Exxon Valdez Oil Spill
Restoration Project Final Report

Detecting and Understanding Marine-Terrestrial Linkages in a Developing Watershed: Nutrient Cycling in the Kenai River Watershed

Restoration Project 02612

Final Report

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Study History

In March 2001, a group of individuals representing agencies and organizations with interest in the Kenai River watershed met to discuss and identify issues related to marine and terrestrial derived nutrients in the watershed. A proposal was subsequently developed by ADF&G staff with co-principal investigators from University of Victoria, (UVic, British Columbia, Canada) and funded by the *Exxon Valdez* Oil Spill Trustee Council, Kenai River Sportfishing Association, and The Nature Conservancy to develop a long-term project integrating interdisciplinary knowledge on the watershed and links to the Gulf of Alaska ecosystem. Two workshops and a number of smaller meetings were convened to bring together those interested in potential collaboration in a larger research initiative for the Kenai River watershed. Three technical bulletins, a CD ROM and this final report have been created as background and study plan to foster an understanding of watershed issues and stakeholder interest and input on the Kenai River Watershed (Kenai RW). This work has led to a second proposal to fund further development of the Kenai RW research plan through ongoing community and stakeholder involvement, agency participation into a directed and implemented research program. Based on the information developed from the first study, we recognize the need to build this dialogue and maintain interest and momentum on research issues in the Kenai RW. A message from our recent August 2002 workshop indicated a strong interest to take the research plan and build it beyond a single completion EVOS report. The concensus expressed by Kenai RW participants, was that a research plan should be developed and implemented that: (a) captures the continued involvement of local, state and federal perspectives; (b) develops a *white paper* that presents scientific issues and interests in a plan with broad political, agency and stakeholder support; (c) extends the time needed to establish and maintain dialogue and interests beyond the initial research planning process; and (d) develops a detailed research program with management structure, specific project outlines and methods, project funding, and tangible research products. The report herein on Restoration Project 02612 describes an integrated and interdisciplinary study plan for the purpose of understanding nutrient and energy pathways and terrestrial-aquatic linkages in the Kenai RW.

Abstract

The Kenai River watershed (Kenai RW) in southcentral Alaska is a rich diverse, ecosystem supporting a variety of anadromous and non-anadromous fish species, wildlife and forest resources. We developed an interdisciplinary watershed – level research plan to implement a long-term integrated program on nutrient cycling and energy pathways that link freshwater habitats, their surrounding drainage basins including riparian areas, wetlands and terrestrial environments and downstream nearshore marine ecosystems. There is a critical need for this kind of research in order to develop tools, techniques and models for restoration and management of the Kenai RW. More importantly, the science and integration developed from this project can be applied to other Alaskan, and international watersheds exposed to similar human and resource use and development towards sustainable management. The Kenai RW research initiative is intended to ***integrate interdisciplinary knowledge*** on nutrients and energy and their sources and pathways within the Kenai RW, and link the cycle of nutrients / energy with watershed and resource productivity that ***cuts and integrates across habitat types*** (terrestrial, freshwater of lakes and streams and marine systems) and watersheds within the larger Gulf of Alaska ecosystem. The project will involve long term research to develop intergrative science and to communicate and transfer knowledge to a broad group of partners and stakeholders. The science and information will allow us to better manage diverse ecosystems in the Kenai RW and potentially provide a template for other watersheds towards sustainable multiple resource development.

Key Words

Kenai River Watershed, habitat linkages, Nutrients, Energy, Pathways, Lake Ecosystems, River Ecosystems, Wetlands, Forest ecosystems, Estuarine Ecosystems, Anadromous and non-anadromous fish, Salmon, Salmon Productivity, Marine Derived Nutrients, Wildlife.

Project Data

Description and format of data – Data used in this study are stored electronically at University of Victoria (UVIC), and Alaska Department of Fish and Game (ADF&G), Commercial Fisheries Division, Soldotna. Data are formatted as follows: maps (JPEG – From ArcView 3.2), physical data and zooplankton information (Microsoft Excel), water chemistry, nutrient and chlorophyll concentrations (Microsoft Excel), and fisheries (adult spawning timing, adult abundance) data (Microsoft Excel). *Custodian* - Custodian of the data used in this project is A. Mazumder, UVIC.

A. Mazumder, Environmental Management of Water and Watersheds, Department of Biology, University of Victoria, Victoria, V8W 3N5BC, Canada. telephone: (250) 472-4789, facsimile: (250) 472-4766, electronic mail: mazumder@uvic.ca. Website: www.uvic.ca/water.

J.A. Edmundson, ADF&G, Commercial Fisheries Division, 43961 Kalifornsky Beach Road, Suite B, Soldotna, AK 99669, telephone: (907) 260-2917, facsimile: (907) 262-4709, electronic mail: jim_edmundson@fishgame.state.ak.us. *Availability* – UVIC and ADF&G holds proprietary research rights to the data. Requested data will be made available under the discretion of the data custodians.

Citation:

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Executive Summary

The Kenai River Watershed (Kenai RW) is a unique site within Alaska and the Pacific Northwest and deserves attention to be sustained as a national treasure. It is a productive, diverse system supporting a wide variety of anadromous and non anadromous fish species, marine, freshwater, sport, commercial, subsistence and personnal use fisheries, wildlife, and forest resources contained within a large scale terrain setting comprised of lakes, streams, wetlands, mountains and glaciers connected to the Cook Inlet and the greater Gulf of Alaska ecosystem.

The resources of the Kenai RW have high economic and ecological value to the function, health and prosperity of ecosystems and human settlements in the Kenai Peninsula and Alaska. These resources include Alaska's largest sport fishery for chinook and sockeye salmon, wild rainbow trout, and marine fisheries (crab, salmon, eulachon, razor clams etc.) and abundant populations of moose, bears, wolves, caribou, whales, sea lions, and otters in a landscape reaching from the Gulf of Alaska, the Cook Inlet to the Kenai RW and the height of land in the Harding Ice Field.

The original focus for interest in nutrients and energy in the Kenai RW was associated to a large extent with the potential influence of marine-derived nutrients supplied by returning anadromous salmon on overall salmon population and watershed productivity. A number of researchers have suggested that there may be negative consequences to the productivity of watersheds and individual stocks of salmon with the loss of marine derived nutrients from salmon and carcasses resulting from exploitation, changes in freshwater and ocean productivity and habitat loss. The diversion of nutrients from many salmon watersheds, including the Kenai, has prompted interest in examining and understanding the role of salmon and other nutrient and energy sources in maintaining the productivity of watersheds. During the past three decades the Kenai RW has experienced considerable changes from a number of anthropogenic activities including: fish and forest harvesting, mining, oil and gas exploration, climate change, habitat degradation, increased land use, and invasive species. For example, the annual fish harvest in the Kenai RW have diverted approximately 80% (5.3×10^6 kg) of salmon biomass and nutrients over the past two decades destined to return to the watershed.

The Kenai RW comprises unique and diverse landscapes and networks of lakes, rivers, streams and wetlands with strikingly different geomorphology. Each sub-basin, wetland and tributary contributes different levels and compositions of nutrients to the Kenai River and the downstream nearshore marine ecosystems, where each component benefits differently from the input of marine-derived or nutrient sources. These observations have created strong community and

stakeholder support for a research initiative to explore and examine the diversity of sources, sinks and pathways of nutrients and energy, how nutrients cycle and the sensitivity of the Kenai RW to changes in nutrient inputs in the context of regional and global climatic scenarios coupled with anthropogenic impacts.

In March 2001, a group of individuals representing agencies and organizations with interest in the Kenai River watershed met to discuss and identify issues related to marine and terrestrial derived nutrients in the watershed. A proposal was subsequently developed by ADF&G staff with technical assistance from independent researchers (University of Victoria, UVic) and funded by the *Exxon Valdez* Oil Spill Trustee Council, Kenai River Sportfishing Association, and The Nature Conservancy to develop a long-term project integrating interdisciplinary knowledge on the watershed and links to the Gulf of Alaska ecosystem. Over the past year, we developed a broad research plan including an extensive literature review on nutrients and productivity in the Kenai RW, coastal watersheds and salmon ecosystems, a meta-analysis showing information and knowledge gaps in the Kenai RW, proposed major research themes including near-shore marine, river/stream, lake, and wetland/terrestrial components, critical research objectives, research timeline and deliverables, general field and laboratory approaches, research program management and communication, and preliminary multi-year budget. The science and integration developed from this project can be applied to other Alaskan and Pacific Northwest watersheds exposed to similar anthropogenic impacts and used to develop sustainable management of their diverse aquatic and terrestrial resources.

Kenai River Watershed Project Study Plan

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The following agencies, NGO's and institutions are partners, contributors and participants for this project:

Exxon Valdez Oil Spill Trustee Council www.oilspill.state.ak.us

Gulf Ecosystem Monitoring program www.oilspill.state.ak.us/Future/GEM.htm

University of Victoria www.uvic.ca/water

Alaska Department of Fish and Game www.state.ak.us/adf&g

Kenai River Sportfishing Association www.kenairiversportfishing.org

U.S. Environmental Protection Agency www.epa.gov

Kenai River Center www.borough.kenai.ak.us/KenaiRiverCenter/

Alaska Depart. of Natural Resources www.dnr.state.ak.us/

Kenai National Wildlife Refuge

Cook Inlet Aquaculture Association www.ciaanet.org

U.S. Geological Survey www.usgs.gov

U.S. Forest Service www.fs.fed.us

Chugach National Forest http://agdc.usgs.gov/data/usfs/chugach/

U.S. Fish and Wildlife Service www.fws.gov

Prince William Sound Science Center www.pwssc.gen.ak.us

Kenai Watershed Forum www.kenaiwatershed.org

University of Alaska Fairbanks www.uaf.edu

University of Alaska Anchorage www.uaa.alaska.edu

University of Washington www.washington.edu

University of British Columbia www.ubc.ca

The Nature Conservancy http://nature.org/wherewework/northamerica/states/alaska/

Northwest Ecosystem Institute www.ecosystems.bc.ca

Natural Sciences Engineering Research Council of Canada www.nserc.ca

Cook Inlet Information Management and Monitoring System http://info.dec.state.ak.us/ciimms

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We thank members of the Scientific and Public Advisory Committees including:

Keith Boggs—Alaska Natural Heritage Program, University of Alaska, Anchorage,

James Brady—ADF&G, Commercial Fisheries Division,

Robert Clark—ADF&G, Division of Sport Fish,

Robert DeVelice—U.S.D.A. Forest Service, Chugach National Forest,

Gary Fandrei—Cook Inlet Aquaculture Association,

Mike Gracz—Alaska Natural Heritage Program,

Russel Hopcroft—University of Alaska, Fairbanks,

Brett Huber —Kenai River Sportfishing Association,

Tom Kline—Prince William Sound Science Center,

Alexander Milner—University of Birmingham, University of Alaska, Fairbanks,

Phil Mundy—*Exxon Valdez* Oil Spill Trustee Council,

Phil North— Kenai River Center, Soldotna,

John Richardson—University of British Columbia,

Daniel Schindler—University of Washington.

1.0 Background and Context

The Kenai RW is considered by many to be a national treasure for its abundant fish and wildlife and diversity of landscapes unique to the State of Alaska and the Pacific Northwest. The Kenai RW is at a cross roads; now feeling the cumulative stresses of human activities through urban development, land exchanges and exploitation of natural resources. In order to effectively sustain watershed landscapes, human activities, ecosystems and the plant and animal communities within it, there is a dire need to understand the major biological, biogeochemical and hydrological processes and interactions within and among the various components of the watershed. To do this, we need to integrate the mechanisms by which fish, wildlife and landscape interact, function and produce as function of nutrients derived from marine and other sources. Furthermore, it is critical to characterize, quantify and model how human activities modulate these interactions and overall watershed productivity by effecting the sensitivity of each of the ecosystem components to nutrient inputs.

The following document has been developed to help guide and define "research" approaches to examine and understand nutrient and energy sources and pathways joining sensitive aquatic, terrestrial and marine ecosystems within the Kenai River watershed. This is a working document intended for continued development.

Figure 1: Satellite imagery of the Kenai RW, 1996, indicating physiography, drainage (lakes – dark blue) and glaciers (light blue – white).

1.1 Kenai River Watershed Project

In 2001, a group of state agency and university researchers proposed to develop a study plan on nutrient cycling and marine-terrestrial linkages in Kenai RW. This initial study was developed by state agency staff (ADF&G) and researchers at University of Victoria and funded by the *Exxon Valdez* Oil Spill Trustee Council, Kenai River Sportfishing Association, and The Nature Conservancy to develop a research plan to explore the state of knowledge on fisheries, nutrients and energy in the Kenai RW. The funded project is led by co Principle Investigators: W.J. Hauser, A. Mazumder, and J.A. Edmundson with support from a Scientific and Public Advisory Committee. A number of workshops (January and August 2002) and smaller meetings were convened to bring together those interested in potential collaboration in a larger research initiative for the Kenai RW. Two technical bulletins have been created as background to communicate issues and ideas about the watershed and developed a state of knowledge literature review and GAP analysis for the Kenai RW.

The document to follow is intended to serve as a guide to assist researchers, managers and stakeholders to build background information towards collaboration to successfully create and manage a long term integrated interdisciplinary research initiative on nutrient and energy pathways in the Kenai RW.

1.1.1 Research Objectives

The Kenai RW research initiative is intended to integrate interdisciplinary knowledge on nutrients and energy and their sources and pathways within the Kenai RW as the sensitive link between resource productivity and habitat types (terrestrial, freshwater and marine systems) within the larger Gulf of Alaska ecosystem. The project is also intended to evolve as a long term research initative, to communicate and transfer knowledge to a broad group of partners and stakeholders. The science and information will allow researchers, stakeholders, local government and policy and government institutions to better manage diverse ecosystems in the Kenai RW and potentially provide a template for other watersheds towards sustainable multiple resource development.

1.1.2 Project Rationale

The Kenai RW (Fig.1) is a unique site within Alaska and the Pacific Northwest (Fig. 2). It is a productive, diverse system supporting a wide variety of anadromous and non anadromous fish species, marine, freshwater, sport, commercial, subsistence and personnal use fisheries, wildlife, and forest resources contained within a large scale terrain setting comprised of lakes, streams, wetlands, mountains and glaciers connected to the Cook Inlet and the greater Gulf of Alaska ecosystem (Boggs et al. 1997).

The resources of the Kenai RW have high economic and ecological value to the function, health and prosperity of ecosystems and human settlements in the Kenai Peninsula and Alaska. These resources include Alaska's largest sport fishery for chinook and sockeye salmon, wild rainbow trout, and marine fisheries (crab, salmon, eulachon, razor clams etc.) and abundant populations of moose, bears, wolves, caribou, whales, sea lions, and otters in a landscape reaching from the Gulf of Alaska, the Cook Inlet to the Kenai RW and the height of land in the Harding Ice Field.

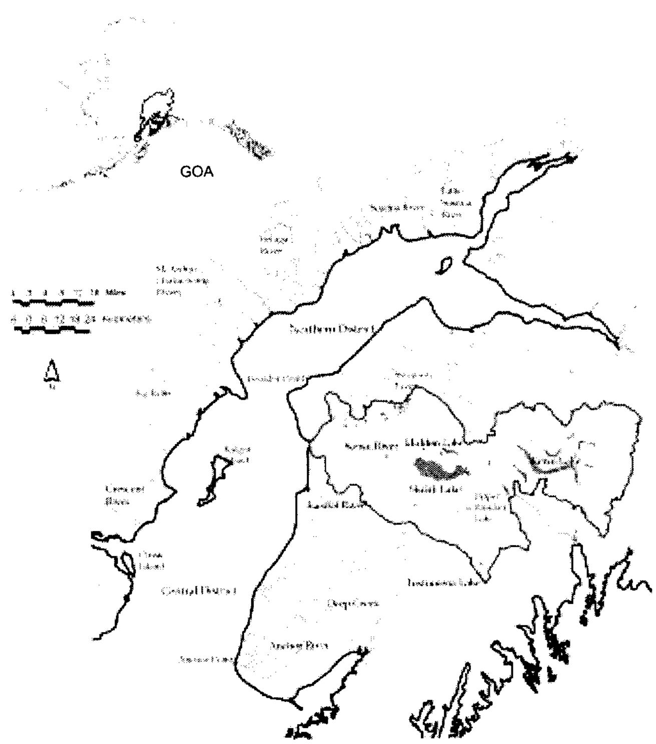


Figure 2. Location of the Kenai River Watershed within the Cook Inlet and Gulf of Alaska (GOA).

1.2 Nutrients and Energy in the Kenai RW

Nutrients and energy in the Kenai RW and most coastal watersheds in the Pacific Northwest have been linked with the input of marine derived nutrients supplied by returning and spawning anadromous salmon positively influencing the level of watershed productivity; the recruitment of subsequent generations of salmon; and the energy transfer and productivity of marine, freshwater and terrestrial ecosystems (Willson et al. 1998, Cederholm et al 1999, Gende et al. 2002). Willson and Halupka (1995), Larkin and Slaney (1997), Cederholm et al. (2000), Gresh et al. (2000), and Naiman et al. (2002) have suggested that there may be negative consequences to the productivity of watersheds and individual stocks of salmon with the loss of marine derived nutrients from salmon and carcasses by harvesting fish biomass destined to return to the natal watersheds. The diversion of nutrients from exploitation, declining salmon stock sizes related to climate change and habitat degradation in salmon watersheds, including the Kenai, has prompted interest in examining and understanding the role of salmon, nutrients and energy linking many ecosystems components and potentially maintaining watershed productivity.

During the past three decades the Kenai RW has experienced considerable change associated with a number of anthropogenic stresses including: fish and forest harvesting, climate change, fish habitat use and degradation, increased land use, and invasive species. The Kenai RW also comprises a unique diversity of landscapes and network of lakes, rivers and wetlands. The aquatic systems in Kenai RW have a strikingly different geomorphology including: 1) the Moose River and Beaver Creek - slow-moving, low-lying meandering systems which drain wetland areas and lakes; 2) the Snow and Killey Rivers - higher-gradient, glacier headwater systems; and 3) the Russian River - high-gradient, clear-water system. Each sub-basin, wetland and tributary provides unique links, which may be variably sensitive to changes in nutrients and energy input / output in the Kenai RW. Aquatic systems by their nature provide a critical link for nutrient and energy contributions and downstream movement to other ecosystem components in the watershed including marine, terrestrial and aquatic systems. Due to the variety and type of aquatic systems in the Kenai RW, each sub-basin drainage may benefit differently from nutrient and energy inputs including those derived from salmon, terrestrial or climate sources.

These general observations from the literature and from the Kenai RW, have created strong local, regional and science based support for an initiative in the watershed to monitor and investigate:

- ***sources, sinks and pathways*** of nutrients and energy linking various aquatic, terrestrial and marine ecosystem components in the watershed;
- ***nutrients and energy cycling*** within the watershed and their linkages to overall productivity; and
- ***sensitivity*** of the Kenai RW to changes in marine, aquatic, terrestrial or climatic derived nutrient and energy quality and quantity.

The goal of this research plan will be to assist in the development of interdisciplinary research and assessment initiatives to build rigorous empirical and experimental databases and models to examine and test various hypotheses on nutrient / energy inputs, outputs, and links in the watershed. The proposed research will explore the importance of atmospheric, climate driven, terrestrial, riparian, wetland, stream, lake, estuarine and marine sources and pathways of nutrients and energy to the productivity of various forest, wildlife, salmon and other fishery resources as illustrated in a nutrient pathway schematic (Fig. 3).

The Kenai RW study plan is intended to form strong collaboration to seek funding to support integrated ecosystem based research that utilizes consistent long-tern databases in partnership with agencies, stakeholders and communities. The ability of watersheds and ecosystems to support healthy environments, aquatic and terrestrial animal and plant communities, human populations and economies are often threatened by human development and growth (i.e. Foster et al. 1998). Increasing human activities throughout the Kenai RW holds the potential to adversely impact this rich and diverse ecosystem. The fisheries resources of the watershed contribute to commercial, sport and personal use fisheries that are vital to the economy of the Kenai Peninsula and the State of Alaska. These fisheries, along with wildlife, forest, land and water resources will need to be integrated with local and regional planning to form management strategies to support and maintain sustainable land and resource use. Increasing land use, riparian development, altered nutrient pathways and increased use of the waterways, the risk of pollutants, declining water quality, loss of riparian habitats and invasive fish and plant species, spruce bark beetle infestations and climate change, all pose present and future threats to the ecosystem structure and productivity of the Kenai RW. Integration of land and resource management towards sustainable ecosystem

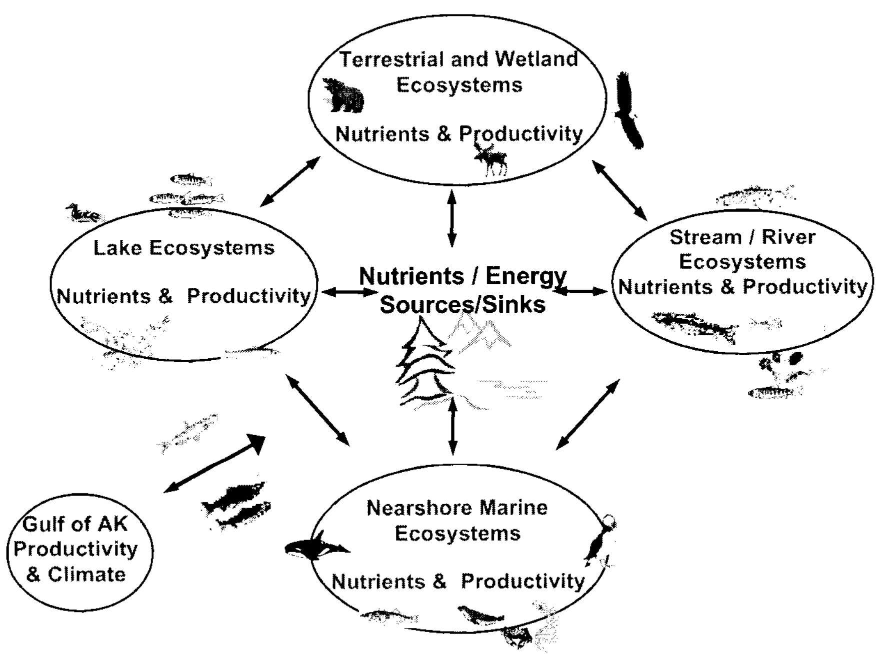


Figure 3: Schematic representation of nutrient / energy links between major systems in the Kenai RW.

management (Grumbine 1997) in the Kenai RW can be supported by research to understand and fill existing knowledge gaps. There is a critical need for integrated research and management to deal with watershed issues and the habitats and nutrients that influence productivity. The key to successful water, habitat, nutrient and watershed research and ultimately management in the Kenai RW, is the integration of natural and social sciences and the involvement of a variety of stakeholders (c.f. Redman 1999). We have identified four major research themes that ***cut across habitat type*** (Fig. 3) for the Kenai RW with a major research link to the Gulf of Alaska Ecosystem Monitoring (GEM Plan). These themes include potentially significant areas of nutrient / energy sources and sinks associated with the major landscape, freshwater and marine components that ultimately determine the overall productivity of Kenai RW including:

- Lakes
- Streams / rivers
- Neashore marine / estuary
- Terrestrial / wetlands / glacier.

1.2.1 Kenai RW – Location / Background

The Kenai RW (Fig. 4) provides a unique setting for research on a coastal watershed with a diversity of clear, glacial, wetland and salmon based ecosystems. Very few other Alaskan or Pacific Northwest watersheds of this size and scale exhibit such varied terrestrial, freshwater and estuarine landscapes. The watershed is 5,054 km^2 in area, with a diversity of landscapes and habitats; at least six important species of salmonids; six abundant mammal species; and large forested tracts and natural areas.

Nutrients such as phosphorus and nitrogen, considered to be critical to limiting ecosystem productivity, enter the watershed from a variety of marine, terrestrial and atmospheric sources. Melt water from headwater glaciers (Fig. 1) also contributes nutrients and large amounts of rock flour and silt to the drainage. The largest lakes in the system (Kenai and Skilak) are hypothesized to function as important buffers to variations in river discharge, silt and nutrient loading from the upper watershed.

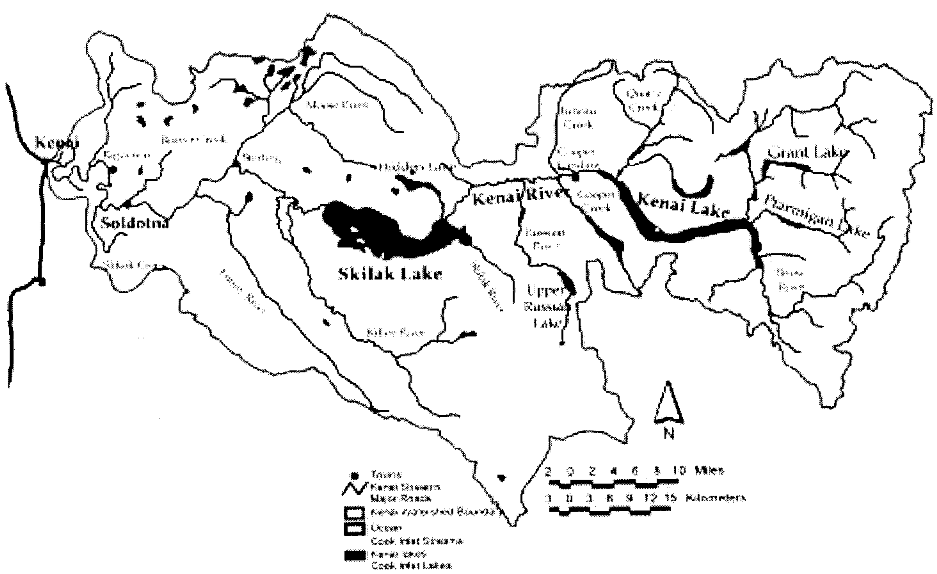


Figure 4: The Kenai RW site location map.

These lakes are the main nursery habitat for juvenile sockeye salmon, the most abundant salmon stock in the watershed. The river channel below the largest lake (Skilak) is lower gradient and meanders through forests and wetlands (peat bogs) (Fig. 1). The wetlands, and the tributaries which drain them, are nutrient rich relative to portions of the upper watershed, and provide complex habitats which support chinook, coho, chum and pink salmon, and a diversity of wildlife species including moose, bear and wolves. On average over two million salmon (Fig. 5), smelt and other anadromous fish enter the drainage annually to spawn (Fig. 6) and die, leaving marine-derived nutrients (phosphorus and nitrogen), lipids and proteins from carcasses in various parts of the watershed.

Figure 6. Anecdotal observations of sockeye, chinook and coho salmon spawning habitats in Kenai RW

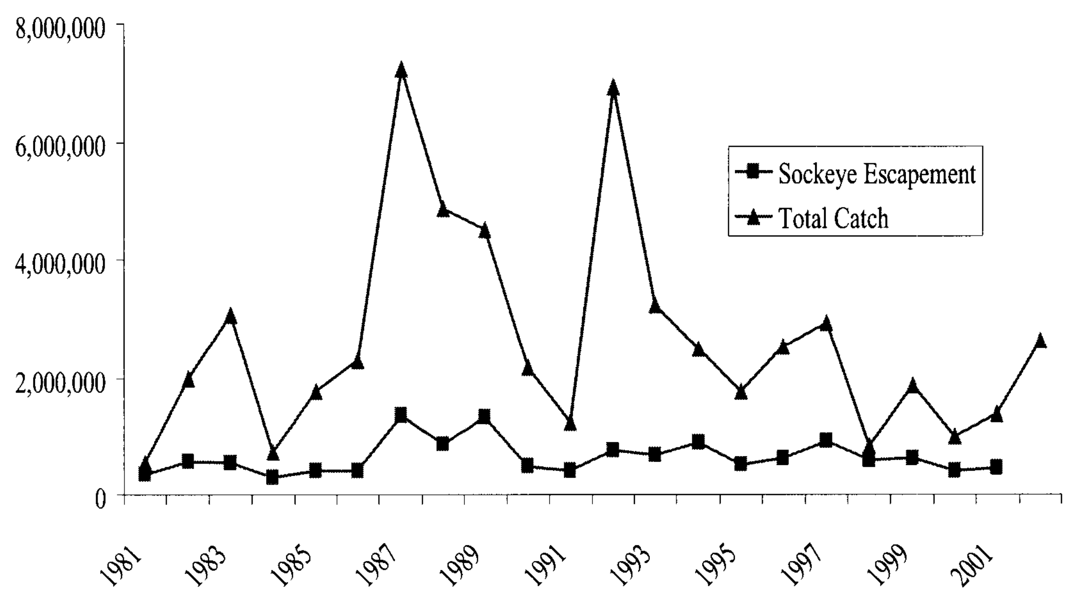


Figure 5. Sockeye salmon total catch and escapement (y-axis total numbers) to the Kenai RW from 1981 to 2001.

2.0 Knowledge Gaps in the Kenai RW

2.1 Literature Database

We compiled an extensive database of available literature as background and review for the Kenai RW, coastal watersheds and salmon ecosystems (***enclosed CD ROM***). The Kenai RW literature database (dated Oct. 2002) includes 7,062 accumulated records compiled based on key words and phrases including:

> Pacific Northwest; Gulf of Alaska; Cook Inlet; Kenai RW; watersheds; aquatic ecosystems; forests; wetlands; estuaries; glacial headwaters; wildlife (brown bears, moose, caribou); streams and rivers (Kenai place names); lakes (Kenai place names); sockeye, (*Oncorhynchus nerka*), chinook (*O. tshawytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*), chum (*O. keta*) salmon; salmonids; salmonid life history stages; and nutrients (marine derived).

The database identifies literature based on reference type (journal article, book, report etc.), keywords, author, title and abstract. Existing bibliographic sources from the Kenai RW, Cook Inlet and Alaska were used to compile the Kenai RW database 2002, including: a) "Aquatic and Terrestrial resources of the Kenai River Watershed: A Synthesis Publication" Boggs, Davis and Milner 1997; b) Alaska's Cooperatively Implemented Information Management System; and c) Cook Inlet Keepers Bibliography.

We searched our literature database based on:

- reference type;
- location or region,
- research theme type based on Fig. 3.
- salmon species and life history component.
- landscape, aquatic and marine habitat types.

Our review produced the following results.

A. The majority of literature, information and data sources are available as limited distribution technical reports and unpublished reports and often exist only in local files.
B. Current publications, particularly non refereed reports, do not have consistent referencing based on key words, topics, subjects and /or phrases.
C. Kenai RW literature accounts for 1440 records.
D. Cook Inlet (including Kenai RW) literature accounts for 1540 records.
E. Alaska State literature (including Cook Inlet, Kenai RW) accounts for 3839 records.

Table 1: Kenai RW literature database records by reference type.

Reference Type	Number of Records
Journal Article	107
Books	141
Theses	36
Proceedings - Conference	52
Reports and other	1104

F. Reporting on the Kenai RW increased rapidly during the 1980's and 90's and has declined in recent years.

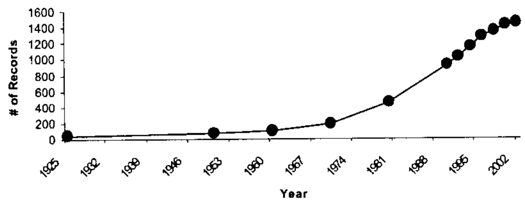


Figure 7. Cumulative number of Kenai RW literature records over time, Pre 1925 to present.

G. literature is principally composed is records dated between

H. Kenai RW literature is comprised of a much higher proportion of aquatic freshwater literature compared with terrestrial / wetland, marine and climate based literature (Table 2).

Table 2 Kenai RW literature database records by research ecosystem habitat theme.

Ecosystem Theme	Number of Records
Lakes	129
Streams / Rivers	422
Wetlands / Terrestrial	106
Nearshore Marine	68
Gulf of Alaska	16
Climate / Atmospheric	18

Note: Many records refer to more than one ecosystem theme

I. Limited reporting exists on nutrients and food web interactions in the Kenai RW (Table 3).

Table 3: Ecosystem literature database records by nutrient and energy components.

Research Theme	Number of Records
Kenai – nutrient / energy	30
Nutrients / Energy	692
Food Webs / Trophic levels	11
Ecosystems - Nutrients	1848

Note: Many records refer to more than one flora or fauna type.

J. River / stream and lake records account for the majority of the literature found in the Kenai RW (Table 4). Limited reporting exists for forest / plants, wetlands, estuary and riparian systems in the Kenai RW.

Table 4: Kenai RW literature database records by habitat type across research themes.

Habitat / Flora Type	Number of Records
Rivers / Streams	422
Lakes	129
Streambank	65
Forest / Plants	57
Soils	41
Marine	34
Glaciers	22
Coastal Marine	20
Wetlands	19
Estuary	9
Riparian	6

Note: Many records refer to more than one habitat type.

K. Reporting of salmonids accounts for the majority of the literature in the Kenai RW. Reporting on moose and caribou is also frequent. Limited reporting exists on non salmonid fish species, birds and smaller size fauna species and types in the Kenai RW (Table 4).

Table 4: Kenai RW literature database records by fauna type.

Fauna Type	Number of Records
Salmonids	549
Wildlife - general	207
Ungulate mammals	110
Fish – non salmonids	74
Predator mammals	53
Birds	31
Plankton	16
Stream Invertebrates	16
Amphibian / Reptile	0

Note: Many records refer to more than one flora or fauna type.

L. The majority of records on fish species are associated with relative commercial and sport fish abundance and economic importance. Limited reporting exists for less important commercial or sports fish species including pink and chum salmon, and eulachon (*Thaleichthys pacificus*) and smelt (Osmerids) (Table 5).

Table 5: Kenai RW literature database records by fish species.

Salmon Species	Number of Records
Sockeye salmon	161
Chinook salmon	143
Coho salmon	91
Chum salmon	29
Dolly Varden	25
Pink salmon	27
Rainbow Trout	13
Grayling	9
Oolichan	0
Smelt	0

Note: Many records refer to more than one flora or fauna type.

2.2 Kenai RW Information GAPS – Research Themes

For each of the research themes described in Figure 2, a simple matrix was designed to identify the state of knowledge (good, fair, limited) for baseline assessment of information and existing research on nutrient / energy linkages.

In general, baseline assessment data on salmonids in rivers and streams, and lake ecosystems and climate – oceanography in the Gulf of Alaska are rated "fair", whereas assessment data for nutrients - energy pathways, terrestrial – wetlands, and nearshore marine – estuary are rated "limited" to "not rated" because of data and study deficiencies. A number of general observations about the knowledge gaps in the Kenai RW can be made from the available information and literature sources.

2.2.1 Lake Ecosystems and Their Role within Kenai RW

There is fair to good baseline biophysical (glacial input, nutrients, temperature, morphometry) information and sockeye rearing habitat (sockeye density, zooplankton) for some lake ecosystems in the Kenai RW. However, the information on nutrient sources and sinks within lake and their links to the rest of the watershed is "limited" or "not rated" due to information and study deficiencies.

There is a critical need to understand nutrient cycling in lakes and how the structure, function and nutrient-foodweb dynamics of lake ecosystems are linked to nutrient conditions and productivity of downstream riverine, riparian, wetland, terrestrial and nearshore marine components of the Kenai RW.

2.2.2 River and Stream Ecosystems and Their Role within Kenai RW

There is "limited" to fair baseline biophysical (glacial input, nutrients, temperature, channel morphology) information and chinook, coho salmon and rainbow trout rearing habitat for some river ecosystems in the Kenai RW. Little quantitative information is available about bank and riparian forest stability and the productivity of salmon and wildlife habitats in the tributaries, streams and rivers of the Kenai RW. There are some quantitative information on the effects of bank trampling and boat wakes (Scott 1982). The information on nutrient sources and sinks within river ecosystems of the Kenai RW and their links to the rest of the watershed is "limited" or "not rated" due to information and study deficiencies.

There is a critical need to understand nutrient cycling from upstream rivers systems links through terrestrial, wetland and riparian areas to lakes and downstream rivers. It is important to understand how habitat quality (substrate type, sediment, flow regimes and available spawning area) and the structure, function and nutrient-foodweb dynamics of headwater and downstream river ecosystems are linked to nutrient conditions and productivity of lakes, riparian, wetland, terrestrial and nearshore marine components of the Kenai RW.

2.2.3 Wetland and Terrestrial Ecosystems and Their Role within Kenai RW

There is some qualitative information on the attributes of riparian areas, wetlands and terrestrial habitats within Kenai RW (Boggs et. al. 1997). For instance, riparian areas provide important habitats for fish, aquatic and terrestrial invertebrates and terrestrial wildlife and they also protect against stream bank erosion, buffer overland flow and stabilize stream channels. Wetlands serve as important fish rearing habitat, regulate water flow, provide a source of insects for food by fish and birds, and provides spawning, nesting, rearing, feeding, and resting habitat for a diversity of aquatic and terrestrial species. Terrestrial habitats support many animal species which benefit seasonally by feeding on salmon, and terrestrial vegetation may also respond to changes in nutrients originating from salmon biomass. However, there is very limited quantitative data in relation to the availability and amount of nutrients within these watershed components and pathways of nutrients throughout Kenai RW. Therefore, the state of knowledge about riparian, wetlands and terrestrial animal and plant systems in the Kenai RW is generally "limited".

We need to understand and quantify nutrient – energy cycling from glaciers, upland slopes and forests, riparian forests and wetlands to freshwater rivers, lakes and the estuary of the Kenai RW.

2.2.4 Nearshore Marine Ecosystems and Their Role within Kenai RW

With the exception of baseline information on marine mammals (beluga, sea lions), the state of information about nearshore marine environments and the Kenai River estuary is rated "limited". There is very limited quantitative data in relation to the availability, amount and pathways of nutrients within river, estuarine and nearshore marine components of the Kenai RW. Therefore, the state of knowledge about estuarine and nearshore marine nutrient transport, sources and sinks in the Kenai RW is rated "limited" to "not rated" because of data and study deficiencies.

There is a critical need to understand nutrient cycling in the Kenai RW estuary and its relationship with the nutrient conditions and productivity of the nearshore ecosystems within Cook Inlet and Gulf of Alaska. One of the fundamental questions is the importance of nearshore habitats as the rearing habitats for outmigrating juveniles (smolts) of salmon and other fish species from freshwater systems. Do nutrients derived from salmon carcasses support the productivity of salmon and other fish and wildlife species by enriching the estuarine habitat as much as the upstream freshwater habitat? In other words, the bulk of *the marine derived nutrient subsidy may be lost through downstream transport and assimilated into nearshore marine foodwebs and productivity?*

2.2.5 Limitations of the Kenai RW Literature Database

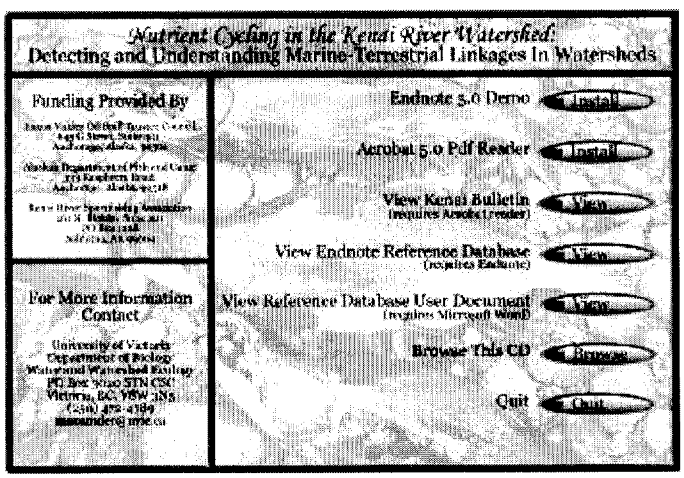
The Kenai RW literature database is a compilation of many available information sources and literature including the Kenai RW synthesis (Boggs et al. 1997). There are several sources of uncertainty that apply to this gap analysis. First, the database provides a representative, rather than exhaustive, compilation of information and literature sources, so that the state of knowledge is potentially under represented. Many search engines were used to explore and retrieve literature from various collections, however the full extent of literature on the Kenai RW and salmon ecosystems remains unknown. Second, many technical studies were conducted at detailed scales in the watershed and can not easily be extrapolated as information and results to the entire watershed. For many of the reasons above, the assessment of Kenai RW knowledge gaps should be considered conservative.

2.2.6 Digital Kenai RW Literature Database – *CD ROM*

An executable CD ROM is enclosed in this report. The CD ROM provides an endnote version of the Kenai RW literature database, in addition to the Final Report (Acrobat pdf file), Bulletin #1 and 2 (Acrobat pdf file).

The Kenai RW literature database is representative of the nutrient / energy literature and does display an exhaustive search of Kenai RW based literature.

The entire literature database, final report and bulletins are available at www.uvic.ca/water.



2.3 Kenai RW Information GAPS – Limits on Fish Information

Of the 498 records compiled by fish species, 90% deal with the five species of Pacific salmon (Table 5). Of these, the bulk (67%) of the literature is specific to sockeye and Chinook salmon. Typically, these papers and reports focus on stock status and provide information on annual sport, commercial, and subsistence harvests and salmon escapements (Table 6, 7). There are few studies concerning the production in the context of nutrient foodweb dynamics in lakes, rivers and streams. We lack consistent and long term data sets that include juvenile salmon growth, survival and abundance at each life history stage coupled with rearing habitat conditions and resource (e.g. nutrient) availability. Without this kind of data, we cannot determine the relative importance of freshwater environments versus marine influences on adult returns. Even less is known about early life history stages, growth and survival of other salmonids, resident fish species, eulachon and smelt.

2.3.1 Sockeye Salmon

- Records of historical adult sockeye escapement, harvest, age compositions and size are available for Russian River, mainstem Kenai River and Hidden Lake.
- Estimates of fall sockeye fry abundance, age composition and size are available for select nursery lakes including Skilak, Kenai and Hidden Lakes.
- Limited sockeye salmon smolt information is available from the major nursery lakes
- From life history based assessments there predictably four subpopulations of sockeye in the Kenai RW including: early and late mainstem Kenai River, Upper Russian, and Hidden Lake.

2.3.2 Chinook Salmon

- Records of historical adult Chinook escapement, harvest, age composition and size are available for early and late run Kenai River.
- Limited information on chinook salmon smolt, fingerling and juvenile abundance, distribution, age and size are available for Kenai River mainstem and Killey River.
- Little information is available concerning growth, survival and recruitment of juvenile chinook salmon.
- From life history based assessments there predictably two known subpopulations of chinook in the Kenai RW including early and late run Kenai River.

2.3.3 Coho Salmon

- Records of historical adult coho escapement, harvest, age and size are available for Kenai River, Russian River and Hidden Lake.
- Limited information on coho salmon smolt, fingerling and juvenile abundance, distribution, age and size are available for Moose River, Russian River and Hidden Creek.

- Little information is available concerning growth, survival and recruitment of juvenile coho salmon.
- From life history based assessments there predictably no known subpopulations of coho in the Kenai RW.

2.3.4 Pink Salmon

- Pink salmon returns to the Kenai RW are large during even years, but their actual abundance is unknown.
- Records for commercial harvest of pink salmon are available, but not considered a reliable index of returns or run strength (Even year 300,000 – 2,000,000; Odd year 10,000 – 200,000).
- Limited information on sport fish catch of pink salmon are available.
- Little information is available concerning growth, survival and recruitment of juvenile, adult pink salmon.
- What is the role of nutrients from returning pink salmon in supporting the productivity of other more economically important salmon species?

2.3.5 Chum Salmon

- Chum salmon returns to the Kenai RW are unknown and potentially minimal (<10,000).
- Commercial harvests of chum salmon are available of the entire Upper Cook Inlet regional salmon fishery

2.3.6 Rainbow Trout

- Rainbow trout are found in many lakes and streams within the Kenai RW.
- Harvest and catch estimates (angular / creel) of rainbow trout are available for the lower, middle and upper reaches of the Kenai River.
- Limited information on seasonal / annual distribution, size and age, growth survival are available in the Kenai RW.
- One of the fundamentally important questions is why there is no known anadromy in rainbow trout within Kenai RW, while other similar river systems in the region support populations of sea run rainbow trout (steelhead).

2.3.7 Dolly Varden

- Dolly Varden are found throughout most of the freshwater sub basins in the Kenai RW.
- Harvest and catch estimates (angular / creel) of Dolly Varden trout are available for the lower, middle and upper reaches of the Kenai River.
- Limited information on seasonal / annual distribution, size and age, growth survival are available.

2.3.8 Other Fish species

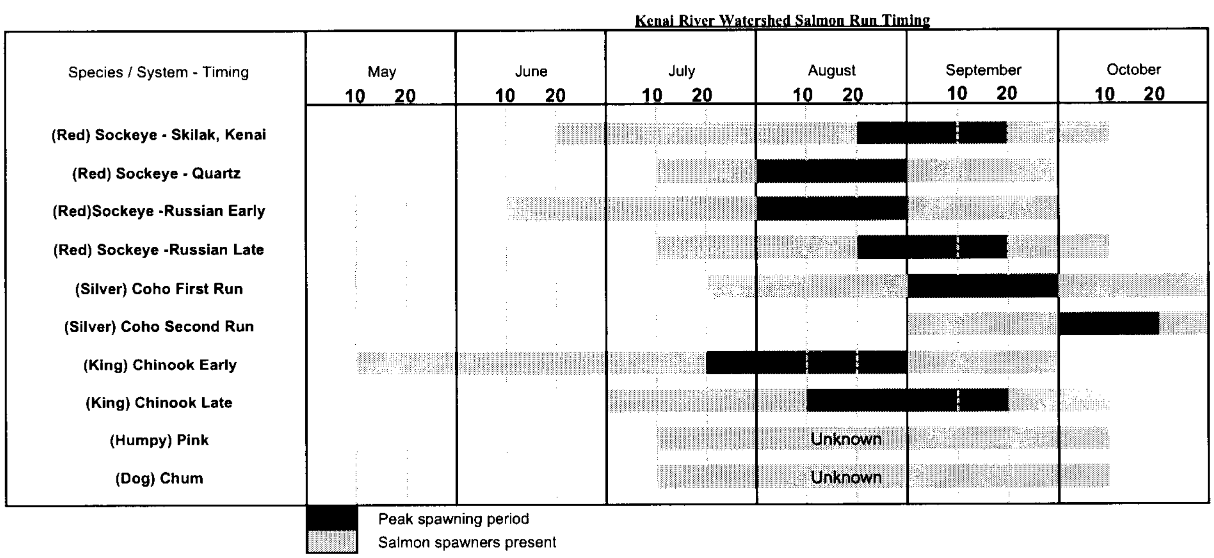
- Records indicate the presence of eulachon, smelt (species unknown) and various other fish species (sticklebacks, sculpins, lake trout, clupeids, grayling, Arctic charr) in the Kenai RW. Little is known about any of these species.

Table 6: Review of available life history and stock assessment information for the major salmon species in the Kenai RW based on literature and reporting compiled in Table 5, Appendix III.

Salmon Life History Stage	Sockeye salmon Kenai, Russian & Hidden	Chinook Salmon Early & Late Runs	Coho salmon Early & Late	Pink salmon	Chum salmon	Steelhead Rainbow Trout
Incubation :	NA	NA	NA	NA	NA	NA
Juvenile rearing:	Fall juvenile in-lake surveys	Anecdotal information	Anecdotal information	NA	NA	NA
Smolt Migration:	Various years, sites 1989-94	Few years, 1983, 84, 97	Various years, sites 1976-94	NA		
Ocean / Nearshore Juvenile:	NA	NA	NA	NA	NA	NA
Open Ocean / Marine Juvenile:	NA	NA	NA	NA	NA	NA
Adult - Ocean Return:	Commercial / sport catch	Commercial / sport catch	Commercial / sport catch	Harvest - commercial	NA	Harvest - limited sport
Adult Migration Corridor	1963, 68-2001 - Kenai, Russian	1984-2001 Sonar, Weir	1987-93	CPUE - Adults	NA	CPUE - Adults
Adult Spawning / Senescence	Spawn timing estimates	Spawn timing estimates	Spawning time estimates	NA	NA	Anecdotal information

Unknown / No assessment
Infrequent assessment, uncalibrated methods, few seasonal and annual estimates
Infrequent assessment or uncalibrated methods, may include seasonal and annual estimates available
Frequent assessment, calibrated methods, missing additional data in years or seasonally, or methods
Good stock assessment data, frequency and method of data collection high

Table 7: Salmon subpopulation run timing in the Kenai RW.



3.0 Kenai RW Study Plan

Program Leader: **Asit Mazumder**, Department of Biology, University of Victoria, BC, Canada.

Theme Leaders:

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3.0.1 Research Statement and Approach

The Kenai RW research initiative is defined by the following research statement.

"We need to understand nutrient and energy cycling to predict and quantify food web dynamics and productivity of critical ecosystem components in watersheds and in particular the Kenai RW. This project will develop integrated science that cuts across ecosystem boundaries and watersheds to support sustainable development and management of multiple resources within Kenai RW. Furthermore, the results from this project will show how the productivity of Kenai RW links to the functioning of greater Gulf of Alaska ecosystem."

3.0.2 Nutrients in Watersheds

Watersheds are recognized as the fundamental hydrological, physical and ecological unit for management and conservation of land and aquatic resources (Hynes 1975, Naiman 1992). Watersheds serve as effective natural units to examine and monitor processes that influence the integrity and function of ecosystems, communities and populations of animals and plants within them (Montgomery et al. 1995). Watersheds are dynamic and act as effective integrators of ecological processes (Vannote et al. 1980), land use, anthropogenic impacts on biological productivity, water quality and quantity and even human health (Naiman et al. 1995).

3.0.3 Watershed Nutrient / Energy Studies

Few studies have attempted to quantify the complex processes and pathways of nutrient and energy cycling in watersheds. Nutrients such as nitrogen and phosphorus often limit primary or secondary production in both terrestrial and aquatic systems. Those watersheds which have been extensively studied and are represented in the literature, are often experiencing declining water quality or quantity related to eutrophication and other forms of pollution from point and non point nutrient sources associated with urban or agricultural development (i.e Vollenweider 1968, 1976).

A review of the literature indicates three types of studies have been undetaken to examine nutrient and energy sources, sinks and pathways across entire watersheds. Nutrients have been quantified based on: (1) across watershed measurement of nutrient concentrations and loading rates to derive estimates of nutrient inputs and outputs over time (Bormann and Likens 1967, Patals and Salki 1973, Bennett et al. 1999, Wheeler et al. 2000, Baker and Richards 2002); (2) isotope markers and analysis used to trace forms of nitrogen and carbon in watershed to identify sources (Fu and Winchester 1994, Brenner et al. 2001, Mitchell et al. 2001a); this has been more frequently used in salmon watersheds in the Pacific Northwest (Mathisen et al. 1988, Kline et al. 1990, 1993, Bilby et al. 1996); and (3) mass balance approaches used to model and predict nutrient input and output rates across watershed (Lewis et al. 1990, Cassell et al. 1998, 2001, Mitchell et al. 2001b).

Whole watershed-scale research on nutrient / energy cylcing and pathways has not been undertaken in the Kenai RW. However, Dorava and Milner (2000) have examined the relative impacts of nutrients and water derived from glacier fed rivers on salmon production. They suggested that the large glacial lake systems of the Kenai RW (Skilak and Kenai) buffer nutrient concentrations, water flow and temperature, which may have important significance for downstream macro-invertebrate production relative to other watersheds without large lake systems. Edmundson and Mazumder (2002) have examined a large set of Alaskan Lakes including some within the Kenai RW lakes (e.g. Skilak, Kenai, Hidden, Upper Russian) and found that water temperature, heat content, and length of growing season are strongly tied to water clarity (glacial, stained, and clear) and climate setting (latitude). Very little has been done to link the upstream terrestrial and aquatic ecosystems in regulating the functioning and productivity of downstream freshwater and nearshore marine ecosystems. The section below describes how this can be achieved by addressing the linkages among ecosystems and habitat types within four focused research themes.

3.1 Kenai RW Research Themes

Our approach to understanding nutrient and energy cycling at the level of a complex whole watershed considers various interdependent components (e.g., aquatic, wetlands and terrestrial) that collectively contribute to the overall functioning and productivity of the Kenai RW. Each dynamic, functioning part is viewed as critical and equally important in relation to its major climatic, hydrological, and biological processes and interactions within the watershed. Consider the complexity of the Kenai RW as exhibited by the topographic features shown in the previous satellite image (Fig. 1). Landscapes and habitats within the watershed differ from one another in many features other than area. However, what is not obvious in Figure 1 are local-scale characteristics of the watershed such as micro-scale climate effects, geology and groundwater discharge, which are important constituents needed to form an inclusive watershed perspective that cuts across ecosystem boundaries. Therefore, given the time and resource limitations imposed on a project of this scope, we identified four specific research themes representing the major components of the Kenai RW and their connection to Cook Inlet and ultimately to the Gulf of Alaska Ecosystem Monitoring (GEM Plan):

- lakes
- rivers and streams
- wetlands and terrestrial
- nearshore marine.

Hyporheic zones, groundwater, soil or atmosphere (vapor, clouds, rain, snow) are considered components of nutrients and energy cycling within a watershed, but outside the scope of our proposed research plan.

We acknowledge that the research themes for lakes and river/stream watershed components are more comprehensively developed in this report, than the near-shore marine and wetlands/terrestrial themes. This is not because of any authors' bias in terms of research interests, but rather to date there has been much less emphasis on studies of near-shore and wetlands/terrestrial habitats in relation to nutrient / energy cycling in the Kenai RW and more diffuse interests in these habitats or watershed components. We recognize that more extensive feedback from researchers with expertise and interest in these areas are needed to elaborate the last two themes. We are actively working to further develop these research themes and we continue to seek input to better integrate these components into the study plan for the Kenai RW. For each of our designated research themes, we identified the scientific theme leaders and provide:

- an overview of the general structure and function of the specific watershed component,
- "what we know" and "what we do not know" about that watershed component,
- "critical" research objectives and deliverables and
- the understanding of how the specific habitat-based research theme cuts across ecosystem boundaries and habitat types.

The last three to four decades of research have shown that the pathways and efficiency of nutrient and energy are the major forces determining the structure, function and productivity of ecosystems. Based on this rich literature and for the simplicity of modeling and linking ecosystem types, we have chosen to use nutrient/energy as the robust and common currency for this research initiative. Furthermore, it is hypothesized that the vast amount of nutrients from returning salmon could be a major factor sustaining the fisheries and watershed productivity of Kenai RW. As this hypothesis is yet to be fully validated with quantitative results, the study of nutrient pathways and cycling becomes a critical way of addressing this issue.

Theme 1

3.1.1 Lake Ecosystems and Their Role within Kenai RW

Theme Leaders

Leader: Jim A. Edmundson, ADF&G, Commercial Fisheries Division.

Co-Leaders: Mark Willette. ADF&G, Commercial Fisheries Division. Daniel Schindler, Department of Zoology, University of Washington, Asit Mazumder, University of Victoria, Biology; Mark R.S. Johannes, University of Victoria, Biology.

Lakes in the Kenai RW have multiple human uses for hydroelectric power, water supply, waste disposal, and recreation including swimming, boating, and wildlife viewing and fisheries. In addition, many of the lakes, rivers and streams are used as nursery and spawning habitats by several populations of anadromous and resident fish species that support commercial, recreational, personal use, and subsistence fisheries. Kenai RW lakes are under ever increasing human exploitation pressure due to continued development and steady population growth. Many of the lakes and streams are now accessible by road or offroad vehicles and several portions of the watershed have been extensively developed for recreation and residential use. Changes experienced by Kenai RW lakes include shoreline alterations, loss of fish spawning and rearing habitats, fishing impacts and the accumulation and / or loss of important nutrients from anthropogenic sources and impacts. Such anthropogenic stresses to lakes have been documented in the nearby Matanuska-Sustina area of south-central Alaska (Woods 1985, Woods 1986, Edmundson et al.1989). There is a genuine need to understand the role and function of lake ecosystems within the larger context of Kenai RW. It will be critical to integrate this knowledge with land and resource use planning to develop a watershed (holistic) management approach to sustain the natural productivity and biodiversity of natural resources within Kenai RW. To effectively manage the watershed, we need to characterize and quantify nutrient and energy pathways, hydrologic input and outputs and ecosystem based links among the various components of the watershed (Fig. 8).

Lakes play an important and critical role in the structure and function of the physical and biological components of Kenai RW.

- Lakes within the watershed buffer downstream water levels and flow and maintain seasonal fisheries habitats;
- lakes retain, transfer and modify

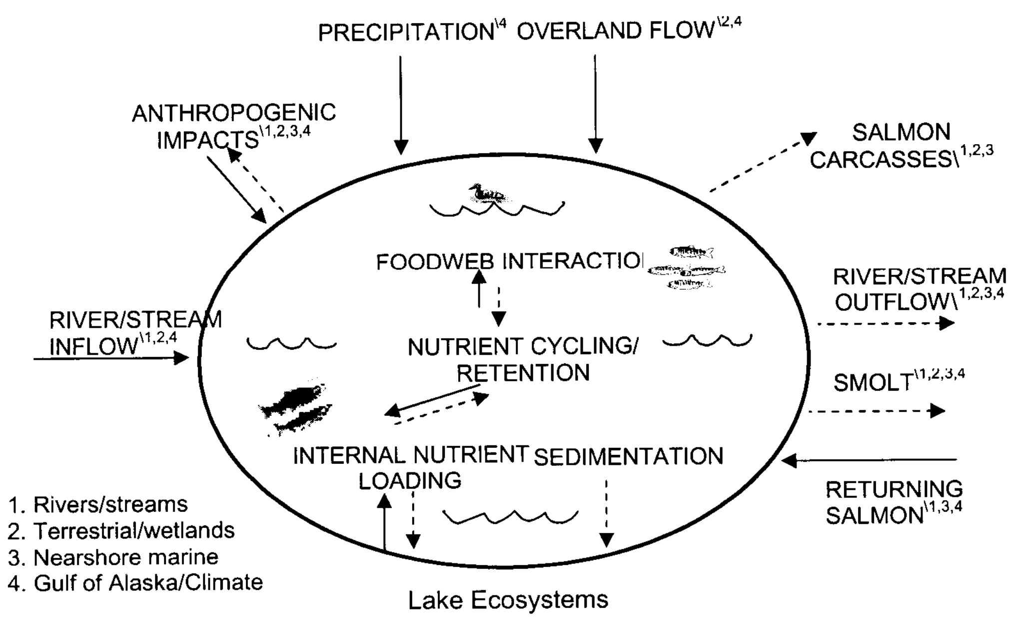

Figure 8: Potential nutrient inputs (solid lines), outputs (dashed lines), and nutrient pathways within a hypothetical KRW lake (oval). Superscripts (1-4) indicate nutrient linkages to other ecosystem components of Kenai RW (see inset for key).

nutrients and energy and deliver nutrients through outflow to downstream habitats;

- lakes are important spawning, nursery habitats for many fish species;
- lakes are important freshwater rearing and staging refuges for many terrestrial and aquatic based wildlife species.

Of the various components of the Kenai RW, lakes have been investigated the most (Boggs et al. 1997, Johannes et al. 2002a, b). However, the role of lake ecosystems in sustaining the functioning and productivity of overall watershed is not known.

What we know about lakes and their role in Kenai RW?

- Three main types of lakes have been identified in the watershed based on variable concentrations of glacial silt, and yellow color (dissolved organic material) derived from the nature of their source water;
- we know some of the basic limnological characteristics (e.g. water clarity, nutrient concentrations and plankton abundance) of the major glacial (e.g., Skilak and Kenai) and clear lakes (e.g., Hidden and Russian) in the watershed;
- lakes within the watershed have highly variable levels of productivity which may be linked to differences in lake typology, food web structure, and nutrient/energy transfer efficiencies;
- we have abundance, size, and age composition data of select adult and juvenile salmonid stocks for a few lake systems;
- lakes in the watershed receive variable quantities of marine-derived nutrients may be linked to returning adult salmon and decomposing carcasses following spawning;
- returning salmon and resulting carcasses may influence the productivity of lakes and downstream habitats including streams, riparian zones, wetlands, and terrestrial components;
- we know increases in glacial turbidity decreases the productive capacity of lakes through impaired light transmission;
- we know some of the lakes within the watershed have been extensively developed, which may be linked to changes in fish and wildlife habitat and productivity.

What we don't know about lakes and their role in Kenai RW?

Many critical questions surrounding the role of lake ecosystems in sustaining productivity of the Kenai RW remain unanswered. (Boggs et al. 1997, Edmundson et al. 2002). Not enough quantitative information is available to fully understand the major biological and hydrological processes and their interactions in Kenai RW lakes in order to define the influence on nutrient loading and pathways with other aquatic and terrestrial components of the watershed.

- We do not know how nutrient and energy transfer efficiencies are modified by lake typology;
- we do not know how the large glacial lakes of the watershed and their outflow

influence downstream nutrient conditions and productivity;

- we know very little about the amount and kinds of nutrients from marine, terrestrial, and atmospheric sources to lakes in the watershed;
- we lack information about nutrient uptake processes and assimilation rates, transformations, sedimentation, transportation mechanisms, and storage and lag effects in lakes of the watershed;
- although decreases in salmon abundance have been suggested to produce a shortage of critical nutrients and organic matter, thereby limiting production, recovery or sustainability of salmon stocks, we do not know whether salmon returns, resulting carcasses and "marine-derived" nutrients influence Kenai RW lakes or salmon;
- we do not know the relative contribution of each salmon life history (freshwater versus marine) on adult salmon production;
- we do not understand if marine derived nutrients and juvenile salmon density, through variations in adult salmon returns, influence lower trophic level production, food web interactions and energy;
- we do not know how regional climate variations alter the physical, chemical and biological conditions of lakes;
- we do not know how the paleolimnological (long term historic) patterns are coupled with current information on salmon abundance, carcass loading and lake productivity as indexed through trophic linkages and nutrients.

Critical Research Objectives and Deliverables on the Role of Lake Ecosystems within Kenai RW.

Based on what we do not know, these are the identified critical research objectives relating the role of lakes ecosystems in sustaining the productivity of the Kenai RW.

- Compile existing data, conduct retrospective and exploratory analysis and develop ongoing lake inventory and assessment;
- characterize and quantify the amount and kinds of nutrients from marine, terrestrial, and atmospheric sources to lakes in the watershed;
- determine the influence of large glacial lakes of the watershed and their outflow on downstream nutrient conditions and productivity;
- identify and model nutrient uptake processes and assimilation rates, transformations, sedimentation, transportation mechanisms, and storage and lag effects in lakes of the watershed;
- predict and model the effects of salmon carcasses and marine-derived nutrients and their influence on lake fish density and productivity in the Kenai RW;
- quantify and model interannual adult salmon production from survival in freshwater and marine life history stages;
- quantify and model the impacts of nutrients and predation on food web

dynamics and population characteristics of macrozooplankton and juvenile salmonids;

- examine and predict the impacts of interannual variability of climatic conditions on the physical, chemical and biological conditions of Kenai RW lakes;
- construct the paleo history in Kenai RW lakes using stable isotopes (marine derive nutrients), fossil records of zooplankton and algae, and other biogeochemical tracers, to evaluate the utility of these records as indicators of past and current lake ecosystem and salmon productivity.

Theme 2

3.1.2 River and Stream Ecosystems and Their Role within Kenai RW

<u>Theme Leaders</u>

Leader: Alexander Milner, Natural Heritage Program, University of Alaska, Anchorage.

Co-Leaders: John Richardson, Forest Sciences, University of British Columbia; Mark S. Wipfli, US Forest Service, Bruce King, ADF&G, Sport Fish Division, Asit Mazumder. Biology, University of Victoria.

Rivers and streams in the Kenai RW have multiple human uses for water supply, waste disposal, and recreation including boating, and wildlife viewing and fisheries. In addition, an extensive part of the rivers and streams are also used as nursery, holding, migration and spawning habitats by several populations of anadromous and resident fish species that support commercial, recreational, personal use, and subsistence fisheries. The mosaic of the river and stream systems within Kenai RW provides critical breeding, rearing and feeding habitats for several bird and mammal species. Rivers and streams within Kenai RW are under ever increasing human exploitation pressure due to development along streambanks and riparian corridors (Isaacs et al. 1994, Weiner 1998). Like Kenai RW lakes, many of the remote streams and rivers are now accessible by road and are being developed. Within Kenai RW, rivers and stream are experiencing a number of changes including: streambank erosion (Scott 1982) from bank trampling, and boat wakes (Reckendorf and Saele (1991), sediment loading, riparian corridor development, timber harvest, loss of fish spawning and rearing habitats, and the accumulation and / or loss of important nutrients from anthropogenic sources and impacts.

These rivers and streams form the fundamental vectors of surface transport and links between the various upstream and downstream ecosystem components of the watershed. Consequently, there is a genuine need to understand the role and function of rivers and stream and integrate this knowledge with lakes, wetlands, terrestrial and nearshore marine ecosystems. Collectively, as the rivers and streams that cut across ecosystems and habitat types, perhaps more critically than other ecosystem components within the watershed, it will be critical to integrate the rivers and stream ecosystems into the context of sustainable land and resource use planning within Kenai RW (Fig. 9).

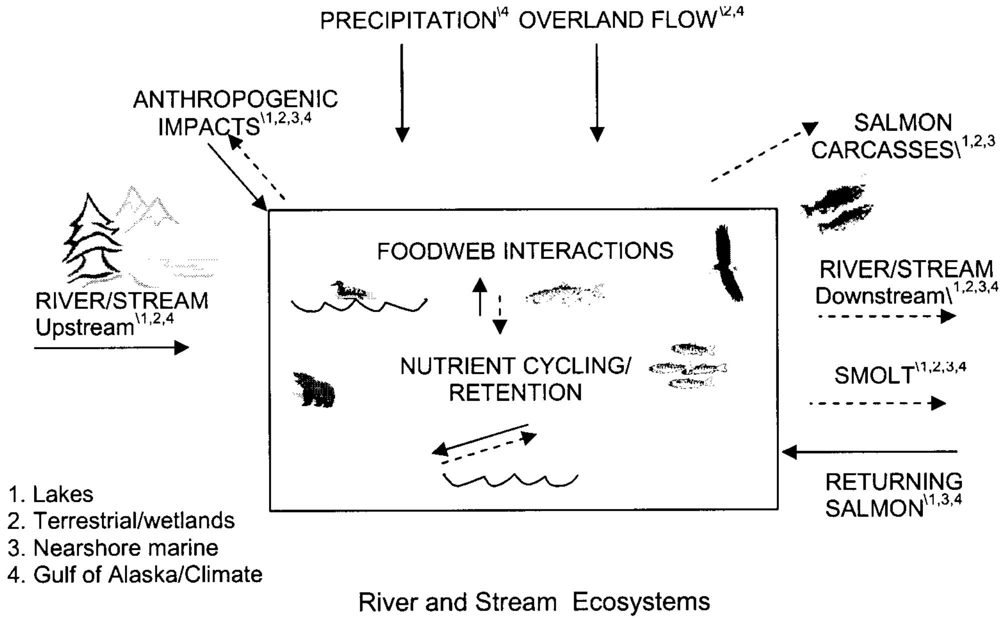

Figure 9: Potential nutrient inputs (solid lines), outputs (dashed lines), and nutrient pathways within a hypothetical Kenai RW rivers (rectangle). Superscripts (1-4) indicate nutrient linkages to other ecosystem components of KRW (see inset for key).

The productivity of streams depends on the complex interactions between streams, surrounding vegetation, seasonal climatic variation and geomorphology. The "River Continuum Concept" (RCC, Vannote et al. 1980) describes energy and nutrient input along a stream / river corridor from headwaters to estuaries and the associated changes in primary production, litter and woody debris input and functional feeding of invertebrate and fish communities. In low order streams, riparian zones play a major role in regulating nutrient and energy flow (Webster et al. 1992). Riparian woody debris, leaf litter and other allochthonous (terrestrial) material entering streams and rivers provide the primary energy base (Cummins et al. 1989, Hax and Golladay 1993). In higher order streams and rivers, light and nutrients and foodweb structure have a greater role in determining the overall productivity of plant and animal communities (Minshall 1978).

The role of riparian vegetation and nutrients / energy illustrated by RCC, may have an influence on macroinvertebrate and fish communities, but the transport of nutrients / energy in the Kenai RW may also be strongly influenced by the large glacial lakes (Milner and Petts 1994; Milner et al. 2001), which buffer the continuum and reduce downstream transport of coarse particulate organic matter (CPOM) and other forms of nutrients and energy. Both Kenai and Skilak Lakes receive CPOM from upstream tributaries. In the Kenai RW, riparian vegetation is limited in the upper reaches due to the braided nature of the river channels. The large lakes of the Kenai River increase the stability of the river downstream and enhance water temperature (Dorava and Milner 1999).

Studies have shown that some of the lower reaches in the Kenai River support a diverse invertebrate community with up to 26 genera with densities approaching 5000 m^{-2} (Milner 1992; Milner and Gabrielson 1993). These invertebrate communities are important primary food sources for rearing juvenile salmonids, particularly juvenile chinook, coho, rainbow and other resident fish species. However, we know little of the nutrient and energy sources supporting macroinvertebrate communities, and juvenile salmonid growth and survival.

General studies of glacier-fed river channels identified epilithic algae and filamentous chrysophytes as dominant food sources for invertebrates in many systems (Zah et al. 2001), but allocthonous particulate organic matter increases in importance where available autochthonous productivity is limited (Zah and Uehlinger 2001). Although during the summer glacial melt, the Kenai River is turbid and primary productivity is largely light limited, there may be windows for extensive algal growth when the river is clear in spring and fall. Milner et al. (2001) identified these times as periods of immense importance for the growth of epilithic diatoms and filamentous algae in glacier-fed rivers and Uehlinger et al. (2000) showed chlorophyll *a* levels exceeding 100 mg m^{-2} even close to the glacier-margin when the river became clearer at lower flows. An abundance of diatoms and algal resources during these windows would allow for extensive periods of growth of juvenile stages of aquatic insects. This may be particularly important during the spring so that insects can emerge and become adults prior to the onset of glacial melt. The timing and duration of these events may impose critical periods of invertebrate abundance and therefore importance links to the growth and survival of salmon and other fish species.

Undeniably, the rivers and streams are probably the most important ecosystem components linking freshwater lakes and marine ecosystems and overall productivity of the watershed. Yet, there is very little quantitative results evaluating these critical linkages from a watershed perspective.

River and streams perhaps play the most important and critical role in determining the structure, function and productivity of the Kenai RW.

- Rivers and streams within the watershed provide the dynamic link / corridor for nutrients / energy, water, sediment – particulate matter transport between upslope, upstream and downstream habitats;
- they retain, transfer and modify nutrients and energy and deliver nutrients through flow to downstream habitats;
- they are important migration, holding, spawning, incubation and nursery, habitats for many fish species;
- they are important freshwater rearing and staging refuges for many terrestrial and aquatic based wildlife species.

Water quality and general conditions of rivers and streams within Kenai RW have been investigated frequently, but inconsistently and without integration to other ecosystem and watershed components (Boggs et al. 1997, Johannes, Mazumder and Edmundson 2002a,b). There are considerable gaps in our knowledge about the role of rivers and streams in determining the pathways, cycling and efficiency of nutrients and energy within the context of the structure, function and productivity of the Kenai RW.

What we know about rivers and streams and their role within Kenai RW?

- There are three main types of rivers and streams within the Kenai RW based on variable concentrations of glacial silt and yellow color (dissolved organic material) derived from the nature of their source water;
- we know some of the basic water quality characteristics and nutrient concentrations of the mainstem glacial river and head water tributaries (e.g. Russian, Killey, Moose, Funny Rivers) in the watershed;
- rivers and streams within the watershed have highly variable levels of productivity which may be linked to differences in surrounding landscape and sub–basin gradient and channel characteristics, food web structure, and energy transfer efficiencies;
- abundance, size, and age composition data of selected adult and juvenile salmonid stocks are available for a few river systems;
- rivers and streams in the watershed receive an unknown and variable quantities of marine-derived nutrients from returning salmon;
- returning salmon and resulting carcasses may influence the productivity of downstream habitats including streams, riparian zones, lakes, wetlands, and terrestrial components;
- we know that increases in glacial turbidity decreases the productive capacity of rivers and streams through impaired light transmission;
- we have some idea of the river corridors and riparian areas within the watershed that have been extensively developed, which may be linked to changes in fish and wildlife habitat and productivity.

What we don't know about rivers and streams and their role within Kenai RW?

Many critical questions surrounding the role of rivers and streams in sustaining structure, function and overall productivity of the Kenai RW are yet to be answered.

- We do not know the loading rates of nutrients from different sources including marine derived nutrients from returning salmon;
- we also do not know the relative contribution of each of the major salmon species to total nutrient loading.
- is there an important compensatory or trade-off "nutrient-productivity relationship" among major anadromous runs?
- We do not know how the nutrient and energy transfer efficiencies of the watershed are modified by the physical and biological characteristics of the rivers and streams;
- we do not know the role of glacial melt waters in determining the downstream nutrient conditions and productivity;

- we lack information about nutrient uptake processes and assimilation rates, transformations, sedimentation, and transportation mechanisms, and lag effects in streams / rivers of the watershed;
- we do not know whether salmon returns, resulting carcasses and marine-derived nutrients influence the productivity of fish, especially juvenile salmonids, and other bird and mammal species within Kenai RW;
- we do not know the relative contribution of each salmon life history (freshwater versus marine) on adult salmon production;
- we do not understand if marine derived nutrients and juvenile salmon density, through variations in adult salmon returns, influence lower trophic level production (macroinvertebrates), food web interactions and energy;
- we do not know how regional climate variations alter the physical, chemical and biological conditions of streams and rivers;
- we do not know if the river and streams are in fact the conduits of nutrient and energy source for nearshore marine ecosystems.

Critical Research Objectives and Deliverables on the Role of River and Stream Ecosystems within Kenai RW.

Based on what we do not know, we have identified the following critical research objectives relating the role of rivers and streams in sustaining the structure, function and productivity of the Kenai RW.

- Compile existing data, conduct retrospective and exploratory analysis and develop ongoing river and stream inventory and assessment;
- use digital elevation and terrain maps, and GIS based models to characterize and quantify the quantity and quality of spawning habitats of major fish species within Kenai RW;
- characterize and quantify the amount and kinds of nutrients / energy from marine, terrestrial, and atmospheric sources to rivers and streams in the watershed;
- determine the influence of glacial melt water on downstream processing and transport of nutrients, organic matter;
- quantify the contribution of lakes in determining nutrients and organic matter inputs to rivers and streams;
- identify and model nutrient uptake processes and assimilation rates, transformations, and transportation mechanisms, and lag effects in rivers and streams within the watershed;
- predict and model the effects of salmon carcasses and marine-derived nutrients and their influence on productivity of algae, invertebrate and fish communities;
- quantify and model long-term patterns of juvenile and adult fish production from nutrients, habitat quality and foodweb characteristics;
- evaluate and model the potential impact of single-species based management

and allocations on multi-species interactions and productivity.

- examine and predict the impacts of interannual variability of climatic conditions on the physical, chemical and biological conditions of Kenai RW streams and rivers.

Theme 3

3.1.3 Nearshore Marine Ecosystems and Their Role in the Kenai RW

Theme Leaders

Leader: Russ Hopcroft, University of Alaska, Fairbanks.

Co-Leaders: Mark Willette, ADF&G, Commercial Fisheries Division; Tom Kline, University of Alaska, Fairbanks; John Dower, Earth and Ocean Sciences, University of Victoria.

There is only one published paper on nutrients in estuaries (Fujiwara and Highsmith 1997) which discusses elevated levels of marine-derived nitrogen in estuarine plankton associated with upstream salmon migration and spawning in central Alaska. This research suggests important links transferring marine-derived nutrients through the foodchain from autotroph to macroinvertebrate prey of juvenile salmon in a nearshore marine site (Kachemak Bay, Alaska).

There are some other reports on the linkage between spawning salmon in freshwater ecosystems and the sensitivity of nearshore environments to changes in productivity, but most of these studies are qualitative and speculative in nature. It is possible that a greater portion of the nutrients from salmon carcasses flow down the streams and rivers to near-shore marine environment, which in return enhance the food base and growth of juvenile fish. Very little or nothing is known on the flow dynamics of nutrients within a watershed and their relative importance to terrestrial/wetland, lake, stream, river and nearshore marine environment in sustaining fish and ecosystem productivity (Fig 10.).

Historically, the nearshore marine ecosystem of Cook Inlet off Kenai River supported a large population of beluga whales. The Cook Inlet population of belugas is considered as one of the most isolated and unique sub-populations of the five identified populations in Alaska. Results of an 8-year aerial survey by NOAA and a review of existing studies suggested that the beluga population within Cook Inlet has been shrinking between 1970s to 1990s. It has been suggested that from 1994 to 1998, this beluga population may have declined by 50%. Much of the available information on Cook Inlet nearshore habitats are descriptive in nature and could be greatly improved by integration of quantifiable data on the foodweb linking belugas in this system. One study recommended that there is dire need for seasonal data on fish run numbers and other habitat data for the rivers flowing into Cook Inlet and the importance of fish in sustaining beluga population (Moore et al. 2000).

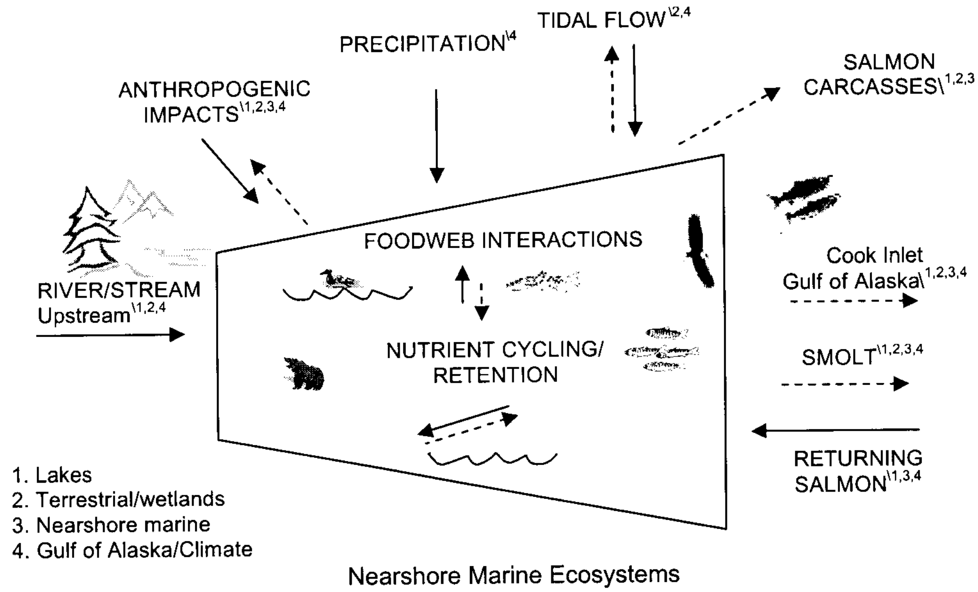

Figure 10: Potential nutrient inputs (solid lines), outputs (dashed lines), and nutrient pathways within a hypothetical Kenai RW estuary nearshore (trapezoid). Superscripts (1-4) indicate nutrient linkages to other ecosystem components of KRW (see inset for key).

Nearshore marine ecosystems are perhaps the most important and critical link between Kenai RW and the greater Gulf of Alaska Ecosystem.

- Nearshore marine ecosystems, because of their strong thermal, density and salinity gradients, play a critical role in the exchange of nutrients between marine and freshwater habitats;
- they are critical habitats for a rich diversity of fish, sea bird and marine mammal populations;
- they are important migration, holding, spawning, incubation and nursery, habitats for many fish species;
- they are critical staging areas for returning adult salmon to Kenai RW;
- they provide important aquatic resources for commercial, sport and subsistence fisheries;
- they show cumulative effects of nearshore development as well as watershed alterations within Kenai RW.

What we know on the role of nearshore marine ecosystems within Kenai RW.

- We know the general oceanographic patterns of currents, sea surface temperature, stratification, tidal mixing and upwelling in Cook Inlet and its nearshore marine environment;
- we know that there are strong salinity and turbidity gradients in the nearshore marine habitats off Kenai River;
- we know that this ecosystem receives a large loading of silt and sediments from the Kenai River system;

- there are some preliminary data on phytoplankton and zooplankton densities, fish abundance and distribution (e.g., herring and sand lance), and breeding rates of selected sea bird species (murres and kittiwakes) from nearshore sites of Cook inlet and Gulf of Alaska;
- we know that nearshore marine areas are important feeding, rearing and breeding grounds for forage fish birds and marine mammals.
- it is also known that this ecosystem supports a unique and isolated population of beluga whales;
- we know that nearshore marine environment in the Cook Inlet receive seasonally variable pulses of nutrients from the upstream freshwater ecosystems and their watersheds;
- we know that the nearshore marine habitats off Kenai River may have been impacted by aromatic hydrocarbons and other contaminants from oil spills and ongoing oil and gas extraction activities;
- we know that regional shifts in ocean-climate conditions can influence the productivity of plankton and fish.

What we don't know on the role of nearshore marine ecosystems within Kenai RW.

- We do not know the extent of sediment and silt loading from Kenai RW to nearshore marine environment and its impact on habitat quality for plankton, fish, sea birds and mammals;
- we do not know the loss of nutrients from Kenai RW to the nearshore habitats of Cook Inlet and its implications for ecosystem productivity;
- we do not know the relationship between anadromous fish runs in Kenai RW and the foodweb productivity of nearshore habitats;
- we do not know the importance of this nearshore ecosystem as a rearing and feeding habitat for outmigrating juvenile fish, especially salmon, from Kenai RW;
- we do not know the extent and dynamics of contaminants in the fish communities in the Cook Inlet.

Critical Research Objectives and Deliverables on the Role of Nearshore Marine Ecosystems within Kenai RW

- Characterize, quantify and model the loading of sediments and silts into nearshore marine habitats as a function of the hydrology and watershed processes of Kenai RW;
- Quantify and model the loss of nutrients from Kenai RW to the nearshore habitats of Cook Inlet as a function of fish runs and watershed hydrology;
- track, quantify and model the transfer of Kenai RW derived nutrients into the foodweb productivity of nearshore habitats;
- determine the abundance, distribution, residency and feeding patterns of outmigrating juvenile salmon in the nearshore marine ecosystem;
- determine the extent and dynamics of contaminants in the fish and marine mammal communities in the Cook Inlet;

- investigate the potential use of long-term data on fisheries and sediment chronology to assess the effects of regional shifts in ocean-climate conditions can influence the productivity of plankton and fish of nearshore marine ecosystems.

Theme 4

3.1.4 Wetland and Terrestrial Ecosystems and Their Role within Kenai RW

Theme Leaders

Leader: Mike Gracz, Alaska Natural Heritage Program, University of Alaska, Anchorage.

Co-Leaders: Robert DeVelice, USDA Forest Service; Keith Boggs, Alaska Natural Heritage Program, University of Alaska, Anchorage; Phil North, USEPA and Kenai River Center; Coowe Walker, Kachemak Bay Research Reserve.

An understanding of the linkages between the terrestrial-wetland and aquatic systems is critical for the maintenance of a healthy and productive Kenai RW, especially for fish and wildlife production (Fig. 11). Threats to wetlands and floodplains adjoining the Kenai River have increased due to steady growth and development within Kenai RW. Contiguous wetlands are known to be an integral part of the river systems by providing natural water filtration processes for the removal of pollutants, reducing flood impacts by acting as by acting as retention areas, and supplying continuous water discharges during times of low river flows (Lands Committee, Kenai River Special Management Area Advisory Board 1986, Alaska Department of Natural Resources 1986, The Nature Conservancy 1994).

Some studies have suggested that energy (organic matter) and nutrient inputs from salmon strongly influence terrestrial (riparian and wildlife) and aquatic ecosystems in oligotrophic watersheds in the Pacific Northwest (Cederholm et al. 1989, Hildebrand et al. 1996, Ben-David et al. 1997, Ben-David et al. 1998, Reimchen 2000, Helfield and Naiman 2001). However, most of these studies are qualitative and speculative in nature. It is possible that a greater portion of the nutrients derived from salmon carcasses flow downstream to near-shore marine environments, which in return enhance the food base and growth of freshwater and marine plankton, fish and marine mammals. Very little to nothing is know on this nutrient flow and the dynamics of nutrients within a watershed and their relative importance to terrestrial, wetland, lake, stream, river and nearshore marine environments in sustaining the productivity of whole watersheds.

Floodplains and wetlands provide organic material in the way of food resources and habitat for aquatic and terrestrial invertebrates, and a primary food source for many fish. Bank-side vegetation provides protective cover for fish, and is the source of woody debris for fish habitat. Wetlands are also a rearing habitat for young coho salmon. If inputs into the aquatic system from the terrestrial ecosystems are high, then alterations of terrestrial and wetland habitats could have a major impact on the nutrient pathways and productivity of aquatic resources.

The use of wetland habitats by waterfowl on the lower Kenai River and tidal marshes has

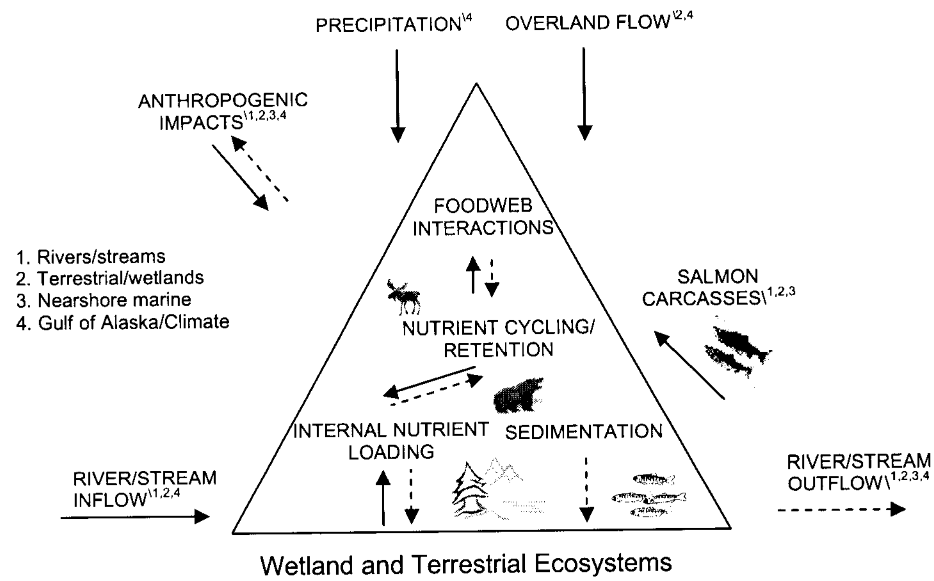

Figure 11: Potential nutrient / energy inputs (solid lines), outputs (dashed lines), and nutrient pathways within a hypothetical Kenai RW wetland / terrestrial landscape (triangle). Superscripts (1-4) indicate nutrient linkages to other ecosystem components of Kenai RW (see inset for key).

been studied (Rosenberg 1986). These wetlands and tidal influenced habitats are unique because they support migrating cranes, snow geese, other waterfowl, and nesting habitat for many other avian species. It may also be the most vulnerable ecosystem component within Kenai RW due to its proximity to current and future industrial development.

Bangs and Bailey (1982) found that along the Kenai River corridor, bald eagles (and other birds) are susceptible to disturbances in wetlands and nearby terrestrial ecosystems. For upland forest sites, the US Forest Service (1978) made several research recommendations about avian habitats including determining the amount of habitat necessary to maintain bird populations in forest ecosystems and conducting studies that link disturbance regimes and forest successional stages to avian habitats. As to other plant-animal relationships, Bangs (1979) stated that little is known about the effect of changes in the community structure and diversity of plants on small mammal populations within Kenai RW.

A comprehensive baseline study or literature review of nutrient, hydrologic and energy inputs from the terrestrial-wetland ecosystems to the freshwater and nearshore marine ecosystem is highly recommended (Rosenberg 1986). Cumulatively, the effects of small scale timber harvesting and filling/draining of wetlands can have a profound negative impact on nutrient and sediment processes and associated productivity of the various aquatic systems within Kenai RW. Watershed and land use planning based on results from our proposed study would help determine the level of sustainable development of Kenai RW with special sensitivity to wetlands, floodplains and adjacent terrestrial landscapes.

An understanding of groundwater discharge rates between lowland wetlands and tributary streams would also help assess the potential impacts of groundwater pumping or surface water diversion from these wetlands and associated nutrient transport within Kenai RW (The Nature Conservancy 1994; Lehner 1994).

To have a good idea of the importance of wetlands and terrestrial ecosystems on the productivity of overall Kenai RW, we first need to inventory these ecosystem components and store this information within a GIS database. In addition, the major modification or disturbances to wetland and terrestrial components need to be identified, quantified and incorporated into a broader watershed management plan. As an example, insect-caused mortality of spruce trees within Kenai RW has increased dramatically since the mid 1980s. Dead and fallen trees from beetle larvae drastically transform the terrestrial landscape and modify transport and cycling of nutrients, which may also alter the productivity of anadromous and non-anadromous rivers and streams. The extent and distribution of these affected forest tracts need to be delineated from those areas unaffected and integrated with current and future information/databases on water quality, nutrients and productivity of wetlands, lakes, and rivers and streams and nearshore marine ecosystems within Kenai RW. The following list identifies the major gaps on the role of wetland and terrestrial ecosystems within the context of the structure, function and productivity of Kenai RW.

Structure and function of wetland and terrestrial ecosystems can have significant impact on overall watershed productivity through the alteration of nutrient and sediment processing within Kenai RW.

- wetlands are critical rearing, feeding, breeding and migratory habitats for a rich diversity of fish and wildlife;
- wetlands could be important sources and sinks of nutrients derived from marine, freshwater, terrestrial and atmospheric inputs;
- wetlands are critical nursery habitats for juvenile coho, chinook and other fish species;
- wetlands act as an important buffer zone between terrestrial and aquatic ecosystems, particularly in the lowland areas and lower reaches of Kenai RW.

What we know on the role of wetland and terrestrial ecosystems within Kenai RW.

- we know the distribution and size (area) of wetland tracts adjacent to the upper, middle and lower reaches of the Kenai River and some of it's tributaries;
- wetland and terrestrial ecosystems within Kenai RW currently face variable levels of alteration, habitat fragmentation and degradation linked to regional development;
- we know spruce bark beetle infestations have impacted large stands of white and Sitka spruce within Kenai RW;

- we know wetlands serve as important rearing areas for Dolly Varden, chinook and coho salmon;
- we know that wetlands are critical habitats for populations of brown and black bears, moose and caribou within Kenai RW;
- we know that the seasonal availability of adult salmon provide an important food resource for terrestrial wildlife and may be linked to larger litter size and cub survival of brown bears;
- we know that the regional climatic changes (winter warming) may be responsible for receding wetlands and increasing level of spruce bark beetle infestations.

What we don't know on the role of wetland and terrestrial ecosystems within Kenai RW.

- We do not know the influence of riparian and wetland development on nutrient and sediment transfer to lakes, rivers and streams;.
- we do not know the role wetlands and riparian zones play in the contribution of nutrients and energy to benthic algae, invertebrates and fish;
- we do not know the quantitative contribution of wetlands as a source or sink of marine derived or other nutrients within the context of Kenai RW;
- we do not have the quantitative estimates of wetland use as rearing habitats by juvenile salmon and other fish;
- we do not know the contribution nor the role of large woody debris derived from terrestrial ecosystems that function as substrate, habitat cover and nutrient supply to downstream watershed components including nearshore marine ecosystems;
- we do not know what effects regional climatic shifts have on the structure, function and productivity of wetland and terrestrial ecosystems within Kenai RW.

Critical Research Objectives and Deliverables on the Role of Wetland and Terrestrial Ecosystems within Kenai RW

- Develop a more thorough study plan based on the literature review of nutrient, hydrologic and energy inputs from the wetland - terrestrial system to the aquatic system;
- develop GIS database to characterize and quantify the distribution of wetlands and terrestrial habitat types within Kenai RW;
- use digital elevation and terrain database on a GIS framework to model loading of nutrients from wetland and terrestrial ecosystems to aquatic habitats;
- develop functional profiles of wetlands and floodplains within the Kenai RW;
- enhance monitoring of bird populations and habitats of the lower Kenai River wetlands, including the tidal marshes;
- quantify the transport of marine derived nutrients from lakes, rivers and streams to wetland and terrestrial ecosystems by birds, bears and other predators.

4.0 Research Timeline and Deliverables

We envision a long-term (7-year) research program to address the complex and interdisciplinary issues of nutrient – energy cycling, marine derived nutrients and their linkages to the structure, function and productivity of whole Kenai RW. Given the significant inter-annual variability in climatic conditions, fish runs, continued watershed development and regional economic situations, a shorter term study will not provide the robust models and predictions required for making sound management decisions for this precious natural heritage. To link freshwater productivity through the functioning of each of the component ecosystems, which cycle at highly variable time frame, it is critical to deal with temporal and spatial heterogeneity in a longer-term research plan. For example, to link habitat quality to the productivity of each of the major salmon species, we must integrate data for each of the freshwater and marine life stages of at least 2-3 cohorts, which will require 5-7 years of consistent data collection that cuts across the major habitat types and watershed components. Kenai RW has received significant research attention during the last 20 years, but one of the problems with the past efforts has been a lack of consistent multi-year data and a lack of consistent databases linking major ecosystem components within the watershed. Furthermore, there has been no effort to co-ordinate and integrate ongoing research activities of various agencies, stakeholders and scientific disciplines into a focused research management plan.

The tables below show the specific timelines, objectives and deliverables for the overall program as well as for each of the four research themes.

Themes				**Year**			
	1	2	3	4	5	6	7
Program Management / Communication							
Lake Ecosystems							
River and Stream Ecosystems							
Nearhsore Marine Ecosystems							
Wetland and Terrestrial Ecosystems							

	Active Data Collection / Reporting – Communication / Data Assembly
	Active Data Assembly / Reporting - Communication
	Active Reporting / Communication

4.1 Program / Research Management

Objective	Deliverable	Start	Completion
Program Initiation and Coordination	Management of research theme, implementation and integration, funding and budget management	Year 1	Year 7
Communication and Dissemination	Bi-annual science/public workshops and bulletins; bi-monthly conference calls with Board, Scientific Committee, and Theme Leaders	Year 1	Year 7
Database / Information System	Manage bibliography, database, GIS support	Year 1	Year 7

4.2 Timelines, Objectives and Deliverables by Theme

4.2.1 Theme 1: Lake Ecosystems and Their Role in Kenai RW

Objective	Deliverable	Start	Completion
1. Retrospective analysis / lake inventory	Comprehensive digital and geographic databases, reporting, primary papers	Year 1	Year 2
	Ongoing monitoring program	Year 1	Year 7
2. Lake nutrient budget / models	Mass balance models for nutrients and energy	Year 2	Year 4
3. Major lake influences downstream	Mass balance and hydrologic models for nutrients and energy	Year 2	Year 4
4. In lake nutrient processes	Nutrient loading model to quantify the role of marine derive nutrients	Year 1	Year 3
5. Role of MDN in lakes	Nutrient loading model to quantify the role of marine derive nutrients	Year 1	Year 3
6. Salmon life history based productivity	Nutrient foodweb models to predict juvenile sockeye growth and survival	Year 1	Year 7
7. Food web and nutrient impacts	Nutrient foodweb models to predict lower trophic level production	Year 2	Year 5
8. Climatic impacts	Model the influence of climatic change on fish and lake productivity across KRW lakes	Year 1	Year 3
9. Long term historic records	Reconstruction of historic record of fisheries and lake productivity, calibration of mass balance model	Year 1	Year 3
10. Integrating lakes within Kenai RW	Produce a monograph on the role of lake ecosystems in sustaining the productivity of Kenai RW		Year 6,7

4.2.2 Theme 2: River and Stream Ecosystems and Their Role in Kenai RW

Objective	Deliverable	Start	Completion
1 Retrospective analysis / stream - river inventory	Comprehensive digital and geographic databases, reporting, primary papers	Year 1	Year 2
	Ongoing monitoring program	Year 1	Year 7
2 Stream - River nutrient budget / models	Mass balance models for nutrients and energy, hydrologic model	Year 2	Year 4
3 Glacial, riparian and wetland nutrient processes	Nutrient loading model to quantify the role and derivation of nutrients	Year 1	Year 3
4 Role of MDN in streams ./ rivers	Nutrient loading model to quantify the role of marine derive nutrients	Year 1	Year 3

5 Salmon life history based productivity	Nutrient foodweb models to predict juvenile salmon growth and survival in stream and rivers	Year 1	Year 7
6 Climatic impacts	Model the influence of climatic change on fish and river productivity across KRW	Year 1	Year 3
7 Long term historic records	Reconstruction of historic record of fisheries and river productivity, calibration of mass balance model	Year 1	Year 3
8. Integrating river basins within Kenai RW	Produce a monograph on the role of river ecosystems in sustaining the productivity of Kenai RW		Year 6,7

4.2.3 Theme 3: Nearshore Marine Ecosystems and Their Role in Kenai RW

Objective	Deliverable	Start	Completion
1 Retrospective analysis / estuary inventory	Comprehensive digital and geographic databases, reporting, primary papers	Year 1	Year 2
	Ongoing monitoring program	Year 1	Year 7
2 Estuary nutrient budget / models	Mass balance models for nutrients and energy	Year 2	Year 4
3. Role of MDN in estuaries / nearshore marine	Nutrient loading model to quantify the role of marine derive nutrients	Year 1	Year 3
4. Salmon life history based productivity	Nutrient foodweb models to predict juvenile salmon growth and survival in nearshore marine environments	Year 1	Year 7
5. Climatic impacts	Model the influence of climatic change on fish and estuary productivity	Year 1	Year 3
6. Long term historic records	Reconstruction of historic record of fisheries and estuary productivity, calibration of mass balance model	Year 1	Year 3
7. Integrating estuary input within Kenai RW	Produce a monograph on the role of estuary ecosystems in sustaining the productivity of Kenai RW		Year 6,7

4.2.4 Theme 4: Wetland and Terrestrial Ecosystems and Their Role in Kenai RW

Objective	Deliverable	Start	Completion
1. Retrospective analysis / terrestrial / wetland inventory	Comprehensive digital and geographic databases, reporting, primary papers	Year 1	Year 2
	Ongoing monitoring program	Year 1	Year 7
2. Terrestrial / wetland nutrient budget / models	Mass balance models for nutrients and energy	Year 2	Year 4
3. Role of MDN in wetlands riparian corridors	Nutrient loading model to quantify the role of marine derive nutrients	Year 1	Year 3
4. Food web and nutrient impacts	Nutrient foodweb models to predict influences on trophic level production (wildlife, plant)	Year 2	Year 5
5. Climatic impacts	Model the influence of climatic change on plant and animal productivity across Kenai RW landscapes	Year 1	Year 3
6. Long term historic records	Reconstruction of historic record of riparian / wetland productivity, calibration of mass balance model	Year 1	Year 3
7. Integrating terrestrial / wetland systems within Kenai RW	Produce a monograph on the role of terrestrial / wetland ecosystems in sustaining the productivity of Kenai RW		Year 6,7

5.0 Field and Laboratory Approaches

We envision numerous partnerships, collaborations and substantial in-kind support from various federal, state, private non-profit agencies and academic institutions including U.S. Environmental Protection Agency (USEPA), U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service (USFS), Alaska Department of Fish and Game, Cook Inlet Aquaculture Association (CIAA) and University of Victoria (UVic) to facilitate field logistics and provide laboratory facilities. These agencies have on-going field projects within Kenai RW directed at fisheries and wildlife assessments, productivity investigations, habitat inventory and evaluations and water quality monitoring.

ADF&G, Central Region Limnology (Edmundson et al. 2002), operates a ***centralized laboratory*** in Soldotna where water chemistry, nutrient, bacteria, plankton, benthic invertebrate and fish samples can be processed and analyzed (Koenings et al. 1987). This facility is a logical place to act as clearing house for processing water and biological samples and staging area in the proposed Kenai RW research. The UVic Regional Facility for Interdisciplinary Environment Research (www.uvic.ca/water) is a certified laboratory **with *advanced, state-of-the-art technology*** for water chemistry, nutrients, stable isotope, plankton, fish, lipids and fatty acids, paleolimnological research and GIS. Together these two laboratories are equipped with instrumentation and methods for analyzing algal nutrients (nitrogen and phosphorus), algal pigments, size and species composition of plankton, growth rates and age of fish, fish diet composition, facilities for the acquisition of lake and stream sediment cores, stable isotope mass spectrometer to measure carbon and nitrogen compositions and stable isotope ratios of sediment cores and biota, chronological techniques for paleoclimatic and salmon abundance reconstruction and tracking environmental changes. UVic and ADF&G have substantial database, and information system capabilities for geographical information systems (GIS), field inventory through global positioning systems (GPS) technology and methods for spatial and statistical analysis of watershed components, data compilation and storage.

With these partnerships, collaborations, in-kind financial support, and capital investment, the development of the infrastructure support and logistics to implement the Kenai RW research plan is viewed with a high potential for success. Nonetheless, ***there is presently little integration*** of current project data collection, objectives, and results of the research in the context of understanding nutrient cycling and sustaining the overall productivity of the Kenai RW. To prevent potential duplication of research efforts and to develop a holistic approach for studying and managing the Kenai RW, we will coordinate relevant aspects of existing or planned research and projects by partners, that deal with nutrient processes, aquatic and terrestrial productivity, and marine-freshwater-terrestrial ecosystem linkages, with our proposed research. This approach will require Kenai RW project funding to support additional field data collection, analytical services, and technical oversight to tie field and laboratory activities associated with research and management programs that are currently underway.

6.0 Research Management and Communication

The proposed management structure (Figure 12) will ensure effective management, communication and integration activities. The Kenai RW research project will be governed by a ***Board of Directors*** of four to six representatives from state and federal agencies, public, local government, universities and community groups. The Board of Directors will be accountable to funding organizations and will ensure that research funds are effectively used and properly administered. Accountable to this Board will be the ***Scientific Committee,*** composed of six to eight members from Kenai RW researchers, and stakeholders, and responsible for reviewing, approving, and monitoring research projects and for developing future research agenda. We have decided that 2 to 3 of the Scientific Committee members will be from outside the affiliated research institutions or agencies. Chaired by the ***Program Leader***, the Scientific Committee and the ***Theme Leaders*** will serve the most critical jobs to ensure collaborations, effective networking and the integration of specific research activities into comprehensive management strategies for Kenai RW. The Scientific Committee will also provide overall quality control on the various research projects to ensure that research objectives are being met, and that the research undertaken is truly inter-disciplinary. Theme Leaders will work with the Project Leader to identify the best researchers to tackle strategic projects, and to ensure that bright and promising researchers are brought into the program. An ***External Advisory Committee***, composed of external experts, will review annual progress reports and the excellence of the Kenai RW researchers and approve continuation of projects and funds.

A ***Public Advisory Committee*** will work with and advise the Scientific Committee on ongoing stakeholder issues to help support research and stakeholder collaboration and ongoing interactions with the Kenai community at large.

An administrative office, including the Program Leader, a Program Manager and an Administrative Secretary will manage the business and communication activities. This office will attend to the accounting of funds, management of information, internal and external communications, maintenance of the Kenai RW web site, liaison, promotion of science to stakeholders, and co-ordination of the periodic workshops, and other necessary meetings and discussions. The Research Administration and Accounting Dept. at the host institution will manage the financial administration and auditing of funds, and will provide annual audited financial statements.

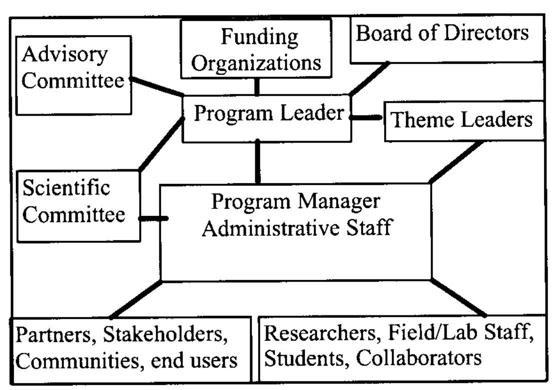

Figure 12: Proposed management structure.

7.0 Relationship to Gulf Ecosystem Monitoring Program (GEM)

The goals for development of research in the Kenai RW are consistent with the Gulf Ecosystem Monitoring (GEM) program. This project is considered within ***"watershed habitat"*** component of GEM. This project is inter-disciplinary that clearly ***cuts and integrates across habitat and ecosystem types*** that links watershed processes and productivity to the nearshore marine ecosystems of ***Gulf of Alaska (GOA).*** The mission of the GEM program is "to sustain a healthy and biologically diverse marine ecosystem in the northern GOA and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural changes and human activities". The goal of this project is to detect, and better understand the dynamics of nutrients in the Kenai RW ecosystem to provide information about how its productivity is influenced by natural changes and human activities so that better land use and resource management decisions can be made in the future.

The proposed research plan is consistent with the GEM Monitoring and Research Plan (EVOS TC June 5, 2001).

- GEM - chapter 2.2 identifies a variety of human activities, which may impact the GOA ecosystem. These impacts can have a profound response in the Kenai River watershed and information that leads to a better understanding about how that watershed functions will aid in land use planning and regulation of those human activities and preservation of important habitat.

- GEM - chapter 4 identifies the interactions of key ecological factors, including physical forcing, productivity, food, and habitats as the main theoretical controls on ecosystems and its animal / plant populations. Research from the Kenai RW plan will help to answer questions about productivity, food, habitat and removals and how they will affect the Kenai RW and the GOA ecosystem and the interdependence of these ecosystems.

- GEM - chapter 5 identifies the importance of marine-terrestrial interactions and physical and chemical oceanography of the GOA. Research from Kenai RW will contribute through examination of how marine-derived nutrients are used and cycled in freshwater and how nutrients and freshwater that are derived from watersheds contribute to the productivity of the GOA ecosystem. A river that supports runs of anadromous fish provides a two-way conduit for the transport of nutrients, which enhance both the freshwater watershed and the marine ecosystem (i.e. Willson and Halupka 1995, Larkin and Slaney 1997), but a detailed study of nutrient origin, flow and processing is lacking from a productive watershed such as the Kenai River. GEM chapter 5 also states: "Watershed studies linking the freshwater and marine portions of the regional ecosystem could pay important benefits to natural resource agencies. As agencies grapple with implementation of ecosystem-based management, conservation actions are likely to focus on ecosystem processes and less on single species." Research from the KRW plan will support important for decision making by local, state and federal agencies for management of resources, people and lands.

8.0 Preliminary Kenai RW Research Budget

The summary budget outlined below is only a preliminary estimate of research costs. These estimates are only for initial discussion and are intended to be augmented through a stage 2 Study plan implementation (current submitted proposal EVOS project no. G-030684). Budget details are given in Appendix II and are based on Theme timelines, objectives and deliverables presented above using broad estimates of cost for research. Theme budgets include a 20% program management cost under the contractual line items.

Summary Estimates of Budget

Themes				Year				USD $ (000's)
	1	2	3	4	5	6	7	**Totals**
Research Management / Communication	62.3	48	48	53.5	53.8	47	54.5	367.1
Lake Ecosystems	407.5	471	435	395.5	383.5	312.4	206.3	2611.2
Streams / River Ecosystems	385.5	445	436	434.5	380.5	260.4	196.3	2538.2
Nearhsore / Estuary Ecosystems	153.3	246.8	303.8	298.8	164.8	40.2	35	1242.5
Terrestrial / Wetland Ecosystems	159.8	217.8	227.8	222.8	152.3	59.7	35.5	1075.4
Budget Totals	**1168**	**1429**	**1451**	**1405**	**1135**	**719.6**	**527.5**	**7834.2**

Note: This budget is intended for initial planning and discussion purposes only. No adjustment has been made for cost sharing and efficiencies, and in-kind support. It is expected that the Theme Leaders of each of the research themes, in conjunction with Program Leader, will pursue varied funding sources for each respective themes and overall integration activities.

9.0 Literature Cited

Baker, D.M. and R.P. Richards. 2002. Phosphorus budgets and riverine phosphorus export in Northwestern Ohio watersheds. J. Environmental Quality 31:96-108

Bangs, E.E. 1979. The effects of tree crushing on small mammal populations in south central Alaska. M.Sc. Thesis. University of Nevada, Reno.

Bangs, E.E.; and T.N. Bailey. 1982. Moose movement and distribution in response to winter seismological exploration on the Kenai National Wildlife Refuge, Alaska. .S. Fish and Wildlife Service, Kenai National Wildlife Refuge. Unpublished Report, Soldotna, Alaska. Prepared for ARCO, Alaska Inc. 46p.

Ben-David, N, Hanley TA, Klein DR, and Schell DM. 1997. Seasonal changes in the diets of coastal rinverine mink: the role of spawning Pacific salmon. Canadian Journal of Zoology 75:803-811.

Ben-David M, Hanley TA, Schell DM. 1998. Fertilization of terrestrial vegetation by spawning Pacific salmon: the role of flooding and predator activity. Oikos 83:47-55.

Bennett, E. M., T. Reed-Andersen, J. N. Houser, J. R. Gabriel, and S. R. Carpenter. 1999. A phosphorus budget for the Lake Mendota watershed. Ecosystems 2:69-75.

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

Boggs, K., J.C. Davis, A. M. Milner. 1997. Aquatic and terrestrial resources of the Kenai River watershed : a synthesis of publications. U.S. Environmental Protection Agency, Region 10,, Seattle, WA.

Bormann, F.H., and G.E. Likens. 1967. Nutrient cycling. Science 155:424-429.

Brenner, D.L., R. Amundson, W.T. Baisden, C. Kendall, and J. Harden. 2001. Soil N and N-15 variation with time in a California annual grassland ecosystem. Geochimica Et Cosmochimica Acta 65:4171-4186.

Cassell, E.A., J.M. Dorioz, R.L. Kort, J.P. Hoffmann, D.W. Meals, D. Kirschtel, and D.C. Braun. 1998. Modeling phosphorus dynamics in ecosystems: Mass balance and dynamic simulation approaches. Journal of Environmental Quality 27:293-298.

Cassell, E.A., R.L. Kort, D. . Meals, S.G. Aschmann, J.M. Dorioz, and D.P. Anderson. 2001. Dynamic phosphorus mass balance modeling of large watersheds: long-term implications of management strategies. Water Science and Technology 43:153-162.

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

Cederholm C.J, D.H. Johnson, R.E. Bilby, L.G. Dominguez, A.M. Garrett, W.H. Graeber, E.L. Greda, M.D. Kunze, B.G. Marcot, J.F. Palmisano, R.W. Plotnikoff, W.G. Pearcy, C.A. Simenstad, and P.C. Trotter. 2000. Pacific salmon wildlife-ecological contexts, relationships, and implications for management. Special Edition Technical Report, Prepared for DH Johnson and TA O'Neil (Manag. Dirs.) Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia.

Cederholm, C.J., D.B. Houston, D.L. Cole, and W. J. Scarlett. 1989. Fate of coho salmon (Oncorhynchus kisutch) carcasses in spawning streams. Canadian Journal of Fisheries and Aquatic Sciences 46:1347-1355.

Cummins, K.W., M.A. Wilzbach, D.M. Gates, J.B. Perry, and W.B. Taliferro. 1989. Shredders and riparian vegetation – leaf litter that falls into streams influence communities of stream invertebrates. Bioscience 39: 24-30

Dorava, J.M., and A.M. Milner. 2000. Role of lake regulation on glacier-fed rivers in enhancing salmon productivity: the Cook Inlet watershed, south-central Alaska, USA. Hydrological Processes [Hydrol. Process.] 14:3149-3159.

Edmundson, J.A., J.M. Edmundson and V. P. Litchfield. 2002. Central Region Limnology 2002 annual report of progress. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 2A02-29:36 pp.

Edmundson, J.A., J.P. Koenings, and T.C. Wilson. 1989. Finger Lake water quality: August 1988. Ak. Dept. Fish and Game, FRED Division Technical Report Series 92:31p.

Edmundson, J.A. and A. Mazumder. 2002. Regional and hierarchical perspectives of thermal regimes in subarctic, Alaskan lakes. . Freshwater Biology :1-17.

Edmundson, J.A., T.M. Willette, J.M. Edmundson, D.C. Schmidt, S.R. Carlson, B.G. Bue, and K.E. Tarbox. 2002. Sockeye salmon overescapement, Exxon Valdez Oil Spill Restoration Final Report (Restoration Project 96258A-1), Alaska Department of Fish and Game, Commercial Fisheries Division, Anchorage, Alaska.

Foster, D.R., G. Motzkin, and B. Slater. 1998. Land-use history as long term broad scale disturbance: regional forst dynamics in Central New England. Ecosystems 1:96-119.

Fu, J. M., and J. W. Winchester. 1994. Sources of Nitrogen in 3 Watersheds of Northern Florida, USA - Mainly Atmospheric Deposition. Geochimica Et Cosmochimica Acta 58:1581-1590.

Fujiwara, M., and R.C. Highsmith. 1997. Harpacticoid copepods: Potential trophic link between inbound adult salmon and outbound juvenile salmon. Marine Ecology Progress Series 158:205-216.

Gende, S.M., R.T. Edwards, M.F. Wilson, and M. S. Wipfli. 2002. Pacific salmon in aquatic and terrestrial ecosystems. BioScience 52(10): 917-928.

Gresh, T, J. Lichatowich, and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem: Evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. Fisheries 25(1):15-21.

Grumbine, R.E. 1997. Reflections on "What is ecocsystem management?" Conservation Biology 11(1) 41-47.

Hax C.L. and S.W. Golladay. 1993. Macroinvertebrate colonization and biofilm development on leaves and wood in a boreal river. Freshwater Biology 29: 79-87.

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

Hilderbrand, G.V., S.D. Farley, C.T. Robbins, T.A. Hanley, K. Titus, and C. Servheen. 1996. Use of stable isotopes to determine diets of living and extinct bears. Canadian Journal of Zoology 74:2080-2088.

Hynes, H.B.N. 1975. The stream and its valley. Internat. Vereingung fuer Theoretische und Angewandte Limnologie Verhandlungen 19:1-15

Isaacs J., L. Moore, and N. Wainwright. 1994. Kenai River fish habitat cumulative impacts project. Report to the Policy Working Group and the Kenai Peninsula Borough, Kenai Peninsula Borough Coastal Management Project. IC.

Johannes, M.R.S., Mazumder, A. and J.A. Edmundson. 2002a. Nutrient cycling in the Kenai River Watershed: detecting and understanding marine-terrestrial linkages in watersheds. January 2002. University of Victoria, Victoria, BC. Technical Bulletin 2(1):8p. ISSN 1492-5532

Johannes, M.R.S., Mazumder, A. and J.A. Edmundson. 2002b. Nutrient cycling in the Kenai River Watershed: detecting and understanding marine-terrestrial linkages in watersheds. March 2002. University of Victoria, Victoria, BC. Technical Bulletin 2(2):6p. ISSN 1492-5532

Kline, T.C., Jr., J.J. Goering, O.A. Mathisen, P.H. Poe, and P.L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. ^{15}N and ^{13}C evidence in Sashin Creek, southeastern Alaska. Can. J. Fish. Aquat. Sci. 47:136-144.

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

Koenings J.P., J.A. Edmundson, G.B. Kyle and J.M. Edmundson J.M. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, FRED Division Report 71, Juneau.

Larkin, G.A., and P.A. Slaney. 1997. Implications of trends in marine-derived nutrient influx to south coastal British Columbia salmonid production. Fisheries 22 (11):16-24.

Lehner, D. 1994. Kenai River cooperative river basin study : technical report. USDA Soil Conservation Service.

Lewis, W.M., F.H. Weibezahn, J.F. Saunders, and S. K. Hamilton. 1990. The Orinoco River as an Ecological-System. Interciencia 15:346-357.

Mathisen, O.A., P.L. Parker, J.J. Goering, T.C. Kline, P.H. Poe, and R.S. Scalan. 1988. Recycling of marine elements transported into freshwater systems by anadromous salmon. Verh. Int. Ver. Limnol. 23:2249-2258.

Mazumder A, Edmundson J.A. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon. Canadian Journal of Fisheries and Aquatic Sciences 59:1361-1373

Milner, A.M. 1992. Unpublished notes on the Kenai River macroinvertebrate sampling. Unpublished report.

Milner A.M., J.E. Brittain, E. Castella , and G.E. Petts. 2001. Trends of macroinvertebrate community structure in glacier-fed rivers in relation to environmental conditions: a synthesis. Freshwater Biology 46:1833-1847.

Milner, A.M., and E.B. Gabrielson. 1994. Bioassessment of the Kenai River May 1993. Environment and Natural Resources Institute, for the Alaska Department of Fish and Game, Limnology Section. Anchorage, Alaska. 22p.

Milner A.M., J.G. Irons, and M.W. Oswood. 1997. The Alaskan landscape: an introduction for limnologists, pages 1-44, in Milner A, Oswood M (editors). Freshwaters of Alaska: Ecological Synthesis, Ecological Studies 119. Springer-Verlag, New York.

Milner, A.M. and G.E. Petts. 1994. Glacial Rivers - Physical habitat and ecology. Freshwater Biology 32: 295-307.

Mitchell, M.J., C.T. Driscoll, J.S. Owen, D. Schaefer, R. Michener, and D. J. Raynal. 2001. Nitrogen biogeochemistry of three hardwood ecosystems in the Adirondack region of New York. Biogeochemistry 56:93-133.

Mitchell, M.J., B. Mayer, S. W. Bailey, J. W. Hornbeck, C. Alewell, C. T. Driscoll, and G. E. Likens. 2001. Use of stable isotope ratios for evaluating sulfur sources and losses at the Hubbard Brook Experimental Forest. Water Air and Soil Pollution 130:75-86.

Montgomery,D.R., G.E. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. Water Resources Journal 31(3): 369-386

Moore, S.E., K.W.W. Shelden, L.K. Litzky, B.A. Mahoney and D.J. Rugh. 2000. Beluga, *Delphinapterus leucas*, habitat associations in Cook Inlet, Alaska. Mar. Fish. Rev. 62:60-80.

Naiman, R.J. 1992. (ed.) Watershed management: balancing sustainability and environmental change. Springer Verlag. N.Y. 542pp.

Naiman, R.J., J.J. Magnuson, D.M. McKnight, and J.A. Standford, editors. 1995. The freshwater imperative: a research agenda. Island Press, Washington, DC.

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

Patalas, K., and A. Salki. 1973. Crustacean plankton and the eutrophication of lakes in the Okanagan Valley, British Columbia. 30:519-542.

Reckendorf, F. and L. Saele. 1991. City of Soldottna, Alaska. Kenai River Bank Inventory Report. U.S. Soil Conservation Service, in cooperation with the Kenai Soil and Water Conservation District. 35p.

Redman, C.L. 1998. Human dimensions of ecosystem studies. Ecosystems 2:296-298.

Reimchen, T.E. 2000. Some ecological and evolutionary aspects of bear-salmon interactions in coastal British Columbia. Canadian Journal of Zoology 78:488-457.

Rosenberg, D.H. 1986. Wetland types and bird use of Kenai lowlands. U.S. Fish and

Wildlife Service, Special Studies, Anchorage, Alaska, 189p.

Scott, K.M. 1982. Erosion and sedimentation in the Kenai River, Alaska. U.S. Geological Survey professional paper in cooperation with U.S. Fish and Wildlife Service. 35p.

Weiner, A. 1998. Kenai River restoration and management. Fisheries 23:6-10.

Willson, M.F., S.M. Gende, and B.H. Marston. 1998. Fishes and the Forest: Expanding perspectives on fishwildlife interactions. BioScience 48:455-462.

Willson, M.F., and K.C. Halupka 1995. Anadromous fish as keystone species in vertebrate communities. Conservation Biology 9:489-497.

Woods, P.F. 198a. Potential for circumventing internal nutrient-recycling in Lucile Lake at Wasilla, Alaska, Pages 39-49 *In* Dwight, L. P. [ed.] resolving Alaska's water resources conflicts: Proceedings, Alaska Section, American Water Resources Association, Institute of Water resources/Engineering Experiment Station, University of Alaska Fairbanks, report IWR-108.

Woods. P. F. 1986. Deep-lying chlorophyll maxima in Big lake: implications for trophic state classification of Alaskan lakes, Pages 195-200 In Kane, D. L. [ed] Proceedings of the Symposium: Cold regions Hydrology, University of Alaska Fairbanks. American Water Resources Association, Bethesda, MD.

Uehlinger U., C. Konig, and P. Reichert 2000. Variability of photosynthesis-irradiance curves and ecosystem respiration in a small river Freshwater Biol. 44 (3): 493-507

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD Report. Water management research, 194p.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33:53-83.

Zah R, Niederost M, Rinderspacher H, et al. 2001. Long-term dynamics of the channel network in a glacial floodplain, Val Roseg, Switzerland Arct. Antarct. Alp. Res. 33 (4): 440-446.

Zah R, and U. Uehlinger. 2001 Particulate organic matter inputs to a glacial stream ecosystem in the Swiss Alps Freshwater Biol. 46 (12): 1597-1608.

Appendix I: Participating Organizations and Individuals

Alaska Department of Environmental Conservation

Alaska Department of Fish and Game – Habitat and Restoration, Sport and Commercial Fish Divisions

Alaska Department of Natural Resources

Chugach National Forest

Cook Inlet Aquaculture Association

Cook Inlet Keepers

Exxon Valdez Oil Spill Trustee Council

Gulf Ecosystem Monitoring Program

Kachemak Bay Research Reserve

Kenai National Wildlife Refuge

Kenai Peninsula Borough

Kenai Sportfishing Association

Kenai River Center

Kenai Watershed Forum – KRW Program

Northwest Ecosystem Institute

Prince William Sound Science Center

The Nature Conservancy

United Cook Inlet Drift Association

University of Alaska – Fairbanks

University of Alaska – Anchorage

University of Victoria, Environmental Management of Water and Watersheds

University of British Columbia

University of Washington

US Environmental Protection Agency

US Forest Service

US Fish and Wildlife Service

US Geological Survey

Appendix II: Preliminary Budget Details

	Project Year 1	2	3	4	5	6	7	Total
1.0 Research Management, Communication and Integration								
Salary	USD$ (000's)							
Research Program Manager	Integrated into individual theme budgets							0
Administrative / communications assistant								0
Database / GIS Technician								0
Senior Scientist - Program Leader								0
Travel - 2 Kenai RW workshops per year								
Scientific and Public Management Committee	16	16	16	16	16	16	16	112
Subsidy for travel (Kenai / Alaska)	10	10	10	10	10	10	10	70
Per diems (misc., meals, accomodation)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	52.5
Contractual								
EVOS Conference travel	4	4	4	4	4	4	4	28
Communication Expenses (phone, fax, digital)	4	4	4	4	4	4	4	28
Bulletin / Print / Digital / WWW / Postage	6	3	3	6	3	3	7	31
Commodities								
Office supplies	1.5	1.5	1.5	1.5	1.5	1.5	1.5	10.5
Software	6	2	2	1	4	1	1	17
Equipment								
Computers	3.8	0	0	0	3.8	0	0	7.6
Printers / Plotter	3.5	0	0	3.5	0	0	3.5	10.5
Program Management - Annual Totals	**62.3**	**48**	**48**	**53.5**	**53.8**	**47**	**54.5**	**367.1**

	Project Year 1	2	3	4	5	6	7	Total
Theme 1 Lake Ecosystems and Their Role within Kenai RW								
Salary								
Biologist	60	60	60	60	60	60	60	420
Technician - Field	45	45	45	45	45	45	45	315
Technician - Lab	45	45	45	45	45	45	45	315
Students M.Sc	15	30	30	30	30	30	0	165
Students Ph.D.	0	18	18	18	18	18	0	90
Post Doctoral Fellow (PDF)	0	35	35	35	35	35	0	175
Travel								
Admin Travel Per Diem	4	4	4	4	4	4	4	28
Contractual								
Overall Program Management and Communication	68	78	72	66	64	52	34	434
Truck	4.5	4.5	4.5	4.5	4.5	4.5	4.5	31.5
Communications	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3.5
Freight / Shipping	1	1	1	1	0.5	0.4	0.25	5.15
Lab Analysis - Core Samples	24	32	24	6	0	0	0	86
Air Charter	12	15	15	15	12	8	8	85
Acoustic - Trawl*	40	40	40	20	20	0	0	160
Smolt	42	40	20	20	20	0	0	142
Commodities								
Office supplies	2	1	1	1	2	1	1	9
Lab Analysis Supplies	8	12	10	8	6	4	2	50
Sampling Equipment	15	10	10	8	5	5	2	55
Software	3	0	0	0	2	0	0	5
Equipment								
Computers	3	0	0	0	3	0	0	6
Hydrolab	8.5	0	0	8.5	0	0	0	17
Zodiac	4.5	0	0	0	4.5	0	0	9
Outboard	2.5	0	0	0	2.5	0	0	5
Project Management								
Lake Ecosystems - Annual Total	407.5	471	435	395.5	383.5	312.4	206.25	**2611.2**

	Project Year 1	2	3	4	5	6	7	Total
Theme 2 River and Stream Ecosystems and Their Role within Kenai RW								
Salary								
Biologist	60	60	60	60	60	60	60	420
Technician - Field	45	45	45	45	45	45	45	315
Technician - Lab	45	45	45	45	45	45	45	315
Students M.Sc	15	30	30	30	30	30	0	165
Students Ph.D.	0	18	18	18	18	18	0	90
PDF	0	35	35	35	35	0	0	140
Travel								
Admin Travel Per Diem	4	4	4	4	4	4	4	28
Contractual								
Overall Program Management and Communication	64	74	72	76	63	43	32	424
Truck	4.5	4.5	4.5	4.5	4.5	4.5	4.5	31.5
Communications	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3.5
Freight / Shipping	1	1	1	1	0.5	0.4	0.25	5.15
Juvenile Sampling / Smolt	85	85	75	75	40	0	0	360
Macroinvertebrates	15	20	25	15	10	0	0	85
Commodities								
Office supplies	2	1	1	1	2	1	1	9
Lab Analysis Supplies	8	12	10	8	6	4	2	50
Sampling Equipment	15	10	10	8	5	5	2	55
Software	3	0	0	0	2	0	0	5
Equipment								
Computers	3	0	0	0	3	0	0	6
Dat Recorders	8.5	0	0	8.5	0	0	0	17
Zodiac	4.5	0	0	0	4.5	0	0	9
Outboard	2.5	0	0	0	2.5	0	0	5
River and Stream Ecosystem - Annual Total	385.5	445	436	434.5	380.5	260.4	196.25	**2538.2**

	Project Year 1	2	3	4	5	6	7	Total
Theme 3 Nearshore Ecosystem and Their Role within Kenai RW								
Salary								
Biologist	30	30	30	30	30	15	15	180
Technician - Field / Lab	22.5	45	45	45	22.5	0	0	180
Students M.Sc	0	15	15	15	15	0	0	60
Students Ph.D.	0	18	18	18	18	0	0	72
PDF	0	0	35	35	0	0	0	70
Travel								
Admin Travel Per Diem	4	4	4	4	4	4	4	28
Contractual								
Overall Program Management and Communication	25	41	50	49	27	6	6	204
Truck	4.5	4.5	4.5	4.5	4.5	4.5	4.5	31.5
Communications	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.8
Freight / Shipping	1	1	1	1	0.5	0.4	0.25	5.2
Juvenile Sampling / Smolt	20	50	65	65	20	0	0	220
Invertebrates	10	15	15	10	5	0	0	55
Commodities								
Office supplies	2	1	1	1	2	1	1	9
Lab Analysis Supplies	8	12	10	8	6	4	2	50
Sampling Equipment	15	10	10	8	5	5	2	55
Software	3	0	0	0	2	0	0	5
Equipment								
Computers	3	0	0	0	3	0	0	6
Dat Recorders	5	0	0	5	0	0	0	10
Nearshore Marine Ecosystems - Annual Total	153.25	246.75	303.75	298.75	164.75	40.15	35	**1242.4**

	Project Year 1	2	3	4	5	6	7	Total
Theme 4 Wetland and Terrestrial Ecosystems and Their Role within Kenai RW								
Salary								
Biologist	30	30	30	30	30	15	15	180
Technician - Field / Lab	22.5	22.5	22.5	22.5	22.5	0	0	112.5
Students M.Sc	0	15	15	15	15	0	0	60
Students Ph.D.	0	18	18	18	18	18	0	90
PDF	0	35	35	35	0	0	0	105
Travel								
Admin Travel Per Diem	4	4	4	4	4	4	4	28
Contractual								
Overall Program Management and Communication	26	36	38	37	25	10	6	178
Truck	4.5	4.5	4.5	4.5	4.5	4.5	4.5	31.5
Communications	0.75	0.75	0.75	0.75	0.75	0.75	0.75	5.3
Freight / Shipping	1	1	1	1	0.5	0.4	0.25	5.2
Nutrient Sampling / Runoff	25	30	40	20	15	0	0	130
Commodities								
Office supplies	2	1	1	1	2	1	1	9
Lab Analysis Supplies	8	12	10	8	6	4	2	50
Sampling Equipment	10	8	8	6	4	2	2	40
Software	3	0	0	0	2	0	0	5
Equipment								
Computers	3	0	0	0	3	0	0	6
DAT Recorders	20	0	0	20	0	0	0	40
Wetland & Terrestrial Ecosystems - Annual Total	159.75	217.75	227.75	222.75	152.25	59.65	35.5	**1075.4**
Budget Totals	**1168.3**	**1428.5**	**1450.5**	**1405**	**1134.8**	**719.6**	**527.5**	**7834.2**