHA was triggered by the Alaska Department of Fish and Game designating Kvichak River sockeye salmon a stock of “yield” concern in 2001 (Alaska Department of Fish and Game 2003). During fishery openings, pressure on migrating stocks can be intense, nearly cutting off the flow of fish up the Naknek River. In contrast, fishing pressure on Alagnak stocks has been relatively light and record returns have been observed since 2003.

Table 1. Commercial catch and escapement of sockeye in the Naknek-Kvichak District, in thousands of fish, Bristol Bay, 1982-2006. Source: Alaska Department of Fish and Game 2002, Westing et al. 2006.

Year	Naknek-Kvichak Catch	Escapement		Naknek-Kvichak Total Run
		Alagnak River	Naknek River	
1981	10,993	82	1,796	14,626
1982	5,006	239	1,156	7,535
1983	21,559	96	888	26,114
1984	14,547	215	1,242	26,495
1985	8,179	118	1,850	17,357
1986	2,892	230	1,978	6,278
1987	4,986	154	1,062	12,268
1988	3,481	195	1,038	8,779
1989	13,810	197	1,162	23,487
1990	17,272	169	2,093	26,503
1991	10,475	278	3,579	18,554
1992	9,396	225	1,607	15,953
1993	8,908	348	1,536	14,817
1994	16,328	243	991	25,899
1995	20,280	216	1,111	31,646
1996	8,212	307	1,078	11,024
1997	589	218	1,026	3,336
1998	2,595	252	1,202	6,346
1999	9,453	482	1,625	17,757
2000	4,727	451	1,375	8,382
2001	5,281	267	1,830	8,473
2002	1,419	767	1,264	3,722
2003	3,348	3,676	1,831	8,976
2004	4,715	5,397	1,939	15,066
2005	6,706	4,219	2,745	13,484
2006	7,571	1,774	1,953	14,367
25 year average	8,516	807	1,5633	14,953

The timing of the harvest can have an effect on individual fish stocks as shown in the following example. Straty (1963a) learned in the early 1960s that Brooks Lake receives a higher proportion of its escapement from the early portion of the Bristol Bay run than do other lakes in the Naknek drainage. Most other areas derive their escapements from a wider portion of the run. Managing the fishery so that more effort is concentrated early in the season could be detrimental to the number of fish returning to Brooks Lake streams. Over exploitation of the Brooks Lake portion of the run could have disastrous results eventually. In 1960 the first portion of the Naknek run coincided with the Bristol Bay fishermen’s strike, allowing a large escapement of fish early in the season (Hoopes 1962). This was also the year that Up-a-Tree Creek on Brooks Lake received a very large escapement as shown in table 2. The increased escapement observed in Up-a-Tree Creek was not evident in other Brooks Lake tributaries. The run on Up-a-Tree Creek ascended a full two weeks before that of Hidden Creek, the largest sockeye spawning stream of Brooks Lake.

Table 2. Estimated salmon escapement in Up-a-Tree Creek, tributary to Brooks Lake, 1959-1963.

Year	Total fish counted	% of Net Brooks Lake Escapement
1959	542	2.5
1960	1,334	10.8
1961	813	10.2
1962	149	5.5
1963	534	5.4

Source: Hoopes 1962, and Hartman et al. 1962, 1960-63 and 1964 in Buck et al. 1978:226.

The timing of the commercial salmon fishery can also affect wildlife populations which depend on returning salmon. For example, more than 35 bears typically congregate along the Brooks River during the salmon run. Mid-way up the river, a small waterfall slows the upstream migration of salmon to spawning grounds and the resulting congregation of salmon provides an excellent food source for bears. However, extended periods of commercial fishing in the Naknek River can result in fewer fish migrating into Brooks River. With fewer fish at the falls, bears disperse to other areas to feed or to resort to feeding on inferior nutritional sources. These unpredictable cycles, based on the commercial harvest, do not mimic natural cycles in fish abundance or availability.

Fish biologists don’t fully understand why Bristol Bay salmon runs fluctuate so. In the summer of 2001 they were alarmed at the paucity of “two ocean” fish, salmon that have spent two years at sea. The lack of these fish was a bad sign for the strength of next summer’s run. Theories abound for the missing sockeye salmon. Scientists ponder survival rates of small fish entering the ocean from fresh water or subtle changes in the ocean’s food chain. Some fishermen suspect high seas poachers in Russian waters (Anchorage Daily News, Tuesday, November 13, 2001, by Wesley Loy, Section A, Page 1 and 6).

Poor salmon returns, an over-capitalized fishery, and competition from foreign farmed salmon have all contributed to eroding a once lucrative commercial salmon fishery in Bristol Bay. As the fishery and seafood processing change, fishermen struggle to make marginal profits from their catch.

What effect will changes in returns, farmed fish and consumer demands have on the fish populations in Katmai? On the economy of the region? On population genetics? These questions are not easily answered in the short term, but the effects may become apparent as time passes. Clearly, although most of the headwaters of important salmon producing streams are protected in the park, this protection isn't sufficient to provide these fish immunity from either large scale human or environmental impacts that may occur today.

C. Lessons Learned – Preserving Aquatic Ecosystems in Katmai

Less than 200 years ago, or about three lifetimes ago, Lewis and Clark set out on their epic journey in search of a route across America, immersed in expansive wilderness. Not knowing that future generations would have to look through Clark's eyes for a glimpse of what the full American wilderness once was and that his account would become a mystical, national legend, Clark recorded their adventures in the style that captured most landscape painters of the day.

> *From hence [the summit of a mountain near a waterfall], I over looked a most beautiful and extensive plain reaching from the river to the base of the snow-clad mountains to the S. and S. West. I also observed the Missouri, stretching its meandering course to the south through this plain to a great distance, filled to its even and grassy brim. Another large river flowed in on its western side, about four miles above me, and extended itself through a level and fertile valley of three miles in width… In these plains, and more particularly in the valley just below me, immense herds of buffalo are feeding. The Missouri…bearing on its watery bosom, flocks of geese which feed at pleasure in the delightful pasture on either border… (Bakeless 1964)*

Today, many of the ecosystems that they saw have drastically changed or have been lost forever. Once influenced solely by nature, the aquatic ecosystems, in which fish were an integral part, became dramatically altered by human activities. Along the west coast of North America, for example, large runs of chinook (king) salmon occurred in large rivers toward the southern limit of the species' range in the Sacramento-San Joaquin River of California and the Columbia River of Washington. The Sacramento had runs of a million or more until the early 1900s (Clark 1929). Between 1970 and 1989, the winter chinook run alone in the Sacramento-San Joaquin River declined from 40,000 to 500 fish (National Marine Fisheries Service 1996). The primary reason for the collapse of the chinook is thought to be the "degradation of spawning, rearing, and migration habitats"…due mainly to the construction of the Shasta Dam, which was completed in 1945 (National Marine Fisheries Service 1996).

Activities such as logging, mining and especially dams changed the habitat and squelched the populations of "June Hogs," the chinook in the Columbia River that once doubled the size of the Sacramento-San Joaquin River population (Healy 1991). As a result, these chinooks have also declined; and, like other populations of salmon or trout in the Northwest, they are now listed as either threatened or endangered under the Endangered Species Act.

The debate over environmental restoration and waterway usage, which has polarized the state of Washington, was recently described in the April issue of National Geographic Magazine (Montaigne 2001). Along the Columbia River, 14 dams reduce the free-flowing river to reservoirs for cheap power and irrigation water. Today smolts going downstream to the sea get free rides in the cargo holds of boats or in barges operated by the U.S. Army Corps of Engineers. A lot of work, time and money is being spent saving wild stocks of salmon and the fisheries. Also, there is a fierce debate about whether to breach the dams. Other species of salmon and other anadromous fish are either listed or will be proposed as threatened or endangered. Time will tell what will come of the ecosystems in that region of the country, but there certainly will be a passionate debate before a final decision is rendered.

What is different in Katmai National Park and Preserve and most areas in Alaska, however, is that the ecosystems that are essential for fish and other wildlife and the populations of wildlife themselves are largely intact. Therefore, as long as preventive instead of reactive measures are taken to preserve these populations and their habitats, future generations will be able to see and experience wilderness and wild salmon runs for themselves. People will be able to understand the truth to Clark's incredible story and the great American loss that followed in only a blink of time.

We are quickly learning that protection of fish in their natal spawning habitats, although important, may not be enough. Alaska's fish are not immune from suffering environmental and human catastrophes of a magnitude that rivals the declines in west coast fish populations. Climate change and change in sea surface temperatures may cause of some of the salmon population crashes recently observed. Our continual need for petroleum products presents an ongoing threat for contamination of waters.

IV. Status of fish species in Katmai

Katmai supports stocks of salmon and other anadromous and resident species of fish. In all, there are 24 species of freshwater or anadromous fish present (table 3) in the park. Sockeye is the most abundant salmon species in the Naknek and Alagnak drainages.

Three species that are primarily marine have also been found in the park (Heard 1969, Buck et al. 1978, National Park Service 1999). Due to euryhaline abilities (tolerance of a wide range of salinities), they are able to penetrate freshwater "boundaries." Four other marine species have been found off beaches in bays along the Shelikof Strait (Fechhelm et al. 1999). These species and their locations in Katmai are listed in appendix C along with available information about the presence or absence of particular species in a water body. Information in reports cited above primarily is from the Naknek drainage where most research has been focused.

None of the species of fish that are native to Katmai and Alaska is federally listed as threatened or endangered. However, Alaska Department of Fish and Game (2001a) has classified the Kvichak River sockeye as a stock of concern under the guidelines established in the Sustainable Salmon Fisheries Policy.

Table 3: Fishes of Katmai.

Genus/Species	Common Name
Onchorhynchus nerka	Sockeye Salmon/Kokanee
Oncorhynchus tshawytscha	Chinook Salmon
Oncorhynchus kisutch	Coho Salmon
Oncorhynchus keta	Chum Salmon
Oncorhynchus gorbuscha	Pink Salmon
Salmo gairdneri	Rainbow Trout
Salvelinus fontinalis	Lake Trout
Salvelinus alpinus	Arctic Char
Salvelinus malma	Dolly Varden
Prosopium cylindraceum	Round Whitefish
Prosopium coulteri	Pygmy Whitefish
Coregonus nasus	Broad Whitefish
Coregonus pidschian	Humpback Whitefish
Coregonus sardinella	Least Cisco
Thymallus arcticus	Arctic Grayling
Lampetra japonica	Arctic Lamprey
Gasterosteus aculeatus	Threespine Stickleback
Pungitius pungitius	Ninespine Stickleback
Cottus cognatus	Slimy Sculpin
Cottus aleuticus	Coastrange Sculpin
Leptocottus armatus	Pacific Staghorn Sculpin
Osmerus mordax	Rainbow Smelt
Hypomesus olidus	Pond Smelt
Catostomus catostomus	Longnose Sucker
Lota lota	Burbot
Esox lucius	Northern Pike
Dallia pectoralis	Alaska Blackfish

A. Fish and Their Habitat

Salmon and their relationship to freshwater habitats are of great importance. Pacific salmon are believed to have derived from a marine population that evolved to depend more on the freshwater habitat and less on the sea (Thorpe 1982). Collectively, all species of salmon reside in the lakes, main stems of rivers, tributaries and estuaries in Katmai for varying lengths of time at different life stages. The timing of their migration to and from the sea varies by species, allowing for an almost continuous run of salmon throughout the ice free period.

Katmai provides spawning, rearing and migratory habitats for salmon and other anadromous fish; and it provides habitats for resident fish as well. The Alaska Department of Fish and Game (1998) has identified and mapped specific waters throughout Katmai that are important to the spawning, rearing and migration of anadromous fish. The NPS and the Alaska Department of Fish and Game also collaborate periodically to conduct overflight surveys of spawning grounds in the fall (T. Hamon, pers. comm., 2001). Habitats for anadromous and freshwater fish in Katmai are discussed briefly in survey reports (Heard 1969, Buck et al.1978).

Although fish are present throughout most of Katmai, they are noticeably absent in certain areas. Most notable among these areas are Iron Springs Creek, Iron Springs Lake and the streams draining the Valley of Ten Thousand Smokes. In those waters, volcanic ash and bedrock geology contribute to conditions too harsh for most aquatic life. Although some coastal streams are too steep or sediment laden to support salmon, many support aquatic communities that include a variety of fish species. Estuaries are used as nursery habitat by a number of fish species, including smelt, sticklebacks, sculpins, pink salmon and chum salmon.

B. Salmon, Trout, Char, Whitefish and Grayling

Fish in the Salmonidae family that are present in Katmai include Pacific salmon, trout, char, whitefish and grayling. Species of anadromous Pacific salmon in Katmai include sockeye (red), chinook (king), coho (silver), chum (dog) and pink (humpy) salmon. Rainbow trout is the only species of trout known to occur in the park. Species of char include lake trout, arctic char and Dolly Varden. Whitefish that are present include round whitefish, pygmy whitefish, broad whitefish, humpback whitefish and least cisco. Arctic grayling is also present in the park.

All salmon species have similar basic habitat requirements and life history patterns although they typically reside in different areas of freshwater for different lengths of time. Sensitivities to environmental disturbances and activities that may cause disturbances are discussed for each species where information is available. A thorough review of habitat requirements for each species was compiled by the Alaska Department of Fish and Game (1985). Detailed descriptive information about freshwater residence of anadromous salmon in Katmai is relatively sparse and fragmented. Most information available concerns sockeye salmon.

1. Sockeye Salmon

Most sockeye salmon that have returned to their natal streams to spawn are about five years old although the age composition of returning sockeye salmon varies between and within populations from year to year. Returning females vary in age and size more than any other Pacific salmon (Healy 1991). Most anadromous sockeye spawn and rear for 1-3 years in lakes although some rear in streams and others migrate to the sea on emergence from gravel (Burgner 1991). In the sea they grow for another 1-4 years.

After undergoing significant morphological and physiological changes, adult sockeye salmon migrate from the ocean into freshwater rivers and lakes. During their upstream migration, they swim rapidly upstream in schools along the bottom where current is slower, stopping to conserve energy in slow moving water behind objects such as rocks. Throughout migration and until death, they do not feed and depend only on their body reserves of fat and protein to complete their journey and reproduce. Sockeye migrate into many different tributary streams and lakes within Katmai and peak spawning time varies from stream to stream (National Park Service 1999). Sockeye enter the Naknek drainage in late June and peak spawning generally occurs in August; peak spawning in Brooks and Savonoski Rivers and Hardscrabble and West Creeks usually occurs in September (National Park Service 1986b).

Once they reach the spawning grounds, the female sockeye begins the spawning behavior, characteristic of all salmon species. She digs a nest, or depression in the gravel, in which she deposits her eggs and at the same time, the male releases his sperm. Immediately the female covers the eggs with gravel. Mathisen (1962) found that the female repeats this process several more times to build a redd, usually consisting of seven nests. Burgner (1991) notes that under natural conditions, egg loss due to retention, or not dispelling eggs, is not significant; but factors such as disease, parasitism, injury, delay of migration due to stream obstruction, high water temperatures, high spawning density or the lack of available spawning habitat and superimposition of eggs can significantly increase egg retention. Also, like other salmon species, salmon eggs are also vulnerable to mechanical shock, especially early in development. Therefore, any activity such as jet boat use that moves eggs and the gravel in which they are incubating would significantly increase egg mortality.

Typically, sockeye spawning habitat is associated with a lake system which is used for juvenile rearing; and spawning habitats may include rivers, streams, springs, and lake beaches (Burgner 1991). Spawning habitats are often associated with springs and upwelling groundwater which provide clear, cool, and well-oxygenated water to developing embryos. At Katmai, Grosvenor Lake is known to support a high number of beach spawners while Naknek Lake, a rearing area for young salmon, has less beach spawning habitat.

Oxygen is crucial to egg development in all salmon species and, therefore, circulation is an important requirement of spawning habitats. Leonetti (1997) found that along two beach spawning areas at Lake Iliamna, wind-driven currents create microhabitats due to significant differences in water flow. As wind speed increased, he found that the intragravel water flow increased disproportionately as depth decreased. Shallower areas received more circulation. Adequate circulation of redds and nests is necessary for pushing away oxygen depleted water and replacing it with oxygen rich water so that eggs have an adequate supply of oxygen during incubation. This is the stage at which human disturbance, in the form of jet boats, could have their greatest impact on egg mortality.

Eggs and alevins, yolk-sac fry which remain in the gravel after hatching, are vulnerable to environmental disturbances. For example, eggs may hatch prematurely as alevins because of poor circulation due to siltation. Alevins have adaptations that allow them to cope with elevated concentrations of CO_2, low O_2 concentration, decreased water flow and particulates suspended in the water. However, these processes consume energy and with a fixed supply of energy, alevins that must cope with suboptimal conditions expend energy that would otherwise be used for development. This results in a fully formed yet smaller fry (Bams 1969). Size of the fry is important because smaller fry are more vulnerable to predation by fish, and larger fry have an easier time swimming upstream to rearing habitats (Burgner 1991).

Adequate water flow, current, and light are other important factors in the upstream migration to rearing habitats. Brannon (1972) found that changes in current could reverse the rheotactic response of fish, causing them to swim in a different direction. Vision also plays a role in migrating to the rearing nursery area. Thus, clear water is also a requirement. Therefore, for salmon to travel upstream, there must be no obstructions in the water that disturb the water current, flow and turbidity.

Newly emerged sockeye fry occupy limnetic zones, or shallow areas, of rearing lakes from early June through mid-July before moving into the littoral zones, or open water, to feed. In limnetic areas, they feed on primarily aquatic insects under adequate light conditions. Rogers (1968) found that fry are opportunistic feeders; but that in Lake Aleknagik of Bristol Bay, they fed on dipteran larvae, pupae and adults, cyclopoid copepods and cladocerans during the spring and early summer in the limnetic zone. In midsummer they moved into littoral areas, or deeper, open water, to feed on zooplankton. Especially when sockeye populations are large, habitat overlap with other lake resident species, especially threespine sticklebacks, in the Wood, Kvichak, Naknek, Chignik and Karluk River systems, may cause competition (Burgner et al. 1969). Other competitors for food resources include ninespine sticklebacks, pond smelt and pygmy whitefish. Predators of sockeye fry in the nursery and migration corridors include lake trout, arctic char, Dolly Varden char, rainbow trout, northern pike and juvenile coho salmon (Buck et al. 1978). After smoltification, they begin their migration to the sea where they grow for 1-4 years.

Sockeye in some drainages may have a different life history than what has been described. Anadromous sockeye are thought to have two different evolutionary forms: a river and lake type (Wood 1995:200). The type described above is the lake type, which is more ubiquitous in Katmai waters. It is a more precise homer and is adapted particularly to a specific lake system. Genetic variation among tributaries to a specific lake may not be evident, but differences between drainages are common. In 2000 and 2001 a joint study by the ADF&G and U.S. Fish and Wildlife Service showed greater genetic variation than previously speculated. The study showed that Brooks Lake sockeye populations were genetically distinct. Migration obstacles, like Brooks Falls, create an effective bottleneck in the system caused by reproductive isolation of the population. Through genetic drift subpopulations form that are genetically distinguishable from the more homogenous population in the main lake system (Habicht et al. 2003). An additional report on genetic samples from fish in the Naknek drainage is expected to be released in January 2004 (Habicht, C., J.B. Olsen, L. Fair, and J.E. Seeb 2003 from Seeb, pers. comm., 2003).

The sea-river type exhibits a different life history strategy than lake-type sockeye. Rather than rearing in a lake, newly emerged fry either rear in a river or migrate directly to the ocean, spending little time in fresh water. These river-type populations are commonly colonizers of coastal areas and are believed to have colonized habitats after the last ice age. These river-type life histories are more common in northern river systems and have been documented in streams in Alaska, Western Canada and Russia (Wood 1995). Heard et al. (1969) reported a population of sea, or river type, sockeye salmon in Swikshak Creek and mentioned unverified reports of sea-river type sockeye in the Katmai River drainage as well. Sea-river populations of sockeye have been reported in nearby drainages of the Nushagak and Mulchatna Rivers (Russell et al. 1989).

2. Kokanee (Sockeye) Salmon

Katmai is unique in that it contains three populations of landlocked, freshwater sockeye salmon, called kokanee salmon. Kokanee are rare in Alaska (Burger 1991). These salmon are fully adapted to freshwater and, therefore, reside in streams and lakes without migrating to the sea. They live in water accessible or inaccessible to anadromous sockeye. In Katmai, kokanee populations are known to occur in Dakavak Lake (National Park Service 1999), a small, unnamed lake above the Devils Cove portion of Kukak Bay (Heard 1969), and Jo-Jo Lake (Miller et al. 2007). The importance of these fish is that in recent geologic time, kokanee salmon populations have evolved from anadromous runs separately all over the world; and biologists are studying how and why these multiple, replicated divergences occur.

3. Chinook Salmon* (* Denotes anadromous form only.)

From what we know about spawning time and spawning locations, chinook spawn heavily in the Nonvianuk River and downstream in the main stem Alagnak River, with peak spawning occurring at the end of August. They are less abundant in the upper section of the Alagnak, downstream from Kukaklek Lake. They are also less abundant in the Naknek drainage, although they are one of the main sport and subsistence fishes taken in the Naknek River.

4. Coho Salmon*

Coho are present in the Naknek, Alagnak/Nonvianuk, Egegik and Shelikof Strait river systems (Heard 1969). In the Alagnak, they use the main stem and tributary streams for rearing and Nonvianuk and Kukaklek Lakes for spawning. Peak spawning throughout Katmai occurs in early September. Coho are an important sport fish taken in the Naknek system and one of the predominant species present in the Shelikof drainages.

5. Chum Salmon*

Chum salmon occupy the Naknek, Alagnak and Shelikof Strait river systems (Heard 1969). They spawn heavily in the main stem of the Alagnak River and the upper King Salmon River of the Egegik drainage. They are the least abundant salmon in the Naknek system (Buck et al. 1978).

6. Pink Salmon*

Pink salmon spawn heavily in the Alagnak, but they are also present in the Naknek and Shelikof Strait drainages. Pinks, along with coho, are one of the predominant species in the Shelikof drainages, although their abundance peaks every two years.

7. Rainbow Trout

Rainbow trout are a very important species of fish in Katmai. While rainbows are not harvested commercially and are minimally harvested by subsistence users, they support a world class sport fishery and attract anglers from all over the world, especially to the

Alagnak River. All access to the Alagnak is by air, and this area is considered one of the most popular fly-in destinations in Southwest Alaska (U.S. Geological Survey 1999). Rainbow trout are slow growing, freshwater resident fish, inhabiting the large lakes and rivers in the Naknek and Alagnak drainages. They mostly reside in lakes in the winter and migrate to the clearwater main stems to feed and spawn as temperatures begin warming between March and July. Some rainbows permanently reside in rivers (National Park Service 1999, Alaska Department of Fish and Game 1994e).

An interagency study that involved the Alaska Department of Fish and Game, U.S. Fish and Wildlife Service and NPS (U.S. Fish and Wildlife Service and Alaska Department of Fish and Game 1986) tagged and followed the movement patterns of 46 spawning rainbow trout in 1984-85. Their results suggest that there may be distinct populations of trout. Rainbows radio tagged in the Naknek River in the spring did not use the Brooks River or any other tributary to Naknek Lake. Their summer range appeared to be Bay of Islands. In contrast, rainbow trout tagged in Brooks River in June did not move far. Their summer range included Brooks River, Brooks Lake and, to a limited degree, the North Arm of Naknek Lake where some intermingling with Naknek River trout occurred. The data did not definitively indicate whether Brooks Falls provides an effective barrier separating rainbow trout into two distinct populations.

Further study of the abundance and movements of rainbow trout was initiated by the Alaska Department of Fish and Game in 2000. The department sought to improve their understanding of this little known population because of increased sportfishing pressure on rainbow trout in the upper reaches of the Naknek River, the second largest rainbow trout fishery in Bristol Bay. Through radio telemetry they estimated 80% of the adult rainbow trout tagged leave the upper Naknek River by June 8 and move into Naknek Lake for the summer (Schwanke 2003). Some radio-tagged fish moved back into the Naknek River in the fall and both the lake and river were used for over-wintering; although it appears that the river is preferred winter habitat (Schwanke 2003).

Recent research by U.S. Geological Survey fishery biologist, Julie Meka, found that rainbow trout in the Alagnak drainage are from several distinct populations, some residing in lakes for varying portions of the year and traveling to the Braids of the Alagnak to spawn (Meka 2003). Populations from the Kukaklek and Battle River areas mix with fish from the Nonvianuk and Kulik River areas at the Braids but overwinter in their respective lake systems.

Angler days have increased on the Alagnak from about 1,900 in 1981 to an all time high of 13,000 in 1995. Since 1995, the number of angler days has fluctuated. The next highest number of angler days in 1997 totaled 11,062 days. The actual numbers of rainbows harvested during this period have been less than 1,000 fish every year between 1981 and 1999. However, the numbers of fish caught and then released jumped from zero between 1981 and 1990 to about 23,000 fish in 1991. Between 1991 and 1999, the numbers of rainbow trout caught and released have fluctuated, however the number of fish each year has been between about 10,000 and 30,000 fish (Alaska Department of Fish and Game 2001e). The trends and effects of this fishery, especially in relation to rainbows, are largely unknown.

Creel censuses, tagging, mapping of fish concentrations and spawning surveys have been conducted periodically by state and NPS personnel in various areas of the park since the 1950s. Between 1981 and 1985, 2,800 rainbow trout in the Naknek River were tagged. Length frequencies, length/weight relationships and length/age relationships were calculated. The study (U.S. Fish and Wildlife Service and Alaska Department of Fish and Game 1986) concluded that levels of sportfishing were not adversely affecting the size, age, composition, or numbers of rainbow trout in the Naknek River system in 1986. Spawning surveys indicated that there were enough individuals to perpetuate the numbers of trout year after year and provide quality fishing opportunities.

However, more recent data collected by the Alaska Department of Fish and Game (2001c) suggests an overall decline in the number of large rainbows and a decline in the average length and weight of fish caught by anglers. This prompted the Alaska Department of Fish and Game to restrict the catch of rainbows. In 2001, the Alagnak drainage was closed to all sportfishing between April 10 and June 7; gear and bait restrictions were also implemented.

Catch and release practices may be contributing to the decline in rainbow trout. On average a fish can typically be caught 10 times before it dies (National Park Service 1999), and 45% of rainbow trout captured in a recent survey in the Alagnak drainage showed hooking injuries (U.S. Geological Survey 1999). Fish under stress may experience a loss in fitness, reproductive success and premature mortality. In recent studies on the Alagnak Wild River, the fin parasite, genus Salmincola, was observed on approximately 80% of the fish caught (Julie Meka, pers. comm., 2003). Although the parasite is naturally occurring in wild populations, its presence in the Alagnak may be caused by the high stress of multiple hooking injuries due to the popularity of the fishery. The U.S. Geological Survey collected plasma samples to analyze cortisol and glucose levels related to physiological and behavioral stresses in response to handling, exhaustion and repeated air exposure (Meka and McCormick 2005). Their study found increased cortisol and lactate levels in angler captured rainbow trout with an extended angling time. Water temperature was also a factor with fish captured in warmer water having elevated levels of cortisol and lactate. Results from this study indicate the importance of minimizing the duration of angling in catch and release fisheries.

In the same study, hooking injuries were observed in rainbow trout captured in the Alagnak River. The researchers found that, using typical fishing gear, the most commonly injured area was the jaw; the eyes were the next most commonly injured area (Meka 2004). Most injuries were inflicted with barbed, rather than barbless hooks and novice anglers injured proportionally more fish than experienced anglers.

Apart from the Alagnak examples, there are numerous other waterways where recreational fishing is having similar effects on rainbow trout, as well as other species of fish. Recreational fishing has increased since the early 1980s; its popularity is reflected in the increasing visitor use of the park described in the following chapter.

8. Lake Trout

Lake trout are large resident freshwater fish, some probably exceeding 50 pounds (Alaska Department of Fish and Game 1994d). They are top predators and live their entire lives in large, deep, cold lakes. They have a widespread presence throughout the Naknek drainage and are also found in the Alagnak drainage. Their diet depends on available prey and may include macroinvertebrates, zooplankton, small mammals, young birds and other fish such as juvenile sockeye salmon, sticklebacks, pond smelt, whitefish, ciscoes, grayling and sculpins (Alaska Department of Fish and Game 1994d, National Park Service 1999). Because lake trout prey on juvenile sockeye, they were the focus of a predator control program between 1920 and 1925. In total, 9,000 lake trout were destroyed under that program.

Lake trout grow about as slowly as rainbow trout (National Park Service 1999). The Alaska Department of Fish and Game (1994d) characterizes lake trout as typically spawning after seven to eight years, and spawning occurs only once every two years along clean, rocky lake bottoms from September to November. Thus, the Alaska Department of Fish and Game (1994d) states that while the mortality of lake trout under natural conditions is low, this species is sensitive to overharvesting by commercial and recreational fishers.

9. Arctic Char and Dolly Varden Char

The taxonomy of these two species is complex and because of this somewhat confusing taxonomy, there is doubt about exactly where each species occurs, and if distinct populations are present in Katmai. However, previous surveys have identified both arctic char and Dolly Varden char occurring in Katmai lakes, streams and isolated beaver ponds. This location information is presented in table 2, appendix C and listed under “char” instead of the individual species.

Char are thought to occur in Kaguyak Crater Lake – an interesting location given it is a crater lake with no outlet. Heard (1969) reported that he found Dolly Varden char in Kaguyak Crater that were supposedly dropped by local bush pilot, Ed Siler, in 1956. This event is the topic of local legend and lore. If the char are naturally occurring they may provide important information about the environmental history of the area.

Char consume insects, mussels, snails and juvenile fish. Arctic char in Alaska usually occur as lake residents. However, a recent study found the first anadromous arctic char in Alaska in the Bristol Bay region, so it is possible that there may be seagoing arctic char in Katmai (Scanlon 2000). They reach sexual maturity at six or nine years and are thought to spawn every other year from August to October, making them sensitive to overharvest. The spawning habitat is probably steep, broken substrates or gravel shoals deep enough to be protected from winter ice. Arctic char have a homing ability to locate feeding and spawning sites in distinct populations (McBride 1979). Some of the largest arctic char occur in Bristol Bay lakes. These fish are taken in the sports fishery between May and July, as fish feed on salmon smolts.

Dolly Varden char may be anadromous or resident, taking up freshwater residence in lakes and streams. Spawning in streams occurs from mid-August to September. Eggs incubate in the cold streambed gravel usually for four to five months, hatching in March. After hatching, the young Dolly Varden remains in the gravel, subsisting on the energy stored in their yolk sac. Emergence from the gravel occurs between April and June. Migration and movement patterns in fresh water are not well understood, but Dolly Varden, similar to arctic char, are believed to possess a homing ability. Dolly Varden are harvested by both sport and subsistence fishers. The rising popularity of Dolly Varden as a sport fish will likely increase the pressure on this species.

10. Round Whitefish, Pygmy Whitefish, Broad Whitefish, Humpback Whitefish and Least Cisco

Whitefish are another group of salmonid species that live in the waters of Katmai. Their taxonomy is also complex. These fish are important to the ecosystem as a food source for other predatory fish species and some birds. Little is known about the population structure, life history and movement patterns of these fish in watersheds in Katmai although general information is available about this group of fish in Alaska (Alaska Department of Fish and Game 1994f). Spawning generally occurs during September and October in flowing waters and eggs are broadcast into the water column where they sink to the bottom and adhere to the gravel substrate. Eggs develop through the winter and larvae hatch in the spring, emerging during spring runoff.

Round and pygmy whitefish are very common throughout the Naknek drainage in the main stem, lakes and streams. Round whitefish were recently documented in waters of the Alagnak drainage as well (Miller 2003). The greatest density of round whitefish occurs in Coville Lake where they feed on snails, zooplankton, aquatic insects, amphipods and clams. Locally referred to as “candlefish,” they are sometimes the target of sportfishers. Pygmy whitefish principally feed on aquatic insects and zooplankton. Both round and pygmy whitefish move out of Naknek Lake into the lower Brooks River to feed on aquatic insects. There they are known to occasionally eat salmon eggs and are fed on by trout and terns.

Humpback whitefish are also present throughout the Naknek drainage and are concentrated heavily in the principal lakes, particularly Coville Lake. They feed on clams and aquatic snails, and spawning occurs between October and November. They are rarely caught by anglers, but they are subject to subsistence harvest in some areas.

Least ciscoes generally occur in the estuaries, streams and lakes in the larger Bristol Bay drainages and are known to occur in the principal lakes of the Naknek drainage. Whereas other least cisco fish are known to be migratory, the fish in Katmai are believed to be a non-migratory, lacustrine form (Buck et al. 1978, National Park Service 1999). They feed on zooplankton and dipteran insects. They are also a food source for other predatory fish, including northern pike and burbot.

11. Arctic Grayling

Little information is available about arctic grayling in the park; however, they are known to be present as freshwater residents in the Naknek and Alagnak systems (Jones et al. 2005), especially near the vicinity of lake outlet streams. They are considered to be an important sport fish.

Grayling are interesting because they evolved multiple life strategies to cope with harsh conditions while surviving in unglaciated areas in Alaska during the last ice age (Alaska Department of Fish and Game 1994b). For example, unlike other salmonid species, they can survive in water that is very cold and has a low oxygen concentration. Using their homing ability, some grayling migrate to spawning and feeding grounds; and, like other salmonid species, they use these areas year after year. Others complete their life cycle in the same lake or stream. Spawning occurs multiple times after age four or five. They feed on drifting aquatic and terrestrial insects, salmon eggs, salmon smolts and occasionally small mammals, such as shrews swimming on the water's surface.

C. Non-Salmonid Species

1. Arctic Lamprey

Arctic lamprey naturally occurs in Katmai in anadromous and freshwater forms throughout the Naknek system in the main stem, lakes and other rivers. This species was also recently discovered in the Alagnak River (Miller 2003). Most lampreys are freshwater residents. Immatures migrate to Naknek Lake and move to streams to spawn. Arctic lampreys parasitize trout, char, whitefish and sticklebacks. No evidence suggests they are a threat to other fish populations (Heard 1966).

2. Threespine and Ninespine Stickleback

Threespine and ninespine sticklebacks can be characterized in a number of different ways, but most notably and interestingly they have body armor, bony, serrated spines and bony lateral plates, on a short, streamlined body to protect them from predation, especially in marine habitats.

Threespine sticklebacks in Katmai are not known to be anadromous. They are present in the Naknek, Alagnak and coast drainages and may have a wider distribution in habitats where they are known to occur elsewhere. It is possible they are distributed throughout coastal marine, brackish, non-isolated and isolated freshwater habitats in the park. In areas that are recently deglaciated and geologically active, threespine sticklebacks are known to rapidly colonize new freshwater habitats and diverge from the marine populations (Bell 1994).

Divergence from their marine characteristics occurs through rapid morphological changes and reproductive isolation, making them interesting subjects for studying evolutionary biology. As lake or even stream residents, their distribution and number of plates varies extensively among populations, especially those that are isolated. Most of the morphological divergence is due to differences in foraging, predation and reproduction. Recent evidence suggests that morphological changes can occur remarkably fast in freshwater habitats, even within five generations (von Hippel, pers comm., 2001).

By nature, these fish are tolerant to environmental disturbances and colonize harsh environments without faunal competitors. They feed on aquatic insects and are a food source for lake and rainbow trout. Thus, they are not good indicators of environmental disturbances; but they can be described as briefly flourishing and vulnerable to extinction or to periodic recolonization from the sea. However, they are an important component to the ecosystem, and there is interest in studying these fish to understand their distribution and evolution throughout Alaska (von Hippel, pers comm. 2001).

Less information is available about the ninespine stickleback, although they have a similar body structure with bony, serrated spines and bony lateral plates. This fish is present in Katmai with threespines in the Naknek and Alagnak drainages (Miller 2003), but it also inhabits a few other rivers and waters that are isolated, including shallow bog lakes, tundra ponds and beaver ponds. They are also present in isolated waters in association with submerged aquatic vegetation. The "Beaver Pond" near Brooks River is known to contain ninespine sticklebacks. This gives the impression that ninespine sticklebacks may have colonized further into isolated, remote freshwater habitats and may be an integral part of wetland ecosystems.

3. Slimy Sculpin, Coastrange Sculpin and Pacific Staghorn Sculpin

Slimy sculpins and Coastrange sculpins are found in freshwater habitats in Katmai, but the Pacific staghorn sculpin is a marine species that has been found in the park in the Katmai River (Heard 1969). Coastrange sculpins are the predominant sculpin in streams in the Naknek, King Salmon and Shelikof Strait systems (Heard 1969). Slimy sculpins are predominantly found in lakes and are known to occur in the Naknek and King Salmon systems and the Alagnak drainage (Miller 2003) in lakes at depths greater than 100 feet (Heard 1969).

4. Rainbow Smelt* and Pond Smelt

Sometimes called rainbow, arctic or boreal smelt, this smelt is an anadromous species that is known to move into the Naknek River in October and remain in the river until late May. It spawns in Naknek tributaries in April and May (National Park Service 1999). Pond smelt is also present in lakes and rivers in the Naknek system. It is particularly abundant in Coville Lake. It feeds on cladocerans, copepods and dipteran insects and is a food source for other fish and birds, including lake trout, Dolly Varden, gulls and terns.

5. Longnose Sucker

Other than some location information, little else is known about the longnose sucker. They are present in lakes and rivers throughout the Naknek. Spawning in the Brooks River occurs in late May to early June.

6. Burbot

In Katmai, burbot is the only freshwater species of the marine Codfish family. It is a slender fish, resembling an eel, giving it one of its nicknames, the eelpout. It has tube-like extensions from each nostril and from the tip of the lower jaw. It also has dorsal and anal fins that run from the middle of its body to its rounded tail. Burbot are known to be in parts of Naknek Lake and move into the upper eight miles of the Naknek River to spawn. They were recently documented in Nonvianuk and Kukaklek Lakes as well (Miller 2003). They are sometimes associated with submerged vegetation.

Bizarre and interesting spawning behavior has been observed in this species. Individuals group together into a twisting and turning mass under the ice generally between February and March (Alaska Department of Fish and Game 2000b). There they are prey for bald eagles and river otters. They typically broadcast their eggs over a wide area of the streambed. Immature burbot grow rapidly, feeding primarily on invertebrates. Adult burbot feed on invertebrates, fish, and occasionally small mammals.

7. Northern Pike

Northern pike are widely distributed through shallow, sluggish water in lakes, streams and ponds in the Naknek drainage and were recently found in the Alagnak drainage as well (Miller 2003). They naturally inhabit some landlocked ponds and are particularly abundant in the north end of Coville Lake and the northwest basin of Naknek Lake.

8. Alaska Blackfish

The Alaska blackfish has a unique respiratory adaptation that affects its distribution and life history in Katmai. This species not only relies on gills for respiration, but it also has a modified esophagus, which allows it to absorb atmospheric oxygen. Unlike salmon or other fish that are very sensitive to low oxygen conditions, the Alaska blackfish is able to survive using this adaptation in hypoxic, stagnant tundra or muskeg ponds and moist tundra mosses that dry up. They use this organ for respiration until rains fill up the pools again. This adaptation is very rare and the only other fish in the world that is known to have a modified esophagus for respiration is the tropical swamp eel (Alaska Department of Fish and Game 1994a).

Alaska blackfish are typically distributed throughout shallow tundra lakes and ponds where there is densely packed submerged vegetation (Heard 1969). They are known to be present in several lakes in the Naknek system and within the Alagnak drainage (Miller 2003). Aquatic invertebrates are the main food of this species. Larger blackfish eat juvenile northern pike and also other small Alaska blackfish. These fish are slow moving and slow growing. They may spawn multiple times from May to August. Their eggs adhere to the vegetation. Incubation time is sensitive to temperature (Alaska Department of Fish and Game 1994a).Young fish begin feeding after about 20 days.

D. Marine and Euryhaline Fish

Several species of fish have been reported either in freshwater or estuarine parts of rivers in Katmai or along the coastal boundary. These fish are typically marine, but possibly due to euryhaline characteristics, they are able to wander up streams or into waters of reduced salinity. Starry flounder are generally found in the tidally influenced portion of Naknek River, just downstream from the park boundary. They have also been reported in the Katmai River. Greenbank (1954) reported that he collected a Pacific cod from Naknek Lake. Pacific staghorn sculpins were collected from Katmai River (Heard 1969). Fechhelm (1999) collected Pacific herring, a type of sole, tubenose poacher and Pacific sandfish by beach seining in Kukak, Hallo and Swikshak Bays.

Chapter 6: Patterns of Human Use

Although the Katmai area is relatively isolated from major urban centers and the population density is low, the waters are not immune from impacts that plague large population centers. Understanding how water resources are used will allow us to evaluate factors that may contribute to degradation of these primarily pristine waters. It will help us to understand what the risk factors are and focus efforts on the most probable causes of contamination or impact.

I. The Importance of Katmai's Waters to Local People

Waterways have long served as transportation routes for Native Alaskans and early explorers. Following European contact, this trend continued; and it continues today. Waters in Katmai not only provide drinking water for local people, but provide a major source of sustenance for many people in the Bristol Bay region. For these reasons their protection is important to the local people and the economy. The sections to follow describe the various uses of park waters for transportation, drinking water, subsistence harvests and commercial ventures and how these uses are changing.

Bristol Bay is generally conceded to be the richest single fishing ground in the world, with sockeye salmon being the principal species harvested. Four major fishing districts comprise the Bristol Bay fishery: Naknek-Kvichak, Nushagak, Egegik, Togiak and Ugashik.

For more than a century Bristol Bay and Alaska's wild salmon industry dominated the world salmon markets. Then in the mid-1990s the farmed salmon industry emerged and subsequently flooded the world salmon markets. The farmed salmon industry supplied large amounts of cheap, high and consistent quality salmon year round. It caused salmon prices to drop and caused a severe economic disruption in the wild salmon industry. The drop was steep and precipitous for the region's economy.

Only 20 years ago the Anchorage Times (August 19, 1981) read, "Commercial fishermen smash newest record." In Bristol Bay fishermen raked in a record 25.5 million reds, weighing an average of six pounds (an unusually high average) at 76 cents per pound.

Ten years later as salmon runs paled in comparison, the headlines read "Tough season casts pall over Southwest" (Alaska Journal of Commerce, August 19, 1991). The estimated exvessel value (dockside value of fish sold by fishing vessels) of the commercial catch of sockeye was less than $104 million, well below the 20 year average of $128 million and nearly half the previous year's value (Alaska Department of Fish and Game 2002:119). Tough times were to follow, leaving local fishermen with heavy loans and little income.

In recent years, the Bristol Bay area has been declared an economic disaster area due to declining revenue from fishing. In 1997 and 1998 both the state and federal governments declared the area an economic disaster because of failed salmon returns. In 2001 about 15% of the Bristol Bay fleet of over 1,800 boats and 900 beach seiners did not fish because of bleak forecasts for low catch and low prices. Only 13 processing companies operated, compared with about 25 in the mid-1990s. The price for salmon was 40 cents a pound, the lowest since 1975. In 2001 Governor Knowles declared the region a state economic disaster because of combined low salmon returns and weak salmon prices. The value of the commercial sockeye catch for Bristol Bay that year was a mere $38 million – the lowest recorded since 1980 (Alaska Department of Fish and Game 2002:119). The total value of the salmon catch for Bristol Bay in 2001 was only $38 million, compared to an excess of $200 million in 1990 and an annual average of $132 million over the previous 20 years (Alaska Department of Fish and Game 2002:119).

Commercial fishers are not the only losers. The boroughs count on collecting a 2% tax on fish landings. The fishery funded as much as $2.9 million to the Bristol Bay Borough in 1995. This money funded services in 18 villages in the Bristol Bay and Lake and Peninsula Boroughs. With dwindling commercial catches, borough functions began to decline as well. Low escapements in the Kvichak forced managers to close even sport harvest of sockeye, causing a decrease in lodging bed taxes.

Local governments were quick to realize that diversifying the region's economy was a necessary step to keep their communities alive. At least one organization – the Bristol Bay Native Association (BBNA) – recognized the importance of local conservation system units in their long term plan.

The Bristol Bay Native Association developed a comprehensive economic development strategy aimed at shoring up a failing salmon industry and diversifying the region's economic opportunities to sustain them for the long term (Bristol Bay Native Association 2002). BBNA, representing more than 10,000 tribal members and 32 tribal councils in the Bristol Bay region, recognized the importance of protected federal and state lands in the area as being the cornerstone of an increased tourism trade. Almost half the lands in the region (about 14 million acres) are state and federal conservation units. The BBNA plan also recognizes that protecting salmon migratory routes and spawning grounds from impacts is paramount to area residents.

Some developments the BBNA strategy supports are: 1) 6,000 foot runways in villages, allowing direct flights to and from Anchorage, 2) construction of a road from Chignik to King Salmon and 3) examining costs for construction of a road or railway from Anchorage to King Salmon. This latter project is supported by both the King Salmon Traditional Council and the Bristol Bay Borough.

II. Demographics of Surrounding Communities

The area surrounding Katmai National Park and Preserve and the Alagnak Wild River is largely roadless. A 15-mile paved road connects King Salmon and Naknek, and a gravel road leads from King Salmon to Lake Camp on the upper Naknek River. No other roads exist in the area. King Salmon has daily, year round air transportation to and from Anchorage. Many small Bush carriers fly between King Salmon and surrounding villages, lodges and fish camps. Freight is hauled via by-pass mail from Anchorage or by barge from Seattle and Anchorage. Local people travel in the area by vehicle, snowmachine, four wheeler, skiff and airplane.

Surrounding Katmai National Park and Preserve are several communities and military sites, including Naknek, South Naknek, King Salmon, Kokhanok, Igiugig, and Big Mountain. Regional differences exist among these places with respect to their populations, history and the activities of their inhabitants.

A. Naknek River Region

Today, people are living in the Naknek River region in communities that are located nine to 24 miles west and downstream along the Naknek River from Katmai National Park and Preserve. South Naknek and Naknek are located about 24 miles downstream from Katmai's western boundary. South Naknek has a population of 74 people (Alaska Department of Community and Economic Development 2006). In Naknek, the largest community on the river, there are 577 people (Alaska Department of Community and Economic Development 2006). King Salmon is located about 15 miles upriver from Naknek and South Naknek and only nine miles from the park boundary. In 2000 there were 409 people in the community (Alaska Department of Community and Economic Development 2006).

Current population information for communities is provided by the U.S. Census Bureau every 10 years, but that agency does not provide information about future population sizes or trends in growth. Information about population trends is useful in forecasting and reducing impacts to park resources.

To precisely estimate future population trends accurately in these communities, one would need to account for changes that would affect the population number from year to year, including birth and death rates, the age of the population, emigration and immigration. However, the state demographer suggests simply tallying the difference between the past two censuses in 1990 and 2000 and then adding this difference to the 2000 census (Williams pers. comm. 2001). This estimate relies entirely on population figures and assumes constant rates of change from previous years. He based this judgment on his observations that most rural

Alaska villages have had and most likely will continue to have little or no economic development, so these communities would have little or no growth potential that would significantly alter the rates of change and, therefore, population numbers (Williams pers. comm. 2001). Therefore, constant rates of population growth would occur from year to year, and most populations would show a constant trend. Using the U.S. Census information (Alaska Department of Community and Economic Development 2001) and the method previously discussed for estimating future populations, it is possible to estimate population trends in communities along the Naknek River. These projections are shown in the figures that follow for each community.

1. Naknek

Naknek has had a history of human occupation for more than 6,000 years (Alaska Department of Community and Economic Development 2006). The community was first settled by Yup'ik Eskimos and Athabascan Indians, and they compose about 47% of the population (Alaska Department of Community and Economic Development 2006). The population had been steady in the past, but generally increased since about 1980. Figure 1 shows the population trend for Naknek with historical and future projected figures.

In Naknek, jobs are available through a variety of organizations, and people also spend much of their time involved in subsistence activities. Some people work in salmon fishing and processing businesses that operate seasonally. Also, jobs are available through government-funded education, health-related, sewage, trash, airport and cargo dock services and facilities. Private businesses supply electricity, refuse collection and taxi services. There are also two Native organizations, including the Bristol Bay Native Corporation and the Bristol Bay Native Association.

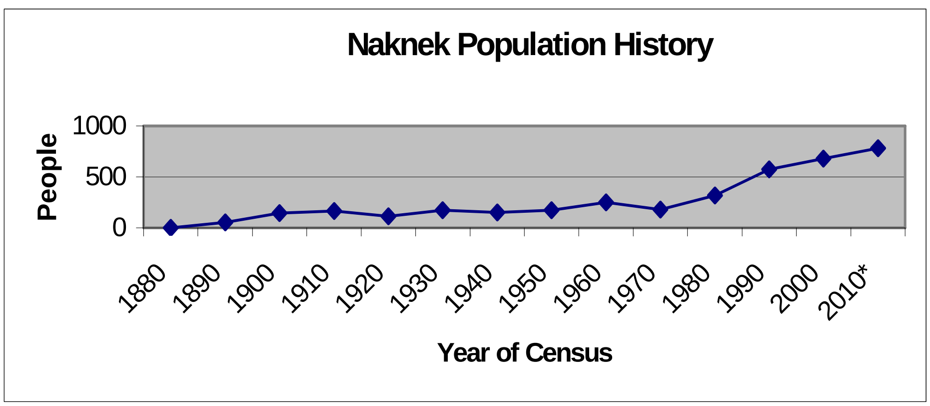


Figure 1. Population trend for Naknek. The population remained steady from 1880, but increased from 1980 to 2000. Extrapolation from the previous decadal census suggest the population is likely to continue increasing [U.S. Census data. NPS projection.]

The economy and population rise seasonally with the salmon fishing season. There is a 15.5 mile road, connecting Naknek to King Salmon, over which salmon are trucked daily. The

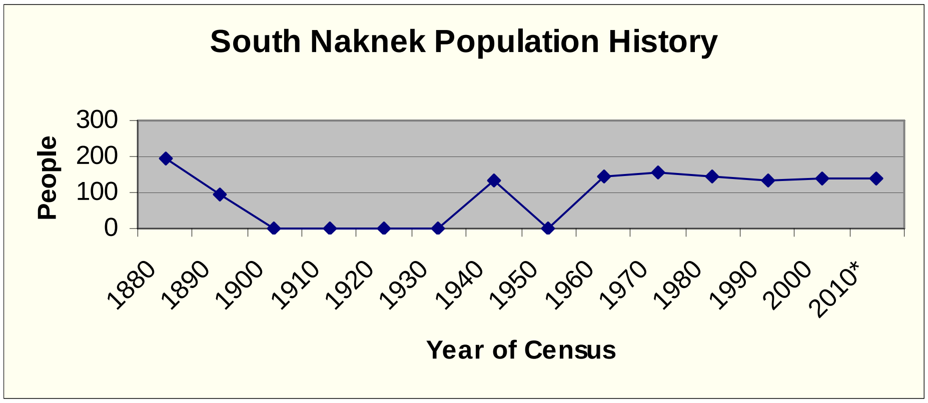
King Salmon airport is large enough to accommodate jets so fish are trucked to the airport and then flown to markets.
Cash that is earned and input into the Naknek economy is generally used to purchase different types of personal equipment for subsistence related activities. For example, people buy skiffs, motors, snowmachines, rifles, nets and other gear from companies outside of Naknek (Alaska Department of Community and Economic Development 2001).

2. South Naknek

Like its neighbor, South Naknek has had a history of human occupation for about 6,000 years. The South Naknek area was originally considered Sugpiaq Aleut territory. People traveled through the Naknek drainage from the South Naknek area and down the Valley of Ten Thousand Smokes to the old village of Katmai and back. They followed the movements of wild food resources throughout this region. After the volcanic eruption in 1912, many people forced to abandon the village of Savonoski relocated to South Naknek. The community was permanently settled following development of the salmon cannery (Alaska Department of Community and Economic Development 2001).

South Naknek is inhabited by a diverse group of people. Although about 84% of the people are Alaska Native or Indian, the remainder of the population is White, Hawaiian Native, Black or Hispanic (Alaska Department of Community and Economic Development 2006).

Figure 2. Population trend for South Naknek. The population figures remained steady for the 40 years from 1960 to 2000, and this stability is expected to continue. [U.S. Census data. NPS projection.]



A variety of activities in South Naknek contribute to its economy. The local economy is dependent on subsistence activities, commercial fishing and fish processing. About 75% of the residents depend on subsistence resources for food (Alaska Department of Community and Economic Development 2001).

Figure 3. A winter's stash of fish is drying on a rack.

3. King Salmon

The population of the community of King Salmon has been declining since 1990. The decline coincides with and could be related to the closure of the King Salmon Air Base in 1994. During that year, almost a third of the population left the community. The method previously used to predict population trends through 2010 is not useful, given the large migration of people out of the area due to the base’s closing. Figure 4 shows the population trend for King Salmon, excluding a projection of a decline in 2010.

Originally, King Salmon was settled by a group of Alaska Native people who were forced to relocate after the eruption of Novarupta in 1912. Today, about 30% of the people are Alaska Native or Indian. Almost 70% of the population is White (Alaska Department of Community and Economic Development 2006).

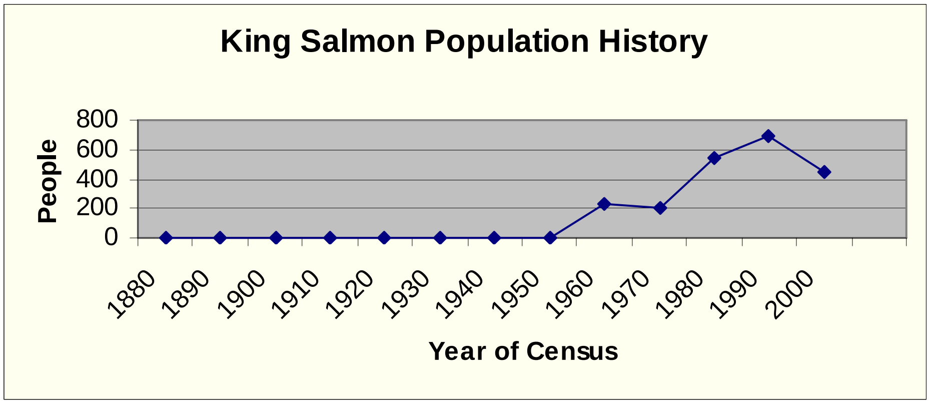


Figure 4. Population trend for King Salmon. The U.S. Census figures show that after 1960, the population increased until 1990. After the peak in 1990, the population decreased. [U.S. Census data.]

More recent settlers in the area were partially a result of increased U.S. military activities in the area. In 1943, the U.S built an air station and later included an aircraft control and warning radar facility as part of a larger effort to build an Alaskan air defense system. Fighter jets and about 300 military, civil service, and contractor personnel were ready and on alert. They accomplished more than 100 intercepts of Soviet aircraft. When the air station was converted to a contractor-maintained contingency field in 1994, all military personnel departed with all jets en route to Elmendorf Air Force Base in Anchorage. Now, the King Salmon military site is operated by 30 contracted personnel and is maintained by a private corporation. The military still continues activities at the site, including Air Force, Army, and Marine training missions, North American Air Defense (NORAD) missions, and the U.S. Coast Guard law enforcement, search, and rescue missions (Elmendorf Air Force Base 2001).

The airport that was built now serves the military and the city of King Salmon. Because of the air base, King Salmon has developed into a transportation, commercial fishing, and government center for Bristol Bay. Jets and smaller aircraft use the airport, especially for transporting fish. Several offices for state and federal government agencies are located in King Salmon (Alaska Department of Community and Economic Development 2006).

B. Southern Iliamna Lake Region

North of Katmai and near Lake Iliamna are the communities of Kokhanok and Igiugig, as well as the military site – Big Mountain. In 2000 there were 53 people in Igiugig and 168 people in Kokhanok (Alaska Department of Community and Economic Development 2006). Big Mountain is an abandoned military site and is currently unoccupied (Wilhelmie pers. comm. 2001).

Kokhanok has steadily grown since 1950. Using the method for projecting population figures discussed earlier, its population is likely to increase in 2010. Figure 5 shows the population trend for Kokhanok.

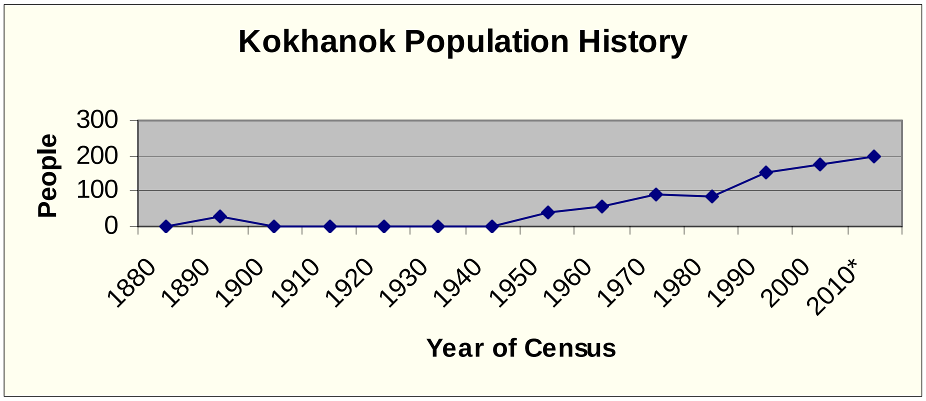


Figure 5. Population trend for Kokhanok. [U.S. Census data. NPS projection.]

Kokhanok is located about halfway along the southern shore of Lake Iliamna in the Kvichak-Alagnak drainage. Based on available information, this community was a fishing village that relocated to avoid unusually high waters of Lake Iliamna. It has had a history of human occupation at least since the first census was conducted in 1880. Today, nearly 91% of the people in this community are Alaska Native. The Alaska Native people now in this community are primarily of Aleut descent, but some people are of either Eskimo or Indian descent (Alaska Department of Community and Economic Development 2006).

Igiugig is another community near Katmai, located west of the village of Kokhanok and at the mouth of Lake Iliamna on the south shore of the Kvichak River. The population in this community has remained relatively stable for the last 40 years, and this trend is expected to continue in 2010.

People have lived in the present day location of Igiugig since at least just before the twentieth century. The current location of the village was originally a fish camp that was used by people in two communities downstream, including Branch (lower Alagnak River) and Kaskanak (Alaska Department of Community and Economic Development 2001). Kaskanak was located on the north shore of the Kvichak River and was populated by Kiatagmuit Eskimos. By the early 1990s villagers from Kaskanak relocated to the present day location of Igiugig. As the community developed over the years, villagers from Branch relocated to Igiugig. Today, the community of Igiugig is primarily Alaska Native, with 83% of the population of mostly Aleut descent (Alaska Department of Community and Economic Development 2006).

In Igiugig, some of the residents travel to Naknek to commercial fish or work in canneries for the summer. Also, seven commercial lodges serve sportfishermen and hunters seasonally (Alaska Department of Community and Economic Development 2006).

III. Subsistence Use of Wild Resources

The subsistence harvest of resources is important to local people in the region. Current regulations only allow subsistence harvest of resources in Katmai National Preserve and along the Alagnak Wild River. Subsistence harvests are not allowed in Katmai National Park.

A. Naknek River Region

People in the Naknek River region harvest, process and distribute various kinds of resources, which are listed in table 1, showing only fish, birds, mammals and eggs. However, people may also harvest vegetation and marine invertebrates.

Table 1. Wild resources used for subsistence by people in the Naknek River region. Vegetation and marine invertebrates that might be harvested are not listed.

Subsistence Resources			
Fish	Mammals	Birds	Eggs
Alaska Blackfish	Arctic Hare	**(Ducks)**	Seagull
Arctic Char	Beaver	American Widgeon	Tern
Arctic Grayling	Beluga Whale	Barrow's Goldeneye	
Broad Whitefish	Caribou	Bufflehead	
Burbot	Harbor Seal	Canvasback	
Dolly Varden	Land Otter	Common Goldeneye	
Humpback Whitefish	Lynx	Common Merganser	
Lake Trout	Marten	Gadwall	
Least Cisco	Mink	Greater Scaup	
Longnose Sucker	Moose	Green-winged Teal	
Northern Pike	Porcupine	Mallard	
Rainbow Smelt	Red Fox	Northern Pintail	
Rainbow Trout	Snowshoe Hare	Northern Shoveler	
Round Whitefish	Walrus	**(Geese)**	
Salmon (all species)	Wolf	Canada Goose	
	Wolverine	Emperor Goose	
		White-fronted Goose	
		(Other species of birds)	
		Lesser Sandhill Crane	
		Snipe	
		Spruce Grouse	
		Willow Ptarmigan	

Harvested subsistence resources are normally taken within a certain geographical range outside of the community. Salmon and non-salmon species, including smelt, rainbow trout, pike, Dolly Varden and grayling, are harvested by people in Naknek, South Naknek and King Salmon. None of the communities extensively rely on freshwater fish for food. Salmon is harvested in quantities of about five times the amount of freshwater fish that is harvested.

B. Southern Iliamna Lake Region

In both Igiugig and Kokhanok, the cash economy is dependent on commercial salmon fishing and guiding. But people are also dependent on the food resources that are harvested in subsistence activities, including salmon and freshwater fish, moose, bear, rabbit, porcupine and seal (Alaska Department of Community and Economic Development 2001). These harvests provide food throughout the year. Table 2 lists resources that are harvested in Igiugig and Kokhanok. Vegetation and marine invertebrates are also harvested, but they are not included in this table.

Subsistence resources are harvested within general harvest use areas, some of which overlap the boundaries of the park and preserve.

Table 2. Wild resources harvested in Igiugig and Kokhanok (Morris 1985 and 1986).

Subsistence Resources			
Fish	Mammals	Birds	Eggs
Alaska Blackfish	Arctic Hare	**(Ducks)**	Cormorant
Arctic Grayling	Beaver	American Widgeon	Duck
Burbot	Black Bear	Barrow's Goldeneye	Herring Gull
Chinook Salmon	Brown Bear	Bufflehead	Seagull
Dolly Varden	Caribou	Canvasback	Tern
Halibut	Dall Sheep	Common Goldeneye	
Humpback Whitefish	Harbor Seal	Common Merganser	
Lake Trout	Lynx	Gadwall	
Least Cisco	Moose	Greater Scaup	
Longnose Sucker	Porcupine	Green-winged Teal	
Northern Pike	Snowshoe Hare	Mallard	
Rainbow Trout		Northern Pintail	
Round Whitefish		Northern Shoveler	
Sockeye Salmon		**(Geese)**	
		Canada Goose	
		Emperor Goose	
		White-fronted Goose	
		(Swans)	
		(Other species of birds)	
		Lesser Sandhill Crane	
		Snipe	
		Spruce Grouse	
		Willow Ptarmigan	

IV. Land Ownership and Use

Not all the lands in the park are federal public lands. A tract of state land near the Kamishak River is the largest inholding in the park (see land status map following this page). Native allotments, village corporation and other private tracts of land also exist along the coast, at the west end of Naknek Lake, at Brooks Camp (see land status map in Appendix D), along the Alagnak and on Nonvianuk, Grosvenor and Naknek Lakes.

The greatest concentration of Native allotments in the Katmai/Alagnak units occurs along the Alagnak Wild River (see land status inset A following this page). The lower end of the river (below the 67-mile-long Wild River) is surrounded by land owned by the Levelock Village Corporation. Much of the land along the Alagnak River near the outlet of Kukaklek Lake is owned by the Igiugig Village Corporation.

Katmailand, Inc. owns and manages five lodges in the park: Brooks Lodge, Kulik Lodge, Grosvenor Lodge, Battle Camp and Nonvianuk Camp. Brooks Lodge is capable of housing up to 60 people per night, Kulik 25 and Grosvenor 6. Battle and Nonvianuk Camps are smaller and do not operate continuously throughout the summer. The lodges are primarily accessible by floatplane. Kulik Lodge is in the unique situation of having a gravel runway for transporting guests from Anchorage directly to the lodge. Kulik, Brooks and Grosvenor Lodges provide guided fishing activities for guests at the lodge or as part of a fly out fishing package.

In 2002 there were seven lodges based along the Alagnak River located on private lands (see land status map in Appendix D), four in the lower 20 miles, one lodge near the outlet of each of the headwater lakes and one about midpoint on the river. Many other lodges from the surrounding area fly clients to the river for day-trip fishing. The easy access and abundant fish populations are major reasons the popularity of the river has grown so quickly. The Alagnak is the second most popular fishing destination in Southwest Alaska.

Enchanted Lake Lodge on Nonvianuk Lake had functioned as a fly out fishing lodge for more than 20 years until sold in the late 1990s. It is now a private lodge with a fleet of airplanes that functions much like other lodges in the park but is not a public use facility. The lodge is on private lands.

There is only one road in the park. The 22-mile Valley of Ten Thousand Smokes Road was constructed during the summer of 1962 at a cost of $150,000. A bus service operated by Katmailand, Inc. transports people along the one lane road to and from the valley trail head at Three Forks Overlook. There is one scheduled trip per day. The road crosses three forks of Margot Creek as it winds its way to the valley.

There are numerous commercial businesses with permits to engage clients in various activities in the park, and commercial use has steadily increased. In 2002, there were 106 Commercial Use Authorization permits (CUAs) for Katmai and 34 CUAs on the Alagnak. There were also five concessions contracts on American Creek, two hunt concessions contracts in the Preserve, and one large contract at Brooks Camp. By comparison, in 2006, there were 133 commercial use authorization permits for Katmai and 41 CUAs for the Alagnak; plus six concessions contracts on American Creek, two hunt concessions contracts, and one large contract at Brooks Camp.

Military Camps and Installations

U.S. military installations near Katmai National Park and Preserve include the King Salmon Air Station and Big Mountain, a White Alice site near Lake Iliamna. Like King Salmon, Big Mountain was built as part of a larger effort to develop an Alaska air defense and communications network. Big Mountain was one of four White Alice installations that were hubs for the entire system of which there were 31 sites in all. It was a tropospheric scatter station, or a long-range radar site that operated from 1957 to 1979. At its peak, there were about 50 to 75 people in Big Mountain to run the facility; but now this site is inactive, and no personnel are stationed there (Elmendorf Air Force Base 2001; Wilhelmie pers. comm. 2001).

The site consists of a 402 acre area on the south shore of Iliamna Lake, near Kokhanok. The main structures on the site are a 7,200 square foot equipment and power building, a dormitory, runway and an automotive maintenance shop. The U.S. Air Force is planning to remove all of the structures and clean up contaminated sites. (Elmendorf Air Force Base 2001; Wilhelmie pers. comm. 2003).

V. Visitor Use in Katmai

Visitation to Katmai National Park and Preserve primarily comes through commercial tour and air taxi operators. Visitors arrive in the park via one of several methods from a number of access points making tracking visitor use difficult. Counting table 3 lists the visitation figures from 1979 and 2000, and figure 6 represents this information in a line graph. There are some significant limitations in the value of these data, but they do represent the best available information to date and show relative trends in visitation over time.

Counts are dependent on the accuracy of information that is submitted and the methods used to create final figures for each year. Counting methods have changed over the years, and the information submitted may not be complete. Therefore, the data do not reflect the actual number of people per year although visitation figures for recent years are have become more accurate as methods are improved.

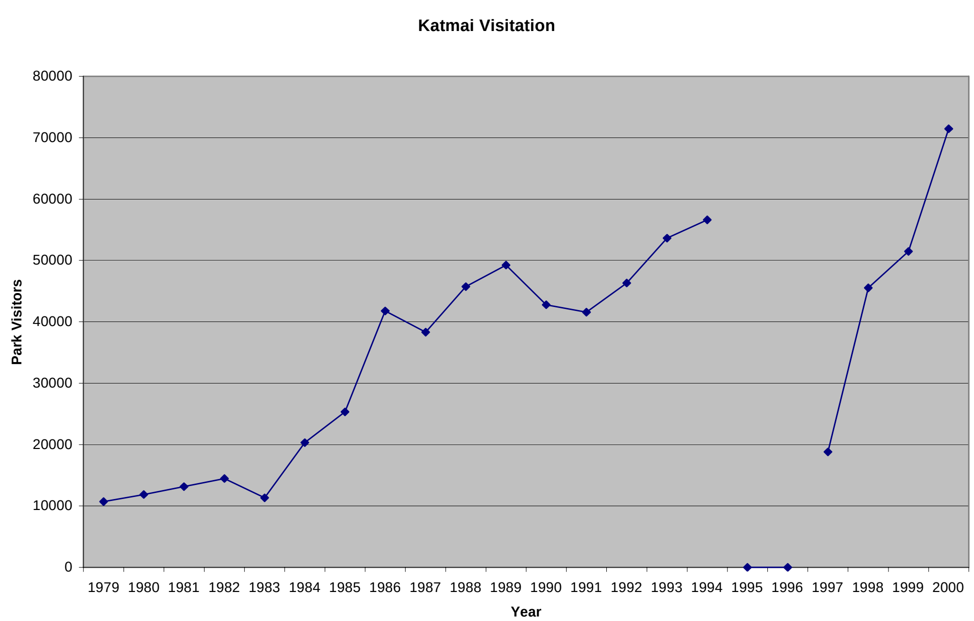


Figure 6. Visitation trend, 1979-2000. The numbers underestimate visitation. Chaotic trends are due to inadequate counting methods.

Table 3. Recreation and non-recreation visitors to Katmai National Park and Preserve between 1979 and 2000. Recreation visitors are people that come to the park for their enjoyment. Non-recreation visitors are those that come to the park for official business, whether it is for the park or for a tour or some other type of organization.

Year	Recreational Visits	Non-recreational Visits	Total
1979	10,659	47	10,706
1980	11,824	44	11,868
1981	13,115	44	13,159
1982	14,377	106	14,483
1983	11,182	157	11,339
1984	20,074	255	20,329
1985	25,142	198	25,340
1986	41,663	113	41,776
1987	38,212	98	38,310
1988	45,710	20	45,730
1989	40,247	9007	49,254
1990	40,778	1991	42,769
1991	41,417	151	41,568
1992	46,196	117	46,313
1993	53,421	201	53622
1994	55,728	896	56,624
1995	No data	No data	No data
1996	No data	No data	No data
1997	18,802	0	18,802
1998	45,470	75	45,545
1999	51,399	75	51,474
2000	71,389	75	71,464

Alaska tourism figures from 1985 show the dramatic increase in out-of-state visitation in the past 16 years. Visitation in 1985 was reported as 450,000 people, jumped to 1.16 million in 1995 and by 1999 had risen to 1.5 million people (Alaska Wilderness Recreation and Tourism Association and Alaska Institute for Sustainable Recreation and Tourism 2001:7). Katmai visitor use statistics reflect that trend.

VI. Recreational Use of Waterways

Along with increasing visitation has come an increase in recreational use of waterways. Access and recreational activities concentrate along water bodies. Commercial operators offer a range of recreational services based solely on water, such as: boating trips, charter boat rental, kayak touring, sportfishing, lake touring, and river trips. Although specific numbers of people engaging in each of these activities is not recorded, the number of commercial operators offering these services is an indictor of the level of visitor use. Commercial operators for Katmai National Park and Preserve and the Alagnak Wild River numbered only 54 in 1993, but had more than doubled by 1999. In 2003 their numbers rose to 140 (Katmai concessions database, Michael Groomer, pers. comm. 2003). Of the total number of commercial operators in 2003, only 33 were permitted for the Alagnak Wild River. Overnight backcountry users have averaged about 2,608 nights in the period from 1982-1992 (NPS file data A2615). However, in the 1990s backcountry overnight stays appeared to be on the rise with a three year average (1990-1992) of 5,521 nights, more than double the 11 year average (NPS file data A2615).

The river and lake route known as the Savonoski Loop on the east end of Naknek Lake is a 5-night, 85-mile boat/portage route. The trip generally begins at Brooks Camp, moves through the Bay of Islands, down Grosvenor Lake and the Savonoski River, along the Iliuk Arm of Naknek Lake and back to Brooks Camp. The number of visitors per year using this route has not been recorded.

Float fishing trips have become more popular during the 1990s. Moraine and Funnel Creeks in the Preserve, American Creek and other areas provide opportunities for fishing and bear watching.

American Creek is a popular and somewhat exclusive fishing destination. Only 6 limited concessions permits are issued for this river, which limits the size of boat and motor that can be used and other activities along the river. Jet boats allow anglers to fish in the shallows of the river where fish congregate.

The Alagnak River has seen an increase in visitor use since the early 1980s, including an increase in high-horsepower motorboats in the 1990s (figure 7). The river supports all five species of salmon, rainbow trout, grayling, arctic char, Dolly Varden and pike and is particularly popular for remote, fly-in sportfishing.

VII. Environmental Risk Factors

Among the highest potential risk factors at Katmai are fuel storage tanks and transfer facilities, fueling operations, and sewage waste systems in developed areas. There are documented problems in some developed areas, and aging systems in all areas should be considered suspect.

Also of great concern is the potential risk of another oil spill along the coast. Some additional training and preparation for such an event has been accomplished. But given another spill near the magnitude of the *Exxon Valdez*, it is doubtful resources exist that could protect the shores from becoming heavily oiled again. This issue is described in detail in chapter 7.

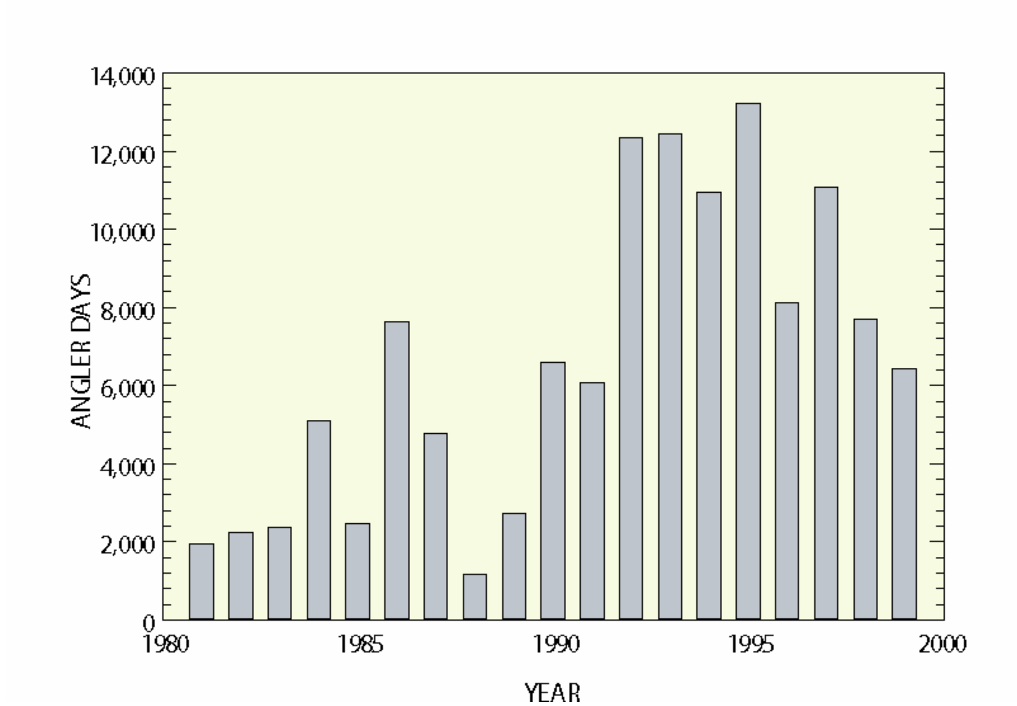


Figure 7. Visitor use of the Alagnak Wild River (as measured in angler days). The angler days number is the sum of the number of anglers on the river multiplied by the respective number of days they fished. These statistics are compiled annually by the Alaska Department of Fish and Game (Naughton and Gryska 2000, Howe et al. 2001 *in* Curran 2003).

Listed Contaminated Sites

Unfortunately, as a result of military use of the area surrounding King Salmon and improper disposal of hazardous wastes, local waters and soil have become contaminated. In the vicinity of King Salmon Airport, there are 22 identified contaminated sites, ranging as far away as Lake Camp at the outlet of Naknek Lake (inside the park). Contaminants include petroleum, oil, and lubricants (POL), trichloroethylene (TCE), total petroleum hydrocarbons (TPH 2,000), a type of petroleum hydrocarbon (DRO), polychlorinated biphenyls (PCBs), arsenic, mercury and lead. Table 4 lists all known contaminated sites at King Salmon, the contaminants and their relative risk rated by the U.S. Air Force.

Two sites, the upper and lower seep, have leaked POL and TCE into the Naknek River. These sites are particularly important because the Naknek River serves as the migration corridor as well as habitat for salmon, resident fish and other organisms. The upper seep is a wetlands seep and connects to the Naknek River. The lower seep is along the river embankment (Elmendorf Air Force Base Environmental Division 2001).

Table 4. Fuel spills and seeps cause most of the contaminants at King Salmon Air Station. They pollute soil, ground water, wetlands, or nearby streams eventually entering the Naknek River. Although these contaminants do not enter the park, they may have an impact on salmon and their food supply, which is a concern for future generations of fish.

Site Name	*Contaminant(s)*	*Relative Risk*
Fire Training Area #1	POL, TCE	High
Fire Training Area #2	TPH 2,000	High
Fire Training Area #3	TPH 2,000	High
Fire Training Area #4	TCE, TPH 2,000	Low
South Barrel Bluff	DRO, Arsenic	High
Landfill #2	None	Medium
Landfill #3	Arsenic	High
Landfill #5	None	Low
Road Oiling	No information	N/A
White Alice Site	PCB's	Medium
Fuel Seep, Eskimo Creek	POL, TCE	High
Fuel Seep, Naknek River	POL, TCE	High
Dry Wells Site	No information	Medium
North Barrel Bluffs	POL, Mercury	High
POL tanks 11, 12, 13, 14	POL, TCE	Medium
Waste Accumulation Area #2	POL	No rating
Waste Accumulation Area #3	POL	High
Pesticide Site	None	Low
Mogas Station	DRO, GRO	Low
Old Power Plant	TCE, DRO	High
Refueler Shop	TCE, POL	High
Eskimo Creek Dump	TCE, Lead	High

Section 305(b) of the Clean Water Act requires that states prepare and submit, every two years, a water quality summary report to the U.S. Environmental Protection Agency (EPA). EPA then forwards the states' water quality reports to the U.S. Congress, which uses this information to make statutory and funding adjustments to national water quality programs. In addition, Section 303(d) of the act requires states to submit to EPA lists of water bodies that meet 303(d) listing criteria. Surface water bodies that are water quality-limited by point or non-point source pollution are listed if they may require additional controls to meet state water quality standards. The water bodies are prioritized based on the severity of the pollution and other factors.

Alaska's 303(d) list and prioritization schedule are divided into two tiers. Two additional tiers added by the state track water body recovery for those water bodies that do not meet the Section 303(d) listing criteria but are of concern. The four tiers are defined as follows:

Tier I: water quality-limited water bodies that require a comprehensive assessment to verify the extent of pollution and determine the controls needed to meet state water quality standards.

Tier II: water quality-limited water bodies with complete assessments that now require a water body recovery plan to meet water quality standards. Sites identified at this level in parks may require participation by NPS in developing TMDLs (A TMDL, or total maximum daily load, is a tool for implementing state water quality standards and is based on the relationship between pollution sources and in-stream water quality conditions.).

Tier III: water quality-limited water bodies that do have a recovery plan that is being implemented but are not Section 303(d) designated. These water bodies are tracked and monitored by the Alaska Department of Environmental Conservation to help ensure complete recovery.

Tier IV: water bodies that are not water quality-limited and do not require any further action.

Water quality-limited water bodies are surface waters with documentation of actual or imminent persistent exceedances of water quality criteria and/or adverse impacts to designated uses as defined in the state's water quality standards. A professional judgment determines "persistent" exceedances of water quality standards and is based on pollutant characteristics and sources, size of the water body and the degree of remediation required.

Criteria for listing a water body under 303(d) include water quality-limited surface waters that do not or are not anticipated to meet applicable water quality standards solely through the implementation of existing technology based on similar controls by the next Section 303(d) listing cycle, which occurs every two years.

ADEC maintains an internal list of suspect surface water bodies and contaminated sites. The process for placing a water body on the 303(d) list begins with the department's internal list of suspected water bodies affected by some type of pollution (Alaska Department of Environmental Conservation 1999). Alaska's 1998 Section 303(d) list and prioritization schedule was revised in June of 1999 (Alaska Department of Environmental Conservation 1999) and is the most current list available. The list includes four water bodies near, but not inside, the park (http://www.state.ak.us/dec/dawq/tmdl/98onepage.htm).

Red Fox Creek, Eskimo Creek and King Salmon Creek are designated high priority, Tier II sites, indicating that a water quality assessment has been completed and a water body recovery plan is required. All creeks are in the town of King Salmon and drain into the Naknek River. King Salmon Creek was placed on the list for petroleum hydrocarbons, metals and pesticides seeping in from a landfill and leaking fuel storage containers. Red Fox Creek is water quality-limited for petroleum hydrocarbon and metals contamination from a landfill and leaking fuel storage containers. Seeps from a dump site adjacent to Eskimo creek have led to stream water contamination by metals, pesticides and petroleum hydrocarbons. A record of decision was signed by ADEC and the Air Force in 2002, formally defining cleanup levels, monitoring requirements, remediation timeframes and specific restoration objectives for these sites (Alaska Department of Environmental Conservation/Department of Defense 2002).

The Naknek River near King Salmon is a high priority, Tier III site contaminated from petroleum hydrocarbons and toxic substances. An inactive landfill and fuel storage site are the sources of contamination, but pollutant sources coming from listed tributary water bodies – Eskimo, King Salmon and Red Fox Creeks - are contributing to already degraded water (Alaska Department of Environmental Conservation 1999). TCE has not been detected above cleanup levels for three consecutive monitoring events occurring in 2000, 2001 and 2002; and petroleum hydrocarbon levels in surface waters are declining (Alaska Department of Environmental Conservation/Department of Defense 2002).

Water bodies affected by oil from the *Exxon Valdez* spill are also in the Tier III list, including beaches along the Alaska Peninsula and adjacent marine waters. These areas were not placed on the Section 303(d) list because a TMDL process would have unnecessarily duplicated efforts of the *Exxon Valdez* Trustee Council and restoration projects specified in the *Exxon Vald*ez Restoration Plan. The restoration plan, which includes the phases of injury assessment, restoration, replacement, enhancement of natural resources and acquisition of equivalent resources, provides long-term guidance for restoring the natural resources and shorelines injured by the oil spill. Scientists and agency representatives funded through approved restoration funds will continue to track and monitor recovery of the natural resources impacted by the oil spill.

Chapter 7: Water Resource Issues

I. Water Rights

A. How important are water rights?

Major water uses compete in some areas of Alaska, including the Bristol Bay region. Mining, oil and gas and fishing industries are the three largest competitors. Tourism and export of water are emerging industries that may produce more conflicts. In addition, developments on, within or adjacent to the park could draw the NPS into conflicts over water rights. The construction of new roads through the area and development associated with oil and gas leasing appear to be the most imminent threats. A determination of water rights is data intensive and may take years requiring both planning and foresight.

Given the fact that in Katmai the headwaters of all major drainages are under park protection, the need to protect instream water rights for park purposes is less critical than in other areas. However, this does not obviate the need for planning and prioritization of data collection to support NPS water rights claims in the future.

The United States (National Park Service) may hold both state appropriative and federal reserved water rights at Katmai National Park and Preserve. As discussed earlier in chapter 2, state water rights are based on the Doctrine of Prior Appropriation. Under this doctrine, the party who first utilizes water for a beneficial use has a prior right to use, against all other appropriators, e.g. “first in time, first in right.” The water must be put to beneficial use as defined by the state. In Alaska, beneficial uses include, but are not limited to, domestic, agricultural, irrigation, industrial, manufacturing, fish and shellfish processing, navigation and transportation, mining, power, public, sanitary, fish and wildlife, recreational uses and maintenance of water quality. An appropriative water right is a property right; under state law it can be bought, sold, and its place of use, purpose, and point of diversion may be changed without loss of priority provided there is no injury to the water rights of others.

Alaska allows the state, an agency or a person, including the United States, to apply to the state to reserve sufficient water to maintain a specified instream flow or level of water at a specified point on a stream or body of water, for (1) protection of fish and wildlife habitat, migration and propagation; (2) recreation and park purposes; (3) navigation and transportation purposes and (4) sanitary and water quality purposes (AS 46.15.145). The state may issue a certificate under this section if it finds that: (1) the rights of prior appropriators will not be affected by the reservation; (2) the applicant has demonstrated that a need exists for the reservation; (3) there is unappropriated water in the stream or body of water sufficient for the reservation and (4) the proposed reservation is in the public interest. The state must review each certificate issued at least once every 10 years and may revoke or modify the certificate if it is considered in the best interest of the state. Alaska is encouraging NPS and other federal agencies to secure instream flow water rights through this reservation process in lieu of federal reserved water rights.

Federal reserved water rights arise from the purposes for which the land was reserved by the federal government. When the federal government reserves land for a particular purpose, it also reserves, by implication, enough water unappropriated at the time of the reservation as is necessary to accomplish the purposes for which Congress or the President authorized the land to be reserved, without regard to the limitations of state law. These purposes at Katmai could include resource and wilderness preservation, wild and scenic river values and purposes defined in ANILCA. The rights vest as of the date of the reservation, whether or not the water is actually put to use, and are superior to the rights of those who commence the use of water after the reservation date. Because these rights are established by federal law, they can only be determined as binding on the U.S. and other water users by a court adjudication. The McCarren Amendment (66 Stat. 560, 43 U.S.C. 666, June 10, 1952) provides the mechanism by which the United States, when properly joined (under AS 46.15.166), consents to be a defendant in an adjudication.

Once adjudicated by the courts, the water rights of the United States, reserved and appropriated, fit into the state priority system along with those of all other appropriators. In general, when it is brought into a general adjudication, the United States is given its only opportunity to assert its claim to water rights. Unless legally absent from the proceedings, it is generally understood that failure to assert a claim to water rights in such a proceeding may result in forfeiture of these rights. No active administrative or judicial adjudications have been initiated by Alaska for the area containing or near Katmai National Park and Preserve.

B. What should be done to address this issue?

√ NPS should develop a prioritized plan for addressing water rights/instream flow data needs in all the Alaska parks. Because water rights determinations will be very costly, this task may be best accomplished as part of an NPS statewide plan, giving consideration first to water bodies threatened by development or other activities.

II. Coordination

Today, multi-agency coordination is essential in all Alaska national park units to effectively monitor and manage the natural resources. Unfortunately at Katmai, 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. Another reason is that Katmai, along with other undeveloped areas in Alaska, lacks the time-sensitive water resource issues or impacts, which typically drive information-gathering projects. The one exception at Katmai is the 1989 *Exxon Valdez* oil spill where multi-agency monitoring projects supported by a monetary settlement are on-going along the Shelikof Strait coastline.

However, NPS has slowly increased its involvement in watershed research and planning with state and federal agencies. As a result, Katmai has been able to take advantage of the hydrological expertise of these cooperators and has generated interest and some limited funding for research. There are several examples of success, including partnerships with USGS, participation on interagency committees and cooperative agreements developed with universities.

Through 2002, 76 USGS/NPS partnership projects have been initiated in 56 NPS units, and the program continues today under the guidance of a revised implementation plan (National Park Service 2002c). One of these partnership projects was recently completed for the Alagnak Wild River. This is a result of the Clean Water and Watershed Restoration Initiative, where the NPS and U.S. Geological Survey are working together to reduce the backlog of NPS water quality monitoring and assessment needs. This program has allowed the USGS to conduct water quality studies on a number of NPS rivers. One result of these three-year projects is the establishment of a water quality baseline for a particular stream or river. The program does not fund long-term water quality studies. In addition, the NPS and USGS have had a 10-year running interagency agreement that allows USGS to assist NPS in gaging, floodplain delineation and watershed analysis.

The U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program has one study unit in Alaska, the Cook Inlet Basin Study Unit. Initiated in 1996, the Cook Inlet Study Basin includes the extreme northeastern part of Katmai (U.S. Geological Survey 1997). Funded by the NPS Water Resources Division as a demonstration NPS/USGS partnership project, a synoptic investigation was conducted by Frenzel and Dorava (1999), of the U.S. Geological Survey, on the Kamishak River in Katmai, which is located within the NAWQA Cook Inlet Study Basin. There have been no permanent NAWQA sampling sites established within the park (Frenzel pers. comm. 2003). The U.S. Geological Survey's water quality monitoring in the Cook Inlet Basin documented both the largely undeveloped areas and the small, but locally significant urban areas. The primary water quality issue in the Cook Inlet Basin is related to salmon spawning and rearing.

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 1997a). It is important for the NPS to be actively involved in these and other similar efforts to effectively voice its natural resource needs and contribute to the information databases. The Alaska Department of Environmental Conservation has expressed an interest in coordinating with Katmai and other NPS units in Alaska on water resource issues (Decker pers. comm. 2002).

In 1998 the Department of Interior bureaus in Alaska developed a strategic plan for DOI waters (U.S. Department of Interior 1998). The agencies recognized that inadequate information about water resources could lead to costly litigation and poor management decisions. The most critical needs where water resource data does not exist were identified for: 1) water rights, 2) ownership of submerged lands, 3) protection of parks, refuges and wild and scenic rivers, 4) management of fish and wildlife, 5) flood warning and risk analysis and 6) allotment of land to Alaska Natives (U.S. Department of Interior 1998:5). The group developed an ambitious five year program to begin rectifying the long list of data needs. Unfortunately, lack of funding has not allowed implementation of many critical components of the plan. Without funding, implementation of the plan can only be realized through individual activities of the bureaus.

The USGS designed the National Streamflow Information Program (NSIP) to establish long term stream gauges throughout the nation. If fully implemented, the program would provide Alaska with a set of index gauges. However, the program has not received financial support from Congress. In fiscal year 2002 two new gauges were installed as a result of Congressional add-ons but the fiscal year 2003 budget does not provide funding for any additional gauges (Gordon Nelson pers. comm. 2002).

A key element for effective use of 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 ensures that data are collected in an efficient and effective manner, without duplication of efforts. All USGS data are available on the National Water Information System web site. Other bureaus may serve data on the web as well, but there is no coordinated effort to merge databases. 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).

Katmai has had some success in coordinating water-related projects with other agencies (in addition to the USGS) and universities. In 1996, the NPS and U.S. Fish and Wildlife Service entered into an interagency agreement, which specified that the U.S. Fish and Wildlife Service would conduct a baseline study of potential hydrocarbon contamination within selected waters in Katmai. A final report that summarizes the findings from this effort was completed in 1999 (Johnson and Berg 1999). Also in 1996, the University of Alaska Fairbanks completed the report, *Water Quality Inventory and Monitoring – Katmai National Park and Preserve* as part of an Interagency Agreement with the NPS (LaPerriere 1996). Katmai should continue to encourage these and other partnerships to meet the information needs of the park.

Village and borough strategic environmental plans often contain water resource goals and objectives that mirror those of NPS. Actively working with local villages may provide opportunities in the future for cost sharing, for collaboration to achieve common goals or provide opportunities for NPS staff specialists to assist in implementing education goals set by village leaders.

What can be done to improve communication and coordination?

- ✓ Continue to coordinate and assist in the multi-agency coastal monitoring projects to evaluate impacts and recovery of natural resources from the 1989 *Exxon Valdez* oil spill.
- ✓ Work closely with the U.S. Geological Survey on studies occurring in Katmai and synoptic studies associated with the Cook Inlet NAWQA program (i.e., Kamishak River).
- ✓ Work with the Soil and Conservation Service to assist in the establishment of snow depth survey stations.
- ✓ Continue to participate in the Alaska Department of Environmental Conservation and U.S. Environmental Protections Agency's statewide effort to improve watershed management.
- ✓ Participate in the state's Alaska Clean Water Action initiative.
- ✓ Initiate cooperative efforts between Katmai and the Alaska Department of Environmental Conservation, supported by Clean Water Act funding, to address high priority water-related issues.
- ✓ Work in concert with tribes, boroughs and local communities in achieving common goals such as wetlands mapping and education programs.

III. Coastal Zone Management

With the exception of the Little Kamishak River drainage, Katmai encompasses the entire watersheds of coastal streams within its boundaries. Nonetheless, these waters may still be at risk. Water quality as well as the nutrient budget of the aquatic and terrestrial ecosystems could be significantly affected by anything that affects the upstream migration of salmon.

Oil and gas exploration in Bristol Bay has long been a concern. Local people and their representatives have fought against oil and gas lease sales in the Bay in hopes of protecting their subsistence and commercial harvest of salmon. Now with several years of disastrous salmon seasons behind them and perhaps dim memories of the *Exxon Valdez* spill on the opposite shore, the Bristol Bay Native Corporation is supporting oil development in the region (Anchorage Daily News, Sunday, June 15, 2003). In 1988, leases were sold in the North Aleutian Basin Sale 92 area, and the federal government received bids for leasing 122,000 acres. The *Exxon Valdez* oil spill occurred several months later, intensifying opposition to the sale; and it was eventually canceled and the monies returned to the oil companies.

Although Bristol Bay is not directly adjacent to the park, salmon entering the Naknek and Alagnak drainages pass through Bristol Bay waters on their journey to the sea as smolts and on their return again as adults. Salmon populations destined for park waters would therefore be vulnerable to any adverse environmental conditions that may result from oil and gas production in Bristol Bay.

Katmai's 398 miles of marine coastline along the Shelikof Strait are at constant risk from environmental threats associated with petroleum development, storage, and/or transportation. Oil and gas development in Shelikof Strait as well as Cook Inlet is a potential risk factor. Nine exploratory wells were drilled in Southern Cook Inlet in 1979 and 1980. Two were drilled in Shelikof Strait in 1984-85. Periodic offshore oil and gas lease sales have occurred in this area; and with diminishing supplies of oil in the United States, these areas may become more attractive as time passes.

The Valdez terminal in Prince William Sound receives approximately 24 billion gallons of oil per year via the Trans Alaska Pipeline. Shipping from the terminal has proven to be hazardous to lands far from the Port as evidenced by the spill from the *Exxon Valdez* that quickly reached the Katmai Coast. Closer to the park, there are 15 production platforms operating in Cook Inlet. Explosions, fires and blowouts are risks of these offshore platforms, and several small fires and blowouts have occurred on Cook Inlet platforms since the 1960s. Fortunately, the safety record of Cook Inlet platforms is far better than platforms operating in the Gulf of Mexico. Between 1956 and 1990 at least 1,075 large explosions, fires or blowouts erupted from platforms in U.S. waters, most in the Gulf of Mexico (O'Harra 2001). Industry authorities in Alaska cite a workplace culture that has an emphasis on safety above production for their good record. 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 more than 3.3 billion gallons of oil per year (Potts et al. 1993).

The strong currents and a high tidal range along the Alaska coast can transport spills great distances from their source. The current runs up the east side of Cook Inlet toward Anchorage and flows back down the west side along the Alaska Peninsula coastline. The current, coupled with storm patterns in the area, almost assure that wastes will come ashore along the Katmai Coast.

As a result of the *Exxon Valdez* oil spill, visitation along the Katmai Coast has increased dramatically. The once little known coastline became a major attraction for tourists as fishermen who lost their livelihood following the spill began transporting groups to the Katmai Coast for bear viewing trips. Since 1989 a lodge has been established at Kukak Bay, and vessels from Kodiak and even cruise ships are discharging passengers on the coast for bear viewing and fishing. In 2002 commercial operators brought 2,980 clients to various areas on the coast staying a total of 3,280 user days (Katmai concessions database, pers. comm. Michael Groomer 2003).

The State of Alaska Department of Natural Resources (DNR) manages the tidelands adjacent to Katmai's coast. Several years ago, the DNR received applications for the placement of permanent mooring buoys adjacent to Katmai to accommodate commercial operators who are engaged in conducting bear viewing and fishing trips. The NPS objected to the issuance of such mooring buoy permits adjacent to the designated wilderness, especially in ecologically sensitive bays such as Amalik/Geographic Harbor, Kaflia Bay and Kukak Bay, until such time as a joint management agreement or plan could be drafted. The state expressed interest in working with the NPS, and the NPS worked jointly with the state to assemble baseline information about resources and uses along the coast. Public input was also solicited. The DNR has identified the coastal area adjacent to Katmai as a potential "Special Use Area" to be designated in recognition of the complexities of the rich coastal and upland resource, the rapidly increasing public and commercial uses of the area and the conflicting demands for public use. (Alderson pers. comm. 2003).

No water resource data has been collected on waters along the Katmai Coast, except for a limited study of the Kamishak River on the north end of the coast. Effects of increased visitor use, contaminants or changes in the marine environment or climate that influence coastal intertidal areas are difficult to determine without some baseline information on existing resources.

The world's climate has warmed about 1^{o}C during the last 100 years, and sea level has been rising about 1mm-2mm per year due to reduction in ice and thermal expansion of ocean water. If these trends continue many of the world's mountain glaciers will disappear. For example, at Glacier National Park it is predicted that all glaciers will be gone by the middle of next century (http://pubs.usgs.gov/factsheet/fs2-00/). Closer to Katmai, in Lake Clark Pass, pilots navigating the pass talk about the recession of glaciers that once bisected the drainage. In 1943 the glaciers in Merrill Pass were observed to a level of 1,100 feet, but have since disappeared (Ray Petersen pers. comm. 2001). The estimated potential maximum sea level rise from the total melting of present day glaciers is 80.32 meters (U.S. Geological Survey 2000:1 at http://pubs.usgs.gov/factsheet/fs2-00/)). Coastal salt marshes and wetlands can be created or destroyed by sea level changes. These areas are very productive and important to many species of fish, marine invertebrates, birds and terrestrial mammals. Loss of these areas could result in substantial changes to coastal communities.

What can be done to protect coastal resources?

- ✓ Continue to assess recovery of coastal environments and biota impacted by the 1989 *Exxon Valdez* oil spill.
- ✓ Monitor the expansion of oil and gas exploration in Cook Inlet and the Shelikof Strait.
- ✓ Evaluate visitor use impacts on coastal water resources.
- ✓ Coordinate with the state of Alaska concerning coastal planning work.
- ✓ Conduct a synoptic survey of streams, bays and estuaries along the coast.
- ✓ Monitor relative sea level changes and position and morphology of coastlines.
- ✓ Develop a backcountry management plan.

IV. Baseline Inventory and Monitoring

A. The Need for Baseline Studies

National Park Service (NPS) managers are faced with increasingly more complex and challenging issues and are asked to provide scientifically credible information to defend management actions. Management of national parks is an extremely difficult and complicated task. Many threats to parks come from outside the park boundaries and sometimes from outside the state. Understanding the natural variability of complex ecosystem functions is critical if we are to determine whether changes observed in these systems are a function of natural variability or human activities. Furthermore, an understanding of ecosystem processes allows park managers to determine appropriate actions when human induced changes are identified. This knowledge does not occur in a two year study. This knowledge is only gained through long term research and monitoring. As Ralph Waldo Emerson so aptly put it, "*The years teach much which the days will never know.*"

National Park Service policy and recent legislation (National Parks Omnibus Management Act of 1998) require that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the NPS mission of conserving parks unimpaired. Also, the Wild and Scenic Rivers Act standard of protecting and enhancing the outstanding values for which these rivers were designated also require that NPS know the condition of the resource to assure its protection. Baseline data are crucial for the protection of water quality-dependent, or flow-dependent, outstanding resource values. Furthermore, *NPS Management Policies* (2000) says that NPS will use results of monitoring and research to understand and detect change and to develop appropriate management actions.

To effectively manage natural resources, inventory and monitoring activities should integrate into the overall natural resource planning and management process. Information obtained from these activities assists the NPS's understanding of how various environments in a park unit function naturally and helps to isolate anthropogenic changes. Once baseline conditions are established, monitoring is the feedback mechanism that triggers management actions and evaluates their effectiveness.

Establishing a quantifiable measure of resource conditions is a difficult task. But without a target condition, monitoring cannot detect changes and quantify trends in the resource condition. Baseline conditions for water resources in Katmai have not been established. Information is lacking in many areas that would contribute to the understanding of these ecosystems. Thus a primary focus of the water resource management program must be devoted to generating basic data to establish resource condition.

Freshwater ecosystems, whether lakes, streams or wetlands, have specific requirements in terms of quantity, quality and seasonality of their water supplies. To maintain itself over the long term, the system must be able to fluctuate within a natural range of variation. Flow regime, sediment and organic matter inputs, thermal and light characteristics, chemical and nutrient characteristics and biotic assemblages are fundamental attributes that define freshwater ecosystems. These attributes impart relatively unique characteristics of productivity and biodiversity to each ecosystem and vary within a natural range. We know very little about these attributes of Katmai's aquatic ecosystems.

One of the best examples of how little is known about Alaska's water resources comes from the nationwide U.S. Geological Survey (USGS) stream gaging program. The USGS calculated that Alaska has an average of one stream gaging station per 8,000 square miles, compared to an average of one gauge per 400 square miles in the lower 48 states (Brabets 1996). This equates to waterflow measurements on only 1% of Alaska's water bodies.

Without site specific data on instream flow, regional flow models provide the basis for evaluating naturally occurring hydrologic patterns at ungaged sites. This is particularly alarming because, in 1998, only 45% of the Alaska stream gauge sites met the USGS minimum 10-year record length, which is necessary to support a statistically reliable regional flow analysis (U.S. Department of the Interior 1998). Many of the major rivers are not gauged, including the Copper, Colville, Koyukuk, Noatak and Alagnak Rivers. Many of these rivers flow through or adjacent to parks. In the case of the Alagnak Wild River, protection and enhancement of outstanding resource values that are flow or water quality dependent are mandated by the Wild and Scenic Rivers Act.

Inventory and monitoring programs for natural resources in the park will 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 wildlife management on federal lands. In Katmai subsistence activities are only allowed in the preserve and along the Alagnak Wild River. Federal subsistence fisheries management began on October 1, 1999. Fisheries management, more than wildlife management, can be a very complicated task. The two major issues that concern subsistence managers at Katmai are the conservation of renewable resources and the opportunity for rural residents to participate in traditional subsistence harvests. ANILCA identifies specific activities related to subsistence that require NPS participation. These include population monitoring studies, determination of rural residents, administration of cabin and access permits, administration of special harvest permits, limiting subsistence activities, if necessary, and review of park programs for compliance (National Park Service 1994).

B. What are some of the questions?

Detecting change in a watershed is predicated on knowing its condition in the past. How did the watershed evolve following glacial retreat? When did vegetation emerge and how has natural vegetative succession affected nutrient loading, runoff and other factors important to these cold, subarctic waters? What is the range of natural variability in chemical, biological and physical properties of these waters?

Likewise, if ecosystem processes are not well understood, human caused impacts to the system may be difficult to distinguish from naturally occurring changes through time. What factor is most limiting to ecosystem productivity? What are the background levels of the chemical constituents of these waters commonly associated with human caused contamination, such as polycyclic aromatic hydrocarbons, aliphatic hydrocarbons and others? How do nitrogen, carbon and phosphorus flow through the system? These are examples of some of the most basic research needs identified for Katmai watersheds.

Some of the questions can be sufficiently answered by a single baseline study while others are more complex and may require years of data before some understanding of processes can be gained. An example of a more complex question involves water levels in Naknek Lake. Since the end of the Pleistocene, there has been a decline in Naknek Lake's water level, with a rapid drop within a few years after the 1912 Novarupta eruption. Possible causes for the change include: 1) a long-term change in the regional precipitation regime, 2) a change in the mass balance of the glaciers at the headwaters of the Naknek drainage, 3) downcutting of Naknek River through the terminal moraine that dams Naknek Lake or 4) a seismically induced shift in the elevation of the Naknek River bed (National Park Service 1994). Understanding the mechanism (s) causing changes in lake levels and the magnitude of the change will necessarily require more than a short term project.

C. What is being done to improve our understanding of park waters?

Congress verbally and financially committed to help NPS achieve inventory and monitoring goals in appropriation language for the fiscal year 2000 budget. In the bill Congress recognized that the preservation of diverse natural elements and great scenic beauty of parks is as high a priority as providing for visitor services. They challenged park managers to commit themselves to carrying out a systematic, consistent, professional inventory and monitoring program that will be regularly updated to ensure the NPS makes sound resource decisions based on sound scientific data.

NPS began implementing a program of inventory and monitoring (I&M) in Alaska parks in 2001. The initial I&M program included only five taxa. Vital signs monitoring, which includes basic water quality parameters, conceptually began in 2002 for parks in Southwestern Alaska as part of the I&M program. Vital signs are the key elements that indicate the health of an ecosystem. The purpose of this monitoring effort is to determine the status and trends in selected indicators of water health from which a better understanding of natural variability can be gained providing a reference point for comparison. A team of technical experts convened in November 2002 to establish priorities for sample sites, constituents, methods and so on. Fieldwork began in 2003 in Katmai as well as other parks in the southwest network, which includes: Kenai Fjords, Aniakchak, Lake Clark and the Alagnak Wild River, as well as Katmai National Park and Preserve.

Monitoring objectives for this network include:
1) coastal shoreline mapping and aerial survey video imagery,
2) baseline water quality sampling,
3) river gaging and lake bathymetric surveys,
4) development of a hydrographic model,
5) lake coring to reconstruct salmon abundance and lake productivity in nursery lakes,
6) compilation of historic photopoints and development of a monitoring protocol and
7) establishment of weather stations.

During the summer of 2003 shoreline mapping in Katmai was begun and included a biophysical inventory of the intertidal and backshore zone along the coast. The mapping will result in a shoreline classification and dataset suitable for generating a “shorezone” map. Aerial survey video imagery will accompany the map.

In addition, sediment cores were collected from several Katmai lakes (Naknek, Brooks, Idavain and JoJo) during the summer of 2003. Core analysis and a final report are scheduled for completion by May of 2006 (Interagency agreement F9855030030, undated).

D. Past Studies Contribute to the Knowledge Base

Terry E.C. Keith, of the USGS, initiated a water sampling program in 1979 to collect and analyze waters entering and draining the 1912 deposits. Her purpose initially was to collect some background geochemical data on cold water leaching of the 1912 deposits (Keith et al. 1992:209). However, soon after the effort began, chloride-rich thermal springs were discovered (1987); and the emphasis of the study turned to identifying the source and significance of the springs. Before Keith's work only limited chemical data on waters from the Valley of Ten Thousand Smokes region had been reported.

Keith's data on waters in the Valley of Ten Thousand Smokes date back to 1979. Physical and chemical properties of the waters of River Lethe, Knife and Windy Creeks, as well as the cold and thermal springs constitute one of the longest standing water resource databases in the park. While there have been a number of other datasets generated from past studies of park lakes and streams, Keith's work provides a unique look at an area where no generalities from other places in the park will apply. These data contribute to our understanding of a young igneous environment as well as to our knowledge and understanding of aquatic ecosystems in Katmai.

Although there are 20 years of data on waters in the valley, each additional year of Keith’s research results in new insights and further unanswered questions. Continuation of her studies, at some level, should be a priority for inventory and monitoring at Katmai.

Goals and objectives for continuation of this research will need to change as time passes. For the near-term, efforts should focus on the following:

- ✓ Distribution of trace metals in fumarolic incrustations - how gases alter ashflow tuff and concentrate trace metals; and how trace metals weather, break down and end up in the water.
- ✓ Development of a long term monitoring program.
- ✓ Monitoring of thermal features in the Novarupta vent area. Studies on the cooling of the area around Novarupta and in Peasoup Pass and along ridges was begun some 10 years ago and should be repeated (Keith 1991).
- ✓ Development of cryptogamic soils. There is visible evidence of fossil fumaroles mobilizing trace minerals, giving microfauna a foothold. Trace element content in incrustations and in biota should be determined and evolution of biotic communities documented.
- ✓ Measuring discharge in upper valley streams.

In 2001 graduate student, Noor Hogeweg, initiated a thesis project designed to examine the cooling of the ashflow sheet in the Valley of Ten Thousand Smokes using the springs as a source of indirect information on subsurface processes. The beneficial purposes of this work were to: 1) better estimate volcanic hazards in these areas, 2) understand the potential of using such systems for geothermal energy and 3) better understand hydrologic properties of ashflows as potential disposal sites for nuclear waste (Hogeweg 2002:14). Predictive features of a numerical model led to some interesting insights into the cooling of deep layers of the ashflow sheet. Insufficient field data collection resulted in a numerical cooling model that was difficult to link with the actual hydrothermal system in the Valley of Ten Thousand Smokes. Additional data collection could lead to an improved understanding of processes involved in groundwater systems in active volcanic areas (Hogeweg 2002:47).

In 2001 the Ukak River, River Lethe, Windy and Knife Creeks, mid-valley thermal springs and Overlook hill springs were sampled for trace metals. The results of this effort are forthcoming.

In addition to trace metals, samples were collected for a USGS study of the Arctic sunrise effect. Mercurial storms were discovered in 1995 by researchers from Environment Canada working on Ellesmere Island. Mercury readings remained stable throughout the winter months; but in late March–with the return of the sun they began to fluctuate wildly–plummeting rapidly and shooting up again–the process repeating itself for two months. Separate tests revealed that mercury was being transformed from a gas into a solid in the frigid polar atmosphere after sunrise. The aerosol form of mercury falls to the earth's surface much faster than gaseous mercury and accumulates in ice, snow and spring meltwater in an oxidized form that is much more easily assimilated into the food chain. The mercury showers take place in the spring just as the ecosystem is coming to life, exposing humans, plants, animals and fish to another form of toxic pollution. Scientists believe the conversion of mercury into aerosol form is closely related to ground level ozone depletion. These changes occur only in areas where tropospheric ozone has been depleted over the frozen surface of the Arctic Ocean. Evidence of such mobilization of mercury is being studied in Katmai samples (Rytuba and Keith, forthcoming).

During the summers from 1990-1992, a study was initiated to establish some water quality baseline information on large lakes in Katmai. This study, conducted by the late Jackie LaPerriere of University of Alaska, Fairbanks, assessed conditions in 10 large lakes and some of the important inlet, outlet, and connecting streams along the Naknek and Alagnak drainages in Katmai. Data needs and long-term monitoring recommendations for Katmai were presented by LaPerriere (1996) at the conclusion of the study and included:

- ✓ Bathymetrically map large lakes as needed to complement future studies.
- ✓ Establish Global Positioning System (GPS)-fixed stations in the deepest spot of major basins of each lake to be monitored. These sites will provide comprehensive water quality and biological profiles for each lake.
- ✓ Take monthly Secchi disc readings during the ice-free season and calculate seasonal averages. Data will provide “early detection” of possible eutrophication and justification for intensive limnological studies.
- ✓ Gauge the largest streams in Katmai in conjunction with the U.S. Geological Survey. Flow data are needed for any stream where water quality characteristics are being measured.
- ✓ Monitor streams used for drinking water by staff and visitors for comparison to drinking water standards.

To follow-up with LaPerriere’s study, Katmai staff collected data on some basic water quality parameters (pH, turbidity, temperature, dissolved oxygen, Secchi depth readings, etc.) once during the ice-free season since the study concluded (Hamon pers. comm. 1999). Continuation of even a limited monitoring effort is contingent upon development of a monitoring plan and funding for access to study sites. The inventory and monitoring program should provide the means for additional monitoring to be completed.

As a result of low alkalinity recorded in waters in the Alagnak drainage, Gunther (1992) recommended that this drainage be a high priority for study if acidic deposition were to occur in the region. Future studies would need to examine soil development and base-cation exchange capacity, the relative importance of surface and groundwater inflow in each drainage and internal alkalinity generation in the lakes. While rain collections in 1985-86 from 16 precipitation events revealed an average pH of 5.0 – a common value for remote areas where precipitation carries small quantities of both weak and strong acids of natural origin (Schindler 1988:149) – a trend toward more acidic precipitation would be cause for concern. Heavy metals were also found in the precipitation samples (National Park Service 1994). Further analysis of precipitation and snowmelt may be warranted.

The Environmental Protection Agency (EPA) has endorsed the use of biological integrity as an indicator of environmental condition and ecological health. It is unique among currently used indicators in that 1) it uses 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) it combines multiple, community level, biological response characteristics into an indicator of cumulative environmental impacts (Karr 1991, 1993). The Alaska Department of Environmental Conservation has supported bioassessment projects in Southcentral and Southeastern Alaska. The objective of these projects is to develop regional reference condition criteria by region. In the initial 1996 study, the objective was to evaluate and modify EPA's Rapid Bioassessment Protocols for use in Alaska (Barbour et al. 1999, Plafkin et al. 1989, Davis et al. 1996). The Rapid Bioassessment Protocols were designed as a relatively inexpensive screening tool for determining whether aquatic environments were supporting biological communities (Plafkin et al. 1989). To date the protocol has been revised for stream macroinvertebrate sampling and applied in both Southcentral and Southeast Alaska. A regional reference condition and stream condition index has been developed for Southcentral Alaska. Although these protocols are designed for use in fluvial environments, EPA has also completed the protocols for lake systems, which are of interest for Katmai (Environmental Protection Agency 1998).

In 2003 the University of Alaska Anchorage's Environment and Natural Resources Institute (ENRI) proposed using a scientifically defensible scheme for characterizing reference conditions with a framework of land use/land cover attributes in the Cook Inlet Ecoregion. The proposal called for selecting sites, using this scheme, to characterize regional reference conditions using the periphyton community. Biological indicator data, appropriate for streams in Alaska, would be collected at reference and test sites. This data will be used to begin the development and calibration of periphyton as biological indicators for Southcentral Alaska. If successful, rapid bioassessment protocols will be developed for periphyton as well. Unfortunately, this effort was not funded in 2003.

The NPS Water Resources Division prepared a comprehensive summary of existing surface-water quality data for Katmai. This two volume report titled, *Baseline Water Quality Inventory and Analysis, Katmai National Park and Preserve*, includes data with some limited data analysis from several EPA national databases (i.e., STORET). It provides a comprehensive source of information focusing on water resource research conducted in Katmai. The report was completed in January 2002.

The NPS is looking forward to completion of a large project that will provide an invaluable aid to watershed projects statewide. The Hydrography Subcommittee's *Alaska Watershed and Stream Hydrography Enhanced Datasets* (AWSHED) project led by the Bureau of Land Management has undertaken the task of preparing the National Hydrology Dataset (NHD) for use in Alaska and developing a routed hydrography dataset with standardized water body identifiers. It has also undertaken the task of delineating watersheds at the fifth level and subwatersheds at the sixth level.

There has been a clearly expressed need in Alaska for the delineation and standardization of watersheds at a finer scale than the fourth level sub-basin currently existing in the Hydrologic Unit system established and maintained by the Natural Resources Conservation service and the USGS. The national standard for the number of fifth level watersheds is 5 to 15, with 8 to 15 sub-watersheds nested within one watershed. These subdivisions will provide the detail necessary for watershed planning and research purposes. Watershed boundaries will be clearly delineated and accessible to all users via the Alaska State Geospatial Data Clearinghouse on the World Wide Web.

The National Hydrography Dataset (NHD) is a digital hydrographic dataset defining the nation's streams and water bodies. The dataset includes unique identifiers for each individual stream section or reach, a flow network and the GNIS naming convention. Stream routes are uniquely identified using a longitude/latitude identifier (LLID) located at the mouth of each stream. This allows the ability to query and display reaches and sites of a certain type in GIS coverage. In Alaska the LLID water body identifiers serve as standardized common keys for the named and unnamed rivers, lakes and other water sources that are represented graphically in GIS.

Routing gives linear features measurements, allowing users to retrieve accurate location-specific information. Route number and measure coordinates define event attributes, or sites and reaches, along linear features. Examples of events that could be displayed through a simple query are water quality sample sites, stream gauges, habitat features such as fish barriers, navigable reaches, water quality discharge points, range of anadromy, spawning areas, bridges, culverts and white water classes.

E. What factors are frustrating progress?

Funding is always important in the development of a new program, and Katmai has not successfully competed for a large sum of money to implement the type of research program necessary to begin answering some of the basic questions. In fact, very few water resource studies have been funded by NPS since the park was established. New funding from

Congress for the Inventory and Monitoring program should help move Katmai's Water Resource Program forward, but will not be enough to address many of the important questions.

Many of the basic questions about the functioning of Katmai aquatic ecosystems were first identified in the park's Natural Resource Management Plan (National Park Service 1986). They were reiterated in subsequent plans and proposals, but it wasn't until 1990 that a baseline study of Katmai lakes was funded. Later, Potts et al. (1993) prepared a proposal for long-term ecological monitoring for Katmai in 1993. This proposal provides a good example of an integrated science study that looks broadly at ecosystem processes. The objectives of this proposal were to establish Katmai as one of the national Inventory and Monitoring prototype NPS units and to develop and implement a program of long-term ecological monitoring of the large lakes and large rivers in Katmai. Unfortunately, this proposal was never funded.

NPS funding mechanisms do not allow for changing priorities or quick responses to events or situations that arise unexpectedly. Years of effort must precede funding of a project proposal. Furthermore, Alaska's proposals are often not as competitive in the funding process. National funding sources tend to focus more dollars on issue driven research than baseline studies of pristine ecosystems.

An example of a need that may arise in Katmai that would require immediate funding is in response to a volcanic activity. Another volcanic eruption and/or catastrophic lahars and floods in response to increased seismicity in or near Katmai are inevitable. Two major eruptions affecting developed areas of Anchorage and Kenai have occurred in the past 10 years alone. An eruption in Katmai may not only affect the health and safety of people living in the area, but may have both short and long term effects on water resources. Short term, immediate effects on water resources (including public water supplies) could come in the form of increased turbidity and acidity. Rain events with accompanying increases in discharge may also result in higher sulfate, fluoride, chloride, and borate concentrations and total dissolved solids in the water depending on the content of the ash (Wilcox 1959:446). Because health and human safety concerns are paramount, emergency funding to look at water supplies would become available. However, a mechanism for immediate start up for baseline studies of biotic communities and water chemistry, for example, is not as readily available.

F. Recommended Actions

- ✓ Establish permanent gaging stations to establish a regional hydrographic model and to protect and enhance the outstanding resource values of the Alagnak Wild River that are flow or quality dependent.
- ✓ Develop a sustainable water quality monitoring program, and establish permanent water quality monitoring stations in select streams and lakes.
- ✓ 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.
- ✓ Conduct phytoplankton and aquatic invertebrate species distribution studies.

- ✓ Correlate park's aquatic ecology needs with the annual nutrient loading from salmon.
- ✓ Establish meteorological monitoring stations in remote areas, in cooperation with the U.S. National Weather Service.
- ✓ Core select lakes to characterize the chemical, physical and biological nature of aquatic sediments over time. These records can provide a finely resolvable record of environmental change in which natural events may be clearly distinguishable from human inputs.
- ✓ Fund a USGS analysis of park watersheds to establish monitoring units.
- ✓ Monitor stream sediment storage and load. Sediment loads determine channel shape and pattern and are indicators of basin dynamics. Fluctuations in sediment affect many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with sediment. Stream deposits represent a huge potential sink for and source of contaminants.
- ✓ Investigate plankton nutrient requirements, seasonal changes in these requirements, and the trophic relationships of the consumers in individual lakes.
- ✓ Prepare for a rapid assessment of impacts from catastrophic natural events, such as volcanic eruption. Such events can have a devastating and long term impact on fish and their food sources (Eicher and Rounsefell 1957), on vegetation (Griggs 1920, Eicher and Rounsefell 1957) and shorter term effects on species, such as stream macroinvertebrates (Dorava and Milner 1999, Ball 1914:59-64, and Evermann 1913:64-65).
- ✓ Support continuation of USGS water studies in the Valley of Ten Thousand Smokes, and encourage development of a long term monitoring plan for that project.

V. Wetlands Protection

Katmai's coastal wetlands provide important habitat for arthropods, mollusks, echinoderms, fish, birds and mammals. Because the park contains a wide variety of different wetlands types (from estuarine, to riverine, to freshwater lakes and marshes) they provide a variety of functions including fish and wildlife food, nesting and rearing habitat support; control of shoreline erosion and sedimentation; flood water storage; ground-water recharge; and others.

LaPerriere (1996) elevated the need for water quality and biota studies (i.e., vascular aquatic plant productivity and function) on the small lakes and ponds associated with wetlands in Katmai. The influence of wetlands on nearby lakes and streams in the park is not understood, especially with respect to nutrient dynamics.

The diversity of plant and animal life that wetlands support makes them a valuable resource for wildlife viewing, exploration, education and photography.

Many freshwater, saltwater and anadromous fish species feed in wetlands or on food produced by wetlands within the park. Coastal wetlands and streamside marshes are used as nursery grounds. Wetlands adjacent to rivers are important to fish in their regulation of hydrology and temperature, their input of organic matter for feeding and habitat structure, and they serve as protective buffers between rivers and surrounding uplands. Anadromous species, such as salmon, utilize the fresh and salt water habitats in both coastal and riparian wetlands.

Because of their beneficial values, the NPS implements a "no net loss of wetlands" policy in its park units. Executive Order 11990 directs the NPS to:

1) provide leadership and to take action to minimize the destruction, loss or degradation of wetlands;
2) preserve and enhance the natural and beneficial values of wetlands; and
3) 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 1998a).

Director's Order 77-1: *Wetlands Protection* requires the NPS to conduct or obtain wetland inventories in each park unit. Presently, Katmai 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. The U.S. Fish & Wildlife Service (USFWS) has developed National Wetlands Inventory (NWI) maps for portions of Alaska. At this time, wetlands have been delineated according to NWI standards on one quadrangle (out of the 48 that cover the park area) within Katmai and the map is available in digital format.

In FY98, Katmai was unsuccessful in seeking funding for a wetlands mapping project along Katmai's coast. Visitation is increasing rapidly, and several commercial operators have recently requested permits for mooring buoys along the coast. The coast is on the schedule for several major tour operations; and the current impacts from these activities to coastal wetlands, if any, are unknown. Katmai's coastal wetlands provide important habitat for arthropods, mollusks, echinoderms, fish, birds and mammals (National Park Service 1998b). It is important for the NPS to establish baseline wetland information to assist with separating anthropogenic impacts from natural processes.

Furthermore, impacts from the effects of climate change on wetlands may be significant. Decreasing water levels, desiccation, elevated water temperatures and salt water intrusion are some of the concerns. Refer to the section on climate change in this chapter for more discussion on this topic.

What actions should be taken?

- ✓ Assist the U.S. Fish and Wildlife Service to develop National Wetlands Inventory (NWI) maps for Katmai.
- ✓ Determine wetlands aerial extent, plant species composition, wildlife and fisheries habitat conditions and hydrology.
- ✓ Conduct baseline studies on select wetlands to monitor effects of climate warming on wetland function.

VI. Impacts Associated with Development at Brooks River

In remote areas most of the environmental risk factors are associated with developed sites although this is not universally true. NPS developments, lodge and other commercial use areas provide some of the greatest risk factors in the park. However, chronic, low-level pollution from aircraft, motorboats and other surface transportation can also constitute a more widespread risk factor, particularly in popular use areas.

Brooks Camp is one of the most visited sites in the park and contains the largest facility in the park. The camp is situated at a site that has been inhabited for thousands of years by Native people. For this reason, a development concept plan from 1996 proposed to move camp facilities to a site adjacent to the Beaver Pond on the south side of Brooks River, alleviating foot traffic and the human imprint currently imposed on a sensitive archaeological site.

A. Facilities in the Brooks River Area

The Brooks River Area, including a concessionaire facility and NPS operation collectively known as “Brooks Camp,” is the most visited destination in the park. The camp lies 35 miles southeast of King Salmon near the Brooks River outlet, a 1.5-mile long river that drains from Brooks Lake into Naknek Lake. Access to this seasonal use area is by floatplane or boat. The Brooks River divides the developed area into two parts that lie north and south of the river. The north side of the river (North Camp) includes Brooks Lodge, guest cabins, visitor center, ranger station, auditorium, maintenance shop, incinerator building, generator building and numerous staff cabins and tent platforms. South Camp includes a former vehicle refueling area, park housing, and two bear viewing platforms. The lodge can accommodate up to 60 people per night, and the NPS campground holds up to 100 people. In 1998, between June and September, there were approximately 4,171 overnight-stays in Brooks Lodge and 1,269 overnight-stays in the campground (Brock pers. comm. 1999).

Two 100 kw generators supply power to all Brooks Camp facilities at a cost of about 75 gallons of fuel per day (National Park Service 1997:23). Water is supplied from the NPS well where water is stored and treated in three 12,000 gallon tanks. The sewer main runs to the former fish cleaning building where it is distributed to 8,000-gallon, 4,000-gallon and 2,000-gallon tanks. Effluent is pumped directly into the leach field, with ADEC’s approval, bypassing the intermediate sand filter system, which failed prematurely (Heubner pers. comm. 2003). NPS discovered that water meters at Brooks were not functioning properly. When wastewater usage was measured at the lift station, it was determined that water usage was less than was measured previously, making the leach field large enough to handle the load.

B. Changing River Morphology and Bank Erosion

The mouth of the Brooks River, which divides the north and south camps, is in a constant state of flux. It is unclear to what extent the changes in river morphology are a response to the intensive use and development or result from natural processes (i.e., Naknek Lake longshore sediment transport). At times structures built in the river have influenced channel morphology, but what remains today is a single floating bridge across Brooks River, installed seasonally during the ice free months. The floating bridge has been used since about 1981-82.

Crossing Brooks River has been an issue for more than 50 years. During the 1950s there was little demand to cross the river. Good fishing holes were accessible from the north side; and those who wanted to cross did so by boat supplied by the concessioner (Norris 1996:126). Several plans for construction of a foot bridge emerged, and by 1954 at least a rudimentary bridge had been constructed "halfway between the camp and the falls" (Russell Todd 2000 in Norris 2000:2). However, in 1956 the bridge had become damaged by high water and the concessioner returned to ferrying guests across the river by boat.

In the early 1960s a 40-foot linear dock was built on the north side of the river in an embayment just upriver of the mouth. On the south side a small L-shaped dock was built near the present day bus loading area. The docks were used to ferry guests across the river for access to the newly constructed road leading to the Valley of Ten Thousand Smokes. The dock on the north side was lengthened to 60 feet in 1974-5 by R.D. Peterson Company along with construction of some other new developments at the camp including a fish cleaning station, generator and water treatment building (Norris 1996).

By the following year (1975), erosion from currents began to narrow the small spit between the boat dock and Naknek Lake. Then in 1977 high runoff caused the area surrounding the concessions buildings to flood (Norris 1996:196). Water levels reached almost 18 inches above the level of the new dock. The beach was lost, and the bank protecting the boat dock eroded away on the south side of the river. On the north side continuing erosion threatened to undercut and destroy the new dock. Sandbags were placed underneath the dock to ward off further damage, but only served as a holding action. The dock was eventually destroyed.

Changes in natural riparian vegetation density and/or composition can produce unstable conditions for certain stream types (Rosgen 1994). The heavy NPS/visitor use and development along the mouth of Brooks River have also contributed to the observed morphological changes in the river. Pathways along the north side of the river are heavily eroded. Stabilizing vegetation along the bank was long ago removed to provide for a more open pathway with better visibility. The result was a highly eroded pathway on top of loose, unconsolidated bank deposits requiring continual maintenance.

C. Petroleum Contamination

Water contamination in Alaska's pristine backcountry areas is, fortunately, relatively uncommon. However, leaking underground storage tanks are probably the most insidious sources of groundwater contamination in the state. Of all the contaminated groundwater, more than 70% is the result of spills or leaks of petroleum products; the rest being caused by septic system effluent, chemical spills, landfill leachates and saltwater intrusion (Munter and Maynard 1987). Although most spills occur in urban areas, the threat exists in any environment where fuel storage and transfer operations occur.

The primary and time-sensitive water resource issue at Brooks Camp is petroleum contamination of soils and groundwater that resulted from a leaking NPS fuel distribution system. According to a National Park Service report (1997:1), this system, constructed in 1974-1975, included two 8,000-gallon diesel underground storage tanks (USTs) that were connected by underground fiberglass piping to a 2,000-gallon UST, a 500-gallon UST and numerous 62-gallon above ground storage tanks located at individual cabins. The 8,000-gallon tanks were filled from a fuel barge through an underground line that connected to a diesel fill box on the shore of Naknek Lake. At the southern portion of Brooks Camp, three 2,000-gallon USTs were used for bulk storage and to refuel vehicles. One 2,000-gallon gasoline UST was located near the barge landing (immediately east of the Brooks River). These tanks were filled by the NPS fuel barge through separate underground pipes about 1,750 feet long, extending from a fill box near the beach landing site at the mouth of Brooks River (National Park Service 1997:4). Two other USTs, one gasoline and one diesel, were located in the vehicle parking area. In 1992, all USTs and underground piping failed to meet EPA tightness test standards.

Groundwater contamination from leaking fuel tanks has apparently been a concern for some time. Documented fuel releases date back to the early 1980s when a noticeable taste of diesel fuel was evident in drinking water at the camp. In the mid-to-late 1980s a gasoline tank was overfilled at the vehicle refueling area on the south side of the river (Shannon and Wilson 1995). At the time leakage along the line from the parking lot to boat dock was suspected (Norris 1996:241-42). In 1991 a diesel pipeline leak was discovered at the Skytel building north of the river, contaminating about 8 cubic yards of soil. That same year an unused 300 gallon tank was removed from near the waste incinerator building. Soil tests in 1992 found contamination in excess of allowable levels (Shannon and Wilson 1995). Spills, underground storage tank and fuel line leakages ranked Brooks Camp number 24 on the Alaska Department of Environmental Conservation’s list of contaminated sites (Shannon and Wilson 1995).

1. The Risks of Aging Underground Storage Systems Become Apparent

A lakeshore well was used until 1983 as a source of drinking water for Brooks Camp. It was discontinued when it began producing water that tasted and smelled like diesel fuel (National Park Service 1997:4). NPS then established a sand point well in Naknek Lake annually about 50 feet offshore. By the spring of 1992 the well point had reportedly become contaminated with diesel fuel, as had two shallow groundwater wells at Brooks Camp.

As a result, two new replacement wells were installed in 1992 into the deeper, confined bedrock aquifer (62 ft. depth at Brooks Camp and 110 ft. depth at Brooks Lake). Bill Heubner (pers. comm. 2002) stated that this deeper saturated unit was observed to be under pressure during the drilling operations. Static water levels in Brooks Camp #2 well were measured to be two inches above the ground level, clearly indicating that the drinking water aquifer is not hydraulically connected to the perched aquifer that is receiving contamination from the former fuel tank spills (Heubner pers. comm. 2003). Semi-consolidated sedimentary deposits form a confining layer, separating the shallow water table aquifer (3-15 feet) from the bedrock aquifer and minimizing the vertical migration of petroleum contamination, thus limiting the potential for contamination of the new water source (Ecology and Environment 1992:3-2).

A wellpoint exists beneath Brooks Lodge used to supply water for dishwashing and other non-consumptive purposes. The wellpoint was drilled to an estimated depth of 21 feet (Ecology and Environment 1992:7-1). It is unknown if this well is contaminated, but the well is no longer in use.

2. Testing Confirms Suspicions

A site characterization performed at Brooks Camp in 1992 confirmed soil and groundwater contamination from gasoline and diesel fuels and delineated a series of contamination plumes (Ecology and Environment, Inc. 1992:6-8, 6-9). Total Diesel range petroleum hydrocarbons were detected in soil reaching 21,000 mg/kg, 602 mg/kg in sediment, 580 mg/L in groundwater and 0.27 mg/L in surface water (Shannon and Wilson 1995). Many samples exceeded the ADEC required-cleanup levels for contaminated soils (18 AAC 78.315) when diesel range organic levels exceeded 100 mg/kg. No maximum contaminant levels were established at the time for this constituent in groundwater. Petroleum hydrocarbon (TPH) FS/TPH concentrations that ranged from 22 to more than 10,500 mg/kg were measured in samples at the Skytel, generator building and solid waste storage building on the north side of Brooks River and at the vehicle refueling area south of the river (Ecology and Environment 1992:6-4, 6-8). The areas of greatest contamination were at the generator building and solid waste and incinerator buildings on the north side of the river.

Groundwater is the most likely pathway for contaminant migration from spill sites and is expected to be rapid (Ecology and Environment 1992:7-1). Groundwater velocities are estimated at 6 to 16 feet per day, but migration is expected to be slowed by saturated soils (National Park Service 1997:7). Surface runoff does not provide a significant transport mechanism due to the lack of permanent surface drainages at the spill site and the fact that contamination is known to be subsurface in nature. Groundwater discharge into Naknek Lake was suspected based on reported diesel fumes on the Naknek Lake beach and the presence of petroleum hydrocarbons saturated in beach sediments collected during field investigations (Ecology and Environment 1992:7-2). Groundwater flows eastward toward the lake.

Sediment samples were collected between 1992 and 1996 from the beach along Naknek Lake. In 1992 sediment showed 5,900 ppm total petroleum hydrocarbons (TPH) at one site, while four others ranged from clean to 184 ppm TPH. In 1994 no detectable quantities were found, but Diesel Range Organics concentrations ranged from 13 to 602 ppm in six samples. In 1995 and 1996 results ranged from no detectable quantities to 59.8 ppm DRO (National Park Service 1997:15). No BTEXs (benzene, toluene, ethylene and xylene) were detected in any of the samples.

Diesel Range Organics (DRO) concentrations in wells along Naknek Lake would indicate hydrocarbons are most likely migrating into the lake (Bristol Environmental Corp 1998:6-1). However, no hydrocarbon contamination was detected in water or sediment samples collected from the lake, indicating that wave action along the shore may be dispersing the pollutants.

The horizontal extent of contamination at Brooks Camp was estimated at 132,000 square feet and to depths of 2 to 17 feet below the ground level (Ecology and Environment 1994). Contaminated soil volume was estimated at 21,500 cubic yards.

Tank testing was performed in September 1992 and all tanks and piping failed to meet EPA standards. As a result, the leaking fuel distribution system was removed and a new system installed in 1993. About 1,000 feet of pipe north of the river and 200 feet south of the river were drained, capped and left in place to avoid disturbing archeological sites (Bristol Environmental Corp 1998:1-2).

3. Bioremediation Becomes the Key to Clean Up Operations

In 1994, NPS retained Versar, Inc. to review previous environmental investigations and evaluate additional information needs, as well as remedial action alternatives for Brooks Camp. Their report (Versar 1995) recommended an in situ bioremediation and air sparging (agitation) program for the source and plumes of contamination at or near the generator and incinerator buildings. Shannon and Wilson, Inc (1995) installed monitoring wells and collected additional information on ground and surface water quality to assist in the selection of the most appropriate remedial action for reducing the level of contamination to meet ADEC regulations.

Bioremediation and natural attenuation were considered as possible remedial actions and populations of oil degrading bacteria and nutrients evaluated (Shannon and Wilson 1995). Both bacteria and nutrient levels were low in soil and groundwater; and due to the shortage of available free hydrocarbons, oxygen and nutrients and low temperatures, natural attenuation potential was considered to be low. However, in 1997 Bristol reported that geochemical indicators (dissolved oxygen, nitrate, sulfate and ferrous iron) measured in the plume near the generator building were consistent with that expected for an area where petroleum hydrocarbon contaminants are being biodegraded (Bristol Environmental Corp 1998:3-7). Aerobic biodegradation and anaerobic biodegradation appeared to be occurring. Data for the contaminated site near the incinerator were inconclusive with regard to anaerobic biodegradation of contaminants. The difference between contaminated sites was attributed to the more recent age of the spill near the incinerator, the smaller size of the contaminated area and lower levels of contaminants. Dissolved oxygen data for the incinerator site indicated that aerobic petroleum hydrocarbon biodegradation was occurring (Bristol Environmental Corp 1998:3-7).

In 1997 Bristol Environmental Corporation (Bristol) installed monitoring wells and a remediation system to address the presence of hydrocarbons at Brooks Camp. The remediation system included 10 remediation wells consisting of five air sparging wells, two bioventing wells and three soil vapor monitoring nests (Bristol Environmental Corp. 1998:1-1).

Low levels of petroleum hydrocarbons were also detected in soil and groundwater from a monitoring well at the barge loading spit south of the Brooks River. Natural attenuation of the petroleum was recommended for this area as well, and continued monitoring was recommended (Bristol Environmental Corp 1998:6-2).

4. Annual Monitoring Shows Continued Improvement

The National Park Service contracted Hart Crowser to perform annual groundwater sampling at Brooks Camp. Twenty-five monitoring wells at the Brooks Camp North (BCN), Brooks Camp South (BCS), and the Brooks Camp Vehicle (BCV) area were sampled during the August 2002 annual sampling event. In addition, 10 surface water and sediment samples were taken from locations along the shores of Naknek Lake and Brooks Lake to assess potential impacts to the lakes.

Most wells had petroleum hydrocarbon concentrations below Alaska Department of Environmental Conservation (ADEC) Cleanup Levels (Title 18 of the Alaska Administrative Code, Chapter 75 [18 AAC 75] Section 345, Table C) or below method detection limits. However, areas of concern remain at each of the three sites (BCN, BCS, and BCV). These areas are described below (Hart Crowser 2002):

- While benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations were all below ADEC cleanup levels at BCN, diesel-range organics (DRO) concentrations ranged from below detection values to 3.03 mg/L in the areas of concern (compared to an ADEC cleanup level of 1.5 mg/L). No BTEX or DRO was detected in the drinking water well (BC Well #2). Historic results of the surface water and sediment sampling at Naknek Lake indicate that all soil and sediment results from samples taken during the 2002 sampling event had results near or below detection limits. All surface water/sediment samples have had BTEX and DRO concentrations near or below detection limits over the past five years, with the exception of the SW-2, which had DRO concentrations of 1.5 to 1.75 mg/L in 1999 and 2000. Since then, SW-2 DRO concentrations have been below detection limits;

- All BTEX and gasoline-range organics (GRO) concentrations were below ADEC cleanup levels at BCS, similar to historic results. However, down gradient of the generator building, DRO values ranged up to 8.39 mg/L at one site, exceeding the 1.5mg/L cleanup level. DRO concentrations in wells above clean up levels show a decreasing trend. GRO and BTEX values in these wells have dropped from higher historic values to values now below ADEC cleanup levels; and

- Benzene values in the BCV area were seen as high as 5.38 mg/L (compared to a cleanup level of 0.005 mg/L), GRO concentrations were seen up to 37.0 mg/L (compared to an ADEC cleanup level of 1.3 mg/L) and DRO concentrations were seen up to 20.6 mg/L. The eastern (down gradient) area of BCV is the most impacted area with levels of BTEX, GRO and DRO generally increasing since the monitoring began in 2000.

In comparison with historic data, petroleum hydrocarbon concentrations in groundwater, surface water, and sediment samples have, with very few exceptions, decreased significantly over time (Hart Crowser 2002). Geochemistry data indicate that microbial degradation is continuing to occur at all sites. The use of air sparging systems has likely enhanced aerobic degradation.

Hart Crowser (2002) recommended continued annual groundwater sampling at all three sites to monitor contaminant concentrations and to assess remediation success. Sediment and surface water monitoring will also continue in areas of concern. In addition, because of low concentrations of petroleum hydrocarbons at Brook Camp North, they recommend discontinuing the use of the air sparging system.

A site investigation at the BCV was conducted in early August of 2003. Petroleum constituents exceeding allowable ADEC groundwater parameters were detected in two of the 12 monitoring wells sampled but the contamination plume is not migrating offsite. The groundwater flow direction was to the north, with a gradient varying across the site. A marsh, located to the east of the site, has not been impacted by the release. This site will be monitored semi-annually in June and August every year to determine if the contamination is naturally degrading and to determine if the plume is migrating offsite. (Heubner pers. comm. 2003).

D. Brooks River Area Wastewater Management

Disposal of wastes has been a problem at Brooks Camp, resulting in failed septic systems and possibly leakage of effluent into Naknek and Brooks Lakes. Old systems, shallow groundwater, disposal of fish wastes, porous soils and the proximity of the leach fields to the lakes have contributed to the problems. A past practice of disposing of ground fish wastes into the septic system contributed to system failures and increased maintenance. For many years the tanks were not completely pumped, allowing solids to remain in the septic system at the end of the season. Fluids were pumped out onto the ground in an area that was within the Brooks River floodplain to avoid freezing and damage to pipes. Finally, in 1995, a complete pump of the system was attempted. What wasn't apparent at the time was that the ice in one of the tanks sheared off the outlet tee. This device keeps solids, both floating and sinking, in the tank. Without the tee, solids (including fats from the fish cleaning station and grease from the lodge kitchen) were discharged into the leach field. The buildup of solids caused the leach field to fail in the fall of that year. Since 1995, the practice of cleaning fish at Brooks Camp is no longer allowed, and the facilities for fish cleaning have been removed.

In 1996, a new leach field was installed at Brooks Camp. In addition, the park replaced all fixtures at Brooks Camp with water saving fixtures to minimize the volume of wastewater disposed of in the leach field (Heubner pers. comm. 2003). Septic solids are no longer discharged adjacent to the lift station. Solids are now hauled to an ADEC approved sludge disposal pit located along the Valley Road (Heubner pers. comm. 2003).

Although the system has been improved, Sharrow (1993:4) believes the limitations of the site will probably result in continued problems. The leach fields are located within 300 feet of Naknek and Brooks Lakes. They are at least four feet but not more than 10 feet above the groundwater table. Soils in Brooks Camp are shallow and composed of sand and course fragments varying in size from cobbles to boulders. Underlying parent material is volcanic or morainal. Both appear to be moderately to highly permeable and as such are poorly suited for wastewater disposal in close proximity to ground and surface waters (Sharrow 1993:4).

NPS data on performance of the leach field do not support Sharrow's assessment. Percolation tests on the sands in the leach field show they are optimal for a leach field (Bill Heubner pers. comm. 2003). They allow for the highest effluent rate allowed by ADEC regulations. In Heubner's opinion, the biggest problem will be to retain the leach field in the existing footprint into the future as concerns for protecting archeological sites limit its expansion.

Heubner (pers. comm. 2003) also disagreed with Sharrow's concern over the proximity of the field to the lakes. ADEC allows as little as 100 feet of separation from a septic system and a body of water. Furthermore, groundwater testing downhill of the leach field showed no appreciable levels of nitrates in the water.

E. Removal of Brooks Falls Fish Ladder

In the 1940s, research conducted by the U.S. Bureau of Commercial Fisheries led to the conclusion that during seasons of low waterflow, salmon were dying in their attempt to negotiate Brooks Falls before they spawned. Apparently mortality of unspawned sockeye salmon was observed below the falls, and this was attributed to injuries caused by unsuccessful attempts to leap the falls. This observation led to the construction of a fish ladder at the falls by the Bureau of Commercial Fisheries personnel in 1949-50. The ladder has been the subject of controversy ever since.

The presence of the fish ladder in Katmai is in direct conflict with proclamations establishing the park, as well as long-standing policies of the NPS. At Katmai the NPS strives to maintain the natural abundance, behavior, diversity and ecological integrity of native plants and animals as part of their ecosystem. The fish ladder interferes with these objectives. The ladder as an artificial enhancement measure for the purpose of maximizing the productivity of fish and wildlife is clearly contrary to the purposes and values for which the park was set aside by the President and Congress and NPS policies for management of national parks in Alaska.

Furthermore, fish counts conducted before and after installation of the fish ladder, an economic analysis conducted by ADF&G and genetic studies indicate that the fish ladder is unnecessary and that it makes no appreciable contribution to the production of sockeye salmon in Bristol Bay.

The ladder was built into the bedrock of the streambank along the south side of the Brooks River as opposed to being constructed in the riverbed. The ladder was constructed of reinforced concrete and is approximately 30 meters long by 3 meters wide. It is a 7-step pool and weir design with orifices. The principal disadvantage of this design is its tendency to plug with debris (Burger et al. 1985:22).

In 1979, the NPS blocked the ladder upstream with wooden planking, thus stopping the flow of water over the ladder. However, by the early 1980s the water had eroded the riverbank around the upper end of the ladder, allowing a small stream of water to run through the eroded slot onto the ladder and the fish to pass through it and bypass the falls. The ladder is further compromised by substantial deposits of gravel in its pools, causing blockage of the orifices that fish migrate through.

In 1984-85 NPS funded a hydrological and biological assessment of the Brooks Falls fish ladder by U.S. Fish and Wildlife Service personnel. The engineering analysis determined that the ladder could be closed off with minimal effect on river hydraulics. The NPS then began plans to block off the ladder. An environmental assessment was prepared in 1986, but was never finalized. NPS concerns centered around the ecological and genetic results of permitting fish, including species other than salmon, to bypass the falls, and the erosion of the bank occurring at the upper end of the ladder, which could eventually divert water away from the falls. Scientists still question whether only one population of rainbow trout is in the Brooks River drainage or two populations are there, but separated by the falls. In addition, recent studies have identified a genetically distinct population of sockeye in Brooks Lake that is able to negotiate the falls (Jeff Olson pers. comm. 2002). For the purpose of this plan consideration will only be given to the hydrological merits of removing the ladder.

U.S. Fish and Wildlife biologists measured flow and other conditions surrounding the ladder in 1984 and outlined five options for the ladder. It was their opinion that the ladder could be removed totally, without causing major hydraulic changes in Brooks River and Falls because of its location on the inside of a meander in the river where energy is minimal (Burger et al. 1985:24). However, they could not recommend this option because without proper backfilling some bank erosion could result where the ladder is situated.

Covering the fish ladder was considered the best option, and the recommendation consisted of filling the ladder with boulders, gravel and earth fill to minimize the ladder's visual effect. Later plantings of native vegetation would further minimize the intrusion and help restore the bank. Other options discuss various methods to modify or remove the ladder.

In 1987 NPS proposed a plan to stop the flow of water to the fish ladder, dismantle and remove it and restore the bank and natural vegetation within five years of dewatering. Although there was a great deal of opposition, NPS continued to work toward eventual removal of the structure. The final blow to their plan came in 1987 in the form of a Supplemental Appropriations Bill sponsored by Alaska's U.S. Senator Ted Stevens. The bill directed the NPS not to remove, obstruct, dewater, fill or otherwise damage the Brooks Falls fish ladder (Senate Report 100-48, May 1, 1987, National Park Service, Operation of the National Park System).

No action has been taken to initiate discussions on this issue since that date.

F. What can be done to resolve these issues?

- ✓ Continue to monitor petroleum contamination remedial efforts at Brooks Camp.
- ✓ Consider alternate, less fuel consumptive strategies for providing power to the camp.
- ✓ Evaluate options for wastewater management at Brooks Camp.

- ✓ Determine how to accommodate foot traffic along the lower Brooks River with the least impact on stream morphology through a technical assistance request to the NPS Water Resources Division.
- ✓ Implement the Brooks Camp Development Concept Plan (National Park Service 1996) to eliminate or at least alleviate many of the issues identified.

VII. Airborne Contaminants

Atmospheric deposition of toxic pollutants is a concern at Katmai National Park and Preserve (Air Resources in chapter 3). We do not know the risk to the park from these pollutants or the extent of current distribution or impacts of these toxics in the food web. Pollutants of concern are "persistent organic pollutants" (POPs) such as DDT, PCBs and furans and metals, such as mercury. These pollutants can travel long distances (in some cases from Europe and Asia), persist in the environment for a long time and tend to accumulate at higher levels of the food chain, causing toxic effects in fish, mammals and in humans who consume them. The NPS has initiated a six-year air toxics inventory process that will address some of the unknowns for Katmai and other parks in Alaska (as well as in the western U.S.). This inventory effort will focus on sampling snow, lake sediments, water, plants and fish and/or mammal tissue at eight selected parks, including Denali, Noatak and Gates of the Arctic. Vegetation has also been sampled in Katmai to assess the distribution and extent of air toxics across regional scales (Tamara Blett pers. comm. 2003, 2007) and http://www2.nature.nps.gov/air/studies/air_toxics/wacap.cfm).

Many plant species that are widespread in the park are known to be sensitive to air pollutants. Lichens, in particular, are among the most highly sensitive species and play a vital role in contributing to the productivity of park ecosystems. Willow is another species that is both ubiquitous and sensitive to air pollutants. Change in the abundance or distribution of these species could be an indication of air quality changes, but will not provide an "early warning" device for managers. Shifts in vegetation may not be apparent until many years of contamination have occurred.

Rock types on the northeastern portion of the park are largely granitic and offer little buffering capacity from acidic inputs. Likewise, lakes and streams in this area (Alagnak drainage) have naturally low buffering capacity, and some are naturally acidic (Chapter 4). Sensitive fish species are very vulnerable to acidic deposition. However, the amount of increase in acidic deposition would have to be fairly large to cause this effect in Katmai.

Evidence of acidification can be obtained from analysis of long term trends, comparison of older with more recent chemical analysis or paleoecological analysis. Through paleoecological analysis, pH levels can be reconstructed from diatom remains in lake sediments, providing a longer term view of biological and chemical changes in the system.

Protection of airsheds of acid-sensitive lakes in the Alagnak drainage (four largest) and the two lakes at the highest elevation in the Naknek drainage is paramount (LaPerriere 1996). Smelting of metal ores, power generation from fossil fuels and automobile exhaust are examples of activities that may be of concern for these sensitive lakes. Although the probability of any of these activities occurring adjacent to the park seems remote, there are recent proposals to construct a road between Anchorage and King Salmon and develop a mine site north of the Alagnak Wild River.

What should be done to monitor airborne pollutants?

- ✓ Establish weather and particulate samplers in the park.
- ✓ Support USGS studies of the arctic sunrise effect (discussion in this chapter under "Inventory and Monitoring").
- ✓ Support National Park Service – Air Resource Division's project, "Western Airborne Contaminants Assessment Project"

VIII. Climate Change and Its Influence on Water Resources

One of the more significant natural resource issues in Alaska is climate change. The National Assessment Synthesis Team (2001:287), part of the U.S. Global Change Research Program, suggests that, aside from direct fishing pressure on marine ecosystems, the greatest present environmental stresses in Alaska are climate related. 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 changed dramatically in the past and the global mean temperature has increased an average of approximately one degree Fahrenheit in the last 100 years (Trenberth 1997, Rouse et al. 1997). Alaska has warmed two degrees Centigrade since the 1950s on average, with the largest change about four degrees Centigrade in the Interior in winter (Chapman and Walsh 1993 and Weller et al. 1998). Most of this warming occurred very recently – beginning about 1977 – coincident with the most recent of the large scale Arctic atmosphere and ocean regime shifts (Weller and Anderson 1998). Current global climate models predict that warming in the twenty-first century will cause temperatures to greatly exceed those of the mid-Holocene when temperatures were only 1-2^{o}C warmer than the mid-twentieth century (Schindler 2001:19). The environmental concerns associated with climate change have 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 experiencing is primarily human-induced.

Alaska also grew substantially wetter in the twentieth century. Historical records since 1900 show mixed precipitation trends with increases of up to 30% in the south, southeast and interior regions. The trend toward higher precipitation has been stronger recently, a 30% average increase between 1968 and 1990 for most of the state (Groisman and Easterling 1994). Continued precipitation increases are projected for most of the state but climate models predict reduced summer precipitation for parts of the Alaska Peninsula. Northern hemisphere spring and summer snow cover, monitored by satellite imagery since 1973, has decreased by 10% since 1987 (Trenberth 1997).

Models also predict increased rates of evaporation due to warmer summer temperatures, resulting in drier soils for most of the state, exacerbated by lower precipitation in the south, including the Alaska Peninsula (National Assessment Synthesis Team 2001:289). Unless the warming trend is accompanied by an increase in precipitation, we can expect to see declines in lake levels, water renewal rates, stream flow, the extent and water level in wetlands, soil moisture and groundwater levels (Schindler 1997:1044). In the Experimental Lakes Area in northwestern Ontario all these effects have been observed. There, first order streams that flowed continuously during the ice free season in the early 1970s were dry for up to 150 days during the summers of the late 1980s (Schindler et al. 1996).

Changes in the seasonal pattern of runoff are likely to cause disturbance to fish habitat and affect recreational uses of streams and wetlands. Lower water levels may also cause transportation issues for boats and aircraft as well. Conversely, higher water levels in coastal areas present a different, unique set of concerns.

Declining waterflows can cause drastic changes in water chemistry. Lower waterflows mean declines in chemical outputs from lakes and resulting longer residence times. Increased residence times can cause concentrations of biologically conservative constituents to increase. In contrast, biologically active constituents would have longer time periods for biological activity to occur. Phosphorus, dissolved organic carbon and silica in the Experimental Lakes Area of Canada declined in lakes and streams presumably because longer residence times increase their exposure to biological removal processes (Schindler et al. 1996). Sulfate, for example, is removed by reduction as a function of contact time between water and sediment (Baker et al. 1986 in Schindler 2001:21). Few, if any, ions are unaffected by changes in inputs, outputs, or soil processes, causing significant changes in lake chemistry (Schindler et al. 1996).

A. What are the predicted effects of climate change?

Greater increases in temperatures are expected in northern latitudes as a result of global warming than in other areas (Root 1989). These areas are predicted to be particularly sensitive to changes in available energy, causing changes in precipitation/evaporation ratios and runoff, duration of ice cover, thickness of snow cover and fires (Schindler et al. 1990). Lake physical and chemical processes may be disrupted with subsequent effects on productivity and decomposition rates. In short, fundamental changes in hydrological processes will likely result.

Glacier retreat, rising timberlines, the desiccation of small ponds and the black spruce invasion of wetland perimeters are all visible signs of the current warming trend (Berg 1997). Likewise, permafrost melting is expected to increase throughout most of the discontinuous zone (National Assessment Synthesis Team 2001:291), affecting hydrology, erosion, vegetation and human activities. Complete thawing of even discontinuous permafrost is projected to be a slow process over centuries (Osterkamp and Romanovsky 1999 in National Assessment Synthesis Team 2001:291).

Indirect effects of temperature increases may be evident as well. Higher air temperatures may result in a larger volume of meltwater from glaciers increasing turbidity of affected waters. A decrease in productivity will likely accompany the expected decline in the trophogenic zone in these waters.

Forest and tundra ecosystems of the Alaska Peninsula could suffer moisture stress and loss of productivity from increasing temperatures and evaporation and decreasing precipitation. This phenomenon has been observed on the Kenai Peninsula where moisture stress has resulted in forest disturbances, such as a spruce bark beetle outbreak with accelerated beetle development times and increased tree vulnerability, and fires (Juday et al. 1998). Over the long term climate change is likely to bring large landscape level vegetation changes to the region. Chapin and Starfield (1997) predict the westward migration of the coastal forest on the Alaska Peninsula in one or two centuries, expansion of forests to higher elevations and colonization of formerly glaciated lands.

But wetlands may be most at risk. During the dry mid-Holocene there were few wetlands in the southern prairie regions of Canada under conditions less extreme than predicted to occur from increased greenhouse warming (Schindler 2001:20). The scenarios predicted for the Alaska Peninsula could result in lower water levels or disappearance of shallow wetlands. Drought and warm temperatures can significantly change the vegetation of wetlands as well. As might be expected, waterfowl production is greatly affected by these conditions (Larson 1994 in Schindler 2001:20).

Studies on the effects of climate change on the structure and function of freshwater ecosystems are few (Bruns et al. 1992:288), with the bulk of the research to date focusing on the terrestrial environment. Because of the linkage between terrestrial and aquatic environments, these studies are useful in determining the type and magnitude of the effects that might be expected on aquatic ecosystems and reinforce the need to monitor both habitats. High latitude areas are known to be very susceptible to large scale shifts in vegetation. Emmanuel et al. (1985 in Firth and Fisher 1992:288) looked at major shifts in vegetative zones worldwide, and for high latitudes significant loss of tundra was evident. Changes in vegetative type can affect the quantity and quality of terrestrial inputs to the aquatic environment, perhaps changing sedimentation levels or nutrient inputs.

Modern day stories attest to the rapid changes in vegetation in the past century. Early southward expansion of trees and shrubs onto the Alaska Peninsula was probably slow due to strong southerly winds during the pollen producing season (Detterman 1986:154). However, this expansion became fairly rapid during the twentieth century – 60 km southward migration of the forest edge in 75 years – an average rate of 0.8 km/yr (Detterman 1986:154). In the first decade of the twentieth century Martin and Katz (1912 in Detterman 1986:154) showed the southern edge of the spruce forest as being just south of Lake Iliamna. Present day observations place it in the area of Naknek Lake.

Biotic species shifts may also occur eventually. Streams and rivers are likely to show the greatest shifts, given their greater sensitivity to climate than lakes and have a greater responsiveness to runoff (Sala et al. 2000:1772). While progressive warming may alter biotic communities, Meisner et al. (1988 in Firth and Fisher 1992:287) predicts that climate change may enhance salmonids in high latitude and high elevation tundra and arctic freshwater environments, but optimum thermal habitats may decrease in lower latitude and low elevation areas.

Effects have been recorded to many trophic levels in the system. Some aquatic invertebrates are thermally intolerant, and detrimental impacts on their populations may occur as a result of elevated water temperatures. Habitats for cold stenothermic organisms may be reduced, resulting in changing species ranges or behavioral modifications. Studies show reductions in fish growth rate (Edmundson and Mazumder 2001), changes in life history, changes in competitive interactions between species, reductions in fecundity of adults and increased susceptibility to disease (Cedarholm et al. 2000:20). Eaton and Scheller (1996 in Schindler 2001:22) studied the temperature tolerances of 57 freshwater species in the United States and predicted that climate warming would reduce habitat for cold and cool-water species by 57%. Effects on lower trophic levels are equally numerous.

Biotic interactions may also be altered through stress incurred by change in climate. The change in interactions between species, the loss of specialized species and resulting shift toward a greater proportion of generalists and loss of species with vulnerable life histories are a few of the changes that could be observed. Aquatic invertebrate communities are populations that could be affected by climate change.

Changing processes are expected to be especially pronounced in carbon and nitrogen cycling (Murdoch et al. 2000 in Jackson et al. 2001:1036). According to Schindler (2001:21), changes in dissolved organic carbon (DOC) may be one of the most important effects of climate warming. In small lakes where colored allochthonous (of foreign origin) DOC inputs are decreased as a result of decreased stream flows, drier soils and lower water tables, waters become clearer and increased penetration of solar radiation occurs (Schindler 2001:21). The effects may be further amplified by increasing processes such as bacterial action. In lakes and ponds DOC provides protection to freshwater communities from UV radiation. Lakes with less than 300μM DOC are particularly vulnerable to decreases in DOC (Schindler 1997:1057).

B. Using Natural Laboratories to Study Climate Change

Because global warming is predicted to be greatest in high latitudes, the northern location and pristine condition of Alaska’s parks make them excellent ‘science preserves’ or ‘natural laboratories’ for investigating relationships between the physical, biological and cultural resources of the Arctic and sub-Arctic. Investigating past changes in climate, landscape processes, vegetation, animals and human practices can help us understand how the *system* works and how it might respond to future environmental changes of both natural and human origin.

Katmai’s environment is thought to be very susceptible to climate change. For example, Pinney and Begét (1991b) reported that rapid environmental changes and glacial fluctuations on the Alaska Peninsula might be responses to transient changes in the concentration of atmospheric greenhouse gases and solar intensity. Climate also has a great influence on peatlands, which are found in Katmai’s lowlands and lake country (Belland and Vitt 1995). 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 complement 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 of the carbon budget of freshwater systems. According to a 1993 report by Potts et al., the U.S. National Weather Service has expressed a desire to assist Katmai with the establishment of meteorological stations in the park. A proposal was also made by the Soil and Conservation Service in 1993 to assist the park in the establishment of one or more snow depth survey stations (National Park Service 1994). Currently, two snow depth survey stations are established near the Brooks River area and Valley of Ten Thousand Smokes. These sites are monitored on a scheduled frequency with the data provided to the Soil and Conservation Service.

C. Some of the Indicators of Climate Change

Geoindicators can be important in detecting long term environmental change, such as global warming, provide insights into ecological consequences of those changes and help determine whether observed changes can be corrected. They also can be used to assess whether changes are within a normal or anticipated range of variation. Geoindicators that would provide indicators of change in a watershed include glacier advance and retreat, shoreline movement, sediment storage and loading, soil erosion, lake levels, stream channel morphology and streamflow.

Glaciers are highly sensitive, natural, large-scale, representative indicators of the energy balance at the Earth’s surface. Their capacity to store water for extended periods exerts significant control on the surface water cycle. The length of mountain glaciers and their ice volume have decreased throughout the world during the past century or two, providing strong evidence of climate warming. Local correlations associated with decreasing precipitation may also be occurring. Analysis of air photos and high resolution satellite images and ground surveys may be useful in detecting glacial surges and estimating the volume of ice being transferred. Surveys should be conducted annually where glaciers are surging. At Katmai glaciers are retreating, but the rate is unknown. Aerial photos provide a means of estimating the rate in recent time.

In studies of the six glaciers descending the slopes of Mount Griggs, Hildreth et al. (2000:109) has shown that the northerly glaciers were 2 km-3 km longer earlier in the Holocene. Aerial photographs taken in 1951 and 1987 reveal marked differences in the behavior of the six glaciers; with all either retreating, thinning or both during the 36-year interval. The youngest of the six glaciers has receded about 400 meters, withdrawing upward from 4,800 ft elevation in 1951 to about 5,500 ft elevation by 1987 (Hildreth et al. 2000:109).

Of the five northerly glaciers, two have retreated since 1951, two show little change and one has advanced slightly (Hildreth et al. 2000:110). The inconsistent patterns are attributed to a number of factors. More systematic patterns of glacier behavior have been observed at nearby Mageik, Trident, Katmai, and Snowy Mountain volcanoes (Hildreth et al. 2000, 2001).

Scientists studying glacier mass balances in Alaska and the Pacific Northwest suggest that snowpack may be a particularly sensitive variable for use in investigating climate variations (Hodge et al. 1998:2177). They found that in coastal, maritime situations, glacier net balance is controlled primarily by winter accumulation, but primarily by summer ablation in the interior, continental regime (Hodge et al. 1998:2177). Katmai glaciers, residing mainly in the maritime or transition zone, may be monitored by snowpack as well as conventional methods of glacier monitoring.

Stream channel morphology is a reflection of water and sediment discharges and provides an understanding of environmental changes in the watershed. Stream flow is a direct reflection of climate variation. Changes in basin dynamics are indicated by streams and streamflow.

Sediment load determines channel shape and pattern. A change in sediment load is a reflection of changes in basin conditions such as climate, soils, rates of erosion, vegetation, topography and land use. Fluctuations in sediment discharge affect both terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

D. What should be done to monitor the effect of climate change on the aquatic ecosystems of Katmai?

- ✓ Monitor glacier fluctuations.
- ✓ Develop a program for monitoring stream flow and water temperature.
- ✓ Determine the ecological role of salmon in freshwater and riparian communities and on the life history of organisms living there.
- ✓ Determine how vegetation communities have changed over time, and correlate species shifts with nutrient cycling in the watershed.
- ✓ Assess the changes in paleo-lake levels in relation to aquatic productivity since the last ice age.
- ✓ Develop a water balance model for wetlands, and document changes in wetland structure and function in response to changing climate over time.

IX. Nutrient Cycling

Salmon are important in the transport of energy and nutrients between the ocean, estuaries and freshwater environments. Salmon reverse the flow of nutrients back upstream, playing a vital role in determining the overall productivity of a watershed and the productivity of salmon populations as well. Salmon directly affect the ecology of many aquatic and terrestrial consumers and indirectly affect the entire food web (Cederholm et al. 2000:iv).

Katmai's aquatic ecology is heavily dependent upon the annual influx of nutrients (e.g., carbon, nitrogen and phosphorus) with the upstream return of millions of adult salmon. All five Pacific salmon (*Oncorhynchus*) are found in Katmai. Spawning runs of fish produce nutrients to streams and lakes by recycling and direct consumption. The processes of excretion, decomposition, and release of gametes constitute the major forms of recycling (Allan 1995). A large run of 20 million sockeye, for example, in Bristol Bay can yield as much as 5.4×10^7 kg of biomass, equating to 2.4×10^4 kg of P, 1.8×10^5 kg of N and 2.7×10^5 kg of Ca, plus other macroelements (Gende et al. 2002:918).

Either nitrogen or phosphorus is generally the limiting factor in subarctic lakes, as in Katmai; and the contribution salmon make to restoring and recycling these nutrients is substantial. Both phosphorus and nitrogen have been shown to stimulate the primary production of aquatic systems. All trophic levels benefit from the influx of nutrients. In Sashin Creek, Alaska, isotope analysis showed that nitrogen and carbon derived from a spawning run in Pacific salmon (*Oncorhynchus spp.*) were incorporated into periphyton, macroinvertebrates and fish (Kline et al. 1990).

Salmon affect food webs at the landscape level - even terrestrial ecosystems derive a benefit. The effects of the influx of salmon derived nutrients have been found 70 meters or more from edge of a stream (O'Keefe and Edwards forthcoming, Bartz 2002) as consumers from invertebrates to large mammals disperse decomposing salmon along the banks. In the Tongass National Forest, in southeastern Alaska, are more than 5,000 salmon supported streams (Halupka et al. 2000 in Gende et al. 2002:919). Nearly 47% of the forested area in the Tongass falls within 1/2 km of a salmon stream (Willson et al. forthcoming in Gende 2002:919), effectively extending the interface between ocean and land, expanding the surface area over which ecological exchanges take place (Gende et al. 2002:919).

Several studies in Southwestern Alaska have shown the importance of marine derived nutrients to freshwater and riparian ecosystems (Bartz 2002, Helfield 2001, Helfield and Naiman 2001, 2002). In nitrogen limited systems, such as Katmai, riparian foliage contained ~15-30% of marine derived nitrogen. Some species actually contained significantly higher amounts, while alder, a nitrogen fixing genus, showed little uptake. These studies also found marine derived nitrogen in plant species up to 200 m from a stream (Bartz 2002, Naiman et al. 2002) although this distance varies by site and plant species and the proportion of marine derived nitrogen declines with distance. Marine derived nitrogen also decreases the competitive advantage of nitrogen fixing species, such as alder, resulting in decreased abundance near salmon spawning streams (Helfield and Naiman 2002).

Although the importance of marine derived nutrients on all trophic levels in the aquatic environment, and on terrestrial ecosystems as well, are quite well known, little research designed to understand their importance in Katmai has been undertaken. In fact, only Margot Creek in Katmai has been included in any studies, and then Bartz (2002) focused on nitrogen uptake in riparian zones.

It has long been reported that a key factor in salmon production is the continued supply of nutrients their decomposing carcasses supply to the system. However, although Katmai may benefit from studies done outside the park, it is clear that the relative importance of marine derived nutrients varies by location. If population levels become too depressed, nutrient levels may not be high enough in some nursery lakes to sustain the population. However, recent studies suggest the productivity of some lakes may be less impacted by changes in nutrients derived from salmon. Finney et al. (2000:797) reported that salmon derived nutrients constitute a small proportion of total nutrient input to the Ugashik and Becharof Lakes. Therefore, disruptions in the nutrient feedback cycle only had minor effects on salmon production. This underscores the need to evaluate the implications of both climatic factors and altered nutrient cycles in determining the best strategy for managing salmon. Furthermore, there are few lakes in the database, and those that have been analyzed do not explain the variation in runs that have been observed in the Kvichak and Naknek systems. Additional work should be done in other drainages, including those in Katmai, to determine whether the pattern observed elsewhere is repeated or there are other factors affecting salmon productivity.

Recommended Actions

- ✓ Determine the role of marine derived nitrogen and phosphorus on ecosystem function.
- ✓ Construct a model of nutrient flow, loading and cycling in Katmai watersheds.
- ✓ Determine the link between salmon production and watershed productivity over time.
- ✓ Determine the key factors driving productivity in the freshwater environment.

X. Recreational Use Impacts

Sightseers, anglers and hunters routinely fly or boat into Katmai to take advantage of the park's pristine natural resources. As word of the park's unique and varied resources spread, park visitation began to rise. In fact, over the last 15 years the number of park visitors has grown from roughly 25,000 to more than 71,000 annually (chapter 6, visitor use).

With the increase in visitor use has come increased concern for resource impacts. For example, the recreational demands by freshwater anglers in Southwestern Alaska have more than doubled in the last decade. As angling pressure increases in Katmai, boat operators venture farther into headwater streams to avoid crowding. Today, jet-driven boats are becoming more popular because of their shallow draft. These shallow headwaters are preferred by Pacific salmon (*Oncorhynchus*) and rainbow trout (*Oncorhynchus mykiss*) as sites of egg deposition and may be impacted by compression and siltation of redds by motorboat traffic.

Furthermore, as recreationists begin to explore areas previously little traveled, increased use of high horsepower motors, varying boat types and heavier loading and the sheer numbers of boat passes by any given point increase concerns for the level of bank erosion occurring. Hydrocarbon contamination of water, sediment and air is also a concern where boat use is heavy.

In response to increased visitation in Glacier Bay National Park and Preserve, the NPS has required cruise ships operating in Glacier Bay to record smokestack emissions and measure underwater noise so the NPS can research cruise ship effects on the park. Katmai may warrant a similar assessment with increases in coastal visitation in the past 10 years.

Not all impacts are associated with boat travel. A concern expressed by many visitors and NPS managers alike is the management of wastes in popular use areas. There are no facilities to handle human waste along waterways in the park, except at lodges and the few permanent NPS camps. Although guides are careful to contain and remove wastes they and their clients generate from fish cleaning and lunch preparation, the less savory task of removing and/or disposing of human waste is left undone. Complaints of poor human waste disposal practices are most consistent along the Alagnak River where there are no restroom facilities available for visitors. Although park regulations prohibit leaving toilet paper or other sanitary products on site and require human waste be buried at least six inches deep and 100 feet from any freshwater source [§2.14(a)(9) and §2.14(b) Katmai, Aniakchak and Alagnak compendium 2007], disposal of human waste continues to be of concern. River users have raised concerns for exposed human wastes and toilet paper along the sides of rivers and on gravel bars causing an unsightly mess as well as a human health risk. Contamination of surface waters may also result from these practices.

Several ideas have been advanced to place the burden for removing human wastes on commercial operators, but none may prove to be a viable way of controlling or eliminating the problem. Waste control measures are being implemented on the Alsek River at Glacier Bay National Park and Preserve with some success. Concessions permits prohibit disposal of human waste within a half mile of the Alsek River, and solid wastes must be carried to the NPS dump station at Dry Bay or another approved facility. The draft Gulkana (Southcentral Alaska) Comprehensive River Management Plan may also provide some useful ideas for controlling waste on the Alagnak. The draft plan identifies a monitoring program that results in a series of steps for decreasing waste along the river. Early actions include increased patrols and education and the requirement that guides carry out human waste. All users are required to carry out human wastes when monitoring levels indicate wastes have reached a predetermined maximum level (Bureau of Land Management 2002).

A. Impacts from Powerboat Use

Concern over the effects of boats and motors on water quality and fish are used more and more frequently as the rationale for limiting watercraft on popular waterways. In fact, the Levelock Village Council, Levelock Natives Limited and Bristol Bay Native Association signed a resolution in September 2001 (Resolution 2001-09-24B) requesting that the Lake and Peninsula Borough develop and implement measures to protect the Alagnak River from further degradation. Residents of Levelock are concerned about the increasing number of lodges on the river, increasing number of visitors and competition between subsistence and sport hunters and fishers. Increasing use has resulted in bank erosion from oversized boats and motors, trespassing on private property, vandalism of subsistence camps and illegal use of vehicles in the park. They propose the following measures be implemented:

1. Extend catch and release policy to include grayling.
2. Restrict the size of boats to no more than 18 feet with a floor width of no less than 48 inches.
3. Restrict the size of outboard motors to 50 horsepower.
4. Reduce the number of non-subsistence users to 12 guided and unguided per week.

In turn the Lake and Peninsula Borough Planning Commission passed Resolution 01-28 in October 2001, supporting watershed and river management planning on the Alagnak Wild River and adjacent uplands. The resolution recognized the value of protecting the resources of the Alagnak River corridor from increasing visitor use, but fell short of actually adopting the restrictions that the Levelock resolution had asked for.

1. What are the causes for concern?

Sediment resuspension resulting in decreased water clarity, water pollution, disturbance of fish and wildlife, destruction of aquatic plants and shoreline erosion are the major areas of concern with respect to boating. Each of these factors is affected by natural phenomena as well as human activities, but often the human activities are more concentrated and frequent. The sections that follow include a synthesis of the literature on the potential concerns related to motorized boat recreation.

The NPS has been concerned about jet boat use for some time and funded research on American Creek and Alagnak Wild River in an attempt to understand and quantify impacts to these waterways specifically from boat traffic. The latter sections discuss this research in the context of the wider body of literature available.

a. Effects on Water Clarity. Studies by Yousef et al. (1980), Hilton and Phillips (1982), Johnson (1994), U.S. Army Corp of Engineers (1994), and Asplund (1996) indicate that boats affect water clarity, particularly in shallow lakes and streams and channels connecting lakes. Propeller wash can cause a direct disturbance of river or lake bottoms particularly in shallow water and contribute to accelerated shoreline erosion. Wash and turbulence from the engines stir up fine sediments, causing a decrease in water clarity through suspension of sediment. Fine sediment suspended in the water column can settle into a redd, suffocating eggs at critical times in the growth process. The depth of the impact varies depending on the boat size, engine speed and substrate type. Few impacts have been observed in water deeper than 10 feet (Asplund 2000).

Yousef et al. (1980) studied motorboat impacts in shallow Florida lakes. He looked at turbidity, as well as other factors, before and after motorboat passage. On 18-inch- deep lakes he saw significant increases in turbidity, phosphorus and chlorophyll *a*. Maximum increases in turbidity occurred within the first two hours of boating activity and declined at a slow rate, taking more than 24 hours to return to initial levels.

Johnson (1994) and Asplund (1996) also measured turbidity and other factors affected by boat activity on the Mississippi River and Wisconsin lakes, respectively. Water clarity decreased following boat passage in both studies as a result of increased turbidity. In the

Mississippi River turbidity increased most near the bottom of the river. In the Wisconsin lakes study shallower lakes and clear water lakes experienced the greatest changes in water clarity due to motorboat use.

A model predicting the amount of turbidity generated by boat passage on a stretch of river was developed by Hilton and Phillips (1982). The model was based on field measurements of turbidity and timing of boat passage. Their model assumed that each boat pass generates the same level of turbidity and that the level of turbidity decays exponentially with time. They determined that turbidity returned to background levels 5.5 hours after boat movements ceased. The model also predicted that 8%-44% of the turbidity in the river annually could be attributed to boat activity.

b. What can be done to reduce the impact?

- ✓ Minimize boat use in shallow areas.
- ✓ Reduce the number of passes over spawning beds.

2. Effects on Water Quality

Small boat engines and aircraft introduce limited amounts of fuel into waters near developed areas. Brooks Camp with its high traffic volume probably suffers most from this form of pollution, but other camps and lodges in the park probably experience similar contamination to varying degrees.

Due to their inefficiency boat engines discharge unburned fuel into the waters. Two-stroke engines are known to deliver as much as 25%-30% of their fuel into the water column, depending on the boats' speed, tuning, oil mix and horsepower (Jackivicz and Kuzminski 1973:1761, Asplund 2000). Nonvolatile oil, volatile oil, lead and phenols are also discharged in motor exhausted water. In high enough amounts petroleum products can be toxic to fish, wildlife and other aquatic organisms.
Schenk et al. (1975) observed an increase in lead and hydrocarbon concentrations resulting from motorboat traffic in a small, shallow pond studied for a three-year period. Higher levels of these two constituents were found in the water column and sediments although no acute toxicity was observed for any species.

Mastran et al. (1994) found detectable levels of polyaromatic hydrocarbons (PAH), a group of organic compounds found in petroleum products released into the environment through the combustion process, in the water column during times of peak boating activity, but not when boating activity was minimal. PAHs were found in sediments during both times. PAHs are a known carcinogen and therefore of concern in areas where people are drinking water. Atmospheric deposition is another source of PAHs, and background levels of this constituent have not been reported for Katmai water or sediment.

Motorboat engines can also influence nutrient levels in the water. Hallock and Falter (1987) showed that motorboat exhaust contributed about 1% of the total nitrogen loading to the lake. Phosphorus level increases were negligible.

Numerous studies on this effect have concluded that there are minimal toxic effects from outboard motorboat exhaust and fuel leakage on aquatic organisms in the short term primarily because hydrocarbons are volatile and disperse quickly and the amount of the pollutant is small compared to the volume of most water bodies. However, buildup of pollutants in sediments could cause long term detrimental effects on aquatic organisms. Furthermore, detection of any level of PAH or fuel additives in the water is always a concern for humans drinking the water.

a. What can be done to diminish the input of contaminants in the water?

- ✓ Boat operators should be encouraged to use cleaner technology, such as four stroke engines and more efficient two stroke models, which eventually reduce the input of fuels and exhaust into the water. The down side is that new technology may have the opposite effect on physical impacts as engines sizes continue to increase and manufacturers emphasize speed and power.
- ✓ Carefully control and handle fuel near the water to reduce sediment contamination from fuel transfer and storage.
- ✓ Keep engines well tuned, use manufacturers recommended mix of oil and gas to help two stroke engines run more efficiently and reduce the amount of unburned fuel that is discharged.

3. Effects on Shoreline Erosion

Boat wakes produce a wave that will propagate outward until it hits the shoreline and dissipates. This effect varies with boat type, engine, hull displacement and distance from shore. River systems, channels connecting lakes and small lakes are most affected by boat wake since boats operate close to shore. Banks consisting of loosely consolidated, steep and unvegetated banks, such as those on the Alagnak Wild River, are most susceptible to erosion.

Studies by Bhowmik et al. (1992), Nanson and Knighton (1996), Johnson (1994) and Johnson (in prep, in Asplund 2000) have shown the effects of boat wakes on bank recession. In all cases shoreline erosion was attributed to boat traffic on the rivers measured. In lake or still water environments, it is still unclear what effects boat wakes have on shoreline erosion or bank recession (Asplund 2000:8). In addition, little is known about the cumulative effects of boat wakes coupled with wind induced waves or on how much boat traffic a given shoreline can sustain.

In a recent study on the Kenai Peninsula, Maynord (2001) compared wave characteristics of two boats on the Kenai River and five boats on Johnson Lake under a variety of configurations of: loadings, speed, distances, motor powers and direction of travel (table 1). The study is part of an assessment of the effects of boat waves on bank erosion. Although it is premature to draw conclusions on the impact of specific boat/motor/loading configurations on bank erosion, this study provides some interesting conclusions on which configurations and boat types result in the largest wave energies.

The height of the wave generated by a boat depends on the boat's speed, hull shape, draft, trim, length, water depth and distance from the boat. Wave height is also heavily influenced by the combination of hull type and engine power sufficient to allow the boat to plane or get "on-step" (Maynord 2001:3). Maximum wave height is often correlated to shoreline damage.

Table 1: Boat type, loading, and motor power evaluated in Kenai Peninsula studies of bank erosion.

Model	**Hull**	**Length (feet)**	**Beam (in.)**	**Weight (lbs.)**			**Model**	**Type***	**Horse-power**
				3	4	5/6			
Klamoth	V	16	75	1475	1640	1805	Yamaha	2-stroke	40
Lowe	Flat	16	52	1195	1360	1525	Yamaha	2-stroke	40
Koeffler	Flat	20	95	2155	2320	2650	Yamaha	4-stroke	50
Willie Predator	V	20	84	2675	2840	3170	Honda	4-stroke	50

Source: Maynord 2001:8, 15 * All were long shaft.

The wave produced by a given boat configuration at maximum power and the maximum wave a boat was capable of producing at some given power setting (which varied by boat/engine/loading) were determined. Results of the study are as follows:

- Marked differences in wave characteristics produced by "V" hull versus flat bottom hull types were observed. With a 35 hp engine and *equal numbers of passengers* in the boat, the V-hull boats (Willie Predator and Klamoth) produced a wave height at maximum power 66% greater than the flat bottom boats due to hull shape and heavier total weight (Maynord 2001:61). With a 35 hp engine and *equal total weights* of the boats, the V-hull had an average wave height at maximum power 29% greater than the flat bottom boats. When power/weight is increased, the differences in hull type diminish (Maynord 2001:61).

- The maximum wave height a boat was capable of producing was larger than the wave height produced at maximum power for all boats (Maynord 2001:61). Maximum wave heights occurred at about 9 mph for all boats tested (Maynord 2001:61).

- As the load increased, all boats tested showed an increase in wave height at maximum power settings. The maximum wave height at maximum power settings was reduced by 22% when loading decreased from heavy (5-6 passengers) to light (3 passengers) and by 10% when loading decreased from heavy to medium (4 passengers)(Maynord 2001:62).

- Except for the Lowe, boats equipped with 35 hp engines produced greater wave energy and higher wave heights at maximum power than did boats with a 40 hp or 50 hp engine, whose wave heights were 12%-20% smaller than those of the 35 hp engines (Maynord 2001:60).

The conclusions reached as a result of this limited study were to:

1. Encourage use of flat bottomed boats.

2. Set minimum limits on motor power to weight ratio that depend on hull type (greater motor power or lesser total boat weight will achieve this).
3. Avoid continuous operation around 9 mph, which is the approximate speed at which the maximum wave height is exhibited in all boats tested.

4. Effects on Fish and Other Aquatic Biota

Pollution from powerboats and boat movements can have a negative effect on fish populations and other aquatic organisms. Engine exhaust and fuel spillage are of the most concern as pollutants as they can be toxic to some fish. Individual fish may be disturbed from normal nesting, spawning or feeding behavior by boat movements. Habitat alternation, suffocation of larvae and interference of spawning activity may result from increased turbidity caused by boat wakes or engines themselves and egg mortality. The mechanisms by which motors may affect aquatic biota and human enjoyment of waters and the actual effects documented are summarized in table 2.

As mentioned previously, petroleum hydrocarbon pollution is not likely to cause immediate or short term effects on fish populations, but long term effects of chronic exposure are largely unknown. These products from the emissions of boat engines accumulate in sediment and may become resuspended by boat traffic, particularly in shallow waters.

In laboratory trials Hilmer and Bate (1983:314) found that fuel oil in an estuary can have a measurable effect on photosynthesis of marine microalgae. Some species showed a significant reduction in photosynthesis, while others showed only a tendency toward reduction in rate. Chlorophyll *a* concentrations were not significantly affected. Numerous studies have attempted to characterize the sensitivity of various algal species to fuel oil pollution only to find that generalizations cannot be made. The sensitivity of microalgae to hydrocarbons depends on both the type of hydrocarbons they are exposed to and the algal species involved. Toxic effects of crude oil are further increased by reduced light intensity (Hilmer and Bate 1983:314) and in lower temperature waters (Kusk 1981 in Hilmer and Bate 1983:314).

Table 2: Mechanisms by which boats can affect aquatic ecosystems and human enjoyment of waterways.

Mechanism⇒ **Effect⇓**	**Emissions or exhaust**	**Propeller or hull contact**	**Turbulence**	**Waves and wake**	**Movement**
Water clarity (turbidity, nutrients)		XXX	XXX	XXX	
Water quality (hydrocarbons and other pollutants)	XXX				
Shoreline erosion or bank recession				XXX	
Fish	XXX	XXX	XXX		XXX
Wildlife				XXX	XXX
Aquatic organisms	XXX				
Human enjoyment	XXX			XXX	XXX

Studies on bluegill and largemouth bass production, nest locations, mortality of eggs and fry and habitat alternation by Lagler et al. (1950) indicated that motorboat traffic had little effect on these factors although later studies refuted some of these findings. Ogle (1972:88-89) and Sutherland and Ogle (1975) in a study in New Zealand reported that jet boats generate pressure fluctuations that are capable of killing salmon eggs during early stages of incubation (ninth day is most critical in terms of physical damage). Mortality was measured as high as 40%. Their study included both direct measurements of pressure fluctuations in artificial redds in a stream and laboratory experiments on salmon eggs at various stages of development. These findings were called into question. Critics noted that salmon eggs in natural redds do not have the degree of freedom to move through intragravel pore spaces as they did in the laboratory experiment and that the laboratory simulation created a degree of disturbance that would occur only from prolonged or repeated passes by a jet boat over the same redd or the “worst case” scenario (Ogle 1972:98 and Sundberg 1990:5). Regardless of the limitations of the experiments, even critics of the study admit that jet boats may cause egg mortality. Additional research to test laboratory experiments in field conditions is warranted.

Later, an unpublished study in a Missouri Ozark stream of wake height and substrate disturbance indicated that both jet driven and propeller driven johnboats caused significant disturbance of substrate at depths of 7 inches-10 inches. They also showed there was no significant effect at 17 inches and that jet boats had a lesser effect at 14 inches than propeller boats (Bush 1988:7). Biological effects were not directly measured.

Mueller (1980:249) found that boating affected fish behavior. Boats caused spawning sunfish to abandon their nests for varying periods of time, depending on the speed and proximity of boat passage to the nest. Sunfish left their nests for longer periods following boat passage directly overhead than under any natural circumstance that caused their movement, leaving eggs vulnerable to predation. He also observed that slower moving boats caused nest abandonment more frequently and resulted in a higher rate of predation on eggs (Mueller 1980:249-250). Although fish were shown to abandon their nests, at least temporarily, studies have not shown that breeding success has been affected. However, fish habitat alteration, as it relates to water clarity and water quality, are of concern to managers (previous section).

Several other studies were conducted to quantify the effects of humans on fish production. Post et al. (1974) studied the effects of underground nuclear detonations on survival of rainbow trout embryos, Boussard (1981) considered the response of small fish (roach and rudd) to high speed boating and Roberts and White (1992) studied the effects of angler wading on survival of trout embryo and larvae, providing justification for restrictions on anglers in insufficient or deficient spawning areas.

In 1989, the Ozark National Scenic Riverways in Missouri successfully codified a regulation prohibiting jet boats on certain tributaries in the Riverways (36 CFR 7.83). This regulation was not implemented to protect fish, but reduce conflicts between recreational users. So far no states have prohibited jet boats based on concerns for fish eggs or fry.

Effects of boat traffic on waterbirds, eagles and other species are of concern, but will not be addressed in this plan. Disturbance of many wildlife species has been documented in the literature.

5. What is being done at Katmai to address this issue?

Although a body of literature on the effects of boat wakes and engines exists, those studies primarily focus on areas outside of Alaska, on large vessels and high frequency uses and on large rivers such as the Mississippi. Many factors must be analyzed in determining what effects, if any, a particular boat or motor may have on stream characteristics or fish.

In Alaska, jet driven johnboats are preferred for transport because of their speed, maneuverability and shallow draft. There is concern that the use of jet boats allows anglers and others access to shallow streams where both may affect salmonid reproduction. The NPS has been concerned about this issue for some time and funded research on American Creek and Alagnak Wild River in an attempt to understand and quantify impacts to these waterways specifically from boat traffic. The following sections discuss this research in the context of the wider body of literature available.

<u>a. American Creek Jet Boat Impacts.</u> American Creek is in the headwaters of the Naknek drainage in Katmai. It flows 63 km from its source in Hammersly Lake to Lake Coville. This creek is an important spawning stream for sockeye salmon. Before 1978, only the lower one-mile of American Creek was within the boundary of Katmai. During that time, motorboats were prohibited within the monument, except on Naknek Lake. The creek was incorporated into Katmai's boundary in 1978 when the monument was expanded. At the same time when ANILCA redesignated the monument as a park and preserve in 1980, it opened the park unit to motorized access by floatplanes and motorboats. Now, most recreational uses of American Creek are concentrated within the lower six miles of the river below where the creek becomes heavily braided although rafting the length of the river is becoming an ever popular trip.

In 1985 a limited concessions permit program was implemented on American Creek, limiting use to seven commercial boat operators. In 1986 and 1987 a study by NPS staff was carried out to evaluate resource conditions under the permit system. The most serious consequence of human activity along American Creek identified during the study was the increased rate of erosion and alteration of streambed morphology that resulted from jet boat use (Jope and Welp 1987). Permanent photo points were established in 1989 with the intent of monitoring riparian vegetation cover and erosion along the creek every two to four years.

Uncertainty continues over the effects of jet boats on salmonid reproduction because objective information is quite limited (previous section). For this reason NPS funded a University of Alaska Fairbanks graduate student to study the effects of boat-induced turbulence on salmonid reproduction in 1992 and 1993 on American Creek (Horton 1994). Both field and laboratory experiments were conducted to determine embryo mortality under varying conditions, evaluate conditions that increase embryo mortality, and to determine the effects on behavior of spawning adults.

Pressure, water depth and substrate movement were the variables selected to evaluate boat effects. Pressure measurements were conducted in the laboratory and in field trials. An 18 foot johnboat, with a 40 horsepower jet unit was used on American Creek to measure mortality of known numbers and developmental stages of embryos in artificial redds and to observe adult fish behavior. Boats of varying size and hull configuration were evaluated on other streams (Rogue River in Oregon for the large boat and motor and the Chatanika and Chena in Alaska, using smaller vessels and engine configurations) for their effects on pressure and substrate movement.

Pressure measurements in 30 cm of water indicated a jet boat produced 0.59 psi pressure difference (positive peak minus negative peak) (Horton 1994:4). The pressure difference was reduced by half when the water level increased from 30 to 60 cm. But in the end, the role and importance of water depth on egg mortality were inconclusive.

Laboratory trials on embryos of different sensitivity (developmental stages) were subjected to varying amounts of pressure. Mortality was 10% or less in both control and pressure induced samples, indicating that pressure alone was not responsible for embryo mortality (Horton 1994:5).

In field trials, gravel was significantly displaced directly under the boat where high velocity water is discharged from the jet nozzle. Videography of salmon eggs showed no egg movement when a jet boat passed overhead. However, in 1993 Horton found that embryos killed in place and those lost from the treatment area accounted for a mortality rate of 52%-62% as opposed to a rate of 8%-15% in the control area. Gravel movement and fine sediment deposition were severe in treatment areas compared to control areas. Mortality of embryos that were displaced from the redd resulted from predation once an egg left the redd or by impact with substrate. Mortality within the redd was largely due to sedimentation causing low intra-gravel water velocity (Horton 1994:65). Oxygen and waste exchange are important to survival of embryos and play an increasingly important role as embryos develop.

Adult salmon only responded in an observable way to jet boat passage when the boat passed within a few feet of the fish. They responded by briefly scattering, but returned to their original position within a few seconds to a minute (Horton 1994:7). Salmon were most disturbed by bears and humans wading in the stream or walking along the bank, in which case they did not return to their original positions for 3-5 minutes (Horton 1994:7). At low levels of jet boat activity, alteration of sockeye spawning behavior is probably unimportant (Horton 1994:69).

Based on his study, Horton concluded that jet boat operation can lead to salmonid embryo mortality (independent of the stage of development) 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 displacement of eggs (Horton 1994:7). Low levels of jet boat passage result in little or no effect on spawning sockeye salmon (Horton 1994:71), and the zone of gravel displacement from a jet boat with a single outboard engine is restricted to an area near the mid-line of the boat.

The importance of jet boat induced embryo mortality relative to other factors is not conclusive although Horton suggests that limiting jet boat use (by size and intensity of use) may be warranted in shallow, constricted stream channels where substrate disturbance may be high (Horton 1994:71). This may be a consideration for streams where stocks are depressed or where a stock is reliant on specific or restricted stream reaches for spawning. However, for healthy stocks that spawn over broad reaches of stream, Horton concluded that jet boat induced embryo mortality should be expected to be lower than natural, density dependent factors such as flooding, dewatering, freezing and channel scouring or the near total excavation of the streambed by spawning sockeye salmon in the highest quality spawning habitat (Horton 1994:72, West and Mason 1987 and Chebanov 1991 in Horton 1994:72).

Research findings to date indicate that jet boats can cause mortality in salmon eggs during early stages of incubation. The studies have not conclusively demonstrated the conditions where such mortality would occur under natural conditions. Streambed composition, water depth, number of passes over the redd, boat size, horsepower, type of jet unit used and loading all play a role in the outcome.

Recommendations for further study include testing the amount and depth of substrate movement by boats in various hull/motor configurations and motor types over a range of gravel sizes, water depths and velocities used by spawning salmon. Further study is also warranted on the effects of boat passage on spawning behavior of fish species besides sockeye salmon.

<u>b. Alagnak Wild River Bank Erosion.</u> The Alagnak and its tributary, the Nonvianuk River, were designated as a Wild River in 1980 under ANILCA and the National Wild and Scenic Rivers Act. The river flows some 127 km from the outlet of Kukaklek Lake to Kvichak Bay. Downstream from the Nonvianuk River confluence the river is characterized in its upper reaches by numerous shallow channels, then a few larger channels, and finally a single channel with islands.

In 1983, a management plan was developed that presented the management objectives and the issues pertinent to the Alagnak. Since 1983, recreational use on the river has increased, as have the water resource impacts. Although the river’s riparian areas are generally undeveloped, the banks are actively eroding in several areas. In 1998, the U.S. Geological Survey initiated an erosion monitoring effort on the Alagnak at the request of the NPS (Dorava 1998a). After monitoring 14 sites from July to September 1998, bank erosion measurements ranged from 0 to > 28 inches, where erosion exceeded the length of the erosion pin (Dorava 1998b). Subsequent to the completion of this pilot study, the U.S. Geological Survey prepared and implemented a plan for erosion monitoring along the river. Fieldwork was conducted for this project between 1998 and 2000.

Hydrologist Janet Curran of U.S.G.S. was the principal investigator on the Alagnak project. As part of the study, bank erosion monitoring along the river corridor and boat-wake monitoring at three gaging stations were used to characterize bank erosion processes and to assess the effects of boat wakes. Water quality sampling and discharge measurements at three gaging stations provide an assessment of present water quality conditions on the Alagnak.

Repeated erosion pin measurements, photography and bank surveys since 1998 indicate that bank erosion is localized and ranges from a few centimeters to more than one meter per year (Curran 2003). Erosion is most prevalent on tall, steep, unvegetated sand and gravel banks in lower reaches and is linked to seasonal changes in river stage. Following breakup, water levels are low on the river, and a thick wedge of colluvium (loose sediment eroded by gravity) lies at the base of the banks. As the water level rises, the colluvial wedge is slowly eroded and the colluvium is redeposited on a shallow shelf adjacent to the bank. At peak discharge from mid-June to mid-July, water levels had typically risen more than 0.5 meter and the colluvial wedge had disappeared completely, allowing erosion of the undisturbed bank. As water levels drop in late summer and fall, water driven bank erosion decreases, but banks continue to erode by gravity driven processes until stabilized by accumulation of a new colluvial wedge. The shallow underwater shelf slowly erodes and is absent by spring. In contrast, erosion in reaches where numerous shallow channels are separated by vegetated bars appears to occur as infrequent channel migration rather than progressive bank retreat.

Measurements of bank erosion processes and visual observations suggest that boat wakes increase bank erosion rates, especially at high, exposed banks (Curran 2003:2). Analysis of boat traffic, bank material, historical channel changes and hydrologic data suggest that boat wakes have increased lateral erosion rates in reaches downstream of kilometer 65 (Curran 2003:22). Downstream reaches (below kilometer 65) of the Alagnak are naturally susceptible to erosion, which is compounded by downstream increases in boat traffic (Curran 2003:22). Boat use was generally no more than a few wakes per day at the upper river site, but appeared to remain consistent throughout the season while boat use peaked at 40 wakes per day mid-river and more than 130 wakes per day at the lower river site (Curran 2003:11). In the lower river banks are noncohesive with particle size in the sand and gravel range. Upstream particle sizes are larger such that boat wakes are less effective at generating erosion.

Aerial photographs and measurements indicate that the increase in erosion rates has not altered the mechanisms of channel change (Curran 2003:2). The lack of additional major channel changes between 1982 and 2000 lends support to the concept that the effect of boat wakes is primarily an increase in erosion rates, not a shift in the major processes of channel change (Curran 2003:22).

Water samples were collected at three sites along the Alagnak during low, medium, and high discharge in 1999 and 2000 and at Kukaklek and Nonvianuk Lake outlets on one occasion in 2000. These samples were analyzed for nutrients, major ions, suspended sediment and total and suspended organic carbon. Results indicate that the waters are nutrient poor, calcium-bicarbonate with low suspended sediment concentration. Water chemistry changes little over time or in a downstream direction although some weak patterns were observed. High late May/early June concentrations of some nutrients, carbon and iron, as well as downstream increases in iron, manganese and phosphorus, were characteristic of these waters (Curran 2003). No pervasive human impacts on Alagnak River water chemistry were detected.

c. Resolving Impacts and User Conflicts. The NPS recognizes that local people and commercial operators depend on motorized boats and aircraft as transportation, for fishing and other recreational pursuits. Boat access to the park and preserve is important to everyone, but an excess in their use can lead to sociological as well as ecological consequences. NPS will actively pursue input from all users on how to avoid impacts that may cause user groups to become embattled and result in the need for mediation and/or impacts that NPS will be forced to address. There is already indication that user groups differ markedly on resolution of sociological and environmental solutions to these complex problems.

6. Recommended Actions

- ✓ Evaluate streambed morphology and biota impacts from visitor use on popular fishing streams.
- ✓ Establish continuous bank erosion monitoring on the Alagnak Wild River.
- ✓ Document recreational fishery information compilation and needs assessment .
- ✓ Prepare a fisheries management plan.
- ✓ Working with all user groups, identify issues of concern on the Alagnak and develop alternatives for resolution.
- ✓ Develop a seasonal newsletter for park user groups, asking for voluntary compliance on factors that will reduce impacts to resources. For example, 1) ask boat operators to voluntarily refrain from operating in shallow waters (<18 inches) in known spawning areas during spawning and early incubation of eggs, and 2) on the Alagnak River, encourage boat operators to avoid running boats near the bank where possible.
- ✓ Continue photo transects to monitor bank erosion at American Creek. If erosion becomes apparent, then conduct a detailed study of channel geometry, using surveyed cross section measurements.

B. Impacts from Backcountry Facilities

Katmai's developed areas are growing. What began as a few camps run by Wien Consolidated in 1950 has grown to numerous lodges scattered across the interior of the park and along its coast. Private homes have been built near the western shore of Naknek Lake and facilities at existing developed sites, such as Brooks Camp, have been expanded to meet the greater demand. Developments naturally occur in easily accessible areas along lakes and streams in the park where water quality issues inevitably become a concern. Underground fuel storage tanks and wastewater and sewage disposal are generally the highest concerns for contaminants, but increasing and/or repeated use of an area brings a whole host of other activities that may affect water quality such as erosion, changing sediment deposition/accretion patterns and so on.

Although large lakes and rivers may be highly resistant to alteration from localized inputs, smaller lakes and streams prove to be less resilient and require greater care and monitoring for human induced changes. Temporary, local changes in water transparency could result if careless waste disposal practices or land clearing activities were to occur on even large water bodies (LaPerriere 1996). Protection of smaller lakes and streams from developments that attract heavy visitation is critical. Nitrogen and phosphorus inputs could markedly change the chemical and biological components of these water bodies and should be avoided. Large developments should be concentrated on larger water bodies that can absorb unintentional inputs.

Eleven lodges are in the park (map in Appendix D). Five of these are owned by the park concessioner, Katmailand, Inc. including Kulik, Brooks, and Grosvenor Lodges and Nonvianuk and Battle Camps.

Grosvenor Lodge houses a total of six guests and two employees per day. In 2002 the concessioner upgraded facilities at the camp, including the construction of a new wastewater treatment system. The sewage pit that was replaced was wood lined and approximately 6' x 12' x 4' deep. A concern that sewage from the system could mix with groundwater during times of high water necessitated the installation of a new system.

The new wastewater system was designed to meet Alaska Department of Environmental Conservation's requirements and accommodate current estimated wastewater flow of approximately 253 gallons per day. The system can accommodate wastewater from the kitchen and bathhouse. The design includes a septic tank with a capacity of 1,000 gallons and an infiltrator field buried into an existing sand layer with an absorption area of about 216 ft^2. An additional 30 feet was added in 2003 (Sonny Petersen pers. comm. 2003). The field is approximately 30 feet long, 3 feet wide, a foot high and buried 3 feet below the original ground surface and mounded on the surface. The new leach field is 150 feet from surface water. Sewer lines extend from the kitchen and bathhouse to the leach field.

Brooks, Grosvenor and Kulik Lodges all use leach field septic systems. Brooks system was updated in 1997 and Kulik in about 1983. Other developments have pit toilets or seepage tanks for gray water disposal. Petroleum filled generators provide electricity for most developments.

Although there is considerable information on a few popular facilities (i.e., Brooks Camp, Lake Camp), water resource impacts from most backcountry facilities and sites (i.e., concentrated camping areas) are not well documented. The National Park Service (1994) identified several on-going activities that could affect natural resources in Katmai’s backcountry, including:

1. landing and beaching of floatplanes on lake shores and river banks;
2. landing of wheeled planes on beaches and gravel bars;
3. beaching of boats and rafts along riverbanks;
4. concentrated camping sites associated with water access (i.e., along river or lake banks); and
5. use of all-terrain vehicles (ATVs) and four-wheel drive vehicles within Katmai boundaries.

This list focuses on physical impacts, but there are several examples of chemical impacts that could influence Katmai's water resources.

Katmai staff conducted a Level 1 hazardous waste survey at the Grosvenor concessions area (Grosvenor Lodge) in 1993. The lodge is located on the northeast side of a narrow neck of land that separates Lakes Coville and Grosvenor. This particular facility has a lodge, three cabins, bathhouse, kitchen, dining area, employee facilities, generator shed and maintenance shed. During the survey, areas adjacent to the generator shed were void of vegetation, and the floor of the generator shed appeared to be contaminated from petroleum spills (McClenahan 1993). In 1996, a hydrocarbon sampling effort at the lodge by the U.S. Fish and Wildlife Service revealed low levels of polycyclic aromatic hydrocarbons (PAHs) (Johnson and Berg 1999).

U.S. Fish and Wildlife Service also collected water and sediment samples at Kulik Lodge in 1996 for hydrocarbon analyses. According to the laboratory results, total PAHs did not indicate significant contamination at the site (Johnson and Berg 1999). Since the sampling was conducted, fuel storage at Kulik Lodge has been upgraded to an approved double wall tank, and an approved Spill Prevention, Control and Countermeasure Plan (SPCC) has been put in place.

The United States Air Force established two recreation areas immediately east of King Salmon in the 1950s. One site is located approximately four miles southeast of King Salmon and approximately 3.5 miles west of Katmai's boundary on the Naknek River. The other site is six miles east of King Salmon inside the park's boundary, along the banks of Naknek Lake (Lake Camp). The Naknek River and Lake Camp sites were used by the Air Force from 1956–1977 and 1956–1979, respectively. Along with these two sites being used as recreational areas, they were also used by the Air Force as landfills for hazardous materials. Lake Camp contains a drum landfill, former vehicle maintenance area, former generator pad and former lodge and disposal pit. Waste oils, fuels, and polychlorinated biphenyls (PCBs) were among the wastes disposed of at these sites. A 1989 report prepared by the Hazardous Material Technical Center for Elmendorf Air Force Base concluded that the potential exists at both sites for contamination of surface water, soils and/or groundwater. The Naknek River was listed by the Alaska Department of Environmental Conservation (1996) as a high-priority water quality limited water body, which requires water quality assessments to define the extent of pollution and the remedial efforts needed to be employed. The pollutant sources were identified as "landfill" and "fuel storage." The area has since been removed from the state list of contaminated sites after meeting state and federal cleanup levels.

In 2002 a record of decision was signed by ADEC and the Air Force for Lake Camp. The following remedies were selected for Lake Camp sites:
1) remove surface drums and debris,
2) excavate contaminated soil and treat off-site,
3) monitor groundwater contamination trends,
4) place a vegetated soil cap over the drum landfill and inspect for integrity, and
5) practice land use controls to restrict excavations, drinking water well installation and other intrusive activities until cleanup levels have been reached (Alaska Department of Environmental Conservation and Department of Defense 2002).

What should be done to address this issue?

- ✓ Conduct periodic backcountry facility contamination assessments.
- ✓ Monitor surface waters at developed sites for fecal coliform/streptococcus contamination.
- ✓ Consider the purchase of screening tools (i.e., Organic Vapor Analyzer) that could be a cost effective way to screen soils for petroleum contamination. Screening instruments are portable and easy to operate and provide real time data. After testing a plan for sampling for specific parameters may be devised.

C. Management of Stream Crossings and Borrow Pits Along the Valley Road

The road to the Valley of Ten Thousand Smokes (Valley Road) is a 23-mile gravel road that connects Brooks Camp with an NPS facility at Three Forks Overlook near the trail head to the Valley of Ten Thousand Smokes. This road is used daily during the summer by the park concessionaire to transport visitors via bus from Brooks Camp to the Valley of Ten Thousand Smokes. The road crosses two Margot Creek tributaries at mile 12.2 and 16.0, and Margot Creek at mile 16.8. Katmai staff maintain these three stream road crossings by excavating gravel upstream and/or downstream from each respective crossing and transporting the material to the existing roadbed (Gavin pers. comm. 2002). According to Kathleen Kuná of the U.S. Army Corps of Engineers (pers. comm. 1998 in Weeks 1999), the park has a permit for annual maintenance of these stream crossings that is valid until 2007.

The two most northerly crossings are small with a flow of less than two cubic feet per second. Little grading is required in most years to maintain these two crossings. The third crossing is larger, and channel modifications are readily apparent. Flow is estimated at 15-20 cubic feet per second. Mechanical widening of the channel extends about 100 yards upstream and 60 yards downstream of the crossing. The channel has been widened from 30 feet to more than 100 feet at the widest point (Sharrow 1993:2). Although disturbance is obvious, impacts to aquatic organisms and stream morphology appear to be localized. The road crossing occurs at a natural transition point between a single sinuous channel that is either erosional or at equilibrium, to a braided depositional channel. It crosses at a natural slope break, and the braided channel continues for several miles downstream (Sharrow 1993:3).

Approximately three miles separate the first stream crossing from Margot Falls, below which significant numbers (> 5000 in 1991) of sockeye salmon spawn. The falls provide an effective barrier to fish migration. Impacts from Valley Road maintenance on salmon spawning habitat, if any, appear to be minimal because effects are localized around the graded third crossing, which is substantially removed from spawning salmon.

A multi-million dollar NPS project, in cooperation with the Federal Highways Administration, to repair and improve the Valley Road was active during the summer of 1998. The Valley Road project is incomplete with only six miles of the 23-mile project completed. Plans are underway to complete the work and revegetate disturbed sites.

What can be done to address this issue?

- ✓ Determine whether there is an influence from Valley Road maintenance on aquatic biota in the creek, on stream morphology and salmon spawning habitat below Margot Falls.
- ✓ Vegetate disturbed sites.
- ✓ Consider alternative stream crossing methods.

XI. Management of Hazardous Wastes

A. Oil Spill Contingency Planning

The potential for petroleum spills along Katmai's Shelikof Strait coast will continue to threaten natural resources as long as mineral interests exist in the region. The greatest annual input of petroleum hydrocarbons into the marine environment worldwide is through municipal and industrial sources with transportation discharges following a close second (table 3).

Table 3: Estimated annual input of petroleum hydrocarbons into the marine environment by source.

Source	**Estimated input (tons)**		
	1973[a]	**1981**[b]	**1990**[c]
Transportation (total)	2,133,000	1,470,000	564,000
Bilge/fuel discharge	500,000	300,000	
Tanker operations	1,080,000	700,000	
Tanker accidents	200,000	400,000	
Marine terminals	3,000	20,000	
Non-tanker accidents	100,000	20,000	
Dry-docking	250,000	30,000	
Scrapping of ships	N/A	N/A	
Municipal and Industrial	2,700,000	1,180,000	1,175,000
Atmosphere	600,000	300,000	305,500
Natural sources	600,000	200,000	258,500
Offshore production/ exploration	80,000	50,000	47,000
Total	6,113,000	3,200,000	2,350,000

Sources: a=National Research Council 1975, b=National Research Council 1985, c=Joint Group of Experts on the Scientific Aspects of Marine Pollution 1993 *in:* Irvine 2000:268.

Of all the causes of inadvertent spillage of petroleum products into the environment, the Trans Alaska oil pipeline did not even make the list. Ironically, until the fall of 2001 — when a man shot a hole in the pipeline spewing thousands of gallons of crude before the flow could be shut off — construction and operation of the Trans Alaska pipeline from Valdez on Prince William Sound to Prudhoe Bay on Alaska's North Slope has resulted in relatively minor impacts to freshwater ecosystems. However, the pipeline has been the focus of long-term studies on arctic ecosystems and extensive examination of the effects of oil on freshwater ecosystems (Milner, Irons and Oswood 1997).

Freshwater systems are also at risk from leaking underground storage tanks and fuel transfer and dispensing operations at developed sites. Smaller chronic spills result from boat and aircraft operations with the infrequent larger spill occurring as a result of a boat or aircraft accident. Regardless of the source of contamination, planning for an oil spill, given the risk this park has of a future spill, is time well spent.

The NPS is too severely limited in qualified personnel, spill response equipment, and baseline natural resource information to effectively respond to petroleum spills in Katmai. Emergency response to a major spill (i.e., *Exxon Valdez*) requires expertise and field equipment that extend beyond the capabilities of the NPS. To manage future spills, a communication process (i.e., Spill Prevention Control and Countermeasure Plan [SPCC]) should be completed so designated park staff can request assistance from qualified federal, state and/or private contractor personnel in a time-efficient manner.

Katmai manages numerous fuel storage systems (i.e., heating oil, diesel, gasoline) to accommodate visitor and NPS operations. Due to petroleum contamination problems encountered with the underground fuel storage system in the Brooks River Area and federal compliance requirements, Katmai has closed all existing underground fuel systems and upgraded to double-walled, above-ground storage tank systems (Gavin pers. comm. 2001). Although replacement tanks will greatly reduce the threat of accidental releases, the potential for petroleum contamination from NPS operations will still exist. For example, a 700 gallon fuel spill occurred at Brooks Camp during the summer of 2001, and fuel contamination from floatplanes and motorboats has been observed along the Naknek Lake shore at Brooks Camp. In 1990, a fuel spill resulted from an accidental release of a drum from a sling load at Kukak Bay (National Park Service 1994). Gasoline and heating fuels are transported via the park barge 30 miles across Naknek Lake to Brooks Camp throughout the summer months. Thus, there is the potential for an accidental fuel release during the fuel-loading process, transportation of fuels across Naknek Lake and the fuel-unloading process of the tanker at Brooks Camp.

Katmai has a n SPCC plan consistent with the 1990 Oil Pollution Act (OPA) standards, which established new requirements for oil spill response and natural resource damage assessment. (Gavin pers. comm. 2006).

State Contingency Plans. In accordance with AS 46.04.200, Alaska Department of Environmental Conservation must prepare, review and revise the statewide master oil and hazardous substance discharge prevention and contingency plan. The plan must identify and specify the responsibilities of state and federal agencies, municipalities, facility operators, and private parties whose property may be affected by an oil or hazardous substance discharge. The plan must incorporate the incident command system, identify actions to be taken to reduce the likelihood of occurrence of "catastrophic" oil discharges and "significant discharges of hazardous substances" (not oil) and designate the locations of storage depots for spill response material, equipment and personnel. The state master plan has been combined with the federally required area plan to create the "Alaska Federal/State Plan for Response to Oil and Hazardous Substance Discharges/Releases," also known as the Unified Plan (Alaska Department of Environmental Conservation 1996).

Alaska Department of Environmental Conservation must also prepare, review and revise a regional master oil and hazardous substance discharge prevention and contingency plan (AS 46.04.210). The regional master plan must contain the same elements and conditions as the state master plan, but is applicable to a specific geographic area. The state regional plans are developed in conjunction with the federally required sub-area plans as "Sub-Area/Regional Contingency Plans" for each of the 10 designated contingency planning areas. The "Cook Inlet Sub-Area Contingency Plan" was finalized July 1997 and is reviewed and revised on a regular basis.

State and federal agencies, the industry and citizens groups are currently exploring the possibility of preparing geographic response plans (GRP) for Cook Inlet. GRPs are site-specific response plans for protecting environmentally sensitive areas and other areas of public concern from the damage caused by an oil or hazardous substance spill. The plans would provide immediate decisive action for specific areas by identifying sensitive areas and resources and specifying the response equipment and tactics that would be used to protect or cleanup those areas.

B. Hazards of Oil and Gas Exploration and Production

The water resources of Katmai are threatened by the potential exploration and development of oil and gas in Cook Inlet and Shelikof Strait under the Outer Continental Shelf program. Oil and gas seeps are fairly common on the Alaska Peninsula and were first reported in Katmai during the early 1900s by Martin (1905) and Smith (1925), respectively. During 1979 and 1980, the U.S. Geological Survey conducted fieldwork to assess the petroleum potential of the Shelikof Strait based on outcrops in Katmai. The results from this fieldwork revealed promising petroleum exploration targets in the Shelikof Strait (Smith and Petering 1981).

Leases for oil and gas production in lower Cook Inlet are offered by the federal government, which owns the Outer Continental Shelf beyond the three-mile offshore boundary of the state. In recent years, both federal and state governments have focused energy on oil and gas resources in Cook Inlet and Shelikof Strait near Katmai (Weeks 1999:32). In May 2002, five companies bid $1.2 million on 30 tracts in the Cook Inlet Area (www.gov.state.ak.us). Potential impacts of those sales were highlighted in the environmental impact statement written for the Cook Inlet Area in 1999 (Alaska Department of Natural Resources 1999b). Ten exploration wells have been drilled in conjunction with the sales; two of the wells produced oil, but neither in quantities sufficient for commercial production. The Minerals Management Service plans to hold two new federal lease sales in Cook Inlet between 2002 and 2007. MMS issued a final EIS in November 2003, regarding Cook Inlet Planning Area Oil and Gas Lease Sales 191 and 199. MMS will issue consistency determinations later in the presale process. Applicants for OCS exploration and development and production plans will prepare a consistency certification for review by the state (Minerals Management Service 2003).

The oil and gas transportation system in the Cook Inlet region consists of; 1) offshore and onshore pipelines, 2) marine terminals with offshore loading platforms, and 3) tank vessels. Oil and gas produced in the Cook Inlet region are transported by a combination of these elements and constitute the greatest risks of oil contamination to the water.

The Cook Inlet pipeline, jointly owned by four oil companies, transports crude oil from production facilities at Trading Bay, McArthur River and Granite Point on the west side of Cook Inlet to the Drift River Terminal on the west side of Cook Inlet (Belmar Management Services 1993). The marine terminal has been in operation since 1967. Oil is stored in tanks at Drift River and shipped by tanker across the inlet to the Tesoro Refinery. Currently no Cook Inlet crude oil is shipped out of state. The Drift River terminal is located about 14 miles north of the Lake Clark National Park shoreline and about 112 miles from Kamishak Bay in Katmai National Park.

Offshore and onshore pipelines have operated in the Cook Inlet region since the 1960s. The existing infrastructure includes 5 onshore and 14 offshore crude oil pipelines systems with a total of about 156 miles of pipe. About 84 miles of pipeline transport crude oil from offshore platforms to shore. After processing, the oil is further transported through two onshore pipelines to the Nikiski Marine Terminal on the east side of the inlet or to the Drift River Marine Terminal on the west side (Belmar Management Services 1993).

Offshore weighted pipelines are used in Cook Inlet because tidal currents are exceptionally strong. These pipelines are normally buried in trenches in shallower waters to avoid creating a navigational hazard or being damaged by a ship's anchor, by sea ice or caught in a fishing net. In deeper water, the weighted pipelines may become silted-in or self-buried. Subsea pipelines have transported petroleum liquids under Cook Inlet waters since the 1960s and have demonstrated their durability. The risk of spills from subsea pipelines is considerably less than for tankers (Anderson and LaBelle 1988). Subsea pipelines are expensive to build and maintain. They can be difficult to monitor for leaks, defects and corrosion problems; significant advances, however, have been made in recent years.

Crude oil terminal facilities generally store quantities of oil equivalent to several large tanker loads. Therefore, the possibility for a very large spill exists at these facilities. A strong earthquake or extensive natural disaster could damage the facilities and initiate a large spill. The risk of explosion or sabotage at the facilities also exists. Accidental ballast discharge or loading or unloading accidents could also cause a spill. However, environmental risks have been minimized through improved design, construction, operating techniques and other prevention measures (Alaska Department of Natural Resources 1999b).

The Alaska Oil and Gas Conservation Commission compiled statistics for all types of offshore petroleum spills in the Cook Inlet region for the 1965 to 1980 period. During that period, 187 recorded spills occurred that were associated with the production and transportation of crude oil, resulting in a total of 7,596 barrels (bbl) (319,032 gal) of petroleum spilled. These records also show that there were 206 non-industry spills (e.g., fishing vessels, product transportation vessels and other vessels not related to the oil and gas industry spills). The spills totaled 22,746 bbl (955,332 gal). (Alaska Oil and Gas Conservation Commission 1981:1-2)

The 1997 "Cook Inlet Sub-Area Contingency Plan" lists significant petroleum and hazardous substances spills in the inlet and on land from July 1987 to January 1997. Cook Inlet crude oil spilled in the inlet during this time totaled about 219,410 gallons. The *Glacier Bay* spill in 1987 constitutes 210, 000 gallons of this total. Crude oil spilled on land totaled 2,000 barrels. The reader is referred to the sub-area contingency plan for a full description of the inland and navigable waters spill history (Alaska Department of Environmental Conservation 1997a: E-14-18). Cook Inlet platform spills totaled approximately 250 barrels (10,500 gallons) during the period from 1984 to 1994.

Both the Nikiski and Drift River Marine Terminal facilities generally have good safety records. Volcanic activity associated with Mt. Redoubt in 1989 and 1990 caused the temporary closure of the Drift River facility between January and mid-June 1990 due to the threat of flooding. By August 1990, following construction of new protective dikes, the terminal resumed normal operations.

In March of 1990, approximately 2,300 bbl (96,600 gal) were spilled at Drift River when a valve on tank number three was accidentally left open. The entire spill was contained within protective dikes, and none was released into the water. Nearly all of the spilled oil was cleaned up by returning it to the storage tank or by direct treatment. In December 1990, another incident occurred when ice carried by swift currents forced the UNOCAL tanker *Coast Range* away from the dock at the Drift River facility. This caused a spill of approximately 15 bbl (630 gal) of oil located in the pipes between the dock and the ship. Cleanup workers used absorbents to clean up the spill because booms and skimmers were ineffective in the heavy ice (Anchorage Daily News, 1990: B-1 in Alaska Department of Natural Resources 1999b). Alaska Department of Environmental Conservation estimates that 30 percent of the spill was cleaned up and 10 % to 20 % evaporated. This left approximately 7.5 bbl (315 gal) unrecovered.

C. Potential Impacts of Oil Production on Aquatic Biota.

Potentially negative impacts on wildlife may result from oil production. For example, gas blowouts resulting from natural gas accumulations may cause fatalities in insect, bird and fish populations (Cook Inlet Areawide EIS [http://www.dog.dnr]). Additionally, lower trophic levels may be vulnerable to oil production discharges such as drilling muds and cuttings, which may be introduced in the water column. The impact of drilling muds and cuttings depends on the amount and type of material deposited, the environmental conditions, the current speed and water depth (http://www.dog.dnr). Drilling operations will likely also require building oil and gas pads, and pipelines. Inevitably, organisms in lower trophic levels will be displaced and vegetation will be disturbed ((http://www.dog.dnr)). Organisms that rely on soft substrate such as bivalves and polychaetes will be affected because of their relative immobility (http://www.dog.dnr). Petroleum hydrocarbons released during oil production may have an impact on the photosynthesis of phytoplankton, the effects of which may trickle up the food web rapidly. Zooplankton and macrozooplankton may also be negatively affected by oil operations causing direct mortality, tissue contamination, inhibition of feeding and altered metabolic rates in fish populations, such as pink salmon and herring (http://www.dog.dnr). Oil spills may affect fish in five main ways: direct mortality, impaired spawning habitat, altered spawning behavior, impaired food source and reduced fitness due to environmental stress (http://www.dog.dnr).

D. Exxon Valdez 1989 Oil Spill

In January of 1970 the first recorded oil spill occurred that affected resources along the coast of Katmai. An unknown source, believed to be a tanker, discharged between 3,000 and 6,000 gallons of dirty ballast or slop oils somewhere in waters of Southcentral Alaska. State and federal officials were powerless to deal with the spill, and it spread from Montague Island southwest to Shelikof Strait. Some of the oil came ashore at Swikshak Bay in February. The Federal Water Quality Administration (FWQA) investigated, and lacking obvious signs such as dead mammals or birds, concluded no damage had occurred. Unfortunately, this was not to be the worst or last oil spill to cause harm to the coast.

On March 24, 1989, the tanker vessel *Exxon Valdez* grounded in Prince William Sound, on the eastern side of the Kenai Peninsula from Cook Inlet, rupturing cargo tanks and spilling approximately 11 million gallons of crude oil into the sea. The spill focused world attention on the potentially catastrophic impacts of oil development, particularly to marine ecosystems. Massive wildlife casualties resulted, including more than 2,650 sea otters and 250,000 sea birds (www.oilspill.state.ak.us). Subsequent crashes in fish and mammal populations suggested damage at many trophic levels.

The *Exxon Valdez* accident resulted in the most extensive, single, man-caused disaster to ever strike a national park (National Park Service 1990). Coastal winds and currents transported the oil slick southwest along the north shore of the Gulf of Alaska (figure 1). The storm-tossed crude oil degraded and weathered into an oil-and-water emulsion called “mousse.” The viscous mousse rafts continued southwest through the Shelikof Strait. In the end, oil from the *Exxon Valdez* stranded in various concentrations on the shores of Kenai Fjords National Park, Katmai National Park and Preserve and Aniakchak National Monument and Preserve. Oil was first spotted on April 18 on the Katmai coast, and by May 2 more than 90% of Katmai’s coastline had been oiled (Norris 1996). In the end, Katmai’s coast received the greatest impact of the NPS units (National Park Service 1990).

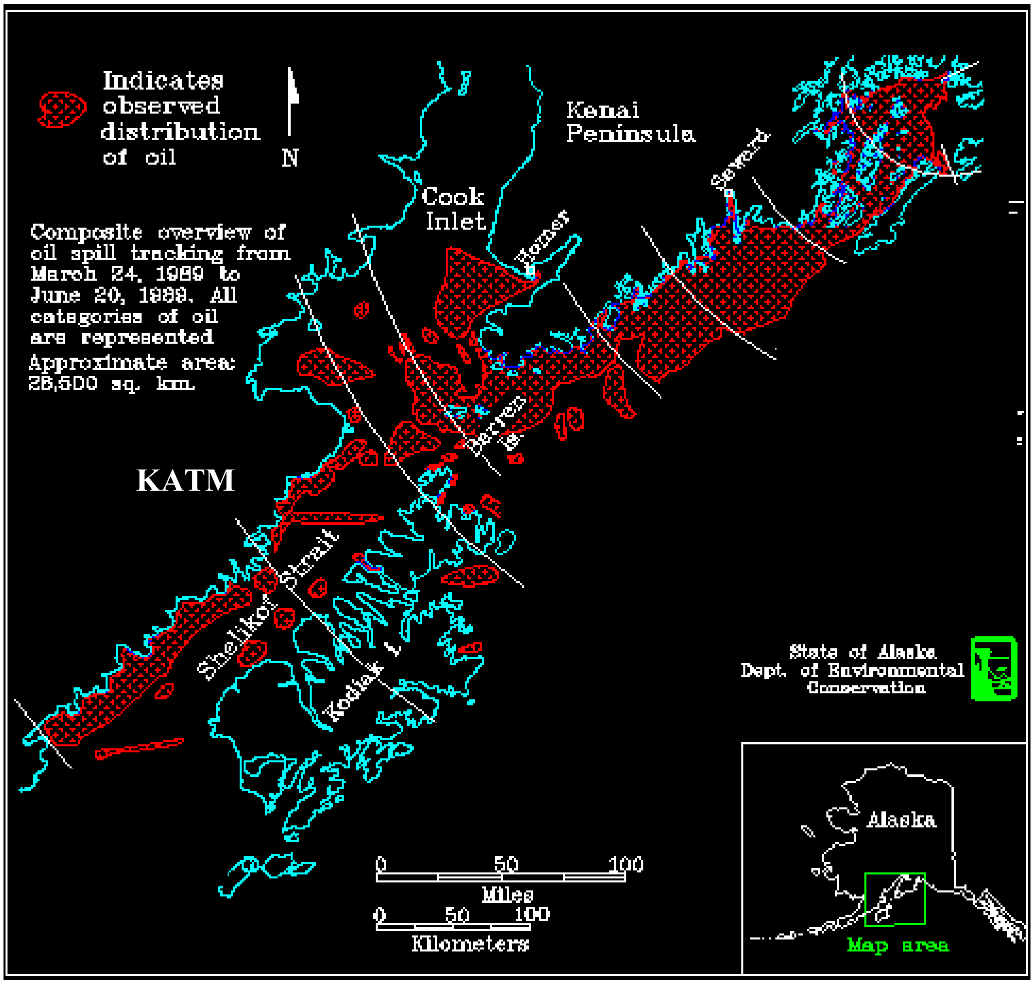


Figure 1. Observed Distribution of *Exxon Valdez* Oil Spill, March 24 – June 20, 1989 (modified after Alaska Department of Environmental Conservation 1999).

The hardest hit areas of the park were Cape Chiniak and Chiniak Lagoon, Hallo Bay beach and lagoon, the south shore of Cape Gull and Kaflia Bay, offshore islands and Cape Douglas (Norris 1996). The National Park Service spent $7 million on the spill and employed 500 workers for cleanup efforts in its parks (National Parks 1990). Daily cleanup costs for Katmai alone were estimated at $200,000 per day (Hanable 1990:81).

During the summers of 1989-1991, Exxon, with the cooperation of numerous state and federal resource management agencies, engaged in an unprecedented cleanup effort in an attempt to restore the oiled shoreline to an environmentally stable condition. More than 10,000 workers assisted in cleanup efforts that lasted three years and exceeded $2.1 billion (www.oilspill.state.ak.us). Despite all the effort, in 2001 a study found oil persistence on beaches to be unexpectedly high (58% of the 91 sites surveyed), suggesting recovery of these once pristine ecosystems may not be as close as once thought (www.oilspill.state.ak.us).

Most of the oil in Katmai was removed manually with shovels or by rock washing. In total, 99,000 bags of oiled material were collected from 70 miles of Katmai's shoreline (National Parks 1990). By September 15, cleanup efforts for the year were finished. Cleanup activities recommenced in the spring of 1990, but it was clear by September that little additional oil could be removed without the use of potentially harmful chemicals (Norris 1996). Cleanup activities also took place in 1991, but each successive year cleanup activities were scaled back (Norris 1996).

In 1991, cleanup efforts on Katmai beaches focused almost entirely on the use of bioremediation. It promised to be one of the most effective cleanup techniques available. Bioremediation involves stimulating a natural system to repair itself. In the case of oil, bacteria that live on beaches can break down the structure of oil molecules, breaking them down over time. To speed up the process, fertilizers consisting primarily of nitrogen and phosphorous are applied to encourage more bacteria, giving the community power in numbers (Piper 1993: 73-74). Customblen was selected as a more benign fertilizer and used within a two-week period (Endres et al. 1992).

In other areas, beaches were inoculated with additional bacteria to supplement the population (Piper 1993:75). Scientists were skeptical of the efficacy of these bacteria outside of a laboratory environment (Piper 1993:73-74). Tests were conducted on a few beaches and were visually dramatic. The most optimistic projections claimed that the beaches were cleaned 3-4 times faster than beaches that were left alone (Piper 1993:85). Although the tests were considered effective by most, some scientists claimed the results were not statistically significant (Piper 1993:85).

In 1991, the federal government and the state of Alaska negotiated a monetary settlement for natural resource damage assessment claims against Exxon Corporation and Exxon Shipping Company. Through this monetary settlement, the NPS received funding to study the oil-related impacts on the coastal environments. The objective of the study was to determine the relative physical and chemical degradation rates of stranded oil mousse on Gulf of Alaska beaches and to correlate the degradation rate with geomorphological controls such as energy regime, slope, aspect and substrate particle composition (Schoch 1993).

Ten permanent transects were installed in 1989 on oil-impacted beaches along the Katmai National Park coastal shoreline. Data recording from each transect included characteristics and penetration of oil, and quantitative measurements of percent cover of oil, mineral and biota. Transects were permanently marked for future relocation and monitoring (Cusick 1989).

Aside from persistence of oiling and mussel studies, little effort was made to understand the effects of the *Exxon-Valdez* oil spill on Katmai's water resources. Most all of the research regarding effects of the spill took place in Prince William Sound. Although effects of the oil may vary in other locations, the studies in Prince William Sound aid in understanding the potential damage to coastal areas affected by the spill. For an excellent overview of persistence of oil on shores and its effects on biota refer to “Seas at the Millennium: an environmental evaluation” and in particular chapter 126 by Gail V. Irvine (2000:267-281).

Persistence of oil on Katmai’s beaches has been observed for a number of years. Surveys on permanent transects were performed in 1989, 1992 and 1994. A survey performed in 1992 found that surface oil had declined from 40%-100% in 1989 to the single digits in 1992 (Irvine et al. 1999: 578). However, subsurface oil has not significantly declined (Irvine et al. 2000:19). These studies used polynuclear aromatic hydrocarbons, which can be used to determine if stranded oil was indeed released from the *Exxon-Valdez,* and found a positive result (Irvine et al. 1999: 574, 577). The persistence of oil on Katmai’s beaches can be linked to two main factors: shoreline type and physical state of the deposited oil (e.g., mousse vs. recently spilled oil). Most, if not all of the oil that reached Katmai was in the form of “mousse,” which is more persistent than fresh oil. Because “mousse” does not rapidly deteriorate, it is still as toxic as the crude in the early stages of the spill. Samples analyzed in 1989, 1992 and 1994 showed that the oil in 1994 (5 years old) was virtually the same chemical composition as *Exxon-Valdez* crude collected from the sea surface 11 days after the spill (Irvine et al. 1999: 580). Only slight chemical weathering had taken place compared to freshly spilled *Exxon Valdez* oil. Therefore, the armored beaches retain the potential for future release of toxic oil. Biota and wilderness characteristics of the Katmai coast may continue to be impacted for years to come from residual oiling.

Concern for the longer-term effects of such oiling became focused in 1991 on mussel beds, which showed the highest levels of contamination at that point, and persistent contamination of national park coastlines at Katmai and Kenai Fjords National Park (Irvine et al. 2000). An oil spill can have disproportionately large biological effects when it affects key species or processes, such as structurally important species, predators, prey, recruitment or succession (Irvine 2000:267). Mussel (*Mytilus trossulus*) beds were of concern both because of their structural importance intertidally and their importance as prey for numerous consumers, including other species that had not recovered since the spill. Furthermore, mussel beds are thought to influence the persistence of oil by setting up a situation that increases oil entrapment (Babcock et al. 1996 and Babcock et al. 2000 in Irvine 2000:271).

Although some mussel beds in Katmai have shown declines in oiling (Kinetic Laboratories Inc. 1997:39), some sites still possess high concentrations of hydrocarbons (Irvine et al. 2000:3). The apparent oiling of mussel beds has gradually declined at most sites since 1991 when the beds were first sampled, but most oiled beds are not expected to reach background levels until three decades after the spill (Babcock et al. 2000 in Irvine 2000:271). The persistence and lack of weathering of oil on such high energy beaches was quite unexpected prior to this study. In areas in Prince William Sound, growth and mortality rates of mussels were affected on oiled beaches. Additionally, length/weight ratios were poorer in oiled areas (Houghton 1991:64-67, Trowbridge 1991:7).

The effects of oil on plants are not well understood in Prince William Sound or at Katmai. However, one study in Prince William Sound focused on the impacts of oil on eelgrass. Eelgrass was affected by oil, as it caused rhizome/ratio biomass to increase unnaturally and the density of reproductive parts to decrease (Houghton 1991: 94-97). In a 1990-1995 study, eelgrass (*Zostera spp*.) beds impacted by the *Valdez* oil spill were compared with reference (non-impacted) sites to assess possible impacts from the 1989 oil spill. Based on the study, injuries to eelgrass appeared to be slight and did not persist for more than a year after the spill (Dean et al. 1998). Many other species of plants were likely also damaged but have not been studied.

The oiling of beaches in Katmai may have affected fish and invertebrate populations that are dependent on estuaries that have been damaged. A study in 1984 examined the effects of hydrocarbons on a number of species and found that salmon (*Oncorhynchus spp.*) alevins are particularly sensitive to oil (Rice et al. 1984: 30). Crustacean larvae are also vulnerable to mortality from oil within minutes of exposure (Rice et al. 1984: 35). Moreover, sublethal effects may be experienced such as failure to molt, swim, feed or reproduce and inhibited growth (www.dog.dnr.state.ak). The study found that feeding rates of both fish and invertebrates are depressed by oil over the long-term (Rice et al. 1984). Additionally, hydrocarbon exposure that is not lethal may cause fish to be smaller and more subject to predation or disease (Rice et al. 1984: 32). For example, many scientists feel that oil exposure from the *Exxon-Valdez* oil spill caused herring populations to be more susceptible to VHS (a fish disease) and to *Ichthyophonus,* leading to deplenished fish stocks (www.dog.dnr.state.ak).

Perhaps the least understood species are plankton, which may also be the most vulnerable to oil damage (Rice et al. 1984:15). Plankton may be very important forage species for many organisms. Therefore, increased mortality in plankton species or in planktonic larvae may have pronounced effects throughout the food web.

In Alaska's 1996 Draft 305(b) Water Quality Assessment Report, Cape Douglas, located in the northeastern portion of Katmai, was identified as impaired because aquatic resource injury was still evident due to the *Exxon Valdez* oil spill (Alaska Department of Environmental Conservation 1996). This site was later removed from the list because of the involvement of the *Exxon Valdez* Trustee Council in monitoring shorelines and resources injured by the oil spill. The listing was thought to be redundant given this focused effort.

A survey of oiling on Katmai beaches was conducted between March and June 1990 by a multi-agency team. The survey was not comprehensive, but instead looked in the areas where oil was most likely to have accumulated and remained. For the purposes of this plan, the team's mapped data, on the degree of oiling, were merged into a single data layer showing observed oiling. All line shoreline types were derived from two different Environmental Sensitivity Index studies: 1) the Sensitivity of Coastal Environments and Wildlife to Spilled Oil and 2) the Cook Inlet to Kenai Peninsula environmental sensitivity index. The data from these two studies has been generalized into eight different categories for cartographic purposes on these maps. The observed oiling layer was then overlain on the index of environmental sensitivity layer to generate the maps that follow on the next two pages (Coastal Resources-North and Coastal Resources-South maps following this page). The Katmai shoreline is color coded by shoreline type and legendized, generally, according to sensitivity – from the highly sensitive marshes to the least sensitive exposed rocky shores. An important point to be gained from these maps is that prominent points and islands most exposed to currents were also most obviously oiled. They generally constitute the least sensitive of the shoreline types exhibited on the Katmai Coast. However, what the map does not show is that these areas are often the most heavily used areas for seabird nesting and sea mammal haulouts. Consequently, although geomorphologically these areas are least sensitive, biologically the oil took a toll on sensitive resources occupying these exposed shorelines.

In addition, while it may appear that many areas of the Katmai Coast escaped oiling, those who have been on the ground know otherwise. At the scale the map was produced for this plan, it is impossible to see all the areas where oil was documented by this survey effort.

In 1990 National Park Service biologists conducted a more comprehensive shoreline inventory mapping coastal resources, such as bird nesting areas, marine mammal haulouts, kelp beds and shellfish concentrations, as well as oiling. The resulting product included a set of aerial photography and photomosaics with coastal resources overlain on top (National Park Service 1990). This study clearly indicated that sensitive marshes and sheltered tidal flats that had not been surveyed by the state in previous efforts contained residual oil mousse, patties and oil debris. Unlike the exposed rocky shorelines, oiling in marshes and tidal flats impacted some of the most sensitive shoreline types geomorphologically, as well as some of the most sensitive biologically.

The Alaska Department of Environmental Conservation (1996) identified 19 beach areas that still have shoreline impacts as a result of the spill. Water bodies adjacent to these oiled beaches may still suffer adverse effects and are being restored through efforts of the *Exxon Valdez* Trustee Council (EVTC).

Under the terms of the December 1991 *Exxon Valdez* Settlement approved by the U.S. District Court, Exxon paid $125 million in criminal penalties and a total of $900 million between 1992 to 2001 to state and federal agencies to settle damages to publicly owned resources affected by the spill. The EVTC decides annually how the money will be spent. The Trustee Council adopted the *Exxon Valdez* Restoration Plan in 1994, which contains policies for making decisions on restoration and describes how restoration activities will be implemented on oiled beaches.

E. What should be done?

✓ Conduct baseline studies of PAH levels in coastal sediments and mussels at both pristine beaches not hit by previous oil spills and at beaches that were impacted by the *Exxon Valdez* oil spill. Analysis should include an expanded PAH scan including alkylated homologues, as well as alkanes. Mussels should be taken at a consistent tide height (for example, -5). Some bile work should also be done with a fish species, using NOAA or FWS approved labs for analysis. Take at least 3-5 samples at each site with no compositing between replications. Sample at least once every three years as a minimum, taking triplicate samples the sixth year. Use no less than 10 ppb (1 ppb is better) as a detection limit for PAHs in tissues and sediments. Peggy Krahn at the Northwest Fisheries Center NOAA lab near the University of Washington in Seattle recommends the following screening methods:

1) size exclusion high-performance liquid chromatography (HPLC)/fluorescence method, utilizing sonic extraction, to screen sediments for polynuclear and heterocyclic aromatic compounds and
2) HPLC screening analysis of polycyclic aromatic hydrocarbon metabolites in bile, using fluorescence detection.

- ✓ Determine resources at special risk during various seasons of the year.
- ✓ At the park or the Alaska Regional Office have some basic oil spill response supplies ready for immediate use, such as clean jars for collections and other basic sampling equipment.

XII. Energy Initiatives

Periodically proposals have been advanced seeking to harness the power from Katmai's water resources for energy production. In the 1970s the Alaska Power Administration identified potential hydroelectric power sites on the Naknek River and on the Alagnak River below Kukaklek Lake. The Naknek project would have raised the elevation of the lake from the present 34 feet to 50 feet and would store 4.6 million acre-feet of water. The Kukaklek project proposed to raise the lake's elevation from the present 810 feet to 825 and would store 710,000 acre-feet. Given the Alagnak River's designation as a wild river, predicated on being free of impoundments, this project would probably not be allowed under the Wild and Scenic River Act's provisions if it were proposed today.

The Bureau of Reclamation (1952:160) assessed the potential development of water resources in Alaska for irrigation and power production, among other uses. At the time it was deemed feasible to tap the subsurface energy of the Naknek area although no plans were conceived to achieve such development. Presence of active steam vents and fumaroles in the Valley of Ten Thousand Smokes, which later subsided, led engineers to suspect that a volcanic energy source in the basin was conceivable.

The Geothermal Steam Act of 1988, as amended, 30 U.S.C. §§ 1001-1028, requires the National Park Service to establish and maintain a monitoring program for the thermal features that have been designated as significant according to provisions of the Act. Currently, the act lists 16 units of the National Park system, including Katmai, as containing significant thermal features. The act requires the NPS to establish a research and monitoring program to collect and assess data on these significant thermal features. The act also requires the NPS to determine whether activities covered by geothermal lease applications outside park units would be likely to adversely affect significant thermal features within park units. The purpose of the research and monitoring program required in the act is to provide the scientific basis upon which impact determinations of development proposals will be made by the NPS, as required by the act.

The Federal Register Notice of August 3, 1987 (Vol. 52, No. 148), describes the specific significant thermal features within each park unit listed in the act. In Katmai, Novarupta is listed as a volcanic feature of interest.

In 2001 NPS commissioned a Department of Energy geologist to assess the geothermal potential of several parks, including Katmai. The report (Barr 2001) generated from that study listed Novarupta as a medium priority for monitoring based on the state of technology for geothermal resource development of deep, dry thermal resources such as Novarupta.

It is believed that for volcanic features, the most important parameters to measure are seismic and GPS. This gives information on the activity generated by the injection and/or withdrawal of fluids. For hydrothermal features in the area of volcanic features, a suite of additional monitoring must also be performed, including surface temperature and fluid chemistry, which can be used to calculate subsurface temperatures. Although hydrothermal features are not the significant thermal features listed in the act for Katmai, they are a useful and sensitive tool in measuring impacts on the system as a whole.

Recommendations would generally include installation of a permanent, continuously recording seismic station at volcanic features, but Barr's (2001) analysis suggests the existing U.S. Geological Survey – Alaska Volcano Observatory's network in the vicinity of Novarupta is adequate to monitor seismic activity. Installation of 6-8 continuous recording GPS stations is recommended at a cost of $100,000. The monitoring will allow for a measurement of background values prior to exploitation, followed by monitoring changes due to subsidence caused by mass removal from the geothermal development or swelling caused by injection should geothermal development occur.

The report further recommends that for seismic and GPS measurements, it would be to the NPS's advantage to utilize the infrastructure the USGS already has in place to mitigate the costs of this program. In most cases, the USGS already has a network in place for collecting and transmitting data from its network of seismic and GPS instruments. For parks in Alaska, there is already a seismic network in place; however it is insufficient for the purposes of measuring small-scale changes. The monitoring system for evaluating large-scale magma movement would need to be supplemented with additional stations to see smaller-scale behaviors. The existing network can already detect unrest - when detected additional instruments could be added and tied into the existing network to monitor small scale changes.

Several other countries have been developing geothermal energy longer and to a greater degree than the United States. Their programs are well developed, and we can learn much from their experiences. One such country is New Zealand. With its history of geothermal energy development, it may have a long period of observational and test information on geothermal development's impacts on the natural system. The following information is taken mostly verbatim from the website of the Institute of Geological & Nuclear Sciences Limited, a New Zealand Crown Research Institute, a government-owned research company (http://www.gns.cri.nz/). Some additional material has been added on experiences from geothermal development within the United States.

Geothermal energy is considered a sustainable, environmentally benign energy source. Geothermal power stations do not emit nitrogen oxides that harm crops, animals and humans; and the amount of emitted carbon dioxide is less than 1% of that from coal- and oil-fired power stations of similar size. Sulfur gases are less than 2% of those from other power stations.

The exploitation of high-temperature geothermal systems, however, has some environmental impacts that have begun to cause concern. Negative environmental impacts come from four main causes:

- drilling,
- mass withdrawal,
- waste liquid disposal and
- waste gas disposal.

There is also a risk that geothermal surface features such as geysers, hot springs, fumaroles, and others may be permanently lost due to geothermal development. The impacts of geothermal resource development on volcanic (non-hydrothermal) features are not well understood, and care must be taken to prevent irreversible impacts on these features, as well.

With the new U.S. Energy Plan and its emphasis on alternative forms of energy, we are likely to see a resurgence of interest in geothermal energy development. As required by the Geothermal Steam Act, the NPS will need to be prepared to make determinations about the effect of any leasing applications on designated significant thermal features.

Geothermal resources exist on federal lands in Alaska, but extreme climatic conditions and the lack of energy transportation infrastructure and viable markets makes them generally unprofitable to extract. As of 2000, BLM had not issued a geothermal steam lease in Alaska. Some lease applications on Alaska lands were received in the early 1980s; however, they were all withdrawn.

Aside from the fact that no major population centers would benefit from a geothermal energy source in Katmai, U.S. Geological Survey volcanologist Terry Keith (pers. comm. 2001) suggests the risk of geothermal development in Katmai should be low due to the fact that the temperature of the heat source below Novarupta is lower than a temperature that would be useful for a main power supply source (Lowell and Keith 1991:1554, Table 1), considering the distance to a viable market.

Furthermore, current technology in geothermal resource development has not reached the point of utilizing deep, dry thermal resources. Because of this, Katmai does not appear to be at immediate risk of having its “significant thermal feature” impacted by geothermal resource development. However, monitoring of the resource should not be postponed indefinitely. A baseline of information will take time to acquire. The state of technology for geothermal resource development should be monitored periodically to be aware of when this will become an issue.

What actions need to be taken?

✓ Monitor the state of technology for geothermal resource development.

- ✓ Work with USGS to develop a plan for installing and monitoring GPS units to monitor crustal deformation and for monitoring of hydrothermal features.

XIII. Shortage of Hydrologic Expertise

The Katmai Natural Resource Management Division staff currently comprises four permanent positions as indicated in the organizational structure presented in Figure 2. The division is augmented by anywhere between 5-15 seasonal project support personnel each year including biological science technicians, Student Conservation Association resource assistants, student interns, graduate students and volunteers. The chief of resource management reports directly to the Katmai superintendent and is responsible for the park's natural resource management program. The resource manager is responsible for programs in Katmai National Park and Preserve, Aniakchak National Monument and Preserve and the Alagnak Wild River unit areas. All positions indicated are based at the park's field headquarters in King Salmon.

Current projects in the park that directly or indirectly relate to water resources have already been summarized in the preceding sections of this plan. The numerous fisheries projects that focus on management and species population dynamics and habitat will be fully detailed and addressed in a forthcoming fisheries management plan. Considering the immensity of Katmai water resources and the complex issues associated with these resources, the park has forged close working relationships with a wide variety of federal, state and local agencies and other coalitions in an effort to collaborate on effective water resource management. Included are the USGS-Biological Resources Division, USGS-Water Resources Division, Bureau of Land Management, Alaska Depart of Fish and Game, Alaska Department of Environmental Conservation, Bristol Bay Borough and various private organizations and individuals too numerous to list here. Collectively, all these sources have expressed a sincere interest to assist the park in preserving its riparian, lacustrine and coastal habitats and to prevent degradation to the park's water resources that so many park biota are vitally dependent upon for their very survival.

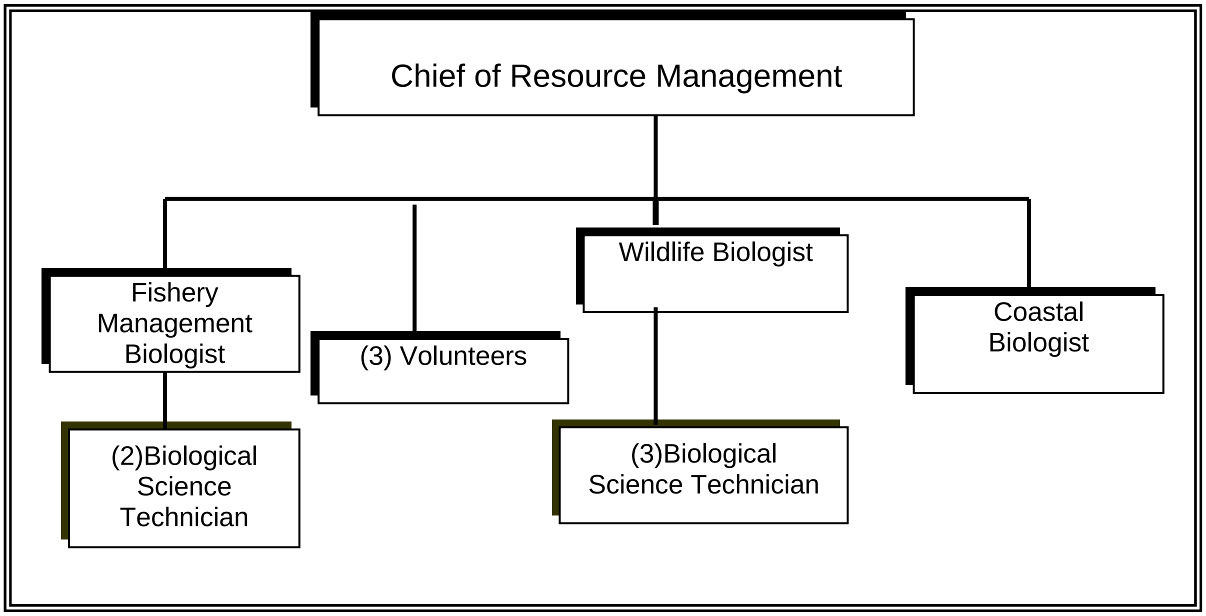


Figure 2. 2007 Katmai National Park and Preserve, Natural Resources Program: Organization and Structure.

NPS in Alaska, until December 2003, had only one hydrologist stationed in the Alaska Regional Office in Anchorage and who provided technical and policy assistance to NPS units across the state; and that position is now vacant. The nature and extent of Katmai's water resource issues warrants a full time aquatic position dedicated to these issues.

Chapter 8: Recommended Actions

I. Public Input into Development of the Water Resource Report

On March 29, 2001, a scoping meeting was held in Anchorage, Alaska. The purpose of the meeting was to review and clarify known issues affecting Katmai's water resources. In addition, other water resource issues or concerns identified by meeting participants were discussed and evaluated. Input into the process was solicited from a broad cross section of federal, state and local agency people as well as environmental groups, tribes, village representatives and university personnel. The result was a prioritized list of concerns that formed the basis for development of this Katmai Water Resource Information and Issues Overview.

Prior to the scoping workshop, the Alaska Regional Office distributed a survey of water resource management issues affecting Katmai National Park and Preserve and the Alagnak Wild River to 51 watershed stakeholders for a more extensive scoping of the issues. The purpose of the survey was to generate discussion on the water-related issues during the workshop and begin to identify the highest priority issues. It also allowed those who were unable to attend the meeting an opportunity to participate in the process. The Alaska Regional Office received and analyzed 20 completed responses.

One of the survey questions asked how well NPS has been communicating on water resource issues. Several local people responded that there was room for improvement. We heard their responses and began trying to be more inclusive and communicative in the water resource planning process. Newsletters were prepared for the villages, advisory groups, borough meetings and commercial operators as a start at better communication.

During the scoping meeting participants were asked to choose their top five priorities from a list of issues generated by NPS and survey comments, to add issues they felt were overlooked, argue for deletion of issues that should be removed from consideration or consolidate issues where appropriate. While no one chose to delete any of the issues identified, several new issues were added to the list and consolidation of some issues occurred.

The top ranked issues were as follows:

- Lack of baseline information to determine whether water quality is degrading and to understand the relationship between water quality and quantity
- Need for integrated science studies
- Need to better understand the effects of increased visitor use on the aquatic environment
- Need for long-term coordination relationships with other agencies, universities, tribes and the private sector
- Inadequate data to protect and enhance flow dependent resource values and quantify minimum instream flow levels
- Inadequate understanding of fishery utilization on nutrient cycling and system sustainability
- Need for data on the impacts of global climate change on water resources
- Need to understand factors controlling the fertility/functioning of the system

The project statements that follow were generated from the list of priorities developed by scoping meeting participants. Projects were selected that address the needs of more than one issue, that would significantly increase our understanding of ecosystem processes or that would likely provide critical data for decision making and ultimately resource protection. All priorities have been addressed to some degree in the project statements, except for one. Acquiring data to support instream water rights was purposely set aside to allow for more discussion on NPS priorities statewide. These data are expensive and time consuming to acquire, and efforts need to be directed at the most critical areas in Alaska.

II. Goals for Management of Water Resources in Katmai

Consistent with general management planning goals and the purposes and values for which Katmai was set aside, the water resource management program has three goals:

1. to protect ground and surface water quality and quantity,
2. increase understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations, and;
3. to participate in management on a watershed basis in close coordination with other agencies, universities, tribes, and the private sector.

To meet these goals and work toward an understanding and resolution of the top ranked issues identified by stakeholders, the Katmai water resource management program recommends implementing the projects that follow as funding becomes available and the appropriate level of environmental analysis is completed, consistent with NEPA. A brief description of each project follows with respect to the issue(s) it addresses.

With respect to two of the issues identified, "**need for integrated science studies**" and "**need for long term coordination relationships with other agencies, universities, tribes and the private sector**," all project statements were written with these two issues in mind. For example, installing a stream gage is proposed not only to meet the needs of the hydrologist for information on discharge and stage, but to assist in studies identified by archaeologists, bear biologists and ecologists working in the park. Gage locations were selected to meet the needs of as many people as possible.

The need for long-term coordination relationships can only be met through continued effort, which began with the process of developing the Katmai Water Resource Information and Issues Overview and will be further developed and sustained through dialogue over time. The management strategies identified in Chapter 1 to:

1. use the park as a classroom to involve the public in education, research and planning,
2. manage and distribute data to improve accessibility of information regarding water resources, and
3. coordinate an integrated research program designed to increase knowledge of water resources and ecosystem processes in the park and along the wild river

are intended to be more inclusive in both research and planning in the park, involving everyone from school children to park visitors, to commercial services personnel. Our hope for this park’s future lies in the hands of the children and the value they place on these resources. Today protection of these resources falls squarely with people using the park – they are the eyes and ears of the resource – and they speak loudest for its needs and –ultimate protection. Including all users in water resource protection may assure that we will be able to retain the area’s natural beauty and productivity for generations to come.

In trying to fulfill the need for **baseline information on water quality** there are many alternative strategies that could be pursued. An understanding of a watershed includes identifying key processes, functions and condition of its waters. Toward this end a suite of proposals have been developed to look at both historical condition of the watershed and modern day processes and functioning. Completion of these studies will provide: 1) a description of past and current conditions of the watershed, 2) a means to assemble analytic information needed to address key questions and 3) a description of condition trends and the ability to predict the effects of future land management practices on the watershed.

Historical variability in the watershed’s aquatic and terrestrial components will be looked at to understand 1) long-term variability in productivity of post glacial lakes in the park (ecological factors affecting productivity of Katmai waters), 2) post-glacial vegetative succession in Katmai watersheds (Terrestrial Ecosystem Processes and Aquatic Productivity) and 3) lake level changes as they relate to productivity (Landscape reconstructions). These studies are accomplished through analysis of lake/pond sediments, using proxy data to make inferences about environmental conditions at a given point in time. Volcanic ash layers, fires and other phenomena provide the markers for dating sediment profiles.

Complementary to paleoecological analysis are proposals to look at how the aquatic ecosystem functions. Both nitrogen and phosphorus have been cited as factors limiting productivity of Katmai lakes. But there has been no effort to look at the sources of these important nutrients. One proposal is designed to get a sense of the nutrient budgets of Katmai lakes (Determine the Relative Contribution of Nitrogen and Phosphorus to the Aquatic Ecosystem from Allocthonous and Authocthonous Sources). Another proposes to look at intermediate trophic level interactions. Each of the proposals described would aid in our understanding of **fishery utilization on nutrient cycling and system sustainability**, of the **impacts of global climate change on water resources** and the **factors controlling the fertility/functioning of the system.**

Of great concern at Katmai are the **impacts of human use on the aquatic environment.** All activities in the park are focused on water, and therefore it will likely be first to show injury. Although not all of the key characteristics of Katmai watersheds are understood or known, LaPerriere (1996) found in her studies of large lakes in the 1990s that water clarity was key to the long-term preservation of these waters. Water eutrophication, enrichment by dissolved nutrients, from human use or climate change or changes attributed to ecosystem succession would be marked by a change in water clarity. Therefore, a project designed to monitor water clarity has been given a prominent position in program objectives (Monitoring Key Characteristics of Water Bodies as a Measure of the Health of the System).

Data to support water rights claims for instream flows in Katmai are clearly lacking, but is both time-consuming and expensive to acquire. Priorities for collecting the necessary information must be made on a statewide basis as other parks may have higher priority needs for such information. Although this concern is not being addressed directly, proposals to install gage stations on the Alagnak Wild River and American Creek (Establish a Stream Gaging Station on the Alagnak Wild River and Establish a Stream Gaging Station on American Creek) would provide data to support future water rights claims. The proposals were primarily designed to meet a baseline information need to understand watershed processes.

III. How Accomplishing Defined Goals Will Aid in Water Resource Management

Conducting basic science projects in Katmai provides benefits beyond the scientific community – visitors will benefit from the new information and insights gained through interpretive programs, school children will better understand their local environment through participation in projects and through contact with researchers, and so on. To make this information more accessible and to facilitate management of park water resources, several end products would be desirable. Generation of these products is a long-term goal of the water resource management program and will only be possible after accomplishment of the research objectives described in this plan. Desirable products include:

1) a description of watersheds, including natural and cultural features;
2) a description of the processes and functions operating in the watersheds and their relative importance;
3) a description of the watershed's present condition relative to its associated values and uses;
4) a description of resource needs and capabilities;
5) the range of natural variation; and
6) spatially explicit information that will facilitate environmental and cumulative effects analysis for NEPA regulations.

The following are the proposed studies that, if funded, would begin realizing some of the goals established for the water resource management program at Katmai.

Project Statements

A. Establish a Stream Gaging Station on the Alagnak Wild River

Stream gages provide a useful tool for collecting data for a variety of purposes. Developing regional flow models useful in estimating streamflow characteristics at ungaged sites, determining current hydrological conditions and trends through time and predicting floods or low flow periods are some of the most fundamental purposes for which gages are installed. In Katmai additional benefits may be realized as well in understanding fish movements, predation, patterns of bear use of streams and documenting water flow for water rights appropriation.

In 1997 Alaska had 75 active stream gages in operation; an average of one stream gaging station per 8,000 mi^2, compared to an average of one gage per 400 mi^2 in the contiguous 48 states (Brabets 1996). Most of the existing gage sites are not on Department of Interior lands; and, as of 1998, only 45% met the minimum 10-year-record length necessary to support a statistically reliable regional flow analysis (U.S. Department of Interior 1998:7). Today many of Alaska's major rivers in or adjacent to parks are not gaged, including the Copper, Colville, Koyukuk, Naknek, Noatak and Alagnak rivers.

The USGS designed the National Streamflow Information Program (NSIP) to establish long-term stream gages throughout the nation. If fully implemented, the program would provide Alaska with a set of index gages. However, the program has not received funding. In fiscal year 2002 two new gages were installed as a result of congressional add-ons, but the fiscal year 2003 budget does not provide funding for any additional gages (Gordon Nelson pers. comm. 2002).

In the mid-1990s the U.S. Geological Survey conducted an evaluation of the existing streamflow gaging network in Alaska. The study concluded that in the Arctic, Southwest and Yukon regions of the state there was insufficient data available to develop regional regression equations (Brabets 1996:1). In these areas proposed locations for streamflow gaging stations were selected, using clustering and spatial analysis techniques to define similar areas within the region and using precipitation, physiographic, permafrost and hydrologic unit maps of Alaska. The proposed streamflow gaging network for Southwest Alaska consists of 48 sites with only two sites active in 1996 (Brabets 1996:36). In and around Katmai gaging sites were recommended at Kejulik River, Knife Creek, Eskimo Creek (discontinued station), Naknek River, Nonvianuk River and Alagnak River. These sites were chosen from the three physiographic regions represented in Katmai: low mountains (Knife Creek), generally rolling plains and lowlands (Naknek, Nonvianuk, Eskimo, Alagnak), moderately high rugged mountains (Kejulik) (Wahfhaftig 1965 in Brabets 1996) and three precipitation regions: 15-20 inches (Eskimo), 20-30 inches (Alagnak, Nonvianuk, Naknek) and greater than 80 inches (Knife Creek and Kejulik River; Jones and Fahl 1994).

Of the streams recommended, only Knife Creek and the Naknek, Nonvianuk and Alagnak Rivers are in the park. The Alagnak, and its major tributary Nonvianuk River, are designated wild rivers under the Wild and Scenic Rivers Act. Protection and enhancement of the outstanding resource values for which the rivers were set aside and the Wild and Scenic

Rivers Act requirement for data on flow and stage make the Alagnak and Nonvianuk Rivers good candidates for gaging.

It is not always desirable to locate a stream gaging station at the outlet of a lake, which attenuates peak flows and may bias peak flow analysis. For this reason, the Nonvianuk has been excluded from further consideration. A stream gaging site would necessarily have to be located at the outlet and would be redundant if a gage were established on the Alagnak as well. The Alagnak provides better opportunities for site selection along the 67 miles of river protected within the wild river corridor.

The Alagnak River is one of the major tributaries in the Bristol Bay region. It originates at Kukaklek Lake and its main tributary, the Nonvianuk River, at Nonvianuk Lake. Headwater elevations range from 300 to 1,570 meters along the eastern edge of the basin. Snowfields and glaciers comprise less than 1% of the basin. Long, narrow lakes entrap much of the upland generated sediment load, resulting in a clear water flow in the Alagnak. The Alagnak River flows westward to the Kvichak River along its 74-mile course, draining an area of 3,600 square kilometers, meeting the Kvichak about 10 miles upstream of Kvichak Bay.

The first 20 miles of the river are steepest, falling roughly 17.8 feet/mile. After the confluence of the Nonvianuk and Alagnak Rivers, the remaining 54 miles are more gradually sloping, averaging 7.8 feet/mile (Clay, Inghram, and Carrick 1983:3). The Nonvianuk River measures 11.5 miles in length from the lake to the confluence with the main stem of the Alagnak. The average gradient is 15.2 feet/mile (Clay, Inghram, and Carrick 1983:3).

The largest streams located in the Alagnak River drainage in Katmai are the Alagnak (Branch), Nonvianuk, Kulik and Battle Rivers and Nanuktuk, Moraine and Funnel Creeks.

One of the long-term goals for the Water Resource Management Program at Katmai is to gage at least one large and one small river. The Alagnak Wild River provides the best fit for a larger stream in the park and is proposed for gaging as the first priority for funding. If data can be collected over a long period (10 years or more), this river could provide an index station for the region. American Creek provides an excellent river to estimate the effects of lesser, flashy weather events on a small water course as well as providing a good place to address some unanswered questions regarding bear and fish behavior at varying water levels and rates of flow (see project statement "Establish a Stream Gaging Station on American Creek").

What Needs Would the Alagnak Stream Gage Address?

Establishing a stream gage on the Alagnak Wild River would accomplish a number of objectives. It would not only meet some of the high priority needs of the Katmai water resource management program, but could address questions raised by wildlife and fishery biologists and archaeologists working in the park. Water rights appropriations, baseline data on hydrology and a number of variables or species that are dependent on adequate flow are a few of the most important needs addressed.

Quantification of Instream Flow Needs

The objective of the Department of the Interior's water rights program in Alaska is to acquire and protect water rights for lands managed by the respective bureaus. Agencies cannot consumptively use water in Alaska without a water right and must file applications for existing and future diversions and depletions. Instream flow uses will continue, but are unprotected until the NPS files for either state appropriative or federal reserved water rights in the appropriate forum (state reservation or administrative/judicial adjudication). Without a perfected water right, the NPS is at risk of having future uses impact flow regimes and resource values at Katmai.

Recent proposals pose new threats to Katmai, and the NPS should initiate data collection and consider filing instream flow claims. The prospect of a road linking Anchorage and King Salmon gained momentum during a few recent years, and its effects on flow are unknown.

Current data for quantifying NPS water rights for instream flows in Alaska and Katmai are insufficient. The state has no statutory criteria for data requirements to support state reservation of instream flows. Currently, Alaska encourages agencies to use the Tennant Method (Tennant 1972, 1976) for quantifying instream flow requirements, which suggests five years of streamflow data to adequately quantify water rights. Claims for federal reserved water rights for instream flows are also factually and legally intensive and are primarily guided by the standard that instream flows will be the minimum amount necessary to support the primary purpose or purposes of the reservation. The NPS will require flow data and water-related resource studies to support federal reserved water rights claims. The NPS has not initiated data collection on streams in Katmai because existing threats have been minimal and due to the cost of data acquisition to support either state reservations or federal reserved water rights claims. Due to the data intensive nature of determining instream flow needs, the NPS should prioritize data collection efforts, including stream gage installation, and initiate studies as funding becomes available.

Determining Variables Dependent on Flow

The integrity of freshwater ecosystems depends upon adequate quantity, quality, timing and temporal variability of water flow. Many species depend on an adequate flow of water at specific times of year for their survival. Many stages in the life history of stream macroinvertebrates, for example, are dependent on flow, as are spawning salmon and their eggs.

Although a great deal of research money has been devoted to understanding bear behavior and population numbers in Katmai, many questions are still unanswered regarding their feeding strategies and what affects their ability to successfully catch salmon. Water levels, water chemistry, fish spawning locations, timing and duration of spawning, bear fishing locations, bear numbers and timing on streams may all play a role. Likewise, salmon spawning behavior, location of spawning beds, availability of prey species, egg mortality and risks from predation may be dependent on water flow.

Both high and low flow can affect salmon. Low streamflow can impede summer-run spawners, and high flows can disrupt the spawning of fall and winter sockeye. Low streamflows can limit early run sockeye spawner distribution to sub-optimal stream reaches and force fish to spawn in the center of the stream channel, which can increase egg and alevin mortality during winter floods. All sockeye stocks can be negatively impacted by high flows during the fall and winter incubation period. The erosion and downstream movement of spawning gravel is a major cause of egg and alevin losses, and severe flooding can cause mortality exceeding 90%.

Salmon may be more vulnerable to predation at low flow levels, while at higher rates of flow bears have a difficult time fishing and may choose to disperse. USGS Research Biologist Tom Smith (pers. comm. 2002) first observed how dynamically linked bears and water were at Kulik River when heavy fall rains nearly instantly raised the river's water level two feet. The rush of water flushed spawned salmon carcasses out into Nonvianuk Lake and resulted in the dispersal of more than 100 bears. Bears’ risks in aggregating are substantial wherever they gather; and a high water event, such as that observed at Kulik River, which reduces fish catchability, will apparently clear them out.

Predicting Regional Flow Characteristics

One of the fundamental, and perhaps most useful, purposes for measuring rates of flow is in predicting regional flow characteristics, which can be useful in estimating streamflow characteristics at ungaged sites in the region. Current hydrologic conditions and changes and trends over time may also be documented through stage and discharge measurements. Little stage or discharge information currently exists for Katmai or the surrounding region. A stream gage at Eskimo Creek in King Salmon has been discontinued. Given the small size of the stream and few years of gage operation, the site was not considered an index station for the region.

Sporadic stage and discharge measurements have been made on rivers and streams in Katmai primarily in association with a water quality study conducted in the early 1990s by LaPerriere. In a 2000 pilot study on macroinvertebrates some additional data was collected. Both studies only collected one-time flow and discharge measurements during the summer on select streams.

A U.S. Geological Survey study of bank erosion on the Alagnak provided the longest term stage and flow data in the park to date. Janet Curran established three gage stations on the river in association with the study and collected data seasonally in a period of three years.

Proposed Action

To better understand flow regimes in Katmai for the purposes of protecting and securing instream flows, developing regional flow models, and determining flow dependence of water-related resources, we propose to install a stream gaging station in the Alagnak River. Weather and water monitoring capabilities will be installed in the stream gaging station to complement stage, elevation and discharge data for the river. Equipment will be installed to measure precipitation, water temperature, air temperature and wind speed. Wind speed monitoring will require installation of an elevated tower, which may not be feasible on the Alagnak. This component of the proposal will have to be evaluated once the site for the gaging station is selected.

Stream gage instrumentation will be accessible remotely, allowing for real time data access from this site on the World Wide Web. These data will be readily available to NPS and other interested agencies, including USGS and NOAA.

If appropriate, sediment traps will be placed across the floodplain to systematically monitor the rate of sedimentation – a factor critical to floodplain evolution. Monitoring of sediment traps or plates will be conducted annually and ideally within three weeks of a flooding event.

This action addresses two of the goals established for the water resource program at Katmai to: 1) protect ground and surface water quality and quantity and 2) increase our understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations.

Budget

Installation and maintenance of the gage and weather station will require ***funding for 5 years to achieve the minimum level of data.*** However, 10 years or more of data is highly desirable and would be more cost effective eventually.

Initial startup costs include $3,000 to locate the site for installation of the gage somewhere below the confluence of the Nonvianuk with the Alagnak and to determine the actual costs of installation/maintenance and the type of structure required.

Year 1: ~$35,000* - Includes gage construction, purchase of weather/water sampling equipment, installation of the gage/weather station and six months of discharge data collected at 6-8-week intervals. Only six months of data is planned, assuming gage installation will occur during the summer months.

Years 2-5: ~$35,000* - per year for four years of operation/maintenance every 6-8 weeks and discharge measurements.

*Yearly operating costs would be determined after the reconnaissance trips are completed. In addition to locating the best site for the gaging station, the recon trips also provide the USGS an idea of travel costs to sites (i.e., by fixed wing aircraft or by helicopter), and travel costs from Anchorage to King Salmon, the starting point to access the Alagnak River. An initial estimate for yearly operation of these gages would be $35,000. However, these costs are highly dependent on several factors:
1) Will more than one gage be operated at the same time (which reduces some travel cost)?
2) Can the NPS provide some in-kind services (housing, field assistant)?
3) Will gages be operated year-round or just during open-water periods?

NEPA compliance required

An environmental screening form (Director's Order 12, Appendix 1) will be completed to determine the appropriate level of compliance for this proposal.

References

Brabets, Timothy P. 1996. Evaluation of the streamflow-gaging network of Alaska in providing regional streamflow information. U.S. Geological Survey Water Resources Investigations Report 96-4001. Prepared in cooperation with Alaska Department of Natural Resources and U.S. Forest Service. Anchorage, Alaska. 73 pgs + appendixes.

U.S. Department of the Interior. 1998. Water Resources in the Final Frontier: A Strategic Plan for DOI Waters in Alaska. Dept. of the Interior Bureaus in Alaska (U.S. Geological Survey, National Park Service, Bureau of Land Management, Bureau of Indian Affairs, Minerals Management Service). Anchorage, AK. 61 pp.

B. Establish a Stream Gaging Station on American Creek

Stream gages provide a useful tool for collecting data for a variety of purposes. Developing regional flow models useful in estimating streamflow characteristics at ungaged sites, determining current hydrological conditions and trends over time, predicting floods or low flow periods are some of the most fundamental purposes for which gages are installed. In Katmai additional benefits may be realized as well in understanding fish movements, predation, patterns of bear use of streams and documenting water flow for water rights appropriation.

In 1997 Alaska had 75 active stream gages in operation; an average of one stream gaging station per 8,000 mi^2, compared to an average of one gage per 400 mi^2 in the lower 48 states (Brabets 1996). Most of the existing gage sites are not on Department of the Interior lands; and, as of 1998, only 45% met the minimum 10 year record length necessary to support a statistically reliable regional flow analysis (U.S. Department of Interior 1998:7). Today many of Alaska's major rivers in or adjacent to parks are not gaged, including the Copper, Colville, Koyukuk, Naknek, Noatak and Alagnak Rivers.

The USGS designed the National Streamflow Information Program (NSIP) to establish long-term stream gages throughout the nation. If fully implemented, the program would provide Alaska with a set of index gages. However, the program has not received support from either the Clinton or Bush administration. In fiscal year 2002 two new gages were installed as a result of congressional add-ons, but the fiscal year 2003 budget does not provide funding for any additional gages (Gordon Nelson pers. comm. 2002).

In the mid-1990s the U.S. Geological Survey conducted an evaluation of the existing streamflow gaging network in Alaska. The study concluded that in the Arctic, Southwest and Yukon regions of the state there was insufficient data available to develop regional regression equations (Brabets 1996:1). In these areas proposed locations for streamflow gaging stations were selected, using clustering and spatial analysis techniques to define similar areas within the region and using precipitation, physiographic, permafrost and hydrologic unit maps of Alaska. The proposed streamflow gaging network for Southwest Alaska consists of 48 sites with only two sites active in 1996 (Brabets 1996:36). In and around Katmai gaging sites were recommended at: Kejulik River, Knife Creek, Eskimo Creek (discontinued station), and Naknek, Nonvianuk and Alagnak Rivers. These sites were chosen from the three physiographic regions represented in Katmai: low mountains (Knife Creek); generally rolling plains and lowlands (Naknek, Nonvianuk, Eskimo, Alagnak); and moderately high rugged mountains (Kejulik) (Wahfhaftig 1965 in Brabets 1996) and three precipitation regions: 15-20 inches (Eskimo); 20-30 inches (Alagnak, Nonvianuk, Naknek); and greater than 80 inches (Knife Creek and Kejulik River) (Jones and Fahl 1994).

Of the streams recommended, only Knife Creek and the Naknek, Nonvianuk and Alagnak Rivers are in the park. Of these streams, only Knife Creek would be considered a small stream. Although it would provide information on the response of a small stream to flashy, weather events, the creek is located in an extremely different ecological environment and would only provide an indication of the most dramatic response possible in the region. Knife

Creek flows through the unvegetated ashflow from the 1912 eruption of Novarupta. The Creek's response to precipitation and snow melt is swift and dramatic. Likewise, weather phenomena in the Valley of Ten Thousand Smokes tend to be more extreme than in other areas of the park and therefore would not provide a representative sample site.

Small streams flowing from the west side of the Aleutian Range tend to be steep, rocky and exhibit a high degree of variability of flow, depending on glacial and snowmelt characteristics of the basin, making them poor candidates for gaging. Lowland streams are generally low flow and most representative of snowmelt effects on water levels. The best candidates for gaging, given the nature of smaller streams west of the range, are Kulik or Brooks Rivers or American Creek. These waters are by no means small streams. Kulik and Brooks are a mere half mile long and resemble in characteristics a short river more than a small stream. Discharge at Brooks River has been measured at 386 ft^3/sec (LaPerriere 1996:69, September 1990). Both may be more representative of the lake systems they connect than an overall drainage pattern representative of the basin. However, observations at Kulik attest to its rapid response to weather phenomena in the area as it is situated adjacent to mountainous terrain.

American Creek, in contrast, is in the headwaters of the Naknek drainage, flowing approximately 55 miles from the outlet of Hammersly Lake to Coville Lake and descending an average of 30 feet per mile. The upper section is swift and rocky and about two feet deep as it flows through rolling tundra highlands south of Nonvianuk Lake. The stream passes through two canyons in mid-reaches and in the lower section is braided, forming numerous islands and side channels. Water depth near the mouth is shallow (2-4 feet), muddy and bordered by extensive flat marshland. The river drains an area of just more than 300 square miles and average streamflow at the mouth is 530 ft^3/sec (LaPerriere 1996:69). There are no glaciers in the drainage.

One of the long-term goals for the Water Resource Management Program at Katmai is to gage at least one large and one small river. Small streams are more responsive to local storm events and provide more detailed information on runoff and water retention than a large, glacial stream would. The Alagnak Wild River provides the best fit for a larger stream in the park and is proposed for gaging as the first priority for funding (see project statement "Establish a Stream Gaging Station on the Alagnak Wild River"). If data can be collected for a long period of time (10 years or more), this river could provide an index station for the region. The American Creek provides an excellent river to estimate the effects of lesser, flashy weather events on a small water course, as well as providing a good place to address some unanswered questions regarding bear and fish behavior at varying water levels and rates of flow.

What Needs Would the American Creek Stream Gage Address?

Establishing a stream gage on the American Creek would accomplish a number of objectives. It would not only meet some of the high priority needs of the Katmai water resource management program, but could address questions raised by wildlife and fishery biologists and archaeologists working in the park. Water rights appropriations, baseline data on hydrology and a number of variables or species that are dependent on adequate flow are a few of the most important needs addressed.

Determining Variables Dependent on Flow

The integrity of freshwater ecosystems depends upon adequate quantity, quality, timing and temporal variability of water flow. Many species depend on an adequate flow of water at specific times of year for their survival. Many stages in the life history of stream macroinvertebrates, for example, are dependent on flow, as are spawning salmon and their eggs.

Salmon spawning behavior, location of spawning beds, availability of prey species, egg mortality and risks from predation may be dependent on water flow. Low streamflow can impede summer-run spawners, and high flows can disrupt the spawning of fall and winter sockeye. Low streamflows can limit early run sockeye spawner distribution to sub-optimal stream reaches and force fish to spawn in the center of the stream channel, which can increase egg and alevin mortalities during winter floods. All sockeye stocks can be negatively impacted by high flows during the fall and winter incubation period. The erosion and downstream movement of spawning gravels is a major cause of egg and alevin losses, and severe flooding can cause mortalities exceeding 90%.

Likewise, beach spawning salmon suffer high egg mortality when lake levels drop and shore ice freezes or mechanically abrades redds.

Salmon may be more vulnerable to predation at low flow levels while at higher rates of flow bears have a difficult time fishing and may choose to disperse. USGS Research Biologist Tom Smith (pers. comm. 2002) first observed how dynamically linked bears and water were at Kulik River when heavy fall rains nearly instantly raised the river's water level two feet. The rush of water flushed spawned salmon carcasses out into Nonvianuk Lake and resulted in the dispersal of more than 100 bears. Bears' risks in aggregating are substantial wherever they gather; and a high water event, such at that observed at Kulik River, which reduces fish catchability, will clear them out.

Although a great deal of research money has been devoted to understanding bear behavior and population numbers in Katmai, there are still many unanswered questions regarding their feeding strategies and what affects their ability to successfully catch salmon. Water levels, water chemistry, fish spawning locations, timing and duration of spawning, bear fishing locations, bear numbers and timing on streams may all play a role.

Predicting Regional Flow Characteristics

One of the fundamental, and perhaps most useful, purposes for measuring rates of flow is in predicting regional flow characteristics, which can be useful in estimating streamflow characteristics at ungaged sites in the region. Current hydrologic conditions and changes and trends over time may also be documented through stage and discharge measurements. Little stage or discharge information currently exists for Katmai and the surrounding region. A stream gage at Eskimo Creek in King Salmon has been discontinued. Given the small size of the stream and few years of gage operation the site was not considered an index station for the region.

Sporadic stage and discharge measurements have been made on rivers and streams in Katmai primarily in association with a water quality study conducted in the early 1990s by LaPerriere. In a 2000 pilot study on macroinvertebrates some additional data was collected. Both studies only collected one-time flow and discharge measurements during the summer on select streams.

Proposed Action

To better understand flow regimes in Katmai for the purposes of developing regional flow models, as well as determining how it may affect fish, their prey species and predators, we propose to install a stream gaging station in American Creek. Weather monitoring and limited water monitoring capabilities will be installed in the stream gaging station to complement stage, elevation and flow data for the river. Weather and water monitoring equipment will include precipitation, water temperature, air temperature and wind speed gages. Wind speed monitoring will require installation of an elevated tower, which may not be feasible on the American Creek. This component of the proposal will have to be evaluated once the site for the gaging station is selected.

Stream gage instrumentation will be accessible remotely, allowing for real time data access from this site on the World Wide Web. These data will be readily available to NPS and other interested agencies, including USGS and NOAA.

If appropriate, sediment traps will be placed across the floodplain to systematically monitor the rate of sedimentation – a factor critical to floodplain evolution. Monitoring of sediment traps or plates will be conducted annually and ideally within three weeks of a flooding event.

This proposal addresses two of the goals established for the Water Resources Program at Katmai to 1) protect ground and surface water quality and quantity and 2) increase our understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations.

Budget

Installation and maintenance of the gage and weather station will require ***funding for 5 years to achieve the minimum level of data.*** However, 10 years or more of data is highly desirable and would be more cost effective eventually.

Initial startup costs include $3,000 to locate the best site and determine actual costs of installation, continued maintenance and the type of structure required.

Year 1: ~$35,000* - Includes gage construction, purchase of weather equipment, installation of the gage/weather station and six months of discharge data collected at 6-8 week intervals. Only six months of data is planned, assuming gage installation will occur during the summer months.

Year 2 - 5: ~$35,000* - per year for four years for operation/maintenance and discharge measurements every 6-8 weeks.

*Yearly operating costs would be determined after the reconnaissance trips are completed. In addition to locating the best site for the gaging station, the recon trips also provide the USGS an idea of travel costs to sites (i.e., by fixed wing aircraft or by helicopter), and travel costs from Anchorage to King Salmon, the starting point for access to the Alagnak Wild River and American Creek. An initial estimate for yearly operation of these gages would be $35,000. However, these costs are highly dependent on several factors:
1) Will both gages be operated at the same time (which reduces some travel cost)?
2) Can the NPS provide some in-kind services (housing, field assistant)?
3) Will gages be operated year-round or just during open-water periods?

NEPA compliance required
An environmental screening form (Director's Order 12, Appendix 1) will be completed to determine the appropriate level of compliance for this proposal.

References
Brabets, T.P. 1996. Evaluation of the streamflow gaging network of Alaska in providing regional streamflow information. USGS Water Resources Investigations Report 96-4001, 73 pp.

U.S. Department of the Interior. 1998. Water Resources in the Final Frontier: A Strategic Plan for DOI Waters in Alaska. Dept. of the Interior Bureaus in Alaska (U.S. Geological Survey, National Park Service, Bureau of Land Management, Bureau of Indian Affairs, Minerals Management Service). Anchorage, AK. 61 pp.

C. A Window on the Past: Using Paleoecological analysis of lake sediment to understand natural variability of post-glacial lakes in Katmai

Compared to the life span of humans, water bodies seem like permanent features on the landscape. However, on the geological timescale, lakes and ponds are only transient aspects of a continuously evolving landscape. Lake basins are formed by various processes – in Katmai primarily glacial activity – but then slowly fill with sediment; and eventually succession proceeds to the point that the lake ultimately becomes dry land. Generally, this process is imperceptibly slow, on the order of thousands to millions of years because the sediment accumulation rate in many lakes is only about one millimeter or so per year. New sediment is constantly accumulating over older sediment in lakes, producing a depth-time profile that potentially dates back to the time of the lake basin's inception. A great deal can be learned about a lake’s life history by studying the sediment record.

Paleoecological analysis can be a powerful tool for understanding patterns of long-term ecological changes, providing insight into how lakes and watersheds evolve and respond to environmental change. Past climatic and vegetation changes may be inferred from geochemical analysis of sediments and proxy climatic data (tree rings, sea surface temperatures). Impacts from distant human activities and natural events affecting the wider ecosystem may also be inferred. It can also be invaluable in providing a baseline for management decisions in a watershed.

Most importantly for a park like Katmai where data is sparse, paleoecological analysis does not require the existence of historical data or a thorough understanding of all important watershed and in-lake biogeochemical processes. This analysis can provide a foundation for building an understanding of processes about which we currently have little knowledge. From sediments we can infer past chemical conditions for many variables, averaged over one to a few years, with accuracy comparable to that of modern chemical monitoring programs (Charles and Smol 1994:4).

What Can Be Learned?

Climate change we are experiencing is not unprecedented. Oxygen isotope measurements of microscopic fossils in the Pacific Ocean provide a picture of long-term trends in global temperatures over the last 20 million years. Studies show that during the last 2.5 million years climate changes have been extreme oscillating between relatively long periods (~100,000 years) of predominantly cold, dry glacial climates and shorter intervals (~10-20,000 years) of warmer, moister interglacial climates (U.S. Geological Survey 1997).

During the warm interglacial periods, such as we are now experiencing, average growing season temperatures rose and spruce dominated forests spread to areas where lowland tundra vegetation now grows. Warmer temperatures also allowed trees to grow into higher elevations reducing the coverage of upland tundra communities. Both colder and warmer conditions than what we have experienced have been recorded. The ecological responses to climate changes are variable and may be quite dramatic in higher latitudes, such as Alaska. Whether climate change today is human induced or part of a natural cycle, it will result in vegetation species composition changes, as well as distribution of some vegetation types.

Looking at Katmai's watersheds today we ask questions about the importance of salmon in contributing marine derived nitrogen and other nutrients to the ecosystem (a question addressed in a complementary proposal), but other important questions must also be asked, such as: what changes have occurred in the last 2,000 years since salmon have inhabited these waters? What factors affected the development of the watersheds since glacial retreat 10,000 years ago? How have the factors driving the system changed through time? Have the relative contributions of various inputs into the water changed and in what manner? Have salmon always played a dominant role in nutrient cycling, or were there other factors? And how do changes in salmon population levels affect productivity of the system? To answer these questions terrestrial, atmospheric or climatic and geologic inputs and changes in the system must be determined.

These basic research projects are needed to complement long-term monitoring efforts currently underway, to more effectively manage salmon populations, as well as to complement on-going regional and global efforts to better understand the causes and consequences of climate change.

Because global warming is predicted to be greatest in high latitudes, the northern location and pristine condition of Alaska's parks make them excellent 'science preserves' or 'natural laboratories' for investigating relationships between the physical, biologic and cultural resources of the Arctic and sub-Arctic. Investigating past changes in climate, landscape processes, vegetation, animals, and human practices can help us understand how the *system* works and how it might respond to future environmental changes of both natural and human origin.

A three part approach has been proposed to better compete for limited project funding. However, the suite of proposals, if funded simultaneously, could be an excellent project for a team of interdisciplinary graduate students and the greatest benefits both financially and scientifically would be gained from such a collaborative approach.

These projects could present excellent opportunities for development of educational and interpretive products from these projects that should be explored as well – particularly if a holistic approach is taken.

<u>Phase 1: Ecological Factors Affecting Productivity of Katmai Waters</u>

<u>Project Summary</u>
Katmai contains some of the most productive sockeye salmon nursery lakes in the world. Its relatively undisturbed watersheds provide an excellent opportunity to study the freshwater habitat that is so vital to salmon survival. Many unanswered questions remain about why these lakes are so productive. Are cyclic salmon returns driving the productivity of the system or factors inherent in the lakes affecting salmon production? Furthermore, what was the natural environmental history of these lakes following glacial retreat, and how did salmon contribute to their evolution?

Factors affecting salmon production in different systems are not completely known. Evidence suggests a relationship between climate and salmon production, but the mechanisms that influence salmon production remain uncertain. From the analysis of temperature records from the North Pacific and historical catch data for Pacific Salmon, there appears to be coherent interdecadal variation (Cederholm, Michael and Pittman 2001). Paleolimnological analysis of lake sediment allows a means of hindcasting past sockeye salmon abundances. Using proxies from the sediment, such as $\partial^{15}N$, diatoms and cladocerans along with tree ring, sea surface temperature reconstructions and other proxy data, it is possible to create an understanding of the relationship between climatic shifts, nutrient levels and salmon production. Additionally, lake trophic status through time can be determined through microfossil records. This understanding may allow us to explain and better manage for changes in salmon abundance and the factors that are important to their survival, considering past trends.

Past aquatic ecosystem research and planned vital signs monitoring in Katmai necessarily focus on modern day attributes of the ecosystem. These data are invaluable in providing a snapshot of attributes and numbers, but can they be used in comparisons with future research given the short window of time in which the data are gathered? Paleolimnological approaches are integrative in that the biota preserved in lake sediments provides information on average or typical conditions as opposed to "snapshot" water chemistry analysis (Charles and Smol 1994:7). Modern methods are computer intensive and capable of providing inferred chemistry values and error estimates with a great deal of accuracy and precision (Charles and Smol 1994:10).

Vital signs monitoring studies may play a greater role in understanding eventual change if we are able to place monitoring data in the context of known natural ecological variability. Using paleoecological analysis, we will provide a context for understanding variability in the system.

Measuring long-term variability in the aquatic environment

National Park Service (NPS) managers are faced with increasingly more complex and challenging issues and asked to provide scientifically credible information to defend management actions. Management of national parks is an extremely difficult and complicated task. Many threats to parks come from outside the park boundaries and sometimes from outside the state. Understanding the natural variability of complex ecosystem functions is critical if we are to determine whether changes observed in these systems are functions of natural variability or human activities.

National Park Service policy and recent legislation (National Parks Omnibus Management Act of 1998) require that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources to fulfill the NPS mission of conserving parks unimpaired. Furthermore, NPS Management Policies (2001) says that NPS will use results of monitoring and research to understand detected change and to develop appropriate management actions.

Establishing a quantifiable measure of resource conditions is a difficult task. But without a target condition, monitoring cannot detect changes and quantify trends in the resource condition. Baseline conditions for water resources in Katmai have not been established. Information is lacking in many areas that would contribute to the understanding of these ecosystems. Thus a primary focus of the resource management program must be devoted to generating basic data to establish resource condition.

Although inventory and monitoring activities are important, they alone are not capable of establishing a true baseline condition. Instead, these short-term studies provide a snapshot of the condition of the resource at a particular point in time, which is valuable for monitoring purposes. However, it is questionable whether these data can be used in a comparative analysis in years to come when we do not understand what the range of natural variability really is.

Long-term environmental data is crucial to management of aquatic resources in parks. However, in Alaska, post-glacial lacustrine environments are poorly documented (Ritchie and Harrison 1993 and Anderson and Brubaker 1994 in Hu et al. 1996:188); and Katmai is no exception. Because long-term observations are rarely available, indirect proxy methods must be used to substitute for these missing historical datasets. Major advances have been made in paleolimnology over the last decade, and many of these advances can be applied directly to integrated and cost-effective assessments of aquatic ecosystem health.

Understanding the Effects of Long-term Climate Variability on Waters

Evidence of climatic warming since the Little Ice Age has been found through the sediment record, particularly in the Arctic, and indicates that recent rates of environmental change are unprecedented in the context of the Holocene (Wolfe and Perron 2001:747). Diatom communities respond quickly to limnological changes influenced by climate. Shifts in diatom and chrysophyte assemblages have been observed, and species considered more typical of boreal lakes have been found in the Arctic (Wolfe and Perron 2001:750). A prolonged algal growing season, decreased severity of lake ice conditions and expanded littoral habitat are cited as plausible explanations for these shifts (Wolfe and Perron 2001:748).

Natural climate-forcing mechanisms must be considered in explaining variability before human influences can be blamed for changes in the earth's climate that we see today (Overpeck et al. 1997:1252). In the Arctic scientists have found that enhanced and prolonged arctic cooling can be attributed to volcanic eruptions. The finding for volcanic forcing of arctic temperatures agrees with the 200-year record of volcano-climate linkages for sub-arctic North America, as well as assertions that volcanic activity plays a role in modulating climate of the Northern Hemisphere (Overpeck et al. 1997:1253). Scientists believe that the low period of volcanic activity between 1935 and 1960 may have contributed to peak arctic summer temperatures at that time (Overpeck et al. 1997:1253). Also, decadal scale fluctuations in the state of the Pacific Oscillation or to the transport of heat northward by thermohaline circulation can also modulate climate for decades and centuries.

Because many limnological changes can be directly or indirectly related to climate variability, paleolimnology can provide a “window” on past climatic changes. Proxy information offers an opportunity to study climatic variability and change at a variety of time scales. Only with this historical perspective can we understand past natural climatic variability and change and thereby increase our ability to predict and plan for future climatic changes (Smol and Cumming 2000:987). We poorly understand even natural changes in climatic variability, let alone understand the potential consequences of some of today’s large-scale, human induced climatic changes that the earth is experiencing.

Variability in salmon abundance over time: effects of climate, nutrient loading and regional landscape altering events on their numbers

The numbers of fish entering a watershed varies temporally over several scales. Salmon abundance has varied dramatically in past centuries in response to geological changes in land and ocean conditions (Francis and Hare 1994). Primary productivity is thought to oscillate over a multidecadal cycle (Mantua et al. 1997) and probably affect growth and survival of salmon (Gargett 1997 in Gende 2002:918). Natural variations also occur over shorter time scales in response to varying levels of precipitation and streamflow, disease and population feedback mechanisms. Harvest levels, since the 1800s, also play a role in the numbers of fish returning to spawning streams (Finney et al. 2000).

Other theories regarding salmon population variations center on the freshwater ecosystem and the effects of nutrient loading on subsequent generations of salmon. Data from the Karluk Lake system on Kodiak Island (Finney et al. 2000:796) indicate that a positive feedback loop exists where higher adult salmon abundance leads to increased nutrient loading, thus increasing primary and secondary lake productivity. The result is an increased carrying capacity for juvenile salmon and ultimately higher numbers of adult salmon returning in later years. Disruptions in the feedback loop coincide with lower salmon numbers.

Kodiak Island lakes seem to have a built in dependence on nutrients from decaying salmon where Bristol Bay lakes (Ugashik, Becharof and Tazimina) continue to produce large numbers despite high commercial harvest. Bristol Bay lakes appear to be less affected by the boost of nutrients from decomposing salmon perhaps because the boost is small compared to nutrients coming from other sources (Finney et al. 2000:797). Are Bristol Bay lakes, therefore, less susceptible to the steep declines in salmon numbers when the feedback mechanism evident in Kodiak Island lakes is disrupted? Aside from salmon derived nitrogen, what are the other major sources of nutrients to the system? These questions are addressed in other project proposals prepared in conjunction with this Katmai report.

Some insight into whether climatic or oceanic changes are causing variation in salmon populations may be possible. Francis and Hare have clearly shown that, historically, salmon populations fluctuate in accordance with the Pacific Interdecadal Oscillation (PDO). This relationship provides a historical context for understanding how the marine and freshwater ecosystems are likely to change naturally in the future under various climatic conditions and may provide some additional tools for managers setting escapement goals.

Reconstructed records of salmon abundance from sediment in sockeye nursery lakes on Kodiak span a period of about 2,200 years and tell a different story. Large scale variability in salmon abundance occurred over the past two millennia in these lakes (Finney et al. 2002:729). Salmon variability for that time period far exceeds the decadal scale variability recorded over the past 300 years in these lakes attributed to PDO (Finney et al. 2000 and 2002). These long-term records indicate a multi-centennial regime corresponding to major changes in ocean-atmosphere circulation patterns in the northeast Pacific (Finney et al. 2002:732). Unique high and low frequency relationships observed in the two studies highlight the importance of long-term records in examining patterns of fish stock dynamics (Finney et al. 2002:732).

Major landscape altering events such as volcanism, tectonic activity, fires, glaciation or other regional phenomena may also contribute to variability in salmon numbers and ultimately nutrient loading in Katmai lakes. Regional analysis of salmon returns is justified by this variability as well as by drastically differing salmon returns in adjacent drainages that call into question the viability of salmon nursery lakes.

Eicher and Rounsefell (1957) suggest that the fertility of lakes in Katmai receiving ash from the 1912 eruption would have significantly increased in the years following the eruption, but no studies have confirmed their theory. Both Brooks and the Iliuk Arm of Naknek Lake received a maximum thickness of 20 inches of ash (Martin 1913 in Goldman 1960:224).

Reconstructions of salmon abundance can be determined by analyzing concentrations of biological markers: diatoms, cladocerans and stable nitrogen isotope ratios ($\partial^{15}N$) in lake sediments. Diatom species composition are an indicator of past nutrient dynamics, tending more toward eutrophic taxa when salmon numbers and $\partial^{15}N$ levels are higher, while cladocera provide information on secondary production. Fluctuations in salmon returns are approximated by the variability in stable nitrogen isotope ratios in the sediment. Using the markers, the “normal” variation in salmon populations over time can be ascertained.

Suitability of Katmai Lakes for Paleoecological Analysis

Lake coring has occurred in several locations in Alaska with varying objectives. Gregory-Eaves et al. (1999) looked at surface sediment diatom assemblages from 51 Alaska lakes along a north-south transect and corresponding surface water chemistry (Gregory Eaves et al. 2000). Abbott et al. (2000) examined vegetation change, among other factors, at Birch Lake; and Anderson et al. (2001) looked at sediment records of Meli and Tangled Up Lakes in the interior of the state. Closer to Katmai were studies by Finney (2000 and 2002) to reconstruct salmon population levels in Kenai Peninsula, Prince William Sound, Alaska Peninsula and Kodiak Island lakes over the last several thousand years. Recently, Woody and Finney (1999) began a study of historical salmon production in Lake Clark beginning in 2000. Sediment analysis has not been completed on the three sites sampled.

Paleohydrology of lakes in Interior and along the Arctic Coastal Plain were conducted by Edwards et al. (2000) and Barber and Finney (2000). Methods for reconstructing lake levels were evaluated and correlated with vegetation change in the drainages studied.

Given the number of studies done and the fact that several lakes near Katmai (Sixmile, Lake Clark, Tazimina, Becharof, Ugashik and Karluk) have had sediment core analysis completed, would additional studies in Katmai be redundant? Considering the degree of variability observed in the lakes sampled, we conclude it would not be. A study of Katmai waters would contribute to a growing state-wide database and help sort out some lingering questions on lake responses to various factors. Several types of proxy data are necessary from many lakes in the region to understand the range of vulnerability of lakes to factors such as climate change. Lakes in this region may have different sensitivities to similar climatic changes due to biological, physical, chemical and hydrological characteristics.

Geological settings may be a significant factor in determining effects of climate change and land altering events, as well as the productivity of sockeye nursery lakes. Over a 10 year period of warming, lakes surrounded by extensive surficial deposits exhibited stronger increases in conductivity than non-glaciated catchments (Gregory-Eaves et al. 2000:213). From these findings Gregory-Eaves et al. (2000:213) recommend long-term monitoring and paleolimnological studies of lakes in different geological settings to help determine if recently glaciated basins are affected more by climatic warming than others. Katmai provides some unique geological settings, across ecoregions, which provide a good cross section of lakes for additional study. Battle Lake, for example, has been recognized for its deep, clear, naturally acidic waters and its vulnerability to anthropogenic factors like acid rain.

Furthermore, levels of salmon returning to Kvichak and Naknek drainages in recent years have differed markedly. While the Naknek had an abundant return in recent years, Kvichak fish destined for northern streams in Lake Clark suffered severe declines (returns to the Alagnak Wild River, tributary to the Kvichak, were similar to the Naknek). What makes adjacent watersheds so different in their ability to support salmon populations?

Biologists have also observed that smolts leaving the Kvichak, in recent years, are 20% smaller than those leaving Naknek and Egegik streams (Regnart pers. comm. 2001). Furthermore, these smolts are leaving at one year where typically salmon remain in freshwater for two years to attain a larger size and improve their competitive advantage in the ocean environment. At the same time the Naknek and Alagnak drainages are producing high numbers of fish and smolts, those leaving the system do not appear stressed.

Perhaps regional landscape altering processes, such as volcanism, are more prominent in Katmai than in other areas of the region, and local geology may contribute to some of the variability observed. Katmai lakes may provide some new insights into local factors that affect salmon returns, nutrient loadings and productivity that were not evident in other areas.

<u>How does this issue relate to Katmai water resource program goals and priorities?</u>
This project relates to the water resource planning goal to “Increase understanding of unique physical, chemical and biological characteristics of Katmai’s waters and their importance in sustaining fish populations.” It addresses the issues of global climate change and basic inventory and monitoring of Katmai’s aquatic ecosystems and supplements other proposed studies on nutrient cycling. In addition, these data will contribute to a growing statewide

database on salmon populations, climate change and natural variability in post-glacial lake systems.

Project Objectives

Three primary objectives have been identified. Sediment cores will be collected, dated and used to:

1) Reconstruct salmon population levels through time using stable isotopes ($\partial^{15}N$, $\partial^{13}C$).
2) Document long-term changes in ecosystem productivity/nutrient dynamics; and identify contributing factors through biogeochemical analysis (elemental composition, biogenic silica (diatom abundance), organic carbon and nitrogen isotopes and species assemblages (diatom and cladoceran microfossils).
3) Determine the relationship between algal assemblages, salmon escapement and environmental variables such as climate change, nutrient loading and regional landscape altering events.

Historical salmon escapement levels for Naknek and Alagnak drainages will supplement sediment core data.

Lake sediment cores will be collected from several lakes in the park. Lakes will be selected based on a given set of criteria that will represent the variability in salmon nursery lakes, geology and ecology of the region. A control lake will also be chosen from which comparisons may be made. Idavain Lake, inaccessible to salmon due to a high falls, would be a good candidate as would Box Lake, inaccessible to salmon and located solely in the Naknek formation.

A final technical report, published papers in refereed journals, a reference collection and photos will be products of the research. Data will be made available through appropriate web based data storage and handling systems such as STORET and/or paleolimnological databases.

Budget

FY1: $50,000
FY2: $50,000
Total all fiscal years = $100,000

Costs include: core dating, isotope analysis, travel, supplies, phone and so on, salaries, publication costs and overhead.

Funding pathways

Water resource competitive
NRPP
NPS-USGS Water Quality Partnership program funding

NEPA compliance required

An environmental screening form (Director's Order 12, Appendix 1) will be completed to determine the appropriate level of compliance for this proposal.

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Phase 2: Terrestrial Ecosystem Processes and Aquatic Productivity

Project Summary

Natural climate cycles are well documented and known to result in changes in species composition and distribution of vegetation types. On the basis of the fossil record and climate history in Alaska, we expect that future periods of cooler, drier climate will result in shrinkage of forest boundaries, lowering of altitudinal tree line and expansion of tundra vegetation in lower elevations (U.S. Geological Survey 1997:3). The record also shows that the magnitude of future global scale climate changes and ecological responses will be more dramatic at higher latitudes. This project will look at post-glacial vegetation succession in relation to climate trends and correlate it with productivity of watersheds in Katmai.

Studies on the effects of climate change on the structure and function of freshwater ecosystems are few (Bruns et al. 1992:288,) with the bulk of the research to date focusing on the terrestrial environment. Because of the linkage between terrestrial and aquatic environments, these studies are useful in determining the type and magnitude of the effects that might be expected to aquatic ecosystems and reinforce the need to monitor both habitats. High latitude areas are known to be very susceptible to large scale shifts in vegetation. Emmanuel et al. (1985 in Firth and Fisher 1992:288) looked at major shifts in vegetative zones worldwide, and for high latitudes significant loss of tundra was evident. Changes in vegetative type can affect the quantity and quality of terrestrial inputs to the aquatic environment, perhaps changing sedimentation levels or nutrient inputs.

Modern day stories attest to the rapid changes in vegetation in the past century. Early southward expansion of trees and shrubs onto the Alaska Peninsula was probably slow due to strong southerly winds during the pollen producing season (Detterman 1986:154). However, this expansion became fairly rapid during the twentieth century – 60 km southward migration of the forest edge in 75 years – an average rate of 0.8 km/yr (Detterman 1986:154). In the first decade of the twentieth century Martin and Katz (1912 in Detterman 1986:154) showed the southern edge of the spruce forest as being just south of Lake Iliamna. Present day observations place it in the area of Naknek Lake. Other observations point toward the southern expansion of spruce particularly along the Katmai Coast (Spencer pers. comm. 2003).

Little information exists about the history of aquatic productivity in relation to terrestrial vegetation changes. In addition, relatively few fossil pollen records are available outside the central boreal forest region and the northern forest-tundra ecotone (Anderson and Brubaker 1994;) and no continuous record of postglacial vegetation change is yet available from the vast area of transition from boreal forest to tundra in Southwestern Alaska (Hu et al. 1995). It is the post glacial vegetation changes and its effects on aquatic ecosystem productivity that we propose to address.

Introduction

Natural processes structure the diversity, productivity and availability of natural resources on which humans depend and for which parks are protected. The challenge is to understand natural system variably and function and to predict environmental consequences of human activities on these systems. Natural systems are constantly changing in a complex mosaic of time periods and spatial dimensions. Riparian zones, for example, are structured by a complex array of dynamic and spatially variable hydrological processes that erode and deposit materials, deliver nutrients and remove waste products.

Characterizing the persistence and invasiveness of species and their ecological processes is important to watershed management. These components are sensitive to change, integrate change over broad spatial and temporal scales and can be used as measures of change (Naiman and Bilby 1998:644). Persistence of ecological attributes over the long term requires maintenance of a naturally variable environmental regime. If the natural environmental regime is altered, species abundance and biogeochemical processes, for example, produce a new biophysical environment, one in which non-native ecological processes and structures may develop (Naiman and Bilby 1998:644).

Natural climate-forcing mechanisms must be considered in explaining variability before human influences can be blamed for changes in the earth's climate that we see today. In the Arctic scientists have found that enhanced and prolonged arctic cooling can be attributed to volcanic eruptions. The finding for volcanic forcing of arctic temperatures agrees with the 200-year record of volcano-climate linkages for sub-arctic North America, as well as assertions that volcanic activity plays a role in modulating climate of the Northern Hemisphere (Overpeck et al. 1997:1253). Scientists believe that the low period of volcanic activity between 1935 and 1960 may have contributed to peak arctic summer temperatures at that time (Overpeck et al. 1997:1253). Also, decadal scale fluctuations in the state of the Pacific Oscillation or to the transport of heat northward by thermohaline circulation can also modulate climate for decades to centuries (Overpeck et al. 1997:1253).

Fossil records indicate that the magnitude of ecological change in response to global climate change is greater in high latitude regions such as Alaska (U.S. Geological Survey 1997:1). During the Miocene major global warming occurred from 17 million to 14.5 million years ago. This event profoundly changed vegetation from a conifer dominated forest with few temperate hardwoods to a temperate forest with species that are now found far to the south in Asia and North America. For temperate vegetation to grow at such high latitudes, the mean annual temperature of Interior Alaska had to have been about 15^{o}F-30^{o}F warmer than today (U.S. Geological Survey 1997:1). Global cooling began about 14.5 million years ago, and its effects on vegetation in Alaska were again swift and dramatic with temperate trees disappearing at a rapid rate, leaving behind a much simpler forest (U.S. Geological Survey 1997:2). Global climate continued to change with relatively long periods of cold, dry glacial climates followed by shorter intervals of warmer, moister interglacial climates (U.S. Geological Survey 1997:2). Changes in vegetation resulted from each of these climate shifts.

Many of the changes to lakes and streams are the result of strong effects of climatic warming on terrestrial catchments. Therefore, understanding changes in vegetation composition and introduction of new species is important to our understanding of freshwater productivity through time. The fossil record provides a valuable way to assess how past climate changes influence vegetation. In a study of surface sediments of 51 lakes across Alaska, the strongest variables explaining shifts in diatom assemblages were lake water conductivity, total phosphorus concentration and lake depth (Gregory-Eaves et al. 1999, 2000). All these variables are related to shifts in vegetation and/or climate.

Terrestrial ecosystem processes and aquatic productivity

A mid-Holocene spread of Alnus sp. has been documented in several pollen records in Alaska and Western Canada (Anderson and Brubaker 1994 and Cwynar and Spear 1995 in Hu et al. 2001:364-365). This widespread range expansion of Alnus suggests a response to a climatic change throughout much of Alaska (Hu et al. 1995:388). In Southwestern Alaska pollen records show marked increases in abundance of the species between 7000-8000 BP (Anderson and Brubaker 1994, Hu et al. 1995:382, Hu et al. 2001:358).

Studies have shown that the presence of Alnus significantly increases rates of primary productivity, carbon accumulation and nitrogen cycling (Binkley et al. 1995 and Vogel and Gower 1998 in Hu et al. 2001:358). Soil nitrogen also shows dramatic increases with the expansion of Alnus. However, little information exists about the history of aquatic productivity in relation to such terrestrial vegetation changes.

Isotopic analysis of riparian vegetation in Alaska watersheds indicates that trees and shrubs near spawning streams derive 24%-26% of their foliar nitrogen from salmon (Helfield and Naiman 2002:573); and terrestrial plants in riparian zones sampled derived as much as 18%-24% of their foliar nitrogen from salmon (Bilby et al. 1996, Ben-David et al. 1998, Hilderbrand et al. 1999 and Helfield and Naiman 2001). This input may be less important in areas where Alnus is prevalent as a nitrogen fixer, but salmon may contribute other important nutrients that affect productivity of riparian vegetation (Helfield and Naiman 2002:573).

Hu et al. (2001:363) looked at the effect of the expansion of Alnus into Southwestern Alaska at Grandfather Lake in the western Nushagak lowlands and found evidence of increased aquatic productivity at 8000 BP. N_2 fixation by Alnus increased nitrogen in the watershed and stimulated diatom productivity until about 5000 BP when nitrogen cycling reached a level similar to that seen today (Hu et al. 2001:365). Following establishment of the species, the relative abundance of aquatic vs. terrestrial organic matter in lake sediments changed, showing an increase in aquatic inputs consistent with increased primary productivity. The widespread vegetation change exerted a profound influence on ecosystem productivity and nutrient cycling in the region (Hu et al. 2001:367).

Birch Lake (Interior Alaska) diatom analysis seems to support Hu’s findings. Coincident with Alnus expansion, oligotrophic assemblages changed to mesotrophic assemblages, consistent with a finding of nitrogen fertilization from Alnus on the aquatic ecosystem (Gregory-Eaves 1998).

Climatic change was ultimately the reason for the changes evident in the Birch and Grandfather Lake environments at 8000 BP (Hu et al. 2001:366). Later, about 4,000 years BP, the dominant tree species in the northern Bristol Bay region, *Picea glauca*, was replaced by *Picea mariana* (Hu 1996), suggesting yet another climatic change, if only regionally. The chronology of vegetation changes needs to be improved by additional radiocarbon ages, and additional palynological studies need to be carried out at other sites to determine the regional extent of these changes. Other more direct indicators, such as oxygen isotopes and midge remains, should be examined as well to understand the nature of vegetation changes (Hu et al. 1995:390).

Marine and freshwater lakes commonly accumulate deposits derived from bedrock, soils and organic remains within the drainage basin through fine particles blown by winds from distant sources. These aquatic deposits preserve a record of past or on-going environmental processes and components both natural and human induced. Fossil pollen, spores and seeds reflect past terrestrial and aquatic vegetation while diatom assemblages and other characteristics provide a record of changes in productivity. Sediment deposits can, thus, provide an indication of the degree and nature of impact of past events on the system and a baseline for comparison with contemporary environmental change.

Paleoecological analysis can be a powerful tool for understanding patterns of long-term ecological changes. Past climatic and vegetation changes may be inferred from geochemical analysis of sediments. It can provide insight into how lakes and watersheds evolve and respond to environmental change. The objectives of this proposal are to look at post-glacial vegetation succession in relation to climate trends and correlate it with productivity of watersheds in Katmai.

What we know about the issue in general as it has been addressed elsewhere in Alaska

Lake coring has occurred in a few locations in Alaska. Gregory-Eaves et al. (1999) looked at surface sediment diatom assemblages from 51 Alaska lakes along a north-south transect and corresponding surface water chemistry (Gregory Eaves et al. 2000). Abbott et al. (2000) looked at vegetation change among other factors at Birch Lake, and Anderson et al. (2001) looked at sediment records of Meli and Tangled Up Lakes in the interior of the state. A study by Finney at the University of Alaska Fairbanks is looking at reconstructing salmon population levels in Kenai Peninsula, Prince William Sound and Kodiak Island lakes over the last several thousand years.

Woody and Finney (1999) began a study of historical salmon production in Lake Clark in 2000. Sediment analysis has not been completed on the three sites sampled.

Paleohydrology of lakes in the Interior and along the Arctic Coastal Plain was conducted by Edwards et al. (2000) and Barber and Finney (2000). Their methods for reconstructing lake levels were evaluated and correlated with vegetation change in the drainages studied.

Hu analyzed a sediment core from Grandfather Lake in Southwestern Alaska for a suite of geochemical indicators, including elemental composition, biogenic silica content, and carbon and nitrogen isotopes of organic matter. These data, in conjunction with a pollen record from the same site, were used to infer biogeochemical processes associated with the mid-Holocene Alnus expansion.

Suitability of Katmai Lakes for Paleoecological Analysis

Katmai provides not only a very suitable area for this type of analysis, but will make a fundamental contribution to the literature on vegetation change and its effects on aquatic productivity for the state.

A mid-Holocene spread of Alnus has been documented in numerous pollen records in Alaska and Western Canada (Anderson and Brubaker 1994 and Cwynar and Spear 1995 in Hu et al. 2001:364-365). However, little information exists about the history of aquatic productivity in relation to terrestrial vegetation changes. In addition, relatively few fossil pollen records are available outside the central boreal forest region and the northern forest-tundra ecotone (Anderson and Brubaker 1994); and no continuous record of postglacial vegetation change is yet available from the vast area of transition from boreal forest to tundra in Southwestern Alaska (Hu et al. 1995).

Several types of proxy data are necessary from many lakes in the region to understand the range of vulnerability of lakes to climatic changes. Lakes in the same region may have different sensitivities to similar climatic changes due to biological, physical, chemical and hydrological characteristics (Smol and Cummings 2000:987). This proposal, in conjunction with another proposal to look at salmon abundance and lake trophic status through time, will provide a clearer understanding of the processes that may be affected by climatic change in this region.

How does this issue respond to Katmai water resource program goals?

This project works toward accomplishment of the goal to “Increase understanding of unique physical, chemical and biological characteristics of Katmai’s waters and their importance in sustaining fish populations.” It addresses the issues of global climate change and basic inventory, monitoring of Katmai’s aquatic ecosystems and supplements other proposed studies on nutrient cycling.

Objectives

The chronology and nature of vegetation change will be documented through the collection, analysis and dating of sediment cores used to:

1) Identify the timing and effects of Alnus expansion into Katmai watersheds.
2) Map changes in major taxa.
3) Correlate major vegetation changes with climatic trends and productivity of waters.

Site Selection

Sediment cores will be collected from several places in the study area, giving consideration to lakes that would provide a broad representation of the ecoregions that exist in Katmai. In addition, correlation with other complementary proposals must be considered in the selection of appropriate sample sites.

<u>Budget</u>
FY1 = $50,000
FY2 = $50,000
Total all FYs = $100,000

Costs include: core dating, isotope analysis, travel, supplies, phone and so on, salaries, publication costs and overhead.

<u>Funding pathways</u>
Water Resource competitive funding
NRPP
NPS-UGSG Water Quality Partnership program funding

<u>NEPA compliance required</u>
An environmental screening form (Director's Order 12, Appendix 1) will be completed to determine the appropriate level of compliance for this proposal.

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Phase 3: Landscape Reconstructions

Project Summary

Natural climate cycles are well documented and known to result in changes in lake levels. Contemporary climate models predict reduced summer precipitation for parts of the Alaska Peninsula and higher temperatures resulting in increased rates of evaporation, evapotranspiration and less water on the landscape. The record also shows that the magnitude of future global scale climate changes and ecological responses will be more dramatic at higher latitudes. This project will use sediment analysis and contemporary hydrologic models in relation to climate trends to reconstruct paleolake-levels in Katmai.

Proposal

Evidence of climatic warming since the Little Ice Age has been found through the sediment record, particularly in the Arctic, and indicates that recent rates of environmental change are unprecedented in the context of the Holocene (Wolfe and Perron 2001:747). Current global climate models predict that warming in the twenty-first century will cause temperatures to greatly exceed those of the mid-Holocene when temperatures were only 1^{o}-2^{o}C warmer than the mid-twentieth century (Schindler 2001:19). The environmental concerns associated with climate change have produced varied explanations from natural causes to human-induced impacts (i.e., burning fossil fuels, deforestation, and so on). Most of the scientific community believes the climate change we are currently experiencing is primarily human-induced.

Alaska has also grown substantially wetter over the twentieth century. Historical records since 1900 show mixed precipitation trends with increases of up to 30% in the south, southeast and interior regions. The trend toward higher precipitation has been stronger recently, a 30% average increase between 1968 and 1990 for most of the state (Groisman and Easterling 1994). Continued precipitation increases are projected for most of the state, but climate models predict reduced summer precipitation for parts of the Alaska Peninsula. In addition, northern hemisphere spring and summer snow cover, monitored by satellite imagery since 1973, has decreased by 10 % since 1987 (Trenberth 1997).

Models also predict increased rates of evaporation due to warmer summer temperatures resulting in drier soils for most of the state exacerbated by lower precipitation in the south, including the Alaska Peninsula (National Assessment Synthesis Team 2001:289). Unless the warming trend is accompanied by an increase in precipitation, we can expect to see declines in lake levels, water renewal rates, streamflow, the extent and water level in wetlands, soil moisture and groundwater levels (Schindler 1997:1044). In the Experimental Lakes Area in northwestern Ontario all these effects have been observed. There, first order streams that flowed continuously during the ice free season in the early 1970s were dry for up to 150 days during the summers of the late 1980s (Schindler et al. 1996).

Changes in the seasonal pattern of runoff are likely to cause disturbance to fish habitat and affect recreational uses of streams and wetlands. Lower water levels may also cause transportation issues for boats and aircraft as well. Conversely, higher water levels in coastal areas present a different, unique set of concerns.

Declining water flows can cause drastic changes in water chemistry. Lower water flows mean declines in chemical outputs from lakes, resulting longer residence times. Increased residence times can cause concentrations of biologically conservative constituents to increase. In contrast, biologically active constituents would have longer time periods for biological activity to occur. Phosphorus, dissolved organic carbon and silica in the Experimental Lakes Area of Canada declined in lakes and streams presumably because longer residence times increase their exposure to biological removal processes (Schindler et al. 1996). Sulfate, for example, is removed by reduction as a function of contact time between water and sediment (Baker et al. 1986 in Schindler 2001:21). Few, if any, ions are unaffected by changes in inputs, outputs or soil processes, causing significant changes in lake chemistry (Schindler et al. 1996).

<u>What we know about the issue in general as it has been addressed elsewhere in Alaska</u>
Lake level changes in response to climate change have been well documented in the tropics and in temperate zones, but similar studies are less common in arctic and sub-arctic environments (Barber and Finney 2000:30).

Lake coring has occurred in a few locations in Alaska. Gregory-Eaves et al. (1999) analyzed surface sediment diatom assemblages from 51 Alaska lakes along a north-south transect and corresponding surface water chemistry (Gregory Eaves et al. 2000). Abbott et al. (2000) evaluated vegetation change, among other factors, at Birch Lake and Anderson et al. (2001) looked at sediment records of Meli and Tangled Up Lakes in the interior of the state. A study by Finney at the University of Alaska Fairbanks is attempting to reconstruct salmon population levels in Kenai Peninsula, Prince William Sound and Kodiak Island lakes from the last several thousand years.

Woody and Finney (1999) began a study of historical salmon production in Lake Clark beginning in 2000. Sediment analysis has not been completed on the three sites sampled.

Paleohydrology of lakes in the Interior and along the Arctic Coastal Plain were conducted by Edwards et al. (2000) and Barber and Finney (2000). Methods for reconstructing lake levels were evaluated and correlated with vegetation change in the drainages studied.

<u>Suitability of Katmai Lakes for Paleoecological Analysis</u>
Katmai provides a very suitable area for this type of analysis and will make a fundamental contribution to the literature on the effects of lake level changes on aquatic productivity. There have been no comparable studies in this region of the state.

Several types of proxy data are necessary from many lakes in the region to understand the range of vulnerability of lakes to climatic changes. Lakes in the same region may have different sensitivities to similar climatic changes due to biological, physical, chemical and hydrological characteristics (Smol and Cummings 2000:987). This proposal in conjunction with other proposals to look at salmon abundance, vegetation change and lake trophic status over time will provide a clearer understanding of the processes that may be affected by climatic change in this region.

How does this issue respond to Katmai water resource program goals?

This project works toward accomplishment of the goal to "Increase understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations." It addresses the issues of global climate change and basic inventory, monitoring of Katmai's aquatic ecosystems and supplements other proposed studies on nutrient cycling.

Objectives

Lake level reconstructions based on interpretation of sediment properties and compilation and collection of field data will be used to:

1) develop a multi-proxy record to provide insight into responses of aquatic ecosystems in Katmai to climate change,
2) determine late-Quaternary lake levels, and
3) develop a water balance model.

Budget

FY1 = $50,000
FY2 = $50,000
Total all FYs = $100,000

Costs include: core dating, isotope analysis, travel, supplies, phone and so forth, salaries, publication costs and overhead

Funding pathways

Water Resource competitive funding
NRPP
NPS-USGS Water Quality Partnership program funding

NEPA compliance required

An environmental screening form (Director's Order 12, Appendix 1) will be completed to determine the appropriate level of compliance for this proposal.

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D. The Role of Wetlands in Sustaining Salmon Populations in Katmai.

Katmai National Park and Preserve contains extensive freshwater and saltwater wetlands. ANILCA, Section 202 stated that one of the park's foremost purposes is, "To protect habitats for, and populations of, fish and wildlife … to maintain *unimpaired the water habitat* for significant salmon populations; and to protect scenic, geological, cultural and recreational features." Wetlands provide crucial habitat for salmon that contribute to the world's largest commercial sockeye salmon fishery. The integrity of salmon stocks depends on retaining the natural character of wetland and other aquatic habitats.

Despite their importance, there has been no work done in Katmai to characterize wetland ecosystems or to understand the function or contribution of wetlands to aquatic and terrestrial systems and their biota. With concerns for the effects of climate change on wetland systems and sometimes disastrous runs of sockeye salmon into Bristol Bay watersheds, the need to understand the functional role of wetlands and threats to them is greater than ever.

This proposal will address the following questions: Are theories about wetland losses due to changing climate regimes already evident in Katmai? And how can we monitor change in wetland structure and function through time to determine how salmon may be affected?

<u>Concern for Sometimes Disastrous Runs of Salmon</u>
The Bristol Bay sockeye salmon fishery is one of the largest in the world. The Naknek and Alagnak drainages in Katmai support a significant portion of the population. Between 1972 and 1991, the annual run of sockeye salmon bound for the Naknek, Alagnak and Kvichak drainages averaged 15.3 million fish, 53% of the total Bristol Bay run (National Park Service 1999).

In 2000, 98% of all salmon species harvested in the Naknek/Kvichak District were sockeye, totaling about 4.7 million fish (Alaska Department of Fish and Game 2001). The other 2% were incidentally harvested salmon, including chinook, chum, pink and coho. This amount totaled about 90,000 fish. Alaska Department of Fish and Game (2001) reported that the return of sockeye salmon to this district was 45% less than the preseason forecast. The Kvichak drainage, which includes Lake Iliamna, the largest sockeye producing lake in the world, had a return 68% below the forecast. Alaska Department of Fish and Game (2000) has identified the Kvichak River sockeye as a stock of concern based on the definition of "yield concern" in their Sustainable Salmon Fisheries Policy. Alaska Department of Fish and Game staff (Sands pers. comm., 2001) does not know why the sockeye salmon populations from the Kvichak River have apparently declined. In contrast, the Naknek was 9% below the forecasted run during 2000, but the Alagnak River had a run 233% greater than the forecast. However, this run totaled 733,000 fish and only represents about 8% of the run for the entire district.

Then, in 2001, while the Naknek and Alagnak run information was not extraordinarily different from the preseason forecasts, the Kvichak River run was the lowest since 1955 (Alaska Department of Fish and Game 2001).

Questions remain concerning what causes the salmon returns to adjacent drainages to differ so markedly? Could successive years of high escapement produce more fry than the system can sustain in the long term? Are conditions in the ocean responsible? These questions continue to baffle fisheries managers and make run forecasting a very inexact science.

Alaska Department of Fish and Game manages the commercial fishery in the Naknek River for an escapement of 1.0 million (range of 0.8 million to 1.4 million) sockeye salmon. The escapement goal is based on historical spawner-recruit data and limited smolt data. The number represents the best estimate of the number of spawners required to produce the maximum-sustained-yield (Crawford and Cross 1995). In 1991 a record of almost 3.6 million fish escaped the fishery and entered the lake system to spawn (Table 1). The number was 40% higher than the previous recorded high of 2.6 million in 1980.

The University of Washington’s Fishery Research Institute forecasts an estimated return for 2003 at 14.5 million fish for the Kvichak, Naknek and Alagnak (Branch) River with an overall Bristol Bay forecast of 30.7 million fish – a substantial increase from the previous year.

Fish biologists don’t fully understand why Bristol Bay salmon runs fluctuate so. In the summer of 2001 they were alarmed at the paucity of “two ocean” fish, salmon that have spent two years at sea. The lack of these fish was a bad sign for the strength of next summer’s run. Theories abound for the missing reds. Scientists ponder survival rates of small fish entering the ocean from fresh water or subtle changes in the oceans food chain. Some fishermen suspect high seas poachers in Russian waters (Anchorage Daily News, Tuesday, November 13, 2001, by Wesley Loy, Section A, Page 1 and 6). But while most consider variability in salmon production to be mostly influenced by ocean-climate changes, freshwater conditions have been shown to be important determinants of growth and production of juvenile sockeye salmon.

Most of the headwaters of important salmon producing streams are protected within the boundaries of Katmai, making it an ideal place to look at the factors critical to sockeye production. The role wetlands play in salmon productivity has not been explored. Studies by the Alaska Department of Fish and Game propose to look at nutrient-food web dynamics of Lake Iliamna. This study will complement their efforts and contribute to the larger question of productivity in sockeye nursery lakes.

Table 1. Commercial catch and escapement of sockeye in the Naknek-Kvichak District, in thousands of fish, Bristol Bay, 1981-2001. Source: ADF&G 2002.

Year	Naknek-Kvichak Catch	Escapement		Naknek-Kvichak Total Run
		Alagnak	Naknek	
1981	10,993	82	1,796	14,626
1982	5,006	239	1,156	7,535
1983	21,559	96	888	26,114
1984	14,547	215	1,242	26,495
1985	8,179	118	1,850	17,357
1986	2,892	230	1,978	6,278
1987	4,986	154	1,062	12,268
1988	3,481	195	1,038	8,779
1989	13,810	197	1,162	23,487
1990	17,272	169	2,093	26,503
1991	10,475	278	3,579	18,554
1992	9,396	225	1,607	15,953
1993	8,908	348	1,536	14,817
1994	16,328	243	991	25,899
1995	20,280	216	1,111	31,646
1996	8,212	307	1,078	11,024
1997	589	218	1,026	3,336
1998	2,595	252	1,202	6,346
1999	9,453	482	1,625	17,757
2000	4,727	451	1,375	8,382
20 year average	9,684	236	1,470	16,159
2001	5,281	267	1,830	8,531

<u>Potential Effects of Climate Change Predicted to be Greatest in Northern Regions</u>

One of the more significant natural resource issues in Alaska is climate change. The National Assessment Synthesis Team (2001:287), part of the U.S. Global Change Research Program, suggests that aside from direct fishing pressure on marine ecosystems, the greatest present environmental stresses in Alaska are climate related. 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 changed dramatically in the past and the global mean temperature has risen approximately 1° Fahrenheit on average the past 100 years (Trenberth 1997, Rouse et al. 1997). Alaska has warmed 2°C since the 1950s on average, with the largest change about 4°C in the Interior in winter (Chapman and Walsh 1993 and Weller et al. 1998). Most of this warming occurred very recently – about 1977 – coincident with the most recent of the large scale arctic atmosphere and ocean regime shifts (Weller and Anderson 1998). Current global climate models predict that warming in the twenty-first century will cause temperatures to greatly exceed those of the mid-Holocene when temperatures were only 1°C-2°C warmer than the mid-twentieth century (Schindler 2001:19).

Alaska also grew substantially wetter over the twentieth century. Historical records since 1900 show mixed precipitation trends with increases of up to 30% in the south, southeast and interior regions. The trend toward higher precipitation has been stronger recently, a 30% average increase between 1968 and 1990 for most of the state (Groisman and Easterling 1994). Continued precipitation increases are projected for most of the state, but climate models predict reduced summer precipitation for parts of the Alaska Peninsula. Models also predict increased rates of evaporation due to warmer summer temperatures resulting in drier soils for most of the state, exacerbated by lower precipitation in the south, including the Alaska Peninsula (National Assessment Synthesis Team 2001:289).

Northern hemisphere spring and summer snow cover, monitored by satellite imagery since 1973, has decreased by 10% since 1987 (Trenberth 1997). The environmental concerns associated with climate change have 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. Regardless of the cause, reduced snow cover means less surface runoff and reduced flow.

Greater increases in temperatures are expected in northern latitudes as a result of global warming than in other areas (Root 1989). These areas are expected to be particularly sensitive to changes in available energy, causing changes in precipitation/evaporation ratios and runoff, duration of ice cover, thickness of snow cover and fires resulting in less water being on the landscape (Schindler et al. 1990, Schindler 1997). Lake physical and chemical processes may be disrupted with subsequent effects on productivity and decomposition rates. In short, fundamental changes in hydrological processes will likely result.

Glacier retreat, rising timberlines, the desiccation of small ponds and the black spruce invasion of wetland perimeters are all visible signs of the current warming trend (Berg 1997). Likewise, permafrost melting is expected to increase throughout most of the discontinuous zone (National Assessment Synthesis Team 2001:291), affecting hydrology, erosion, vegetation and human activities. Complete thawing of even discontinuous permafrost is projected to be a slow process over centuries (Osterkamp and Romanovsky 1999 in National Assessment Synthesis Team 2001:291).

Forest and tundra ecosystems of the Alaska Peninsula could suffer moisture stress and loss of productivity from increasing temperatures and evaporation and decreasing precipitation. This phenomenon has been observed on the Kenai Peninsula where moisture stress has resulted in forest disturbances, such as a spruce bark beetle outbreak with accelerated beetle development times and increased tree vulnerability and fires (Juday et al. 1998). Over the long-term, climate change is likely to bring large landscape level vegetation changes to the region. Chapin and Starfield (1997) predict that in one or two centuries the coastal forest will migrate westward on the Alaska Peninsula, expansion of forests to higher elevations and colonization of formerly glaciated lands.

But wetlands may be most at risk. During the dry mid-Holocene there were few wetlands in the southern prairie regions of Canada (Schindler 2001:20). Most contemporary wetlands were formed 3000-4000 years ago (Zoltai and Vitt 1990 in Schindler 2001:20). The scenarios predicted for the Alaska Peninsula could result in significantly lower water levels or complete disappearance of shallow wetlands. 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). As might be expected, waterfowl and fish production could be greatly affected by these conditions.

Desiccation of wetlands can lead to changes in species composition that alter water chemistry. For example, the spread of Sphagnum sp. is thought to accompany a change in hydrology of a wetland, resulting in a more acid system that is intolerable to many aquatic biota, including fish.

Wetlands are known to be a significant global carbon sink and are thus important in terms of the global carbon budget (Schindler 2001:1054). If models predicting warmer temperatures and lower rates of precipitation for the Alaska Peninsula prove to be true, climate warming may decrease carbon stores through warming and drying of cold, waterlogged soils and subsequent production of carbon dioxide via soil microbial respiration (Oswood et al. 1992:199).

Coastal wetlands may be at risk from different factors than interior freshwater wetlands. Increasing sea level coupled with storm surge may alter the hydrology and salinity of these important areas. In fact, sea level rise scenarios for the year 2100 predict an increase of 22.1 inches (56.2 cm) on the conservative side and as much as 135.8 inches (345 cm) on the high side (Hoffman et al. 1983). Periods of uplift followed by subsidence have been documented for coastal areas of Katmai at Kinak and Kukak Bays (Crowell and Mann 1996:26). Archaeological site and terrestrial peat analysis suggest that relative sea level was at least 1.25 meters lower than present 10,000 years ago, followed by higher than present levels that peaked about 7000 BP. Sea level then declined to somewhat lower than present, then remained stable until rising slightly in the last 200-300 years (Crowell and Mann 1996:26). Peat up to 4,000 years old is now about 0.5 meter below sea level due to the recent rise.

Similar sampling techniques and refined analysis could provide some useful information on eventual wetland changes. Core sample analysis can show change in vegetative communities, water chemistry and biota, allowing for construction of predictive models for anticipated future conditions given climate scenarios.

<u>Proposed Action</u>

Because of the potential effects of climate change on fish production and the questions regarding fish production in general in Bristol Bay drainages, we propose to test a theory of wetland decline in Katmai. Knowledge of wetland types, boundaries, distribution, function and volume is essential not only to protect critical habitats, but to aid in management of park lands. Using available imagery (circa 1950s black and white photography, 1980s color infrared photography, 2000 satellite imagery, etc.) and other appropriate methods, wetlands will be mapped and characterized in selected drainages. Ground verification of photo interpretation will be required. Products resulting from this effort include: a wetlands map of the highest resolution photo interpretation will allow in an ArcView compatible format, and a written description of wetland types following the Cowardin classification system.

Descriptions should include size, distribution, function, vegetation types and so on to the extent that photography allow.

In addition we propose to initiate an intensive, ground based study of selected wetlands to monitor actual changes with time of predictive physical, chemical and biological variables of wetland systems. Drainages will be chosen that contain significant populations of salmon, such as the Naknek or Alagnak drainage, and that contain the range of variability in wetland types observed in Katmai. Wetlands will be stratified by physiographic region. In selecting representative wetlands for study, consideration should be given to wetlands that occupy different positions on the landscape and that consequently provide different functions. Another factor critical to the choice will be observed productivity – ombrotrophic (nutrient poor wetlands fed primarily by precipitation) to eutrophic tidal wetlands flushed with new nutrients on each tide.

Gradient oriented transects will be established. Fieldwork will include the analysis of features of wetland systems that respond to long-term changes in lake level or river channel that alter the flux and source of water; vegetation structure and composition such as species diversity and richness and vertical zonation, rates of sedimentation, soil properties including saturation, organic matter content, depth of horizons and so on; fundamental water chemical and physical parameters such as pH, alkalinity, conductivity, major ions, temperature, seasonal and temporal variation in hydrology and cycling of nutrients. Vegetation classification will follow the multilevel Alaska Vegetation Classification System (AVCS) (Viereck et al. 1992) and vegetation will be type mapped and classified down to level IV/V (a species descriptive level) at the ground.

<u>Is Katmai Uniquely Suited for This Work?</u>
Katmai's environment is thought to be very susceptible to climate change. For example, Pinney and Begét (1991b) 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. Climate also has a great influence on peatlands, which are found in Katmai's lowlands and lake country (Belland and Vitt 1995).

Because global warming is predicted to be greatest in high latitudes, the northern location and pristine condition of Alaska's parks make them excellent 'science preserves' or 'natural laboratories' for investigating relationships between the physical, biologic and cultural resources of the Arctic and sub-Arctic. Investigating past changes in climate, landscape processes, vegetation, animals, and human practices can help us understand how the *system* works and how it might respond to future environmental changes of both natural and human origin.

A study of wetland ecosystems in Glacier Bay is underway. Components of this project include interpretation of aerial photography for wetland extent, creating five digital photo mosaics of the Dry Bay area. Work in Katmai would not duplicate this project and, in fact, may provide data for other Alaska parks on eventual wetland changes. Sampling protocols will be transportable to other areas.

How does this issue respond to Katmai Water Resource Program goals?
This project works toward accomplishment of the goal to "Increase understanding of unique physical, chemical and biological characteristics of Katmai's waters and their importance in sustaining fish populations." It addresses the issues of global climate change and basic inventory, monitoring of Katmai's aquatic ecosystems and supplements other proposed studies on nutrient cycling and ecosystem variability over time.

Budget
Phase 1: Aerial photo interpretation and fieldwork to generate a wetlands map and descriptions.

Phase 2: Select wetlands for more intensive study. Develop sampling protocol, conduct field studies, analyze samples, synthesize data and generate a written report. In addition, the following tasks must be completed: 1) develop a monitoring plan and recommendations for additional studies as part of the final report, 2) develop an educational product for use in local schools and for park visitors suitable for printing and displaying on the Katmai web page *or* involve local schools in the scientific process by including students on the project and/or making presentations at local village schools, and; 3) publish a peer reviewed journal paper to share results with the scientific community.

BUDGET

Task	FY 1	FY2	FY 3	Total
Acquire photography	$5,000			$5,000
Sample analysis		$10,000	$5,000	15,000
Travel	4,000	4,000	4,000	12,000
Supplies	3,000	1,500	1,500	6,000
Phone/Xerox/shipping	500	500	500	1,500
Salaries	20,000	20,000	16,500	56,500
Publication costs			4,000	4,000
Totals	**$32,500**	**$36,000**	**$27,500**	**$100,000**

Funding pathways
Water resource competitive – limited to $100,000 per project
NRPP – if project costs exceed $100,000

Funding Strategy
An experienced team of wetland scientists with expertise in wetland delineation and functional analysis, plant ecology, soil science, and monitoring is needed to conduct this work. Scientists on staff must be able to provide a broad array of expertise and produce publications of known quality.

NEPA compliance required
An environmental screening form (Director's Order 12, Appendix 1) will be completed to determine the appropriate level of compliance for this proposal.

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Katmai Water Resource Scoping Participants List

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Note: Telephone and fax numbers and email addresses are not included for people no longer with NPS in Alaska. The NPS Alaska Regional Office and Alaska Support Office moved in July 2003 from 2525 Gambell St. to 240 W. 5th Avenue, Anchorage, AK 99501, reflected in addresses above of current employees in those offices.

Appendix B: Issues and Priorities Identified at the Scoping Workshop

Results of the Katmai/Alagnak Water Resource Scoping Workshop

The following summarizes the Katmai/Alagnak Water Resource scoping meeting that occurred on March 29, 2001. The summary is not intended to reiterate all comments made at the meeting, but to serve as a summary of major areas of agreement among the participants. Minutes were taken at the meeting, which captured people's individual comments on issues. These comments were very important and will also be used in development of the Water Resource Information and Issues Overview. Copies of the minutes are available for anyone interested.

Meeting Summary

Deb Liggett, Superintendent of Katmai and Lake Clark National Park and Preserve, opened the meeting by providing an introduction to the planning process and thanked everyone for their participation. She expressed her desire to continue the dialog on water resource issues between NPS and meeting participants beyond the meeting.

National Park Service (NPS) Hydrologist, Don Weeks, described the NPS water resource planning process. The discussion centered on the need for a Water Resources Management Plan and how it relates to the General Management Plan and other resource plans for the park.

NPS Alaska Inventory and Monitoring (I&M) Coordinator, Sara Wesser, gave a brief overview of the I&M program. She also provided an overview of the vital signs monitoring program, which involves establishment of water quality monitoring stations throughout Southwest Alaska. The Southwest Alaska network of parks includes Katmai National Park and Preserve, Aniakchak National Monument and Preserve, Alagnak Wild River, Lake Clark National Park and Preserve and Kenai Fjords National Park. Initial funding for water quality monitoring in the southwest network will begin in October 2001 and will be recurring.

Janis Kozlowski (Meldrum), project lead for the Katmai Water Resource Management Plan, discussed the results of the Water Resource Management Issues survey. The survey was distributed before the meeting to 51 people representing local, state and federal government entities, tribal organizations and other interested organizations. The results of the survey were displayed on posters in the meeting room and used to initiate discussions of the issues and for an exercise designed to refine priorities.

Meeting participants were asked to choose their top five priorities from the lists of issues displayed, to add issues they felt were overlooked, argue for deletion of issues that should be removed from consideration or consolidate issues where appropriate. While no one chose to delete any of the issues identified, several new issues were added to the list and consolidation of some issues occurred.

The top ranked issues were as follows:

- Lack of baseline information to determine if water quality is degrading and to understand the relationship between water quality and quantity
- Need for integrated science studies
- Need to better understand the effects of increased visitor use on the aquatic environment
- Need for long-term coordination relationships with other agencies, universities, tribes and the private sector
- Inadequate data to support instream water rights applications for recreation, water quality, aesthetics, navigability and fish and wildlife
- Inadequate understanding of fishery utilization on nutrient cycling and system sustainability
- Need for data on the impacts of global climate change on water resources
- Need to understand factors controlling the fertility/functioning of the system

This list of top priorities will be used to generate 10-15 project statements. Each project statement will address our understanding of the issue we hope to resolve, why it is important, how it should be addressed and how much money and resources will be required. Communication and coordination between NPS and stakeholders will be key to the development of project statements that will be competitive for water resource funding. Likewise, development and implementation of projects, once funded, will require the cooperation of and coordination with stakeholders.

Informal discussions on management of watersheds beyond park boundaries, the importance of acquiring data to support water rights applications, data dispersal and management and the need for a monitoring plan occurred throughout the day. These discussions led to several specific recommendations that will be implemented during the planning process.

One group's recommendation was to develop an inventory of projects that are or have occurred in or around the vicinity of Katmai National Park and Preserve and the Alagnak Wild River. NPS is taking the lead on developing the initial list of projects. Meeting participants agreed to make contributions to the list once a format was developed. Several methods of distribution and inquiry were suggested at the meeting. We will try to employ as many of those ideas as we can in building a comprehensive list of information. An email message will be sent out shortly, providing more details on how contributions can be made to the list and how it will be updated. A web site for the Katmai Water Resource Management Plan is currently under construction. The web site may provide one format for viewing the most current list of projects. However, other means of distributing the list will also be employed to accommodate those who do not have access to the World Wide Web.

We felt the workshop was very successful. We were able to identify and prioritize the top issues affecting Katmai, and the meeting provided a forum where stakeholders could meet and express their ideas and opinions on management of water resources in the park. We were positively influenced by the recommendations and ideas brought to the table. Consequently, the Water Resource Information and Issues Overview for Katmai/Alagnak will be a more thorough, well thought out document as a result of the workshop.

The report is scheduled for completion by November 30, 2002. In September of 2002 a draft copy of the report will be distributed for your review and comment. In the meantime, there will be on-going updates throughout the project development. For those of you who are web oriented these updates will appear on the web site that we are working on. For others, updates will be distributed using more traditional methods of communication.

Please feel free to contact me at (907)644-3447 or janis_kozlowski@nps.gov if you have questions or want additional information on the report.

Thanks, once again, for the time and effort you put into making this workshop a success.

Janis Kozlowski (Meldrum)

Appendix C: Fisheries Resources of Katmai

Locations and Fish Varieties

Category / PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
Bays						
Amalik						
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Dakavak						
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Hallo						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Fechhelm 1999
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC HERRING marine	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC SANDFISH marine	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC STAGHORN euryhali	☑	☐	☐	☐	Fechhelm 1999
	PINK SALMON anadromous	☑	☐	☐	☐	Fechhelm 1999
	STARRY FLOUNDER euryhali	☑	☐	☐	☐	Fechhelm 1999
	SURF SMELT marine	☑	☐	☐	☐	Fechhelm 1999
	TUBENOSE POACHER marine	☑	☐	☐	☐	Fechhelm 1999
	Unidentified sole	☑	☐	☐	☐	Fechhelm 1999
Kaflia						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Kaguyak						
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Kashvik						
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Katmai						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Kinak						
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Kukak						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Fechhelm 1999
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC HERRING marine	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC SANDFISH marine	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC STAGHORN euryhali	☑	☐	☐	☐	Fechhelm 1999
	PINK SALMON anadromous	☑	☐	☐	☐	Fechhelm 1999
	STARRY FLOUNDER euryhali	☑	☐	☐	☐	Fechhelm 1999
	SURF SMELT marine	☑	☐	☐	☐	Fechhelm 1999
	TUBENOSE POACHER marine	☑	☐	☐	☐	Fechhelm 1999
	Unidentified sole	☑	☐	☐	☐	Fechhelm 1999
Kuliak						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Missak						
	PINK SALMON anadromous	☐	☑	☐	☐	Heard 1969
Swikshak Lagoon						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
Swikshak/Shakun Islets						
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Fechhelm 1999
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC HERRING marine	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC SANDFISH marine	☑	☐	☐	☐	Fechhelm 1999
	PACIFIC STAGHORN euryhali	☑	☐	☐	☐	Fechhelm 1999

Category PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	PINK SALMON anadromous	✓				Fechhelm 1999
	STARRY FLOUNDER euryhali	✓				Fechhelm 1999
	SURF SMELT marine	✓				Fechhelm 1999
	TUBENOSE POACHER marine	✓				Fechhelm 1999
	Unidentified sole	✓				Fechhelm 1999
Lakes						
Brooks						
	ALASKA BLACKFISH freshw	✓				Heard 1969
	ARCTIC CHAR freshwater	✓				Heard 1969
	ARCTIC GRAYLING anadrom	✓				Heard 1969
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	CHINOOK/KING SALMON an		✓			Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969
	COHO/SILVER SALMON ana	✓				Heard 1969
	DOLLY VARDEN freshwater	✓				Heard 1969
	LAKE TROUT freshwater	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	NORTHERN PIKE freshwater	✓				Heard 1969
	PINK SALMON anadromous		✓			Heard 1969
	POND SMELT freshwater				✓	Heard 1969
	PYGMY WHITEFISH freshwa	✓				Heard 1969
	RAINBOW TROUT anadromou	✓				Heard 1969
	ROUND WHITEFISH freshwat	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
	SOCKEYE/RED SALMON ana	✓				Heard 1969
	THREESPINE STICKLEBACK	✓				Heard 1969
Coville						
	ALASKA BLACKFISH freshw	✓				Heard 1969
	ARCTIC CHAR freshwater	✓				Heard 1969
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	BURBOT freshwater	✓				Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969

Category						
PlaceName	**FishVariety**	**Collected**	**Reported**	**Observed**	**Expected**	**Citations**
	COHO/SILVER SALMON ana	✓				Heard 1969
	HUMPBACK WHITEFISH fres	✓				Heard 1969
	LAKE TROUT freshwater	✓				Heard 1969
	LEAST CISCO freshwater	✓				Heard 1969
	LONGNOSE SUCKER freshwa	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	NORTHERN PIKE freshwater	✓				Heard 1969
	POND SMELT freshwater	✓				Heard 1969
	PYGMY WHITEFISH freshwa	✓				Heard 1969
	RAINBOW TROUT anadromou	✓				Heard 1969
	ROUND WHITEFISH freshwat	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓		✓		Heard 1969
	SOCKEYE/RED SALMON ana	✓				Heard 1969
	THREESPINE STICKLEBACK	✓				Heard 1969
Cozy Lakes						
	COASTRANGE SCULPIN fres	✓				Heard 1969
	COHO/SILVER SALMON ana	✓				Heard 1969
	LEAST CISCO freshwater	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	ROUND WHITEFISH freshwat	✓				Heard 1969
	SOCKEYE/RED SALMON ana			✓		Heard 1969
Dakavak						
	DOLLY VARDEN freshwater	✓				Heard 1969
	SOCKEYE/RED SALMON fres	✓				Heard 1969
Devils Cove						
	DOLLY VARDEN freshwater	✓		✓		Heard 1969
Grosvenor						
	ALASKA BLACKFISH freshw	✓				Heard 1969
	ARCTIC CHAR freshwater	✓				Heard 1969
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	COHO/SILVER SALMON ana	✓				Heard 1969
	HUMPBACK WHITEFISH fres	✓				Heard 1969

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	LEAST CISCO freshwater	☑	☐	☐	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	POND SMELT freshwater	☑	☐	☐	☐	Heard 1969
	PYGMY WHITEFISH freshwa	☑	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Hammersly						
	LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	PYGMY WHITEFISH freshwa	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
Idavain						
	ARCTIC CHAR freshwater	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
Jo-Jo						
	LEAST CISCO freshwater	☐	☑	☐	☐	Greenbank 1954
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON fres	☐	☑	☐	☐	Greenbank 1954
Kaflia Bay						
	COHO/SILVER SALMON ana	☐	☑	☐	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Kaguyak crater						
	ARCTIC CHAR freshwater	☐	☑	☑	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
Kukaklek						

Category	PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
		BURBOT freshwater	☐	☐	☑	☐	Miller 2002
		NINESPINE STICKLEBACK f	☐	☐	☑	☐	Miller 2002
		ROUND WHITEFISH freshwat	☐	☐	☑	☐	Miller 2002
		SLIMY SCULPIN freshwater	☐	☐	☑	☐	Miller 2002
		THREESPINE STICKLEBACK	☐	☐	☑	☐	Miller 2002
	Kuliak Bay						
		DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	Murray						
		LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	Nonvianuk						
		COASTRANGE SCULPIN fres	☐	☐	☑	☐	Miller 2002
		NINESPINE STICKLEBACK f	☐	☐	☑	☐	Miller 2002
		ROUND WHITEFISH freshwat	☐	☐	☑	☐	Miller 2002
		SLIMY SCULPIN freshwater	☐	☐	☑	☐	Miller 2002
		THREESPINE STICKLEBACK	☐	☐	☑	☐	Miller 2002
	Unnamed lake or pond on Martin Creek						
		DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
		NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
		NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
		SOCKEYE/RED SALMON ana	☐	☑	☐	☐	Heard 1969
		SOCKEYE/RED SALMON ana	☐	☑	☐	☐	Heard 1969
		SOCKEYE/RED SALMON fres	☑	☐	☐	☐	Heard 1969
	Unnamed stream trib of Katmai R						
		SOCKEYE/RED SALMON ana	☐	☑	☐	☐	Griggs 1922
Naknek Lak							
	Bay of Islands						
		ALASKA BLACKFISH freshw	☑	☐	☐	☐	Heard 1969
		BURBOT freshwater	☑	☐	☐	☐	Heard 1969
		COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
		LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
		NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
		NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	PYGMY WHITEFISH freshwa	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Iliuk Arm						
	ARCTIC CHAR freshwater	☑	☐	☐	☐	Heard 1969
	ARCTIC LAMPREY freshwater	☑	☐	☐	☐	Heard 1969
	BURBOT freshwater	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	HUMPBACK WHITEFISH fres	☑	☐	☐	☐	Heard 1969
	LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	POND SMELT freshwater	☑	☐	☐	☐	Heard 1969
	PYGMY WHITEFISH freshwa	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
North Arm						
	ARCTIC CHAR freshwater	☑	☐	☐	☐	Heard 1969
	ARCTIC GRAYLING anadrom	☑	☐	☐	☐	Heard 1969
	ARCTIC LAMPREY freshwater	☑	☐	☐	☐	Heard 1969
	BURBOT freshwater	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	HUMPBACK WHITEFISH fres	☑	☐	☐	☐	Heard 1969
	LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	POND SMELT freshwater	☑	☐	☐	☐	Heard 1969
	PYGMY WHITEFISH freshwa	☑	☐	☐	☐	Heard 1969

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	RAINBOW TROUT anadromou	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
	SOCKEYE/RED SALMON ana	✓				Heard 1969
	THREESPINE STICKLEBACK	✓				Heard 1969
Northwest Arm						
	ALASKA BLACKFISH freshw	✓				Heard 1969
	ARCTIC CHAR freshwater	✓				Heard 1969
	COHO/SILVER SALMON ana	✓				Heard 1969
	LAKE TROUT freshwater	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	NORTHERN PIKE freshwater	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
	SOCKEYE/RED SALMON ana	✓				Heard 1969
	THREESPINE STICKLEBACK	✓				Heard 1969
South Bay						
	ARCTIC CHAR freshwater	✓				Heard 1969
	ARCTIC GRAYLING anadrom	✓				Heard 1969
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	BURBOT freshwater	✓				Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969
	COHO/SILVER SALMON ana	✓				Heard 1969
	HUMPBACK WHITEFISH fres	✓				Heard 1969
	LAKE TROUT freshwater	✓				Heard 1969
	LONGNOSE SUCKER freshwa	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	NORTHERN PIKE freshwater	✓				Heard 1969
	POND SMELT freshwater	✓				Heard 1969
	PYGMY WHITEFISH freshwa	✓				Heard 1969
	RAINBOW TROUT anadromou	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
	SOCKEYE/RED SALMON ana	✓				Heard 1969
	THREESPINE STICKLEBACK	✓				Heard 1969

Category	PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	Unnamed stream	trib east of Swikshak R					
		SOCKEYE/RED SALMON ana	☐	☑	☐	☐	Heard 1969
	West End						
		COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
		HUMPBACK WHITEFISH fres	☑	☐	☐	☐	Heard 1969
		LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
		NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
		PACIFIC COD euryhaline	☐	☐	☐	☑	Greenbank 1954
		RAINBOW or ARCTIC SMEL	☐	☐	☐	☑	Heard 1969
		SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
		SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
		THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
River Syste							
	Alagnak						
		ALASKA BLACKFISH freshw	☐	☐	☑	☐	Miller 2002
		ARCTIC LAMPREY freshwater	☐	☐	☑	☐	Miller 2002
		COASTRANGE SCULPIN fres	☐	☐	☑	☐	Miller 2002
		NINESPINE STICKLEBACK f	☐	☐	☑	☐	Miller 2002
		NORTHERN PIKE freshwater	☐	☐	☑	☐	Miller 2002
		ROUND WHITEFISH freshwat	☐	☐	☑	☐	Miller 2002
		SLIMY SCULPIN freshwater	☐	☐	☑	☐	Miller 2002
	Katmai						
		PINK SALMON anadromous	☐	☐	☐	☐	Heard 1969
		SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Griggs 1922
	King Salmon						
		CHINOOK/KING SALMON an	☐	☐	☐	☐	Heard 1969
		COHO/SILVER SALMON ana	☑	☐	☑	☐	Heard 1969
		LEAST CISCO freshwater	☑	☐	☐	☐	Heard 1969
		SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	Naknek						
		ALASKA BLACKFISH freshw	☑	☐	☐	☐	Heard 1969
		ARCTIC CHAR freshwater	☑	☐	☐	☐	Heard 1969

Category	PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
		ARCTIC GRAYLING anadrom	✓				Heard 1969
		ARCTIC LAMPREY freshwater	✓				Heard 1969
		ARCTIC LAMPREY freshwater	✓				Heard 1969
		BURBOT freshwater	✓	✓	✓		Heard 1969
		CHINOOK/KING SALMON an					Heard 1969
		CHUM SALMON anadromous					Heard 1969
		COASTRANGE SCULPIN fres	✓				Heard 1969
		COHO/SILVER SALMON ana					Heard 1969
		COHO/SILVER SALMON ana	✓				Heard 1969
		HUMPBACK WHITEFISH fres	✓				Heard 1969
		HUMPBACK WHITEFISH fres	✓				Heard 1969
		LAKE TROUT freshwater	✓				Heard 1969
		LEAST CISCO freshwater	✓				Heard 1969
		LEAST CISCO freshwater	✓				Heard 1969
		LONGNOSE SUCKER freshwa	✓				Heard 1969
		NINESPINE STICKLEBACK f	✓				Heard 1969
		NORTHERN PIKE freshwater	✓				Heard 1969
		PACIFIC COD euryhaline				✓	Greenbank 1954
		PINK SALMON anadromous	✓				Heard 1969
		POND SMELT freshwater	✓				Heard 1969
		PYGMY WHITEFISH freshwa	✓				Heard 1969
		PYGMY WHITEFISH freshwa					Heard 1969
		RAINBOW or ARCTIC SMEL				✓	Heard 1969
		RAINBOW TROUT anadromou	✓				Heard 1969
		ROUND WHITEFISH freshwat	✓				Heard 1969
		SLIMY SCULPIN freshwater	✓				Heard 1969
		SOCKEYE/RED SALMON ana	✓				Heard 1969
		SOCKEYE/RED SALMON ana	✓		✓		Heard 1969
		THREESPINE STICKLEBACK	✓				Heard 1969
	Unnamed stream into Devils Cove of Kukak B						
		PINK SALMON anadromous	✓				Heard 1969

Streams

Category PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
Alagoshak Crk						
	PINK SALMON anadromous	☑	☐	☐	☐	Heard 1969
American Crk						
	ARCTIC CHAR freshwater	☑	☐	☐	☐	Heard 1969
	CHINOOK/KING SALMON an	☑	☐	☐	☐	Heard 1969
	CHUM SALMON anadromous	☐	☐	☑	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
Bay of Islands Crk						
	ARCTIC GRAYLING anadrom	☑	☐	☐	☐	Heard 1969
	CHINOOK/KING SALMON an	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
Big Crk						
	CHINOOK/KING SALMON an	☐	☐	☑	☐	Heard 1969
Big R						
	CHUM SALMON anadromous	☐	☑	☐	☐	Heard 1969
	COASTRANGE SCULPIN fres	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☐	☐	☑	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	PINK SALMON anadromous	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Brooks R						
	ARCTIC GRAYLING anadrom	☑	☐	☐	☐	Heard 1969
	ARCTIC LAMPREY anadromo	☑	☐	☐	☐	Heard 1969
	ARCTIC LAMPREY freshwater	☑	☐	☐	☐	Heard 1969
	CHINOOK/KING SALMON an	☑	☐	☐	☐	Heard 1969
	CHUM SALMON anadromous	☐	☐	☑	☐	Heard 1969

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	COASTRANGE SCULPIN fres	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	LEAST CISCO freshwater	☑	☐	☐	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☐	☑	☐	Heard 1969
	POND SMELT freshwater	☑	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Coville R						
	ARCTIC LAMPREY freshwater	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	LAKE TROUT freshwater	☑	☐	☐	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☐	☑	☐	Heard 1969
	POND SMELT freshwater	☑	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Grosvenor R						
	ARCTIC LAMPREY freshwater	☑	☐	☐	☐	Heard 1969
	COASTRANGE SCULPIN fres	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969

Category PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	LONGNOSE SUCKER freshwa	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Hardscrabble Crk						
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
Headwater Crk						
	ARCTIC GRAYLING anadrom	☑	☐	☐	☐	Heard 1969
	CHINOOK/KING SALMON an	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☐	☑	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☑	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Hidden Crk						
	ARCTIC GRAYLING anadrom	☑	☐	☐	☐	Heard 1969
	CHINOOK/KING SALMON an	☑	☐	☐	☐	Heard 1969
	COASTRANGE SCULPIN fres	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☑	☐	☐	☐	Heard 1969

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	PINK SALMON anadromous	☐	☐	☑	☐	Heard 1969
	ROUND WHITEFISH freshwat	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Katmai R						
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	PACIFIC STAGHORN euryhali	☑	☐	☐	☐	Heard 1969
	PINK SALMON anadromous	☑	☐	☐	☐	Heard 1969
	STARRY FLOUNDER euryhali	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
King Salmon Crk						
	CHINOOK/KING SALMON an	☐	☐	☑	☐	Heard 1969
Margot Crk						
	ARCTIC CHAR freshwater	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	☑	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	☑	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	☑	☐	☐	☐	Heard 1969
Naknek R						
	ARCTIC LAMPREY anadromo	☑	☐	☐	☐	Heard 1969
	CHINOOK/KING SALMON an	☐	☑	☐	☐	Heard 1969
	PACIFIC COD euryhaline	☐	☑	☐	☐	Greenbank 1954
	RAINBOW or ARCTIC SMEL	☑	☐	☐	☐	Heard 1969
	SOCKEYE/RED SALMON ana	☑	☐	☐	☐	Heard 1969
	STARRY FLOUNDER euryhali	☑	☐	☐	☐	Heard 1969
One Shot Crk						
	COASTRANGE SCULPIN fres	☑	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	☑	☐	☐	☐	Heard 1969
	DOLLY VARDEN freshwater	☑	☐	☐	☐	Heard 1969
	PINK SALMON anadromous	☐	☐	☑	☐	Heard 1969

Category						
PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
	SLIMY SCULPIN freshwater	✓				Heard 1969
Savonoski R						
	NINESPINE STICKLEBACK f	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
Takayoto Crk						
	CHINOOK/KING SALMON an	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
Ukak R						
	COASTRANGE SCULPIN fres	✓				Heard 1969
	LONGNOSE SUCKER freshwa	✓				Heard 1969
	SLIMY SCULPIN freshwater	✓				Heard 1969
Unnamed stream	Trib Brooks L					
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	ARCTIC LAMPREY freshwater	✓				Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969
	COASTRANGE SCULPIN fres	✓				Heard 1969
	DOLLY VARDEN freshwater	✓				Heard 1969
	DOLLY VARDEN freshwater	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	NINESPINE STICKLEBACK f	✓				Heard 1969
	PINK SALMON anadromous			✓		Heard 1969
	PINK SALMON anadromous	✓				Heard 1969
	PINK SALMON anadromous	✓				Heard 1969
	PINK SALMON anadromous		✓			Heard 1969
	PINK SALMON anadromous	✓				Heard 1969
	THREESPINE STICKLEBACK	✓				Heard 1969
Up-a-tree Crk						
	DOLLY VARDEN freshwater	✓				Heard 1969
	PINK SALMON anadromous			✓		Heard 1969

Category PlaceName	FishVariety	Collected	Reported	Observed	Expected	Citations
West Crk						
	ALASKA BLACKFISH freshw	✔	☐	☐	☐	Heard 1969
	ARCTIC GRAYLING anadrom	✔	☐	☐	☐	Heard 1969
	COASTRANGE SCULPIN fres	✔	☐	☐	☐	Heard 1969
	COHO/SILVER SALMON ana	✔	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	✔	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	✔	☐	☐	☐	Heard 1969
	POND SMELT freshwater	✔	☐	☐	☐	Heard 1969
	RAINBOW TROUT anadromou	✔	☐	☐	☐	Heard 1969
	ROUND WHITEFISH freshwat	✔	☐	☐	☐	Heard 1969
	SLIMY SCULPIN freshwater	✔	☐	☐	☐	Heard 1969
	THREESPINE STICKLEBACK	✔	☐	☐	☐	Heard 1969
Wetland						
beaver pond	ponds above West Creek and at head of Hidden Creek					
	NINESPINE STICKLEBACK f	✔	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	✔	☐	☐	☐	Heard 1969
bog lake	Naknek River drainage (but possibly ubiquitous) - above West Creek					
	NINESPINE STICKLEBACK f	✔	☐	☐	☐	Heard 1969
lagoon	below outlet of Grosvenor L					
	NORTHERN PIKE freshwater	✔	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	✔	☐	☐	☐	Heard 1969
marsh	small, shallow, sluggish, along streams, with submerged vegetation (Chara and Nitella).					
	ALASKA BLACKFISH freshw	☐	☐	☐	✔	Heard 1969
tundra lake or pond	collected from head of West Creek; ubiquitous in small ponds or lakes, shallow, with subm					
	ALASKA BLACKFISH freshw	✔	☐	☐	☐	Heard 1969
	NINESPINE STICKLEBACK f	✔	☐	☐	☐	Heard 1969
	NORTHERN PIKE freshwater	☐	☐	☐	✔	Heard 1969
Unnamed stream	trib of South Bay of Naknek L; base of Dumpling Mtn					
	RAINBOW TROUT anadromou	✔	☐	☐	☐	Heard 1969

Appendix D: Maps

Map Title

Katmai region (1:2,000,000)
Landscapes (1:650,000)
Generalized bedrock geology
Water sample stations (1:650,000)
Water sample stations, inset A (1:350,000)
Water sample stations, inset B (1:350,000)
Physiography (1:650,000)
Landcover (1:650,000)
Katmai Land status (1:650,000)
Land Status – inset A
Land Status – inset B (1:650,000)
Coastal Resources - North (1:350,000)
Coastal Resources - South (1:350,000)

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NPS D-112, October 2007

National Park Service
U.S. Department of the Interior

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