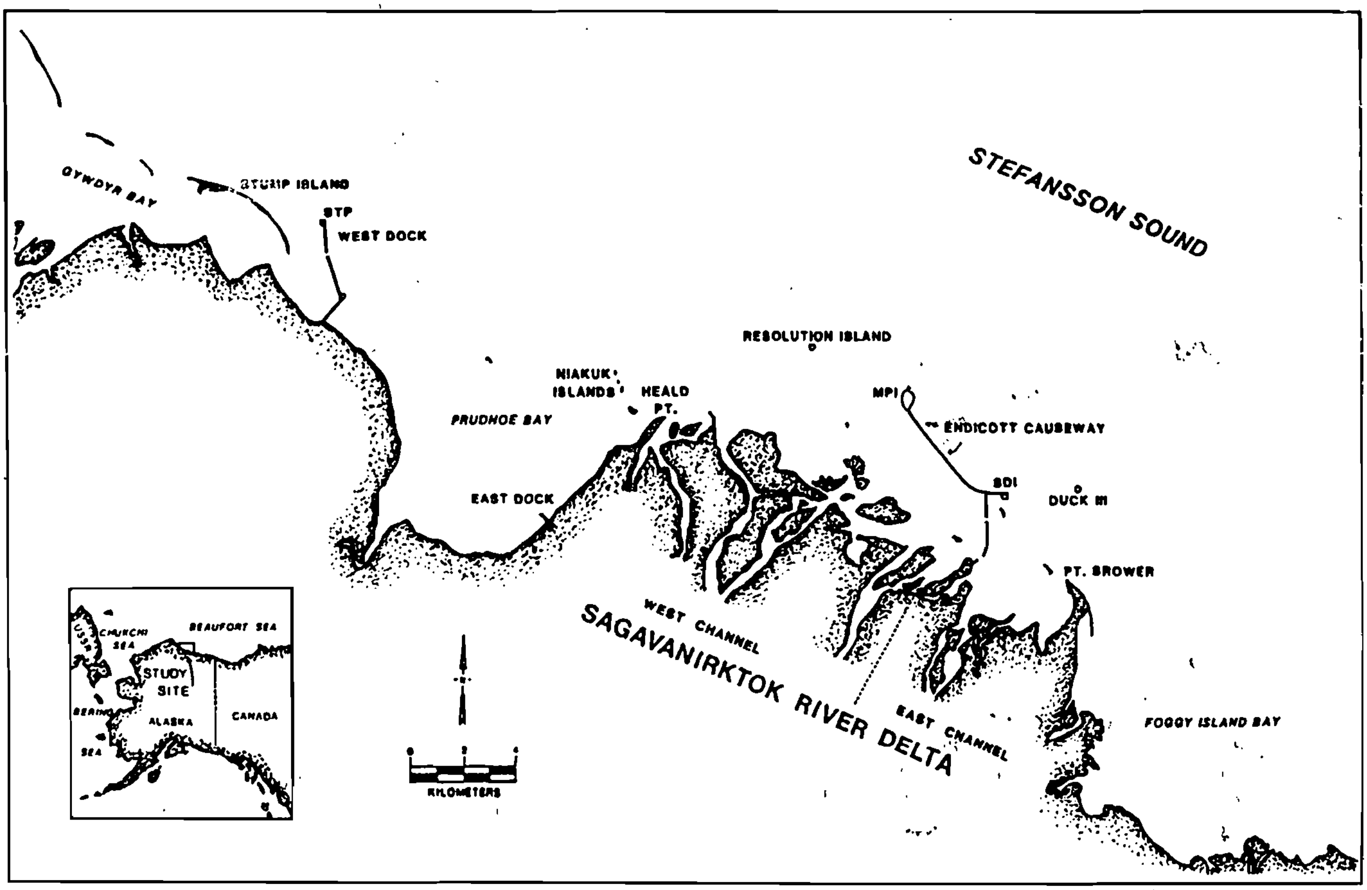
OCS Study
MMS 89-0038

ALASKA OCS REGION

A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA

WORKSHOP PROCEEDINGS



MAY 1990

MMS
U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

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A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA

WORKSHOP PROCEEDINGS

April 17-20, 1989
Clarion Hotel
Anchorage, Alaska

Prepared for:

U.S. Department of the Interior
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Alaska OCS Region
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DISCLAIMER

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BACKGROUND

Robert M. Meyer

Meeting Coordinator
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"... there has been too much jumping to conclusions and reinforcement of persuasive paradigms and too little testing of theories through attempts to falsify null hypotheses" (Southwood 1985, Science, p. 871-873)."

INTRODUCTION

The U.S. Department of the Interior (USDOI)--through the Minerals Management Service (MMS)--is charged with leasing submerged lands on the Outer Continental Shelf (OCS) off Alaska for oil and gas exploration. Before MMS issues leases, the agency identifies and evaluates the potential environmental consequences of leasing and subsequent exploration, development, and production of oil and gas resources on the Nation's outer continental shelf. In 1973, the national leasing program was expanded to include Alaska. As a result, the Alaska OCS Region is responsible for evaluating the potential environmental effects of leasing 230 million hectares in the Gulf of Alaska, Bering Sea, and Arctic Ocean (Figure 1).

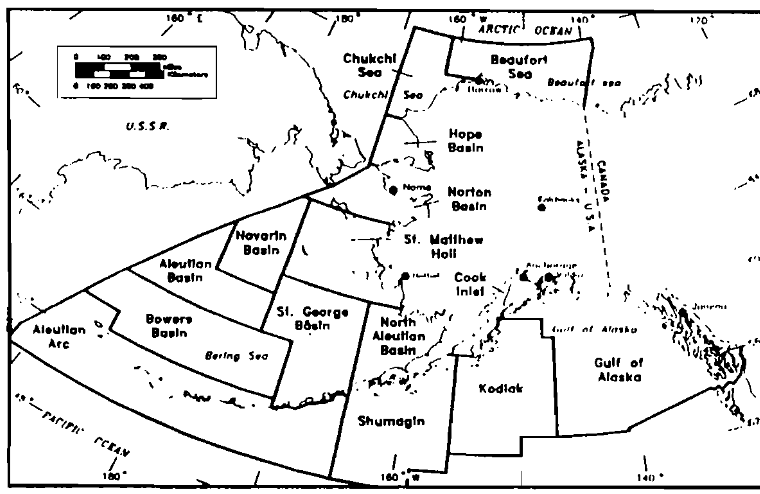

Figure 1. Alaska Outer Continental Shelf planning areas.

The discovery of commercial quantities of oil at Prudhoe Bay in 1968 (Tremont 1987) accelerated industrial development in the American Arctic. The specter of industrial activities in the Arctic has raised concerns about the potential effects that offshore oil- and gas-related activities may have on arctic ecology. In 1975, the U.S. DOI – as part of its OCS leasing program – initiated an Environmental Studies Program to determine which arctic resources were at risk from potential oil and gas activities and to assess potential effects on these resources. Studies initially focused on identifying and mapping the aerial and temporal distribution of natural resources in the region that might be affected by offshore oil and gas activities. These studies evolved into more integrated ecosystem-process studies, such as the Beaufort Sea barrier-island-lagoon-system study (Truett 1984).

In preparing for its first OCS oil and gas lease sale in the Arctic, MMS initiated in 1975, a series of information update meetings and synthesis meetings as part of the Environmental Studies Program and the environmental assessment process (See References).

To synthesize available environmental information for an area, MMS provides scientists with a forum within which to exchange information, i.e., the latest findings and unpublished information, to review and critique the available data base, to integrate new information into the existing information base and most importantly, to expose existing theories to scientific scrutiny reflecting this previously unavailable information. The synthesis meeting is one of the steps in the process to access available information. The synthesis process is completed following the meeting after the lead authors have had time to further review and synthesize all pertinent information, the draft synthesis report is circulated for peer review, and the final report prepared and published.

The involvement of as wide a spectrum of scientists as practical has insured that the data bases and conclusions based on these data are exposed to rigorous scientific scrutiny and that defensible conclusions and consensuses are developed. Results from MMS synthesis meetings have made significant contributions to our understanding of how man's activities may affect the marine environment and have also been used to mitigate these potential effects.

CAUSEWAY SYNTHESIS

The MMS has had a long-term and continuing interest in and involvement with the topic of causeways. In 1975, MMS initiated the Simpson Lagoon Study as part of the Environmental Studies Program. An important aspect of this study was the objective to determine the potential effects of causeways on water circulation in the nearshore portions of the Lagoon and the potential effects on Arctic biota. During the first MMS-sponsored Beaufort Sea Synthesis meeting, January 1978, the potential effects of causeways was a major topic of discussion. In 1983, MMS conducted a second synthesis effort, The Diapir Field Environment and Possible Consequences of Planned Offshore Oil and Gas Development, and again, causeways were a topic of discussion .

Since 1980, MMS has analyzed the potential effects of causeways in the Environmental Impact Statements for Beaufort Sea oil and gas sales 71, 87, and 97. For example, in the recent Final EIS for Beaufort Sea Sale 97 (Becker 1988) the effect of causeways was analyzed in the context of other resources and activities (Section I), solid fill causeways are discussed under Basic Assumptions for Effects Assessment (Section IV), and, then when appropriate, effects of causeways potentially associated with Major Projects Considered in the Cumulative-Effects Assessment are considered (Table IV-A-7 and other text, Section IV).

MMS views the collection, analysis, and synthesis of environmental information pertaining to causeways in the Arctic as a continuing process and this synthesis meeting was but a step in the process not the end of the process.

SYNTHESIS MEETING, A CHRONOLOGY

The Assistant Secretary - Land and Minerals Management, Department of Interior instructed the Director, Minerals Management Service to synthesize information relevant to the causeways in the nearshore Beaufort Sea, Alaska and suggested that the synthesis process frequently used by the MMS Alaska OCS Region be employed. To expedite planning for the synthesis, MMS invited representatives from Federal, State and local agencies, University of Alaska, Petroleum Industry, and Environmental groups to participate in planning the synthesis. The U.S. Fish and Wildlife Service, Environmental Protection Agency, Corps of Engineers, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Bureau of Land Management, State or Alaska (Departments of Governmental Coordination, Environmental Conservation, and Natural Resources), North Slope Borough, University of Alaska, Exxon, ARCO, BP (Alaska) Exploration, National Wildlife Federation, Northern Alaska Environmental Center, and Trustees for Alaska participated in planning the synthesis (Table 1).

The planning process for the synthesis meeting was detailed and inclusive, so that the concerns and interests of those involved with the causeway issue could fully participate in designing the meeting.

Table 1. Agency representatives at planning meetings.

Name	Agency
David J. Friis	NOAA/Ocean Assessment Division
Ron Morris	NOAA/National Marine Fisheries Service
Jon Nelson	U.S. Fish and Wildlife Service
Mary L. Plumb-Mentjes	U.S. Army, Corps of Engineers
Dan Robison	Environmental Protection Agency
John Santora	Bureau of Land Management
Elizabeth A. Benson	Division of Governmental Coordination
Bill Van Dyke	Department of Natural Resources
Michael D. Kelly	Arctic Environmental Data and Information Center
Michael E. Wheeler	Division of Environmental Conservation
Dave Germann	North Slope Borough
Michael Philo	North Slope Borough
Robert Disotell	Trustees for Alaska
Leone Hatch	Northern Alaska Environmental Center
Ann Rothe	National Wildlife Federation
Debra Beaubien	BP Exploration
Chris Herlugson	BP Exploration
Al Maki	Exxon Company USA
Scott Robertson	ARCO Alaska, Inc.
Thomas Boyd	Minerals Management Service
Cleve Cowles	Minerals Management Service
Joy Gieselman	Minerals Management Service
Jerry Imm	Minerals Management Service
Gail Irvine	Minerals Management Service
Fred King	Minerals Management Service
Robert Meyer - Coordinator	Minerals Management Service
Tom Newbury	Minerals Management Service
Dudley Platt	Minerals Management Service
Jim Regg	Minerals Management Service
Nancy Swanton	Minerals Management Service
Charles T. Mitchell	MBC Applied Environmental Sciences

Between 14 December 1988 and 22 March 1989, MMS conducted seven coordination meetings. The meeting planners determined that success of the synthesis effort depended, in part, on active participation by those directly effected by construction of causeways in the Beaufort Sea. They then determined that the selection of a synthesis report editor, lead authors, peer reviewers, meeting facilitators and meeting participants and discussion topics (hypotheses) for use in guiding synthesis discussions would be by unanimous decision. They also determined that the causeway synthesis meeting was meant to provide a forum for sharing and discussing available information regarding causeways in the Beaufort Sea and developed a meeting objective (Table 2) to express this goal. To help ensure objectivity, the meeting planners also decided that a National Academy of Sciences panel be convened to review the report.

Meeting planners concurred with MMS that because of the volume of information and data relating to causeways in the Arctic, it was more practical to provide the lead authors with summary material. However, because of the volume of material available and divergent opinions on what information should be provided, they were unable to reach a unanimous decision. MMS, therefore, elected to provide the lead authors with MMS synthesis reports and Biological Papers of the University of Alaska (Table 3).

Table 2. Meeting objective and discussion hypotheses.

MEETING OBJECTIVE

"The objective of the synthesis meeting is to provide a forum for the peer review of data and conclusions relevant to (the potential effects of) nearshore structures, including the evaluation of the data's quality and its appropriateness to address the following specific hypotheses."

DISCUSSION HYPOTHESES

OCEANOGRAPHY

$H^{O}1a$ Causeways* do not significantly affect the distribution and dynamics of oceanographic properties nearshore.

$H^{O}1b$ Causeways significantly affect the distribution and dynamics of oceanographic properties nearshore.

BIOLOGY

$H^{B}1a$ The presence of causeways do not significantly affect the life cycle of anadromous fish populations.

$H^{B}1b$ The presence of causeways significantly affects the life cycle of anadromous fish populations.

CAUSEWAYS AND ALTERNATIVES

$H^{CA}1a$ Causeways are currently the only technological, economic, and environmental feasible method to develop all nearshore oil fields.

$H^{CA}1b$ Causeways are currently not the only technological, economic, an environmental feasible method to develop all nearshore oil fields.

* causeways = solid filled causeways

Table 3. Synthesis documents provided to the lead authors and NAS reviews.

Norton, David, ed. 1989. Research advances on anadromous fish in Arctic Alaska and Canada: Nine papers contributing to an ecological synthesis. Biological Papers on the University of Alaska No. 24, January 1989.

U.S. Minerals Management Service, Alaska OCS Region. 1988. Arctic Information Transfer meeting conference proceedings. OCS Study MMS 88-0040 (June 1988).

Becker P., and W. Sackinger, eds. 1987. The Diapir field environment and possible consequences of planned oil and gas development-(Sale 87): Proceedings of a synthesis meeting, 25-28 January 1983, Chena Hot Springs, AK. USDOC/OCSEAP and USDOI/MMS. MMS Rep. No. MMS85-0082 (Misprinted as MMS 85-0092 on cover).

Meyer, R. M., and T. M. Johnson, eds. In Press. Fisheries oceanography: A comprehensive formulation of technical objectives for offshore application in the Arctic. In: Proceedings of a workshop, 5-7 April 1988, Anchorage, AK. OCS Study MMS 88-0042. USDOI/MMS, Alaska OCS Region.

To insure that as much information pertaining to causeways in the Beaufort Sea was available at the synthesis meeting, most of the organizations, scientists, and engineers who have worked on causeway related studies and projects during the past decade were invited to participate in the meeting. In addition, participants were urged to bring with them all of their applicable information and data. Therefore, all of the available information on causeways in the Beaufort Sea was available at the meeting either in terms of written reports or personal knowledge.

The synthesis process continued following the meeting while the lead authors synthesized information provided at and following the meeting and prepared a draft synthesis report. The draft report was circulated for peer review. This synthesis effort was completed following the peer review of the report and the final synthesis report prepared and published.

PROCEEDINGS AND SYNTHESIS REPORT

Three synthesis documents have been prepared as a result of the synthesis meeting, "Summary of Preliminary Findings", "Draft Workshop Proceedings", and "Workshop Proceedings". The "Summary of Preliminary Findings" contains copies abstracts of formal presentations made during the meeting plus workshop summaries prepared by the lead authors at the conclusion of the meeting. Copies of this report were distributed shortly after the meeting to each of the meeting participants and other interested parties.

The "Draft Workshop Proceedings" contains most of the information presented in the "Summary of Preliminary Findings" plus synthesis chapters prepared by three of the lead authors. Two of the lead authors, E. Maughan and J. Harville, concluded that their workshop summaries provided an adequate synthesis of the information on habitats and ecological relationships, and, therefore, elected not to provide additional synthesis chapters. The draft document was distributed to meeting participants, other interested parties, and the National Academy of Sciences for review and comment. Review comments were distributed to the lead authors for consideration when assembling their synthesis chapters in final form.

The "Workshop Proceedings" contains in addition to the material mentioned above, review comments from the National Academy of Sciences (NAS) review board and discussions by the lead authors on how they responded to the NAS review comments.

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INTRODUCTION

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Future offshore oil and gas development in the Arctic may involve the transportation of offshore-produced fluids onshore. One of the proposed methods for traversing the nearshore bottom-fast-ice zone with a pipeline is by gravel-filled causeways. At present there are two such structures, West Dock and Endicott Causeways, installed and operational. The environmental impact of these structures has been the subject of debate since their installation, and is the primary subject of review of this Workshop. For those in attendance who are not familiar with Beaufort Sea causeway history, the collection of papers on arctic fishes edited by Dave Norton (1989) contains an excellent summary.

Since the first causeway, "The West Dock", was installed at Prudhoe Bay in 1975 to offload grounded barges, the potential or perceived impact of such structures has been debated. As of 1988, approximately $25 million had been expended on monitoring and impact studies. By 1985, data from these studies had been deposited into the DATABANK, a data file of unprecedented proportions that contained all of the data collected during the monitoring programs. A review of the database in 1985 indicated a number of subject areas that required additional study effort. During that year, a concerted effort was made to close data gaps, and additional studies were implemented. More data were collected during that single year than had been collected during the 50 studies conducted from 1970 to 1980. The data from this database provided the basis of the nine scientific papers presented in the volume assembled by Dave Norton, and represents only a portion of the database that will be discussed during this Workshop.

The Alaska Region of the U.S. Minerals Management Service was directed to provide a synthesis of the available database. In order to make a proper evaluation of this database and its applicability for future needs, MMS assessed the need for a Synthesis Meeting. To provide maximum participation and input, MMS conducted several meetings of representatives from federal, state, and local agencies and oil and gas industry, and public interest groups. By consensus, this group provided the agenda, Meeting Chair, Speakers, Lead Authors, and other participants were determined.

The objective of this Workshop was to provide a forum for the peer review of data and conclusions relevant to the potential effects of nearshore structures, including the evaluation of the present database quality and appropriateness for use in assessing the potential environmental effects of nearshore structures. As part of this peer review, the results of these proceedings will be independently reviewed by representatives of the National Academy of Sciences and their comments included in the final document.

The Workshop and Proceedings were organized around four primary subject elements with Lead Authors selected for each. The responsibility of the Lead Authors was to synthesize the results of the discussions and, with the assistance of Workshop Co-Chairs, to direct the discussions in their specific topic areas. Each of the Lead Authors was provided with general resource documents approximately two weeks prior to the Workshop.

The Lead Authors for primary subject elements were:

Dr. Douglas Segar: Physical Oceanography
Dr. John Harville: Ecological Relationships
Dr. M. James Allen: Movements and Migration
Dr. Eugene Maughan: Habitats
Dennis Padron, P.E.: Causeways and Alternatives.

The Workshop was formatted so that, during the first day, investigators who had performed the monitoring studies associated with the causeways that formed the database, or who were intimately familiar with the nearshore environment, reported on the status of the current knowledge and summarized recent findings on the physical oceanography and biology of the area. The day ended with a panel discussion of the results.

On the second day, participants were divided into three concurrent interdisciplinary workshop groups to address biological aspects of the database. The workshops addressed habitat, movements and migrations, and ecological relationships. Participants were assigned to specific workshops in an attempt to distribute the effort and knowledge evenly. Workshop Co-chairs acted as facilitators to help guide and focus the discussions and were guided by a suite of hypotheses and discussion items formulated by the planning group.

On the third day, representatives from engineering and drilling firms provided presentations on the engineering aspects of causeways and alternate methodologies for the transport of products onshore. Each presentation was followed by a panel discussions and questions from the participants.

Day four of the workshop concluded with Lead Authors presenting summaries of the discussions and workshops.

During the Workshop there was a reluctance on the part of some presenters and participants to provide specific information. As a result, Lead Authors were required to work with incomplete information. After the Workshop some of the Lead Authors were approached individually and provided with additional information, which in some cases was incorporated into their respective sections. Since the resulting documents represented a synthesis of information provided at the Workshop, and additional selected documents provided outside the Workshop, they have been presented separately under the title "Syntheses" to avoid confusion with the Workshop Summaries.

WHAT IS A CAUSEWAY?

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For those of us who have been involved in nearshore Beaufort Sea studies for a decade or more, it is difficult to imagine that there is anyone who has not heard of causeways and the associated controversies. The intent of this brief presentation is to provide an introduction to causeways by describing their purpose, some features of their design, and the environment in which they have been placed.

Causeways provide a practical engineering solution to the problem of access to the nearshore Beaufort Sea, where no conventional port facilities are available and water depths remain less than 6 to 8 ft even at distances of 2 mi or more from the shoreline (Figure 1). The earliest gravel-fill structures served as unloading platforms for the annual "Sealift" of barges laden with equipment and materials destined for the North Slope oil fields; however, their major purpose now is to provide all-weather road access to offshore facilities.

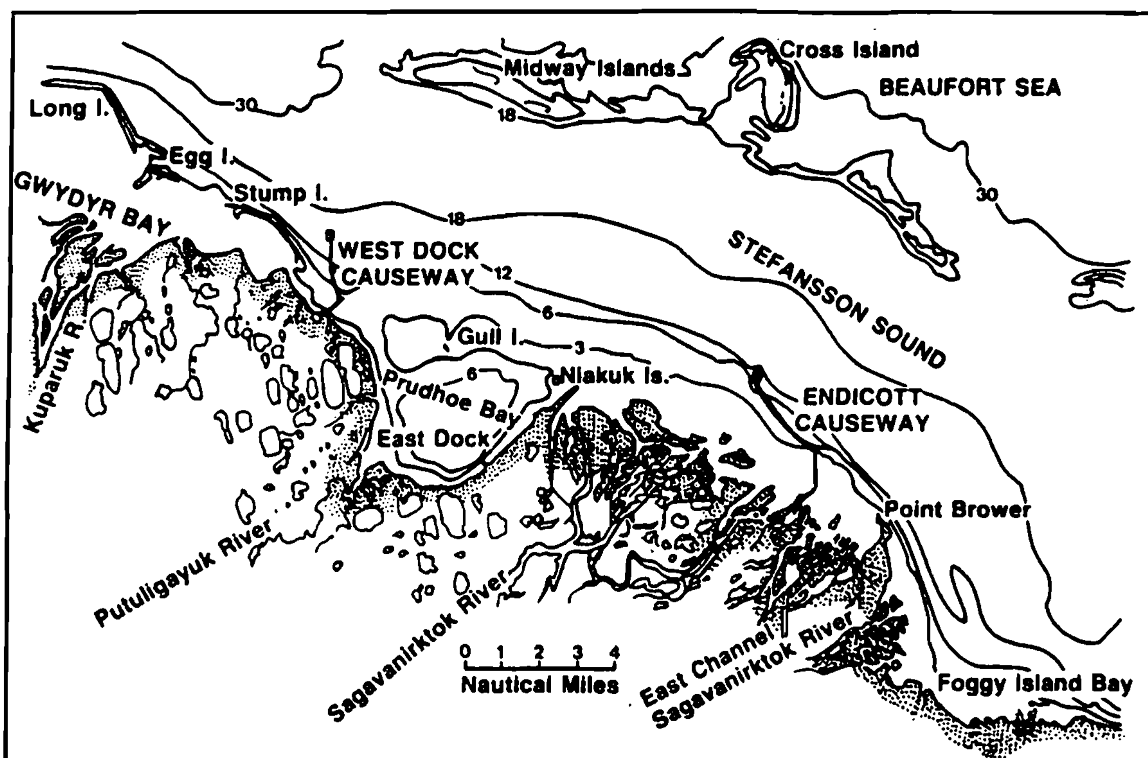

Figure 1. Causeways and bathymetry (ft) in Prudhoe Bay region, Alaska.

The first "offshore" gravel-fill structure in the nearshore Beaufort Sea was East Dock, constructed in 1969 on the southeast shore of Prudhoe Bay (Figure 1). East Dock extends approximately 1,300 ft from the shore to a depth of about 4 ft.

The first leg of West Dock was constructed during the 1974-75 winter; it extends to the north-northeast from the shore for a distance of 4,400 ft and terminates as Dockhead 2 (Figure 2). The second leg was constructed in the 1975-76 summer and winter period, extending the structure another 5,000 ft to the north-northwest and terminating as Dockhead 3 in about 7 ft of water. Access to Dockhead 3 is kept at a depth of 9 ft by dredging. In summer of 1981, West Dock was extended due north from Dockhead 3 another 3,700 ft to a water depth of 14 ft. The purpose of this extension was to provide all-weather access to a facility that treats and supplies seawater for a secondary oil recovery process known as "waterflooding." The third leg of West Dock, known as the Waterflood Extension, is connected to the original structure just north of Dockhead 3 by a bridge that spans a 50-ft breach that is intended to permit passage of fish and small boats through the causeway. To accommodate this expanded purpose of the causeway, the cross-section of the 2.5-mi long gravel-fill structure was enlarged over its entire length to provide a 40-ft wide roadway at an elevation of 18 ft above mean sea level.

The Endicott Development is the first offshore oil field to be developed on the North Slope of Alaska. All-weather access to the 80-acre Main Production Island and the 16.5-acre Satellite Drilling Island, which lie approximately 2 mi offshore, is provided by a 3-mi long causeway that is roughly parallel to the coast (Figure 3). Shore access is provided by a 1.4-mi extension southward to the delta of the Sagavanirktok River. To accommodate east-west fish passage and to ameliorate cross-causeway differences in water temperature and salinity, the latter extension includes two breaches with a total length of 700 ft. Construction of the Endicott Causeway began in the winter of 1985 and was completed in 1986. During 1985 temporary bypass causeways diverted traffic around the two permanent breach locations. The two bypasses included three 50-ft breaches and 28 6-ft culverts for a total opening of 318 ft for fish and water passage through the causeway. Water depths are 6 to 10 ft on the seaward side of the causeway and only 3 to 6 ft shoreward of the structure; however, water depths in the breaches are as much as 15 to 18 ft with an average of about 10 ft.

Prudhoe Bay is located on the Alaskan Beaufort Sea coast immediately west of the Sagavanirktok River (Figure 1). Approximately 12 mi offshore are the Midway Islands, a widely-spaced series of barrier islands which serve as the northern limit of Stefansson Sound. Extending westward from Prudhoe Bay along the Beaufort coast is a 40-mi chain of barrier islands, known as the Return Islands, which form Gwydyr Bay and Simpson Lagoon. To the east of the Sagavanirktok River delta is Foggy Island Bay.

Physical and biological processes in the Arctic marine environment are very strongly influenced by the seasons, which are markedly more extreme than in the temperate environments. Situated at 70° to 71° north latitude, the Beaufort Sea coast experiences subfreezing temperatures for at least nine months of the year. In midwinter the sun does not rise above the horizon for 56 days. Winter air temperatures can drop to -60°F, while high winds can produce wind chills of -100°F and colder. From October through June, the ocean surface of the coastal region is frozen. By midwinter, from the shoreline out to a depth of 6 ft or more, there is no liquid water except for brine pockets that form as salt is expelled from the sea ice during the freezing process. Beyond the barrier islands the Arctic Ocean is covered year-round by a thick layer of permanent pack ice. The southern boundary of the pack ice moves on- and offshore throughout the year, grinding and fracturing the seasonal shorefast ice in the process.

In summer the Beaufort coast enjoys nearly four months of continuous daylight, during which the sun does not set for 75 days and air temperatures occasionally exceed 70°F. During a few weeks in late May to early June, the rivers discharge their spring runoff and sediment load out over the shorefast ice. The freshwater flood brings along sediments, nutrients, and terrigenic debris to the nearshore marine environment. By mid- to late July, the nearshore zone becomes ice-free and the ocean is open from the shore to the edge of the pack ice. The boundary between open water and the permanent pack ice is

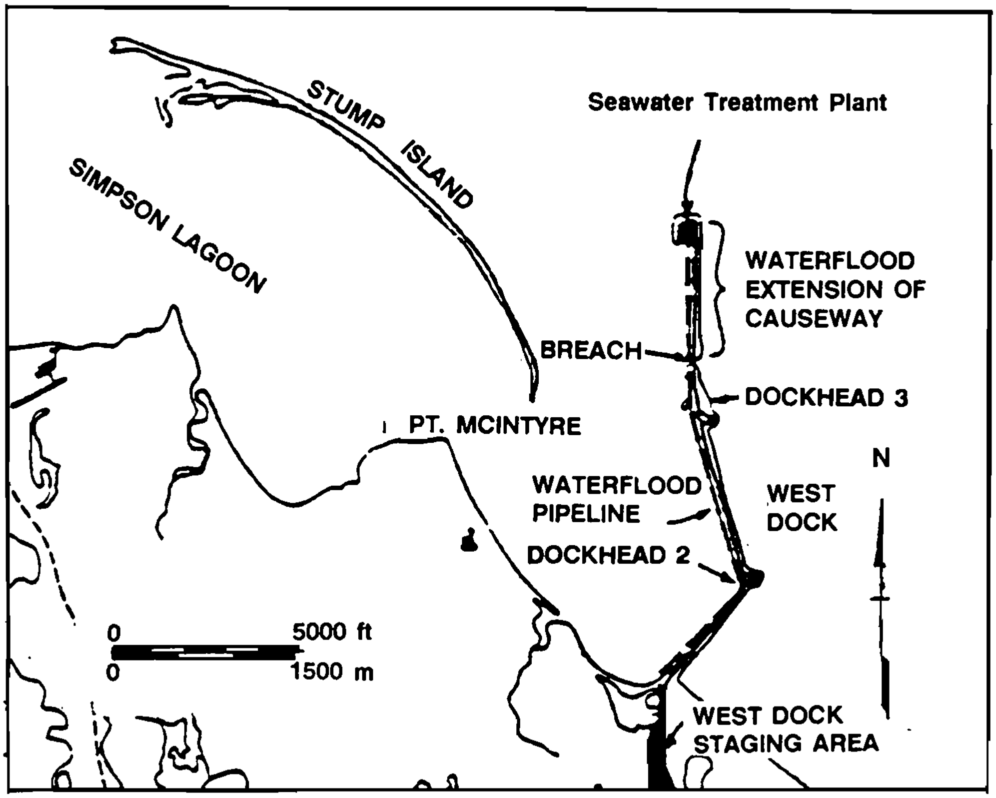

Figure 2. West Dock Causeway.

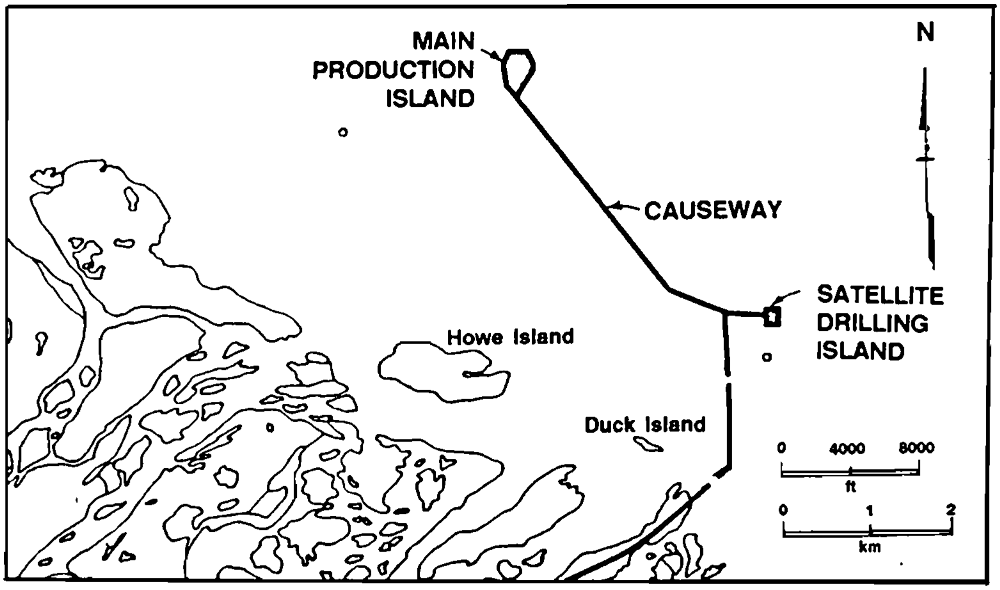

Figure 3. Endicott Causeway.

indistinct, and is composed of scattered ice floes and breaks ("leads") in the ice. The pack ice might retreat as far as 50 to 70 mi offshore or, in some years, will press its ragged edge close to shore for much of the "ice-free season," thereby restricting coastal navigation while also limiting the size and force of the wind-generated waves that serve to shape the shoreline.

The short summer is a period of intense biotic activity. Many invertebrates migrate to shallow rivers, perhaps to take advantage of tundra debris delivered by the rivers and eroding shoreline. These organisms are followed by predators, not least of which are anadromous fish and waterfowl.

The summer is also a major period for physical modification of shoreline features. While wintertime gouging of the ocean floor by sea ice can be locally significant as a sediment transport process, it is during the summer open-water season that waves work the beach sediments and shape the coastline. Blowing predominantly from the east-to-northeast during this period, brisk winds form the waves that shape the shoreline. These easterly winds produce waves and currents that transport sediment westward from the river deltas along the beaches and in shallow bottom areas. Occasional severe storms from the west induce reversals in these processes that are recorded in barrier island forms as complex recurved spits and crenulated shorelines. Waves are generally less than 1 to 2 ft high with periods of less than 4 sec; however, waves with 6-ft heights and 6 to 7 sec periods have been observed during intense storms. Wind-induced water level changes of 3 ft or more often mask the semi-diurnal tides which have a range of less than 1 ft. Beaches are composed mostly of sand and gravel, but are often backed by low ice-rich tundra cliffs that are eroded as much as 10 to 20 ft per year.

The peak discharge period for most rivers is short and occurs in late May-early June. Consequently, the salinity of nearshore waters increases gradually through the summer as river flow decreases. In late September when the ice cover begins to reform, anadromous fish return to their spawning rivers before up-river ice formation precludes their reaching suitable overwintering areas, and birds depart for southern regions.

Biological and oceanographic investigations of the nearshore Beaufort Sea were conducted only sporadically prior to 1981, when the final leg of West Dock was constructed. From 1981 to 1984, the Prudhoe Bay Waterflood Environmental Monitoring Program was conducted to investigate the effects of the West Dock extension on the adjacent marine environment from Prudhoe Bay to Gwydyr Bay. The Endicott Monitoring Program has been underway since 1985 with a study area that extends from Foggy Island Bay to Simpson Lagoon. The overall objective of these monitoring programs has been to validate predictions of the Environmental Impact Statements that served as the scientific basis for permitting the construction of the two developments. The key marine environmental concerns have been:

1) Whether the causeways significantly impede the movements of anadromous fishes along the Beaufort coast,

2) Whether anadromous fish habitat is significantly altered by causeway-induced changes to temperature and salinity patterns, and

3) Whether either or both of the above influences are capable of threatening the continued existence of the affected anadromous species.

Interpretation of results from these monitoring programs has remained controversial. This workshop has been convened as a forum in which to share information and views on the effects of causeways on the marine environment.

SYNTHESES

PHYSICAL OCEANOGRAPHY

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INTRODUCTION

The objective of the synthesis meeting from which this volume is derived was to provide a forum for the peer review of data and conclusions relevant to the potential effects of causeways in the Beaufort Sea, including evaluation of the data's quality. The need to perform a synthesis effort under peer review was created by the controversial nature of the subject and the wide disparity of apparently conflicting interpretations of the data concerning the effects of the West Dock and Endicott Causeways. Unfortunately, several shortcomings were evident in the synthesis meeting that prevented full attainment of the meeting's objectives.

The most important shortcoming was that lead authors who were to participate in the peer review process were not provided adequate information before the workshop. There are a variety of published or unpublished, but widely disseminated, reports that describe the monitoring data for the West Dock and Endicott Causeways and provide widely differing evaluations of the effects or possible effects of the causeways. These documents were not available to the synthesis meeting participants before, or even during, the meeting. Instead, several of these documents were provided to the lead authors during "lobbying" efforts by various workshop participants outside of the meeting process. Lead authors were not able, until some time after the workshop, to obtain copies of several critical reports reviewing the monitoring data and expressing alternate hypotheses, interpretations, and conclusions concerning the impacts of existing causeways.

The hypothesized specific effects of causeways that are the basis of the controversy were not formally introduced or discussed at the meeting. The principal proponents of alternate hypotheses were not invited to formally present their interpretations of the data. Therefore, much of the meeting was taken up with unproductive discussions. Instead of examining the alternate interpretations and the data supporting them, substantial efforts were focussed on identifying the issues and alternate hypotheses.

Several of the organizations or agencies responsible for evaluating the effects of causeways were either not represented at the meeting or were represented only by individuals who were not responsible for that organization's or agency's analysis of the monitoring data. At meetings such as this, there are always key individuals who cannot attend because of schedule conflicts. However, at this meeting, it was apparent that certain key individuals had been prevented from attending, or had declined to attend for purely political reasons.

A number of the scientists attending the meeting were constrained from open participation in the review process for purely political reasons. It was apparent that several scientists had been issued "gag orders" by their superiors. Additionally, many others were apparently afraid to participate fully through fear that they might not faithfully support the political position of their organizations or sponsors (or potential future sponsors) concerning the effects of causeways. It should be noted that these political constraints were apparent among scientists working for both private and governmental organizations.

These shortcomings, and other problems with the synthesis meeting process, limit the value of any conclusions reached by the participants during the meeting. Therefore, in preparing this summary of the Physical Oceanography section of the synthesis, it was necessary to choose between a) reporting only the results of the review and assessment performed by the meeting participants or b) expanding and modifying those results through an assessment of both meeting findings and copies of critical reports obtained after the meeting. The evaluation that follows is the result of the latter approach and represents the findings of the synthesis meeting expanded and modified by the author's personal assessment of additional documentary material reviewed after the meeting. The most important additional publications and reports reviewed by the author are listed in the bibliography. Fortunately, post-meeting document review resulted in only minor modifications to the physical oceanography findings and conclusions reached at the meeting itself.

HYPOTHESES ADDRESSED

Prior to the synthesis meeting, without input from the outside reviewers, hypotheses were established to be addressed at the meeting. The hypotheses to be addressed in the physical oceanography deliberations were as follows.

H^{O}_{1} Causeways do not cause significant adverse effects to the distribution and dynamics of oceanographic properties nearshore.

H^{O}_{2} Causeways cause significant adverse effects to the distribution and dynamics of oceanographic properties nearshore.

Causeways were defined as solid filled breached causeways, nearshore as mean high tide level to the 6 m water depth, and seawater properties as salinity, temperature, freezeup, breakup, etc. "Significant" was defined as having two meanings: a) statistically significant, i.e., measurably different, and b) ecologically significant, i.e., different enough to cause changes of measurable ecological parameters.

These hypotheses are improperly designed and incomplete. Several deficiencies exist. If the "ecologically significant" definition of significance applies, then in order to test the hypothesis it is necessary to specify the lowest detectable magnitudes of all "measurable" ecological parameters *AND* to specify quantitatively the relationship between physical change and ecological changes. If the simpler "statistically significant" definition of significance is used, it is still necessary to specify the time and space scales of interest. For example, undeniably a causeway causes a statistically significant change in the distribution and dynamics of that region of the nearshore that is physically occupied by the causeway gravel itself, i.e., water with some range of salinities and current velocities is converted into immobile solid gravel. Finally, inclusion of the word "adverse" in the hypotheses implies the need to make a value judgment about the nature, size, duration, and biological consequences of any physical change observed. These hypotheses are, therefore, scientifically unsound and untestable.

In the absence of appropriate hypotheses, it was necessary during the meeting to identify and define a number of specific hypothesized effects of causeways on the physical environment that could be evaluated. The hypothesized effects that were identified (and further refined in the author's subsequent review of publications) are not stated as scientifically testable hypotheses since the establishment of such testable hypotheses, if they are to be meaningful to management, requires not only identification of the nature of the effects but also value judgments establishing the geographical scale, temporal persistence, and intensity of the physical effects that cause unacceptable levels of ecological impacts. Testable scientific hypotheses of the effects of causeways on the physical environment could be constructed without a value judgment process if these hypotheses addressed only the presence or absence of statistically significant effects. Each such hypothesis could be tested on a variety of temporal and spatial scales. This would be a valuable exercise since it would result in explicit delineation of the intensity, geographical scale, and temporal persistence of each physical oceanography change caused by a specific causeway (or of the maximum possible intensity, geographical scale, and temporal persistence of a hypothesized change where the data show no statistical difference). However, such detailed hypothesis setting and testing would be a) a lengthy process that is beyond the scope of the current synthesis effort, b) of limited utility unless the relationships between physical change and ecological change were well defined, and c) not useful to decision-makers unless a quantitative value judgment can be made of acceptable versus unacceptable ecological effect levels.

The principal hypothesized effects of causeways on the distribution and dynamics of the nearshore Beaufort Sea identified during the synthesis meeting (and further defined subsequently) are as follows:

1) The causeways deflect seaward the warm, low-salinity water masses moving parallel to the coast under either easterly or westerly winds. This is hypothesized to result in enhanced mixing of freshwater with seawater, with a consequent enhanced loss of freshwater from the nearshore zone. The offshore deflection is also hypothesized to contribute to or create a discontinuity (in the lee of the causeway) in the band of low-salinity water adjacent to the coastline.

2) The causeways are hypothesized to enhance the upwelling of marine waters and result in increased salinities in the coastal water mass.

3) The causeways are hypothesized to delay the removal of ice from the nearshore zone in the spring and to accelerate the freezeup in fall.

4) The causeways are hypothesized to alter the sediment transport regime within the coastal zone.

Each of these hypothesized changes is of concern because of the potential that the physical change can cause an unacceptable adverse ecological change. The appropriate questions that need to be address are, therefore, as follows:

1) Does the hypothesized effect occur at a measurable level (i.e., is it possible to qualitatively identify the effect with the existing data)?

2) What are the intensity, geographical scope, and temporal occurrence and persistence of the effect and how well are these described by the existing data?

3) How do the effects of causeways on the distribution and dynamics of physical properties compare in magnitude and duration with the natural distributions, mixing, and transport processes within the nearshore Beaufort Sea (i.e., what is the scale of the effect compared to natural variability on local and regional scales, and what are the frequency of occurrence and persistence compared to the frequency and persistence of natural events of comparable magnitudes)?

4) Is the scale and persistence of the observed effect of sufficient magnitude compared to the natural characteristics and variability of the physical regime to support a reasonable concern that adverse ecological effects may be caused?

With the limited time available for this review, particularly in view of the relative inefficiency of the synthesis meeting itself, this summary chapter cannot provide complete and detailed answers to these questions or fully evaluate the adequacy of the existing data for future such analyses. Therefore, the conclusions reached in this chapter must be viewed as tentative in nature and subject to review and revision. Additionally, it should be understood that questions of the ecological significance are not addressed in this chapter. Other lead authors discuss the ecological significance and observational biological evidence in more detail in other chapters of this volume.

Ideally, the individual assessments incorporated in each of the chapters of this report should be carefully discussed and modified after review by each of the lead authors and the Beaufort Sea scientific community. Practical constraints prohibit such a process at this time. However, it is recommended that this process be undertaken as soon as possible after publication (or dissemination of a draft) of this report. This report and the referenced documentation constitute a basis upon which a fully effective scientific synthesis and peer review meeting could be planned. Following such a meeting, which should be strictly scientific, an additional meeting of scientists and managers could be planned to address the judgmental issues and attempt to reach a consensus on the future management of causeways in the Beaufort Sea.

GENERAL PHYSICAL PROCESSES IN THE NEARSHORE BEAUFORT SEA

The specific hypothesized effects of causeways on the physical regime of the nearshore Beaufort Sea are best understood in the context of the regional physical processes operating in this area and of the temporal progression of these processes during a typical year. Colonell and Niedoroda (1988) and Niedoroda and Colonell (1990, this volume) have summarized these features of the physical regime of the nearshore Beaufort. Accordingly, the principal features of these processes are only highlighted in this chapter. The adequacy of the data in describing the details of these processes is also assessed.

For ease of understanding we have used the following standard convention to describe wind and current directions. Easterly winds blow *FROM* the east to the west, westerly winds from the west to the east. Eastward currents flow *TOWARD* the east from the west, westward currents flow toward the west from the east .

The basic physical properties of the Beaufort Shelf region during the ice-free summer are well-characterized for the period since causeways were constructed. Data that characterize the general properties in pre-causeway years do exist, but are temporally and spatially limited. The basic physical properties for which substantial multi-year data sets exist include salinity, temperature, current speed and direction, and meteorological parameters. Although the physical data sets extend throughout the open water period, only limited data exist for the period of ice cover. The nearshore zone of the Beaufort Sea is covered by ice for about nine months of the year. Ice thickness is generally about 2 m and is sufficient for the entire water column to be frozen throughout much of the inner portion of the nearshore zone. The 2 m isobath generally follows the shoreline configuration about 2 to 4 km from the shore, except in Prudhoe Bay where the shallow area is wider. The nearshore marine environment appears to be less important to biological processes during the ice-covered period. However, if this assessment changes, additional studies would be needed during the ice-covered period, and for the periods of initial breakup in spring and freezeup in fall.

From the available data, a good generalized description of the dynamics of the inner shelf of the Beaufort Sea during ice-free conditions has been attained. The principal physical processes controlling water characteristics, distribution, and movements include surface wind stress, horizontal and vertical density stratifications due to fresh water input, bottom boundary friction, and the relatively large Coriolis effect at this latitude. There is a seasonal sequence of predominant conditions. In the early season, the nearshore zone within which the causeways lie is dominated by freshwater. A progression period follows when, except for limited regions of very shallow water, freshwater overlies marine water and a sharp pycnocline exists. Subsequently, there is a period of weakening stratification and lowered mean salinity, until the onset of fall cooling.

During the entire open water season, the system is driven by wind stress. Movements of water in the frictionally dominated zone (less than 4 to 5 m, Niedoroda and Colonell 1990, this volume) are predominantly bathymetrically steered and follows local bottom contours unless a strong pycnocline exists. If a strong pycnocline exists the surface layer may be frictionally decoupled from the lower layer and the seabed, and is then steered by winds and the Coriolis effect. Three basic conditions occur: easterly wind, westerly wind, and transition periods. Under easterly wind conditions, dominant flow is in a westward direction and regionwide upwelling can occur. Under westerly winds, dominant flow is eastward, and the water column becomes vertically homogeneous in the nearshore zone. Considerable interannual and seasonal variability exists. This variability primarily depends on the relative frequency, duration, and intensity of the wind events and river discharge rates. The nearshore surface water flow responds quickly to changes in wind speed or direction, flow reversal being affected within several hours of a change from sustained easterly (or westerly) winds to sustained westerly (or easterly) winds. As a result, in some years when winds are consistently from one or another direction, or reverse infrequently, transitional conditions when flows reverse between westward and eastward directions will exist for only a limited percentage of the open water period. However, in other years when wind reversals are frequent, these transitional periods will occur more frequently. Even during periods when winds are consistently from one direction, the flow field will experience fluctuations as the wind speed varies. These fluctuations can affect not only the speed of the horizontal flows but also the degree of vertical mixing and the intensity of upwelling or downwelling.

CAUSEWAY EFFECTS

Both at the synthesis meeting and in reports reviewed subsequent to the meeting, there are major, apparent conflicts between individual scientific interpretations of the Beaufort Sea monitoring data concerning the existence and/or scope of the hypothesized effects of causeways on the physical regime. However, much of the documentation reporting these conflicting interpretations is not peer reviewed scientific literature. Instead, most documents are either agency or organizational "position" papers written from a political perspective, or scientific reports that have been subjected to review, not by the peer scientific community, but primarily by agency or organization technical managers. As a result, in some instances, the apparent conflicts between documents or views expressed at the synthesis meeting are not conflicts of fact but conflicts of perspective. One interpretation of data that shows the existence of a periodic or transient effect is that the effect is negligible compared to natural variations and effects. The opposing view is that the magnitude of the effect is sufficiently large and the effect sufficiently persistent to warrant concern that adverse biological effects occur or may have occurred. This is, of course, akin to classical problem of some seeing the glass as half full and others as half empty. Fortunately, this situation can be resolved through a stepwise evaluation process that entails establishing what is known with reasonable scientific certainty and what are the uncertainties. Although we cannot achieve this process in its entirety, this is the approach we have taken in evaluating and reporting the synthesis meeting results and the associated documentation.

A. Offshore Deflection of Fresh or Brackish Water

It is hypothesized that the causeways deflect offshore those water masses that move either eastward or westward along the coastline (bathymetrically steered) under the influence of easterly or westerly winds. This offshore deflection is thought to enhance mixing of cold, high-salinity, offshore water with the warmer, freshwater and brackish water that normally moves along the coastline under easterly or westerly winds. This enhanced mixing with cold, high-salinity, offshore water is thought to reduce the amount of freshwater in the nearshore zone and, therefore, result in higher salinities and lower temperatures in this zone. Since low salinity and higher temperatures are preferred or necessary habitat (depending on species, and absolute values of salinity and temperature) for anadromous fish, the hypothesized loss of freshwater from the inshore zone is further hypothesized to reduce or degrade habitat. The offshore deflection of low-salinity water moving along the coast under easterly or westerly winds is also thought to block the flow sufficiently to contribute to or cause the area in the lee of the causeways, particularly West Dock, to have a different origin than the water on the windward side of the causeways. This windward side water would move into the lee area if there were no causeway. The possible origins of this lee-side anomalous water are discussed in more detail below in relation to regionwide upwelling, but the origins are such that this water is often colder and more saline than water on the windward side of the causeways. The deflection of alongshore flow and the creation of a cold, high-salinity area in the lee of the causeway are hypothesized to have additional ecological effects such as effects on fish migration. These are discussed by other authors in this report.

The available data indicate that the hypothesized blockage and deflection of alongshore flow are detectable both at the Endicott and West Dock Causeways. The data show that the existing breaching of the two causeways is not sufficient to permit unimpeded alongshore flow of fresh and brackish water during either easterly or westerly winds. At both causeways, during easterly or westerly winds when water masses are moving along the bathymetry parallel to the coast, some warmer, low-salinity water passes through the breach or breaches, but some warmer, low-salinity water is also physically blocked and deflected around the seaward side or end of the causeway. This deflection is evident at both West Dock and the Endicott Causeway especially during persistent easterly wind conditions.

The difference between westerly wind and easterly wind conditions is important. Under westerly winds, the Coriolis effect forces surface (above pycnocline) water from the outer shelf to flow onshore and this causes an elevation of the sea surface toward the shore. Therefore, despite the friction dominated flow of water eastward along the bathymetry in the friction dominated, shallow, nearshore region (about 4 to 5 m or shallower), the onset of westerly winds tends to move water in this zone toward the shore, and the fresh and brackish water zones are laterally compressed. Under easterly winds, the Coriolis effect forces surface waters in the non-friction dominated region (depth greater than about 4 to 5 m) to flow offshore. This causes a compensating flow of marine bottom waters shoreward, resulting in a tilting of the pycnocline upward toward the coast, and regionwide upwelling of this cold, high-salinity water toward or to the surface. If the water column in the shallow, friction dominated zone is strongly stratified, the upper layer is frictionally decoupled from the lower layer and the seabed, and this surface water also responds to the Coriolis effect by being forced offshore by easterly winds. Offshore "transport" of water moving alongshore under easterly winds, therefore, takes place naturally during easterly wind conditions. This offshore component of the alongshore flow is controlled by several factors including the water mass density structure, speed and persistence of the wind, the precise direction of the wind, and bathymetric steering. It is, therefore, highly variable. For example, the offshore flow of the fresh and brackish water zone is enhanced if the winds have a southerly component and reduced if the winds have a northerly component.

Onshore-offshore flows in response to wind driven Coriolis effects take place throughout the entire length of Beaufort Sea coastline affected by the wind. The flows are very sensitive to geographical and temporal changes in wind direction and intensity, in part because of the strong Coriolis effect at this high latitude. Therefore, the regional scale phenomenon will be characterized by a series of local (scale of several kilometers) and highly variable tongues or plumes of offshore or onshore transport distributed along the Beaufort shelf region.

The natural offshore motions occurring during easterly winds will create tongues or "plumes" of low-salinity water of the same geographic scale as the "plume" of lower salinity water observed on the seaward side of the causeways during easterly winds. However, the two should not be confused since the causeway induced offshore deflection is essentially a bathymetrically steered or constrained flow and will occur whenever water is flowing alongshore either westward or eastward. The data strongly support the following conclusions:

1) Lower salinity water from the nearshore region (shallower than the seaward extension of the Endicott and West Dock causeways) is deflected offshore around the causeways, particularly during easterly wind conditions.

2) This deflection occurs under a wider range of wind conditions and is, therefore, more persistent than naturally occurring offshore tongues or plumes of similar size that occur in the region.

3) The deflection of water offshore partially interrupts the normal alongshore flow and, therefore, causes the water in the lee of the causeways to have different origins than it would have under natural conditions.

4) Under certain conditions of wind and water mass distributions, the warm low-salinity water that is deflected seaward by the causeways is placed in greater contact with substantially colder and higher salinity water with which it will tend to mix.

5) The Endicott Causeway bisects the Sagavanirktok River freshwater inflow. Therefore, blockage or offshore deflection of the alongshore flow of warm, low-salinity water by this causeway would be unlikely to result in a major discontinuity in salinity or temperature between the two sides of the mainland-to-interisland leg of the causeway.

6) West Dock appears to provide a more significant impediment to the alongshore flow and the continuity of the warmer, lower salinity zone that is typically present along the shoreface. Under certain easterly wind conditions, West Dock Causeway appears to promote increased salinities and lowered temperatures throughout a limited region at the eastern end of Simpson Lagoon (Stump Island Lagoon).

The general meteorological and oceanographic conditions leading to the establishment of the observed physical oceanographic effects of plume deflection by the two causeways and the approximate scale of the effects are understood. However, the details of the frequency of occurrence, persistence, and geographical extent of the effects have not been fully characterized. Among the information that is not reliably quantified by current studies is the following:

1) The percentage of the alongshore flow that is deflected versus the percentage passed through breaches under different flow conditions.

2) The degree to which the offshore deflection of the plume enhances the rate of mixing of the plume water with colder higher salinity water.

3) Whether the causeway induced deflection enhances the probability that winds with a southerly component can transport low-salinity water offshore, and the quantity of low-salinity water mixed with offshore water during such transport events.

4) The degree to which the offshore deflection changes the mean and variance of salinity and temperature, and their geographical distributions on various spatial scales around the causeways (e.g., major changes that were limited to the area within a few meters of the causeway itself are probably insignificant with respect to the entire Beaufort shelf). The spatial scale of interest is the scale relevant to the anadromous fish. However, this scale is currently poorly defined (i.e., a few tens of meters is probably not significant, the entire Beaufort shelf is definitely significant, but the biology of the anadromous fish is not adequately known to define the intermediate scale of effect that would be relevant to the population of any species).

5) How frequently and for how long during years of different weather patterns, does the blocking of alongshore flow by the causeway lead to salinity and temperature discontinuities of different magnitudes between the two sides of the existing causeways.

Using existing data sets together with appropriate models and limited additional field data, these factors could be more fully specified. However, a major limitation exists in the relative lack of detailed hydrographic data for this region during the period before the causeways were constructed. Therefore, any analysis, even with additional post-causeway construction data, will always leave substantive uncertainties.

Since time scales of a few hours significantly affect the hydrodynamics and water mass distributions, the physical oceanographic measurement programs are discontinuous. Therefore, the data does not fully represent the range of year-to-year climatic variation, and a simple statistical analysis of how many days the existing data show a given distribution or any similar analysis is totally inadequate. Instead, a mathematical model is needed to enable prediction of the physical conditions under different wind and water mass characteristic conditions. Sufficient data exist to verify such a model if the scale of the model is appropriate to the data. It is not certain, however, that the scale of such a model would provide information appropriate to ecological processes since the scales of importance for these processes are not defined.

B. Enhanced Upwelling

It has been observed that under certain circumstances colder, higher salinity water is present at the surface on the lee side of the causeways. This phenomenon is observed most often during easterly winds when the warm, low-salinity water is moving along the shore westward. It has been hypothesized that this cold, high-salinity water is the result of "enhanced upwelling" of offshore bottom waters. Various mechanisms have been proposed as causes of this "enhanced upwelling". These include entrainment of subsurface waters by deflected surface water streaming past the causeway, enhanced divergence due to offshore deflection of water masses moving alongshore, and inducement by an eddy formed as the result of the hydraulic flow past the end of the causeway.

Eddies are known to form on the lee side of all promontories, and other topographic features that extend out from the shoreline when the nearshore waters flow parallel to the coast. The existence of such an eddy at the West Dock causeway has been reported and discussed by Minert *et al.* (1988) and Colonell and Niedoroda (1988). There is evidence of a similar eddy at the Endicott Causeway, but this evidence is not conclusive. The eddy forms immediately shoreward and to the lee side of the furthest point seaward of the physical barrier. With westward flow, this location for West Dock is between the tip of the causeway and east entrance to Stump Island Lagoon in water between 2 and 4 m depth, and for the Endicott Causeway is close to the shoreward side of the west end of the causeway (the main production island) in water less than 2 m depth. With eastward flow, an eddy forms to the east side of the offshore leg of West Dock in waters 2 to 4 m depth, and a similar eddy may form to the east and inshore of the east end of satellite drilling island of the Endicott Causeway.

The mechanisms of formation and the dynamic processes inherent to eddies such as those found at Beaufort Sea causeways are generally known although not fully understood. The environmental concern is that these eddies can enhance "upwelling" of cold, high-salinity water within the warm, low-salinity band found along the coast in the Beaufort Sea.

Topographically induced eddies cause bottom waters to be drawn laterally toward their center, and raise this bottom water toward the surface near this center where it is mixed with the surface waters (Colonell and Niedoroda 1988). Therefore, eddies enhance the mixing of bottom waters with surface waters and will do so when they exist at Beaufort Sea causeways. However, these eddies are geographically limited in size and draw bottom waters only from their immediate location or vicinity. Therefore, the bottom waters that are subject to "upwelling" (the term "locally enhanced vertical mixing" is more accurate and is used here) by these eddies will consist of colder and higher salinity water than the surface waters only if the water column at the eddy's location is stratified and, therefore, cold, high-salinity bottom water is present. During most of the open water season, the water column within the inner shelf of the Beaufort Sea is vertically mixed and the pycnocline between this inner shelf water and the cold, high-salinity offshore water intersects the bottom at depths of several meters or more. When the water column is well mixed in the locations in the lee of the causeways where eddies are formed, the hydraulic processes of vertical mixing associated with the eddy will not result in the vertical transport of cold, high-salinity water. Only when the pycnocline intersects the shelf at the shallow depths where the eddies are formed and cold, high-salinity bottom water is present in the immediate vicinity of the eddy region will the eddies enhance mixing of this cold, high-salinity water with the warmer lower salinity overlying surface waters. In addition, the enhanced vertical mixing in the eddy will be limited when the density difference across the pycnocline is very large. When the pycnocline is strong the eddy induced vertical mixing will be too weak to overcome the strong vertical density gradients since the lower layer is frictionally decoupled from the surface layer.

The conditions under which the causeway eddies enhance transport and mixing of cold, high-salinity water into the warmer, low-salinity coastal water mass are that the pycnocline must be shallow enough to intersect the eddy and that the pycnocline must not be too strong. During the early season when ice-melt, freshwater floods out over the top of shelf water, the pycnocline is generally very strong and the eddies do not effectively mix cold, high-salinity bottom waters upward, even when such cold, high-salinity bottom waters are present at the eddy's location. As the season progresses, a sharp pycnocline is found at depths greater than the depths found at the ends of the existing causeways. This pycnocline is moved onshore under easterly wind conditions by naturally occurring regionwide upwelling processes. The normal excursion of the offshore bottom water during easterly winds is to approximately 3 to 4 m depth, but depending on the speed and duration of the wind and the strength and depth of the pycnocline, the higher salinity water can migrate into water as shallow as 1 to 2 m. Since causeway enhanced vertical mixing of high-salinity water into the nearshore low-salinity water cannot take place unless the cold, high-salinity is present in the vicinity of the eddy location, this effect will occur more often at West Dock (eddy at 2 to 4 m depth) than at the Endicott causeway (eddy at less than 2 m depth). When the pycnocline is transported inshore to depths of about 4 m or less, the necessary conditions exist for regionwide upwelling to occur. Therefore, enhanced vertical mixing of cold, high-salinity bottom waters into the low-salinity, inner-shelf water at the two causeways will occur primarily during persistent easterly winds when regionwide upwelling also occurs in a band (probably discontinuous) oriented along the bathymetry at approximately the same depth at which the eddies occur. Regionwide upwelling becomes more likely as the season progresses, since the pycnocline becomes weaker as the low-salinity inner-shelf water becomes more saline (Colonell and Niedoroda 1988).

These general features of the eddy enhanced "upwelling" mechanisms and its occurrence at the two causeways is confirmed by the existing data. During periods when easterly winds are persistent and regionwide upwelling occurs, a cell of surface water that is colder and higher salinity than the adjacent surface waters (in the same water depth) is observed both at West Dock and the Endicott causeway. Because it is located in shallower water, the frequency of occurrence of cold, higher salinity, surface water in the Endicott eddy is less than at West Dock. Additionally, since the area behind the lee side (west side) of the Endicott Causeway receives the freshwater outflow from the western channels of the Sagavanirktok River, the eddy-induced mixing of cold, high-salinity water in this area appears to affect the water mass characteristics in the lee area less significantly (both area and overall salinity increase) than at West Dock unless the river outflow is low.

The hydrographic data in the region behind the west extension of the Endicott Causeway are not sufficiently detailed in geographical scale to fully evaluate the frequency, intensity, and geographical extent of eddy-induced increases in salinity in this region. However, it appears that this effect is infrequent, occurs only when regionwide upwelling occurs, and is small in comparison to the effects of regional scale processes (regionwide upwelling, river inflow, and westerly wind driven marine intrusions) on the temperature and salinity of water in this region.

Eddy induced mixing of cold, high-salinity water at West Dock appears to be a more significant effect than at the Endicott Causeway. Since the easterly wind driven eddy at West Dock is located in deeper water than the Endicott eddy, cold, high-salinity bottom water intrudes this area more frequently. Weaker or shorter duration easterly wind events are needed for the regionwide upwelling process to raise the pycnocline to the depth of the West Dock Causeway eddy. Additionally, under easterly winds, there is no appreciable freshwater input from shore to the east end of Simpson Lagoon (Stump Island Lagoon) in the lee of West Dock, and the West Dock breach is small, often silted in, and not effective at passing fresher water from the east westward into the lee of West Dock. For these reasons, under easterly wind conditions sufficient to upwell offshore bottom water to 3 to 4 m depth, cold, high-salinity water is mixed by the West Dock eddy into the water mass behind the causeway and into Stump Island Lagoon.

It has been hypothesized that blocking of the alongshore flow of low-salinity water by West Dock and the eddy mixing of cold, high-salinity water causes the water column in large areas of Simpson Lagoon to become cold and high salinity under easterly winds. However, under the regionwide upwelling conditions that bring offshore bottom waters to depths of 3 to 4 m, cold, high-salinity bottom water enters Simpson Lagoon through each of the channels between barrier islands (e.g., Egg Island Channel). Therefore, parts of Simpson Lagoon would be affected by higher salinities and lowered temperatures under easterly wind conditions in the absence of West Dock. Because the pre-causeway, historical, salinity, and temperature data distributions in Simpson Lagoon are limited and the post-causeway data provide limited geographical resolution, there are no reliable estimates of the frequency, geographical extent and intensity of the cold, high-salinity anomaly that is caused by West Dock. However, it can be concluded that, at minimum, major portions of Stump Island Lagoon are filled with cold, high-salinity water under easterly winds that, in the absence of West Dock, would be filled with warmer, lower salinity water.

The cold, high-salinity water introduced to Stump Island Lagoon when easterly wind, regionwide upwelling occurs apparently affects the water properties of Prudhoe Bay when the winds shift from easterly to westerly. When winds switch to the westerly direction, the cold, high-salinity water in Stump Island Lagoon is transported westward around West Dock and then inshore by the westerly wind driven elevation and compression of the coastal water mass. This cold, high-salinity water mixes with Prudhoe Bay water. However, it is not known quantitatively what contribution this water has to the salinity or temperature of Prudhoe Bay water, since under such westerly wind conditions cold, high-salinity water can also be introduced to Prudhoe Bay by regionwide marine intrusion (i.e., transport of offshore surface water shoreward to mix with nearshore lower salinity water).

Under certain easterly wind conditions, a tongue or band of colder, higher salinity, surface water is found extending from the Endicott Causeway (and possibly also West Dock) westward, and lying between the warmer, lower salinity water, moving around the causeway westward and the warmer, lower salinity water inshore. It has been hypothesized that this is evidence of "enhanced upwelling" due to the causeway. There are two hypothesized mechanisms for this "enhanced upwelling". First, the deflection of water offshore by the causeway creates or enhances a divergence. The deflected water moves offshore over deeper, colder, higher salinity water in response to the Coriolis effect while the water in the shallower area in the lee of the causeway is friction dominated and moves westward alongshore in the direction of the wind. Upwelling of bottom waters moving onshore occurs at the divergence between these two water masses. Second, the fast moving, deflected, surface water moving around a causeway entrains colder, higher salinity water from below and this entrained water is replaced by bottom waters moving onshore.

Although both of these mechanisms are likely to occur, they will only do so during the limited times when the conditions for regionwide upwelling are present, bringing cold, high-salinity water to the depth zone of the seaward end of the causeways. It is not possible, at present, to estimate whether any contribution of causeways to regionwide upwelling through these two hypothesized mechanisms is significant compared to the regionwide upwelling itself. This is because a) any "upwelling" due to these mechanisms will occur only during periods when the regionwide upwelling may be expected, b) the scale of regionwide upwelling "patchiness" will be similar to the scale of any causeway enhancement of local vertical mixing, c) the monitoring data are limited in regions outside the area of possible influence of the causeways, and d) pre-causeway monitoring data are not adequately detailed,

In summary, under certain conditions, eddies at both Endicott and West Dock Causeways enhance vertical mixing of cold, high-salinity bottom water into warm, low-salinity surface waters in a geographically limited area in the lee of the causeway. However, this effect occurs only when regionwide upwelling processes bring the pycnocline and cold, high-salinity bottom waters to the shallow waters occupied by the eddies. This effect is more frequent at West Dock because of the greater depth in the lee of the causeway. The effect also has a greater influence on the properties of the water mass in the lee of the West Dock Causeway, because this region has no direct freshwater input and West Dock blocks movement of lower salinity water into this region from Prudhoe Bay. Enhanced "upwelling" caused by divergence and entrainment due to causeway deflection of water masses moving alongshore may also occur, but only under the conditions that must exist for regionwide upwelling to occur. At present, no reliable assessment is possible of the areal extent or intensity of any causeway deflection induced local enhancement of vertical mixing, compared to the regionwide upwelling that would occur in the same areas under the same conditions without causeways.

Although the existing data are adequate to support these qualitative conclusions, the interacting natural and causeway induced processes that are involved in determining water mass properties within areas beyond a few hundred meters from the causeways are many and complex. The existing studies do not provide an adequate quantitative assessment of the effects of causeways on the salinity and temperature distributions on larger scales within the Prudhoe Bay/Simpson Lagoon region. Quantitative estimates could, however, be derived through the development of appropriate mathematical (or physical) models verified by existing and limited additional data.

C. Ice Breakup and Formation

It has been hypothesized that the presence of causeways in the Beaufort Sea alters the dynamics of ice formation and breakup. Several effects have been hypothesized each of which is thought to be caused by the effects of the causeways physically trapping moving ice or river water flooding over the ice.

First, it has been hypothesized that in certain areas the causeways retard the melting of nearshore ice in spring by blocking the normal alongshore spread of overflooding river water. This warmer river water flooding over the ice accelerates melting and breakup. Two mechanisms are suggested: physical blockage of the overflooding water from flowing alongshore, and development of thicker (and presumably more elevated) ice next to the causeways preventing water from overflooding these areas because of gravity considerations. Both of these mechanisms are potentially important at West Dock but physical blocking of alongshore overflooding is less likely at the Endicott Causeway because the Sagavanirktok River discharges approximately equal volumes of water on each side of the shore perpendicular leg of the causeway. At the West Dock Causeway physical blocking may be important because of the lack of freshwater overflood directed into Stump Island Lagoon and the predominant easterly wind direction during the period of breakup.

In contrast, it is also hypothesized that physical blocking of overflooding by the causeways may accelerate the initial breakup in the regions between river channels and the causeways. The Endicott Causeway is hypothesized to prevent the overflooding waters from moving out over the ice offshore from the interisland leg of the causeway, thereby increasing the amount of warm, fresh water retained over the inshore ice. The additional warm, fresh water is thought to accelerate melt-through and early lead formation in this region. A similar effect is also thought to occur on the east side of West Dock.

A second mechanism potentially affecting the timing of breakup and ice removal from the nearshore zone is the sheltering effect of the causeways that could potentially prevent breaking up of the ice by wind and wave action and prevent removal of ice from the inshore region by physically blocking alongshore transport of floating ice. This same physical blocking of floating ice, and the resulting possible reduction of alongshore current velocities, both in front of and behind the causeways, is also hypothesized to accelerate accumulation of ice and freezeup in fall.

The observational evidence concerning these processes is very poor because detailed pre-causeway observations are lacking and year-to-year variability in the pattern and timing of overflood, breakup, and freezeup is large. The available data are inadequate to prove or disprove conclusively that these effects exist or to provide adequate estimates of their maximum possible scope and extent. However, retardation of overflooding of the ice in Stump Island Lagoon by the West Dock Causeway is the potential effect of this nature that is most likely to be significant.

D. Sediment Transport and Distribution

There is only limited observational evidence concerning the possible effects of the two existing causeways on sediment erosion, transport, and deposition processes. The transport processes affecting sediments in the nearshore Beaufort Sea include, and may be dominated by, alongshore transport of wind wave resuspended particles. Therefore, there is the potential for increased accumulation or erosion of sediments and alteration of the bottom sediment characteristics in low or high energy areas respectively that may be created adjacent to causeways. The existing evidence suggests that the causeways do cause changes in the sedimentary regime that may be attributable to one or more of the following: a) alterations of the hydraulic flow regime, b) alterations of the propagation patterns of wind waves, and c) introduction of suspended sediments due to the causeway gravel. However, the limited existing evidence suggests that causeway-induced changes in sediment erosion, transport, and deposition processes are geographically limited. In addition, the poor data set that exists provides no evidence that the physical characteristics of bottom sediments or deposition rates have been altered except in small areas immediately adjacent to (and under) the causeway.

There appears to have been little or no study of the possible effects of the causeways on the concentrations, distribution, and composition of suspended particles. These factors are likely to be ecologically important to the growth of phytoplankton and their availability as food for animals.

RELEVANCE OF PHYSICAL OCEANOGRAPHIC EFFECTS OF CAUSEWAYS

The physical effects of the Endicott and West Dock Causeways can be quantified, and the general processes involved can lend insight to the elucidation of the specific physical effects of any proposed new causeways. However, each proposed causeway will have its own unique effects on the physical environment depending on its location and design. The physical effects of any proposed causeway could be predicted with a high degree of probability if appropriate site specific background data are collected and comprehensive engineering studies performed.

At present, the specific physical characteristics of habitat that are important to the biological populations of the Beaufort Sea are not well defined, although studies have been initiated to remedy this deficiency. Consequently, it is not possible, at present, to evaluate the possible effects of the observed causeway-induced changes in the physical environment on these biological populations. When the physical habitat requirements of Beaufort species are better defined, existing physical data could be incorporated in models of appropriate types and dimensions to evaluate the biological effects of causeways. In particular, information is needed on tolerance and preferred habitat ranges of temperature and salinity, and on the geographical location and physical characteristics of any critical habitat.

The alternate hypotheses posed for this synthesis effort – that causeways do/do not "cause *SIGNIFICANT ADVERSE* effects to the distribution and dynamics of oceanographic properties nearshore" – are untestable at present. It can be concluded with great certainty that causeways *DO* cause *STATISTICALLY SIGNIFICANT* effects to the distribution and dynamics of oceanographic properties nearshore. However, in the absence of a dramatically improved understanding of the relationships between physical characteristics of the Beaufort nearshore environment and ecological processes, it cannot be determined whether the observed effects are adverse and/or ecologically significant.

NEEDED ADDITIONAL STUDIES

Certain studies of the physical environment are needed to improve our understanding of the physical effects of causeways in the Beaufort Sea. These include:

a) A comprehensive synthesis of existing data.

b) Development of diagnostic models to assess the spatial and temporal variation of physical parameters on scales that are relevant to important biological processes.

c) More detailed studies of the effects of causeways on the supply, distribution, and transportation of sediments and suspended sediment.

d) Additional studies and analysis of existing data to evaluate the possible effects of causeways on the timing and progression of the thawing of ice in spring and freezeup in fall.

e) Development of models or other detailed evaluation techniques to assess the effects on the physical environment of variations in the number, size, configuration, and location of causeway breaches.

f) Fundamental studies of causeway design and their effects on the physical environment.

g) Continuation of a limited physical measurement program to monitor the effects of interannual variability on the distribution of physical properties and the effects of causeways on these natural distributions. A limited program is also necessary for future model verification.

h) Extensive continuing efforts to communicate information and ideas among the various disciplinary groups studying aspects of causeway-related problems in the Beaufort Sea.

MANAGEMENT IMPLICATIONS

Management decisions concerning the possible construction of new causeways in the Beaufort Sea nearshore and possible modifications of existing causeways to mitigate impacts must be made in the near future. The results of this synthesis effort (and, it is hoped, the more extensive and focussed efforts to follow) will be critical information sources for managers who must make these decisions. In order that this synthesis of the physical oceanography effects of the causeways can be most useful to these managers, the following comments are made by the author. It should be stated emphatically that these statements are those of the author, that they are based on the findings with regard to physical oceanographic effects of causeways above, plus the authors less extensive study of the biological data and analysis available, and that they are written partly from the perspective of the policy and management community based on the author's own experience in this community.

It is clear that the existing causeways are responsible for measurably altering the physical oceanographic regime of the nearshore Beaufort Sea. There is scientific certainty that the causeways block some of the alongshore flow of fresh and brackish water and deflect these flows offshore. There is also scientific certainty that these effects lead to an enhanced loss of warm, high-salinity water from the nearshore region during certain hydrographic and meteorological conditions. At present, it is not possible to estimate the magnitude of this enhanced loss of warm, high-salinity water compared to natural offshore transport processes. However, comparisons of pre-causeway distributions of hydrographic properties and post-causeway distributions suggest that substantial areas within the nearshore zone within a few kilometers of the causeways may experience small decreases in average temperature and small increases in average salinity due to the causeways. Because the habitat, salinity, and temperature preferences and tolerances of Beaufort Sea fish, particularly anadromous fish, and their food species are not well defined the ecological significance of these observed changes cannot, as yet, be reliably assessed.

In addition to these broad scale effects on the salinity and temperature regime of the nearshore Beaufort Sea, the causeways cause larger increases of salinity and reductions of temperature under certain conditions in more limited areas in the lee of the causeways. These changes are related to the formation of an eddy in the lee of the West Dock Causeway, and possibly to a similar eddy mechanism at the Endicott Causeway. This eddy mixes cold, high-salinity bottom water into the surface waters in the lee of the causeways but only during the limited periods when natural, regionwide upwelling of cold, high-salinity bottom waters brings this cold, high-salinity bottom water into the vicinity of the causeway eddy. These conditions occur more frequently at the deeper West Dock causeway than at the Endicott causeway. Although this effect does under appropriate conditions cause surface waters in an area in the lee of the Endicott causeway to be colder and higher salinity than they would be without the causeway, the area affected is limited and the frequency and duration of such events appears to be low. The low frequency of such events is dictated by infrequency of occurrence of cold, high-salinity bottom waters in the vicinity of the causeway that can be mixed into the surface waters. Additionally, the west side of the Sagavanirktok River discharges directly inshore of this area, mixes with the anomalous water in the causeway lee, and reduces the magnitude and duration of the cold, high-salinity water events.

At the West Dock Causeway the eddy induced cold, high-salinity water anomaly appears to be more persistent and to affect a larger area than that at the Endicott Causeway. This is related to the greater depth of the eddy zone which increases the frequency of occurrence of cold, high-salinity bottom water in this region and to the lack of fresh water input to the lee side of West Dock during the easterly wind regionwide upwelling periods. Cold, high-salinity water is entrained into the surface waters in the lee of West Dock during moderate regionwide upwelling conditions and this water fills the area behind the causeway. This area is physically blocked by the causeway from being flushed by the alongshore flow of fresh or brackish water that would enter this area if the causeway were not present. Therefore, the eddy effect of West Dock causes a discontinuity in the generally warmer, lower salinity, water masses along the Beaufort Sea coastline under regionwide upwelling conditions. This discontinuity consist of an area of cold, high-salinity water that is not preferred and may not be tolerated by certain species of anadromous fish. Such discontinuities may occur in the region naturally but the frequency or intensity of any such natural discontinuities is not known.

Because the salinity and temperature preferences and tolerances of Beaufort sea species are not well known, the possible ecological effects of the cold, high-salinity anomalies in the lee of the causeways, and of causeway effects on salinities and temperatures in the region as a whole, cannot be quantitatively assessed. However, it is known that certain species will avoid cold, high-salinity water. The temperatures and salinities that these fish avoid are poorly defined, but may be within the range found in the lee of the causeways. Additionally, these species may rely on their ability to migrate along the nearshore zone past the causeways during the open water season. Therefore, there is a legitimate concern that the temperatures of the nearshore Beaufort waters should not be reduced and the salinities should not be increased by sufficient amounts in large enough or critically located areas such that favorable fish habitat is significantly (ecologically) reduced or migration significantly (ecologically) hindered. Because of the substantial remaining uncertainties in the data describing the physical effects of the causeways, and the larger uncertainties in the assessment of the ecological effects of these changes, there can be no scientifically certain assessment of the maximum acceptable change in physical oceanography of the Beaufort due to a causeway or the cumulative effects of causeways unless these uncertainties are reduced. Reduction of the uncertainties is possible through further studies but, given the complexity of the system and the current state-of-the-art of the scientific disciplines involved the uncertainty reductions that are possible within a period of several years study are only modest.

In the absence of reasonable scientific certainty of the level of environmental change that produces adverse effects, management must make decisions that, utilizing existing scientific knowledge, provide acceptable environmental protection at acceptable costs (economic and environmental). A trade-off between reduction of environmental risk and costs is necessary. In the case of causeways in the nearshore Beaufort, the necessary trade-off is probably related to the degree of breaching that is required and the number and orientation of causeways that are permitted. It seems reasonable to conclude, on the basis of available evidence, that the reduction of environmental risk that would be achieved by requiring additional breaching of the West Dock Causeway would be much larger than would be achieved by requiring additional breaching of the Endicott Causeway. The location of the Endicott Causeway is favorable, since fresh water flows into the nearshore zone on both sides of the mainland to interisland leg. Additionally, the Endicott Causeway will presumably be removed when production at this facility ends, whereas the West Dock Causeway may be present for a longer period of time.

The greater the degree of breaching of the causeways the greater will be the reduction of environmental risk but also the greater will be the cost. Breaching of the causeways in the shore-perpendicular legs will reduce environmental risk more than breaching offshore, shore-parallel legs, and breaching nearer to shore may be preferred if lower salinity water is passed through the breeches. There are several simple regulatory approaches to establishing the degree of breaching that is necessary for a given causeway. For example, the amount of breaching could be that amount that is required to guarantee passage through the causeway of a specified percentage of the normal alongshore flow within specified distances from shore under specified hydrographic conditions. Alternatively, the amount of breaching could be determined by requiring temperature and salinity differences between the two sides of the causeway to be less than certain values. However, any such regulatory approach must explicitly delineate the precise means by which the measured quantity (e.g., percentage of flow or salinity and temperature differences) is to be measured in the compliance monitoring program. For example the precise locations of monitoring sites, the frequency and timing of monitoring measurements, and the statistical monitoring data evaluation procedures must be specified for each causeway. Less specific monitoring and evaluation requirements will inevitably lead to alternative interpretations of the monitoring data and conflict such as currently exists with respect to the two existing causeways.

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MOVEMENTS AND MIGRATIONS

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INTRODUCTION

In 1975 a solid-fill gravel causeway was constructed at the northwest corner of Prudhoe Bay to provide docking facilities for barges carrying equipment for the construction of the Trans-Alaska Pipeline (Johnson 1988). In 1976 this causeway was extended as an emergency measure to retrieve equipment from barges that had been trapped 2 km offshore because of heavy nearshore sea ice (Johnson 1988, Norton 1989). This causeway became the inshore leg of the present West Dock Causeway. The construction of this causeway initiated concern for the effects that it would have on the biology of anadromous fishes in the Prudhoe Bay area in particular and in the Beaufort Sea in general.

At present, two solid-fill gravel causeways exist on the north coast of Alaska at Prudhoe Bay and additional causeways have been proposed for the area (Johnson 1988). The West Dock Causeway now extends 4.3 km; an additional leg with a 15 m breach was completed in 1981. The Endicott Causeway, which extends 6.1 km from the middle of Sagavanirktok River delta just northeast of Prudhoe Bay, was constructed in 1985; it has two breaches, one of 150 m and one of 60 m. Construction of other solid-fill gravel causeways in the area have been proposed for the Sagavanirktok River delta (Niakuk area west of the Endicott Causeway), the Arctic National Wildlife Refuge, Seal Island, and the Colville River delta. The proposed construction of the Lisburne Causeway in the center of Prudhoe Bay was dropped in 1988. See Colonell (this document) for details on existing causeways.

These causeways cut across much of the narrow (2 km wide) band of brackish water which lies nearshore along the coast (Craig 1989). This shallow, brackish water zone develops during the brief Arctic summer as a result of snow melt and storm runoff which is discharged into the sea by streams and rivers. This zone is used as a migratory corridor and/or primary feeding habitat for several species of anadromous fishes living in the Beaufort Sea. A major concern since the construction of the causeways is whether these structures interfere with the movements and migrations of anadromous fishes which utilize the nearshore zone (Johnson 1988).

Because of this concern, numerous studies have been conducted in the Beaufort Sea since the early 1970s to investigate the effects of the causeways on fish behavior and ecology and on the general and site-specific oceanography of the area (Norton 1989, Slaybaugh *et al.* 1989). Although the number of studies have dwindled since the early 1980s, the amount of data generated has increased exponentially (Norton 1989). However, the generation of an extensive database has not necessarily defined the effects of the causeways to the satisfaction of all concerned parties. Although data exist regarding many issues, differing opinions as to the quality or significance of the data leave the issues unresolved. The objective of this paper is to summarize and evaluate the nature of some of the existing data and literature on the effects of Beaufort Sea causeways on fish movements and migrations, and to recommend areas where further research effort should be directed.

The general evaluation of the information presented here was gleaned from participants of the Movements and Migrations Workshop of the Beaufort Sea Causeway Conference (April 17-20, 1989) (MBC 1989). These participants represented a wide range of experience in studying the effects of the Beaufort Sea causeways and related problems. However, because of concurrent workshop sessions, some individuals who have conducted important research on the subject were not present. The focus of the workshop was to evaluate whether sufficient information exists to determine whether the causeways in the Beaufort Sea significantly affect the movements and migrations (and hence the life cycles) of anadromous fishes in the Beaufort Sea. Some additional information from recent papers which may not have been available to the participants of the workshop is also summarized here. However, this paper does not attempt to represent a thorough summary of all existing information on the subject.

General Migratory Patterns

By definition, anadromous fishes spawn in freshwater but spend much of their lives in marine waters. Among Beaufort Sea species, this pattern generally includes the downstream dispersion of fry during breakup. These fry (i.e., Age-0 fish) then feed in marine or brackish waters during the summer and return to overwintering areas (brackish or freshwater pools beneath the ice) in river deltas or in upstream segments of channels (Craig 1989). After several years of seasonal migrations between feeding and overwintering areas, mature fish migrate upstream to spawn. At least one anadromous species may return to the stream of birth for spawning (Bickham *et al.* 1989). Most Beaufort Sea species are capable of returning to the sea after spawning and of spawning more than once in a lifetime, although not necessarily in every year.

The life cycles of anadromous fish in the Prudhoe Bay area include migrations from the natal streams to feeding areas. This habitat must provide them with sufficient food to survive the winter. Having reached the nursery area from their natal streams, the fish have a very short time (less than three months) to feed and grow sufficiently to be able to survive the winter. Of crucial importance is reaching suitable overwintering sites in streams or deltas (Craig 1989). The overwintering habitat of anadromous fish in coastal rivers accounts for only about 3% of the total water volume available during the summer (Schmidt *et al.* 1989). Suitable overwintering habitat must have water of suitable temperature, salinities, and dissolved oxygen concentration; most species feed little if at all during this nine-month period.

It can be assumed that all anadromous fish that fail to reach suitable overwintering sites die. The nearshore zone along the coast may freeze to the bottom to depths of 2 m, and Prudhoe Bay waters may have salinities greater than 50 ppt (Johnson 1988) and temperatures near -1.8°C. Upstream portions of streams generally freeze to the bottom except where springs or deep pools are present (Craig 1989). The most suitable sites lie in delta regions where warmer, slightly brackish water occurs in deeper channels (Craig 1989, Schmidt *et al.* 1989). Because suitable habitat is extremely limited in the winter, it is of utmost importance that fish reach these sites before freezeup is complete.

However, having reached a site, the fish must have stored sufficient energy reserves to survive with little or no feeding until the spring breakup (Johnson 1988, Craig 1989, Schmidt *et al.* 1989). Mortality resulting from the failure to reach suitable overwintering sites or to survive there may account for a significant, if not primary, source of annual mortality. After reaching maturity, fish must then store sufficient energy to undertake a successful spawning migration and to reproduce. It is only by returning successfully reproducing individuals to the population that the population is able to maintain itself.

KEY SPECIES

The species chosen for discussion by conference organizers were Arctic char (*Salvelinus alpinus*), Arctic cisco (*Coregonus autumnalis*), broad whitefish (*Coregonus nasus*), least cisco (*Coregonus sardinella*), Arctic cod (*Boreogadus saida*), and fourhorn sculpin (*Myoxocephalus quadricornis*). It should be noted that fish that have been called Arctic char in this region may actually be, in part or in entirety, Dolly Varden (*Salvelinus malma*) (Morrow 1980, Craig 1989). The primary morphological difference between the two species is in numbers of pyloric caeca (Morrow 1980). The workshop members also included Bering cisco (*Coregonus laurettae*) among the species to be considered because it has been identified genetically in "Arctic cisco" populations at Point Barrow (Bickham, J. W., Dept. Wildl. Fish. Sci., Texas A&M Univ., pers. comm.). The primary morphological difference between the two species is in numbers of gill rakers (Morrow 1980); hence the two could be confused in the field.

Although Arctic cod and fourhorn sculpin move in and out of estuaries, neither species is anadromous. The Arctic cod is an oceanic species and the fourhorn sculpin is coastal-estuarine (Morrow 1980). Movements of these species were not likely to be affected detrimentally by causeways. However, movements of Arctic cod into the study area after causeway construction has been used to indicate the presence of marine intrusions. Of the remaining species, the potential effects of the causeways on Arctic cisco was considered to be of most concern, followed by those on least cisco and broad whitefish. Effects on Arctic char was also considered to be of less concern, because this species is more euryhaline than the others and hence more capable of swimming around the causeways.

Arctic cisco spawns in tributaries of the Mackenzie River (Craig 1989, Moulton 1989a, Bickham *et al.* 1989). Newly hatched fry are carried downstream and then an unknown percentage are carried along the brackish coastal band to the Colville River or farther west during their first summer (Moulton 1989a). The brackish, ice-free coastal zone west of the Mackenzie Delta exists for about 3 months during the year (Craig 1989). Young Arctic cisco are known to overwinter in the Colville River Delta and to a lesser extent in the Sagavanirktok River Delta (Schmidt *et al.* 1989). Although small individuals are abundant in the Beaufort Sea near Prudhoe Bay, few fish of ages 2 to 6 have been found in the Mackenzie delta (COE 1988). Hence the Alaskan coast of the Beaufort Sea is an important nursery area for Arctic cisco. After about six years of seasonal migrations between feeding and nearshore or riverine overwintering sites in this area, mature adults migrate back to and up the Mackenzie River to spawn (Craig 1989).

The key features of the life cycle of this species which may be significantly affected by causeways are the initial dispersion of Age-0 fish to areas west of the causeways and the return of mature fish to spawning sites. Causeways could delay coastwise movements so that fish cannot reach suitable overwintering sites in deltas before the formation of shore-fast ice. Thus, it is important to determine whether overwintering sites in the Colville Delta are crucial to the survival of young fish from the Mackenzie River in general (or of young fish from specific stocks in the Mackenzie River), and whether the causeways are a significant barrier to their migration to and from the Mackenzie River. Because Arctic cisco spawn in Canada and spend much of their time as juveniles along the Alaskan coast, the international consequences of disruption of their migration must be kept in mind. In addition, Arctic cisco is an important species in the subsistence fishery of coastal communities in the Alaskan arctic (Moulton 1989b).

Least cisco and broad whitefish spawn in local streams and rivers and make less extensive coastwise migrations. The broad whitefish is less tolerant of saline waters than is the Arctic cisco (COE 1988) but the lease cisco can occupy a broader salinity range than the Arctic Cisco in the summer (Dames & Moore 1988, Houghton *et al.*, in press). Least cisco are generally most abundant west of Prudhoe Bay, with the Colville River stock being the major population in the area. Least cisco migrate along the coast to the Prudhoe Bay area during the summer. Causeways could interfere with their ability to return to overwintering sites in the Colville River delta. Broad whitefish are less tolerant of saline conditions than the least cisco and tend to be restricted to low-salinity waters in and just offshore river deltas. The primary stock in the Prudhoe Bay area resides in the Sagavanirktok River. Because they migrate less extensively along the coast, causeways would be less likely to interfere with their migration to overwintering sites; however, if trapped in high-salinity waters to one side of a causeway, they could be adversely affected.

Arctic char also spawn in local rivers and streams from the Colville River to Canada (COE 1988). They prefer streams with large, perennial springs upstream. The major population in the Prudhoe Bay area resides in the Sagavanirktok River. The Arctic char is more euryhaline than the other anadromous species and, at least as adults, less restricted to waters of lower salinities. Because of the greater tolerance of adults to marine waters, the causeways are less likely to affect their movements significantly. However, smaller individuals remain closer to shore in waters of low salinity and hence are more likely to be affected by the causeways. Arctic char is an important sport fish in the Beaufort Sea and Arctic Canada.

KEY ISSUES

Migrations

In the vicinity of Prudhoe Bay, the basic migration patterns of anadromous fishes include migrations from overwintering areas to feeding areas following spring breakup and migrations from feeding areas to overwintering areas in the fall prior to freezeup. Arctic cisco, broad whitefish, least cisco, and Arctic char undertake these migrations. There is also an early summer migration of mature Arctic cisco past the area en route to the Mackenzie River spawning rivers, a midsummer migration of mature Arctic char to spawning rivers, and a late summer migration of Age-0 Arctic cisco from the Mackenzie River to the Colville and Sagavanirktok River deltas (Glass 1988).

Workshop members agreed that the major issues regarding the effects of causeways on anadromous fish migration in the Beaufort Sea still centered around the Arctic cisco. This is because the entire Beaufort population is thought to spawn in the more distant Mackenzie River and because the most desirable overwintering sites west of the Mackenzie River are thought to lie in the Colville River delta, west of the causeways. Thus the migration of Arctic cisco between the Mackenzie River and the Colville River extends over a much greater distance than does the migration of any of the other anadromous fishes of concern. Other species undertake less extensive migrations and have more spawning steams along the Beaufort coast. Further, with spawning grounds in Canada and possibly important nursery grounds in Alaska, interest in the welfare of the species is international.

Migratory issues concerning the other species revolve around whether they are able to reach primary feeding grounds or whether they are able to reach overwintering sites. Failure to reach the latter would be fatal to the fish no matter how successful they were in utilizing their feeding habitat.

Migratory issues examined by the workshop include the following:

1) What are the characteristics of the migratory corridor (primarily of Age-0 fish) from the Mackenzie River to the Colville River? What is its width, distribution in time, and velocity?
2) What are the characteristics of the migration of the Age-0 cohort as it moves from the Mackenzie River to the west-central Beaufort Sea? Does it move as a front or does it spread out over the entire coastal area? To what degree are these fish carried passively to the west and to what degree do they actively migrate?
3) What is the genetic composition of the population of Arctic cisco found near and west of Prudhoe Bay? Is it a single stock or a mixture of stocks? Is the composition the same from year to year or does it vary? What proportion of the fry produced by the entire Mackenzie River population (or of individual spawning stocks in the river) occur in the west-central Beaufort Sea? What proportion of specific spawning stocks in the Mackenzie River consist of Beaufort Sea fish?
4) How crucial are the overwintering sites in the Colville and Sagavanirktok River deltas to the survival of Beaufort Sea Arctic cisco? Are there other important overwintering sites between the Mackenzie and Sagavanirktok Rivers, and if so, how much habitat is available? How large is the overwintering habitat in the Mackenzie River?

Movements

During the summer, movements of fish on their feeding grounds are in response to changing habitat conditions and food availability (Glass 1988). The effects of causeways on these nonmigratory fish movements in the Beaufort Sea involve Arctic cisco, least cisco, broad whitefish, and Arctic char. Because of their low tolerance to higher salinities, the effects on the broad whitefish and least cisco are of greatest concern. The major issues addressed were the following:

1) How well known is the physical oceanography in the vicinity of causeways? How do the causeways affect the temperature, salinity, and current regimes?

2) How well known are the local movements of fishes in the area? How do the fish respond to the causeways? What environmental cues are important in determining their movements?

3) What are the impacts on the bioenergetics of fishes found in suboptimal (e.g., salinity and temperature) waters which sometimes occur near causeways?

4) Are there sufficient data to forecast the effects of future causeway construction on fish movements?

SUMMARY OF IMPORTANT ISSUES

Migration Issues

Characteristics of the Eastern Beaufort Sea Migratory Corridor. The physical processes and mechanisms involved in the transport of water and fish from the Mackenzie River to the west are understood in a general sense. Transport of surface waters by persistent easterly winds are of primary importance (Moulton 1989a). The quality and quantity of data collected from the nearshore area (particularly near Prudhoe Bay) are adequate (although often highly disputed), but few studies have been conducted offshore. It is not known how far offshore the migratory corridor extends. Also, little is known of the characteristics of the eastern portion of the corridor near the Mackenzie River. In addition, natural disruption of the brackish coastal water zone between Prudhoe Bay and the Mackenzie River needs to be examined further. Syntheses of existing oceanographic data from the area would be useful, particularly if these provided a better description of the migratory corridor between the Mackenzie and Sagavanirktok Rivers.

Characteristics of the Age-0 Migration of Arctic Cisco. Biological information on Arctic cisco during their migration through the eastern Beaufort Sea corridor is adequate to describe certain aspects of the migration. These include rate of movement, relative migration speeds of fish of different sizes within the age group, timing of the migration past intermediate points, and the successful passage to the west side of the causeways (Moulton 1989a). The Age-0 migration to regions beyond the causeways is facilitated by persistent easterly winds. However, a consensus has not been reached on the relative roles of active and passive transport of Age-0 Arctic cisco during this migration, or whether they experience a delay at the causeway area (Johnson 1988, Ross 1988, Envirosphere 1989, Moulton 1989a).

The offshore distribution of Age-0 Arctic cisco is not well known. If they occur further offshore than expected (they are more euryhaline than broad whitefish or least cisco), then the causeways are less likely to pose a significant barrier. In addition, the proportion of the population that remains along the way during the migration is not well known. The relationship between the physical and biological aspects of the passive migration (e.g., the importance of wind patterns) has been established; however, the environmental cues and tolerances which affect active migration need to be determined.

Genetic Composition of Beaufort Sea Populations of Arctic Cisco. Genetic studies have indicated that Beaufort Sea populations of Arctic cisco cannot be distinguished from Mackenzie River stocks and suggest that Arctic cisco return to their natal streams (Bickham *et al.* 1989). The methods which are presently being used to identify genetic stocks of Arctic cisco in the Beaufort Sea and Mackenzie River are considered to be appropriate. However, the data are incomplete and additional descriptions of Mackenzie River spawning stocks and the genetic composition of Beaufort Sea populations are needed. In addition, the abundance and distribution of the various stocks are largely unknown. Hence, the proportion of specific spawning stocks in the Mackenzie River which move to the Beaufort Sea cannot be determined at present. It is estimated that 20 to 40% of the total Mackenzie River population occurs in Alaskan waters (Johnson 1988).

Overwintering Sites. Although the migration of Age-0 Arctic cisco from the Mackenzie River to the Prudhoe Bay area is a migration between natal stream and nursery (i.e., feeding) grounds, it is also a migration between overwintering sites, because the summer is short and the occurrence of suitable overwintering sites is limited. Thus a study of the distribution of overwintering sites along the Age-0 Arctic cisco migratory corridor is important to studies of Arctic cisco migration. The importance of the Colville and Sagavanirktok River deltas as overwintering areas for Arctic cisco has been established (Schmidt *et al.* 1989). Overwintering habitat consists of holes and channels in the outer deltas that are sufficiently deep to provide flowing water beneath the ice (COE 1988, Craig 1989). The amount of overwintering area in the Sagavanirktok River delta is small relative to that of the Colville River. Mature adults overwinter in the outer Mackenzie River delta after spawning. However, data on the availability, suitability, and size of overwintering sites east of the Sagavanirktok River are generally inadequate. In addition, the amount of overwintering habitat in the Mackenzie River is not known, although it is probably much larger than any delta along the Alaskan Beaufort coast (Craig 1989).

Movement Issues

Physical Oceanography in the Vicinity of Causeways. The local physical oceanography near the causeways is fairly well understood with regard to its usefulness for studying fish movements. It is generally thought that the causeways alter the nearshore environment of Prudhoe Bay because of their construction perpendicular to the wind and nearshore current patterns. However, the severity of the impact on the nearshore brackish water zone is still open to interpretation. Observed effects include the deflection of coastal water and Sagavanirktok River water offshore, enhancement of upwelling and intrusion of marine water into the nearshore water at depths less than 2 m, and a delay of breakup and acceleration of freezeup in the nearshore zone (Johnson 1988, Ross 1988). The result is a disruption of the typically continuous nearshore brackish water zone, making the nearshore zone along a long stretch of coast more heterogeneous and marine. While many workers are in agreement that such effects occur, they are in disagreement concerning the severity of these effects. However, some workers dispute the general continuity of the nearshore brackish water zone. Thus additional work is necessary before a consensus can be reached.

Local Movements of Fishes Near the Causeways. The local movement pattern of the various anadromous species near the causeways has been fairly well studied. However, consensus has not been reached among workers regarding the validity, interpretation, and significance of many observed patterns. Fish do utilize existing breaches but large numbers do not. Many fish pass around the outside of the causeways without adverse effects. Fish in the area also avoid water with more marine conditions. For example, alterations in the oceanographic regime at West Dock caused by winds from the east may delay or block the eastward dispersal of least and Arctic ciscoes, but westward dispersal is less affected by winds from the west (Fechhelm *et al.* 1989).

There is also a general understanding of the environmental tolerances of the species. However, species prefer only a certain portion of their tolerance range. For instance, Arctic cisco prefer water temperatures of about 14°C (Fechelm *et al.* 1983), which are found only in coastal waters of the Beaufort Sea in midsummer (Neill and Gallaway 1989). There is generally insufficient specific information on the environmental preferences of the species which may direct their movements. Once this information is obtained, the movements can be modeled and compared with patterns observed in the field. However, movements of fishes are often difficult to correlate with physical parameters because where a fish is at a given moment is largely dependent on where it was a short time earlier. Hence, if oceanographic conditions change local conditions faster than the fish can move, their observed movements are not likely to reflect their expected movements (Neill and Gallaway 1989). However, most changes result from currents and since fish are carried in currents, they can move as fast as water changes.

Data on the effects of the causeways on fish movements are in existence but are interpreted differently by different workers. For instance, whether the Endicott Causeway has interfered with movements of broad whitefish from one side of the Endicott Causeway to the other has been interpreted differently (COE 1988, Envirosphere 1989). Inhibition of movements of least cisco and Arctic cisco as a result of the West Dock Causeway are also in dispute, as well as the age composition of the Arctic cisco in the Colville River commercial fishery and the significance of these fish as an indicator of successful passage through the causeway area (Johnson 1988, Ross 1988, Robertson 1989, SAPC 1989). Further, the effects of the Endicott Causeway on Arctic char use of the eastern channels of the Sagavanirktok River are also in dispute (COE 1988, Johnson 1988, SAPC 1989). Because of a lack of consensus, these movements must be studied further or data must be examined objectively to reach a existing better agreement on what effects are actually occurring.

Behavior and Physiology of Fish in Suboptimal Waters. Additional information is needed on the bioenergetic adjustments made by fish found in suboptimal (e.g., saline) waters near the causeways, particularly with regard to how these might affect subsequent movements. Broad whitefish have the lowest tolerance for marine waters, with least cisco and Arctic cisco having broad salinity ranges. Extended stays in waters of high salinities may lead to kidney failure and death for stenohaline species such as broad whitefish and least cisco. At present, data do not exist on the physiological adaptations or age-related salinity tolerances that may allow the species to avoid osmoregulatory stress (COE 1988). Oceanographic conditions may change rapidly in an area and affect fish which are moving through a desired area. Unless conditions are extreme (which would cause torpor or death), fish would be expected to move out of the undesirable conditions. However, frequent movement from undesirable conditions, along with the physiological adjustments made while enduring the conditions, may reduce the energy supplies of a fish.

Baseline Movement Information on Fishes in Areas of Future Causeway Construction. Baseline movement information of fishes in many areas is generally inadequate, although baseline data on fish movements in the vicinity of potential causeways in Prudhoe Bay or the Sagavanirktok delta area are adequate to make predictions. For instance, predictions of the effects of the proposed Niakuk Causeway have been made (COE 1988); it was felt that broad whitefish movements would be most affected, with those of Arctic cisco and Arctic char being little affected. However, there still is little agreement on the interpretation of much of this information. It is likely that information on fish movements at future sites outside the immediate vicinity of Prudhoe Bay will be inadequate unless baseline studies are conducted there after site designation.

RECOMMENDATIONS

Although the workshop did not establish priorities for all issues or data gaps which require further attention, there was a general consensus that those concerning the effects of causeways on the migration of Arctic cisco to and from the Mackenzie River were still the most important. Studies that would improve our understanding of the significance of the causeways on fish migration and movements are listed below. These include studies of the oceanography and movements of Arctic cisco in the area east of Prudhoe Bay. Although these may not deal directly with movements occurring at the causeways, they would aid in the interpretation of the significance of any altered movement occurring at the causeways on the Arctic cisco population of the Beaufort Sea.

Studies to Establish the Importance of Beaufort Sea Populations of Arctic Cisco to the Mackenzie River Stocks. Although estimates have been made concerning the proportion of the total population of Arctic cisco in the Mackenzie River that migrate along the Beaufort Coast of Alaska, estimates of the proportion of specific stocks within the Mackenzie system that occur along this coast have not been made. Further delineation of the genetic composition of Arctic cisco stocks from near and west of Prudhoe Bay need to be made, along with an analysis of the variability of this composition through time. In addition, estimates need to be made of the proportion of various Mackenzie stocks which disperse to the west-central Beaufort Sea and the proportion of Beaufort Sea fish which are found in the various spawning stocks in the Mackenzie drainage.

Studies to Determine Whether Arctic Cisco Migrants Must Reach Overwintering Sites West of the Causeways to Survive the Winter. The Mackenzie River delta probably provides the greatest overwintering habitat for young Arctic cisco; the Colville River probably has the greatest amount west the Mackenzie River. It is known that Arctic cisco overwinter in both the Colville and Sagavanirktok River deltas.

If other overwintering sites exist along the migration corridor from the Sagavanirktok River to the Mackenzie River, then Age-0 fish would not have to reach the Prudhoe Bay area to survive the winter. If so, the significance of a delay at the causeways would be much reduced. Thus, investigations of the availability, suitability, and extent of overwintering sites east of the Sagavanirktok River need to be determined. Further, the extent of overwintering habitat in the Mackenzie River delta needs to be estimated. If small Arctic cisco do overwinter there and in sufficient numbers, then deleterious effects to the west may have little overall effect on the Mackenzie population. Although overwintering sites in the Colville and Sagavanirktok River deltas are well described, conditions at these sites are likely to change from year to year; thus, these sites should be examined periodically.

Studies of the Age-0 Migration of Arctic Cisco and Its Migratory Corridor. The distribution and residency of Age-0 Arctic cisco along the eastern Beaufort Sea coast need to be determined during the summer to establish an estimate of the numbers of Arctic cisco which do not reach the Sagavanirktok River. Monitoring this yearly migration would improve understanding of the interannual variability in recruitment. It would also allow estimates to be made of the strength of the Age-0 year class of young Arctic cisco en route to the Prudhoe Bay area. If strong year-classes are not reflected in sampling to the west of the causeways, then the causeways may be significantly delaying the migration. The continuity of this corridor to the east of the causeways also needs to be monitored, as well as the response of the fish to discontinuities. Additional oceanographic data should also be collected near the outer edge of the corridor and in the eastern Beaufort Sea to define the migratory corridor more accurately.

Studies of the Local Movements of Arctic Cisco, Least Cisco, Broad Whitefish, and Arctic Char Near the Causeways. Movements of the these species have been well studied in the vicinity of the causeways. However, there is still a lack of agreement among workers as to the interpretation of some of this movement data. Movements of these species should continue to be studied until a consensus can be reached as to the details and the interpretation of any altered behavior. In addition, although the environmental tolerances of most species is known, the environmental preferences are not. Thus, determination of the environmental preferences of the species should be made so that their movements can be modeled. Baseline studies of fish movements should be conducted in areas of proposed causeway construction if these do not exist. These would facilitate the analysis of post-construction effects. Bioenergetic studies to determine the effects of suboptimal waters on fish movements should be continued as well as how long fish remain in suboptimal conditions when these overtake them.

Studies on the Oceanography in the Vicinity of the Causeways. Nearshore oceanographic data near the causeways appear to be sufficient for most fish movement studies. However, workers need to conduct the proper studies to allow them to reach a consensus concerning the interpretation of the altered oceanographic conditions. Thus, oceanographic conditions should continue to be monitored there.

CONCLUSIONS

1) There appears to be sufficient information to indicate that the causeways in the Beaufort Sea can and do affect fish movements. However, there is insufficient information to determine whether they affect fish migrations or movements in a way that causes significant impacts on their populations.

2) Arctic cisco is the species that should be studied most carefully because it passes the causeways during migrations to and from its Mackenzie River spawning sites. If important overwintering sites only occur west of the causeways, a delayed migration could be fatal to those fish which could not reach these sites.

3) There is sufficient information to indicate that Arctic cisco are able to get past the causeways and reach western overwintering sites in some years; however, whether they are delayed at the causeways is still in dispute.

4) There is insufficient information at present on the genetic composition of the populations of Arctic cisco in the Beaufort Sea and in overwintering sites east of the Sagavanirktok River to determine whether populations west of the causeway are important in sustaining some Mackenzie River stocks. If so, then negative effects of the causeways could be internationally significant.

5) Sufficient information exists to indicate that causeways alter the local physical oceanography and that these alterations affect the local movements of Arctic cisco, least cisco, broad whitefish, and Arctic char. However, although the environmental tolerances of the species are generally known, the environmental cues which direct the movements of these species need to be defined better so that fish movements can be modeled.

6) Although fish movements in the Prudhoe Bay area are probably sufficiently well known to predict the effects of new causeways, there is insufficient information on the movements of fish in other areas of proposed causeway sites. Additional baseline data and modeling of fish movements in areas of future causeway construction would facilitate the analysis and prediction of impacts.

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NEARSHORE BEAUFORT SEA CAUSEWAYS AND ALTERNATIVES

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INTRODUCTION

The nearshore region of the Beaufort Sea is considered by many organizations to be environmentally sensitive and may be significantly effected by the construction of causeways. While there is a great deal of information available on the local oceanographic environment and the effects that causeways have on this environment, there does not appear to be a consensus regarding whether these effects constitute a negative impact on the species of fish that are of concern.

If offshore oil fields are to be developed in the Beaufort Sea, the oil, and possibly the gas, must be transported somewhere off the North Slope. To date, only the Endicott Field has been developed in the Alaskan Beaufort Sea, and solid-fill gravel causeways were constructed to connect Endicott's two artificial drilling islands to each other and to connect them to shore. The artificial islands are located approximately 2.5 miles offshore in water depths up to 14 ft, approximately 15 miles east of Prudhoe Bay. The unbreached inter-island causeway is 3.8 miles long and the causeway to shore is 1.7 miles long, with two breaches totaling 700 lineal ft. The top of each causeway is 73 ft wide and elevated 14 ft above mean sea level. The inter-island causeway supports four pipelines (sales oil, produced fluids, gas lift, and water injection), while the causeway to shore supports only the sales oil pipeline. The pipelines are supported 8 ft above the causeways on steel vertical support members and the causeways provide year-round road access to the artificial islands.

The West Dock Causeway is the only other significant causeway constructed in the region. It is almost 2.7 miles long and extends out to a water depth of 12 ft.

The objective of this portion of the synthesis is to consider the technical and economic aspects of causeways and to evaluate the various alternatives that are available. This is achieved by addressing the hypothesis that causeways are or are not the only technologically, economically, and environmentally feasible method to develop nearshore petroleum fields. In order to understand the problem, it is necessary to have a clear understanding of the nature of the environment, particularly with respect to sea ice and seabed permafrost. During the winter season, the full depth of the water column, from the water surface to the seabed, is frozen where water depths are approximately 5.5 ft or less. In the Prudhoe Bay area, the 5.5 ft water depth contour can occur 7,000 ft or more offshore. Since the ice serves as a conductor for the cold air temperature, ice bonded permafrost can usually be found near the top of the seabed in these water depths. In water depths greater than approximately 5.5 ft, the top of the permafrost often drops off rapidly to levels that are of minimum concern for construction of causeways and their alternatives. However, even in the deeper water depths, it is possible to encounter bonded or unbonded permafrost and ice lenses.

It is important to understand that actual permafrost conditions can vary considerably and are very site-specific. Also, permafrost is not a particular material. It is a condition of the soil, and just as the soil can have a wide range of properties, permafrost can have a wide range of properties.

The following discussion, as well as numerous published references, provide cost data for Arctic causeways and alternatives. However, extreme care must be exercised in utilizing such construction cost information. Construction costs, particularly for a gravel fill causeway, are highly site-specific. In addition, it must be understood what cost items are included in the cost estimate. For example, the stated cost per linear foot of a causeway normally includes only placing the gravel and does not include the pipelines and the pipeline supports on the causeway. Similarly, the reported cost normally does not include the cost of the breaches, averaged over the full length of the causeway. Also, if the estimate is to be utilized for development comparison purposes, it must be known if the construction cost includes company administration costs, engineering costs, etc., which can be quite substantial. Similarly, the timing is critical. Current causeway cost estimates are based on a depressed construction industry and costs are expected to rise in the future as the industry adjusts to the economy.

When evaluating costs, it is important to consider total life cycle costs, and not simply initial capital costs. The various alternative concepts for bringing offshore-produced hydrocarbons ashore have dramatically different operating and maintenance costs, as well as different capital costs. They also have different removal requirements and costs. While removal costs can be very significant and should be included in the selection evaluation process, they usually are incurred 20 years or more after the initial development. Therefore, when the present value of these costs is considered, they usually do not have a major impact on the decision making process.

Cost data presented below have been obtained from a variety of sources and represent actual construction experience at Prudhoe Bay. Since elevated causeways, subsea pipelines directional drilling, and offshore tanker loading have not been used for nearshore petroleum development in this region, cost data for these alternatives are not presented. A number of proprietary studies of these alternatives have been carried out, but most are not publicly available. Also, since the costs of the various alternatives are highly site specific, and the technical feasibility of each differs, a generalized economic comparison would have no validity.

SOLID-FILL CAUSEWAYS

Two general subcategories of solid-fill gravel causeways can be defined, unbreached and breached. An unbreached causeway is generally the lowest cost alternative, considering both construction and operating costs, but it may have a greater effect on the environment.

Within the subcategory of breached causeways there is a wide variation possible with respect to the percent of the length that is breached, and the methods of constructing the breaches. Presumably, the larger the breaches, the less the resulting environmental disturbance. The existing West Dock Causeway is almost 3 miles long and has only one 50-ft breach, while the Endicott shore-access Causeway is less than 2 mi long and has two breaches totaling 700 ft.

Other than the tip of the West Dock Causeway, the two causeways that have been constructed to date are not provided with slope protection but, nevertheless, are very stable and require relatively little maintenance. It has been reported that maintenance expenditures on the West Dock Causeway amount to an average of approximately $100,000 per year. Maintenance costs for the Endicott Causeway are virtually zero. There was initially a scour problem in the Endicott Causeway whereby, as a result of scouring, the seabed was lowered 23 ft at a breach. However, this should be classified as a design deficiency and not as a maintenance problem. The scour protection was subsequently redesigned and reinstalled, resulting in total elimination of the scour problem. Thus, it has been demonstrated that it is possible to design a solid-fill gravel causeway to be virtually maintenance-free.

It has generally been concluded that a solid-fill causeway is the lowest cost alternative for bringing pipelines ashore in the nearshore Arctic. However, it must be borne in mind that the construction cost of a causeway is very site-specific and this conclusion may not be valid at locations remote from Prudhoe Bay. In the Prudhoe Bay region, gravel is plentiful and easily accessible. In this region it currently costs approximately $10 to $15 per cubic yard to place the gravel in a causeway. This cost includes getting the gravel out of the ground, transporting it, and placing it in the causeway structure, within 10 miles of an existing gravel mine site. It also includes company engineering and administration costs, but does not include other costs that are associated with a causeway construction project such as construction camp development, slope armor, bridges, abutments, and other similar costs.

On the basis of gravel costing between $10 and $15 per cubic yard, it can be estimated that the gravel fill portion of the Endicott Causeway (3.9 million cubic yards), in water depths of 2 to 7 ft, costs between $1,500 and $2,300 per linear ft. The cost of the Endicott Causeway included temporary breach bypasses and culverts, while awaiting the construction of the bridges. New causeways would probably not incur this cost unless schedule constraints existed. It is estimated that it would cost approximately $1,300 to $1,500 per linear ft, in 3.0 to 4.5 ft water depth, for a gravel causeway with a top width of 70 ft and 7:1 side slopes. Increased water depths result in increased gravel quantities and higher costs per foot.

It must be emphasized that these cost estimates apply only to the Prudhoe Bay region. As mentioned above, gravel costs are highly site-specific and consequently, if a source of gravel is not readily available and accessible, the cost of a solid-fill causeway is dramatically increased. Also, the cost is sensitive to the water depth. In the Prudhoe Bay area water depths are very shallow for a considerable distance offshore. However, at other locations, where the seabed slope may be steeper, the cost of a solid-fill gravel causeway increases rapidly with the distance offshore. The volume of gravel required to construct a causeway is proportional to the square of the overall height of the structure and thus increases very rapidly with increasing water depth. Alternatives such as an elevated causeway or a buried marine pipeline are less sensitive to local site conditions and may not be significantly more costly at locations remote from Prudhoe Bay. Thus, it is entirely possible that at some locations an elevated causeway or a buried marine pipeline may be less costly to construct than a solid-fill gravel causeway, depending on gravel availability, water depth, etc.

The construction of the breaches in the West Dock and Endicott Causeways is similar to highway bridge construction. An alternative type of construction that has been proposed is to use culverts in place of the bridge construction. It is questionable whether culverts would actually be a cost-effective alternative because of the number and size of culverts that would be required in order to provide the equivalent flow characteristics that a bridge type construction provides. Also, culverts may present problems of early freeze-up and late breakup of the ice in the culvert, which may require significant operating cost to remedy. In addition, fish response to long culverts is not known.

The cost of breaches is very sensitive to a number of factors, particularly the live load for which the breach is designed, and consequently the cost of causeway breaches has been reported to range between approximately $25,000 per linear ft to approximately $60,000 per linear ft. A conventional highway-type bridge would be designed for a truck weighing approximately 36 tons. The breaches in the Endicott causeway are designed for heavy construction equipment and gravel trucks weighing approximately 120 tons. The breach in the West Dock Causeway is designed for very heavy production modules which weigh approximately 6,000 tons. In addition to being sensitive to the design loading, the cost of the breaches is sensitive to the characteristics of the seabed soils and their ability to support the imposed loading. It is also likely that some portion of the large difference in reported breaching costs reflects a difference in the items that are included in and excluded from the estimates.

For the Endicott Causeway, the cost of the breaches has been variously reported to be between $30,000 and $40,000 per linear ft. This causeway can accommodate normal service vehicles, construction equipment, and gravel trucks which are used on the artificial islands. Thus, it can reasonably be concluded that, in the Prudhoe Bay region, breaches in a solid-fill gravel causeway cost between 10 and 30 times the cost of an equivalent length of gravel section. Again, it must be emphasized that this conclusion is valid only for the Prudhoe Bay region and 120-ton capacity bridges and should not be applied in other regions, where site or design conditions may vary.

Whereas the cost and technological problems associated with constructing alternatives to causeways are exacerbated by the presence of seabed permafrost, this is not the case for solid-fill gravel causeways. The cost of the causeway is sensitive to the bearing capacity of the seabed, and the presence of permafrost enhances the bearing capacity. Since the warm pipelines are generally located above the causeway, and thus well above the seabed, no potential problems associated with thawing of the permafrost exist.

A major advantage of solid-fill gravel causeways is the fact that this concept is a very simple, predictable, proven technology, with little chance of unforeseen problems during construction. Therefore, in addition to the fact that the cost is relatively low (in the Prudhoe Bay region), gravel causeways are preferred by the oil companies because the construction cost, and construction schedule, can be reliably predicted, minimizing the financial risks associated with the oil field development.

ELEVATED CAUSEWAYS

As mentioned above, increasing the extent of causeway breaching reduces the environmental disturbance. Extending this concept to its limit results in the elevated causeway concept, i.e., pipelines and heavy duty roadway supported on piles. An elevated causeway would reduce the impacts to the nearshore environment that are associated with a solid-fill gravel causeway. It has been demonstrated and well documented that the technology exists for the construction of a variety of different structures in the nearshore Beaufort Sea and that design criteria are quite reliable. The key factor is the design of the supports to resist the ice forces and to protect them from scour. Construction techniques are also reliable, and therefore construction costs are fairly predictable.

The cost of an elevated causeway is quite sensitive to the design loading. As pointed out above, this design loading may range from 6,000-ton production modules, as used for the West Dock, to 120 ton construction equipment and light drill rig modules, as used for Endicott, to 36 ton conventional highway bridge loading, to very light loading that will accommodate personnel only. It is also possible to eliminate the roadway completely, resulting in the pile-supported pipeline concept. The heavier loading requires more structure to support it, with larger, more closely spaced piles penetrating the seabed. Thus, the cost of an elevated causeway can be reduced by reducing the carrying capacity of the road way. Reducing the carrying capacity requires that heavy equipment be transported over the ice during winter or by barge during the open water season, increasing operating costs. Complete elimination of the roadway requires that personnel, supplies and equipment be transported by air, by land vehicles over the ice, by supply vessel, by air-cushioned vehicles, or by combinations of these methods, thus further increasing operating costs. A life-cycle economic analysis is required to compare the trade-off between capital costs and operating costs over the expected life of the reservoir that is to be developed. The most cost-effective elevated causeway configuration may be expected to vary, depending on the characteristics of any particular offshore oil field development scenario and its location.

A number of cost-effective innovations in the design of Arctic structures and pile systems have been developed recently and it is quite likely that further improvements will be made in the future. However, these cost reductions are relatively small compared to the cost differential between an elevated causeway and a solid-fill gravel causeway in the Prudhoe Bay region.

Permafrost does not present a significant problem for elevated causeways. Pile supported structures have been installed in permafrost and non-permafrost soils for many years, both onshore and offshore. While the characteristics of the piles and the methods of installation vary depending on whether or not the soil is frozen, designs and construction techniques for both cases are well proven.

As mentioned above, the cost of a solid-fill gravel causeway is very sensitive to the location of the causeway, particularly with regard to the proximity of a source of gravel. This is not the case for an elevated causeway. The major structural elements of the causeway are prefabricated prior to shipment to the Arctic, and the cost of this prefabrication, which constitutes a major part of the total cost, is independent of the causeway location. Transportation costs to deliver the prefabricated elements to the construction site can vary depending on the remoteness of the site and availability of a means of access.

SUBSEA PIPELINES

The common characteristic of each of the above concepts is that the pipelines are supported above the water and ice. Another group of concepts features locating the pipelines below the water and ice, i.e., below the seabed. The only subsea pipeline in the Arctic is the one constructed at Melville Island for Panarctic a number of years ago. That pipeline was constructed under conditions that were very different from those that exist in the Prudhoe Bay region. Also, the Panarctic pipeline utilized a spur causeway to span the nearshore transition zone.

The technology for the design and installation of subsea pipelines in non-frozen or unbonded permafrost seabeds is well developed and reliable. However, in the nearshore transition zone, where water depths are less than approximately 6 ft and bonded permafrost is likely to exist near the top of the seabed, construction and operation is less proven and consequently there exist some technological and financial risks.

There are three general categories of construction techniques available to install a pipeline below the seabed, and within each category there are a number of variations possible. The summer construction techniques category consists of any of a number of methods of excavating a trench during periods of open water, and installing the pipeline in the trench by one of several proven laying or pulling procedures. A number of trenching methods are available for Arctic applications. The cutter suction dredge is the most efficient dredge for deep-trenching in a variety of soils, where water depths are sufficient for the dredge to operate. An alternative method of trenching is to use a subsea plow arrangement. If properly designed plows are utilized, it may be possible to plow 7-ft-deep trenches in a single pass, and up to 15-ft-deep trenches with three passes, provided multipass plowing is feasible. One other system of trenching in sands and silts is to use a jet sled, whereby hydraulic pressure creates a fluidized soil bed around the pipeline and the pipeline is lowered by gravity to the desired depth. The above techniques are viable if the sediments are unfrozen and water depths are sufficient to operate the required equipment.

Using summer construction techniques, long subsea pipelines would be installed by a semi--submersible, barge-shaped, or ship-shaped lay barge, with icebreaker support. The lay barge would require ice-strengthening, a modified mooring system for operations in ice, enclosed work areas, and a heat recovery system. These vessels can lay pipe at a rate of approximately 1.5 mi per day. Alternatively, for pipelines 16 inches or less in diameter, a reel barge may be used whereby the pipe string is pre-assembled in long lengths, spooled onto a reel on the deck of the barge, and then installed by pulling it off the reel and lowering in place. Short pipelines and the shallow-water portion of long pipelines may be installed by the bottom pull method. With this method, long pipe strings are fabricated on shore and then pulled into position. This requires a sizable pipe assembly site to be constructed on shore and, due to the rapid increase in pulling force with distance, would be limited to the construction of relatively short pipelines.

The winter construction techniques category consists of the adaptation of conventional cross-country pipeline construction methods by taking advantage of the land-fast ice as a support for construction operations. In nearshore areas with water depths less than approximately 10 ft, trenching with a trench cutter or ditchwitch may be the most cost-effective alternative. However, depending on trench depth requirements and the condition of the seabed sediments (bonded or unbonded), conventional excavation equipment and blasting could be required. The advantage of winter construction, when compared to conventional open-water methods, is that the winter construction window is relatively long and the majority of the construction equipment utilized in this technique has the versatility for either onshore or offshore pipeline construction.

Another winter construction technique, applicable in deeper water locations of the land-fast ice zone where the ice does not freeze to the seabed, is to prefabricate the pipeline at a convenient remote location and tow it below the ice into its final position. However, this concept requires further development to account for traversing the keels of large ice ridges and for construction in very shallow water depths.

The third category of subsea pipeline construction includes several variations of the directionally controlled horizontal drilling technique that has been successfully used for a number of years for constructing river crossings. To date, the maximum-diameter pipeline installed using horizontal drilling techniques is 40 in. and the maximum length installed is approximately 6,000 ft. A two-stage process is used. The first stage consists of drilling a small-diameter pilot hole. This is accomplished using a specially designed horizontal drill rig in conjunction with directionally controlled downhole drilling tools. After completion of the pilot hole, successively larger-diameter reaming tools are pulled through until a hole diameter is achieved which is suitable for installation of the pipeline. This diameter is larger than the outside diameter of the pipeline, allowing it to be suspended in drilling mud and permitting easier movement of the pull section during installation.

While the concept of installing subsea pipelines by directional drilling appears to be feasible, further technological developments are required to make it practical for Arctic nearshore applications. Failure of the pipeline due to thaw subsidence is a major concern since permafrost can exist to depths in excess of 2,000 ft. The present magnetic guidance control system, which is not accurate near the magnetic north pole, must be replaced with a system based upon inertial gyroscopes or another system. Also, the capacity to install large-diameter pipe must be increased from the present 6,000 ft to 2 or 3 miles.

As mentioned above, permafrost probably exists at or near the top of the seabed in water depths less than 5 or 6 ft, and unbonded permafrost, possibly with ice lenses, may exist in deeper water depths. Although site specific, normally the top of bonded permafrost, in water depths greater than 6 ft, is found more than 30 ft below the seabed and is of minimal concern for pipeline construction.

The temperature at which the produced crude oil is pumped through a subsea pipeline depends on the gravity and wax content of the oil. It is highly likely that this temperature will be well above the freezing point of water. Therefore, it is probable that a subsea pipeline in the nearshore transition zone will cause the permafrost to thaw, possibly resulting in significant settlement. Due to highly variable moisture contents and thaw strains of the permafrost, thaw subsidence would not be uniform, resulting in unpredictable stresses in the pipe if mitigation measures are not taken. Lowering the temperature of the product, if the flow characteristics permit, is one method of eliminating this problem. Insulating the pipeline will moderates the thaw effect, but within practical insulation values over a long period of time thaw still occurs. The pipeline can be installed in a trench that has been excavated overly deep and wide, provided with thaw-stable bedding material, and backfilled with thaw-stable material. Alternatively, the pipeline can be supported on piles in the seabed trench to prevent subsidence. Another possible mitigating measure is to provide a refrigeration jacket around the pipeline to keep the permafrost from thawing. Of course, it is possible to combine some of these mitigating techniques to develop the most cost-effective solution.

Another possibility for solving the thaw subsidence problem is to elevate the pipeline above sea level through the nearshore transition zone. This can be done by means of a spur causeway or an elevated causeway (without a roadway). However, in the Prudhoe Bay region, where the seabed slope is so slight and the transition zone may extend more than a mile offshore, this may not be practical.

In river outflow areas, nearshore subsea pipelines may be subject to unrestrained spans due to strudel scour if not buried to sufficient depths. The strudel scour phenomenon may occur up to several miles offshore and may result in scours as much as 10 to 30 ft deep.

Burial of nearshore subsea pipelines is also required to protect them from ice gouging. Ice gouging is a significant consideration in water depths ranging from 6 to 150 ft. The appropriate burial depth is a subject of some debate and must take into account not only the possibility of physical contact between the ice and pipeline, but also the force exerted by the ice on a pipeline buried below a gouge. A technical analysis is required to determine the burial depth at which the pipe would not be damaged by ice keels.

Burial depth is also a significant consideration in areas where the nearshore seabed is subject to freeze/thaw cycles that may result in excessive frost heave of the pipeline. This can normally be avoided by providing sufficient burial depth.

The most probable cause of a subsea pipeline leak is through corrosion rather than catastrophic failure, assuming any potential permafrost thaw and settlement is properly accommodated. Welding technology and X-ray examination of the pipes before burial are of such high quality that the chances of laying a defective pipe are very low. Once in place, pipes buried in the seabed, in the absence of permafrost, probably are safer than pipes subject to expansion and contraction in the air and safe from accidents. Pipe corrosion, both external and internal, can be checked regularly and, if corrosion is detected, it can be routinely treated. Thus, given present technology, the probability of oil leaks from a pipeline buried in a stable environment is low.

Existing oil leak detection technology is quite advanced and generally very reliable for leaks of more than 0.25% of the flow. However, the technology to detect very small leaks requires further development. Even a very small leak, which may occur during a period of ice cover and go undetected until breakup, can cause significant environmental damage.

A major Arctic subsea pipeline problem remaining to be solved is the development of repair techniques and equipment that are effective and reliable on a year-round basis. Repair procedures effective in the open water season are well established. However, procedures that are effective when ice cover is present, particularly in water depths where the entire water column is frozen, have yet be developed and present a major problem.

Since not all of the technological problems associated with constructing and operating an Arctic nearshore subsea pipeline have been solved, it is very difficult to estimate construction and operating costs. Depending on the method used to solve these problems, the construction cost of a subsea pipeline may or may not be higher than that of a solid-fill gravel causeway. A subsea pipeline alternative presents the problem of access to the offshore drilling/production facilities for personnel, supplies, and equipment. Thus, subsea pipeline operating costs would be significantly higher than those for a causeway in order to maintain this access year-round.

DIRECTIONAL DRILLING

Developing a nearshore reservoir by directional drilling from an onshore location eliminates the need for transporting the produced hydrocarbons across the nearshore region. This procedure may be considered where the reservoir is not located too far offshore. With this alternative, the offshore field is developed by directional drilling from one or more onshore locations in the vicinity of the shoreline. While this alternative reduces risks to the nearshore environment, it increases the financial risks associated with development of the reservoir.

The technology exists, both worldwide and in Alaska, to drill wells directionally with 10,000 to 12,000 ft departures at vertical depths in the 9,000 to 10,000 ft range. But certain problems are inherent in this technology and costly, specialized equipment is required. Also, it is very difficult to drill and control these very high-departure wells, particularly if the area to be developed has fault zones in the geological formations. The presence of fault zones that may have to be penetrated at an oblique angle to reach the reservoir could result in plugging back and re-drilling, an expensive proposition. In addition to fault zones, there are problems with the well bore stability and the selection of the mud systems to be used. The torque and drag required to overcome the well bore friction may limit the reach that can be obtained and may require that oil-base drilling mud be used to reduce friction. Removal of cuttings and handling and disposal of oil-base drilling mud presents significant environmental problems. All of these problems become more severe as the reach of the well is increased.

There is a great reluctance to use the directional drilling technique where the area to be developed is unknown. For the most part, drilling of high-departure wells has been used where the reservoir characteristics are well known and where planning of the drilling process can be carried out with confidence, as in development of existing fields. Drilling of wells in an unknown field is essentially equivalent to drilling exploratory wells, with significant environmental and financial risks.

Horizontal drilling is not used to achieve high departures. This technique is used basically as a well completion method to improve reservoir performance, rather than as a method for achieving high departures. Similarly, slant rig drilling is not used to achieve high departures. The slant rig is used primarily to develop shallow reservoir zones, and it is not likely to produce high-departure wells. Typical experience with slant well drilling is to achieve step-outs of approximately 8,000 ft at 6,000 ft vertical depth.

Conventional directional drilling is controlled using magnetic-based instrumentation. However, as mentioned previously, this type of instrumentation loses accuracy at high latitudes. The smaller the target which the well must hit and the further away it is, the lower is the probability of success, with a corresponding increase in financial risk.

In considering the development of the Niakuk Field, it was estimated that less than 85% of the reservoir's known oil in place could be reached with wells having a departure on the order of 11,500 ft. A reduction in recovery due to waterflood, as compared to drilling from offshore locations, may be expected. It was reported that more than 50% of the probable additional resources could not be recovered using this technique. Additionally, an active fault would have to be crossed in order to develop this field from shore, significantly increasing the financial and environmental risks.

Current Alaskan experience with drilling wells at 10,000- to 12,000-ft departures has proven that the wells can be drilled, but they are financially questionable. It is important to emphasize that specific geologic knowledge is absolutely necessary, along with extremely detailed planning, cost estimating, and risk analysis, prior to undertaking any high departure well drilling project.

OFFSHORE TANKER LOADING

Another offshore oil field development concept that does not require a nearshore pipeline consists of loading the produced crude oil into tankers at a deepwater location, without ever taking it ashore. There is some question regarding the relevance of this alternative for this synthesis conference. If the consideration of causeway alternatives is limited to the Prudhoe Bay region, then it is not relevant. In the nearshore Prudhoe Bay region, with its shallow water depth and proximity to the Trans-Alaska Pipeline System (TAPS), offshore loading is not an economically feasible alternative. However, if other locations are considered, remote from TAPS at the eastern or western ends of the Alaskan Beaufort Sea coastline, then it is quite possible that an offshore loading system is an alternative worth considering.

The concept of transporting crude oil by icebreaker tanker from the Beaufort Sea has been under serious consideration for 20 years. There are no existing offshore loading terminals that would be suitable for the Beaufort Sea, but a number of different concepts have been developed over the years. A considerable amount of computer and physical model testing has been done, and it has been concluded by a number of researchers that the offshore loading concept is technically feasible. It is likely that, at a location where the water depth is approximately 100 ft, the offshore terminal structure would have a circular footprint with a diameter on the order of 350 ft, if it were designed solely for offshore loading. At a deepwater location, where the optimum production platform is a large, prefabricated, bottom-founded structure, the use of the production platform as the offshore loading terminal is probably the most cost-effective alternative. In either case, the crude oil would have to be stored within the structure, below the waterline, and discharged by means of a seawater displacement system.

Model studies have been carried out to evaluate tanker approach and mooring to such a structure and to estimate the magnitude of the forces that the ice would exert on the ship. These forces are very high and would have to be transferred to the structure through the mooring system in order to keep the ship in place. The design of mooring systems capable of sustaining these forces requires further development but is technically feasible.

SENSITIVITY TO ENVIRONMENTAL PARAMETERS

While all of the above concepts are technically feasible, some require more technical development than others, and thus the reliability of estimates of construction cost and schedule varies considerably among the alternatives. Also, the sensitivity of the construction cost and schedule to variations in the environmental design parameters varies greatly among these alternatives. These environmental design parameters include ice conditions, waves, water depth, currents, tides, storm surge, geotechnical conditions, and meteorological conditions. For example, the construction costs of all the alternatives mentioned, with the possible exceptions of extended-reach directional drilling and offshore tanker loading, are impacted by the presence of permafrost in the seabed along the pipeline route. The degree to which the particular concept requires penetration of the seabed determines the magnitude of the cost impact. Thus, the costs of various causeway alternatives, requiring virtually no penetration of the seabed, are relatively insensitive to the presence of permafrost. The costs of the pile-supported concepts, requiring penetration only for the installation of widely spaced support members, are mildly sensitive to the presence of permafrost. However, costs for the installation of pipelines below the seabed can be very severely impacted by the presence of permafrost.

CONCLUSIONS

The construction of solid-fill gravel causeways in the nearshore Beaufort Sea is technically feasible, as are several other alternatives for bringing offshore-produced hydrocarbons ashore. When considering life cycle costs, a solid-fill gravel causeway is the least costly alternative in the Prudhoe Bay region, but may not be so at other locations. Elevated causeways are also technically feasible and are less disruptive to the environment, but are 10 to 30 times more costly than a solid-fill causeway in the Prudhoe Bay region. Subsea pipelines are also technically feasible but require the development of cost-effective solutions to several problems associated with permafrost before they can be considered for implementation. Extended-reach directional drilling is probably not a practical approach for the development of relatively small nearshore oil fields for which the reservoir characteristics and potential fault locations are not well known.

Whether or not a particular offshore oil field development project is economically feasible depends on the particular circumstances of the development scenario. In general, there is a certain quantity of recoverable hydrocarbons available which can be sold at a given price. The development, operating, transportation, and maintenance costs must be low enough to return a reasonable profit over the life of the field, allowing for royalties and taxes. Thus, the selection of the concept for bringing the oil ashore, be it a solid-fill gravel causeway or another, more costly alternative, may or may not have an effect on the financial viability of the development project, depending on the profit margin available.

A wide variety of causeway concepts and alternatives to causeways, as well as methods of constructing each, is available. The performance of these various alternatives, and their effects on the local physical environment, can be predicted reasonably well. The costs and the construction schedules for the various alternatives also can be predicted reasonably well. What is lacking is a clear definition of the environmental disturbance that is tolerable. Thus, it is up to the biologists and the oceanographers to define the extent of disturbance that is acceptable so that offshore development can proceed. While it is recognized that all the information one would like to have in order to make a final decision may not be available, there is sufficient information available upon which preliminary decisions can be based. As more information becomes available, these decisions can be revised as appropriate.

PRESENTATIONS

AND

ABSTRACTS

COASTAL BOUNDARY LAYER PROCESSES IN THE CENTRAL BEAUFORT SEA

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ABSTRACT

The hydrography and circulation in the coastal ocean surrounding Prudhoe Bay, Alaska have been under study for more than a decade. The dynamics of this region are generally similar to those of the coastal boundary layer elsewhere, but there are interesting features brought about by the large density contrasts of water masses as well as the relatively reduced vertical scale of the depths and water mass thicknesses. The special characteristics of circulation and hydrography which occur due to the proximity of the shoreline provide an important framework for the interpretation and understanding of the large set of measured oceanographic data from this area.

The basics of coastal boundary layer dynamics are reviewed and applied to measured data from the Endicott/Prudhoe Bay area to illustrate the causes of several commonly observed hydrographic and circulation features. A sequence to the open water season oceanographic conditions is outlined and demonstrated.

INTRODUCTION

Two causeways have been constructed on the Beaufort Sea coast of Alaska for purposes of developing nearshore petroleum reservoirs. These long (4 to 8 km) gravel-fill structures interact with coastal oceanographic processes and have been observed to alter the local hydrography (Chin *et al.* 1979; Mangarella *et al.* 1982; Savoie and Wilson 1983, 1984, 1986; Hachmeister *et al.* 1987). The environmental significance of hydrographic alterations is a matter of concern to regulatory agencies because of possible consequent alterations to the habitat of anadromous fishes that inhabit the coastal waters each summer. To relieve or substantiate that concern requires that the scale and intensity of the oceanographic interactions be determined and then related to the natural variability of the coastal boundary layer along the Beaufort Sea coast.

In this paper the major features of the Beaufort Sea coastal boundary layer (CBL) are described. This is followed by a more detailed discussion of the upwelling process and the conditions necessary for its occurrence.

LENGTH AND TIME SCALES

The description of the physical oceanography of a coastal ocean system should identify the length and time scales that are relevant to the problems under examination. Along the Beaufort Sea coast, a range of length and time scales bears consideration because: a) there is substantial alongshore variability in hydrography and circulation, b) the quantity and quality of anadromous fish habitat is believed to be governed by the hydrography, and c) issues of concern include the possible impact of present and future causeways on anadromous fish habitat along the coast. That causeways are capable of perturbing coastal flows is undeniable; however, such flow perturbations have dimensions (i.e., length scales) that are similar to those of the disturbing body (i.e., the causeway). The key to evaluating the effects of existing (and future) causeways lies in understanding the interaction of the local flow perturbations with the larger-scale processes.

Because the Beaufort Sea CBL is shallow (<5 m) and dominated by wind forcing, there are at least four relevant time scales. Response times for the coastal circulation to adjust to variations in wind stress are measured in hours. The typical duration of weather events, about 3 to 5 days, is the synoptic time scale and is the one that dominates consideration of CBL processes. The frequency of occurrence of some CBL processes depends on the season-long wind climatology. Finally, there is considerable year-to-year variability in both the wind climatology and freshwater input to the CBL.

The major time, length, and depth scales for defining coastal boundary later dynamics are listed in Table 1. The scales listed correspond to those which are relevant to the synoptic meteorological time-scale of 3 to 5 days. The major length scales are the *barotropic radius* and the *Rossby radius*. The former is the offshore distance within which shoreline-induced changes in the mean water level occur, while the latter is a similar parameter which applies to displacements of the density interface (i.e., the pycnocline) between the shelf water layers (Gill 1982).

When a flow is accelerated suddenly by a wind impulse, inertia dominates initially over bottom friction effects. The duration required for bottom friction to contribute significantly to the balance of forces is called the *frictional adjustment time* (t_f). Another important time scale is the *Coriolis time scale* (t_c), which is the time a flow must persist to be affected by the earth's rotation (Csanady 1982).

Two important depth scales exist. One is the *Ekman Depth*, which defines the thickness of the fully developed turbulent boundary layer created by either surface or bottom drag (Neumann and Pierson 1966). The other is a dimensionless parameter, called the *Ekman Number*, which is used to evaluate the relative importance of boundary friction and earth rotation (Coriolis) forces. The Ekman Number thus indicates the depth to which frictional forces dominate over those associated with earth rotation (Tennekes and Lumley 1972). When the Ekman Number is greater than unity, the dynamics are friction-dominated; when it is less than unity, flows are turned by Coriolis accelerations, with the amount of turning increasing with depth.

Most of the scales defined above are dynamic and thus they change in response to the intensity of the governing forces which, essentially, are the wind stress and differences in water mass densities. Accordingly, the dimensions of the coastal boundary layer and its sub-regions are also variable. Typical values of the pertinent length and time scales on the Alaskan Beaufort Sea coast follow: the maximum depth of the friction-dominated zone is about 4 to 5 m; the Rossby radius is 2 to 4 km; the response times in the friction-dominated and the geostrophic sub-regions of the coastal boundary layer are about 1 to 2 hr and 4 to 5 hr respectively.

SEASONAL HYDROGRAPHY

The seasonal hydrographic trends of the coastal boundary layer along the Alaskan Beaufort Coast are well known. Summary descriptions have been provided in various oceanographic monitoring reports (Mangarella *et al.* 1982; Savoie and Wilson 1983, 1984, 1986; Hachmeister *et al.* 1987) and most recently by Colonell and Niedoroda (1988), from which Figures 1 through 4 were extracted. Because this paper was stimulated by concerns over summer habitat for anadromous fishes, we consider here only that portion of the year when these fish are in the coastal waters. Known as the "open-water" season, this period averages about 11 weeks in length, beginning in mid-July and only rarely extending beyond mid-October.

Table 1. Significant scales.

Length Scales		
Barotropic Radius	$R_1 = f^{-1} [g (h_t + h_b)]^{1/2} = C_1 f^{-1}$	55 km
Rossby Radius	$R_2 = f^{-1} \left[\frac{\rho_b - \rho_t}{\rho_b} g \frac{h_t h_b}{(h_t + h_b)} \right]^{1/2} = C_2 f^{-1}$	2 km
Depth Scales		
Ekman Depth	$D = \sqrt{\frac{2K}{f}} = \frac{0.1 u_*}{f}$	7 m
Ekman Number	$E_v = \frac{K}{f H^2}$	$H = 4.5$ m; $E_v = 1.0$ $H = 15$ m; $E_v = 0.1$
Time Scales		
Frictional Adjustment	$t_f = \frac{H f^{-1}}{10 \sqrt{c_D D}}$	$t_f = 2$ hrs; $H = 3$ m $t_f = 4.5$ hrs; $H = 7$ m
Coriolis Adjustment	$t_c = \frac{\pi}{2} f^{-1}$	3 hrs.

C_D = drag coefficient
f = Coriolis parameter
g = acceleration of gravity
h_t = thickness of upper water layer
H_b = thickness of lower water layer
H = total water depth
K = vertical eddy coefficient
u_* = shear velocity
ρ_t = density of upper water layer
ρ_b = density of lower water layer

The major freshwater input to the CBL occurs when the rivers break up and begin to flow in early June. By the time the sea ice breaks up and withdraws from the coastal waters, a large volume of river water is in the coastal area (Figure 1). During early summer, here named Phase 1, this (relatively) warm freshwater mass separated from the cold, salty, and generally well-mixed shelf water mass by a strong and steeply-sloped frontal zone. For the first few weeks of the open-water season this front is maintained by a balance of processes. Gravity causes the low-density coastal water mass to slide seaward over the shelf water, thereby reducing the slope of the front. Wind-induced waves and currents mix this coastal water downward, which serves to restore the steep inclination of the front. In time, however, gravitational processes prevail, causing the front to weaken and lose its steep inclination (Figure 2), with the frontal zone becoming

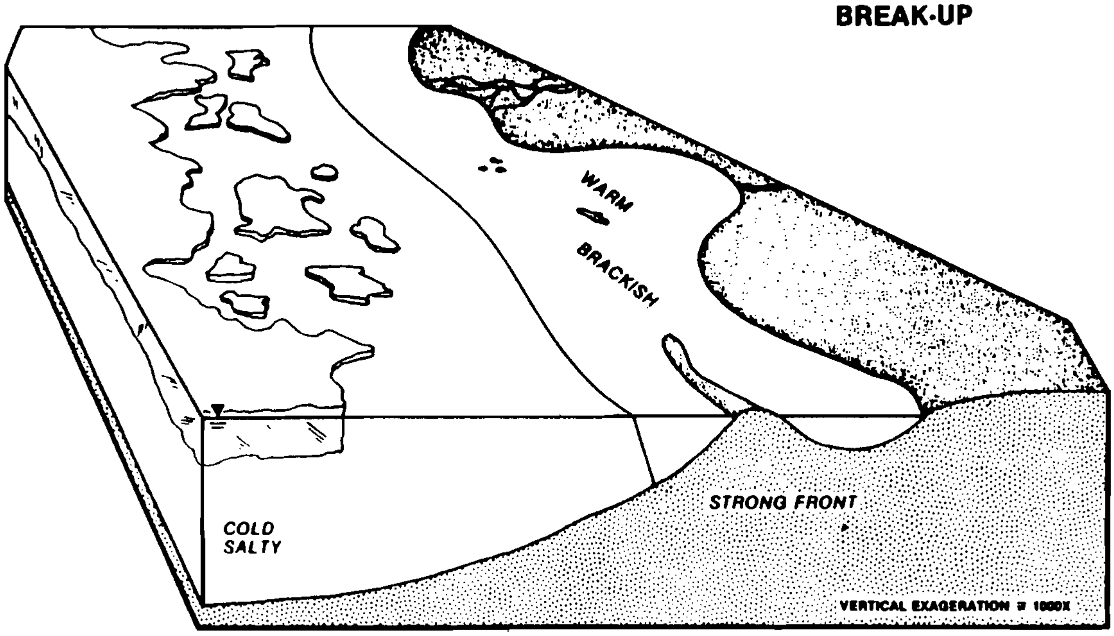

Figure 1. Oceanographic conditions following break-up.

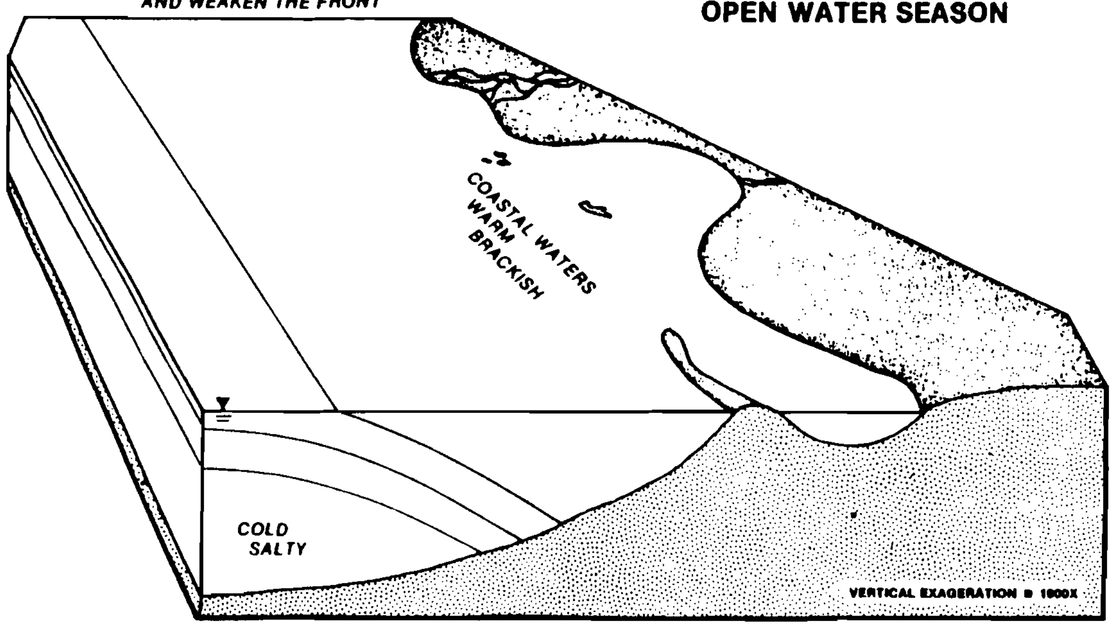

Figure 2. Phase 1 open water oceanographic conditions.

a more gradual transition between the coastal and shelf water masses. This situation is the precursor for a relatively sudden change to a markedly different hydrographic conditions, here named Phase 2.

The transition from Phase 1 to Phase 2 is often promoted by a single major weather event (e.g., a storm), usually occurring in the third or fourth week of July. Phase 2 is characterized by vertically stratified shelf water interacting with the brackish coastal water mass. A large range of conditions can exist within the coastal boundary layer during Phase 2. Figures 3 and 4 illustrate the characteristic hydrographic and circulation patterns that are associated with the dominant wind conditions. The patterns depicted by Figures 3 and 4 develop only after the wind has become steady for an appropriate duration.

Wind records for the North Slope show that, although episodes of relatively steady winds do occur throughout the open-water season, periods of varying winds are more common (Kozo 1984). Under these conditions much of the energy imparted to the ocean can become associated with unknown combinations of long shelf waves (having periods of hours to days and sea surface amplitudes to tens of centimeters), Rossby waves or internal waves (which propagate along the pycnocline), and various modes of inertial oscillations (Csanady 1982). During these periods coastal flows are unsteady and can even appear erratic. In the friction-dominated part of the CBL, mixing occurs rapidly as the winds change. Further offshore, in the deeper portions of the CBL where friction is less effective, the density stratification tends to be maintained.

As the open-water season progresses, coastal waters become colder and saltier as both solar insolation and freshwater input diminish. The season ends with the formation of a continuous ice sheet over the ocean surface in late September or early October (Stringer 1987).

UPWELLING IN THE COASTAL BOUNDARY LAYER

If the oceanographic effects of existing (or proposed) causeways are to be evaluated, it is essential that the interaction of causeway-induced flows with more general CBL conditions be understood. The remainder of this paper describes the conditions necessary for upwelling to occur in the CBL and the results of sample computations that illustrate its character as a regional phenomenon. The latter point is significant because it has been suggested that causeways are capable of "intensifying" the upwelling process (Envirosphere 1987).

Upwelling and downwelling are major features of the flows that occur within the CBL. Depending on its direction relative to the shoreline, the wind acts to displace the surface water mass away from, or toward, the shoreline. When the surface water is displaced offshore, the underlying water moves upward and onshore (upwelling); when the surface water moves onshore, the underlying water is displaced downward and offshore (downwelling). Upwelling and downwelling are well known at the shelf edge (Aikman and Posmentier 1985, Posmentier and Houghton 1981, Brink *et al.* 1981), on the mid-shelf (Leming and Mooers 1981, Endoh et al. 1981), and within the CBL (Csanady 1975, 1982; Niedoroda *et al.* 1984, 1986) in many non-arctic locations.

The scale, magnitude and development rate of CBL upwelling are controlled by the thicknesses (h_t, h_b) and densities (ρ_t, ρ_b) of the water mass layers, wind speed, wind direction (relative to the shoreline), wind duration, and average water depth in the coastal region. These parameters are defined in Figure 5 for relatively small pycnocline displacements. For these conditions, Csanady (1982) derives the following equations for pycnocline displacement for the longshore and cross-shore wind components:

$$\zeta_1 = - \frac{u_*^2 t}{C_2} \frac{h_b}{h_t + h_b} \left[e^{\left[\frac{x}{R_2} \right]} + \left(\frac{\epsilon h_b}{h_t} \right)^{1/2} e^{\left[\frac{x}{R_1} \right]} \right]$$

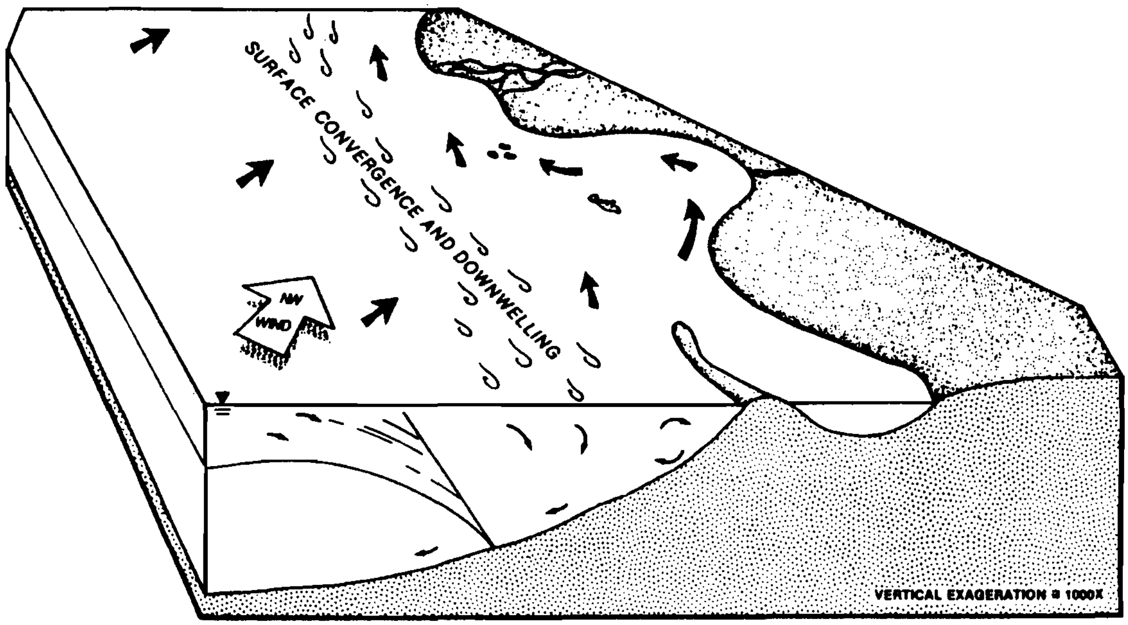

Figure 3. Phase 2 - northwest wind.

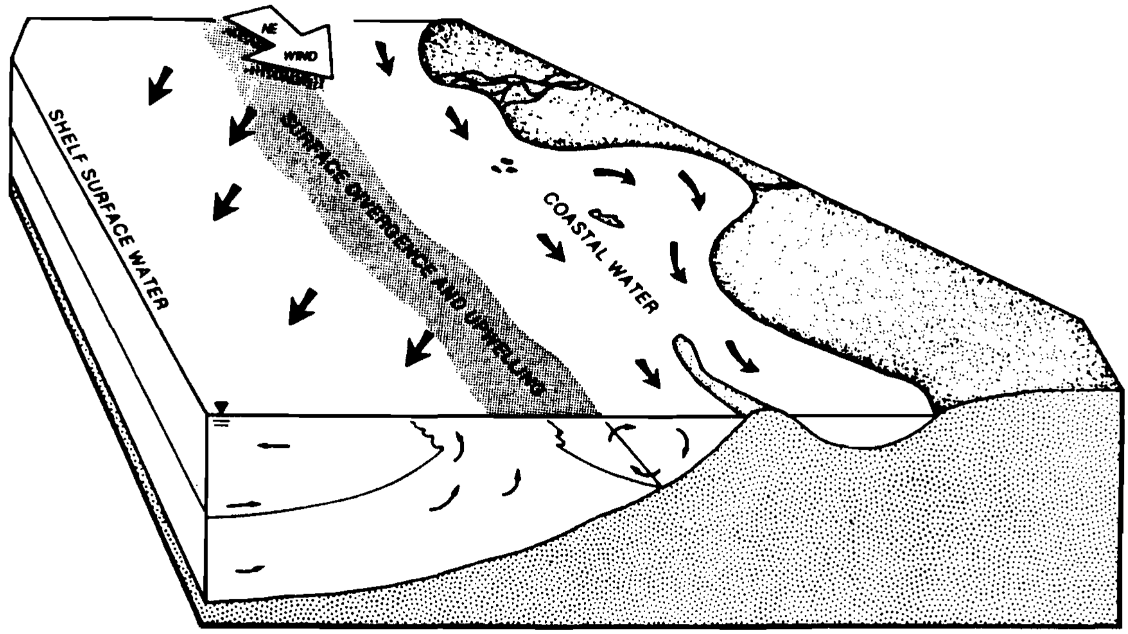

Figure 4. Phase 2 - northeast wind.

where:

$$R_1 = f^{-1} \, [g(h_t + h_b)]^{1/2}$$

$$R_2 = f^{-1} \left[\frac{\rho_b - \rho_t}{\rho_b} \, g \, \frac{h_t \, h_b}{(h_t + h_b)} \right]^{1/2} = C_2 f^{-1}$$

$$C_2 = \left[\frac{\rho_b - \rho_t}{\rho_b} \, g \, \frac{h_t \, h_b}{(h_t + h_b)} \right]^{1/2}$$

$$\epsilon = \frac{\rho_b - \rho_t}{\rho_b}$$

$$\zeta'_c = - \frac{h_b}{h_t + h_b} \, \frac{u_*^2}{f \, C_2} \left[e^{\left[\frac{x}{R_2} \right]} - \frac{C_2}{C_1} \, e^{\left[\frac{x}{R_1} \right]} \right]$$

where:

$$C_1 = \sqrt{g \, (h_t + h_b)}$$

where ζ'_1 and ζ'_c define the pycnocline elevation across the CBL and u_* is the wind friction velocity. The parameters *g, t, x,* and *f* are the gravitational acceleration, time, offshore distance, and the Coriolis parameter, respectively.

When conditions are especially favorable to upwelling, the pycnocline displacement is so large that it can rise to the surface near the coast. If the wind persists, the point where the pycnocline intersects the water surface migrates offshore, leaving bottom water adjacent to the coast, as shown in Figure 6. The longshore wind stress governs this situation and Csanady (1977) derived the following expression for the width of the zone of surface outcropping of bottom water:

$$x_o = \frac{I}{f \, h_t} \, \frac{h_b}{h_t + h_b} + R_2$$

In the above expression *I* is the wind impulse, which is the integration of the wind-stress over the duration of steady wind conditions. The parameter x_o represents the offshore distance of the surface pycnocline to a point at the outer boundary of the friction-dominated sub-region of the CBL.

The above equation can be recast to express the minimum strength and duration of steady longshore wind needed to bring the pycnocline to the surface:

$$I_{min} = \frac{h_t \, (h_t + h_b)}{h_b} \, C_2$$

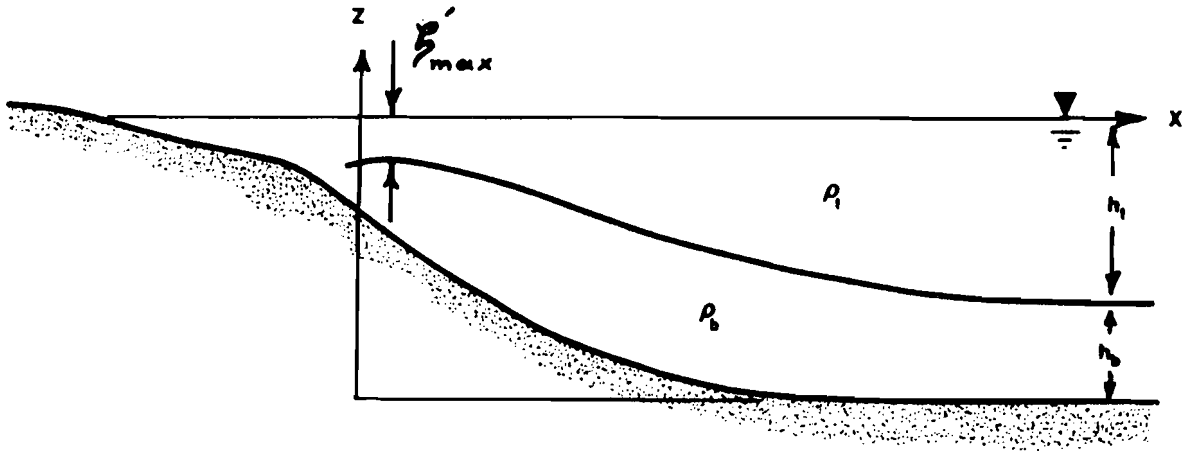

Figure 5. "Small" pycnocline displacement definition sketch.

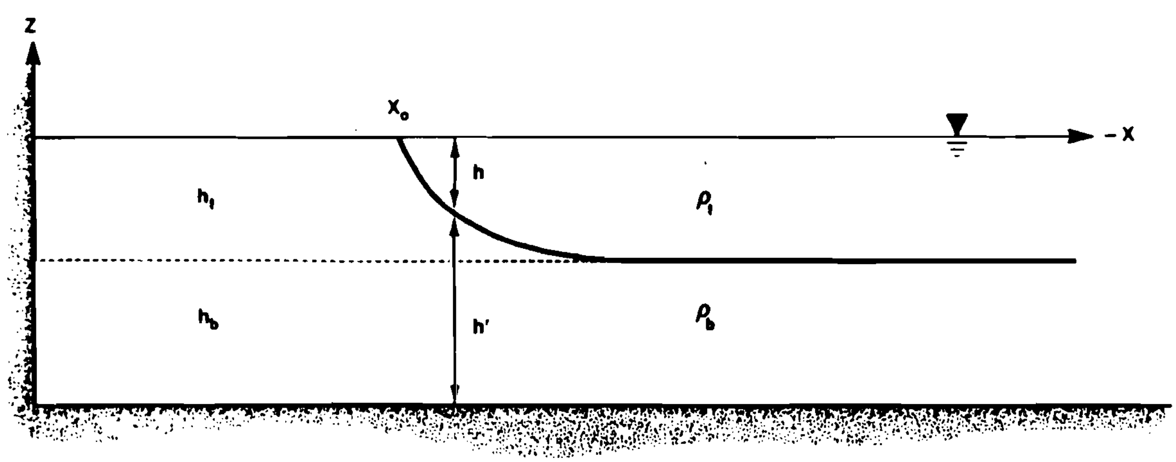

Figure 6. Large pycnocline displacement definition sketch.

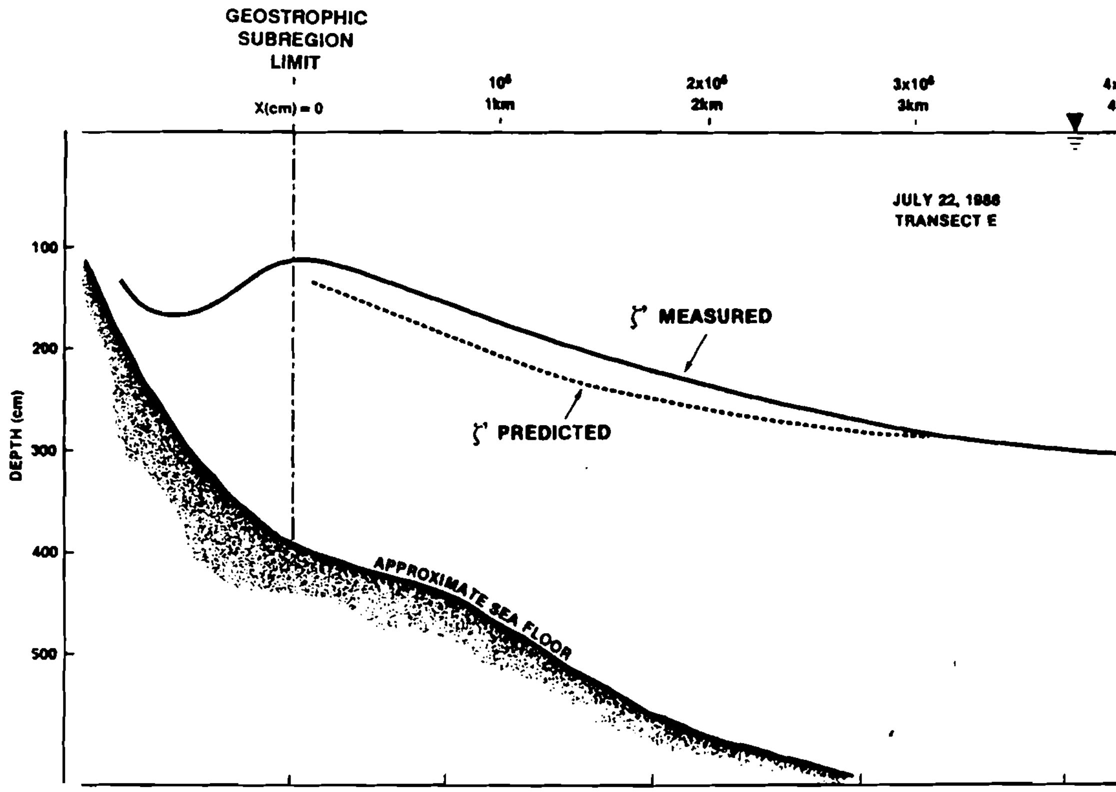

Figure 7. Comparison of measured and computed pycnocline.

Figure 7 illustrates the application of the small pycnocline displacement equations to data collected near the Endicott Causeway on 22 July 1986 (Short *et al.* 1987). The data were collected along Transect E, which extends from the midpoint of the 5.6-km causeway offshore to a depth of 6 m. The agreement between measured and computed positions of the pycnocline is good. Moreover, the absence of reference in the theoretical formulation to any topographic perturbation (such as the nearby causeway) indicates that the pycnocline position is the result of regional-scale forcing functions and water mass properties.

Table 2. Characteristic water layer densities.

	Layer Densities (g cm^{-3})	
	Upper	Lower
Phase 1 (early)	1.001	1.023
Phase 1 (late)	1.003	1.020
Phase 2 (all)	1.009	1.013

Using measured hydrographic data, an analysis was performed to provide a more general characterization of upwelling behavior in the CBL adjacent to Prudhoe Bay. Table 2 shows the upper and lower layer densities used.

The results for "small" displacements were parameterized by ζ'_{max}: the minimum depth (or maximum rise) of the pycnocline below the surface as shown in Figure 6. The surface and bottom layer thicknesses were taken to be 5 and 2 m, respectively. For a longshore wind of 6.5 m sec^{-1} (≈15 mph), minimum pycnocline depths of 4.4 m and 4.2 m (indicating rises of 0.6 m and 0.8 m) were calculated for Phase 1 conditions. The corresponding Phase 2 example yielded a minimum pycnocline depth of 3.0 m (pycnocline rise of 2 m). This demonstrates vividly that reduction of the density contrast between the upper and lower layers over the season has a marked effect on the pycnocline displacement for the same wind, depth, and layer thicknesses. Consequently, hydrographic conditions become more conducive to upwelling as the open-water season progresses.

A similar analysis was made to examine the sensitivity of upwelling to the longshore wind speed, again using the minimum pycnocline depth as the parameter. The Phase 2 densities (Table 2) were used, along with depth and layer thicknesses defined above. The results show that wind speeds of 4 m sec^{-1} (≈9 mph), 6 m sec^{-1} (≈13 mph), and 10 m sec^{-1} (≈22 mph) produce minimum pycnocline depths of 4.0, 3.2, and 0.5 m, respectively. Wind durations for these computations were limited to periods less than the appropriate friction adjustment times of 7, 4, and 2 hrs, respectively.

An additional analysis was conducted to illustrate the large pycnocline displacement case. Layer thickness, layer densities, and water depths were as given above. It was found that a 6 m sec^{-1} (≈13 mph) longshore wind causes the surface outcropping of bottom water to be 0.2 km wide in 18 hrs and 0.7 km wide in 24 hrs. Corresponding values for an 8 m sec^{-1} (≈18 mph) longshore wind are outcropping widths of 1.1 km in 12 hrs and 2.5 km in 18 hrs of steady wind conditions.

It is also instructive to examine the minimum time needed to bring the pycnocline to the surface under these hydrographic and layer thickness conditions. The results show that a 4 m sec^{-1} (≈9 mph) longshore wind will cause the pycnocline to surface in approximately 36 hrs of steady wind conditions, but doubling the wind speed to 8 m sec^{-1} (≈18 mph) produces the same effect in about 7 hrs.

Because the wind and hydrographic conditions selected for these analyses are common, these results show that upwelling within the CBL also is a frequent occurrence. Significant vertical displacements of the pycnocline, and even outcropping of shelf bottom water near the shoreline, occur under very ordinary conditions of wind speed and steady duration. Nevertheless, these results are not represented as comprehensive because only a limited set of "typical" hydrographic and wind conditions have been analyzed thus far.

CONCLUSIONS

1) The open-water oceanographic cycle consists of two well-defined phases, each with a characteristic hydrography.
2) Variable conditions and rapid mixing are common—especially within the friction-dominated part of the CBL.
3) The conditions necessary to promote upwelling are common and the process is <u>regional</u> in scale.
4) Upwelling is the major mechanism by which cold and salty bottom water enters the nearshore zone.
5) Upwelling is a precondition for causeway-induced local scale processes to mix shelf bottom water through the water column.
6) The available data provide a good base from which to evaluate regional and local oceanographic processes.
7) Continued oceanographic monitoring is urged; however, monitoring should focus on the interaction of local and regional scale processes.

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ESTUARINE CIRCULATION AND MIXING: A GENERIC MODEL

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Following Pritchard, an estuary can be defined as a semi-enclosed basin, open to the ocean, where the seawater is measurably diluted by freshwater. An estuary is a transition zone between freshwater inflows derived from runoff and the ocean. The details of circulation and mixing depend on the spatial distribution of the primary physical forcing mechanisms tide, winds, and density differences. Tidal-period sea level variations at the seaward boundary and wind stress at the water surface generate currents and turbulence that are a major source of energy for mixing. Longitudinal density gradients drive an estuarine circulation that is usually important in the flux of salt and other solutes. The vertical density gradient tends to suppress mixing.

The geometry of a particular estuary and the relative balance between the various physical processes then determine the strength of the circulation and mixing that is observed. For instance, a shallow coastal plain estuary such as San Francisco Bay is dominated by tidal forcing. The circulation and mixing is almost entirely dependent on the tides at Golden Gate. On the other hand, Columbia Bay near Valdez is a deep fjord estuary where freshwater inflow from a tidewater glacier is dominant. The circulation is driven by density currents and mixing is suppressed by stratification. These are only two examples from a continuous range of estuaries.

ESTUARINE TRANSPORT

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(No Abstract Submitted)

PHYSICAL OCEANOGRAPHY - SUMMARY OF NEW FINDINGS

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(No Abstract Submitted)

DISTRIBUTION AND GENERAL BIOLOGY OF ANADROMOUS COREGONIDS IN THE BEAUFORT SEA AREA

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Members of the whitefish family are among the most abundant fishes found in Beaufort coastal areas during the summer months. The species involved share a common generalized life history pattern involving fall spawning, a long incubation period, and a complex system of migrations that provide the functional link between several spatially-segregated habitats. Many interspecific differences occur, however, among which are the degree of anadromy exhibited and the range of coastal habitats occupied. The point is made that environmental assessment requires a full understanding of the spatiotemporal relationships of each focal population.

FACTORS LIMITING ANADROMOUS FISH POPULATIONS

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1) Why don't most fish populations "explode" in abundance?

2) How do fishing and habitat alteration impinge on the dynamics of a fish population?

   a) A recruitment curve describes the number of adult offspring produced by parent populations of different density. A diagonal line shows the number of fish needed for replacement reproduction. Harvest management is based on the perception that fish produced in excess of the number needed to replace the parent population can be removed.

   b) If habitat is altered so as to reduce the number of recruits produced each year, the basic recruitment curve is likely to be changed along with associated changes in steady-state conditions.

   c) Habitat change can produce effects at one stage in the life-cycle of a population, but the final effect on recruitment may or may not be significant (see Handout).

3) In the "real world," data to describe the dynamics of a population are rarely available. Worse yet, it may not be feasible to gather the data required to attain the degree of statistical rigor desired, or required, because variability in natural population abundance and environmental conditions is great.

The primary effect of environmental change on juvenile fish may be to reduce the amount of rearing habitat. If loss of habitat is the only direct result of change (leaving habitat quality unchanged), and if there is surplus rearing habitat (i.e., juveniles are limited earlier during incubation or by the number of spawners) so that there is no effect of density, there is no effect on fish production.

Density limitation before the rearing period produces a dome-shaped or asymptotic relation between the number of spawners and the swim-up fry (fry as they emerge from the gravel), while a lack of density-dependent effects during the rearing period produces a linear relation between the number of swim-up fry and the number of smolts (or recruits). Reducing the amount of rearing habitat from level A to level B does not affect the number of smolts or recruits produced in this example because density was restricted to less than "full seeding" (of rearing habitat) before the swim-up stage. When rearing habitat is in short supply, however, the loss of recruits from any given number of spawners is directly proportional to the loss of habitat.

Environmental change may reduce the overall quality of rearing habitat. Survival of juveniles may decline because fish grow slower or avoid predators less effectively in the altered habitat. An overall loss of habitat quality reduces fish abundance, regardless of whether the amount of rearing habitat is limiting.

Density-dependent effects may occur during the juvenile rearing stage even if the actual density bottleneck occurs at an earlier stage. Although density-dependent survival is typified by curvilinear relations and density-independent survival by linear relations, nothing precludes the existence of a curvilinear relation for fry to smolt when the number of fish is limited (by density effects) earlier in life. Because curvilinear relations are expected, the appropriate questions should be, "How much of an effect is there from increased density?" and "Is there sufficient precision in our measurements to detect it?" (rather than "Is there an effect?"). Whereas density limitation during spawning or incubation does not preclude density-dependent effects during the rearing period, testing for density limitation during spawning or incubation cannot be considered a test of whether density-dependent mortality occurs during the freshwater rearing period.

Loss of habitat quality reduces a population so that optimal harvest occurs at reduced harvest rates. Ignoring year-to-year variation in environmental conditions, the equilibrium point for the population is where the replacement line intersects the curve. To achieve maximum sustained yield after the quality of the habitat is reduced, managers must reduce the harvest rate. The new equilibrium is still at maximum sustained yield; however, the actual harvest is now reduced.

GENETIC APPROACHES TO STOCK ASSESSMENT IN ARCTIC ANADROMOUS FISH

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Arctic cisco (*Coregonus autumnalis*) are thought to undergo migrations from their natal streams in the Mackenzie River system to feeding and over-wintering sites along the Beaufort Sea coast in Alaska and the Canadian Yukon and Northwest Territories. Concern over the potential damage to fisheries stocks from the existence of causeways near Prudhoe Bay has led to the present study in which genetic techniques are used in stock assessment. The purpose of the study is to identify genetic markers that can be used in a way analogous to a tag. If such markers exist, fish can be collected at coastal sites, genetically assayed, and identified as to the spawning-river stock to which they belong. Such information can then be used to reconstruct migratory routes used by the various populations. Genetic stock assessment has the potential to allow every fish in the species to be "tagged."

Three genetic techniques were used to assess genetic differentiation within and among populations of Arctic cisco. Fish were collected from five Alaskan and two Canadian coastal sites (ranging from Point Barrow, Alaska, east to Atkinson Point, Northwest Territory) and five rivers tributary to the Mackenzie River (from the Peel River south to the Liard River). Allozyme variation indicates the coastal samples are composed of fish from multiple genetically defined populations. The spawning river samples showed relatively low levels of genetic differentiation, both within and among ostensible stocks. Nuclear DNA content variation indicated some degree of genome size differentiation among stocks. Mitochondrial DNA (mt DNA) analyses showed a fair amount of variation and suggests the possibility of the existence of markers unique to many of the spawning streams. The data reveal some interesting trends. Allozymes and genome sizes suggest the sample of fish from Point Barrow are very different from all other samples. The most divergent spawning population was from the Liard River. The possibility exists that this is not an anadromous population. Both allozyme and mtDNA data suggest that the spectrum of genetic variation sampled from the coastal sites is greater than that of the spawning sites.

In conclusion:

1) mtDNA appears to offer the greatest promise of providing markers unique to specific spawning stocks;
2) Fish from Point Barrow are genetically dissimilar to Mackenzie River Arctic cisco, and their origin is unknown;
3) The presence of alleles unique to Alaskan and Canadian coastal samples indicate that not all spawning populations have been sampled and that spawning sites outside the Mackenzie River system may exist.

DISTRIBUTION, RELATIVE ABUNDANCE AND MOVEMENTS OF FISHES IN ARCTIC NATIONAL WILDLIFE REFUGE COASTAL WATERS, SUMMER 1988

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Fishes inhabiting Beaufort Sea coastal waters within and near the Arctic National Wildlife Refuge, Alaska were sampled at seven fyke net and three gill net stations in three different study areas during the summer 1988 open-water season (approximately mid-July through mid-September). Data were concurrently collected in each study area on water temperature and salinity, current direction and velocity, and wind direction and velocity. Eighteen fish species were collected by fyke net, the six most abundant being Arctic cod (*Boreogadus saida*), Arctic cisco (*Coregonus autumnalis*), fourhorn sculpin (*Myoxocephalus quadricornis*), Arctic char (*Salvelinus alpinus*), ninespine stickleback (*Pungitius pungitius*), and Arctic flounder (*Liopsetta glacialis*). Only Arctic cisco, Arctic char, and least cisco (*Coregonus sardinella*) were collected by gill net.

Species composition and relative abundance were generally consistent with findings of previous studies in Beaufort Sea coastal waters, through capelin (*Mallotus villosus*), which were very abundant in the Camden Bay study area in 1987 were captured in much lower numbers in 1988. Ninespine stickleback were relatively more abundant than reported in prior studies. Arctic cod and least cisco were most abundant in Camden Bay and small (<200 mm) Arctic cisco were most abundant in Pokok Bay. Arctic char, fourhorn sculpin, and Arctic flounder were more abundant in southwestern Kaktovik Lagoon than in the other areas sampled. Large Arctic cisco were least abundant and ninespine stickleback most abundant in Jago Lagoon. Differences in abundance were noted for several species between the two sampling stations in Kaktovik Lagoon. These stations sampled different habitat types.

Gill net sampling in Camden Bay indicated that Arctic cisco and least cisco were more abundant closer to shore than further offshore, although there appeared to be little difference in Arctic char abundance with distance from shore. Gill net data also indicated that Arctic char, Arctic cisco, and least cisco were all more abundant in the upper 2.4 m of the water column than in the deeper waters of Camden Bay.

A total of 5,304 individuals of 10 species were either fin-marked or tagged in the three study areas. Approximately 3% of these marked fish were recaptured. Only 5 of the 134 recaptured fin-marked fish were recaptured in study areas different from where marking occurred. These included an Arctic char that moved from Camden Bay to Kaktovik Lagoon, two Arctic cisco that moved between Camden and Pokok Bays, and two least cisco that moved from Camden and Pokok Bays to Kaktovik and Jago Lagoons, respectively. Seven tagged individuals were recaptured including three fourhorn sculpin and two Arctic flounder recaptured at the same stations where these fish had been tagged. One fourhorn sculpin moved from Jago Lagoon to Kaktovik Lagoon (8 km straightline distance) in 24 days while another fourhorn sculpin moved from the south to the north part of Kaktovik Lagoon (7 km) in 5 days.

GENETIC STOCK IDENTIFICATION OF NORTH SLOPE CHAR

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The U.S. Fish and Wildlife Service began a study under contract with Minerals Management Service on the North Slope of Alaska to attempt genetic stock identification (GSI) of char populations that could be affected by causeway development. Char were collected from North Slope rivers from the Coleville Drainage in the west to the Babbage River Drainage in western Canada. Eighteen variable genetic loci were resolved in these char using protein electrophoresis, resulting in a genetic profile for stocks of char from the North Slope. Samples of char were taken offshore around the Endicott Causeway in June, July, and August, and the genetic makeup of these mixtures was determined by protein electrophoresis. Using a sophisticated computer program developed by National Marine Fisheries Service, the river of origin of fish within these mixtures can be determined. The level of accuracy is very good for some stocks and poor for others. However, the method is very good when a certain stock is present in large numbers. The results indicate that most of the fish are from rivers close to the causeway. There are, however, indications that char from as far away as the Babbage and Firth Rivers in Canada are present in low numbers at certain periods during the summer.

EFFECT OF TEMPERATURE, SALINITY AND PREY ABUNDANCE ON THE GROWTH OF ARCTIC CISCO AND BROAD WHITEFISH FEEDING ON EPIBENTHIC PREY IN *IN SITU* ENCLOSURES

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Juvenile Arctic cisco, *Coregonus autumnalis*, and broad whitefish, *Coregonus nasus*, were raised in 310 m^2 enclosures at two coastal sites near Prudhoe Bay, Alaska. The mesh enclosures permitted ample water and prey circulation while retaining 15 to 45 g, 120 to 180 mm fish. Growth and survival rates varied both between sites and between species. The highest growth rates were measured at the study site adjacent to the Endicott Causeway, where Arctic cisco grew at a rate of 0.63% per day over six weeks. The growth rate for broad whitefish reared in adjacent enclosures was only 0.08% per day. The mean growth rates for Arctic cisco and broad whitefish reared at the Niakuk Islands site were 0.08 and -0.01% per day, respectively. Survival rates for both species were substantially lower at the Niakuk site. Arctic cisco appeared to be six times more "efficient" at consuming the prey items found in the enclosures. The results from the Endicott enclosures suggest that the major determinants of growth for each fish species were water temperature and the biomass of key prey species less than 6 mm in body length. The study has also provided some evidence that the nearshore environments along the lower portion of the Endicott Causeway are suitable habitats for Arctic cisco, and that neither the Endicott or Niakuk site were suitable habitats for broad whitefish.

CAUSEWAYS AND ALTERNATIVES

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The nearshore region of the Beaufort Sea is environmentally sensitive and subject to significant impact by the construction, installation, and operation of pipelines. The development of offshore oil fields, either in nearshore or deepwater regions, will require transportation of crude oil to consumers in the Lower 48. Currently, only one offshore oil field has been developed in the Alaskan Beaufort Sea. For that field, a breached, solid gravel-filled causeway was provided, with the produced fluids, gas lift, water injection, and sales oil pipelines supported on vertical support members above the causeway surface. Causeways, however, are environmentally disruptive and there exist a number of less disruptive, technically feasible, although in most cases more costly, alternatives. Also, there are a number of alternative causeway configurations possible, each with varying degrees of environmental impact.

Within the category of causeways, there are two subcategories, unbreached and breached. An unbreached causeway is generally the lowest-cost but most environmentally disruptive alternative. Within the subcategory of breached causeways, a wide variation is possible with respect to the percent of the length that is breached and the methods for constructing the breaches. In general, the larger the breaches, the less the resulting environmental disturbance. Extending this concept to its limit results in the elevated causeway concept, i.e., pipelines and heavy-duty roadway supported on piles. Variations of this elevated causeway concept consist of reductions in the carrying capacity of the roadway, and ultimately no roadway at all, i.e., the pile-supported pipeline concept.

The common characteristic of all of the above concepts is that the pipelines are supported above the water and ice. Another group of concepts features locating the pipelines below the water and ice, i.e. below the seabed. The pipelines must be located sufficiently far below the seabed to protect them from ice pounding, ice gouging, and strudel scour. To accomplish this, there are three general categories of construction techniques available, and within each category there are a number of variations possible. The summer construction techniques category consists of any of a number of conventional methods of excavating a trench during periods of open water and installing the pipeline in the trench by one of several proven laying or pulling procedures. The winter construction techniques category consists of cutting through the ice, excavating a trench working from the ice, and installing the pipeline in the trench using conventional buried land pipeline construction methods. The third category of subsea pipeline construction includes several variations of the directionally controlled horizontal drilling technique that has been successfully used for a number of years for river crossings.

Two additional concepts feature the elimination of pipelines in the nearshore. Directional drilling from an onshore location may be feasible where the reservoir is not located too far offshore. With this concept, the reservoir fluids reach the surface at an onshore point and no offshore pipeline is required. The second of these concepts consists of loading the produced crude oil into tankers at a deepwater location, without ever taking it ashore.

While all of the above concepts are technically feasible, some require more technical development than others, and thus the reliability of estimates of construction cost and schedule varies among the alternatives. Also, the sensitivity of the construction cost and schedule to variations in the environmental design parameters can differ greatly for the various alternatives. These environmental design parameters include ice conditions, waves, water depth, currents, tides/storm surge, geotechnical conditions, and geologic hazards.

The presently established policy of the U.S. Army Corps of Engineers is that the following alternatives are less environmentally damaging than solid-fill (breached or unbreached) causeways: a) direction drilling, b) subsea pipelines, c) elevated pipelines, and d) elevated causeways. These four alternatives should be viewed as a priority sequencing and must be found to be impracticable before a permit to construct a breached solid-fill causeway will be issued. Unbreached causeways are prohibited.

NEARSHORE ARCTIC STRUCTURE CONCEPTS

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This presentation discusses structures suitable for use in the nearshore arctic as a means of accessing marine locations. A historical review of significant and relevant Alaskan structures will be presented followed by a discussion of critical arctic nearshore design conditions.

Suggested components of various structures will be reviewed along with potential construction methods.

SUB-SEA PIPELINES

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During the recent two decades a considerable amount of money has been expended exploring for hydrocarbons in the Canadian and Alaskan Arctic. The author has been working on projects since 1972 for Polar Gas, Gulf, Pan Arctic, and others for the development of pipeline transportation systems for bringing gas and oil out of the Arctic to the lower Canadian and U.S. markets.

The author will describe the first, and only, pipeline installation in the high Arctic for Pan Arctic Oil, Ltd. to connect the Drake 76 subsea well to Melville Island. This consisted of dual six-inch insulated lines plus four one-inch hydraulic control, one two-inch annulus access, and power and instrumentation lines in a single eighteen-inch casing. The lines were installed under three meters of ice and the first diverless connection was successfully completed. The shore approach was plowed and a freeze back system to grow a permafrost bulb around the pipe was developed.

There were four new and innovative techniques developed which included: the first pipeline installed under ice; the first diverless connection; the first use of a plow for the Arctic shore approach; and the first use of artificial permafrost to protect the pipeline from raft ice.

In later developments, R. J. Brown & Associates has prepared methods and procedures for the Pan Arctic Cisco Field transportation system covering the innovative methods for installation of the pipelines at remote distances from the initial staging areas.

HEALD POINT EXTENDED REACH WELLS

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1) High-angle wells greater than 60 degrees are difficult to drill, log, and complete.

2) High-angle and high-departure wells have been proven by experience to increase cost and risk of operations.

3) Fault zone crossing reduces stratigraphic well bore control while drilling. There may be no meaningful formation indicators until a fault zone is crossed, resulting in plug backs - redrills.

4) High-angle and high-departure wells sometimes require the use of oil-base mud to reduce torque and drag.

5) We have done some wells on the North Slope of Alaska with displacement of 10,000 to 10,600 ft. The average displacement for direction wells is around 4,000 ft.

6) Maximum displacement was 12,569 ft in the Cook Inlet in 1975 by Marathon.

7) ARCO has displaced some wells up to 12,000 ft plus.

8) The longest displaced well to date was drilled off the coast of Australia's Bass Strait by ESSO with a displacement of 14,800 ft. Lessons learned from this well were not forgotten. The hole was lost, and had to be redrilled using oil-base mud. The decision was made to employ aluminum drill pipe.

9) The industry's ability to drill 12,000 to 15,000 ft departures, with such limited experience with high-departure wells, would be very costly and undoubtedly would add significant risk to undeveloped reservoirs.

WORKSHOP SUMMARIES

PHYSICAL OCEANOGRAPHY

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INTRODUCTION

The following is a summary of findings of the Physical Oceanography section of the synthesis meeting on the Environmental Effects of Causeways in the Nearshore Beaufort Sea, Alaska (17-20 April 1989). This summary is a preliminary draft and may require modification after the lead author has completed a detailed review of all technical reports, taped proceedings, and other materials submitted to the workshop for consideration.

GENERAL PROCESSES

The basic physical properties of the Beaufort Shelf region during the ice-free summer are well characterized for the period since causeways were constructed. Data that characterize the general properties in pre-causeway years do exist, but are temporally and spatially limited. The basic physical properties for which substantial multi-year data sets exist include salinity, temperature, current speed and direction, and meteorological parameters. Although the physical data sets extend throughout the open water period, only limited data exist for the period of ice cover. The nearshore zone of the Beaufort Sea is covered in ice for about nine months of the year. Ice thickness is generally about 2 m and is sufficient for the entire water column to be frozen throughout much of the inner portion of the nearshore zone. The 2 m isobath generally follows the shoreline configuration about 2 to 4 km from the shore, except in Prudhoe Bay, where the shallow area is wider. The environment appears to be less important to biological processes during the ice-covered period. However, if this assessment changes, additional studies would be needed during the ice-covered period.

From the available data, a good generalized description of the dynamics of the inner shelf of the Beaufort Sea during ice-free conditions has been attained. The principal physical processes controlling water characteristics, distribution, and movements include surface wind stress, horizontal and vertical density stratifications due to freshwater input, bottom boundary friction, and the relatively large Coriolis force at this latitude. There is a seasonal sequence of predominant conditions. In the early season, the nearshore zone is dominated by freshwater. A progression period follows when freshwater overlies marine water and a sharp pycnocline exists. Subsequently, there is a period of weakening stratification and lowered mean salinity, until the onset of fall cooling.

During the entire open water season, the system is driven by wind stress. Water movements are predominantly bathymetrically steered and follow local bottom contours. Three basic conditions occur: easterly wind, westerly wind, and transition periods. Under easterly wind conditions, dominant flow is in a westward direction and upwelling can occur. Under westerly winds, dominant flow is to the east, and the water column becomes vertically homogeneous. Considerable interannual and seasonal variability exists. This variability depends on the relative frequency and duration of the wind events. The nearshore surface water flow responds quickly to changes in wind direction, flow reversal being effected within several hours of a change from sustained easterly (or westerly) winds to sustained westerly (or easterly) winds. As a result, in some years when winds are consistently from one or another direction, or reverse infrequently, transitional conditions exist for only a limited percentage of the open water period. However, in other years when wind reversals are frequent, transitional periods occur more frequently.

The existing data are adequate to describe the occurrence and general features of the effects of the existing causeways on water movements and the distribution of water properties.

SITE-SPECIFIC EFFECTS

At the Endicott Causeway, under certain conditions, the causeway deflects coastal water and some of the longshore flow of freshwater offshore. In addition, under certain east wind conditions, an anomalous area of higher-salinity water is found in the lee of the causeway. The Sagavanirktok freshwater inflow to the region is essentially bisected by the causeway. Therefore, any blockage or offshore deflection by the causeway of the longshore flow of low salinity water would most likely not result in a major discontinuity in salinity or temperature between the two sides of the causeway.

West Dock appears to provide a more significant impediment to the longshore flow and the continuity of the lower-salinity zone. This zone is typically present along the shore face out to distances of up to several kilometers. Under east wind conditions, West Dock Causeway appears to promote increased salinities throughout a limited region at the eastern end of Simpson Lagoon (Stump Island Lagoon).

The general meteorological and oceanographic conditions leading to the establishment of the observed effects of the two causeways and the approximate scale of these effects are understood. However, the details of the frequency of occurrence, persistence, and geographical extent of the effects have not been fully characterized. Using existing datasets, together with appropriate models and limited additional field data, these could be more fully specified.

There is only very limited observational evidence concerning the possible effects of the two existing causeways on sediment erosion, transport, and deposition processes. The existing evidence suggests that the causeways do cause changes in the sedimentary regime that may be attributable to one or more of the following: a) alterations of the hydraulic flow regime, b) alterations of the propagation patterns of wind waves, and c) introduction of suspended sediments due to the causeway gravel. However, the existing limited evidence suggests that causeway-induced changes in sediment erosion, transport, and deposition processes are geographically limited. In addition, in the poor dataset that exists, there is no evidence that the physical characteristics of bottom sediments or deposition rates have been altered except in small areas immediately adjacent to and under the causeway.

There appears to have been little or no study of the possible effects of the causeways on the concentrations, distribution, and composition of suspended particles. These factors are likely to be ecologically important to the growth of phytoplankton and their availability as food for animals.

It has been hypothesized that the presence of causeways may: a) retard the melting of nearshore ice in spring by blocking the normal longshore spread of overflooding freshwater, b) cause ice thickness to be increased in some regions, again retarding melting, c) prevent the break-up and transport of ice from the nearshore region by sheltering the ice against wind and wave action and by physically blocking its motion, and d) alter, and perhaps accelerate, freeze-up in the fall. The observational evidence concerning these processes is very poor because pre-causeway observations are lacking and year-to-year variability in the pattern and timing of melting and freeze-up is large. The available data are inadequate to prove or disprove that these effects exist, or to provide adequate estimates of their maximum possible scope and extent.

The physical effects of the Endicott and West Dock Causeways can be quantified, and the general processes involved can lend insight to the elucidation of the specific physical effects of any proposed new causeways. However, each proposed causeway will have its own unique effects on the physical environment, depending on its location and design. The physical effects of any proposed causeway can be predicted with a high degree of probability if appropriate site-specific background data are collected and comprehensive engineering studies performed.

At present, the specific physical characteristics of habitat that are important to the biological populations of the Beaufort Sea are not well defined. Consequently, it is not possible to evaluate the possible effects of the observed causeway-induced changes in the physical environment on these biological populations. When the physical habitat requirements of Beaufort species are better defined, existing physical data can be incorporated in models of appropriate types and dimensions to evaluate the biological effects of causeways. In particular, information is needed on tolerance and preferred habitat ranges of temperature and salinity, and on the geographical location and physical characteristics of any critical habitat.

EVALUATION OF THE DATABASE

It is apparent that substantial datasets that are relevant to the assessment of the effects of causeways in the Beaufort Sea were not available to participants in this synthesis effort. It is important that all relevant data be publicly available if a reliable, comprehensive, scientific synthesis is to be performed that can have maximum utility in applicable decision-making processes.

The alternate hypotheses posed for this synthesis effort that causeways do or do not "cause *significant adverse* effects to the distribution and dynamics of oceanographic properties nearshore" are untestable at present. It can be concluded with great certainty that causeways *do* cause *statistically significant* effects to the distribution and dynamics of oceanographic properties nearshore. However, in the absence of a dramatically improved understanding of the relationships between physical characteristics of the Beaufort nearshore environment and ecological processes, it cannot be determined whether the observed effects are adverse and/or ecologically significant.

Certain studies of the physical environment are needed to improve our understanding of the physical effects of causeways in the Beaufort Sea. These include:

- A comprehensive synthesis of existing data.
- Development of diagnostic models to assess the spatial and temporal variation of physical parameters on scales that are relevant to important biological processes.
- More detailed studies of the effects of causeways on the supply, distribution, and transportation of sediments and suspended sediment.
- Additional studies and analysis of existing data to evaluate the possible effects of causeways on the timing and progression of the thawing of ice in spring and freeze-up in fall.
- Development of models or other detailed evaluation techniques to assess the effects on the physical environment of variations in the number, size, configuration, and location of causeway breaches.
- Fundamental studies of causeway design and their effects on the physical environment.
- Continuation of a limited physical measurement program to monitor the effects of interannual variability on the distribution of physical properties and the effects of causeways on these natural distributions. A limited program is also necessary for future model verification.
- Extensive continuing efforts to communicate information and ideas among the various disciplinary groups studying aspects of causeway-related problems in the Beaufort Sea.

HABITAT

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INTRODUCTION

Many of you have been wondering what was going to be written by the outside Lead Authors. Perhaps the ones who wondered the most were those individuals who were designated Lead Authors. Unlike many of the other outside guests, I was not given a financial incentive to come to the conference. I was lured to the conference with promises from friends of an opportunity to see Alaska and an opportunity to learn something about a system with which I have no experience. Based on my visit and my opportunity to see Alaska, I can tell you the Clarion Hotel rooms are as good or better than others I have stayed in, and that the Anchorage airport looks pretty much like many of the other airports across the nation. I want to assure those friends that suggested my name as a Lead Author that I am going to get even. I apologize for any inconvenience my naivete may have caused the experts and the Co-chairman who sought to educate me over the period of the conference. They have responded to my stupidity without the pained looks they reserve for one another when they disagree.

I have spent almost 20 years working as a field biologist. Therefore, I often find myself in the position of the biologists whose data is being evaluated for adequacy. Numerous times I have been forced to try to explain why inclement weather, faulty equipment, or unresponsive bureaucracies precluded me from taking a particular piece of data. Data which, now three years later and viewed with the perspective of 20/20 hindsight, is critical to drawing a conclusion.

This conference is my first experience as a Lead Author, and my first attempt at trying to get a group of biologists to make a decision. After this experience, I have a lot more sympathy for the engineers and oceanographers who just want us (biologists) to tell them what we know and what we want. However, it was reassuring for me to see the engineers shuffle and squirm, just like biologists, when they were asked specific questions during the earlier conference session on causeway alternatives.

The Lead Authors were brought in as neutral, unbiased observers who were ostensibly to focus the group and to synthesize what the group determined. We were not given sufficient data to synthesize nor do I, in retrospect, think it is appropriate for biologically naive (in the sense of Arctic systems) individuals to synthesize data which some of you have spent a whole career coming to understand.

Therefore, I am not going to do much synthesis, but I am going to offer some observations. Some of what I have written may be inappropriate but I hope some of it may be useful. I hope that the readers will take the comments in the spirit in which they are given. They are not intended as a condemnation of any group or a vindication of any group. They are simply my observations after participation in the conference.

The problem that we are dealing with here is deceptively simple. Does the placement of causeways affect fish populations in the coastal zone of the Beaufort Sea? As several people have said, the answer is yes. However, the logical follow-up question – Does it have significant impact on the fish populations? – is much more complex. We have spent the last four days debating that complexity.

There seems to be general agreement over why the fishes in question use habitat in the nearshore Beaufort Sea. For example, Arctic cisco appear to spawn only in the Mackenzie River. After hatching and spending between 0 to 2 years in freshwater, the fish may be passively carried into the nearshore waters by flowing water from ice melt or enter these waters by active movement. Ice melt causes these nearshore waters to be relatively warm (5 to 10°C) and fresh (10 to 25 ppt). Once in the nearshore waters, the fish migrate west and perhaps east along a transportation/feeding corridor formed by freshwater inflow. As freeze-up nears, they seek out refugial areas, which are generally deep brackish pools in the deltas of North Slope rivers. The following spring, the fish again enter the nearshore corridor of relatively warm, brackish waters to forage. Each age class seems to have slightly different patterns or timing of movements into, through, or out of these foraging areas. Upon reaching the reproductive age of 6 to 8 years, the fish return to the MacKenzie River to spawn. They may spawn only every other year after reaching adulthood.

The other species of whitefish (least cisco, broad whitefish) appear to differ somewhat from Arctic cisco in the timing of their movements and the specific habitats used. However, all the species seem to use the relatively warm, brackish water corridor for foraging and for a transportation route between widely separated spawning and wintering areas. Unlike the Arctic cisco, these species may spawn in other areas in addition to the Mackenzie River.

Arctic char also use this warm, brackish water corridor for foraging and for movement between foraging areas and wintering/spawning areas. This species, however, spends much less time in brackish water (1.5 to 2.5 months per summer) than do the whitefish. Arctic char tend to winter and spawn in inland seeps and springs in rivers where some water remains under the ice during winter.

Beyond this general agreement over the way these species use the habitat, there appears to be little information or agreement on the specifics of habitat use or environmental tolerance. Of particular importance is definition of the optimal habitats of the fish species. Information on optimal habitat is much more difficult to obtain than that on tolerances, but is much more useful in assessing impact. Few conclusions were presented in the conference on what constitutes optimal habitats and there appears to be little consensus or data on tolerances. The absence of this information makes it very difficult to relate physical changes associated with causeway construction to changes in fish populations. Inability to relate these factors makes assessing impact almost impossible.

Several times over the four days of the conference, we reminded one another that our objective was to evaluate the adequacy of the data to ascertain the impact of the causeways on fish populations. I do not disagree that that was our charge in this conference, but I would like to emphasize some things that you all recognize. First, the proper scientific way to conduct an experiment, and to apply an experimental treatment, is to study the pretreatment conditions until one is sure he/she understands what is happening. I do not know how long that would take in the Beaufort Sea; but I do know that the greater the variability, the more information that is required to reach understanding. Once we understand the pre-project conditions we can apply the experimental treatment – in this case, the placement of causeways. If we understand the baseline and observe the changes after application of our experimental treatment, then we can determine impact. I recognize that this approach is not the one that we usually use. Generally we are called in after the treatment is applied and asked to assess impact. Under these conditions, we must infer where the baseline was prior to the treatment, and also infer where and how that baseline has changed. I would suggest that any future experimental treatment be preceded by sufficient data collection to understand the baseline.

Another danger of focusing only on the causeways is that a lot of the factors that drive the system around the causeways originate many miles away. If you do not understand the entire system, you increase the probabilities of coming to erroneous conclusions. This danger should be particularly evident if we consider the Arctic cisco. This species originates in the MacKenzie River and ultimately returns there to spawn. However, in between hatching and spawning, the species may move over vast areas of the nearshore Beaufort Sea and winter in areas far removed from its point of origin.

Another important consideration is the context in which we decide what questions we need to answer, and what data we need to collect to obtain those answers. Let me illustrate how much the perspective with which you view a question affects the outcome, with an example out of my past experience. About 10 years ago, I was asked to evaluate the effects of logging on fish populations. It did not make much difference to the agency asking me to do the study that logging had started in the drainage 50 years earlier than the initiation of the study. The system itself had some similarities to the ones on the Beaufort Sea. In our study area, fish became isolated in pools, during summer low flows. If they chose well they survived; if they chose poorly they died. This situation is very similar to the situation you find with wintering habitat in the Beaufort Sea.

The data I collected showed some subtle impacts of logging, but logging alone did not seem to determine what happened to the fish populations. I might have forgotten the data, except that I was asked: What limits populations in this drainage? I had never been asked, nor (I am embarrassed to admit), had I asked myself that obvious question. I responded, with one of those random neuron firings that sometimes pass for brilliance, that it must have something to do with reduced summer flow. Then I realized that we had 5 to 8 years of quantitative habitat availability data and about the same amount of habitat utilization data. We had already tested the hypothesis that there was a relationship between fish numbers and habitat availability. This test showed that population levels were related to available habitat levels only during summer low flows. Logging had affected the fish populations, but it was of limited importance in comparison to the ecological bottleneck of summer low flows.

I would like to suggest that your programs might benefit from renewed consideration of what actually limits the populations of the fish in question. There has been some generation of hypotheses as to what constitutes limiting factors for the species of concern in a workshop entitled "Fisheries Oceanography A Comprehensive Formulation of Technical Objectives for Offshore Applications" (MMS 1989). However, there seems to have been little application of that effort to the question that we are discussing today.

The easiest hypothesis is that fish (you fill in the species or age class) are limited by access to winter refugia. In our considerations earlier in the conference, we bypassed consideration of winter refugia because we had no information and because some people thought that it was not limiting. I would ask if you have enough data on refugial areas to resolve whether they are or are not limiting: 1) Can you identify all refugial areas? 2) Can you account for as many fish in refugial areas as are present in the summer? 3) Do you know of refugial areas that do not contain fish? 4) Can you determine the relationship between refugial quality and environmental severity? 5) Can you relate refugial characteristics to carrying capacity? 6) Have you broken down the data and compared populations following hard winters with those following normal winters? If population parameters are not related to winter severity, you have some indication that winter is not limiting. The questions posed are hard questions to answer, but if winter refugia limit populations, it may make what happens in the summer habitat much less important. If winter refugia limit populations, causeways could impact fish populations by precluding fish from entering a refuge, or by shunting more fish that can be supported over winter into a refuge.

The second possibility is that fish are limited by summer habitat. As I picture the situation described to me during the conference, I envision a constantly changing mosaic of salinity and temperature patches driven by wind and water inflow and bathymetric conditions. Superimposed upon that physical mosaic is another composed of food patches. Superimposed on the physical and food mosaics are the fish. The fish are trying to balance preferences for certain physical conditions with their need for food. In the broadest sense, what was optimal habitat a few weeks, months, hours or minutes ago can cease to provide habitat because of changes in wind and water inflow. Given that constraint, it becomes particularly important to be able to quantitatively define what constitutes optimal habitat and tolerance limits for all of the species and life stages. I would ask: Do you have the data to show temperature and salinity preferences and tolerance limits of each species and life stage? Do you have data to show what is the optimal/minimal condition needed to survive the winter? Do you have data evaluating foraging efficiency as a function of prey density?

These and other related questions are approachable with a carefully designed research program, including laboratory studies to formulate and test hypotheses coupled with carefully designed field studies to validate and apply the laboratory studies. I saw only a small amount of fragmentary data of this type presented at this conference.

The third possibility, and the one that most of the biologists I have talked to ascribe to, is that during some severe years winter habitat might be limiting, and in other years the summer combination of physical and food mosaic might be limiting. If this is in fact the case, then all of the questions posed earlier must be understood and systems and limits defined. Although this task may appear overwhelming, you already know some answers. I heard you talk of poor recruitment years and good recruitment years and relate recruitment to wind direction. I suspect that that data tells you what is critical in determining survival of the recruitment size fish. I also heard some discussion in the conference of good growth years and poor growth years. Relationships of this type in the data should be further explored and needed data sets identified. I would suggest that posing the questions to be asked in the context of limiting factors, and evaluating the data with those questions in mind, might reveal a great deal of useful information on what controls fish populations in the nearshore waters of the Beaufort Sea.

Looking at the existing efforts as an outsider, I was struck by the fact that the selection of what studies are done and how questions are posed are determined by needs of impact assessment rather than by a step-by-step analysis of what data we need to understand the overall ecology. I would suggest that that framework needs to become more balanced.

Now I would like to move on to what we actually did in the habitat group at this workshop. First, as I said earlier, the exercise was extremely frustrating because we were given no clear direction on what it was we were trying to obtain, other than to reach consensus. Second, we were told our function was to evaluate the adequacy of the data; but we were provided with only a smattering of the available data. Therefore, we spent a lot of time trying to define a direction.

Finally, in our group, we agreed that one critical need was to define the limits or habitat tolerance of each species and age group of fish relative to the physical and biological parameters. We decided to assess the amount of information on tolerance limits, because the consensus of the group was that there was not sufficient information to define optimal habitats for any species or life stage. We reasoned that, unless we could define the limits, there was little hope that we could ever define optimal habitats and impacts. I must emphasize that although the following discussion of tolerance limits is important, definition of tolerance limits cannot substitute for the definition of optimal habitats; significant impacts can result from suboptimal conditions even though tolerance limits are never exceeded.

As we began to discuss putting down numbers to define tolerance limits, it soon became apparent that there was no unanimity of opinion over what these limits were. In addition, there was considerable doubt expressed as to whether the data were adequate to define such limits. Further, there was some difference of opinion over what environmental factors should be considered and what species should be included.

In the afternoon we decided that the species to be considered should be the Arctic cisco, broad whitefish, least cisco, and Arctic char. We also included the cod and the four horned sculpin because some individuals believed that their habitat might be enhanced by the causeway, and because there were available data on these species. We next attempted to determine which habitat factors should be considered in defining fish habitat requirements. There was general agreement that temperature, salinity, and food were important; but there was also some support for inclusion of bathymetry, substrate, mixing and turbidity. After some discussion, these factors were also included for further consideration. From these lists of species and habitat factors, we created the matrix shown in Table 1.

Next, we attempted to go through the matrix and put down limits for each of the factors for each of the species. It soon became apparent that either there was no knowledge of where the limits should be,

Table 1. Matrix showing availability of data (sufficient ++, present +, or partial p) for defining habitat tolerances of Arctic cisco, broad whitefish, least cisco, Arctic char, Arctic cod, and Fourhorn Sculpin.

Habitat Factor	Arctic Cisco	Broad Whitefish	Least Cisco	Arctic Char	Arctic Cod	Fourhorn Sculpin
Turbidity	+	+	+		+	+
Mixing	+	+	+	+	+	+
Substrate	p	p	p	p	p	p
Temperature	++	++	++	++	++	++
Salinity	++	++	++	++	++	++
Food Availability	+	+	+	+	+	+
Stomach Contents	+	+	+	+	+	+
Bathymetry	++	++	++	++	++	++

or if knowledge existed, there was a reluctance to put down limits; or there was a lack of agreement on where those limits should be. After struggling with the problem, it was decided to proceed through our matrix and place a single plus beside the parameters for which we had data. I must add that this plus does not indicate that data were collected for the purpose of defining habitat tolerances, but only that data were present that might be used for that purpose. Next we asked the question: Is the data set sufficient to define some aspects of the habitat quantitatively for each species and life stage? After some soul searching, we decided that there were sufficient data on temperature, salinity, and bathymetric condition to define fish tolerance limits. That consensus is indicated in Table 1 by a second set of "pluses". Included in that consensus is a caution that most of the data were obtained from fyke nets and other passive fixed-location sampling devices; and that in a dynamic system such as the Beaufort Sea, this type of data has limitations.

The next consensus really took the application of some leverage. I asked the question: If the biologists or oceanographers were placed in a closed neutral room, devoid of their administrators and employers, could they come up with numbers in the place of the pluses? Somewhat reluctantly they agreed that they could. That point becomes important, so keep it in mind. In the course of the day, we briefly discussed two or three other questions. The first was: Is the data set sufficient to define limiting factors for each of the species and life stages? We did not really deal with this question but moved on to discuss summer habitat because there were some individuals who thought causeways would not affect winter habitat, and because there was much more data on summer habitat. I have already indicated I think that the question "What constitutes limiting factors?" is a critical one to consider. Another question: "Is the data sufficient to determine what changes had occurred in the habitat?" The answer was a qualified yes. The qualification was due to the absence of some baseline data. The final question dealt with whether the data set was sufficient to determine the impact of these habitat changes (i.e., construction of causeways) on fish population. The answer to this question was "it was impossible to determine until the dataset relating temperature, salinity, and bathymetric conditions to tolerance limits had been assembled.

Finally, this brings me to two specific recommendations and a concluding observation.

1) The current set of data obtained from monitoring needs to be synthesized; a starting point is provided by Biological Papers of the University of Alaska #24 (Norton 1989). Such a synthesis has the potential to be used as a guide for biologists/oceanographers to set up experiments that will fill particular data gaps and resolve differences of interpretation.

To accomplish these objectives a meeting including only the principal biologists and oceanographers who collected the data in the Beaufort Sea and environs should be convened in a neutral setting without administrators or employers.

During this meeting, the participants should provide the quantitative data for the matrix (Table 1) we have developed. More importantly, they should synthesize the data and determine what information they need to resolve differences in interpretation and to define optimal habitats. The outcome of this meeting, I would hope, would be not only a consensus of what we understand, but also a list of projects that really need to be done to resolve remaining differences. In addition, the results of the meeting should provide some consensus of how the needed data should be obtained and analyzed.

2) The monitoring program should be reevaluated. The monitoring results have shown that the nearshore fisheries habitat in the Arctic is a patchy, constantly changing mosaic of food, environmental factors and fish. With that understanding, I believe monitoring programs can be redesigned to make it more useful in characterizing the environment, the food and the fish. I would suggest a second meeting of biologist and oceanographers to accomplish this reevaluation.

Throughout this conference there were hints that additional data sets and interpretations were not being presented to the outside reviewers. Much of the controversy surrounding this conference seems to have originated when legitimate differences in the biological interpretations of these data sets became institutionalized as "positions" by one or more of the interested parties. The interpretations in question have not been finalized and therefore the data have not been released. Although there may be some explanation for the failure to finalize these reports, their unavailability to the reviewers gives the perception of suppression of information. Resolution of the differences of interpretation may not be possible, but the release of those documents is needed immediately. Release of the reports, with an appendix outlining areas with differing interpretations, might remove some of the objections to releasing the data.

Once all data are readily available for evaluation, and differences in interpretation have been outlined in writing, the synthesis workshop that I have suggested should be convened.

There was considerable pessimism expressed at the conference about the probability of the differing interpretations being resolved by the proponents of the opposing viewpoints. I have great faith that these biologists/oceanographers are scientists first, and that, operating in an apolitical scientific framework, they can resolve differences in interpretation or at least identify the data that are necessary to resolve differences. However, in the event that those differences cannot be resolved during the proposed workshop, I would suggest that the results of the analysis obtained be provided to a neutral scientific board of experts. After reviewing the data, these experts could either operate as an advisory group whose recommendations would have to be considered or as an arbitration board whose decisions were binding upon all parties.

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MOVEMENTS AND MIGRATIONS

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INTRODUCTION

A major biological concern regarding the construction of gravel-filled causeways in the Beaufort Sea is whether these structures interfere with the movements and migrations of anadromous fishes which utilize the nearshore zone. This concern stems from the fact that these causeways cut across much of the narrow band of brackish water which lies nearshore along the coast. The shallow, brackish water zone develops during the brief Arctic summer as a result of snow melt and storm runoff which is discharged into the sea by streams and rivers. This zone is used as a migratory corridor and/or primary feeding habitat for several species of anadromous fishes living in the Beaufort Sea.

Because of this concern, numerous studies have been conducted in the Beaufort Sea since the mid-1970s to investigate the effects of the causeways on fish behavior and ecology and on the general and site-specific oceanography of the area. The objective of the Movements and Migrations Workshop was to summarize and evaluate the nature of existing data on the effects of Beaufort Sea causeways on fish movements and migrations and to recommend areas where further research effort should be directed. In particular, it addressed the following specific alternatives:

- The presence of causeways does not (or will not) significantly affect the life cycle of anadromous fish populations.
- The presence of causeways does (or will) significantly affect the life cycle of anadromous fish populations.

Definitions

Members of the workshop first agreed upon working definitions for several terms used to describe the movements and populations of fishes. These were the following:

Migration A regular or periodic movement between two locations which occurs on a seasonal or longer time-scale. It may be active or passive but it is generally thought to be the result of a genetic program.

Dispersal Movement from a place of birth to a (different) breeding location.

Movements Periodic or aperiodic, directed or undirected activities which occur on a shorter timescale than seasonal (e.g., daily) . They may result as a response to local environmental conditions.

Stock (Genetic) A genetically differentiated population in which most individuals breed amongst themselves.

Population (Local) A set of individuals captured at a given location, but which may represent one or more stocks.

Species A set of all individuals which can potentially interbreed successfully.

General Migratory Patterns

By definition, anadromous fishes spawn in freshwater but spend much of their lives in marine waters. Among Beaufort Sea species, this pattern generally includes the downstream dispersion of fry during breakup, feeding in marine or brackish waters during the summer, and the return to overwintering areas (brackish or freshwater pools beneath the ice) in river deltas or in upstream segments of channels. After several years of seasonal migrations between feeding and overwintering areas, mature fish migrate upstream to spawn. Most Beaufort Sea species are capable of returning to the sea after spawning and of spawning more than once in a lifetime.

KEY SPECIES

The species chosen for discussion by conference organizers were Arctic char (*Salvelinus alpinus*), Arctic cisco (*Coregonus autumnalis*), broad whitefish (*Coregonus nasus*), least cisco (*Coregonus sardinella*), Arctic cod (*Boreogadus saida*), and fourhorn sculpin (*Myoxocephalus quadricornis*). It should be noted that fish that have been called Arctic char in this region may actually be, in part or in entirety, Dolly Varden (*Salvelinus malma*). The workshop members also included Bering cisco (*Coregonus laurettae*) among the species to be considered because it has been identified genetically in "Arctic cisco" populations at Point Barrow.

Although Arctic cod and fourhorn sculpin move in and out of estuaries, neither species is anadromous. Because of the nature of their habitat (oceanic for Arctic cod and estuarine-sublittoral for fourhorn sculpin), it was not felt that movements of these species were likely to be significantly affected by causeways. Arctic char was also eliminated on the basis of its hardiness and ability to swim into waters offshore of the causeways. Of the remaining species, Arctic cisco was considered to be most likely to be significantly affected by causeway construction, followed by least cisco and broad whitefish.

Arctic cisco spawns in tributaries of the Mackenzie River. Newly hatched fry are carried downstream and then along the brackish coastal band to the Colville River or farther west during their first summer. The brackish, ice-free coastal zone west of the Mackenzie Delta may exist for as little as 2.5 months during the year. Young Arctic cisco are known to overwinter in the Colville River delta and to a lesser extent in the Sagavanirktok River delta. After about six years of seasonal migrations between feeding and overwintering sites in this area, mature adults migrate back to and up the Mackenzie River to spawn.

The key features of the life cycle of this species which may be significantly affected by causeways are the initial dispersion of Age-0 fish to areas west of the causeways and the return of mature fish to spawning sites. Causeways could delay coastwise movements so that fish cannot reach suitable overwintering sites in deltas before the formation of shore-fast ice. Thus, it is of great interest whether overwintering sites in the Colville Delta are crucial to the survival of young fish from the Mackenzie River in general (or of young fish from specific stocks in the Mackenzie River) and whether the causeways are a significant barrier to their migration to and from the Mackenzie River. Because Arctic cisco spawn in Canada and spend much of their time as juveniles along the Alaskan coast, the international consequences of disruption of their migration must be kept in mind.

Least cisco and broad whitefish spawn in local streams and rivers and make less extensive coastwise migrations. Least cisco are generally most abundant west of Prudhoe Bay, but do migrate along the coast to the Prudhoe Bay area seasonally. Causeways could interfere with their ability to return to overwintering sites in the Colville River delta. Broad whitefish are relatively intolerant of saline conditions and tend to be restricted to low-salinity waters in and just offshore river deltas. Because they migrate less extensively along the coast, causeways are less likely to interfere with their migration to overwintering sites; however, if trapped in high-salinity waters to one side of a causeway, they could be adversely affected.

KEY ISSUES

Migrations

Workshop members agreed that the major issues regarding the effects of causeways on anadromous fish migration in the Beaufort Sea involve Arctic cisco. These include the following:

1. What are the characteristics of the migratory corridor (primarily of Age-0 fish) from the Mackenzie River to the Colville River? What is its width, distribution in time, and velocity?
2. What are the characteristics of the migration of the Age-0 cohort as it moves from the Mackenzie River to the west-central Beaufort Sea? Does it move as a front or does it spread out over the entire coastal area? To what degree are these fish carried passively to the west and to what degree do they actively migrate?
3. What is the genetic composition of the population of Arctic cisco found near and west of Prudhoe Bay? Is it a single stock or a mixture of stocks? Is the composition the same from year-to-year or does it vary? What proportion of the fry produced by the entire Mackenzie River population (or of individual spawning stocks in the river) occur in the west-central Beaufort Sea? What proportion of specific spawning stocks in the Mackenzie River consist of Beaufort Sea fish?
4. How crucial are the overwintering sites in the Colville and Sagavanirktok River deltas to the survival of Beaufort Sea Arctic cisco? Are there other important overwintering sites between the Mackenzie River and Sagavanirktok River, and if so, how much habitat is available? How large is the overwintering habitat in the Mackenzie River?

Movements

The major issues regarding the effects of causeways on fish movements in the Beaufort Sea involve Arctic cisco, least cisco, and broad whitefish. These include the following:

1. How well known is the physical oceanography in the vicinity of causeways? How do the causeways affect the temperature, salinity, and current regimes?
2. How well known are the local movements of fishes in the area? How do they respond to the causeways? What environmental cues are important in determining their movements?
3. What are the impacts on the bioenergetics of fishes trapped in suboptimal (e.g. saline) waters which sometimes occur near causeways?
4. Are there sufficient data to forecast the effects of future causeway construction on fish movements?

EVALUATION OF EXISTING INFORMATION

The information relevant to these issues was evaluated with regard to its availability, quality, and utility.

1. Characteristics of the Eastern Beaufort Sea Migratory Corridor

The physical processes and mechanisms involved in the transport of water and fish from the Mackenzie River to the west are generally well understood. The quality and quantity of data collected from the nearshore area (particularly near Prudhoe Bay) are adequate, but few studies have been conducted offshore near the outer edge of the migratory corridor or along the eastern portion of the corridor near the Mackenzie River. Syntheses of existing oceanographic data from the area would be useful, particularly if these provided a better description of the migratory corridor between the Mackenzie and Sagavanirktok Rivers.

2. Characteristics of the Age-0 Migration of Arctic Cisco

Biological information on Arctic cisco during their migration through the eastern Beaufort Sea corridor is adequate to describe certain aspects of the migration. These include rate of movement, relative migration speeds of fish of different sizes, timing of the migration past intermediate points, and the successful passage to the west side of the causeways. However, the data on the offshore distribution of young-of-the-year Arctic cisco in this corridor is less well known. In addition, the proportion of the population that remains along the way during the migration is also not well known. The relationship between the physical and biological aspects of the passive migration (e.g., the importance of wind patterns) has been established; however, the environmental cues and tolerances which affect active migration need to be determined.

3. Genetic composition of Beaufort Sea Populations of Arctic Cisco

The methods which are presently being used to identify genetic stocks of Arctic cisco in the Beaufort Sea and Mackenzie River are considered to be appropriate. However, the data are incomplete and additional descriptions of Mackenzie River spawning stocks and the genetic composition of Beaufort Sea populations are needed. In addition, the abundance and distribution of the various stocks are largely unknown. Hence, the proportion of the Mackenzie population (or of specific spawning stocks from that river) which move to the Beaufort Sea cannot be determined at present.

4. Overwintering Sites

The importance of the Colville and Sagavanirktok River deltas as overwintering areas for Arctic cisco is well established. However, data on the availability, suitability, and size of overwintering sites east of the Sagavanirktok River are generally inadequate. In addition, the amount of overwintering habitat in the Mackenzie River needs to be determined and compared to those to the west.

Movement Issues

1. Physical Oceanography in the Vicinity of Causeways

The local physical oceanography near the causeways is fairly well understood with regard to its usefulness for studying fish movements.

2. Local Movements of Fishes Near the Causeways

The local movement pattern of the various anadromous species near the causeways is fairly well known. There is also a general understanding of the environmental cues which affect local movements of the fishes. However, there is insufficient specific information on the environmental preferences of the species which may direct their movements. Once this information is obtained, the movements can be modeled and compared with patterns observed in the field.

3. Bioenergetics of Fish in Suboptimal Waters

Additional information is needed on the bioenergetic adjustments made by fish found in suboptimal (e.g., saline) waters near the causeways, particularly with regard to how these might affect subsequent movements.

4. Baseline Movement Information on Fishes in Areas of Future Causeway Construction

Baseline movement information of fishes in many areas is inadequate. Hence, it is likely that information on fish movements at future sites will be inadequate unless baseline studies are conducted there after site designation.

RECOMMENDATIONS

Although the workshop did not establish priorities for all issues or data gaps which require further attention, there was a general consensus that those concerning the effects of causeways on the migration of Arctic cisco to and from the Mackenzie River were still the most important. Further priorities given below are based upon the amount of available information on a given issue.

High-Priority Studies

1. Studies to establish the importance of Beaufort Sea populations of Arctic cisco to the Mackenzie River stocks.
   a. Further delineation of the genetic composition of Arctic cisco stocks from near and west of Prudhoe Bay and an analysis of the variability of this composition through time.
   b. Estimates of the proportion of various Mackenzie stocks which disperse to the west-central Beaufort Sea, and the proportion of Beaufort Sea fish which are found in the various spawning stocks in the Mackenzie drainage.
2. Studies to determine whether Arctic cisco migrants must reach overwintering sites west of the causeways to survive the winter.
   a. Investigations of the availability, suitability, and extent of overwintering sites east of the Sagavanirktok River.
   b. Determination of the extent of overwintering habitat in the Mackenzie River delta.
3. Studies to better understand the local movements of Arctic cisco, least cisco, and broad whitefish near the causeways.
   a. Determination of the environmental preferences of the species and the production of a model of their movements.
   b. Conduct baseline surveys of fish movements in areas of proposed causeway construction. This would facilitate the analysis of post-construction effects.

Medium-Priority Studies

1. Determination of the distribution and residency of Age-0 Arctic cisco along the eastern Beaufort Sea coast during the summer to establish an estimate of the numbers of Arctic cisco which do not reach the Sagavanirktok River.
2. Synthesis of physical and biological data along the corridor to model the movement of Arctic cisco between the west-central Beaufort Sea and the Mackenzie River.
3. Collection of additional oceanographic data near the outer edge of the corridor and in the eastern Beaufort Sea to define the migratory corridor.
4. Continuation of bioenergetic studies to determine the effects of suboptimal waters on fish movements.

Low-Priority Studies

1. Nearshore oceanographic data near the causeways appear to be sufficient for most fish movement studies. Nevertheless, oceanographic conditions there should continue to be monitored.

2. Local fish movements appear to be fairly well known near the causeways, but these should continue to be monitored.

3. Overwintering sites in the Colville and Sagavanirktok River deltas are well described, but conditions are likely to change from year-to-year; these sites should be examined periodically.

Causeway Design

It was also recommended that the potential effects of causeways on fish migrations and movements could be lessened or eliminated if future causeways were designed to avoid disruption of the nearshore migratory corridor either by altering the local currents in such a way that the corridor is extended seaward from the causeway or by allowing the corridor to flow through the causeway (e.g., through breaches in solid causeways or under raised causeways).

CONCLUSIONS

1. There appears to be sufficient information to indicate that the causeways in the Beaufort Sea can and do affect fish movements. However, there is insufficient information at the present to determine whether they significantly affect fish migrations or movements.

2. Arctic cisco is the species most likely to be significantly affected, because it passes the causeways during migrations to and from its Mackenzie River spawning sites. If important overwintering sites occur only west of the causeways, a delayed migration could be fatal to those fish which cannot reach these sites. In addition, if genetic studies indicated that populations west of the causeway are important in sustaining Mackenzie River stocks, then causeway effects could be internationally significant. However, there is insufficient information at present on the genetic composition of the populations in the Beaufort Sea and on overwintering sites east of the Sagavanirktok River to reach any conclusion regarding these. It is also clear that Arctic cisco are able to get past the causeways and reach western overwintering sites in some years, suggesting that causeways may not be a significant barrier to migrations of this species.

3. The causeways alter the local physical oceanography and this affects the local movements of Arctic cisco, least cisco, and broad whitefish. However, the cues to which these species respond need better definition so that fish movements can be modeled. The collection of baseline data and modeling of fish movements in areas of future causeway construction would facilitate the analysis and prediction of impacts.

ECOLOGICAL RELATIONSHIPS

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INTRODUCTION

This report first will note certain of the background resources including the oceanography and biology panel presentations on the day preceding the workshop which appear particularly relevant to ecological considerations in the study area. Factors limiting the effectiveness of the workshop then will be discussed, and the workshop discussions and tentative conclusions reviewed. Finally, some overall conclusions and recommendations concerning the research and synthesis processes will be offered, based on the total experiences of participating in this conference.

Before proceeding with that analysis, I wish to thank the Minerals Management Service, on behalf of all concerned agencies, for planning and carrying out this conference. This cannot have been an easy task, given the divergent missions, terms of reference, and inevitable institutional mind-sets of the agencies concerned. Decision making by committee is seldom either satisfying or satisfactory.

Despite any organizational problems, this conference has provided a valuable forum for the interagency and interdisciplinary exchange of ideas concerning the scope and scale of the needed information base; methods and models that could be useful for further investigation; and recommended mechanisms for more effectively deriving relevant conclusions from those studies. Whatever may have been the shortcomings of this conference for immediately achieving meaningful synthesis of relevant information and conclusions, these potentially long-term benefits of interdisciplinary dialogue should be recognized and applauded.

BACKGROUND RESOURCES FOR BIOLOGY WORKSHOPS

External consultants invited to participate as "senior authors" in this causeway conference were provided two useful documents for advance study: the Alaska OCS Region Arctic Information Transfer Meeting Conference Proceedings (MMS 1988), and Biological Papers of the University of Alaska No. 24: Research Advances on Anadromous Fish in Arctic Alaska and Canada (Norton 1989).

Both documents provided useful background information concerning Arctic Ocean and Beaufort Sea oceanography, and the biology/ecology of anadromous fish species of greatest local importance for human use. However, these documents did not provide useful perspectives on the conflicting data interpretations and conclusions which (we learned at the conference) have been focused upon environmental studies of causeway impacts in recent months. For example, a paper by Pope (1988) in the Arctic Information Transfer Proceedings indicates (p. 205) the following, with respect to the Endicott Environmental Monitoring Program:

> *Results of monitoring studies conducted in 1985 and 1986 indicate that there have been no biologically significant impacts on the marine or terrestrial ecosystems within the study area... The program results have not indicated any detrimental impacts to regional distribution, migration patterns, reproductive success, population size, productivity, or other biologically important characteristics of anadromous fish populations in the area either directly or indirectly influenced by the Endicott Causeway.*

The discussions following the presentation of this paper indicated no substantial disagreement with the stated position. Unfortunately, our preparation for the present workshop was frustrated substantially by absence of any data or conclusions arguing that significant impacts have indeed occurred (e.g., as in the EPA 1988, Causeways in the Alaskan Beaufort Sea).

Papers by Aagaard (1988) and by Hameedi (1988) in the Arctic Information Transfer Proceedings provided extremely helpful background on oceanic circulation and general physical oceanography of the Arctic Ocean and Beaufort Sea. The Beaufort Undercurrent injection of Bering Sea nutrients and plankters to the nearshore waters of the Beaufort Sea underscores the degree to which the area is dependent on external sources for food resources. McRoy's (McRoy 1988) description of ISHTAR further describes nutrient transfer and recycling, and Cooney's (Cooney 1988) paper extends this information through a description of arctic plankton communities. Schell's (Schell 1988) paper describes the three sources of Beaufort Sea productivity Bering Sea water via the Beaufort Undercurrent, algae on the underside of ice in the spring, and river run-off. Johnson (1988) effectively reviews the interactive roles of winds and currents a complex interaction crucial to understanding circulation in nearshore Beaufort Sea waters. Hachmeister (1988) explains summer water movements in the shallow nearshore environs of the Endicott Causeway under the drive of winds from the east (for about 60% of the ice-free period) and from the west (for about 30% of that period); as well as the modifying impact of river outflow. Glass (1988) reviews the differing ecological requirements of the more important anadromous fish species of the area and their responses to changes in temperature, salinity, and food supply, which are products of complex interactions of marine upwellings of colder, more saline, waters and the reverse flow of warmer nearshore waters, under the drive of prevailing winds.

The nine papers on research advances on anadromous fish in arctic Alaska and Canada Norton 1989) provided helpful background information on species of local concern, with respect to interactions with environmental factors critical to their needs. From among the extensive materials included, certain informational highlights appear in retrospect particularly relevant to discussions in the current conference workshops. For example, Craig's (Craig 1989 a,b) papers reviewed anadromy as an evolutionary strategy in response to the extreme limiting factors of the Arctic, and also the general distribution of key anadromous species and their contributions to the food supply of native communities of the area.

The extensive paper by Fechhelm *et al.* (1989) discusses the intrusion of West Dock on normal alongshore water movements, particularly under east wind conditions, with deflection offshore of westward-flowing, warmer nearshore waters, and intrusions (upwellings?) of colder offshore waters in the lee to westward of the Dock. Differential impacts are reviewed for least cisco (a species more closely tied to the alongshore band of warmer, low-salinity waters). and Arctic cisco, which in both early and later life stages are more tolerant of cooler, higher-salinity offshore conditions. Segregation of size classes and wind periodicity are seen as major factors influencing eastward movement of fish from the Coleville delta, with the West Dock on occasion providing a significant barrier to that dispersal due to marine water intrusions under strong east wind conditions. The authors found that fish did not use the West Dock Causeway breach to any extent.

Investigations by Schmidt *et al.* (1989) of the overwintering ecology of anadromous fish in the Sagavanirktok River delta appear to show overwintering successes consistent with the view (cited earlier) that causeways have not significantly blocked or otherwise negatively influenced movements of young Arctic cisco. Particularly interesting was the finding that, despite apparent absence of winter feeding, mean weights increased apparently due to die-off of poorer-condition fish in a winter culling process.

Moulton's (Moulton 1989) paper confirms the hypothesis of Mackenzie River spawning origin for Arctic cisco, and their more or less passive westward transport via currents generated by persistent easterly winds during the early part of the open-water summer season. Moulton concludes that both young and old Arctic cisco use their relatively greater salinity tolerance to be positioned far enough offshore to be relatively unaffected by causeway perturbations of normal and highly variable seasonal mixing of water masses. By contrast, lease cisco and broad whitefish which are less tolerant of cold and salt water, remain more closely tied to nearshore warm water.

Gallaway *et al.* (1989) provide descriptions of West Dock and Endicott Causeways, and postulate three potential impacts of those structures on Arctic cisco: 1) block westward transport of Age-0 fish from the MacKenzie River to overwintering sites in the Coleville River delta; 2) prevent movements of intermediate-aged fish from overwintering grounds in the deltas eastward or westward to summer nearshore feeding grounds; 3) prevent return migration of mature fish to MacKenzie River spawning grounds.

The paper reviews use of a model to relate earlier year catch-per-effort data from the commercial Arctic cisco fishery in the Coleville River delta to predicted catches in later years. The model shows promise, based on only a few years of data. Results suggest that neither causeways nor the commercial fishery has produced measurable effects on either regional or local stocks. Moreover, density-independent factors (e.g., seasonally variable wind impacts on nearshore currents, and therefore on the passive westward transport of Age-0 Arctic cisco) may entirely override local factors such as the commercial fishery or causeway impact.

PANEL PRESENTATIONS

While all speakers contributed to the general background, the following had particular significance for subsequent discussions in ecological relationships workshop.

Oceanography Panel

Roy Walters' presentation of generic models of estuarine mixing and circulation developed the concept that the nearshore areas bounded seaward by barrier islands along the Beaufort coast operate as along-shore estuaries, with dynamics much like those of South San Francisco Bay, except that the driving force is wind rather than tides.

Alan Niederoda outlined the general dynamics of nearshore Beaufort Sea circulation during the three to four months of the ice-free season. He emphasized the relationship of marine water intrusions or upwelling to the water depth of the friction zone between nearshore warmer less saline waters and the offshore colder, more saline marine waters. He explained how this critical depth, and therefore vulnerability to wind mixing, varied with wind direction and force. Finally, he concluded that variable conditions and rapid mixing are common in this alongshore estuary, and that upwelling is a common and highly variable mechanism for mixing, whereby saline marine water enters the nearshore. This upwelling he saw as a precondition for some local processes around causeways, with frequency and severity depending on distance offshore of the friction zone and on wind direction and strength.

From ensuing discussions it appeared that, like Douglas Segar, Niederoda saw causeway-created anomalies in the normal estuarine mixing pattern (i.e., the "wake eddy effect" in the lee of the causeway) as only occasional and variable perturbations of highly variable natural mixing. In addition, however, both oceanographers called attention to the offshore diversion of the warmer coastal waters by the causeways under east wind conditions.

Oceanographers also agreed that the existing oceanographic database is good in extent and content, but that future studies may require reductions in scale to match biological needs. The extensive nature of the present database was documented later by Dwight Pollard's review of information derived from the Endicott monitoring program.

David Aubrey's enlightening graphics of factors influencing sediment entrainment and transport through space and time focused attention on carrying capacity of water mass movements for inorganic materials, plankton, and juvenile fishes. Aubrey noted the need to design models to assess causeway impact on that transport, and to refine and extend data collection efforts to supply data scaled to the needs of those models. Other oceanographers clearly agreed to this need.

Biology Panel

Bill Bond's review of the distribution and general biology of anadromous coregonids of the Beaufort Sea extended the general background provided by Craig's (Craig 1989 a,b) papers, with particular emphasis on a Canadian perspective and on the species-unique differences in migrations and habitat preferences of key coregonid species. All species share a requirement for riverine spawning and overwintering sanctuary, and for use of nearshore estuaries for summer feeding and fattening. Bond's review also underscored the more oceanic tolerances and behavior of Arctic chars and Arctic ciscoes, in contrast to the more estuarine and freshwater requirements of least cisco and broad whitefish.

John McIntyre focused attention on some standard recruitment curve models and their interpretation, emphasizing that, in the real world, it can be difficult to supply such models with data of adequate scope and quality. His presentation made clear the need to recognize that critical stages in life history represent stress points on populations, and that impacts at other stages may reduce populations at that point (e.g. summer feeding grounds), when the real limit on population continuity is at some other stage (e.g., overwintering sanctuaries or spawning grounds).

Karl English reported on enclosure studies adjacent to the Endicott Causeway to quantify the effects of temperature, salinity, and prey abundance on the growth of Arctic cisco and broad whitefish. His 20 m diameter enclosures appeared not to alter the availability of food organisms, or to impair significantly the health and well-being of the enclosed fishes. Arctic cisco showed ready tolerance for temperature and salinity fluctuations, feeding on available prey species and growing over the experimental period at a rate comparable to wild individuals. Even though their general physical condition remained good, broad whitefish showed negative growth over that period, doubtless because their favored foods (chironomid larvae and other riverine small organisms) were not available in this more offshore site.

These enclosure studies may offer even greater significance for assessing prey species source and availability as a function of water mass exchanges due to upwellings adjacent to causeways. Given the external sources of so much of Beaufort Sea productivity, it seems important to know what the food resource trade-offs may be as offshore marine water intrudes toward shore, and warmer, less saline nearshore water flows offshore. Properly designed enclosure studies, modeled after those reported by English and integrated with small-scale oceanographic data collection, might provide some useful answers to this food and energy trade-off question with respect to causeway impacts.

DISCUSSION AND CONCLUSIONS

Over the four-day course of this conference, and particularly during the workshop phase (day 2), we became aware that only some of the papers, some of the researchers, and some of the agencies concerned were available for the reviews and discussions. We were lobbied vigorously in the hallways, with allegations of suppression of information, and were given documents supporting these concerns. We learned that some participants were allowed to attend but not to speak. We were frustrated by the fact that our workshop discussions appeared out of phase with the overall program, taking place in advance of the all-day panels on causeway construction and the engineering alternatives to causeways bridges, pilings, subsea pipelines, directional drilling, etc.

Clearly this lack of completeness and balance in the materials available for our review fatally flawed the entire process, and made impossible any valid synthesis concerning either conclusions or the database supporting them. In the final section of this paper, recommendations will be offered for rectifying some of these problems. It must be emphasized here, however, that the *discussions and conclusions of this* *workshop relate only to the partial information and arguments available to its participants*, without the benefit of peer group discussions and debates involving proponents of alternative conclusions.

While these major flaws prevented any comprehensive synthesis, the workshops did provide a productive forum for interdisciplinary discussions concerning data adequacy and scale of resolution, with suggestions for new research and modeling approaches, and other constructive products of the open discussion process. These benefits are to be applauded and supported (as will be discussed in greater detail in the final section of this paper).

Ecological Relationships Workshop Discussions

The following subjective review gives my perceptions of major topics, discussions, and tentative conclusions, in which those present fully recognized the incomplete nature of the basis for the entire process. From my notes on these discussions, I have attempted to reflect the thrust of comments and concerns.

The group first attempted to define some issues of major concern, then settled on an extensive review of Arctic cisco studies under the Endicott Environmental Monitoring Program for the years 1985-87. Those studies were seen as a relevant example of interactions of a key fish species with its environment, as affected by existing causeways.

Perceived issues and concerns relating to causeway impacts on anadromous fishes and their critical habitats

The identified issues focused on fish biology questions which might indicate causeway impacts on key species:

- Can catch-per-unit-of-effort (CPUE) estimates adequately monitor causeway impacts on key anadromous fish species?
- Can we define a minimum population size required to maintain the long-term biological health of key anadromous species?
- Do in-season growth and condition over the course of the open-water season adequately assess the health of fish populations?
- What are the limiting factors on key anadromous fish populations, and how do the causeways impact these factors?
- What is the evidence that any fish populations are in trouble?

Other identified issues focused on possible causeway impacts on the nearshore ecosystem generally and on food chains and the nutritional requirements of fishes in particular, which were seen as key considerations involving potential sublethal effects as well as the more obvious direct impacts on migration routes, etc.

- To what extent does the "wake eddy effect" in the lee of the causeways augment the normal pattern of upwellings, and what is the net effect upon habitats and fish populations?
- How do causeway alterations in water mass circulation affect primary and secondary productivity in nearshore waters?

- What are the quantitative trade-offs of food elements and nutrition gained through offshore marine upwelling, and lost to the nearshore environment by offshore flow of warmer less saline water during upwelling periods?

- What is our best information associating fish habitat requirements with the physical characteristics of nearshore, offshore, and mixed water masses? How might this information help improve assessment and better understanding of natural physical processes and of causeway modifications of those processes?

As I listened to these identified issues and concerns, it was clear that they were derived principally from the research interests of those proposing them. Fisheries biologists quite naturally desire to know all there is to know about fish species of concern habitat requirements and limiting factors, population dynamics and optimum population strength, etc. Physical oceanographers are primarily concerned with the physical characteristics of water masses, and the complex dynamics affecting their transport, mixing, etc. Ecologists are looking for the interactions of all these factors, and often are concerned particularly with food and energy supply and demand. Out of the mix of all these preoccupations can come a valuable synthesis defining needed researches. Too often, however, the product is only a "laundry list" of desired projects, which in total are beyond the reach of available dollar and time resources.

Toward the close of this problem identification process, one of our agency decision makers reminded the group of what he termed "the facts of life" in assessing impacts of developments on the environment. He noted that, under law, there are no prohibitions against *impacts* by a development such as a causeway, or even against *adverse* impacts. The operative term is *significant adverse impacts*, which he recommended be addressed in terms of *dose and response* relationships, and *exposure assessment*. He illustrated these concepts as temperature and salinity tolerance levels of fishes, with the exposure concerns being how much, how long, and when in the life cycle.

Perhaps principally in recognition of the futility in trying to build on the list of issues and concerns so far identified, it was suggested that the group focus on a key anadromous fish species and its responses to causeway-modified environmental conditions. The Arctic cisco was proposed for this review of the species' apparent environmental requirements, and possible vulnerability to measurable adverse impacts of a causeway. Because the most comprehensive available database is for 1985-87 in relation to the Endicott Causeway, the group decided to concentrate its attention there.

The Arctic Cisco in relation to the Endicott Causeway A review based upon the Endicott Environmental Monitoring Program, 1985-87.

Biology of the Arctic cisco (*Coregonus autumnalis*) is relevant to these discussions. The Mackenzie River is the only known spawning source for Arctic cisco along the Alaskan Beaufort Sea. The Mackenzie River plume disperses young-of-the-year fishes offshore where they are transported westward in east wind-driven water masses into and through the study area. The Coleville and Sagavanirktok River estuaries are important overwintering areas, and all ages use warm nearshore waters for summer feeding and nurturing, along with other coregonid species such as the least cisco and broad whitefish. Mature adult Arctic cisco return to the Mackenzie for breeding.

Study area hydrography was reviewed with important assistance from oceanographers Alan Niederoda and Douglas Segar. They stressed the natural forces which bring about mixing of colder, more saline marine waters with warmer, less saline nearshore waters, and the critical relationship of location of the friction zone between those two water masses with respect to water depth and distance offshore, and wind direction and intensity. Causeways would appear to increase upwelling and mixing only as wind and water conditions push that friction zone shoreward to and within the end of the causeway. We were reminded that marine water intrusions and mixing in the shallow waters of the Beaufort Sea coastline are naturally occurring events, relatively small in scale, and highly variable in time and place, and that they are essential precursors to many local processes.

The workshop devoted considerable time and attention to the timing and presumed biological effects of the upwelling phenomenon, and to the influence on it of the West Dock and Endicott Causeways. There is no question that, under certain conditions, marine intrusions of marine waters, or upwelling (or upwelling) occurs "downstream" or westward of these causeways. The real question is to what extent may the causeways increase the frequency, the strength, and the geographic extent of impact of this phenomenon, and what is the response of anadromous fish species to any such perturbations? Major concerns focus on the degree of interference with movements alongshore to satisfy feeding needs, or to reach overwintering sanctuaries or spawning grounds. Interest also surfaced in the workshop concerning upwelling influences on availability of prey species within preferred feeding areas.

Data clearly indicate a more extensive impact from the "wake eddy effect" off West Dock than for Endicott Causeway. Because of the proximity of Stump Island, which is the seaward boundary of Stump Lagoon, the plume from West Dock can be shown to influence mixing conditions deep into that lagoon. No such island channeling of the plume is shown off the Endicott Causeway; moreover, that causeway straddles the Sagavanirktok River outflow, which pushes water offshore on both sides of the causeway. (Our oceanographers commented repeatedly on the fortuitous location of the causeway, and emphasized the need for site-specific evaluation of impacts on natural circulation patterns.)

It is my perception that our oceanographers view this "wake eddy effect," which generates marine water intrusions west of the causeways, as a not very different factor from naturally occuring upwelling, which takes place whenever the friction zone between nearshore and offshore waters is close enough inshore and in shallow enough water to be driven effectively by wind, as a product of wind direction and velocity. In the same manner as natural peninsulas and islands, the causeways provide loci for this mixing of water masses and their advection downstream, along the prevailing direction of nearshore water flow.

Oceanographers note another effect of the causeways which may not have received enough attention to date the offshore deflection of warmer, less saline nearshore waters under east wind-driven westward flow conditions. The degree to which this causes losses in nutrients or in entrained juvenile fishes may need further study and evaluation as to significance. This consideration was not reviewed in the workshop deliberations.

Our oceanographer participants reiterated that the oceanographic database for the study area is remarkably detailed and complete, though there may be merit in future scaling down to match the needs of biological models and researchers (which must be specified if this is to be considered). Participants also generally agreed that the 1985-87 data provided by the Endicott Environmental Monitoring Program is comprehensive and of good quality.

Causeway Impacts of Fish and Fish Habitats

Workshop participants turned their attention to the "bottom line" question of whether the Endicott Environmental Monitoring Program data for 1985-87 demonstrate that the causeways have exerted significant negative impacts on Arctic cisco. It became apparent that principal concerns focused upon three issues identified by the Environmental Impact Statement (EIS) for the Endicott development (U.S. Army Corps of Engineers 1984):

1) The degree to which increased salinity and decreased temperature would degrade water quality as result of marine intrusions (upwelling) on the lee side of the causeway.

2) The degree to which the causeway would interfere with movements of Arctic cisco young-of-the-year westward from the Mackenzie spawning grounds through the study area to the Coleville River delta, and the degree to which any such blockage would shunt excess numbers of fish into the Sagavanirktok River and exceed its carrying capacity.

3) The degree to which causeway-induced changes in water quality would degrade summer foraging habitat to reduce growth and fitness and increase mortality in anadromous fishes.

As the discussion began on these issues, it became clear that a major concern of many participants was with the fact that, in 1988, the anadromous fish portions of the Endicott Monitoring Study were formally discontinued after only three years of a planned seven-year investigation. The basis for this curtailment was that significant damage to fish habitats had occurred, and that mitigation of those impacts was required. Clearly not everyone agreed with that conclusion, or with the resultant decision to close the fish-related studies. It is our understanding that those studies will be continued even without the governmental mandate for them, to satisfy the original seven-year intent.

It was particularly through discussion of this issue that it became clear that political rationales had restricted active participation at this conference, to the extent that our synthesis objectives could not in good conscience be accomplished. We quickly learned that we did not have representation at this workshop of all positions on the issues before us; further, that some of our group were under orders not to comment. We noted also that some agencies with active interests in these issues were not represented at all (e.g., the State of Alaska, the North Slope Borough, the National Marine Fisheries Service). Because of this imbalance in representation of alternative positions, the discussion process had value for an interdisciplinary exchange of information and ideas, but not for a valid synthesis of conclusions.

EIS Concern I: Impact of Causeway-Induced Upwelling on Water Quality (Temperature and Salinity)

Those reporting on the analysis of 1985-87 Endicott monitoring data indicated that those data demonstrated no significant impact on fish habitat as a result of the Endicott Causeway wake eddy effect. They saw the causeway impact as merely a minor extension and localization of the natural upwelling normal to the region. They noted that "worst case" conditions over the three years of data, where the Endicott wake eddy effect was an obvious anomaly in the local mixing pattern, this condition occurred in only 2 to 7% of the times that samples were taken. It was my perception that those participating in the workshop discussion saw this frequency of causeway-induced anomaly as not very significant perhaps lost in the noise of highly variable and seasonal fluctuations in naturally occurring upwelling and mixing. From the oceanographic explanations heard earlier, it would appear that, during much of the upwelling period, upwelling is widespread throughout the area, encompassing and overriding any local impact of the causeway. We were mindful also of upwelling as a necessary precursor for local processes, including transport of sediments and entrained food organisms.

Unfortunately, there was no questioning of these tentative conclusions by others in our workshop group, even though, as I subsequently learned, other highly competent reviewers had concluded that upwelling in the lee of the Endicott Causeway does seriously impact habitat important to key anadromous fish species.

As an explicit example, the EPA Report No. 910/9-88-218, Causeways in the Alaskan Beaufort Sea (EPA 1988) handed to me a day after the workshop ended concludes (p. 23): "The West Dock and Endicott Causeways have significantly altered the balance of fresh and marine waters throughout this area, fundamentally altering water quality and circulation patterns along as much as 65 kilometers of coastline." EPA conclusions then cite four fish population changes believed to demonstrate significant degradation of habitat as result of causeway impacts on water quality and circulation. These conclusions are essentially opposite to those of active participants in our workshop session. EPA, however, was not represented during most of the discussion period.

I am not particularly disturbed by these differences in conclusions, recognizing that differing weights and levels of significance can be assigned different elements of any dataset. Competent scientists often disagree on the meanings and implications of a given array of data, particularly when the data series is short in the context of long-term variability. I am deeply disturbed, however, that for whatever political reasons, we did not have the opportunity as a workshop group to hear the alternative rationales for these opposing conclusions, and to use the opportunity of a peer group discussion to seek some synthesis among them. Perhaps even worse, at the time of our discussions, many of us were not even aware that these significant differences existed.

Despite this absence of basis for real synthesis, the colloquium discussion approach of the workshop paid some strong positive dividends. The conceptual interactions of oceanographers and biologists was stimulating and productive. We found ourselves asking how we might define a common micro-scale for combined oceanographic and biological investigations, whereby data could be applied to agreed-upon models to provide answers concerning temperature, salinity, and food needs of fishes in terms of levels available under varying conditions of water circulation and mixing. Through such modeling, "dose-response" conclusions could be generated concerning the impact on fishes of upwelling injections of cooler, more saline waters into the warmer-water mixing zone alongshore.

As provisional benchmarks for temperature and salinity considerations, we were advised that 5°C appears to be a reasonable floor for effective Arctic cisco functioning. Below that level, fish don't swim very well or grow effectively. Salinity levels of 25 to 26 parts per thousand (ppt) appear to be ceilings for Arctic cisco well-being. Discussion here focused on questions of fish behavior in the estuarine mixing zone in response to those limits the availability of retreat opportunities in the face of unfavorable temperature-salinity levels, and questions concerning possible sublethal effects.

The workshop group agreed that temperature, salinity, and food supply were clearly the prime dose-response elements to be addressed in assessing the impacts of man-made intrusions on fish environments. With respect to food resources, someone recalled that earlier studies of carbon uptake by Arctic fishes indicated that the bulk of carbon consumed by the Arctic cisco is of marine origin. This observation leads one to recall the oceanographers' finding that Beaufort Sea productivity benefits significantly from external nutritional and entrained planktonic food resources carried eastward by ocean currents from the Bering Sea. Group speculation ensued regarding the possible beneficial aspects of periodic marine water intrusions and upwelling into coastal waters, with resultant injection of nutrients and food organisms. A scenario was suggested in which fishes take advantage of the swirling interface of the estuarine mixing zone, briefly entering marine components to snatch food, then retreating to more compatible lower-salinity and higher-temperature coastal components.

It is in the context of assessing food availability and transfer of prey organisms between marine and nearshore water masses that the enclosure research approach reported by English (and cited earlier in this paper) appears to have real promise, using the growth and condition responses of fishes as indicators of effective use of available prey organisms under known variations in temperature and salinity.

EIS Concern 2: Causeway Interference with Migrations/Movements of Young-of-the-year Arctic Cisco

The workshop group generally agreed that there is no evidence of significant interference by the causeways with movements of young-of-the-year Arctic cisco westward through the area to the Colville River delta or to other river systems, and no evidence of significant overtaxing of the Sagavanirktok overwintering carrying capacity. (Again, the EPA (1988) document, not available for these workshop discussions, reaches somewhat different conclusions.)

Much of the evidence concerning movements of young Arctic cisco is derived from passive-collecting fyke nets, which can be used most effectively alongshore. The discussion group urged use of other active sampling means to supplement the fyke net data with more offshore samples and perhaps better representation of older age classes. Not discussed in the workshop, but perhaps important in view of oceanographic evidence of offshore diversion of warmer coastal waters by the causeways under east wind conditions, is the question of loss through entrainment in those waters of young Arctic ciscoes. If young fish are swept seaward in a surface tongue of warm water floating over colder, more saline marine water, they may be lost as mixing occurs and no retreat is possible. This might be particularly serious off West Dock, where offshore warm water plumes move outside the barrier islands.

EIS Concern 3: Degradation of summer foraging habitat, with reduced growth and fitness and increased mortality of anadromous fishes

From data and conclusions available, the workshop group found no evidence of negative population impacts on Arctic cisco. (Again, the EPA (1988) reverse conclusions and rationale were not available for workshop consideration or discussion.) Graphic plots of growth and condition curves over the three years of the project showed no significant differences for these three years of quite different environmental conditions. These conclusions derived from Endicott Monitoring Program data were reported to be consistent with independent growth and condition studies by other investigators.

The quality of the condition factor data, which is dependent on length and weight measurements under often difficult field conditions, was questioned during the discussions, though not at a level of concern to challenge the general conclusion. This leads to the obvious recommendation that every effort should be made to improve field equipment and methods to the extent practicable, and thus, to sharpen the precision of data reported. This seems a useful and cost-effective approach to detecting adverse changes in habitat by comparisons over time of condition and growth in sampled fish. The fish are, after all, the ultimate arbiters of environmental quality.

The general subject of assessing the impact of man-made intrusions such as causeways on environmental quality, and therefore on fish health and population strength, merits far more attention than was possible within the time constraints and structure of the present workshop. The use of growth rates and condition factors to index the health of a fish population demonstrated their usefulness in the studies reported. Clearly some targeting of research approaches will be necessary for future studies. Available time and funding will not permit extensive long-term researches into the total biology and population dynamics of each key anadromous fish species, not to mention the even greater complexities of total understanding of ecological relationships.

For very practical reasons, it seems unlikely that reliable population estimates will be forthcoming for Arctic fish species through any anticipated levels of research. Population estimates of reasonable reliability can be made at manageable costs for the circumscribed populations of lakes; also for fisheries having large and well-established commercial fishing operations subject to reasonably reliable catch-effort analysis, and of a value justifying expensive direct surveys (e.g., Pacific halibut). Good population estimates also are routine for such fisheries as Pacific salmon, where decades of intensive study have produced detailed life history and environmental tolerance information, and where the life cycle permits annual enumeration of spawning stock strength. None of these conditions obtain now, or can be anticipated for the reasonable future, for Arctic Ocean coregonids.

For these reasons, it seems somewhat futile to hope to estimate current population levels of these species, relate those estimates to baseline levels prior to petroleum development along the Beaufort Sea, and then postulate optimum population levels to be maintained into the future through controls on causeway construction, or other human encroachments on the environment. The goal of maintaining strong and healthy fish populations is entirely appropriate, but those conditions may more readily be assessed by some form of indexing stock size and fish health to determine trends, rather than attempting to estimate total population size or establish some absolute growth and condition criteria.

Enumeration of downstream-migrating sockeye salmon smolts provides a useful parallel, in which numbers indexed over time allow estimates of stock strength for that year's seaward migrants, but without any real knowledge of the total numbers. Small fyke nets are anchored year-after-year at the same location on shallow bars in the path of the migrants, and fish counts per unit of time are made in the same manner year-after-year. Based on past history, estimates then can be made of the size of the current year class relative to previous years. Then, under certain assumptions of ocean growth and mortality, predictions can be made of anticipated returns to the fishery two years hence. Trends in these numbers over the years indicate general health and continued productivity of the fishery.

There may be similar access to juvenile coregonid fishes of the Beaufort Sea, where annual index numbers could be used to estimate trends in stock strength. In the case of Arctic cisco, these numbers might be integrated with catch/effort data from the Coleville Delta commercial fishery, to permit some projection back in time of the population estimates. In any case, it would appear prudent and productive, given limits on time and funds, to seek innovative approaches to data required for decisions, short of the biologists' ideal goal of full understanding of species biology, ecological requirements, and optimum population size.

CONFERENCE CONCLUSIONS: A RETROSPECTIVE VIEW

Synthesis Conferences

The present conference demonstrated its value as a forum for exchange of information and ideas across disciplines and among governmental agencies and participating private entities. The conference did not serve a useful synthesis function, for reasons that have been noted throughout this report.

Future synthesis conferences should have the following characteristics:

Participants: A peer gathering of scientists and technicians actively engaged in the researches, and involved in reaching the scientific conclusions, which are the subject of the conference. Outside scientists may be brought in for perspective and balance. Agency decision makers and others with principally political concerns must *not* be included.

Tasking: Participants should be freed from any institutional constraints and directed to interact as scientists, to the extent possible without consideration of institutional biases; or special perspectives. The group objective should be evaluation of adequacy of the database; debate of conflicting interpretations and conclusions; and arrival at *either*:

1) Consensus conclusions and their documentation, where possible, or

2) Clearly defined alternative conclusions and supporting arguments, where no consensus can be reached.

As an outgrowth of the above, participants also should outline needed changes and extensions for future researches, with emphasis on innovative approaches to information needs.

Preparation and Agenda: A strong senior scientist moderator should be designated to keep the agenda on track and to guide and moderate the discussions. A carefully structured agenda must be provided to guide discussions, identifying the specific scope of the issues to be reviewed, and suggesting a sequence for doing so. Background documents must be provided *in advance*, and participants should be expected to have studied them in detail. Planners could review to advantage the preparations and procedures of the highly successful American Assembly conferences (though without the need for multiple concurrent sessions).

Time Frame will, of course, depend upon the amount of material to be considered. For each of the three biological topics of this conference, two to four days would seem appropriate.

Overall Research Planning

From the overall experiences of this Conference, I urge that a workable separation of political and scientific elements of the research and management process be effected. An instructive pattern exists in the Regional Fishery Management Councils, where the research and management processes residing with the Plan Development Teams and the Scientific and Statistical Committee are sharply separated operationally from the political decision making processes of the Council-proper. This separation is, of course, not perfect, but it has functioned effectively to isolate, to a considerable degree, the research processes and conclusions from political torques by agencies and the public.

I think it important also that the scope of research be guided less sharply by issues and problems specified in various permitting documents, and more by scientific judgments of the researches truly needed to answer management questions. In this context, I believe that the greater scientific community could be helpful, both in overall research planning and in refereeing synthesis of conclusions, perhaps via the National Academy of Sciences or a consortium of interested universities.

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NEARSHORE BEAUFORT SEA CAUSEWAYS AND ALTERNATIVES

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INTRODUCTION

It is clear that the nearshore region of the Beaufort Sea is environmentally sensitive and can be significantly effected by the construction of causeways. While there is a great deal of information available on the oceanographic environment, there does not appear to be a consensus regarding whether these effects constitute a negative impact on the species of fish that are of concern.

If offshore oil fields are to be developed in the Beaufort Sea, the oil, and possibly the gas, must be transported somewhere off the North Slope. To date, only the Endicott Field has been developed and gravel, solid-fill causeways were constructed to connect Endicott's two artificial drilling islands to each other and to connect them to shore. The inter-island causeway is 3.1 miles long and is unbreached, and the causeway to shore is 1.9 miles long and has two breaches totaling 700 lineal ft. The pipelines are supported 8 ft above the causeways on steel vertical support members and the causeways provide year-round road access to the artificial islands.

The objective of this session is to consider the technical and economic aspects of causeways and to evaluate the various alternatives that are available. In order to understand the problem, it is necessary to have a clear understanding of the nature of the environment, particularly with respect to the sea ice and seabed permafrost. During the winter season, the full depth of the water column (from the water surface to the seabed) is frozen where water depths are approximately 5.5 ft or less. In the Prudhoe Bay area, the 5.5 ft water depth contour can occur 7,000 ft or more offshore. Since the ice serves as a conductor for the cold air temperature, permafrost can usually be found at the top of the seabed in these water depths. In water depths greater than approximately 5.5 ft, the top of the permafrost drops off rapidly to levels below that which are of concern for construction of causeways and their alternatives. However, even in the deeper water depths, it is possible to encounter bonded or unbonded permafrost and ice lenses.

It is important to understand that actual permafrost conditions can vary considerably and are very site-specific. Permafrost is not a particular material. It is a condition of the soil, and just as the soil can have a wide range of properties, permafrost can have a wide range of properties.

SOLID-FILL CAUSEWAYS

Two general subcategories of gravel, solid-fill causeways can be defined: unbreached and breached. An unbreached causeway is generally the lowest cost alternative, considering both construction and operating costs, but it has the greatest effect on the environment.

Within the subcategory of breached causeways there is a wide variation possible with respect to the percent of the length that is breached and the methods of constructing the breaches. Presumably, the larger the breaches, the less the resulting environmental disturbance. The existing West Dock Causeway is almost 3 miles long and has only one 50 ft breach, while the Endicott shore-access Causeway is less than 2 miles long and has two breaches totaling 700 ft.

The construction of the breaches in these two causeways is similar to highway bridge construction. An alternative type of construction that has been proposed is to use culverts in place of the bridge construction. It is questionable whether culverts would actually be a cost-effective alternative because of the number and size of culverts that would be required in order to provide the equivalent flow characteristics that a bridge-type construction provides. Also, culverts present problems of early freeze-up and late breakup of the ice in the culvert, which may require significant operating cost to remedy. In addition, fish response to long culverts is not known.

ELEVATED CAUSEWAYS

As mentioned above, increasing the extent of causeway breaching reduces the environmental disturbance. Extending this concept to its limit results in the elevated causeway concept, i.e., pipelines and heavy-duty roadway supported on piles. An elevated causeway, properly designed and constructed, would reduce the impacts to the nearshore environment that are associated with a solid-fill gravel causeway. Utilizing standard construction techniques, there are a number of alternative methods of constructing elevated causeways. The key factor is the design of the supports to resist the ice forces and to protect them from scour.

The cost of the elevated causeway can be reduced by reducing the carrying capacity of the roadway, and ultimately eliminating the roadway completely, resulting in the pile-supported pipeline concept. Reducing the carrying capacity of the roadway would mean that heavy equipment would have to be transported over the ice during winter or by barge during the open water season. Complete elimination of the roadway would require that personnel, supplies, and equipment be transported by air, by land vehicles over the ice, by supply vessel, by air-cushioned vehicles, or by combinations of these methods.

SUBSEA PIPELINES

The common characteristic of each of the above concepts is that the pipelines are supported above the water and ice. Another group of concepts features locating the pipelines below the water and ice, i.e., below the seabed. The only subsea pipeline in the high Arctic is the one constructed at Melville Island for Pan Arctic a number of years ago, but there is no doubt that their construction is technically feasible. Subsea pipelines must be located sufficiently far below the seabed to protect them from ice gouging and scour. In addition, the depth must be based not only on gouge and scour depth, but also on consideration of the force exerted by the ice on a pipeline buried below a gouge.

There are three general categories of construction techniques available to install a pipeline below the seabed, and within each category there are a number of possible variations. The summer construction techniques category consists of a number of methods of excavating a trench during periods of open water and installing the pipeline in the trench by one of several proven laying or pulling procedures. A number of trenching methods are available for Arctic applications. The cutter suction dredge is the most efficient dredge for deep-trenching in a variety of soils. An alternative method of trenching is to use a subsea plow arrangement. If properly designed plows are utilized, it may be possible to plow 7 ft deep trenches in a single pass and up to 15 ft deep trenches with three passes. One other system of trenching in sands and silts is to use hydraulic pressure to create a fluidized soil bed around the pipeline, whereby the pipeline is lowered by gravity to the desired depth.

Using summer construction techniques, long subsea pipelines would be installed by a semi-submersible or ship-shaped lay barge with icebreaker support. Alternatively, a reel barge may be used, whereby the pipe string is pre-assembled in long lengths, spooled onto a reel on the deck of the barge, and then installed by pulling it off the reel and lowering it in place. Short pipelines and the shallow-water portion of long pipelines may be installed by the bottom pull method. With this method, long pipe strings are fabricated on shore and then pulled into position. This method requires a sizable pipe assembly site to be constructed on shore. Due to the rapid increase in pulling force with distance, this method is limited to the construction of relatively short pipelines.

The winter construction techniques category consists of the adaptation of conventional cross-country pipeline construction methods, by taking advantage of the land-fast ice as a support for construction operations. The advantage of this method when compared to conventional open-water methods, is that the winter construction window is relatively long and the majority of the construction equipment utilized in this technique has the versatility for either onshore or offshore pipeline construction.

The third category of subsea pipeline construction includes several variations of the directionally controlled horizontal drilling technique that has been successfully used for a number of years for constructing river crossings. To date, the maximum-diameter pipeline installed using horizontal drilling techniques is 40 in. and the maximum length installed is approximately 6,000 ft. A two-stage process is used. The first stage consists of drilling a small-diameter pilot hole. This is accomplished using a specially designed horizontal drill rig in conjunction with directionally controlled downhole drilling tools. After completion of the pilot hole, successively larger diameter reaming tools are pulled through until a hole diameter is achieved which is suitable for installation of the pipeline.

While the concept of installing subsea pipelines by directional drilling appears to be feasible, further technical developments are required to make it practical for Arctic nearshore applications. The present magnetic guidance control system, which is not accurate in areas near the magnetic north pole, must be replaced with a system based upon inertial gyroscopes or another system. Also, the capacity to install large-diameter pipe must be increased from the present 6,000 ft to 2 or 3 miles.

All subsea pipeline alternatives present the problem of access to the offshore drilling/production facilities for personnel, supplies, and equipment. Thus, operating costs are higher than for a causeway in order to maintain this access year-round. If permafrost is present along the pipeline route, the cost of construction is significantly increased because burial by trenching techniques is much more difficult and insulation must be provided around the pipe. Also, the potential for thawing of the permafrost and settlement of the pipeline has to be fully evaluated.

DIRECTIONAL DRILLING

Two additional concepts feature elimination of pipelines in the nearshore. Directional drilling from an onshore location may be feasible where the reservoir is not located too far offshore. With this alternative, the offshore field is developed by directional, extended-reach drilling from one or more onshore locations in the vicinity of the shoreline. While this alternative reduces risks to the nearshore environment, it increases the financial risks associated with development of the reservoir. The technology exists to drill wells with departures of 10,000 to 15,000 ft, but the inability to predict reservoir performance with high departure wells increases the project financial risks. Also, the presence of fault zones that may have to be penetrated at an oblique angle to reach the reservoir could result in plugging back and re-drilling, an expensive proposition.

OFFSHORE TANKER LOADING

The second concept that does not require a nearshore pipeline consists of loading the produced crude oil into tankers at a deepwater location, without ever taking it ashore. This concept is based on the assumption that gas will not be shipped. The concept of transporting crude oil by icebreaker tanker from the Beaufort Sea has been under serious consideration for 20 years, and this alternative may be particularly attractive in situations where the reservoir is in a deepwater location, far from shore. There are no existing offshore loading terminals that would be suitable for the Beaufort Sea, but a number of different concepts have been developed over the years. At a deepwater location, where the optimum production platform is a large, prefabricated, bottom-founded structure, the use of the production platform as the offshore loading terminal is probably the most cost-effective alternative. However, the concept has several areas requiring further technical development.

ENVIRONMENTAL PARAMETERS

While all of the above concepts are technically feasible, some require more technical development than others, and thus the reliability of estimates of construction cost and schedule varies considerably among the alternatives. Also, the sensitivity of the construction cost and schedule to variations in the environmental design parameters can vary greatly for the different alternatives. These environmental design parameters include ice conditions, waves, water depth, currents, tides, storm surge, geotechnical conditions, and meteorological conditions. For example, the construction costs of all of the alternatives mentioned, with the possible exceptions of extended reach directional drilling and offshore tanker loading, are impacted by the presence of permafrost in the seabed along the pipeline route. The degree to which the particular concept requires penetration of the seabed determines the magnitude of the cost impact. Thus, the costs of various causeway alternatives, requiring virtually no penetration of the seabed, are relatively insensitive to the presence of permafrost. The costs of the pile-supported concepts, requiring penetration only for the installation of widely spaced support members, are mildly sensitive to the presence of permafrost. However, cost for the installation of pipelines below the seabed can be very severely impacted by the presence of permafrost.

SUMMARY AND COMMENT

Charles T. Mitchell
Meeting Chair
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As Chair of the Causeway Synthesis Workshop I have been asked to make a closing statement. First, I would like to thank all of the participants for their contributed effort and knowledge. Thanks are particularly due to the Lead Authors and the Co-Chairs for their work over these four days. We have all heard their laments concerning the difficulty of synthesizing such diversity of knowledge and opinion. I too have shared the frustration.

I used to puzzle over why the president of General Motors Corporation was paid millions of dollars per year and I was paid only a few thousand. I was sure that I worked as hard as he. I came to the conclusion that the amount of work must not directly equate to your salary or wage, and there had to be some other parameter involved. One day it dawned on me that it was probably equated to the degree of exposure, and the potential for "looking foolish." Certainly, if we use these criteria the Lead Authors who have occupied this podium over the last few days have been "underpaid." They all have heroically struggled and suffered with the problems and diversity we have presented, and I think that they deserve our collective thanks and applause for their efforts and a job well done. They have certainly extracted more information out of these discussions than I thought possible.

If I could now take a few minutes, I would like to comment on the proceedings and what I have heard over the past few days.

Upon examining the physical oceanographic aspects, the database appears to be reasonably complete. The processes can be described and the oceanographers have identified the major driving forces along this Arctic coast. On a local basis we can see how these events interact with nearshore structures. However, they may work differently a few hundred miles down the coast. There are some site-specific processes that we still do not understand completely, but the solution appears to be near at hand. With a little more work, and some site-specific kinds of information, perhaps we can come up with the numerical or "diagnostic" models that Dr. Douglas Segar referred to earlier. Perhaps in the near future we can develop a reasonably predictive model or process that will allow us to examine the potential impact of nearshore structures that may be proposed for this extreme environment. The most critical aspect of the evaluation process that has become apparent during the last few days is the lack of adequate background information on the environment prior to the installation of nearshore structures with which one can make comparisons. It would seem to be clear that the structures now in place have affected the physical environment on at least a local basis.

In examining these structures and their effects, we periodically have to remind ourselves that we are looking for biological effects and a measure of their ecological impact. With the exception of the physical oceanographers, few persons particularly care about what a Conductivity-Temperature-Depth (CTD) profile of a particular parcel of seawater looks like. We are concerned with biological effects what does the CTD profile mean in terms of biological impact to the resident species? These results have to be related to the biological processes and that can be difficult. It appears that the biologists are not always talking to the oceanographers, or that they are talking in "different languages."

This was illustrated last year during the MMS Arctic Fisheries Workshop, when very knowledgeable Arctic fisheries scientists in attendance were presented with a color-enhanced satellite image of the Arctic coast during one of the physical oceanographic presentations. The impact of this slide on the fisheries persons was notable; two or three fisheries scientists suddenly realized why their data showed the patterns it had. They had, unwittingly, integrated their biological data with the physical data. We need more of this cross communication. I find it remarkable that such communication frequently does not occur, particularly in light of the fact that water quality data are sometimes collected in the field by biologists.

During one of present workshop sessions, Dr. Lon Hachmeister took one of the speaker's overhead transparencies of two annual growth curves for Arctic cisco and superimposed them onto wind direction data for the same periods. The result was amazing. The growth curves for both years were obviously statistically different and appeared to be highly correlated with wind direction. We need this kind of integration of the database and it's not happening at present.

In reviewing the biological database, we have "bits and pieces" of site-specific information that extend back in time for many years. During this Workshop I have had the opportunity to attend all biological workshops for short periods, and based upon the discussions it would appear that database is probably better than what was initially thought. In all of the workshop sessions, time was expended in familiarizing some participants with studies and the results that had been accomplished in the past. This was valuable, since it provided an inventory process for both the experienced and inexperienced participants and allowed a narrowing of the focus to specific potential problem areas. As a result of this inventory, it was immediately apparent that the estimate of biological impact was compromised to some degree by the lack of pre-causeway information. Despite that fact, it appeared that the database provided by causeway monitoring programs contained most of the information needed to proceed with a reasonable evaluation of impact. The controversy at present revolves around the interpretation of the available database. It would appear that the controversy will continue until such time that additional specific questions are addressed, and the resulting data are integrated into the existing database and critically reviewed.

At present, biological impacts or effects associated with the presence of these nearshore structures have been documented. The ecological implication of these impacts and the degree of biological significance remains uncertain.

Engineers have given us some potential and exciting alternatives to such nearshore structures. There are a number of alternatives that are technically feasible, but the question of economic feasibility remains. Is society willing to pay the price of these alternatives? Such societal considerations and ramifications echo through all environmental evaluations of alternatives. All of the alternatives have costs, whether they are environmental, social, or monetary costs. As scientists or managers we must address these costs. They are not going to go away, we have to meet them head-on.

Over the last few days speakers and the Lead Authors repeatedly expressed the need for more synthesis, assembling the database, and generating more cross-disciplinary communication. This was echoed through each of the summary presentations. How is this to be accomplished? The methodologies are available. We do not have to develop new technologies. All we have to do is get together and do it. During the Workshop there was an unfortunate reluctance by some of the agencies and entities to share information. As might be expected, each of these entities has its own set of priorities, its own set of criteria, and its own administrative approach. There is nothing wrong with that; each one has a mandated list of responsibilities. However, we must keep in mind that we are all working for the same employer, and our goals are basically the same. Agency or entity goals, while they may be very important within that group, should share a common effort toward a common solution. Some groups represented at the Workshop, and some who were not, were not as cooperative as perhaps they should or could have been. This was unfortunate and unfair to participants who came to participate actively and openly in an open forum toward a common goal.

As a result of this Workshop, I hope that we can communicate in a more positive manner during the next few years. Data gaps that have been identified need to be filled, perhaps the diagnostic models that Dr. Douglas Segar referred to can be initiated, and eventually the entire database needs to be quantified and synthesized. Dr. Jerry Machemehl commented that "he had a vision"; my vision is that at some time in the future we can come to Dennis Padron, or one of the other engineers present, with "environmental design criteria." With knowledge of the ecological requirements of the resident species, biologists may be able to present engineers with the physical parameters such as: water temperature and salinity on either side of a structure must be maintained to within 1% of background 90% of the time; prevalent water circulation patterns must be maintained; etc. To some extent such data could be provided now, based upon our knowledge of the organisms present.

APPENDIX A

DISCUSSION GUIDES AND CHECKLISTS

OCEANOGRAPHY CHECKLIST

"A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA"

The objective of the synthesis meeting is to provide a forum for the peer review of data and conclusions relevant to (the potential effects of) nearshore structures, including the evaluation of the data's quality and its appropriateness to address the following specific hypotheses.

H^{O}_{1} Causeways[1] do not cause significant[2] adverse effects to the distribution and dynamics of oceanographic properties[3] nearshore[4].

H^{O}_{2} Causeways cause significant adverse effects to the distribution and dynamics of oceanographic properties nearshore.

DISCUSSION CHECK LIST

Properties (affecting habitat)	Processes
Nutrients	Wind
Salinity	Mixing
Temperature	Circulation
Turbidity	Upwelling/intrusions/entrainment
	Spacial (regional[5] and small scale[6])
	Duration
	Frequency
	Interaction of multiple causeways.

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[1] Causeways = Solid filled breached causeways

[2] Significant can have two meanings: 1) Statistically significant, i.e., measurably different. 2) Ecologically significant, i.e, different enough to cause changes of measurable ecological parameters.

[3] Seawater properties and water characteristics are used rather than the term "water quality," which has additional connotations not appropriate to these deliberations. The definition of seawater properties includes salinity, temperature, freezeup, breakup, and etc.

[4] Nearshore = Mean High Tide Level seaward to the 6 meters water depth.

[5] Regional = Beaufort Sea (US and Canadian)

[6] Small scale = Local or site specific

BIOLOGY CHECKLIST

"A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA"

The objective of the synthesis meeting is to provide a forum for the peer review of data and conclusions relevant to (the potential effects of) nearshore structures, including the evaluation of the data's quality and its appropriateness to address the following specific hypotheses.

H^B_1 The presence of causeways[1] does/will not significantly[2] affect the life cycle of anadromous fish populations.

H^B_2 The presence of causeways significantly affects the life cycle of anadromous fish populations.

DISCUSSION CHECK LIST

- Target species, abundance, distribution, and genetic stock identification
    - Anadromous species
        - Arctic char
        - Arctic cisco
        - Broad whitefish
        - Least cisco
    - Marine species
        - Arctic cod
        - Fourhorn sculpin
- Habitats, rearing, foraging, spawning, over-wintering, migration
- Movement/Migrations (spatial and temporal), transport/dispersal
- Transport/Dispersal
- Species composition changes
- Population dynamics and sustained yield consequences
    - Condition factors
    - Growth rates
    - Age structure
    - Reproduction
    - Recruitment
    - Mortality rates
- Harvest (commercial and subsistence)
- Natural variability
- Cumulative effects of causeways

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[1] Causeways = Solid filled breached causeways

[2] Significant can have two meanings: 1) Statistically significant, i.e., measurably different. 2) Ecologically significant, i.e, different enough to cause changes of measurable ecological parameters.

CAUSEWAYS AND ALTERNATIVES CHECKLIST

"A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA"

The objective of the synthesis meeting is to provide a forum for the peer review of data and conclusions relevant to (the potential effects of) nearshore structures, including the evaluation of the data's quality and its appropriateness to address the following specific hypotheses.

H^{CA}_1 Causeways[1] are the only technological, economic, and environmental feasible method to develop nearshore[2] oil fields.

H^{CA}_2 Causeways are not the only technological, economic, and environmental feasible method to develop nearshore oil fields.

DISCUSSION CHECK LIST

I. Technological design parameters

- Permafrost
- Ice forces
- Access
- Safety
- Control
- Water depth
- Soils
- Planning

II. Alternatives

- Breached causeways
- Elevated causeways
- Pile supported pipeline
- Sub-sea pipelines
- Directional drilling
- Tankering/offshore loading
- Utilidors

III. Environmental risk

- Regulatory constraints
- Cost analysis
- Installation/abandonment/removal
- Field size/characteristics
- Price forecasting
- Risk
- Operating costs

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[1] Causeways = Solid filled breached causeways

[2] Nearshore = Mean High Tide Level seaward to the 6 meters water depth.

APPENDIX B

REVIEWS BY REPRESENTATIVES OF THE NATIONAL ACADEMY OF SCIENCES

Institute of Marine Science

UNIVERSITY OF ALASKA FAIRBANKS

Fairbanks, Alaska 99775-1080

10 October 1989

Mr. Charles T. Mitchell
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, California 92627

SUBJECT: OCS Study, MMS 89-0038

Dear Mr. Mitchell:

I regret that I was not able to deliver my comments to you by August 31 as requested. I do hope that they will be useful to you as you prepare the final OCS document. Please let me know if you have any questions.

Sincerely yours,

John J. Kelley
Associate Professor
Director, NSF/PICO

JJK:kkt

Enclosure

Review of "A Synthesis of Environmental Information on Causeways in the Nearshore Beaufort Sea, Alaska"

Prepared by John J. Kelley, Institute of Marine Science and Director, Polar Ice Coring Office, University of Alaska Fairbanks

For the U.S. Minerals Management Office (MMS) and MBC Applied Environmental Sciences

General Comments about the Workshop

The intent of this workshop was to provide a forum for the peer review of data and conclusions relevant to the potential effects of nearshore structures, including the evaluation of the present data base quality and appropriateness for use in assessing the potential effects of nearshore structures.

The amount of scientific information related to causeways from the work of numerous investigators is impressive. The data bases are highly varied in their degree of completeness and presumably quality. The timing was perhaps appropriate for the MMS to sponsor a synthesis meeting to bring together all agencies who are concerned with the construction and deployment of causeways. The task of organizing such a conference devoted to the task of synthesis with so many diverse participants in the monitoring process is certainly a formidable one.

The basic organizational format was a reasonable one. Overviews of current knowledge made a lot of sense for presentation during the first day. These overviews served as focal points for discussion as to the merits or demerits of the existing data bases and their interpretation. It was not unexpected to find resultant controversy. Environmental science issues seldom result in absolute consensus. But out of such discussions we should be able to achieve a sense of status of knowledge or at least an opportunity for interdisciplinary dialogue. Therefore I believe that the presenters of the discussions on the physical oceanography and biology of the area set the stage for future discussion.

During the second day three concurrent workshops were held to address biological aspects of the data bases. Here, I believe, a serious shortcoming occurred that resulted in an impairment to synthesis. The hypotheses, a source of controversy themselves, were not discussed for appropriateness. There was a noticeable lack of organization and data presentation during this phase of the workshop to the point where a comment was made that it would be almost impossible to adequately derive anything of substance from this day's effort. This is indeed a serious shortcoming since these three working sessions offered an important opportunity to provide the basic structure for the hoped-for synthesis.

The third day was devoted to engineering aspects and alternate methodologies. Although the presentations were most instructive it was soon apparent that when questions of cost of alternatives were brought up there appeared to be great confusion.

Finally, the last day concluded with lead authors presenting summaries of the discussions and workshops. It is here that the effectiveness of these discussions was flawed as a result of the generally disorganized workshop discussions. The lead authors did the best they could with what they had.

Although a meaningful data synthesis was not achieved, this workshop did provide a forum for discussion of problems related to causeways. As such, it may have been a valuable forum for the exchange of ideas and strategies regarding future monitoring programs. It may be necessary to limit future meetings with synthesis as an objective to smaller groups who are prepared to disclose at least reasonable summaries of their data for peer review and discussion. A good example of one type of synthesis is the often-quoted Biological Papers of the University of Alaska No. 24 by David Norton on anadromous fish in Arctic Alaska and Canada. This is a peer reviewed document. The Alaska OCS Region Arctic Information Transfer Meeting Conference Proceedings (June 1988) was also another very useful document.

General Comments on the Report

It was apparent from open informal comments during the workshop that participation in the discussions was not totally free from concern about what comments would be made or what data could be freely presented. As mentioned earlier, future synthesis efforts should be more directed to the natural science (minus the political science) with statisticians participating since much of these data bases, especially the biological data, would benefit from statistical oversight at the time of presentation.

The section on synthesis is the most valuable part of this report. These syntheses serve as the only summary of what was discussed at the conference aided by post-conference documents and personal expertise. An executive summary would have been most helpful, especially for the physical oceanography and biological sections.

The synthesis section by Dennis Padron is somewhat addressed to a different subject, that of construction and engineering practice regarding causeways. Although the discussion is informative, it might belong to a separate workshop with a more directed group of experts and reviewers. Nevertheless, this section was included in the workshop and could probably be summarized adequately in an executive summary.

The three synthesis sections are quite uneven as to format and I suspect that this is a result of the general organizational problems associated with the workshop. The assessments presented should serve as a basis for a more fully effective scientific synthesis and peer review in the future, as suggested by Segar and Harville.

The section "What is a Causeway?" is useful but detracts somewhat from the issue and main purpose of the workshop--synthesis. Some of this section could be incorporated in an executive summary, the rest consigned to an appendix.

The "Presentation Abstracts" seem out of place and should be perhaps placed in an appendix. Niederoda and Colonell's article on "Coastal Boundary Layer Processes in the Central Beaufort Sea" is a very useful summary and review of basis coastal boundary layer dynamics. It seems out of place here in contrast to the other presentations.

I have commented on the inadequacies of the workshops earlier. The lead authors apparently share this concern. However, they are to be congratulated in providing what must have been a great amount of post-conference effort to prepare their articles. I especially call attention to the highly useful remarks of John Harville under "Conference Conclusions," p. 89 when plans for future synthesis meetings are contemplated.

Summary and Comment

This section is essentially the comment presented by the chairman immediately after the workshop. Although there are some useful remarks, the report would benefit more from the executive summary which would hopefully tie together the collective thought of the lead authors after they had an opportunity to digest what was presented.

It is apparent that many participants, particularly the lead authors, expended an enormous effort on this workshop. Although a synthesis was not achieved the effort should not stop here. I suggest that strong consideration be given to a future follow-up effort after consultation with the lead authors and others as appropriate.

If the report is published 'as is' with a bit of editorial housekeeping, then I fear that it will read quite disjointedly. In nearly every section there are statements of complaint and excuses for lack of input as well as very useful information. Intensive revision is needed and I fear that such a task must involve the substantial cooperation and participation of the lead authors.

UNIVERSITY OF ALASKA-FAIRBANKS
Fairbanks, Alaska 99775

October 27, 1989

Dr. C. T. Mitchell
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, CA 92627

Dear Dr. Mitchell,

Enclosed you will find the draft report of "Synthesis of Environmental Information on Causeways in the Nearshore Beaufort Sea, Alaska". I have not made a "thorough" review of the document; I only read the following chapters:

Physical Oceanography (of Synthesis section);
Movements and Migrations (of Synthesis section);
Ecological Relationships (of Workshop section).

I have included what comments I had in the text of these chapters.

The primary reason for the lack of a thorough review on my part is that the meeting was not a "synthesis" and the document reflects this. Drs. Harville and Maughn bring out quite well in their chapters that this was not the case. Therefore, I won't say more. A limited attempt was done by Drs. Segar and Allen. Even so the attempt fell short of what was needed to develop a synthesis. This is not a criticism of these two authors but gets to my point. The meeting title of the document does not reflect, no matter what the goal of the workshop was, the true nature of the document. It is a review of the proceedings, not a synthesis of environmental information. The current title will give readers a false impression of what they will be reading.

Sincerely,

W. E. Barber

W. E. Barber, Associate Professor
School of Fisheries and Ocean Sciences

REVIEW OF DRAFT WORKSHOP PROCEEDINGS

By: W.E. Barber, Associate Professor
School of Fisheries and Ocean Sciences
University of Alaska-Fairbanks
Fairbanks, Alaska 99775

Page #	Comments
Title Page	**Harville points out that this wasn't a real synthesis. Thus, a change in title is warranted** from "A Synthesis of Environmental ... to A Conference of Environmental..."
	For Syntheses section cover — **Not a Syntheses, it is a Review of presentations and limited synthesis**
Segar	
p.11; ¶2; ln7	Outside reviewers were not able, until some time after the workshop, to obtain copies of several critical reports reviewing the monitoring data ... **Lead author - not reviewer - it confuses**
p.11; ¶5; ln3	Additionally, ..., were apparently afraid to participate fully through fear of losing future business if they did ... **This was exemplified by one of the engineers**
p.15; ¶2; ln6	Since low salinity and higher temperatures are preferred or necessary habitat ... is further hypothesized to reduce or degrade habitat. **No evidence that physiological processes are negatively impacted**
p.15; ¶6; ln7	The deflection is apparent at both ... **evident**
p.16; ¶9;	West Dock appears to provide a more significant impediment to the alongshore flow ... based on the author's own experience in this community. **But would be a constraint; low salinity conditions west of causeway would originate only from west Sagavanirktok channels and not both channels and waters originating east**
p.17; ¶5; ln5	However, this scale is current poorly defined (i.e., a few tens of meters is probably not significant, the entire Beaufort shelf ... **Careful, this is a relative term and relative to the entire shelf it is very significant. The biology of char and Arctic cisco are known well enough to point this out.**
p.18; ¶2; ln10	Additionally, the Endicott causeway will presumably be removed when ...
p.19; ¶4; ln5	Therefore, parts of Simpson Lagoon would be affected by higher salinities and lowered temperatures under easterly wind conditions in the absence of West Dock. **This is a new twist and perhaps it should be expanded more. This subject is a major bone of contention.**

Page#	Comments
p19; ¶5; ln2	When winds switch to the west, the cold high salinity water in Stump Island Lagoon ... **coming from east or west**
p.19; ¶6; ln1	Under certain easterly wind conditions, a ~~tongue or~~ band of colder, higher salinity, surface water
p.20; ¶1; ln5	... the causeway is friction dominated and moves in the direction of the wind. ???
p.22; ¶12	**What about studies which couple oceanographic and ecologic/biologic components of nearshore ecosystem?**
p.23; ¶2; ln8	within the nearshore zone within a few kilometers of the causeways may experience small decreases in average temperature and small increases in average salinity due to the causeways. **Seems to be inconsistent or am I missing something?**
p.24; ¶2; ln4	In the case of causeways in the nearshore Beaufort, ... would be achieved by requiring additional breaching of the Endicott Causeway. **This was a major bone of contention at meetings. Engineers were adamant that the costs had to be based on exact site conditions. However, ?? gives broad estimates**
Allen	
p.21; ¶4; ln7	The objective of this paper is to summarize and evaluate the nature of some of the existing data and literature on the effects ... **Some of the literature. If did summarize, this document would be much longer**
p.22; ¶5; ln4	After reaching maturity, fish must then store ... (often without feeding) and to reproduce. **To my knowledge, hasn't really been demonstrated. If nothing else, separate FW phase from SW phase**
p.23; ¶3; ln9	... feeding and **nearshore riverine** overwintering sites in this area, ...
p.25;	EVALUATION OF EXISTING INFORMATION — **Change - not a true evaluation of information because original literature was not examined**
p.26; ¶3;	The local movement pattern ... is fairly well known. However, consensus ... regarding the validity, interpretation, and significance of many observed patterns. **Then it is not that well known**
p.28; ¶2;	Monitoring ~~of~~ this **yearly** migration ~~yearly~~ would improve understanding ... ~~Collection of~~ Additional oceanographic data should also be collected ...
p.28; ¶5;	However, there is insufficient information ~~at the present~~ to determine ...
Harville	
p.79; ¶2; ln3	This cannot have been an easy task, given the divergent missions, terms of reference, ... **Perhaps this should be expanded**
p.79; ¶6;	No citation section

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SCHOOL OF ENGINEERING

November 29, 1989

Charles T. Mitchell, President
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, California 92627

Dear Mr. Mitchell:

In accordance with our agreement of October 18, 1989 I have reviewed the Draft Workshop Proceedings titled "A Synthesis of Environmental Information on Causeways in the Nearshore Beaufort Sea, Alaska". During this review I had access to the documents listed below.

1986 Draft Report for the Endicott Environmental Monitoring Program, Volume 1, Prepared for U.S. Department of the Army, Alaska District, Corps of Engineers, Anchorage, Alaska, Prepared by Envirosphere Company, Anchorage, Alaska, September 1988.

1985 Final Report for the Endicott Environmental Monitoring Program, Volume 1, Prepared for U.S. Department of the Army, Alaska District, Corps of Engineers, Anchorage, Alaska, Prepared by Envirosphere Company, Anchorage, Alaska, November, 1987.

Causeways in the Alaskan Beaufort Sea, United States Environmental Protection Agency, Region 10, Prepared by Brian D. Ross, Fisheries Biologist, NEPA and Wetlands Review Section, Alaska Operations Office, Anchorage, Alaska, October, 1988.

Endicott Development Project Causeway Issues, An Evaluation of the U.S. Environmental Protection Agency Position Paper, Causeways in the Alaskan Beaufort Sea, BP Exploration (Alaska) Inc., Environmental and Regulatory Affairs, Anchorage, Alaska, February, 1989.

Beaufort Sea Causeway Issues: A Briefing Paper, Prepared by Craig Johnson, Alaska Region, National Marine Fisheries Service, For Washington Office, National Marine Fisheries Service, May 1988.

Assessing the Impact of Causeways on Beaufort Sea Fish, Comments on the National Marine Fisheries Service Report, Beaufort Sea Causeway Issues: A Briefing Paper, A White Paper Prepared by Standard Alaska Production Company, February, 1989.

An Analysis of the Effects of the West Dock Causeway on the Nearshore Oceanographic Processes in the Vicinity of Prudhoe Bay, Prepared for U.S. Environmental Protection Agency, Region 10, Alaska Operations Office, Anchorage, Alaska, by U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Assessment, Ocean Assessments Division, Alaska Office, Anchorage, Alaska, August 4, 1988 (Revised).

Final Report, Volume 1 of 4, Prudhoe Bay Waterflood Project Environmental Monitoring Program 1981, Department of the Army, Alaska District, Corps of Engineers, Anchorage, Alaska.

Final Report, Prudhoe Bay Waterflood Project Environmental Monitoring Program 1982, Department of the Army, Alaska District, Corps of Engineers, Anchorage, Alaska.

Final Report, Prudhoe Bay Waterflood Project Environmental Monitoring Program 1983, Department of the Army, Alaska District, Corps of Engineers, Anchorage, Alaska.

My review of the subject document is based upon the information available in the documents listed above, information gained while attending the subject workshop, and my background in the area of Arctic Engineering.

In general I found the Draft Workshop Proceedings (July 1989) to be an accurate representation, within the obvious limitations of the document, of the information presented at the workshop and that information contained in the above listed references.

I have a few comments which are listed below.

1. It would be helpful to present a map showing the coast line and water depths from the Mackenzie River to the Colville river. This would give perspective to the discussions regarding fish migrations and nearshore oceanography.

2. The oceanography sections would be much easier to follow if the author used more sketches to illustrate his discussions of the interactions involving wind, water, and salinity.

3. Authors discussing the direction of winds, water currents, and fish migrations should review their work to confirm that these discussions are clear to the average reader. Confusion is possible since wind

directions are noted as the direction from which the wind is blowing but the direction of water or fish movements is noted as the direction that the water and/or fish are moving.

4. On page 36 of the bound report Mr. Padron states that "Insulating the pipeline will moderate the thaw effect, but over a long period of time thaw will still occur." Although this statement is probably true for practical insulation values, it is not true for all insulation values.

5. There are several typographical errors within the report which I assume will be corrected during the final editing.

If I can be of further assistance in this matter please contact me.

Sincerely,

WG Nelson

William G. Nelson

A Review of the Draft Workshop Proceedings:

A Synthesis of Environmental Information on Causeways in the Nearshore Beaufort Sea, Alaska

Prepared for:

MBC Applied Environmental Sciences
947 Newhall St.
Costa Mesa, California 92627

and

Minerals Management Service
Alaska OCS Region
949 East 36th Ave, Room 110
Anchorage, Alaska 99508-4302

Prepared by:

Lewis Haldorson
School of Fisheries and Ocean Sciences
University of Alaska
Juneau, Alaska 99801

GENERAL COMMENTS

The objective of the workshop, as stated on page 1 of the introduction by C. Mitchell, was:

> "The objective of this Workshop was to provide a forum for the peer review of data and conclusions relevant to the potential effects of nearshore structures, including the evaluation of the present database quality and appropriateness for use in assessing the potential environmental effects of nearshore structures."

The success of the workshop in meeting these objectives depends on initial conceptual organization, adequate planning and preparation, efficient workshop agenda and protocols, the quality of contributions of the participants, and the abilities of the lead authors in reporting the results of the various sessions. After attending the workshop meetings, and reading the draft report, it is clear that, with the exception the last category, the workshop suffered serious flaws in virtually every category. Many of the problems are highlighted by lead authors of the Syntheses and Workshop Summaries sections of the draft report.

<u>Conceptual Organization.</u>

A basic question is whether or not the approach used in this workshop was appropriate to the objectives. At least one lead author felt very strongly that the format used was not appropriate. This reviewer agrees with J. Harville's comments on pp. 89, beginning with the statement "Future synthesis conferences should have the following characteristics", and going on to discuss who should participate, tasking, preparation and agenda.

In particular, participants should be those familiar with the available data. A review of the list of participants at the end of the draft report makes it perfectly clear that most individuals in attendance were agency or industry representatives who are policy makers or policy advisors, and not the scientists who generate and interpret data. This led to a politically charged workshop environment that was inappropriate to the objectives. I note J. Harville's comment on page 86:

> " .... it became clear that political rationales had restricted active participation at this conference to the extent that our synthesis objectives could not in good conscience be accomplished".

and D. Segar's statement on page 11:

"There are a variety of published or unpublished, but widely disseminated reports that describe the monitoring data for the West Dock and Endicott causeways and provide widely differing evaluations of the effects of posible effects of the causeways. These documents were not made available to the synthesis meeting participants before, or even during, the meeting. Instead, several of these documents were provided to the outside reviewers during 'lobbying' efforts by various workshop participants outside of the meeting process"

It appears that the basic organizational rationale for this workshop was inappropriate for the stated objectives, and severely limited the utility of the resulting report.

Planning and Preparation.

Preparation is crucial to workshop success, including selection of the key individuals such as the lead authors. It is clear that a decision was made to select as lead authors scientists who were not active in Beaufort Sea research, but who possessed the scientific background and demonstrated abilities to comprehend and write knowledgably about their areas of expertise. Given the political and scientific polarization on issues surrounding the causeways (as noted in the preceding section) this was probably a good decision. However, this approach requires that considerable background material be provided to those key individuals, and that they be given time to study and comprehend it. In the latter task the workshop organizers apparently failed, as the lead authors were not given access to the extensive data that exist for the subjects to be addressed. I note the statements of C. Mitchell (page 1)

"Each of the Lead Authors was provided with resource documents approximately two weeks prior to the Workshop. The documents were:
U.S. Minerals Management Service, Alaska OCS Region. 1988. Arctic Information Transfer Meeting Conference Proceedings, OCS Study MMS 88-0040 (June 1988).
Norton, David, ed. 1989. Research advances on anadromous fish in arctic Alaska and Canada. Nine papers condtributing to an ecological synthesis. Biological Papers of the University of Alaska No. 24, Jnauary 1989."

While these are two useful references, there are numerous other reports and publications that should have been provided, with considerable lead time, to an author in a workshop with the primary goal of evaluating the adequacy of available data. I note the comments by D. Segar (page 11):

"The most important shortcoming was that outside reviewers who were to participate in the peer review process were not provided adequate information before the workshop. ..... Outside reviewers were not able, until some time after the workshop to obtain copies of several critical reports reviewing the monitoring data and expressing alternate hypotheses, interpretations, and conclusions concerning the impacts of existing causeways."

O. E. Maughan (page 70):

"...we were told our function was to evaluate the adequacy of the data; but we were provided with only a smattering of the available data."

and J. Harville (page 82):

"Clearly this lack of completeness and balance in the materials available for our review fatally flawed the entire process, and made impossible any valid synthesis concerning either conclusions or the data base supporting them."

It is apparent that the principal authors were not provided adequate background material, that the materials were not available at the workshop, and that participation of those individuals conversant with data sources was limited - either by absence or the political pressures noted previously. This lack of preparation severely reduced the utility of the resulting report.

Workshop Agenda and Protocol.

The workshop was run in a professional and efficient manner, and the organizers deserve credit for achieving this; especially since the list of attendees was long, and logistics must have been complex. However, a number of problems in the agenda and its implementation appear to have interfered with attainment of the workshop objectives.

The presentations by individual scientists were informative, and in some cases were useful in addressing the objectives of the workshop. For example, the review of coastal boundary layer processes by A. Niedoroda and J. Colonell was very appropriate; and its inclusion as a full paper rather than an abstract adds significantly to the utility of the draft report. However, most of the other presentations, especially those dealing with anadromous fishes, were overviews of recent work by individual scientists or laboratories. While these were interesting, the purposes of the workshop would have been better served by reviews of work conducted in the past - it must be emphasized that the objective of the workshop was to examine the utility of the existing data. Given the fact that very limited background information was provided to the participants, the lack of review presentations was particularily troublesome.

The interdisciplinary workshops were held on the second day of the workshop. There was an advantage to holding these working-group sessions immediately following the first days meeting (the agenda of the first day was primarily oceanographic and biological). However, at least one principal author (J. Harville page 82) felt that having those sessions prior to the presentations on causeways and their alternatives (on day 3) was a severe handicap:

> "We were frustrated by the fact that our workshop discussions appeared out of phase with the overall program, taking place in advance of the all-day panels on causeway construction and engineering alternatives to causeways...."

The three interdisciplinary workshops were well organized, with two co-chairs, who were experienced Beaufort Sea scientists, assigned to assist each of the lead authors. This appears to have been an efficient and well planned procedure. However, the three Workshop Summaries suggest that the lead authors had different views of the workshop objectives, and they produced remarkably different workshop summaries. It appears that the lead authors were not given adequate direction or guidlines. In reference to the interdisciplinary workshops O. E. Maughan states (page 70):

> "The exercise was extremely frustrating because we were given no clear direction on what it was we were trying to obtain, other than to reach consensus. Second, we were told our function was to evaluate the adequacy of the data, but we were provided with only a smattering of the available data. Therefore, we spent a lot of time trying to define a direction."

<u>Contributions of Participants.</u>

There were numerous attendees who made substantial and extemely valuable contributions in various phases of the workshop, and the utility of the draft report was greatly enhanced by their efforts. On the other hand, contributions were limited by the absence of key participants and restricted participation of others. These problems were apparently very obvious, as most of the lead authors commented on them.

J. Harville (page 82):

> "Over the four day course of this conference, and particularily during the workshop phase (day 2) we became aware that only some of the papers, some of the researchers, and some of the agencies concerned were available for the reviews and discussions. We were lobbied vigorously in the hallways with allegations of suppression of information and

were given documents supporting these concerns. We learned that some participants were allowed to attend but not to speak."

O. E. Maughan (page 71):

"Throughout this conference there were hints that additional data sets and interpretations were not being presented to the outside reviewers"

D. Segar (page 11):

"A number of the scientists attending the meeting were constrained from open participation in the review process for purely political reasons. It was apparent that several scientists had been issued 'gag orders' by their employers. Additionally, many others, particularly consultants, were apparently afraid to participate fully through fear of losing future business if they did not faithfully support the relevant contractor's political position concerning the effects of causeways. It should be noted that these political constraints were apparent among scientists working for both private and governmental organizations."

It appears that contributions of many participants (or potential participants) was, in fact, less than complete; and that the lack of some inputs severely hampered the lead author's abilities to meet the objectives of their various sections. Consequently, the quality of the draft report is also degraded.

REPORTS BY LEAD AUTHORS

As noted by C. Mitchell (page 3) the papers included in the draft workshop proceedings are divided into three groups: 1) Syntheses - which incorporate workshop results and selected additional information obtained outside the workshop; these were authored by D. Segar, M. J. Allen and D. Padron. 2) Presentation Abstracts - abstracts of individual presentations from day 2 of the workshop. 3) Workshop Summaries - reports by the five lead authors on the results of their workshop sessions. In addition, there is an introductory paper by J. Colonell and a Summary and Comment by C. Mitchell. I will provide observations on the introductory paper, the Syntheses, the Workshop Summaries and the Summary and Comment.

What is a Causeway by J. Colonell.

This short paper is a very useful introductory section. It is generally well prepared, and subsequent papers should refer to it for details on existing causeways, rather than reiterating details of the West Dock and Endicott projects. Specific comments are:

Page 6, 2nd Para. - Dockhead 2 is not in Figure 2.

Page 6, 5th Para. - Statement that Artic Ocean is covered year round by thick layer of pack ice is inconsistent with statements in the following paragraph.

Page 8, 2nd Para. - Statement that many invertebrates migrate to shallow rivers seems incorrect. Whole paragraph needs to be examined for accuracy.

Page 8, 5th Para. - The statement that only sporadic biological and oceanographic investigations were done prior to 1981 is wrong. Several extensive projects in the OCSEAP program, in both disciplines, were conducted prior to 1981.

<u>Syntheses Papers.</u>

Physical Oceanography by D. Segar.

This oceanographic review paper is a valuable addition to the proceedings. As my oceanographic background is limited, I will make relatively few comments on this paper; however, some of the material presented here have important implications for subsequent papers and should be highlighted. I will also note that this paper gives a remarkably clear picture of the oceanographic processes occurring around causeways.

This paper contrasts the conditions at the West Dock and Endicott causeways, and points out that the West Dock has greater effects on nearshore oceanographic conditions than does Endicott. The author also demonstrates why this is so - one of the factors is that the Endicott causeway is in the middle of the Sagavanirktok River delta, with freshwater inflow on both sides. Consequently, if the objective of this workshop was to examine the general effects of causeways, the West Dock is more likely to represent typical causeway conditions than is Endicott, simply because the number of river deltas available for causeway construction is limited.

Movements and Migrations by M. James Allen.

This overview is generally useful and well prepared. A consistent problem throughout is the practice of citing other review papers as the source of information. Literature citations should reference the original sources of information. However, since lead authors were not provided with original reports and papers, the frequent references to review articles are not unexpected. Specific comments are:

page 21. Refer to lead paper by J. Colonell for details on existing causeways.

page 22 - 2nd paragraph. Homing in arctic fishes has not been widely reported. If specific examples are known they should be cited.

page 25 - 1st paragraph. This paragraph discusses a migration corridor as if it is well documented, and implies that it extends well offshore. If information is available that supports the concept of an offshore corridor is should be cited.

page 25 - 2nd paragraph. In reference to age 0 arctic cisco, data are said to be available on migration of fish of different sizes. Age 0 cisco are unlikely to show wide variation in size. I suspect the author is discussing all ages - if that is so it should be stated.

page 25 - 3rd paragraph. Statements in this paragraph imply that age 0 arctic cisco occur offshore. If there is any evidence that they are offshore it should be cited.

page 25 - 4th paragraph. The first sentence in the paragraph on genetic composition implies that the studies have shown that Alaskan stocks originate in the Mackenzie. What the electrophoretic studies have done is to show that the Mackenzie cannot be eliminated as a possible source of Alaskan arctic cisco. This is considerably different than demonstrating that Alaskan stocks originate in the Mackenzie.

Page 26 - 1st paragraph. The statement that overwintering occurs between the Sagavanirktok and the Mackenzie needs further substantiation. This would be a very important factor in the population structure of arctic cisco, and if conclusive evidence is available it should be provided or cited. If this is merely speculation it should not be included here.

Nearshore Beaufort Sea Causeways and Alternatives by Dennis V. Padron.

This paper provides a very useful summary of the possible ways to get oil off, and people and equipment on, offshore oil production facilities. The author states that his objective is to consider the technical and economic aspects of causeways and to evaluate the various alternative. He goes on to give an excellent review of the technical aspects of the various methods - in a manner that is understandable to a non-technical reader. However, the paper would be improved if it had concentrated on the technical aspects, and avoided the economic analyses. This is so because the economic comments are restricted to the gravel fill causeways, and the breaching in those causeways. Since the paper provides no way to compare the costs of the various alternatives, the economic section is relatively worthless. There surely must be economic analyses of the various ways of reaching offshore production facilities, and a separate paper presenting those analyses would be most welcome. At the workshop there was widespread dissatisfaction with the panel responses to questions about relative costs, and this paper does little to enlighten the concerned reader.

<u>Workshop Summaries.</u>

Physical Oceanography by Douglas Segar.

This brief paper is essentially an addendum to the extensive and valuable synthesis paper this author provided in the Syntheses section of the workshop proceedings. The author points out that evaluation of the adequacy of the data was hampered by the lack of many of the germain data sources. The author states that the data are available to acertain that causeways do produce statistically significant effects on nearshore hydrographic conditions. Nevertheless, his list of 8 recommended studies implies that understanding of oceanographic phenomena associated with causeways is less than complete.

Habitat by O. Eugene Maughan.

Page 68 - 4th paragraph. Makes an important distinction between optimum habitat and tolerances. The differences in utility between these two types of data should probably have been expanded upon here. Data describing optimum conditions are probably much more useful in assessing impacts than are data on tolerances.

Page 68 - 5th paragraph. States that objective was to evaluate the way structures affect fish. This probably reflects the lack of direction identified earlier. The major objective was to evaluate the adequacy of the data - although it can certainly be argued that the two objectives cannot be separated.

Page 69. The advice to identify limiting factors is appropriate. In fact, it would have been within the scope of the workshop to take this approach and see if data was adequate to address the possible limiting factors identified in this section of the paper.

Page 70 - bottom paragraph, and Page 71 - top. The tolerance matrix is of questionable utility. Tolerance data are probably inappropriate for the purposes of assessing the effects of causeways. It would be surprising if fish encountered conditions outside their tolerance ranges in the vicinity of causeways. However, significant impacts could occur due to sub-optimal habitat conditions resulting from causeways. It would probably be more suitable to identify optimum conditions, rather than conditions fish cannot tolerate.

Page 71 - comment 1). The author is correct in identifying the need for a synthesis of the data. A considerable step in that direction has been made in the compilation of a computerized data base that gives good coverage of previous work. This data base is described in detail in the first paper of the volume of

Biological Papers of the University of Alaska that was provided to the authors. Why this data base was not used in the workshop remains a puzzling question.

Page 71 - comment 2). The statement that at the inception of the monitoring program (which monitoring program is not stated) little was known about fisheries habitat is not accurate. Several extensive studies had been accomplished prior to monitoring at either the West Dock or Endicott causeways.

Movements and Migrations by M. James Allen.

This workshop summary appears to be in line with the objectives as stated in the introduction. Apparently this workshop session made significant progress toward analyzing the adequacy of data to address questions dealing with movements and migration.

Page 75 - last paragraph. The processes and mechanisms involved in the transport of fish apparently are not as well understood as the first sentence of the paragraph implies. This discrepancy is highlighted later in the same paragraph when the author points out that few studies have been done offshore.

Throughout this paper the author points out the various gaps in data available to address the concerns identified in this workshop session. The extensive list of high priority studies underscores the apparent lack of suitable data to address the effects of causeways.

Ecological Relationships by John P. Harville.

This paper reports the results of the ecological relationships working session and provides brief reviews of the papers in the volume of Biological Papers of University of Alaska No. 24 and the scientific presentations from the second day of the workshop.

Page 80. The review of the contents of the Biological Papers of the University of Alaska is probably not necessary. Interestingly, the one paper not mentioned is the first, which describes the database. This paper, and the database, were consistently ignored throughout the workshop; this continues to be a mystery, as the objective of the workshop was to evaluate the adequacy of available data.

Page 81. The review of the presentation papers is also probably not necessary. The abstracts are provided for them earlier in the workshop proceedings.

Page 83, 84. The participants in this working session made a decision to focus on the Endicott causeway and the data from

Endicott monitoring studies. This appears to have been a major mistake. As noted earlier in the presentation by D. Segar, the Endicott causeway is a special case because of its location in the middle of a river delta and is probably not representative of a "typical" Beaufort Sea causeway. The West Dock is probably a much better example, and a very extensive data base exists from the Waterflood Project monitoring that took place 1981 - 1984.

Page 84 - 2nd to last paragraph. Statement in this paragraph implies that the Colville and Sagavanirktok River deltas are equivalently important overwintering areas. This is not the case.

Page 86 - 89. The section on the EIS concerns of the Endicott project is a good summary of the potential problems associated with causeways, and the Endicott causeway in particular. However, it again emphasizes the preoccupation of this working group with the Endicott system, whereas more attention should have been given to the West Dock causeway.

Nearshore Beaufort Sea Causeways and Alternatives by Dennis V. Padron.

The objectives of this working session are stated in the third paragraph of the Introduction as: "...consider the technical and economic aspects of causeways and to evaluate the various alternatives". The following pages give no economic information, so it must be assumed that this session did not address that objective. The report is a good "capsule" summary of causeways and alternatives, but provides little additional information that was not present in the Synthesis paper by the same author earlier in the workshop proceedings.

Summary and Comment by Charles T. Mitchell.

This overview is important, as it is the only summary present in this proceedings volume. It is easy to imagine that many readers, wanting to know what was accomplished in this workshop but not having the time to read it all, will simply read this summary. I would strongly urge that an executive summary be included at the beginning of this volume, and that the lead authors of the sections write the appropriate sections of that summary.

Given the major problems that plagued this workshop, many of the conclusions presented in this summary seem unsupported and unjustified. The restricted access to appropriate data sets and the restricted participation in the workshop must necessarily invalidate conclusions about data adequacy. For example, the following statements appear in the summary:

> "During the workshop I have had the opportunity to attend all biological workshops for short periods and based upon the discussions it would appear that database is probably better than what was initially thought."

> ".... it appeared that the database provided by causeway monitoring programs contained most of the information needed to proceed with a reasonable evaluation of impact. The controversy at present revolves around the interpretation of the available database."

> "At present biological impacts or effects associated with the presence of these nearshore structures has been documented."

Such statements may not accurately reflect the content of the workshop proceedings and are not representive of what appears to have occurred at this workshop. I emphasize the need for an executive summary section that accurately reflects the contributions by the lead authors.

APPENDIX C

MEETING AGENDA

A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA
APRIL 17 - 20, 1989
ANCHORAGE, ALASKA

SYNTHESIS MEETING OBJECTIVE

The objective of the synthesis meeting is to provide a forum for the peer review of data and conclusions relevant to the potential effects of nearshore structures, including the evaluation of the data's quality and its appropriateness to address the following specific hypotheses.

AGENDA

April 16, 1989

6:00 - 10:00 pm **Reception/Orientation**: Speakers, Authors, Contractors, Coordinating Committee

April 17, 1989

8:00 - 8:30 am **Registration**

8:30 - 9:00 am **Meeting Introduction**

9:00 - 10:00 am **Panel Discussion: Physical Oceanography** - Status of Current Knowledge

Lead Author: Doug Segar
Panel Co-Chair: Lon Hachmeister
Panel Co-Chair: Jack Colonell

Speakers: Alan W. Niedoroda - Coastal Circulation
Roy Walters - Estuarine Circulation
David Aubrey - Estuarine Transport

Panel Member: Doug Fruge

10:00 - 10:20 am **BREAK**

10:20 - 12:00 pm **Panel Discussion: Physical Oceanography** - Summary of New Findings

Lead Author: Doug Segar
Panel Co-Chair: Lon Hachmeister
Panel Co-Chair: Jack Colonell

Speaker: Dwight Pollard

Panel Members: Roy Walters
David Aubrey

12:00 - 1:30 pm **LUNCH**

1:30 - 3:00 pm **Panel Discussion: Biology** - Status of Current Knowledge and Summary of New Findings

Lead Authors:
Eugene Maughan Habitats
M. James Allen Movements and Migrations
John Harville Ecological Relationships

Panel Chair: Charles T. Mitchell

Speakers & Panel Members:
Bill Bond Biology of Arctic Fishes
Jack McIntyre Fish Population Dynamics
John Bickham Fish Stock Identification
Doug Fruge 1988 Study Results
Richard Wilmot 1988 Stock Identification
Karl English 1988 Environmental Tolerance

3:00 - 3:20 pm **BREAK**

3:20 - 5:00 PM **Panel Discussion Continued:**
Biology - Status of Current Knowledge and Summary of New Findings

5:00 pm **ADJOURN**

A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA
APRIL 17 - 20, 1989
ANCHORAGE, ALASKA

APRIL 18, 1989

BIOLOGY WORKSHOPS

8:00 - 8:15 am	**Introduction to Day's Activities**
8:15 - 8:45 am	**Charge to Interdisciplinary Workshops** Meeting Chairman - Charles Mitchell
8:45 - 11:30 am	**Concurrent discussion sessions**

Workshop B-1 - Habitats

Lead Author:	Eugene Maughan
Workshop Co-Chair:	Tom Cannon
Workshop Co-Chair:	William Griffiths

Workshop B-2 - Movements and Migrations

Lead Author:	M. James Allen
Workshop Co-Chair:	John Bickham
Workshop Co-Chair:	Jim Reist

Workshop B-3 - Ecological Relationships

Lead Author:	John Harville
Workshop Co-Chair:	Benny Gallaway
Workshop Co-Chair:	Larry Moulton

11:30 - 12:00 pm	**Summary of Workshop Progress** (10 min. each)
12:00 - 1:30 pm	**LUNCH**
1:30 - 4:00 pm	**Reconvene Concurrent Discussion Sessions**

Workshop B-1 - Habitats
Workshop B-2 - Movements and Migrations
Workshop B-3 - Ecological Relationships

4:00 - 4:30 pm	**Summary of Workshop Conclusions** (10 min. each)
4:30 - 5:00 pm	**Discussion Period**
5:00 pm	**ADJOURN**

A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA
APRIL 17 - 20, 1989
ANCHORAGE, ALASKA

APRIL 19, 1989
CAUSEWAYS AND ALTERNATIVES

8:00 - 8:15 am **Introduction to Day's Activities**

8:15 - 8:45 am **Environmental and operational considerations associated with bringing offshore produced oil and gas onshore in the Beaufort Sea, Alaska**

Speaker: Dennis Padron

8:45 - 10:15 am **Panel Discussion: Gravel Filled Breached Causeways**

Speaker: Dennis Nottingham

Panel Co-Chair: Alan Christopherson
Panel Co-Chair: Jack Colonell

Panel Members: Barry Santana, Bernard Nidowicz, Will Nelson, Bucky Tart, Max Brewer

10:15 - 10:35 am **BREAK**

10:35 - 12:00 pm **Panel Discussion: Nearshore Structures** (i.e., Bridges, Pile-supported Structures, Docks)

Speaker: Dennis Nottingham

Panel Co-Chair: Alan Christopherson
Panel Co-Chair: Jack Colonell

Panel Members: Barry Santana, Bernard Nidowicz, Will Nelson, Bucky Tart, Max Brewer

12:00 - 1:30 pm **LUNCH**

1:30 - 2:40 pm **Panel Discussion: Subsea Pipelines**

Speaker: Robert J. Brown

Panel Co-Chair: Mike Hazlegrove
Panel Co-Chair: Leon Barry

Panel Members: Will Nelson, Max Brewer

2:40 - 3:00 pm **BREAK**

3:00 - 4:30 pm **Panel Discussion: Directional Drilling**

Speaker: Bob Price

Panel Co-Chair: Rusty McNicol
Panel Co-Chair: Tom Oostermeyer

Panel Members: Pat Havard, Max Brewer, Ted Stagg

4:30 - 5:00 pm **Discussion Period**

5:00 pm **ADJOURN**

A SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA
APRIL 17 - 20, 1989
ANCHORAGE, ALASKA

APRIL 20, 1989

SUMMARY SESSIONS

9:00 - 9:15 am	**Introduction to Day's activities**
9:15 - 9:45 am	**Physical Oceanography: Preliminary synthesis from panel discussions** Presented by: Dr. Doug Segar - Lead Author with Co-Chairs: Dr. Jack Colonell and Dr. Lon Hachmeister
9:45 - 10:00 am	Question and Answer Period
10:00 - 10:30 am	**BREAK**
10:30 - 11:00 am	**Biology - Habitat: Preliminary synthesis from workshop B-1** Presented by Dr. Eugene Maughan - Lead Author with Co-Chairs: Dr. Doug Martin and Dr. Larry Gilbertson
11:00 - 11:15 am	Question and Answer Period
11:15 - 11:45 am	**Biology - Movements and Migration: Preliminary synthesis from Workshop B-2** Presented by Dr. M. James Allen - Lead Author with Co-Chairs: Dr. John Bickham and Dr. Jim Reist
11:45 - 12:00 pm	Question and Answer Period
12:00 - 1:30 pm	**LUNCH**
1:30 - 2:00 pm	**Biology - Ecological Relationships: Preliminary synthesis from Workshop B-3** Presented by Dr. John Harville - Lead Author with Co-Chairs: Dr. Benny Gallaway and Dr. Larry Moulton
2:00 - 2:30 pm	Question and Answer Period
2:30 - 3:00 pm	**BREAK**
3:00 - 4:00 pm	**Causeways and Alternatives: Preliminary synthesis from panel discussions** Presented by Dennis Padron, P.E. - Lead Author with Co-Chairs: Alan Christopherson, Jack Colonell, Mike Hazlegrove, Leon Barry, Rusty McNicol, and Tom Oostermeyer
4:00 - 4:30 pm	Question and Answer Period
4:30 - 5:00 pm	**Synthesis Meeting Wrap Up**
5:00 pm	**End of Synthesis Meeting**

APPENDIX D

LIST OF ATTENDEES

ATTENDEE LIST

SYNTHESIS OF ENVIRONMENTAL INFORMATION ON CAUSEWAYS IN THE NEARSHORE BEAUFORT SEA, ALASKA

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.