EPA/600/R-92/022
January 1992

ALASKA NORTH SLOPE OIL-FIELD RESTORATION RESEARCH STRATEGY (ANSORRS)

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This study was conducted in cooperation with the U.S. Environmental Protection Agency

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U.S. ENVIRONMENTAL PROTECTION AGENCY
ERL-CORVALLIS
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CORVALLIS, OR 97333

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/R-92/022

2.

3.

4. TITLE AND SUBTITLE
Alaska North Slope Oil-field Restoration Research Strategy (ANSORRS)

5. REPORT DATE March 1992

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) James G. Wyant and Charles M. Knapp

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
ManTech Services, ERL-Corvallis;
Technical Resources, Inc. Davis, CA

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
US Environmental Protection Agency
Environmental Research Laboratory
200 SW 35th Street
Corvallis, OR 97333

13. TYPE OF REPORT AND PERIOD COVERED Design Manual

14. SPONSORING AGENCY CODE EPA/600/02

15. SUPPLEMENTARY NOTES
1992. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR

16. ABSTRACT

This document provides a research strategy to support ecological restoration of disturbances related to oil and gas developments on the North Slope of Alaska that is mutually beneficial to the arctic ecorestoration research community and the arctic regulatory community (including at least the following entities: The U.S. Army Corps of Engineers, EPA, National Marine Fisheries, US FWS, BLM, the Alaska Department of Natural Resources, and the North Slope Borough). The purpose of this strategy is to: 1) identify major information or knowledge gaps that have inhibited restoration activities or slowed the regulatory decision process, 2) determine the potential for filling knowledge gaps through research, and 3) suggest tentative priorities for research that are based on the needs identified in steps one and two. Although research priorities are identified, selection of individual research topics and development of research plans will be the joint responsibility of the specific sponsors and researchers involved.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
ecological resources, critical tundra habitat, site preparation, soil regeneration, revegetation methods		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	58
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under contract no. 68-C8-0006 to ManTech Environmental Technology, Inc., and contract no. 68-CO-0021 to Technical Resources, Inc. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

PROBLEM STATEMENT

Disturbances related to oil development on Alaska's North Slope include a variety of physical disruptions of arctic landscapes and ecosystems. There are three major environmental impacts of oil extraction activities on the North Slope: 1) tundra wetland fill sites including abandoned materials storage sites, graveled drill sites, and road beds, 2) borrow pits and gravel mines, and (3) contaminants including spills of oil, petroleum products, and other chemicals, fluids and sediments from drilling reserve pits, flare pits and pigging pits, road dust, and atmospheric releases. Restoring ecosystems impacted by these activities will require active intervention because natural recovery processes proceed slowly in the arctic environment (Walker et al. 1987b). The U.S. Army Corps of Engineers regulates restoration activities on the North Slope through provisions in wetland fill permits. State and local governments regulate restoration through stipulations in oil-extraction leases. Under the provisions of the Clean Water Act (CWA) and other federal mandates, the U.S. Environmental Protection Agency (EPA) provides comments and recommendations regarding restoration plans for North Slope oil fields.

It is not yet evident where the greatest restoration benefits can be realized, or even that restoration will result, in a net ecological or environmental benefit in all cases. When restoration is needed, currently available ecological engineering techniques may not be capable of greatly enhancing the rate of habitat recovery. Furthermore, ecological engineering techniques are not available to address all habitats and ecosystem conditions of concern. By conducting research to describe restoration needs and develop restoration methods, industry and regulatory agencies will help define restoration performance standards, and identify ecological benefits and costs of restoration options. Research suggested in the Alaska North Slope Oil-field Restoration Research Strategy (ANSORRS) will be employed to develop and test methods and technologies to establish and/or restore natural functions in damaged or degraded ecosystems based on sound ecological principles. In addition, research suggested here may help identify areas that should not be disturbed in the future to avoid impacts that cannot be mitigated through restoration.

APPROACH

As used in this strategy, ecological restoration is the process of facilitating natural ecosystem recovery by manipulating physical, chemical, and biological components to initiate processes that will lead to functional recovery of the ecosystem (Walker et al. 1987b). "Restored" ecosystems may not have exactly the same dominant species, species diversity, production rates, or nutrient cycling rates as similar undisturbed sites. However, levels of biological activity and essential functional roles of the system will have been reestablished (Kusler and Kentula 1989).

Conceptually, the landscape scale is the level of organization where physical, chemical, and biological attributes of arctic tundra wildlife habitats are best integrated given the migratory habits of important wildlife groups. The landscape ecosystem concept is an integral part of the ANSORRS approach. Although local processes will be studied, their significance must be evaluated on a broader spatial scale.

RESEARCH STRATEGY

Assessment of Restoration Benefits

Assessment of restoration benefits will be accomplished by applying ecological principles to evaluate past and new restoration activities. Assessment will include the 1) identification of the effects of restoration on physical processes, 2) evaluation of restored tundra habitat, and 3) determination of net benefit in terms of habitat for critical wildlife groups.

Spatial classification and assessment of landscape ecosystem water and energy budgets will help to determine 1) the background physical instability of tundra, 2) the effects due to industrial development, and 3) the potential risk of loss of wildlife habitat. Wildlife habitat is the ecosystem resource at greatest risk on the North Slope. Definition, classification and elucidation of the spatial and temporal relationships of tundra habitat types will help to determine the value of tundra habitats for crucial wildlife groups and to focus restoration efforts on critical wildlife habitat types that have been lost or are at risk.

Industrial development affects the physical and biological environment of the tundra. For example, installation or removal of roads or drill pads modifies the heat balance and affects hydrologic drainage. These actions can result in thawing of permafrost and physical instability of the tundra, which in turn may result in altered plant species composition. Reestablishing near-natural dynamics of physical processes can be expected to increase the success of ecological restoration efforts (c.f. Walker et al. 1987b).

Identifying Ecological Engineering Options

Reestablishing physical stability of disturbed sites entails avoiding thawing of the permafrost and reestablishing substrate water holding capacity to maintain water availability for plants. On gravel pads, this may require manipulating the soil structure (pore size, bulk density, etc.) or composition to provide plant-available water. It also means providing the soil organic matter content and particle size distribution needed to support retention of plant-available nutrients. Once measures to promote physical stability have been implemented, efforts to reestablish native tundra vegetation are necessary. Enhancing the reestablishment of native tundra vegetation involves establishing early successional species of plants and soil organisms to begin nutrient cycling and accumulating ecosystem reserves (e.g., pool of available plant species, below-ground biomass including plant roots, soil organisms, and soil carbon). Ecosystem reserves augment the system's ability to withstand disturbance or periodic fluctuation in the physical environment. When the structure and function of tundra habitats are reestablished, self-sustaining wildlife habitat will be recovered.

Techniques to physically manipulate gravel pads to establish physical stability and provide environmental conditions that will hasten plant establishment are called for. Research is needed to explore the application of mycorrhizae and soil organisms to facilitate nutrient retention and nutrient cycling, as well as to enhance biorestoration of hydrocarbon spill sites on the tundra by stimulating growth of tolerant native or adapted bacterial, fungal, or algal microflora.

Integrating Research and Developing Restoration Planning Tools

The effective application of scientific knowledge to problems of North Slope ecorestoration requires assembling information from existing and new sources, and developing new methods of presenting this information. Restoration planning methods and tools are needed to assist regulators in making scientifically defensible decisions, and new methods of presenting available information are needed to assist in identifying economically feasible and ecologically desirable methods for achieving restoration. Two areas of activity represent informational components needed for implementing restoration on the North Slope: 1) developing an information base containing the pertinent information from research and regulatory activities, and 2) developing practical analytical and decision support tools to expedite the regulatory permitting process. enhance the capabilities of regulatory agencies to assess ecological risk, and facilitate the selection of economically viable ecological engineering options.

PRODUCTS OF THE RESEARCH EFFORT

This research will produce a methodology for identifying when and where ecological restoration will provide a net benefit, as well as the level of effort that will be required to attain a beneficial response. Priorities can then be set for implementing specific restoration actions. In addition, the data bases and techniques acquired during the project will support planning of future developments in a manner that will require minimal restoration following abandonment. This research also is expected to produce new ecological engineering techniques for tundra habitat restoration.

CONTENTS

LIST OF ACRONYMS

ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
ADGC	Alaska Department of Governmental Coordination
ADNR	Alaska Department of Natural Resources
ANSORRS	Alaska North Slope Oil-field Restoration Research Strategy
ARCO	ARCO Alaska, Inc.
BPX	BP Exploration (Alaska), Inc.
CRDA	Cooperative research and development agreement
CRREL	Cold Regions Research and Engineering Laboratory (USACE)
EPA	United States Environmental Protection Agency
FTTA	Federal Technology Transfer Act of 1986
FWS	Fish and Wildlife Service (United States Department of the Interior)
ORD	Office of Research and Development (EPA)
OEPER	Office of Environmental Processes and Effects Research (EPA)
NMFS	National Marine Fisheries Service (United States Department of Commerce)
QAMS	Quality Assurance Management Staff (EPA)
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey (United States Department of the Interior)
WES	Waterways Experiment Station (USACE)

ACKNOWLEDGEMENTS

We acknowledge the contributions of our colleagues, particularly Greg Linder, C. Jeffrey Brandt, and Christine Ribic for their support in the development of this document. Mike Joyce, ARCO (Alaska) Inc., Chris Herlugson, BP Exploration (Alaska) Inc., and their staffs provided invaluable support for the workshops, as well as technical information and critical review of this document. We also acknowledge the important efforts of more than 15 technical reviewers.

SECTION 1

INTRODUCTION

PURPOSE

This document presents a research strategy developed for the U.S. EPA Environmental Research Laboratory-Corvallis (ERL-C) to support ecological restoration of disturbances related to oil and gas developments on the North Slope of Alaska. To understand the purpose of this strategy, it is important to distinguish between it and a research plan. The Alaska North Slope Oil-field Restoration Research Strategy (ANSORRS) establishes an integrated approach to identifying needed restoration research. It is not intended to present specific time tables, logistic plans, or management structures as would be required of a research plan. Nor was ANSORRS intended to provide a complete evaluation of pertinent literature. Rather, the purpose of this strategy is to 1) identify major information or knowledge gaps that have inhibited restoration activities or slowed the regulatory decision process, 2) determine the potential for filling knowledge gaps through research, and 3) suggest tentative priorities for research that are based on the needs identified in steps one and two. Although research priorities are identified, selection of individual research topics and development of research plans will be the joint responsibility of the specific sponsors and researchers involved.

OBJECTIVES

This document provides a strategy for addressing restoration research issues in a manner that is mutually beneficial to the arctic ecorestoration research community and the arctic regulatory community. The regulatory community involved in North Slope oil and gas development includes at least the following entities: the United States Army Corps of Engineers (USACE), EPA, The National Marine Fisheries Service (NMFS), the United States Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM), the State of Alaska, and the North Slope Borough. The ecorestoration research community includes private oil companies, the academic community, and federal and state agency researchers. In this document, we describe information needs and research approaches to fulfill those needs. Because this is a research strategy, specific studies are not described in sufficient detail for actual implementation. Specific research plans will be prepared before particular studies are undertaken.

This research addresses technical needs that have been identified by EPA, industry and the ecological restoration community. The goals of the research outlined in this document are to:

- provide regulatory offices with objective, reliable and understandable information to support establishment of restoration performance standards that are based on sound ecological principles;
- facilitate coordination of restoration planning among public agencies and private entities by providing tools to anticipate the ecological and economic benefits and costs of restoration activities;
- expand the state of knowledge of environmental condition, risks and trends in landscapes and ecosystems of northern Alaska through development of arctic ecological indicators; and

- advance arctic ecorestoration success by developing and testing innovative methods and technologies to reestablish and/or restore natural functions in damaged or degraded ecosystems.

PLANNING THE ANSORRS APPROACH

We approached ANSORRS with the following premise: research programs that are specifically designed to assist in the formation of policy should be developed with the needs of policy makers in mind. To facilitate this goal, we employed an iterative process to generate ANSORRS that employed input by restoration experts in two workshops.

The workshops made use of the expertise of the academic, industrial, and governmental research communities. Active participation from state and federal regulatory interests helped to focus workshop participant thinking on policy-related problems that might be addressed by research or demonstration projects. Participation by industrial and academic researchers provided insight to existing knowledge and viable approaches to investigating the problems identified.

Each workshop was designed to address a specific range of topics. The first workshop was held April 29 through May 4, 1991 in Anchorage; the second was held July 29 through August 4, 1991 at oil field sites on the North Slope. Participants at each workshop included a cross-section of academic, industry, and government researchers and regulators (see Appendix A for lists of participants). The first workshop was used to identify the problems associated with setting restoration goals and to identify the spatial and temporal scales of data required for setting restoration performance goals and standards. The second workshop was used as a forum to solicit suggestions for any "midcourse correction" that might have been needed, and to expand the thought process and strategy from goal setting to the problems of identifying research needed to develop pragmatic techniques for accomplishing site-specific restoration tasks. This document is the product of these two workshops.

From the initial planning meetings, when the need for a research strategy was identified through the review of this document, the ANSORRS effort has had the active participation and cooperation of the private sector, principally ARCO Alaska, Inc. (ARCO), and British Petroleum Exploration (Alaska), Inc. (BPX). Presentation of industry-sponsored research results and field visits to restoration research sites on the North Slope oil fields enhanced the workshop process.

Scientists and staff from the EPA Office of Research and Development (ORD), and Office of Policy, Planning and Evaluation (OPPE), and from the USACE Anchorage District, Waterways Experiment Station (WES), and Cold Regions Research and Engineering Laboratory (CRREL) played key roles in advising the direction and tenor of ANSORRS. Other federal agencies represented were the FWS, NMFS and BLM. The State of Alaska was represented in one or both of the workshops by scientists and staff from several agencies, including the departments of Environmental Conservation (ADEC), Natural Resources (ADNR), and Fish and Game (ADF&G), and the Division of Governmental Coordination (ADGC). Additional participants included academic researchers from several universities and laboratories. The North Slope Borough was invited to participate in both workshops and to represent local interests, but unfortunately, was unable to attend.

OPPORTUNITIES FOR PUBLIC AND PRIVATE COOPERATION

Both public regulators and private industry seek new, cost effective methods to avoid or mitigate the ecological and environmental costs of oil field development and abandonment. How might the efforts of private industry and federal agencies fit together to form an integrated, comprehensive program of arctic ecorestoration research? A coordinated research program that is founded on cooperative agreements among federal, state, and industrial entities is expected to be more cost effective than separate, narrowly focused or uncoordinated programs. Furthermore, joint acceptance of quality assurance standards employed by EPA to ensure that the data collected are scientifically sound, legally defensible, and of known and documented quality (see Appendix B) will facilitate the rapid application of quality research results by all parties. Since enactment of the Federal Technology Transfer Act (FTTA) of 1986, there are several mechanisms by which such a cooperative program might be established.

Legal and institutional barriers have prevented coordinated government and industry research efforts in the past; however, the FTTA removes some of these barriers. The FTTA allows the development of cooperative research and development agreements (CRDAs) between federal laboratories, industry, and academic institutions. CRDAs set forth the terms of government/industry collaboration to develop and commercialize new technologies. Under the FTTA, industry and government cooperation is encouraged, and because CRDAs are not subject to federal contracting or grant regulations, cooperative activities can be engaged rapidly. Each EPA laboratory director has the authority to establish CRDAs for that particular laboratory and this decentralization of the decision-making process reduces the administrative procedures involved. Under these CRDAs, EPA may provide technical expertise, facilities, equipment, staff, or services. EPA may not provide direct funding to acooperating industry, although the cooperator may provide funds to EPA, and the two can work together to develop, refine, evaluate, and test technologies for commercialization (USEPA 1990).

SECTION 2

PROBLEM STATEMENT AND SCIENTIFIC APPROACH

OVERVIEW

In 1968, oil was discovered at Prudhoe Bay, Alaska, and this field has been in production since 1977. The Kuparuk oil field west of Prudhoe Bay was discovered in 1969 and has been in production since 1981. These two oil fields, the largest in North America, and several smaller fields encompass approximately 1000 square kilometers (km)[2] where oil development is occuring on the North Slope. In this area, approximately 12,000 hectares (ha) have been directly impacted by gravel filling (Thomas et al. 1991, Walker et al. 1986) estimated that indirect impacts affected additional areas equal to nearly 60 percent of the directly impacted tundra.

The original leases for these oil fields indicate that upon abandonment, restoration will be accomplished to the satisfaction of the District Engineer of the U.S. Army Corps of Engineers (Lloyd Fanter pers comm.). This wording provides no indication of the objectives of restoration, the intended extent of restoration activities, relative priorities for expenditure of material and funding for restoration, or even what constitutes abandonment (e.g., whole oil field or single pad). It also leaves the determination of satisfactory targets for restoration in a state of uncertainty, since different District Engineers could have different views of satisfactory restoration.

Although Alaskan oil fields supply approximately one-fourth of the domestic oil production for the United States, production has been declining at Prudhoe Bay since 1989. Production in the Kuparuk oil field will also eventually decline, and ultimately, portions of these fields will be removed from production.

As production from the Prudhoe Bay and Kuparuk oil fields declines and facility abandonment is considered, questions arise with respect to options for restoration: what is the need for restoration, what is the range of restoration options, where will restoration be most effective, and what are the potential environmental and ecological costs and benefits of restoration? These questions stem from fundamental inadequacies in our understanding of landscape-scale effects of oil industry related disturbances and of the appropriate use of restoration tools to mitigate these impacts.

REGULATORY CONTEXT

Disturbances related to oil development comprise a variety of physical disruptions of the landscape and ecosystems (c.f. Jorgenson 1989b; Walker et al. 1987b). On the North Slope, major environmental impacts of oil extraction activities include 1) tundra wetland fill sites such as abandoned material storage sites, gravel pads for drill sites, and road beds, 2) gravel mines, 3) contaminants, including spills of crude oil, petroleum products and other chemicals, fluids and sediments from drilling reserve pits and pigging pits, and 4) air-borne contaminants such as road dust, hydrocarbon combustion gasses, and flare residues.

The North Slope of Alaska is predominantly a landscape of wetlands (see Appendix C for an overview of the environmental and ecological features of the North Slope). Because most North Slope oil and gas developments occur on wetlands, the USACE, FWS, and the EPA are required to make decisions about future restoration requirements for new oil development. Under the provisions of Section 404 (b)(1) of the Clean Water Act (CWA), the USACE regulates the discharge of dredge or fill material from a point source to waters of the United States by evaluating permit applications under guidelines developed by the EPA. CWA Section 404(b)(1) guidelines provide environmental performance standards for permit decisions and include the following statements: "Fundamental to these guidelines is the precept that dredge or fill material should not be discharged..., unless it can be demonstrated that such discharge will not have an unacceptable adverse impact either individually or in combination with known and/or probable impacts of other activities affecting the ecosystem of concern...."

Wetland filling on the North Slope is necessary to provide structural support and insulate the underlying permafrost. Consequently, most facilities (drilling sites, and housing and support structures) are built on gravel pads 1.5 to 4.6 meters (m) thick. However, much progress has been made in reducing the acreage of fill required by oil field development. One of the original Prudhoe Bay drilling pads covered 17.8 ha; the newest pads are substantially smaller covering about 5.5 ha. (M. Joyce pers comm.). Additional reductions in filling have come as a result of reduced road-building requirements. When oil fields were originally developed, gravel roads were required for constructing both pipelines and drilling pads. Development of techniques for building pipelines in winter using ice roads has reduced the amount of permanent gravel road construction that is required to support new facilities. Now, gravel roads are necessary only for hauling materials and providing access to drilling pads and support facilities.

Gravel for tundra wetland filling is usually mined from sites associated with riverine deposits. At inland sites, gravel removal can induce thawing of permafrost around mine pits and erosion of surrounding tundra. Gravel extraction and similar land use activities that physically alter habitat are regulated by federal and state laws like the Surface Mining Reclamation Act.

The possibility of potentially toxic contamination arises from accidental spills and from drilling and production wastes. In some instances, drilling for oil on the North Slope of Alaska has resulted in the release of drilling wastes into arctic wetlands. These releases usually represent seepage from reserve pits constructed to hold drilling fluids and muds which may contain toxic levels of heavy metals. Although reserve pits once were built into the drilling pads as containment areas for drilling fluids and cuttings, advances in drilling technologies have eliminated the need for reserve pits for most new drilling operations.

Within a regulatory context, contaminants characteristic of the North Slope potentially fall under the auspices of the Resource Conservation and Recovery Act of 1976 (RCRA) and its reauthorizations. Although RCRA focuses on waste impacts in all environmental media (air, land, and water), other specific programs also regulate discharges of such contaminants. The Clean Air Act (CAA) and its ammendments apply to atmospheric contaminants, and the CWA and its ammendments apply to contaminants in fresh and estuarine waters.

PROBLEM STATEMENT

Identifying the Need for Restoration

In the absence of legislation, or other guidance, regulatory agencies are responsible for identifying environmental and ecological goals (i.e., which ecological values and functions must be maintained during the operational period of an oil field, and which values and functions must be replaced or added upon oil field abandonment). We suggest that in the absence of clearly delineated legislation or litigation, the best scientific information available or obtainable should be applied to goal setting. Ideally, the regulatory decision process would be based on quantitative knowledge of the ecological values and functions existing at a site and in the surrounding area, as well as information on the possible ecological responses of these attributes to a human-caused disturbance or restoration action. This information would make it possible to weigh the risk of excessive or permanent loss of desired ecological values that could result from disturbances against the possible outcomes of restoration. How should ecological restoration alternatives be weighed in relation to other management options? In general, questions arise as to 1) the environmental and ecological constraints, and 2) the relative risks to ecological values arising from the cumulative impacts of human-caused stresses.

When the need for restoration of a site or area has been identified, regulators must develop scientifically defensible performance standards for restoration. Performance standards are formal statements of the minimal integrity of ecological structure and function (based on identified goals) that regulated industries will be required to meet, maintain, or exceed. Performance standards must have unambiguous operational definitions, have social or biological relevance, and be accessible to prediction or measurement. For example, reestablishing an appropriate level of physical stability on arctic sites entails implementing measures to avoid increasing the depth of thawing of the active layer above permafrost, eliminating artificial impoundments and drainage interruptions, and improving growing conditions for plants (c.f. Walker et al. 1987b). Once measures to promote physical stability have been implemented, efforts to reestablish native tundra vegetation are necessary. This process includes at least two major efforts: (1) establishing early successional species of plants and soil organisms to begin nutrient cycling, and (2) accelerating the rate of accumulation of ecosystem reserves (e.g., pool of available plant species, below-ground biomass of plant roots and soil organisms, and carbon reserves). These two steps are essential to reestablishing the ecosystem's ability to withstand disturbance or periodic fluctuations in the physical environment. Many of these issues are discussed by Brown and Hemming (1980).

Regulatory agencies are also charged with determining compliance. For example, when tundra habitat structure and function are reestablished, self-sustaining wildlife habitat will be recovered. Based on the normal time scale of arctic successional processes, reestablishment of tundra structure and function may require decades or centuries. Therefore, it is not feasible to expect that restoration compliance standards should require complete attainment of long-term successional maturity. Monitoring and assessing crucial ecosystem functions will indicate whether or not changes in the restored system are progressing toward such successional maturity. (Assessing monitoring data for this purpose will require gathering additional information on the normal successional progression of restored ecosystems in the arctic.) When monitoring efforts suggest that restored ecosystem conditions are substantially different from the formally stated standards, a need for additional restoration may be indicated. Finally, after regulated parties have fulfilled their obligations under the performance standards, regulators must decide whether or not the performance standards have successfully addressed societal goals, and if not, how the performance standards should be modified for future applications.

Monitoring is the feedback loop providing a mechanism through which the combined effectiveness of the regulatory process can be assessed. Until the field of restoration ecology develops more robust predictive capabilities, the outcome of any restoration effort will be uncertain (Cairns 1990). However, " in spite of an imperfect knowledge of nature and the limits of technology, regulators must make judgments on the basis of current understanding to plan adequately for the future" (after Masters et al. 1991). Consequently, monitoring will be required to determine whether the goals of restoration are being met in restored ecosystems.

<u>Developing Ecological Engineering Methods</u>

Although a substantial research effort has focused on developing site-specific restoration methods, there is currently no strategy that assembles the results of this effort into prescriptions that can be applied to planning restoration for individual sites: such planning has depended on institutional memory and individual expertise. In addition, because restoration efforts historically have focused on mitigating site-specific problems, the best ecological engineering techniques for use in restoring all types of disturbances (e.g., large road systems) are not yet evident. Furthermore, ecological engineering techniques may not be available to address disturbances to all habitats and ecosystems of concern.

Because of the variety of disturbances and the sites at which they occur, arctic oil field restoration demands the development of an array of physical, chemical, and biological techniques that can be used independently and in concert to achieve the desired outcomes from different initial conditions. For example, techniques must be developed for the physical manipulation of gravel pads to establish physical stability and to provide environmental conditions that will hasten plant establishment. In addition, it may be necessary to enhance nutrient retention and nutrient cycling by stimulating growth of tolerant native or adapted bacterial, fungal, or algal microflora. It also may be desirable to develop innovative techniques for manipulating small-scale thermal and hydrologic regimes to enhance seed production of native vascular plants. The prospects of application of native or bioengineered mycorrhizae and soil organisms, enhanced cold-hardiness of vascular plants, and other innovative approaches to arctic restoration can be explored.

Developing Restoration Planning Tools and Monitoring Methods

The effective application of scientific knowledge to problems of North Slope restoration requires assembling information from existing and new sources and developing new methods for presenting this information. Two areas of activity represent informational components needed for implementing restoration on the North Slope: 1) developing an information base containing the pertinent information from research and other information gathering efforts (e.g., monitoring), and 2) developing practical analytical and decision-support tools. This will assist regulators in making scientifically defensible decisions and assist restoration scientists in identifying economically feasible and ecologically desirable methods for achieving restoration.

CONCEPTUAL APPROACH

Ecological Restoration Defined for ANSORRS

In this strategy, we define ecological restoration as the process of facilitating natural processes of ecosystem recovery by manipulating physical, chemical, and biological components to initiate successional changes that will lead to functional recovery of the ecosystem (Walker et al. 1987b). The purpose of restoration is to provide society with the many sustainable benefits produced by a restored ecosystem more quickly than would be possible under a natural recovery process. This definition implies a pragmatic, goal-oriented, and explicitly value-based approach to restoration.

Ecological restoration is considered by many to be the definitive test for the science of ecology (Bradshaw 1987, Ewel 1987, Cairns 1989, Lubchenco et al. 1991). Restoration definitions, performance standards, and techniques have been evolving for many decades and a variety of definitions for the term have been proposed (Table 1). Frequently, restoration efforts concentrate on reclaiming lands by converting them from a barren state to an endpoint based on historical conditions (Berger 1990). Selection of this specific goal apparently is based on a notion that was once influential in ecology. The balance of nature, or equilibrium concept, implicitly assumes that in the absence of disturbance, biota tend toward a status of persistent equilibrium with climate, site, and other biota -- the climax (Clements 1916).

Current ecological theory, however, allows for discontinuous and irreversible transitions, nonequilibrial communities and stochastic effects in succession (McIntosh 1985, Westoby et al. 1989). That is to say, an equilibrial state does not necessarily occur in nature and the selection of an historical condition may be neither achievable nor desirable as a goal for ecological restoration. Most recent

Table 1. A sample of definitions of ecological restoration and related terms.

Definition	Source
Self-sustaining system based on natural reproduction, succession; Mimicking a presumed successional stage had the system continued with normal ecological processes; Restoration of ecosystem services, either functional or structural, not particular species; Removing an annoyance, unacceptable odors, aesthetically displeasing visual situations;	Cairns, 1990
Recreation of entire communities of organisms, modeled on those occurring naturally	Jordan et al., 1988
As reclamation: deliberate attempt to return a damaged ecosystem to some kind of productive use or socially acceptable condition short of restoration	
Process of intentionally altering a site to establish a defined indigenous historic ecosystem;	Society of Ecological Restoration, Pers. Comm.
General aim is to accelerate reestablishment of balanced plant communities	Louda, 1988
Activities undertaken to recreate or upgrade resources, including land, which have been damaged or destroyed, so their biological purpose and potential can once again be realized	Bradshaw and Chadwick, 1980
Implies maintenance management over the long-term to ensure stability, integrity and natural beauty	Guinon and Allen, 1990
As its ultimate goal, perhaps, the achieving of a status something very close to the ecosystem's original conditions	Hamilton, 1990

restoration efforts have been aimed at rehabilitating an impacted site to an improved condition to satisfy a management goal or agency mandate.

As used in this strategy, the definition of restoration is interpreted as "a process of facilitating natural ecosystem recovery by providing the necessary functional and structural connectivity to support the self-organizing nature of ecosystems that have been degraded and fragmented by human disturbance." This interpretation is consistent with prevailing ecological principles and the recommendation of the EPA Science Advisory Board (SAB) that EPA utilize the sustainability and recovery processes of natural systems to guide risk reduction decision making (USEPA 1990a,1990b). Under this definition a "restored" ecosystem may not necessarily have the same dominant species, species diversity, production rates, or nutrient cycling rates as a similar undisturbed site; however, essential functional roles will be reestablished so that the restored system will be self-sustaining. Restoration of sites underlain by permafrost includes restitution of thermal as well as hydrologic stability (Johnson and Van Cleve 1976, Walker et al. 1987b).

Site Restoration Linked to a Regional Scale

Conceptually, the landscape scale is the level of organization at which physical, chemical, and biological attributes of arctic tundra wildlife habitats are best integrated. Exclusive focus upon restoring a site, without first determining how it relates spatially and temporally to characteristics of the environment that govern it, can lead to mismanagement. Undue emphasis placed upon restoring ecologically insignificant disturbances, insisting on a complete recovery to a "natural state," and mistakenly ignoring potentially significant ecological perturbations can be avoided if the environment of a site is understood, local disturbances are assessed, and restoration possibilities are examined in a broad, spatial, and temporal context. Consider a small site such as an oil drilling pad and its associated roads in the larger landscape of the arctic coastal plain. The environmental characteristics of the site are altered relative to the natural state of the larger area. Determination of the appropriate course of action regarding restoration requires assessing 1) the significance of the alteration with regard to the resources that are placed at risk, 2) the need for undergoing restoration of any kind, and (3) the level of effort required for restoring the site. This example represents our conceptual framework for restoration objectives based on the regional character of the environment.

We see the range of restoration goals being determined by a hierarchical process in which management goals for the region and its component landscapes are considered by the stakeholders prior to the establishment of site-specific performance standards by the regulatory agencies (e.g. What do we want the landscapes to be like after restoration has been completed?). These higher order management goals might include, for example, statements of what mix and spatial arrangement of wildlife habitats is deemed desirable, which ecological characteristics are considered most valuable, etc. Examining the larger scale landscape and regional contexts is a mechanism that limits the realm of choices for site-level activities to those that are ecologically possible, and economically and socially desirable.

Ultimately, resolution of oil field restoration problems will require an integrated understanding of complex regional and landscape ecological processes. Also required will be an understanding of equally complex site-level issues regarding the structure and functions that may be desired for restored ecosystems. It will also be necessary to develop new ecological engineering techniques for tundra habitat restoration, as well as a methodology for selecting when, where, and what level of effort will be required in the application of those techniques to achieve desired restoration objectives. Brown and Hemming (1980) discuss the types of issues that must be assessed in planning specific site restoration actions.

SECTION 3

RESEARCH: QUESTIONS AND CONCEPTS

OVERVIEW

To present research concepts in an organized manner, we have used the problem areas discussed in Section 2 to identify three major areas of research activity: 1) defining the need for restoration and the level of effort required to meet this need, 2) developing ecological engineering methods, and 3) integrating research by developing restoration planning tools and monitoring methods to support the decision making process.

We use a common format to present research concepts for each of the major areas of activity discussed in this section. Our approach is to 1) identifiy specific problems for each major area (e.g., What critical wildlife habitat is present?) and briefly review the state of relevant knowledge in an overview section, 2) identify major information or knowledge limitations that have inhibited or slowed the regulatory decision process (e.g., Has critical wildlife habitat been lost or will it be placed at risk as a result of oil development?), and 3) suggest potential research approaches for filling knowledge gaps (e.g., How can we clearly define critical wildlife habitats?). Section 4 presents somewhat more specific suggestions for research activities that can address these research needs.

IDENTIFYING THE NEED FOR RESTORATION

The regulatory decision to require restoration should depend on a clearly recognized need for restoration (i.e. evidence that restoration will result in a net ecological or environmental benefit). To identify the need for restoration, regulatory agencies require additional information on 1) the structure and function of arctic ecosystems in natural states so that ecological resources can be defined and delineated, 2) the extent, rate, and intensity of human-caused disturbance and concomitant ecosystem responses for use in assessing risk to critical tundra habitats, and 3) changes in tundra ecosystems following restoration efforts to quantify ecological benefits and costs of restoration.

Defining and Identifying Ecological Resources

Ecological resources (i.e. natural goods and services) are derived from the components and processes of ecosystems, their structure, function, diversity, and dynamics. Ecosystems produce commodities as well as less readily visible services, such as nutrient storage and cycling, wildlife habitat, and climate mitigation (Lubchenco et al. 1991, USEPA 1990a). In our preliminary assessment, wildlife habitat is the ecosystem resource at greatest risk from oil field development in arctic Alaska.

Defining Wildlife Habitat--

Definition, classification, and the spatial and temporal relationships among tundra habitat types will help to determine the value of these habitats to wildlife groups. Knowledge of these values will help to focus restoration efforts on crucial wildlife habitats that have been lost or are at risk. Although local processes are important, their significance must be evaluated on a broader spatial scale.

The approach we propose here is to investigate impacts to wildlife as mediated through the habitats used by groups of wildlife species. Use of species groups rather than a species-by-species approach is necessitated by the lack of necessary detail concerning wildlife-habitat relationships, except for a few species of overwhelming concern (e.g., caribou). In addition, questions concerning biodiversity cannot be answered using a species-by-species approach. A key testable assumption in this approach is that wildlife group-habitat linkages are strong and can be defined.

We define tundra habitat types based on utility to functional groups such as intercontinental migrants (e.g., shorebirds and waterfowl), intracontinental migrants (e.g., colonial geese), regional migrants (e.g., caribou), resident herbivores (e.g., lemming), and carnivores (e.g., wolf and bear) rather than by individual species. However, there may be enough information to break down the broad groups into smaller groups that specialize on particular habitats (e.g., Truett and Kertell 1990, though note that their categories are not mutually exclusive).

Identifying critical habitats is a complex task. Questions arise as to the relative quality of apparently similar habitat types in other locals and the wildlife occupancy of habitats. We suggest considering habitats as critical when there is strong inferential evidence that the spatial extent, location, or quality of the habitat can be construed as an important factor limiting the carrying capacity of a functional wildlife group. Such evidence may consist of individual animal growth or condition (e.g., hormone and blood chemistry changes when constrained to a habitat), as well as demographic factors (e.g., population-level survival or reproductive trends). We advocate a multiphased approach to this task. First, it is important to determine the natural habitats used by the species group. (For example, habitats such as calving grounds, insect relief areas, and overwintering areas are each important components, among others, that determine the relative success of regional migrants.) Second, information on nutrient requirements for growth, survival, and fecundity, in conjunction with information on habitat-specific food quality and availability, is essential for defining critical habitats.

Identifying Critical Wildlife Habitat--

Once critical habitat for breeding and survival are identified, the distribution of these habitats in the landscape will be an important element in determining both the future potential risk of habitat loss as well as a preferable habitat mix for restoration planning. The approach we suggest includes spatial classification of vegetation and other habitat attributes (c.f. Walker et al. 1986, Anderson et al. 1991) used with an overlay reflecting the wildlife species group habitats that will require development of new information. There may be some information in unpublished reports (e.g., reports that were prepared by consulting firms for oil companies) that can be used to assess pre-impact features. If appropriate, questions about species diversity within the functional group and the spatial diversity of the habitats can be addressed. If pre-impact information is too sketchy or lacking (as Walker et al. 1987a pointed out for the Prudhoe Bay area), comparisons may have to be made to a currently nonimpacted area that has similar physical and biological characteristics to the impacted area. These issues will have to be evaluated on a case-by-case basis.

Assessing Risk to Critical Tundra Habitat

After the ecological resources have been determined for North Slope oil fields, it is necessary to estimate the potential for loss of critical resources from human-caused disturbances such as gravel filling, the introduction of pollutants, etc. Characterizing risk includes a joint analysis of the intensity of anthropogenic stresses and the likelihood that those stresses may threaten critical ecological resources.

A challenge in assessing risk to ecological resources is the fact that human-caused disturbances frequently are linked through complex indirect pathways to the affected resource. In addition, a series of natural disturbances and normal cyclic instabilities also affect ecological resources. Two fundamental questions must be resolved: first, determining the normal instability in ecological resources that arises from natural disturbances (e.g., thaw-lake cycle) and other temporally dynamic processes (e.g., succession); and second, judging the human-caused reduction, loss or enhancement of ecological resources against this background of natural variation.

The thermal and hydrologic regimes of the North Slope are intricately linked (Shaver et al. 1991a, b, Hinzman et al. 1991, 1992) and these regimes strongly influence the vegetation of the tundra surface (Walker and Walker 1991). If a disturbance to the surface of a moist tundra system alters the surface energy balance to increase surface temperature or thermal conductivity, a pattern of cyclic changes in the subsurface thermal regime may begin. Typically, these changes begin as increased depth of permafrost thawing followed by surface subsidence. Subsidence is followed by ponding that inundates and kills the tundra vegetation leading to further increases in thermal conductivity and depth of permafrost thawing. These problems may be intensified by artificially induced snow drifts that alter the local distribution of water and the timing of snowmelt (Benson 1982, Tabler et al. 1990).

Changes in the physical regimes initiate changes in the floristic composition of plant communities. For example, changes in the availability of water due to inundation may alter the composition of tundra vegetation, thereby altering the value of habitat. Such physical and floristic changes affect the value (e.g., forage abundance or patchiness) of essential habitats that are used by the species group for breeding, foraging, birthing, young-rearing, etc.

Because drill pads and roads are connected in a complex network, indirect impacts may produce more massive disturbances than would have occurred if disturbances of similar areal extent occurred without physical linkage. Such changes may not occur immediately after a disturbance and may not become stable even 30 years following the initial disturbance (Walker et al. 1987b). Assessing system-wide risk associated with various new oil field activities and retrospective estimation of ecological resource changes caused by oil extraction activities cannot be very precise. To provide the best possible level of precision in system-wide risk assessment, we suggest an approach that 1) strategically links site-level process studies with landscape-level risk assessment, and 2) integrates assessment of thermal and hydrologic instabilities in tundra systems as they drive biological cycles.

A review of wildlife responses to industrial impacts (Pollard et al. 1990) investigated how different species and wildlife groups use gravel pads and impoundments. Additional work is needed to assess where impacts occur in relation to the distribution of habitats and the effects of these impacts on species-group habitat requirements. For example, is the major impact occurring in prime breeding habitat or in marginal feeding habitat? It is quite likely that the answers to such questions will differ among different species groups. Therefore, it will be necessary to assess the relationship between the distribution of industrial impacts and the distribution of habitats for all of the species groups of concern (e.g., the landscape is used differently by local and global migrants; therefore, map overlays of habitat requirements will not be the same for different species groups).

For example, Walker et al. (1986, 1987a) documented the rates of increase in spatial extent of direct and indirect impacts of disturbances in the Prudhoe Bay and Kuparuk oil fields using a geographic information system (GIS) to evaluate aerial photographs taken periodically from before the onset of oil field development until the present. Additional analysis of these and newly acquired data such as satellite imagery (e.g., AVHRR, Landsat TM, SAR, etc.) will be useful in determining the spatial characteristics of different habitats, identifying direct and indirect disturbances, and directing the investigation of industrial impacts on physical processes and biological cycles.

Environmental Toxicants--

In this strategy, we primarily focus on evaluating ecological risk associated with gravel fills as a special problem in risk assessment. The regulatory framework is different for mitigation of habitat losses and mitigation of environmental toxicants. Yet, the possibility of contamination of restoration sites with environmental toxicants must be considered in the restoration planning process. Therefore, it is necessary to assess the risk associated with such contaminants on both the North Slope landscape and on restoration activities.

Anthropogenic contaminants occurring on the Alaska North Slope are not unlike those found in other regions of the world. For example, atmospheric dusts and particulate contaminants, heavy metals, and hydrocarbons (Walker et al. 1987b, Walker and Walker 1991) are associated with human activities such as petroleum extraction and transport regardless of the geographic location of these activities. Not surprisingly, North Slope soils and freshwater habitats have been impacted by these activities (Walker et al. 1978, Barsdate et al. 1980, Woodward et al. 1989). In view of the activities that have occurred on the North Slope over the past 25 years, contaminant-related impacts of petroleum extraction activities must be considered in designing restoration plans. Hence, contaminant and toxicity-related impacts must be distinguished from physical alterations in habitat impacts in evaluating restoration plans for the North Slope.

In evaluating contaminant effects on indigenous flora and fauna, both acute and chronic responses must be estimated to determine the extent to which clean-up or remediation is required before initiating restoration activities. However, the ability to assess contaminant effects on North Slope wetlands is complicated by three interrelated problems. First, raw petroleum products and their associated co-contaminants (e.g., heavy metals) are mixtures of numerous organic and inorganic constituents which vary in physical and chemical properties. The mixture also varies with time as its constituent components differentially evaporate into air, dissolve into water, and become adsorbed to the soil. Biological responses to individual components, as well as the mixture itself, may vary both in terms of toxicity and in the adverse effects that may be expressed within populations and communities.

Second, test systems for evaluating contaminant effects in terrestrial and freshwater habitats are poorly developed for use in the arctic. The relatively harsh climates characteristic of the region support a specialized biota (Hobbie 1980, Brown et al. 1980, Remmert 1980), and bioassay methods currently available routinely use test species which are dissimilar from the indigenous species of the North Slope. In addition, the ability to identify contaminated tundra soils, particularly where impacts are less than obvious, may be confounded by matrix effects characteristic of highly organic arctic soils that mask contaminant effects. Such confounding effects are likely when tests for soil contamination are based on the results of soil tests with surrogate species or surrogate soils.

Third, regardless of the habitat being considered, contaminant evaluations for the North Slope must consider the interrelated roles of plants and animals in terrestrial and tundra habitats and the influence of the climate, particularly following remediation and restoration activities. Plants, for example, may express phytotoxic effects ranging from subtle sublethal responses such as altered growth, productivity, and reproduction (Woodward et al. 1989) to death, with each effect potentially impacting the tundra community differently. Extending the example of high arctic plants, if less than acute effects are anticipated, plant tissues can be conduits for chemicals into herbivores and food chain quality may be impacted (reviewed in Pollard et al. 1990). These long-term effects could well be expressed following remediation and restoration, depending upon the extent of clean-up. Additionally, plants may directly or indirectly affect the biological degradation of soil contaminants. The environmental fate of petroleum constituents, for example, could then be altered through plant-microbe associations or the indigenous soil microbial communities, as well as by stimulating growth of tolerant native or adapted bacterial, fungal or algal microflora. In any case, the biodegradation will probably proceed at a slower rate on the tundra than at temperate terrestrial sites due to the prolonged winter and short, cool summer.

Defining the Benefit Added by Restoration Intervention--

How would restoration of habitats altered by industrial impacts affect the classification of habitats, and how would the pattern of spatial distribution of the habitats change? Because the landscape is used differently by different species groups, it will be important to assess the effects of restoration done to benefit one group on the habitat requirements of other species groups. For example, will increasing breeding habitat for one species group (e.g., waterfowl) change the way another species group uses the same habitat (e.g., predators)?

An experimental approach to assessing restoration benefits is the application of the approaches and techniques described above to evaluate new and past restoration activities. Assessment will include restoration effects on physical processes, evaluation of the tundra habitats restored and determination of net benefit in terms of habitat for critical wildlife groups.

DEVELOPING ECOLOGICAL ENGINEERING METHODS

Historically, development of restoration methods has addressed the need to establish persistent vegetation on disturbed sites to control erosion or non-point source water quality and to mitigate aesthetic impacts. A significant amount of research and demonstration-level activities has been conducted to evaluate revegetation and site management methods in North Slope oil field development areas (Jorgenson 1988a, 1988b, 1989a, 1989b, Alaska Plant Materials Center 1988, Miller 1990, DOWL Engineers 1985). However, because our concept of restoration is oriented toward recovery of the landscape-scale functions and values of tundra habitats, we call for the development of new approaches to site-scale ecological engineering. Consequently, this component of ANSORRS focuses on identifying ecological engineering methods that will initiate processes leading to establishment of naturally functioning and self-sustaining ecosystems that are integral parts of the North Slope landscape.

If a need for restoration of North Slope oil fields is demonstrated, it is likely that reestablishment of self-sustaining wildlife habitat will be identified as a critical goal for the restoration. When tundra habitat structure and function are reestablished, self-sustaining wildlife habitat will be recovered. We suggest that the most pragmatic means of hastening recovery of ecological resources on North Slope oil fields will be to identify engineering intervention techniques to mimic natural processes that 1) establish the physical stability of the site, 2) initiate soil development, and 3) facilitate invasion by native tundra vegetation. The following sections discuss these concepts.

Site Preparation

Existing restoration efforts on the North Slope have demonstrated the effectiveness of methods to alter the landform of disturbed sites. Methods employed include removing gravel (DOWL Engineers 1985, Miller 1990, Jorgenson 1988a), reshaping gravel into berms and depressions for improved winter snow retention, importing fine materials to improve the water retention and plant-soil-water relations (Jorgenson et al. 1991, Jorgenson and Cater 1991), and transplanting tundra sod (Jorgenson 1988a). Each of these approaches involves handling substrate materials to either mitigate existing impacts or improve restoration success and the rate of recovery at site-specific scales.

We suggest that future investigations of site preparation methods should focus on two objectives: 1) reestablishing or maintaining landscape thermal and hydrological functions, and 2) establishing favorable seedbeds on gravel substrates. Although a significant amount of research has been conducted to develop favorable seedbeds (e.g., Jorgenson et al. 1991, Jorgenson and Cater 1991, McKendrick 1991c), we believe that additional research is needed. Additionally, research should be conducted to determine if hydrocarbon contaminated gravel can be decontaminated or neutralized and reused, or if it must be stabilized and isolated to prevent leaching and contamination of other materials.

Soil Regeneration

Although previous restoration efforts have incorporated methods of altering physical characteristics of sites and substrates (Jorgenson and Cater 1991, Jorgenson et al. 1991), little effort has addressed soil development processes on disturbed sites in the arctic. We suggest that accelerating or mimicking soil development processes (e.g., through materials manipulation and addition of organic matter) can be expected to result in significant improvements in plant survival during vulnerable periods of germination, establishment and winter dormancy, and in the quality and rate of development of wildlife habitat on restored sites. Basic research results suggest that in native tundra nutrient dynamics govern plant growth and primary productivity, and that available pools of carbon (C), nitrogen (N) and phosphorus (P) vary across gradients in soil fertility and primary productivity. The rate of mineralization of organic N in arctic soils is less sensitive to soil temperature fluctuation than it is to soil pH, the actions of soil microbial populations, or temporal and spatial variation in community nutrient cycling processes among plant community types (Kielland 1990). The soil microbial biomass in arctic soils has a tremendous potential to immobilize mineralized N and P; thus, net N mineralization is only a small fraction of gross mineralization rates. This information can serve as a foundation to the development of soil regeneration goals and methods for restoration.

The surface energy balance and soil organic matter content also affect soil heat flux, hydrology, and soil development processes. Strong seasonal variation in solar radiation drives the development of soil thermal gradients that influence rates of soil hydrological and biological processes (Kane et al. 1989). Surface organic mats have low thermal conductivity (1/2 to 1/6 of mineral soil), and highly organic soil horizons have high thermal capacity as a result of high water holding capacity. These factors regulate the timing and rate of soil thawing and influence the length of the growing season. In addition, the hydraulic conductivity of organic soil horizon can be up to 1000 times greater than that of mineral soils (Hinzman et al. 1991) and most snowmelt and rainwater runoff will occur above the organic/mineral interface. Shaver et al. (1991b) showed that the high hydraulic conductivity of organic arctic soils can affect nutrient availability by mass flow, and that the topographic position of a vegetation type in a hydraulic gradient can strongly influence the availability of nutrients in the active root zone throughout the growing season. Again, these data constitute a foundation upon which pragmatic restoration goals and methods can be laid.

Revegetation Methods

Significant research efforts have been directed toward developing methods for revegetating disturbed sites on North Slope oil fields (Johnson 1981, 1984, Jorgenson et al. 1991, Jorgenson and Cater 1991, McKendrick 1991a, b). Primarily, these efforts have been trials to determine the suitability of individual species and effective plant establishment techniques (McKendrick 1991b) or appropriate levels of seeding, fertilization, and soil amendments to use for different site conditions and species combinations (Jorgenson et al. 1991, McKendrick 1991b).

As it applies to ecorestoration, revegetation must achieve more than just an adequate vegetative cover; it should initiate development of self-sustaining habitat for specified wildlife species groups of concern. Although significant progress has been made in identifying plant species for use in terrestrial (Jorgenson et al. 1991, Jorgenson and Cater 1991) and aquatic (McKendrick 1991a) applications, additional research is needed to develop revegetation prescriptions that can produce the specified habitat types at appropriate sites. Ongoing research is being conducted into the ecophysiological aspects of germination, establishment, growth, and seed production on species used for restoration on the North Slope. However, insufficient results are available to allow development of restoration prescriptions and much additional research is needed. Additionally, early research efforts in revegetation focused primarily on developing methods to merely establish vegetative cover on specific sites rather than on identifying species and species mixtures for establishing specific habitats.

RESTORATION PLANNING TOOLS AND MONITORING METHODS

Integrating scientific knowledge and applying this information to problems of North Slope restoration will require effort to assemble and utilize existing and new information. This information is needed to assist regulators in making scientifically defensible decisions and identifying economically feasible and ecologically desirable restoration methods. The following two areas of information acquisition and management are needed for implementing restoration on the North Slope: 1) developing practical analytical and decision support tools for restoration, and 2) developing monitoring techniques and indicators of landscape- and site-scale ecosystem status.

Restoration planning tools are needed for three major reasons: 1) expediting the regulatory permitting process, 2) enhancing the assessment of ecological risk, and 3) facilitating the selection of economically-viable ecological engineering methods to achieve specified objectives. Monitoring results provide feedback for assessing the efficacy of restoration planning and implementation.

Restoration Planning Tools

Planning for restoration of North Slope oil fields is a complex, semistructured process involving resource identification and risk assessment at site and landscape scales, prescription, and application of ecological engineering approaches and delineation and monitoring of performance standards to determine compliance. Any or all components of this process may require tailoring to meet specific site requirements. That is, restoration problems are neither routine nor repetitive, and a decision maker may not have a generally established approach to solving a specific site restoration problem. It is precisely these situations that are amenable to technological support in the form of a decision support system (DSS) approach. This calls for research to improve information systems for decision making, including the use of data from mapping, baseline data, and other data related to the environmental effects of oil field development.

Computer-Aided Decision Tools--

A decision support system (DSS) is designed to help users address broad semistructured problems. The user directs the problem-solving process. The DSS supports, but does not replace, the user's decision making process (Gorry and Scott-Morton 1971, Newell et al. 1990). Sprague and Carlson (1982) further describe DSS as systems that 1) tend to be aimed at the less well-structured, underspecified problems that professionals typically face, 2) combine the use of models or analytical techniques with traditional data access and retrieval functions, 3) are designed for use by noncomputer people, and 4) focus on features that make them easy to use in an interactive mode, and stress flexibility and adaptability to fit changes in the situation and decision-making approach.

In contrast, use of an expert system on a semistructured problem would impose structure by extracting rules from an expert to address problems that may not have been recorded or expressed. Expert systems are usually system-driven; that is, the computer dictates which step is to be taken next. Because expert systems are expensive to develop, they are usually applied to narrow and very specific operational problems that need to be answered frequently by users (Doukidis 1988). Decision support systems are more like a collection of tools and data that are used to solve problems.

A DSS provides some structure to the problem, but the user must make a series of decisions about how to set up the analysis and represent the problem, how to apply all the available data, and which simulations should be made. To apply relevant data to each site considered, certain questions must be raised. What are the criteria for evaluating and choosing restoration sites? Can or should we take all restoration sites into account? How important is a certain area with regard to others? How shall importance be determined and which characteristics make it important? When should an area be judged worthy of restoration? Which factors should contribute towards distinguishing the degree of disturbance or disruption of ecosystem function?

Such a system would provide a capability to integrate knowledge of all restoration actions taken throughout the disturbed areas of the North Slope, and to identify how each new permit application fits into the overall context of North Slope restoration activities. It would include a modeling component that would allow each new contemplated restoration project to be integrated into the expected restored environment. This feature will allow assessment of the mixtures of habitat types and the effects on wildlife populations that would result from the specific planned project.

Information Review --

One of the critical limitations faced by all parties participating in any research effort is the collection and scoping of the current state of knowledge. Often a limited acquaintance with unpublished, government, internal reports, or other "grey" literature that receives limited peer-review and circulation is a fundamental handicap shared by researchers, regulators, and industrial operators alike. An additional handicap stems from the fact that the quality of the data in much of the "grey" literature may be irregular because of lack of peer review. Ecological restoration research and operations on the North Slope of Alaska are no exception to these generalities.

There is a critical need to establish an information base to support the regulatory decision process and the development of site-specific restoration prescriptions. Without this information base, available knowledge will likely be underutilized in establishing goals and performance standards, augmenting the suite of available ecological engineering techniques, establishing site-specific prescriptions for restoration methods, and developing monitoring strategies. The information gathered and developed under this element is essential to the efficient and effective regulatory and permitting decision process.

The first step in establishing a data base is to determine its purpose. The second is to stipulate its contents. The simplest form of data base is a compilation of references to relevant documents; i.e., a bibliography. Certainly, an annotated collection of bibliographic references is an important part of an information base and can be readily developed. However, we believe that a more operational tool is required for the North Slope. Although recovery from wide-spread disturbances have been studied and provide some insight to development of sound restoration practices (Walker et al. 1987b), restoration efforts have not been undertaken at this geographic scale before. In addition, unique characteristics of arctic systems simplify some of the relationships normally involved in ecosystems (Shaver et al. 1991b) providing a great opportunity for advancing the scientific basis of restoration in temperate climates. The information base for North Slope restoration can be the most important tool for evaluating the state of a habitat, assessing the probable changes that will occur without restoration, prescribing appropriate intervention in the form of restoration treatments, management, or protection, monitoring the changes that occur after implementation of these decisions, and determining the cost effectiveness of restorational decisions in achieving desired levels of restoration.

With computers, information can be stored and accessed using an architecture that is significantly different from the sequential presentation of printed books and manuals (Newell et al. 1990). Integrated data bases, or hypertext, represent a new type of information medium where large amounts of diverse information are connected electronically in computers. Hypertext gives users electronic bridges for reaching referenced information quickly and easily (Young 1986). Developing hypertext documents requires careful design, implementation and testing, and is usually somewhat more time consuming than developing conventional data bases. However, the cost of developing such a system should be carefully weighed against the costs that all parties face when the permitting process becomes delayed due to large numbers of permit applications, and the delays associated with personnel turnover and training. Furthermore, development of a hypertext information system can be seen as the first step in the design and development of an integrated decision support system.

Spatial and Temporal Analysis Tools--

Information on the temporal dynamics of North Slope ecosystems is inadequate, and only limited mapped information of the spacial characteristics is available. More information will be obtained in the future and better information will be discovered once restoration projects and development of the DSS begin. Meanwhile, extant mapped biological, geological, climatic, and cultural information will be analyzed and combined to produce maps that delineate boundaries of homogeneous landscapes in the coastal plain. These maps will comprise several nested layers of information (mapping of informational scales) including base maps that depict only broad regional features and maps, and data that provide detailed information about specific features within the region. Similarly, mapping of spatial scales will be accomplished by nesting detailed site and area maps within more general maps of larger areas to establish linkages among levels of detail. Mapping of temporal scales is conceptually more difficult. The linkages involved in temporal scale mapping will have to represent information such as daily, seasonal, and annual changes in weather and climate conditions, thaw cycles, plant and animal colonization cycles, soil development rates, paleobiological and geological information, and progression of site restoration activities.

From this perspective, developing a regional decision support system can be viewed as a process of partitioning the environment into interconnected scales of informational, spatial, and temporal detail, and providing the tools to assess the effects of proposed actions upon the environment. The extent to which this can be accomplished is dependent upon the extant data and the conceptual framework used in their interpretation.

Monitoring Methods Research

Because restoration goals are inherently long-term, it will be necessary to identify indicators that can be used to evaluate the progress of restoration actions toward achieving these desired goals. This will require the identification of intermediate stages of restorational succession to target habitats and the development of indicators that can, by means of periodic monitoring, identify attainment of these intermediate stages. Monitoring can serve a two-part function. First, monitoring the state of a site relative to performance standards will determine the level of success in achieving performance standards. Second, monitoring is an important feedback mechanism to ensure that regulatory decisions and performance standards have the desired effect on the landscape.

Although some monitoring of site-specific restoration efforts has been conducted by industry (c.f., Jorgenson and Cater 1991, Jorgenson et al. 1991), essentially no research has been conducted to develop effective goal-oriented monitoring programs at the landscape scale on the North Slope. In addition to selecting indicators for monitoring, it will be necessary to develop two types of strategies for monitoring. These strategies necessarily will consider the original intention of the restoration efforts, the rationale for selecting the methods that were used, the indicators that have been selected, and the expected behavior of those indicators after specific periods of time have elapsed.

We suggest that effective monitoring strategies will integrate the monitoring requirements of site-specific monitoring with those of geographically broad monitoring needs. This will contribute to efficiency and improved understanding of overall progress toward a desired landscape condition. For example, efficient methods for remotely assessing the integrated effects of thermal, hydrological, and habitat condition on the condition of whole ecosystems at landscape scales will require innovative approaches to acquire, process, and interpret imagery from several satellite platforms. Monitoring environmental conditions at the site scale requires development of strategies and tools for monitoring physical, chemical, and biological conditions of both undisturbed and disturbed sites. The data generated must be compatible with the data generated by landscape-scale monitoring efforts to allow integration of site and landscape levels of information for assessment.

A meaningful monitoring program will require developing the ability to discern changes in characteristics of restored and non-restored sites. It will be necessary to assess this information at a geographical scale above the level of the site which requires developing networks of monitoring stations located in all types of disturbances and restoration efforts. In addition, it will be necessary to develop methods to statistically and graphically assess the information generated.

SECTION 4

RESEARCH SUGGESTIONS AND ESTIMATED COSTS

OVERVIEW

The ANSORRS goal is to provide guidance on the overall structure and planning of arctic restoration research. In this Section, we summarize the scope and structure of ANSORRS by suggesting restoration research or demonstration projects for North Slope oil fields. However, because ANSORRS is not a research plan, we do not present specific hypotheses, time tables or quality assurance and logistic plans. We have also estimated the level of funding that will be required to conduct the research for each of the three main problem areas outlined in ANSORRS. To be successful, we believe it will be necessary for this effort to become an established long-term program with funding commitments for at least 10 years. Funding suggestions made in the following sections, however, address a five-year budgetary period.

Because we expect that different agencies and industry will conduct the specific research projects encompassed by ANSORRS, we recognize that selection of individual research topics and development of detailed research plans will be the joint responsibility of each sponsor and the involved scientists. ANSORRS facilitates public and private coordination of restoration research planning by focusing efforts to enhance our knowledge of environmental condition, risks and trends in North Slope landscapes and ecosystems affected by oil and gas development. However, we suggest that separate plans be developed to coordinate research projects under the three problem areas (assessing restoration benefits, ecological engineering and planning tools) that we have outlined in ANSORRS.

IDENTIFYING THE NEED FOR RESTORATION

To ascertain the need for restoration following North Slope development, we have suggested (Section 3.2) that it will be necessary to define and quantify ecological resources and assess the risk of resource loss. We recommend consideration of funding investigations in the following areas at an overall level of $1M/yr for five years:

1. Defining and classifying baseline wildlife habitat conditions for all terrestrial and aquatic habitat types, with special attention to identifying habitat requirements for critical wildlife including:

   - intercontinental migrants, such as waterfowl and shorebirds,
   - intracontinental migrants, such as colonial geese,
   - regional migrants, such as caribou, and
   - local resident species, such as mammalian herbivores and predators.

2. Classifying and assessing the spatial characteristics of landscape scale hydrologic and thermal budgets to determine:

   - physical stability of permafrost terrain,
   - effects due to industrial development (including direct effects such as habitat destruction by burial under gravel, and indirect effects such as cumulative effects of altered local water regimes due to snow capture and hydrologic system interruption associated with roads, altered albedo caused by airborne dust, or toxic effects of air-transported pollutants), and
   - potential risk of loss of wildlife habitat from changes in physical conditions.

ECOLOGICAL ENGINEERING METHODS

Ecological engineering for restoration includes manipulations that are intended to hasten the establishment of desired self-regulating terrestrial and aquatic ecosystems. To be effective in full-production, these manipulations must be simple and straightforward, allowing non-scientists to apply relatively few treatments to large areas in a limited amount of time. Research efforts must focus not only on developing new methods of developing desired habitats, but also on methods for applying useful methods on large scales. The three major categories of manipulations that we have included for development under ANSORRS are: site preparation, accelerating soil development and revegetation (Section 3.3). We recommend consideration of funding investigations in the following areas at an overall level of $2M/yr for five years:

1. Site preparation research fostering generation of desirable planting substrates by developing methods for:

   - inventorying gravel recycling opportunities,
   - segregating substrate particle sizes and stratifying segregated materials as they are being replaced prior to planting,
   - decontaminating hydrocarbon-contaminated gravel, and
   - providing soil moisture during the growing season.

2. Site preparation research aimed at developing practical, large scale methods for reconfiguring sites to meet physical system restoration goals by:

   - restoring drainage patterns and eliminating ponding (e.g., breaching road systems and reducing the extent of artificially induced snow-drifts),
   - reestablishing subsurface flow and surface sheet-flow processes (e.g., removing roads and pads in areas of significant surface or subsurface flows),
   - reestablishing metastable thermal regimes (e.g., halting thermokarst development and repairing thermokarst damage),
   - restoring typical tundra patch size and shape (e.g., reducing connectedness of lineal facilities, and reshaping gravel roads and pads), and
   - reestablishing typical mosaics of terrestrial and aquatic ecosystems.

3. Research to accelerate establishment of tundra sod by:

   - adding organic matter from mined tundra mats, stockpiles, sludge, or other sources to exposed gravel,
   - adding amendments to soil and mineral substrates to improve ion exchange characteristics, pH or macro- and micronutrient concentrations,
   - reshaping or otherwise modifying sites to provide suitable physical conditions for establishing desired plant community types, and
   - enhancing establishment of soil microbiota by inoculation or other methods, using nonvascular plants, mycorrhizae, and invertebrates.

4. Modifying or enhancing agronomic practices to establish desired plant species by:

   - increasing the propagation of planted, seeded, or seed-banked plants in all types of aquatic and terrestrial habitat,
   - identifying appropriate methods for using transplants, cuttings, plugs, and sod to establish shrubs on all types of substrates and sites,

- enhancing germination from the seed bank on sites where fresh or stockpiled tundra organic material is available,
- identifying candidate species and ecotypes for planting and seeding in all types of aquatic and terrestrial habitat,
- testing individual species for viability in different types of disturbed site, and
- using nitrogen-fixing and nonvascular plants.

5. Providing adequate materials and supplies to support restoration activities, by increasing existing capabilities for:

    - producing adequate supplies of seed and vegetative materials and
    - supplying specific fertilizer formulations, soil amendments, mulches, matting and similar materials.

RESTORATION PLANNING TOOLS AND MONITORING METHODS

Regulatory decisions rely on information integration which depends on all of the strategies and infrastructures needed to gather, organize, manipulate, and assess existing and new information as it pertains to restoration. We identified two major areas of investigation in Section 3.4: restoration planning tools and monitoring. We recommend funding investigations in these areas at an overall level of $500k/yr for five years:

1. Supporting the regulatory decision process and the development of site-specific restoration prescriptions by establishing an information base for:

    - understanding natural successional processes and time scales for terrestrial and aquatic communities;
    - mapping data of thermal, hydrologic and habitat values; climatic and floristic zones; landscape features: gravel fill locations and other relevant information;
    - identifying and assessing the cumulative impacts of oil field development on the North Slope;
    - developing a GIS interface and support for analysis of map information;
    - compiling references to relevant documents; and
    - developing computer-supported hypertext capabilities.

2. Developing user-friendly, integrated, computer-supported tools for use in analyzing alternate restoration options including:

    - spatial models of wildlife/habitat relationships,
    - spatial hydrologic and thermal models, and
    - integration of hypertext capabilities.

3. Developing strategies and tools for monitoring environmental and ecological conditions at site and landscape spatial scales, as well as over ecologically significant time spans to support:

    - identifying and testing indicators of ecosystem status that are directly linked to specified goals of the monitoring effort,
    - developing defensible sampling frames that accommodate the desired scales of resolution and techniques that will be used for interpretation,
    - selecting appropriate instrumentation for use in data collection,

- developing appropriate quality control and statistical evaluation protocols to interpret the information collected, and
- developing a system for managing the collection of monitoring data.

4. Focusing monitoring efforts on:

- determining the status of terrestrial and aquatic vegetation (i.e., productivity, structure, and composition),
- identifying intermediate stages in restored plant community succession to evaluate the success of revegetation prescriptions,
- assessing the quality of terrestrial and aquatic habitats, and the identification of intermediate stages in development of targeted restored habitats,
- assessing thermal instability on landscape and site-specific scales,
- assessing the extent and distribution of air-transported pollutant effects
- identifying nutrient availability in different habitats,
- assessing local and regional hydrology, including determination of flushing rates for drainage systems, impoundments, ponds, and lakes, and
- assessing surface water quality.

PRODUCTS OF THE RESEARCH EFFORT

Implementing this strategy will result in development of methodologies for identifying which ecosystems affected by oil development that require restoration. Priorities can be set for implementing specific restoration actions in those ecosystems. In addition, the spatial and temporal data bases and analysis techniques acquired during the project will support planning of future developments in a manner that will require minimal restoration following abandonment. This research also is expected to produce new ecological engineering techniques for tundra habitat restoration and a methodology for determining when, where, and the level of effort will be required in the application of those techniques.

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APPENDIX A

LIST OF WORKSHOP PARTICIPANTS

Ecorestoration Workshop
Anchorage, AK
May 2-4, 1991

Dr. Femi Ayorinde, USACE
Ms. Joyce Beelman, ADEC
Dr. Max C. Brewer, USGS
Ms. Anne Brown; BPX
Mr. Michael Brody, EPA
Dr. John Bryant, UAF
Dr. Clarence Callahan, EPA
Dr. Buddy Clarain, USACE
Mr. Fred Crory, USACE
Mr. Lloyd Fanter, USACE
Dr. Craig Gerlach, UAF
Ms. Michelle Gilders, BPX
Ms. Jeanne Hanson, NMFS
Dr. Chris Herlgson, BPX
Mr. Marcus Horton, USFWS
Mr. Torre Jorgensen, ABR
Mr. Mike Joyce, ARCO
Mr. Ken Kertell, LGL Alaska
Dr. Knut Kielland, UAF
Mr. Mel Knapp, TRI
Dr. Peter Lent, LGL Alaska
Dr. Jay McKendrick, UAF
Dr. Rosa Meehan, USFWS
Dr. Rich Meganck, METI
Mr. Phil North, EPA
Dr. Kim Peterson, Clemson
Dr. Mary Lee Plumb-Mentjes, USACE
Dr. Charles Racine, USACE
Mr. Dan Robison, EPA
Dr. Roger Ruess, UAF
Dr. Ron Thom, Batelle
Dr. Robert White, UAF
Dr. Robert Woodmansee, CSU
Dr. Jamie Wyant, METI

North Slope Workshop
Prudhoe Bay and Kuparuk oil fields
July 30 - August 2, 1991

Ms. Joyce Beelman, ADEC
Dr. Rick Bennett, EPA
Dr. Clarence Callahan, EPA
Dr. Ray Cameron, ADF&G
Ms. Terry Carpenter, USACE
Dr. Buddy Clarain, USACE
Ms. Linda Comerci, EPA
Dr. Mary Davis, USACE
Mr. Joe Dygas, BLM
Mr. Lloyd Fanter, USACE
Dr. Craig Gerlach, UAF
Ms. Michelle Gilders, BPX
Dr. Larry Hinzman, UAF
Dr. Fred Huzby,
Mr. Steve Jacoby, ADGC
Mr. Larry Johnson, UAF
Mr. Torre Jorgensen, ABR
Mr. Mike Joyce, ARCO
Mr. Mel Knapp, TRI
Dr. Rick Knight, CSU
Ms. Janet Kowalski, ADEC
Dr. Robert Lackey, EPA
Ms. Jennnifer Loprocaro,
Mr. John Mahaffey, USACE
Ms. Barbara Mahoney, NMFS
Dr. Jay McKendrick, UAF
Mr. Kieth Mueller, USFWS
Dr. Tony Palazzo, USACE
Mr. Roger Post, ADF&G
Dr. Mary Lee Plumb-Mentjes, USACE
Ms. Ann Rappaport, USFWS
Mr. Dan Robison, EPA
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APPENDIX B

QUALITY ASSURANCE POLICIES

OVERVIEW

Policies initiated by the Administrator of the EPA in memoranda of May 30, 1979, June 14, 1979, and April 3, 1984 require that all EPA laboratories, program offices, and regional offices participate in a centrally-managed quality assurance (QA) program. This policy extends to those monitoring and measurement efforts supported or mandated through contracts, regulations, and/or other formal agreements. The intent is to develop a unified approach to QA to ensure the collection of data that are scientifically sound, legally defensible, and of known and documented quality.

The Office of Research and Development (ORD) is responsible for developing, coordinating, and directing the implementation of the Agency's QA program. ORD has delegated this responsibility to the Quality Assurance Management Staff (QAMS) under the Office of Modeling, Monitoring Systems, and Quality Assurance (OMMSQA).

To implement Agency policy, EPA laboratories, program offices and regional offices must prepare QA program plans covering all intramural and extramural activities that generate and process environmentally-related measurement data for Agency use. QA program plans are reviewed annually by laboratory QA staff to determine if significant changes have occurred requiring revision. In addition, all EPA supported projects that generate and process environmentally-related measurement data are required to prepare QA project plans covering the specific quality assurance and quality control (QC) measures to be followed for these projects. These documents are submitted to QAMS for review and approval for implementation. Essentially all field and laboratory investigations involving the measurement of environmental chemical, physical, or biological parameters generate environmentally-related measurements.

QUALITY ASSURANCE POLICY STATEMENT

It is the policy of the EPA that QA will be integral to all research projects that generate or use environmentally-related measurement data. A QA program plan will be established that ensures all data collected are of known and documented quality.

Laboratory and regional management are responsible for ensuring that the QA program plan is implemented. Each project officer is responsible to the QA officer for establishing the protocols that will result in collecting data of known quality. An independent QA staff is responsible for implementing the laboratory's QA program and ensuring that QA policy is followed. Project-level staff may be assigned QA responsibility to provide guidance in preparing QA project plans, to interpret QA requirements, and to function as project advocates to aid in meeting project QA requirements.

The QA program is designed to ensure that laboratory outputs are cost-effective, technically sound, and satisfy project objectives. Key elements of the QA program at the EPA Environmental Research Laboratory in Corvallis, Oregon are:

1. Data Quality Objectives (DQOs): DQOs must be developed as part of the QA planning process before data collection begins, and then compared to the quality of the actual data collected.

2. QA project plan: The QA project plan must be based on the data quality objectives and include integral QA and quality control (QC) procedures. Resources needed to accomplish project objectives will be specified.

3. Audits: Audits shall be conducted to evaluate the conformance of data collection, analysis, and management to the DQOs and the QA project plan.

4. Reporting: All data must be reported at a quality level adequate for the intended use. Journal articles and reports developed as outputs from laboratory projects shall include QC information supporting the data.

Audits serve to communicate the intent of the ERL-Corvallis QA program to those actually collecting the data. These reviews are designed as a training exercise. Personnel are advised of new or revised QA directives through meetings and memos. Since effective QA requires teamwork, it is desirable and useful for both management and operational level personnel to understand the QA function at all levels of the project.

APPENDIX C

ECOSYSTEM FEATURES OF ALASKA'S NORTH SLOPE

GEOMORPHOLOGY

The region of the North Slope of Alaska spans three physiographic provinces from the northern slopes of the Brooks Range through the southern and northern foothills to the Arctic Coastal Plain. The offshore region of the continental shelf is narrow in the east and extends to hundreds of miles in the west before it drops into the Arctic Ocean abyss.

The Coastal Plain is covered by thousands of lakes that develop by combined actions of freezing and thawing in the active (upper) layer of the permafrost, and the ice wedge process that patterns the land into polygons. More than half of the area of coastal plain is covered with thaw lakes that can reach up to 40 km in length and are generally shallower than 3 m. Britton (1966) has described the dynamic aspects of the thaw-lake cycle and the development of the ice-wedge polygon landscape.

Thaw lakes are formed by pooling of water in the depression of low-centered polygons and most of the lakes become oriented perpendicular to the prevailing wind in the region (east-northeast). Low-centered polygons are produced by the dynamics of ice-wedge formation. Marshy basins that constitute 25% of the coastal area are formed when the thaw lakes drain. Polygons are surrounded by ice-wedges and the intersections of ice wedges produce "beaded streams''," which are interconnected string of elliptical pools. The drained thaw lakes and the encroachment of permafrost produce low 'frost mounds' and 'pingos' which can be up to 30 m high. This process occurs over the course of thousands to hundreds of thousands of years (Walker and Walker 1991).

PERMAFROST AND HYDROLOGY

Permafrost is the frozen layer of soil and bedrock and ranges from approximately 400 m to 600 m in thickness at Barrow and Prudhoe Bay, respectively. Only an upper layer is 'active' and thaws in the summer. Seasonal cycles of the melting ice creates local variations in the land surface topography. Permafrost formation is enhanced by shading and insolation, and vegetation cover insulates and preserves it. Major problems can arise when construction on permafrost removes the insulating tundra mat, altering the thermal conductivity of the soil. The result can be an increase in the depth to permafrost caused by solar heating or inadequately insulated heated structures.

In the Arctic, the distribution and the subsurface drainage of groundwater is greatly affected by the permafrost. Groundwater is perched on the frozen material and is available year round only from unfrozen alluvium near large rivers and under large lakes that do not fully freeze. Unfrozen aquifers under permafrost are brackish and unfrozen alluvial and bedrock aquifers are either low yield or difficult to find.

Water saturated sediments flow downslope forming sheets, lobes, and terrace-like features. These permafrost related landforms result from the poor drainage capabilities of the topsoil underlain by impermeable ice.

OPEN WATER

Open water may comprise 35% or more of the surface area of the coastal plain (Walker et al. 1986). Most of this aquatic milieu is shallow ponds that constitute one of the stages in the thaw lake cycle. Other open water habitats are deep water lakes and impoundments created by surface disturbances. The ecology of open waters on the coastal plain has not been thoroughly studied, although many shorebirds and water fowl feed on aquatic plants or invertebrates (Truett and Kertell 1990).

Thaw lakes may form when a disturbance to the surface of a moist tundra system increases surface temperature or increases soil thermal conductivity. This initiates a series of changes that propagate from increased permafrost thaw depth, to surface subsidence, then to surface ponding that inundates and kills the tundra vegetation, and subsequently to further increased thermal conductivity and depth of thaw.

The acreage flooded by shallow impoundments varies with the seasons, reaching a maximum at the end of the snowmelt period. Although temporary flooding does not often kill the flooded terrestrial vegetation, it can alter the vegetative composition and initiate a greening process that coincides with a deepening of the depth of thaw (Walker et al. 1987b). Some deep-water impoundments occupy gravel mine pits, and are suitable for production of resident fish populations since they do not freeze to the bottom (Joyce pers. comm., McKendrick pers. comm.).

SOILS

Arctic soils are greatly influenced by their drainage potentials. In the Arctic Foothills, soils are mixes of well drained soils with a dark non-acidic upper layer and poorly drained soils with a dark non-acidic upper layer in the higher slopes. In the lower slopes and the Arctic Coastal Plain, soils are poorly drained and thaw in the summer only to a shallow depth (approximately 45-50 cm). The quality of soil organic matter varies widely among these ecosystems and is more important than soil temperature differences in controlling rates of nutrient cycling and soil building processes in the field (Nadelhoffer et al. 1991)

The rates and patterns of nutrient dynamics in arctic soils are dependent on the physical and biological characteristics of the soil profiles. The soils of the North Slope are typically wet (soil moisture >75%), cold (temperature < 10° C in the rooting zone during the growing season), acidic (pH < 5.5), and highly organic (organic matter content > 50% in surface horizons). Soil type, pH and moisture holding capacity are strongly dependent on organic matter content and composition. Up to 95% of soil biological activity (i.e., root biomass, root growth, microbial biomass and growth) may be confined to the organic horizons (Kielland pers. comm., Ruess pers. comm.), although roots may penetrate all the way to the maximum depth of soil thaw (Shaver and Billings 1975, Miller et al. 1982).

VEGETATION

The flora of the coastal plain comprises only a few hundred vascular plant species and diminishes along a south to north gradient to about 125 vascular species in the Barrow area. Mosses are an important component of the vegetation in moist and wet sites. Mosses, along with peat soils, form the rooting medium for most vascular plants throughout the region of interest. In many sites, mosses play an important role in restricting thaw depths. Lichens are prevalent in drier locations.

Throughout the coastal plain, vegetational patterning is closely linked to patterns of soil moisture. Soil moisture varies by several orders of magnitude, depending largely upon microtopography. Low precipitation combined with impervious permafrost at shallow depths allows perched water tables to intersect the soil surface in low-lying areas. Small elevations of a few decimeters as are associated with polygon rims and high center polygons result in dry surface soils isolated from the water table. Microtopographic relief results in strong vegetational patterning.

Regional vegetational differences within the wet coastal tundra region are a function of both climatic and substrate differences. The sedge *Eriophorum vaginatum* dominates much of the region, but gives way to dominance by another sedge, *Carex aquatilis*, in the immediate coastal region where frequent fog and cloudy conditions reduce summer temperatures. Much of the eastern region of the coastal plain is under the riparian influence of rivers originating in calcium rich formations resulting in a high soil pH. These areas lack the genus *Sphagnum*. To the west of this region, rivers originate in the northern arctic foothills or on the coastal plain itself and *Sphagnum* is an important component of the vegetation in many wet sites.

In undisturbed arctic tundra, no single environmental factor has been demonstrated to limit the productivity of all plant community members (Chapin and Shaver 1985) and though productivity of individual species varies greatly from year to year, productivity of the whole vegetation is more stable (Chapin and Shaver 1985, Henry et al. 1990). As in more southerly grasslands, there is some evidence that moderate grazing results in greater net production and lower standing crop of dead material (Henry and Svoboda 1989).

WILDLIFE

There are many studies investigating various aspects of the population ecology of large predators and herbivores of the North Slope (Norton 1975, National Petroleum Reserve in Alaska Work Group 3 1979). In addition, the role of small mammals (i.e., lemmings) in nutrient cycling has been studied (Batzli et al. 1980). A common topic of concern is the relationship between wildlife and vegetation communities (i.e., habitat).

Arctic terrestrial animals utilize different vegetation communities to fulfill their basic energy/reproductive requirements. This leads to patterns of association between the animals and the vegetation communities. Because many of the wildlife species are migratory, different parts of the region are associated with these patterns.

In some instances, specific vegetation communities can be associated with a wildlife species. For example, moose rely on riparian shrub communities for winter habitat. In other cases, specific geographical areas may be identified. For example, in the Central Arctic region of Alaska, the barren-ground caribou winter in the northern foothills of the Brooks Range. During spring, the cows migrate to calving areas along the coastal plain, while in summer the animals aggregate near the coast and river deltas (Carruthers et al. 1987).

Waterfowl use of a variety of vegetation communities during the breeding season has been studied by a number of authors using different classification schemes (Bergman et al. 1977, Derksen et al. 1981, Meehan et al. 1986, Meehan and Jennings 1988) making comparisons difficult (see review in Meehan et al. 1986). Understanding is lacking regarding the use of different habitats by waterfowl, especially during brood-rearing. The trophic relationships among waterfowl and habitat types are not well understood, nor is the importance of different plant communities to waterfowl population dynamics.

Because the shallow lakes in the arctic region freeze to the bottom, they do not carry fish populations. Aquatic communities in shallow lakes of the North Slope are dominated by invertebrates such as copepods, rotifers, cladocera, shrimp, and larvae of stonefly, beetles, and snails. These water bodies are also significant waterfowl habitats.

Fish such as arctic char, whitefish, and grayling are found in the large rivers and deep lakes that do not freeze to the bottom in the winter.

THE PEOPLE

In general, the native peoples of the region settled in two major groups roughly corresponding to the physiographic provinces of the Arctic. The Taremuits settled in the coastal region where they hunted marine mammals (Burch 1975, 1976). The Nunamuits settled in the uplands and hunted land mammals. Within each culture, tribal entities can be identified with some of today's settlements. From the west to the east on the coastal arctic there are the Tigeramuits of Point Hope, the Kukparungmuit of Point Belcher and Cape Beaufort, the Utukamuit of Icy Cape, the Knutmuit of Kuk River, the Sidarumuit of Pear Bay, and the Utkiavinmuit and the Nuwukmuit of Point Barrow.

The Coastal Taremuits and the inland Nunamuit were culturally linked by trade and the exchange of goods. The inland people traded caribou skins, fox furs, feathers, birch bark and berries for the seal oil and stone lamps of the coastal people.

Depletion of the whale population, overhunting of the caribou and exploitation of fox and other furbearers, predominantly by people outside the region, combined with changes within the region as a result of outside influences shifted the cultural base of the native people (Hall et al. 1985). These cultural and societal changes brought about a new era leading to the formation of the Arctic Slope Regional Corporation and the North Slope Borough as forces in a regional government of the people.

GLOSSARY

These terms are defined as they are used in this report, and not by reference to other usage except to assist in making distinctions or in clarifying associations.

Decision Support System: Computer systems designed to help users with broad semistructured problems, within which the user directing the problem-solving process. A DSS supports, but does not replace the decision making process of the person solving the problem.

Degraded ecosystem: An ecosystem has been degraded when its pre-disturbance functions or structural components have been altered sufficiently that the value of the system is reduced. For example, disturbances that reduce the ability of vegetative communities to support wildlife degrade the ecosystem as it pertains to wildlife values.

Ecological engineering technique: Any method that can be used to manipulate the physical or biological environment to accelerate achievement of ecorestoration goals is an ecological engineering technique. For example, such methods may include, among others: physically restructuring the land surface, adding soil amendments to planting sites, altering water capture and retention on restoration sites, seeding, or planting vegetative materials.

Flare pits: Waste discharge pits that are designed to allow pressure surges of gas or petroleum to be vented and burned in safety.

Functional roles: Functional roles in ecosystems include all of the attributes that combine to characterize an integrated ecosystem. Functional roles include biological roles (such as producer, consumer, and detritivore) and physical/chemical roles (such as hydrological drainage, chemical buffering, and nutrient transport).

Goals: Expressions of environmental values that are to be preserved or reestablished by restoration activities.

Gravel pad: All facilities on the North Slope are built on gravel pads approximately 1.5 m thick. These pads provide structural support and insulate the underlying permafrost. One of the original Prudhoe Bay drilling sites (A-pad) covered 17.8 hectares (ha). The newest pads are substantially smaller covering about 5.5 ha.

Landscape ecosystem concept: The concept recognizes that several elements may comprise a geographically wide-spread ecosystem, and that, although processes and activities within a landscape element may be studied as if they occur independently from other elements, they are linked through physical, chemical and biological interactions that constrain the ways that the ecosystem as a whole can operate. It also recognizes that activities occurring within a landscape element must be viewed within the context of the entire landscape, rather than on a site-specific basis. Landscape ecosystem elements may comprise entire ecosystems, or they may constitute ecosystem components that normally interact or are perceived at a smaller scale than the landscape. For example, drainage basins on the coastal plain of Alaska's North Slope constitute a group of landscape elements, and the coastal plain is a much larger element of the arctic tundra ecosystem.

Monitoring: The study or surveillance of a system to determine whether pre-established restoration standards are being met.

Performance standards: Formal expressions of ecosystem characteristics that reflect socially desired ecosystem functioning, appearance, composition, and persistence at various scales of ecosystem organization. When ecosystem conditions are found to be substantially different from the formally stated standards, an unsatisfied need for additional restoration may be indicated.

Pigging pits: Sites where the residues cleaned from the inside of pipes are deposited.

Pingos: Conical hills with basal diameters of several tens to several hundreds of meters (m) and heights of 10 m to 60 m; formed on an ice core.

Rehabilitation: The deliberate attempt to return a damaged ecosystem to some kind of productive use or socially acceptable condition.

Reserve pit: Containment areas for drilling fluids, mud and cuttings built into the drilling pads. Drilling fluid and muds may contain toxic levels of heavy metals or other contaminants. Technological advances have eliminated the need for reserve pits for most new drilling operations.

Restoration: The process of facilitating or accelerating natural processes of ecosystem recovery by providing the necessary functional and structural connectivity to support the self-organizing nature of an ecosystem that has been fragmented by resource extraction or other uses. Under this definition, the "restored" ecosystem may not have the same dominant species, species diversity, production rates, or nutrient cycling rates as a similar undisturbed site; however, all essential functional roles of will be reestablished (Kusler and Kentula 1989).

Sampling frame: The geographic and temporal scales at which data collection is appropriate to answer the questions of concern. For example, site-specific monitoring data may not be appropriate for use in assessing landscape-scale ecosystem condition, and daily observation of depth of thaw of the active layer is probably more frequent than necessary for evaluation of potential changes in thermal regime. Appropriate choice of monitoring sampling frame optimizes the use of monitoring funds in light of the questions to be answered.

Species group of concern: Functional groupings of wildlife, such as intercontinental migrants (e.g., waterfowl), intracontinental migrants (e.g., colonial geese), regional migrants (e.g., caribou), year-round resident herbivores (e.g. lemmings) and carnivores (e.g., wolves and bear). This grouping allows assessment of habitat issues to focus on the aggregate of user wildlife, rather than on a single species.

Stakeholder: Individuals or legal entities with an interest or share in an undertaking. For example, private industry, native peoples, Alaska residents, federal regulators and U.S. citizens all have stakeholder interests in the management and restoration of North Slope oil fields.

Thermokarst: Fracturing of the land surface and surficial collapse caused by thawing of ice rich permafrost.