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NEARSHORE AND ESTUARINE ENVIRONMENTS OF THE ALASKAN ARCTIC COAST: PARAMETERS FOR ENGINEERING SOLUTIONS

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ABSTRACT

Oil discoveries on the Alaskan "North Slope" have brought large scale industrial activity to the remote Arctic coast. Environmental restraints, both of a direct and of an ecological nature, limit the development of this resource. Engineering solutions to remove these restraints must be based upon a quantitative knowledge of environmental parameters. Existing nearshore and estuarine data, along with new data being gathered, are discussed in terms of these restraints. Particular attention is given to potential effects of oil pollution.

Thanks to the labors of many people over the years, a fair understanding of the Alaskan arctic exists. However, in light of environmental data needed for the industrial development of a wilderness, coherent data are badly lacking. This paper attempts to review the status of such environmental knowledge for the Alaskan arctic.

The technical problems of development are all potentially capable of satisfactory solution. The essence of controversy is the use and allocation of resources, both of crude oil and of wilderness.

INTRODUCTION

The nearshore areas of the Alaskan Arctic coast consist of extremely shallow offshore waters, extensive barrier islands, and estuaries of small, northward flowing rivers which drain vast expanses of permafrost tundra. These nearshore environments may first be characterized as aquatic. The shallow water extends far offshore, being typically only two-thirds of a meter as far as four miles offshore and ten meters ten miles offshore. No deep ports exist on the entire Alaskan Arctic coast, indeed none exist north of the Aleutian chain. Onshore, the environment is also predominately aquatic due to the great abundance of lakes, ponds, and streams. Black and Barksdale (1) have estimated that water covers from 50-75% of the western coastal plain and in some areas up to 90%. This aquatic environment persists despite only small amounts of precipitation (4-6 inches annually (2)) because of the low evaporation rate and the impermeability of the ground due to permafrost.

Secondly, this nearshore environment is severely cold stressed. Typical freeze-up to break-up times are over eight months, leaving less than three months for the open water summer. Even then the pack ice is close in to shore. Freight barges must then run the coast between shifting pack ice, which can be forced ashore by unfavorable weather, and the extremely shallow inshore waters, which preclude shelter.

The resources of the nearshore Arctic area have historically been harvested by the Eskimo as his only source of livelihood, with forced recognition of and compliance with the laws of this harsh environment. Development of the new resource of oil must likewise recognize environmental restraints. These restraints are of two types. The first type directly effects engineering structures and works; criteria are those of economics and personnel safety. The second type effects undesirable environmental changes; criteria vary from esthetics to the basic balances of life. Physical and biological parameters basic to engineering solutions to such restraints are discussed below.

NEARSHORE PHYSICAL REGIME

Hydrological

Offshore, the general oceanography of the Beaufort Sea, within the context of the total Arctic Ocean, is now reasonably understood. Coachman and Barnes (3, 4) have described the deep ocean water masses. The surface layer, well mixed from the surface to 25 to 50 meters, is much the same across the Arctic Ocean. The salinity, strongly influenced by the melting and freezing of ice, has a wide range from 28 to 33 parts per thousand. Seasonal variations in water properties are limited to this layer and range up to 2‰ in salinity and 0.2 °C in temperature. Average currents offshore in the Beaufort Sea are less than 0.1 knots (5) and to the west because of the large anticyclonic gyre in the Amerasian Basin of the Arctic Ocean. However, it should be noted that the water movement in the vicinity of and through the Canadian Archipelago is predominately from west to east, opposite of that along the Alaskan Arctic coast (6, 7, 8, 9). The brackish and relatively warm summer water developed by the MacKenzie River delta moves eastward towards Banks Island and the associated sediments of the MacKenzie lie in this direction also.

Close inshore, salinity data have been taken in the river-delta-lagoon complex (10) along the central Alaskan Arctic coast and strongly reflect both the estuarine character of this shallow, nearshore area as well as the radically different summer and winter conditions. Summer values of salinity off the delta and in the lagoons vary in the wide range of 10-26 parts per thousand, dropping rapidly to fresh water as one approaches the river channels in the delta. Winter and spring values, on the other hand, are sharply higher, due to essentially zero fresh water flow along with brine concentration because of ice formation. Typical Harrison Bay spring salinity samples under ice are in the range of 30 to 33 parts per thousand and values up to 35 to 40 have been found under ice in the delta. Arnborg et.al. (11) have documented the hydrologic season of the Colville River, including the cessation of the river flow in early October. In contrast, large north-flowing rivers such as the MacKenzie or Lena flow all year. One direct result (11) of the lack of winter flow is the replacement of the fresh water in the river channels of the delta of salt water during the late fall and winter months; the measured maximum salt water intrusion occurs at least 50 Km from the river mouth which includes the entire distributary system of the delta. In spring, approximately 43 percent of the discharge occurs during the three weeks immediately following breakup (11).

Few measurements of sea level changes have been attempted from the Alaskan Arctic coast, especially in winter. At Pt.

Barrow, an early, painstaking series was taken by Ray (12) in 1885 and a 60 day record was obtained by the Coast and Geodetic Survey in August and September, 1945. Beal (13) made winter measurements from 1955-1958; however these were all taken inside a well sunk in a sand spit with no direct ocean connection. Hunkins (14) has reported tide and storm surge observations from a grounded ice island. Matthews (15) has now obtained an almost continuous record of sea level variations at Pt. Barrow since September 1969. The mean lunar tidal range for the Alaskan Arctic coast is roughly a foot. At first sight then the tides appear not to be important along this coast. However, Matthews' records (15) show that the non-tidal components are of unusual dominance. These components are due to wind and pressure fields. Such storm surges can cause changes in sea level as much as five feet over a period of a few days. In addition to these storm surge effects, there are also steric effects (15) which result in seasonal variations of sea level. Such combinations of sea level changes can then be very important on such a coast where water depth may be only ten feet deep ten miles from the coast and where shore relief is also typically small. Observations, local Eskimo knowledge, and available data all indicate a strong correlation of high tides with a west wind.

Inshore, surface currents have been measured (10) and found to be closely coupled with the local wind, characteristically having dominant longshore components which may be either to the east or to the west depending on the wind. Such a nearshore current pattern in the vicinity of the Colville River delta is shown in Figure 2 as measured by surface drogues (10) under conditions of predominant northwest winds of about 15 mph. An example of a current transect of direct measurements of current speeds and directions made during this same time is shown in Figure 3. Current values vary from 0-0.7 knots for these mild weather conditions. In contrast to Figure 3, Figure 4 shows the same current transect a matter of hours after the wind had shifted to the west at 20 mph. A complete reversal of currents can be noted. Tabulated data of Searby and Hunter (2) illustrate the predominance of winds from an easterly direction, particularly during the open water periods, along with the mean wind speeds remarkedly constant at about 10-12 knots. Extreme wind speeds are of the order of 80 knots (2). Available data thus indicate that the nearshore currents are far from steady state as they are strongly influenced by local winds and probably by offshore pressure patterns. They show dominant longshore components, can move either to the east or to the west, but average to the west because of the predominance of winds from the east.

Understanding such hydrological variables is basic to a number of problems. The dominant longshore components of the wind driven coastal currents are important if oil spills should occur in these inshore waters. Nearshore ice movements during the period of open water can be expected to be similar. However, movement of the pack ice further offshore has the additional complications of floe interactions. The low tidal range, but with storm surge components important compared to shore relief, means that sparodic ice-push in winter and water-flood in summer effects beach movements and beach installations.

Geological

Geologically, the arctic coastal plain and its submarine continuation may be considered as a single unit. The emerged portion of the plain has a maximum width of approximately 90 miles at Pt. Barrow. Carson and Hussey (16) and Payne et.al. (17) have noted that the present day surficial deposits are underlain by Pleistocene (Gubik) silts, sands, and gravels. Moore (18) noted preserved beaches of Sangamon age at a height of some eight inches above present datum in the Cape Thompson area of the Chuckchi Sea. This would have been at some 70-100,000 years B.P. and there is indirect evidence to suggest that the general sedimentation pattern in the Arctic has remained unchanged since this time (19, 20). The stable sedimentation pattern indicated is undoubtedly a function of the uninterrupted presence of a polar ice cap over this period.

Considerably more is known of the recent stratigraphy of the arctic slope in the Chukchi Sea area, following the intensive studies carried out by Creager and colleagues (21). Maximum Wisconsin recession occurred some 15-20,000 years B.P. and subsequent post-Wisconsin history has been related to continual diminutation of the polar ice cap and hence more or less steady transgression of the terrestrial slope (21). There is no evidence for a land rise in the Chukchi Sea area (21) but good examples of raised beaches have been recorded in the vicinity of Barter Island (22) far to the east. The original Pleistocene sediments of the present arctic coastal plain have been reworked by the waters of ice-thaw lakes, by continuous lateral stream migrations, and by several minor marine transgressions (16). The present surficial deposits are thus basically lacustrine as a thin sedimentary veneer with a minor aeolian contribution. As might be expected, drowned estuaries are not uncommon.

Sediment data of the Beaufort Sea have been summarized to 1956 and analyzed by Carsola (9). Recently, additional data have been obtained and analyzed by Naidu et.al. (23). Almost all of the sediments are extremely poorly-sorted muds. However, there seems to be a significant textural difference between the muds of the slope and basin regions and that of the shallow shelf. The shelf is generally carpeted by positively-skewed, platykurtic gravelly, sandy muds, whereas the slope and basin essentially have mesokurtic sandy muds with nearly symmetrical size distribution curves. The common presence of gravels and coarse sand in the shelf muds, presumably from the coastal and barrier beaches, explains these differences and suggests that sediment transport to this region by ice-rafting is important (23). There is no conclusive evidence to hypothesize the nature of the gravels deposited in the shelf area of the Beaufort Sea - whether they are relict (Pleistocene) or contempory (Holocene); however Naidu et.al. (23) conclude from the sediment types across the shelf that the gravels are indeed contemporary and have been transported by ice rafting. The shelf sediments have relatively low organic carbon contents (average 0.95%) and average about 4.8% carbonate (23).

As might be expected, the geology and morphology of arctic beaches are also highly distinctive. A good review of characteristics of such beaches has been given by Nichols (24). This author has tabulated in particular the following features which are well represented on the Arctic coast: 1) the presence of underlying permafrost, 2) beach ridges formed by ice-push, 3) poorly rounded material, and 4) frequent breaching of beach ridges caused by spring thaw floods. Moore (20) also has stressed the importance of local "kaimoo" formation whereby a stable ice-beach material rampart is formed each fall which tends to protect hind areas from wave erosion prior to final freeze-up. Throughout the winter months, the beaches are generally protected from severe ice action by the fast ice formed at the margins. However, the common presence of ridges illustrates that such protection is not complete. Hume and Schalk (25) have estimated that sea ice pushed by on-shore winds affects some 1-2% of the Arctic beaches. Rex (26) and Greene (27) have described microrelief structure caused by sea-ice grounding and shore fast ice.

Along the central arctic coast, data have been taken on beach sediments and structures in the vicinity of Oliktok Point, just east of the Colville delta, and on Thetis Island just offshore, Dygas et.al. (28). Sediment on the beaches of the Colville River delta coastal plain, particularly in the vicinity of Oliktok Point vary from sand to gravel. The sediment size distributions, Figure 5-7, are predominately bimodal. Beach sediments at the spit at Oliktok Point contain the greatest percentages of gravel.

The foreshore, the sloping part of the beach lying between the berm and the low water mark, is less than six feet wide, the apparent result of low tidal range and wind velocities from 0-20 mph. However, as noted above, storm surges are capable of flooding a considerable portion of both beaches and tundra. Both berm crest and backshore samples were similar to foreshore samples. Two such beach profiles (28) are shown in Figure 8, one showing the remnant of previous ice push.

Not much is presently known about the rates of long shore sand and gravel movement or about rates of supply, other than that large catastrophic effects are associated with storm surges. Thus the use of such material from beaches and offshore islands has unpredictable effects. Also, the movement and deposition of terrestrial sediments has a very marked effect on benthic organisms (29), thus changes in shore erosion effect such organisms. Such topics are under study.

BIOLOGICAL REGIME

Primary Producers

At the very basis of an ecological system is the first level of the food chain, the photosynthetic fixation of carbon. Historically, Arctic Ocean primary production of fixed carbon has been considered low although it has subsequently emerged that many of the photosynthetic organisms of the Arctic are minute in size and missed in net plankton tows. Braarud (30) suggested the limiting factor for primary productivity was low submarine radiation due to the presence of ice and demonstrated that the surface waters of the Arctic Ocean are not rich in inorganic nutrients as had been supposed. Marshall (31) documented the outburst of phytoplankton which follows the receding ice. Corlett (32) similarly found that arctic spring productivity was relatively high, and Berge (33) came to a similar conclusion for the Norwegian Sea. However, English (34) concluded that the total annual production in the Arctic Ocean is very low relative to other ocean areas. The production season is short and all indices of productivity are low. He feels that the limiting amount of submarine illumination is an adequate explanation. Although English found relatively low nutrient levels in the surface polar water, he did not find experimental confirmation for any nutrient limitation. All the available information tends to confirm as expected low annual primary productivity with, nevertheless, rather high primary production rates for short periods under certain conditions. The role of the sea ice appears to be significant since such ice frequently contains a large number of diatoms which appear as a brownish layer a few centimeters above the bottom surface of the ice (Meguro et.al., 35, 36). The chlorophyll values in this ice layer were from 40 to 100 times greater than in the sea water around the ice. The habitat in the ice is a microbrine cell encased in ice crystals, and some of the nutrients supplied are thought to come from desalination of sea ice. Selective absorption of radiation by the brown layers tends to cause rotting and the layer may become detached resulting in a sudden blooming of phytoplankton under the ice. This production may, subsequently, support the rather large zooplankton populations which are found in the arctic waters.

Detailed observations of the actual phytoplankton populations and their species compositions have been made in the Cape Thompson area (37) and observations were made here on brackish and fresh water lakes (37) but details of productivity were not included. More is known about the biology of small coastal arctic lakes, including a fair body of data dealing with the lakes in the vicinity of Pt. Barrow. Boyd (38) and Boyd and Boyd (39, 40) have concentrated on microbiological studies in arctic coastal lakes. Comita (41), Comita and Edmondson (42), Edmondson (43), Frey and Stahl (44) and Kalff (45, 46) have all studied either the primary productivity or the plankton in such lakes. The chemical characteristics have been studied by Kalff (47). Reed (48) has made plankton collections and limnological investigations in numerous fresh water lakes and ponds, in particular the Colville River complex.

Recently, data of a brief preliminary survey of primary productivity, estimates of plant biomass and diversity (by plant pigments as well as direct counts) and of concentrations of nutrients in the waters of the Colville River, Simpson Lagoon, and nearby fresh water lakes have been given by Alexander and Schell (49). From the fresh water data the following general observations were noted:

1) Dissolved oxygen levels appear to be high and no great depletion or supersaturation is indicated, nor were there any great differences between lakes and streams.

2) pH ranged from 7.0 to 9.0 for the lakes and streams with a mean of 7.7 and from 6.5 to 8.5 for the following rivers with a mean of 2.8. Similarly, the overall alkalinity range does not differ much between types of water, the mean alkalinity is somewhat higher than for the lakes. The variability and range are large, 30-137 mg $CaCO_3$/l.

3) Chlorophyll values are quite low in the river, and somewhat higher in the lakes.

4) The primary productivity rates are in general extremely low, which would be expected on the basis of the low plant pigment levels. However, the photosynthetic rate per unit chlorophyll mass also appears in general to be low. Nutrients, as a limiting factor would be a likely explanation as evidence of Kalff indicates.

Work in the brackish lagoon was incomplete, however, May and August sampling (ice and open water conditions) showed chlorophyll-a levels up to 14.6 μg/l, indicating high primary productivity potential.

The three habitats sampled for direct counts of phytoplankton organisms (pond, river, and marine) are distinct (49). The lakes show the greatest variety of plankton and also the largest populations, often an order of magnitude higher than the rivers. In general, the Oliktok plankton differed from those seen in the river in being chiefly marine forms. The most abundant organisms were usually some combination of the following: Chaetoceros wighami, Diatoma elongatum, Gyrosigma spp., Nitzschia delicatissima, Nitzschia closterium, Thalassiosira spp., Various small pennate diatoms, Platymonas sp., An unidentified 3 micron Flagellate, and 2 micron flagellates.

Several organisms appeared to be identical to those seen in the Colville River, and they occupied a small fraction of many of the samples. Examples of these fresh water forms are Ceratonies arcus, diatoma elongatum, Rhodomonas sp., Cosmarium sp., Ankistrodesmus falcatus, Arthrodesmus sp., Chromulina sp., Cryptomonas sp., and Dinobryon sp.

Generally, diatoms are the most numerous fraction in the river samples. A variety of small pennate diatoms usually composed the largest fraction of the diatom count. Only in three samples (Colville River below Killik River, Fossil Creek, and Seabee Creek) were flagellates more numerous than diatoms. In all three samples the major flagellate was a small 3 micron organism (Kephyrion sp.) common in all the lake samples. All the organisms identified in the river samples were seen in lake samples with the possible exception of Ceratonies arcus.

Nutrient concentrations are also given for estuarine and marine waters (49).

The seasonal trends of nitrate, nitrite, phosphate, and ammonia concentrations in Harrison Bay water near Thetis Island are given in Figure 9. During the winter the concentrations of phosphate, nitrite, and nitrate increase while ammonia remains near 0.5 μg-atoms NH_3-N/liter. The appearance of summer conditions brings a decline in nitrate, nitrite, and phosphate but the ammonia levels increase sharply to near 4 μg-atoms NH_4-N/liter. This effect is primarily due to uptake of the nitrate and phosphate by phytoplankton followed by recycling of the nitrogen as ammonia. However, much of the decrease in nitrate or phosphate concentration can be ascribed to the melting of the ice cover and subsequent dilution by wind mixing with the underlying water.

Comparative summer and winter data (49) show that the major portion of the fixed nitrogen and phosphorus is present as dissolved organic N and P in the nearshore waters, rather than the inorganic species as in the case of more temperate waters. The availability of the combined N and P as nutrients for phytoplankton growth has not been measured in these waters but Schell (50) has demonstrated such utilization of N by subarctic marine diatoms. The possibility also arises that the dissolved organic matter may serve as a carbon source for wintering microorganisms. Utilization of the carbon with nitrogen being released as ammonia followed by nitrification of the ammonia could be one possible process for regeneration of nutrients in the estuary system. As explained below there is distinct circumstantial evidence that this process may be occurring at a rapid rate in the delta channels.

In the Colville delta channels, the cessation of river flow in the early Fall coupled with storm surges associated with westerly winds provide a mechanism by which the fresh water left in the delta channels from the summer's flow is gradually replaced by seawater. The effects of the winter isolation on the nutrient concentrations and salinities in the entrapped water is very pronounced. Salinity variations from 10-38°/oo have been measured in the delta channels. Measured summer nutrient concentrations in the fresh water river flow were nil for nitrate and less than 1.0 μg-atom N/liter for either nitrite or ammonia. Phosphate concentration was in the range of 0.1-0.2 μg-atoms P/liter. The dissolved organic nitrogen, however, was in the order of 10 μg-atoms N/liter, thus constituting the greatest fraction of fixed nitrogen. After the onset of winter conditions, the nitrate level rose to about 10 μg-atoms NO-N/liter by December and by May was at 30 μg-atoms NO_3-N/liter. The highest value, 31 μg-atoms NO_3-N/liter was found immediately prior to breakup. If the water sampled in the Colville channels was essentially stagnant during the winter months, this represents the regeneration of approximately 6 μg-atoms NO_3-N/liter per month between November and March. Some of the apparent increase is certainly due to freeze concentration from the thickening ice cover but the large increase in nitrate must be primarily due to regeneration in situ. Unfortunately, dissolved organic nitrogen concentrations were not determined on Colville River samples prior to August 1970, so as yet it cannot be determined if the dissolved organic nitrogen was the source of N oxidized to nitrate. By elimination of ammonia and nitrite, both of which were never measured above 4 and 1 μg-atoms N/liter respectively prior to May, the argument is strong for the ammonification of dissolved organic nitrogen immediately followed by oxidation to nitrate. Salinity measurements indicate that the concentration factor due to freezing is probably about 1.5-2.0 if it is assumed that the seawater which replaces the fresh water has a salinity of approximately 25°/oo, a reasonable figure for Harrison Bay water.

Average nutrient concentrations in the Colville River delta are shown in Figure 10. Phosphate is interesting in that concentrations increase during Fall and then drop to undetectable levels by March and remain so until breakup. The mechanisms causing this depletion have not been determined. The appearance of fresh water brings with it higher phosphate concentrations.

Additional work underway by the above authors, by Horner (51) on arctic phytoplankton, and by the aquatic portion of the

International Biological Program Tundra Study at Pt. Barrow (52) on tundra ponds. Hopefully, all this work will make predictions on effects of disturbances by man on productivity and predictions on such topics as degradation of waste products possible.

Higher Organisms

Studies of higher organisms provide a less basic but more direct method of predicting and noting ecological effects of man's activities. Good quantitative data are needed for such work and of sufficient magnitude to be statistically valid. Unfortunately, the state of most such data for the Alaskan Arctic is in the form of descriptive or survey material. The most pragmatic and useful results of new surveys of fish, birds, invertebrates, etc., by agencies concerned with oil development are just now beginning to become available in preprint form. However, the aggregate of this data must eventually be used to guide development as wisely as possible.

Invertebrates - A fair amount of invertebrate surveys have been carried out in the Alaskan arctic. For example, Johnson (53) has analyzed zooplankton collections which were made by the USS BURTON ISLAND in the Beaufort and Chukchi Seas and has listed 33 species of copepods along with their observed numerical abundance and distribution. Hand and Kan (54) studied the medusae collected on the same expedition and described 11 species. Bowman (55) and Barnard (56) studied amphripods. Grainger (57) studied copepods in Canadian arctic waters. Zooplankton in Nuwak Lake near Pt. Barrow were intensively studied by Matsudo and Mohr (58) and Mohr (59).

The most intensive collection and description of invertebrates in the Alaskan arctic is that of McGinitie (29) in the Pt. Barrow area. McGinitie was impressed with the abundance of marine invertebrate life, particularly in the rocky areas near Pt. Barrow. In all he collected 722 species of invertebrates and notes their general importance in supporting marine mammal populations.

Recently, Crane *et.al.*, (60) have sampled both inside and outside the barrier islands along the central Alaskan arctic coast using benthic tows and small bottom grabs.

From preliminary analysis it appears that the primary epifaunal organisms are a giant isopod *Mesidotea entomon*, assorted amphipods, and a mysid, with some stalked hydroids also common. The primary infaunal organisms sampled with the small grab were two mollusc species and three polychaetes. In the lagoons proper, life becomes scarcer as one goes shoreward with the sandy, nearshore areas especially sparse. More organisms are found in the deeper, silty trough areas. Organisms outside the barrier islands appear to be much more abundant than those in the lagoon.

Fish - Although Wohlschlag (61, 62) did early work on arctic fishes in the Barrow region and work was done in the Cape Thompson area (63), most of the intensive survey work in the lakes, streams, and estuaries is still underway by various agencies and results are preliminary and still fragmentary. For example, Kogel (64) worked the drainages of the Colville River in the summer of 1970 and reports on relative abundance, distribution, age, growth, and sexual maturity of some 22 species, including valuable data on spawning runs of such species as whitefish, grayling, and arctic char. Work continues the summer of 1971 in the Sagavanirktok drainage (65). Other similar studies are those of McCart and Tepper's (66) survey of the pipeline route and that of Gavin (67) in the Sagavanirktok drainage.

Major points of concern are gravel removal operations, silting from construction activity, destruction of spawning beds or interruption of spawning runs, and rapid containment of any spilled oil.

Birds - The nearshore and coastal environments of the Alaskan arctic coast are rich in bird life. Aquatic birds are noteably vulnerable to oil spills. Less well known, however, are vulnerability of various species to disturbance in nesting areas. No complete treatment will be attempted here other than to note that results of new surveys are becoming available on species, numbers, distributions, and breeding activity of birds along the Alaskan arctic caost, Bartonek (67), Gavin (68). Data are not in quotable form (67) as yet. However, differences in numbers concentration, possibly due to differing survey methods are noted. Also, concern and cautions are expressed for coastal species because of nesting, moulting, or feeding activity along a relatively narrow coastal band.

OIL POLLUTION CONSIDERATIONS

As in other environments, oil related structures will have to be designed to meet environmental restraints of both types mentioned. As in other environments, the setting of reliability criteria for environmental protection against oil spills is an inexact task based upon usually insufficient data. However, several differences need to be considered because of the arctic environment.

First, a topic of primary concern must be the methods and rates of movement and dissipation of crude oil in the different aquatic, often ice covered waters of the arctic nearshore area. Some interesting experiments have been conducted by the Coast Guard (69) in this regard by experimental spills on sea ice, which indicate ice may inhibit the spread of an oil spill making recovery easier. On the other hand (70) lack of turbulence because of ice may severely inhibit bacteriological degradation.

Secondly, how efficient and complete will biodegradation of spilled crude oil in the arctic be? Subarctic data (70) indicate that such degradation may proceed at acceptable rates in spite of low temperatures only if sufficient mixing energy is provided. In spite of negative biodegradation potential reported by the Coast Guard (69), Button's data (71) indicate a normal population of oil degrading microorganisms from marine waters of the Alaskan coast.

Thirdly, what will be the effects on arctic organisms upon introduction of crude oil into such an ecosystem? Toxicity data, especially at low levels likely to be encountered by organisms, are almost non-existant in any environment. However, many expect the arctic systems to be somewhat more vulnerable because of the simplicity and lack of diversity with associated close interdependence of organisms.

Because of the dominant long shore components of the nearshore currents and of the heavy use of a relatively narrow band of coastal area by many birds, operations and spill possibilities in this nearshore area should be especially guarded.

The technical problems of development are all potentially solvable. The essence of controversy is the use and allocation of resources, both of crude oil and of wilderness.

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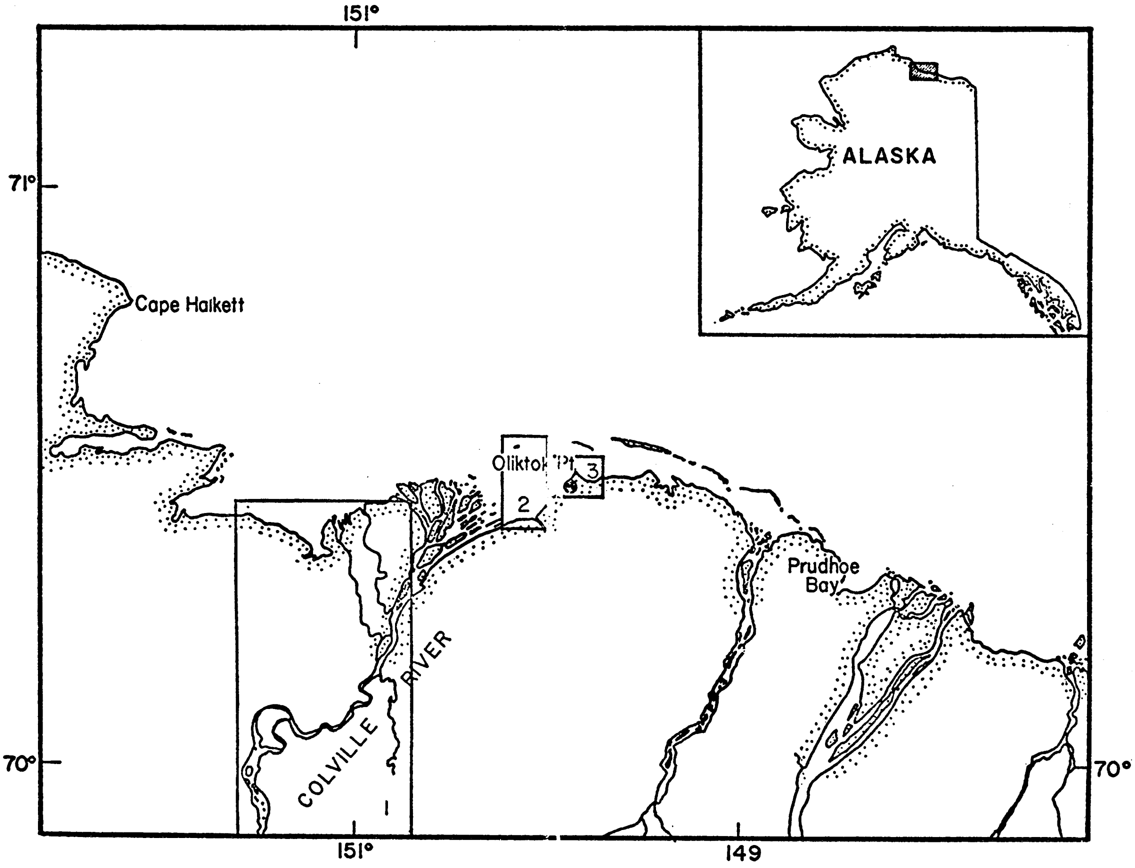


Figure 1 Map, Alaskan Arctic Coast

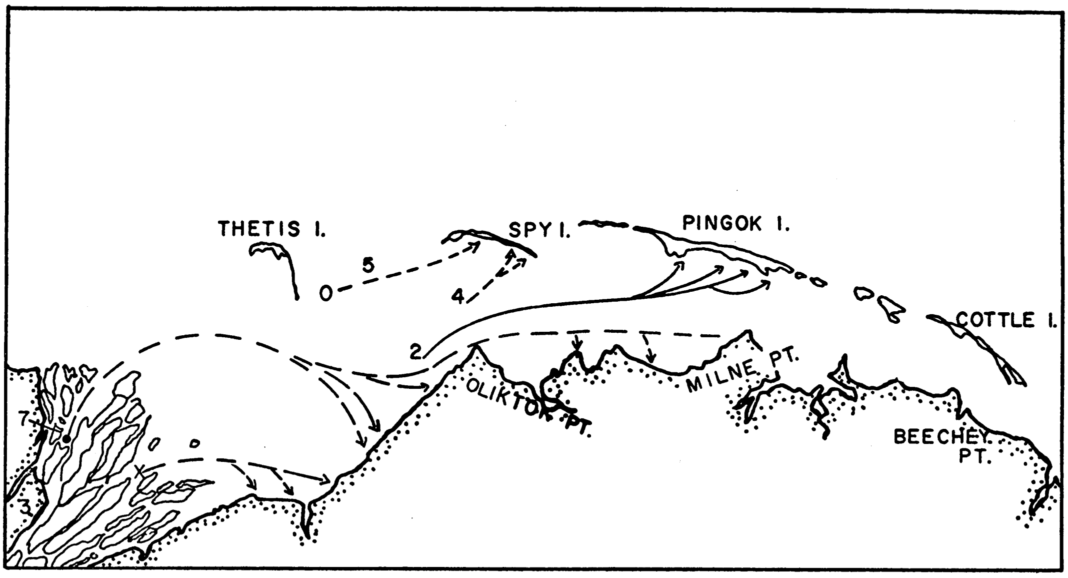
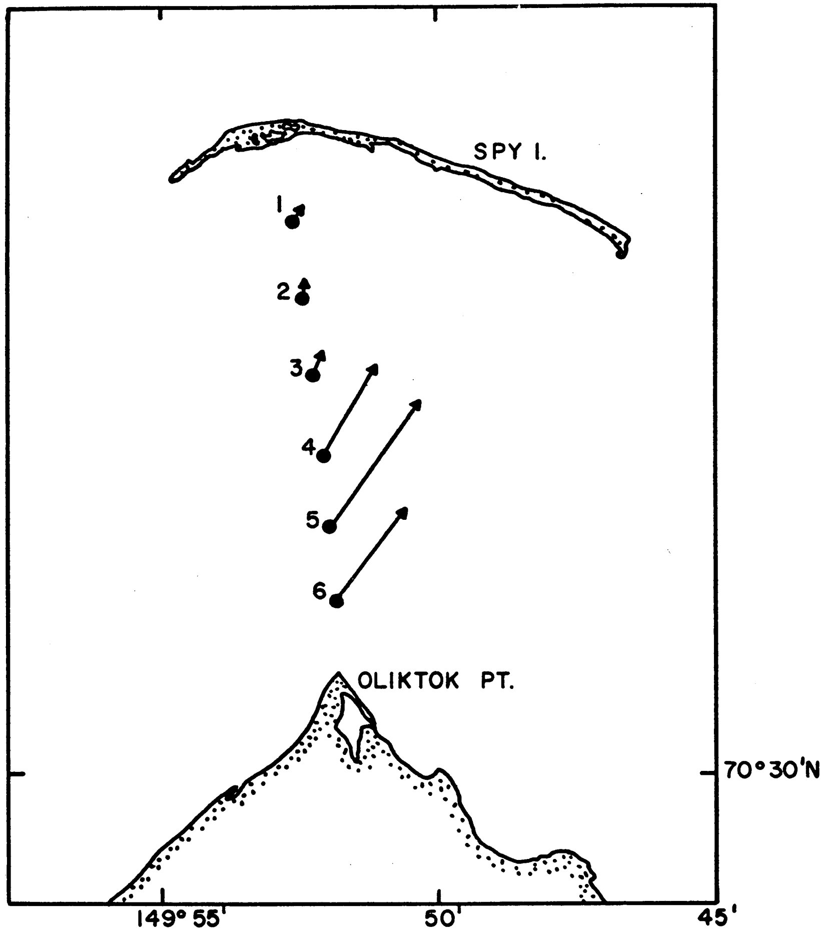
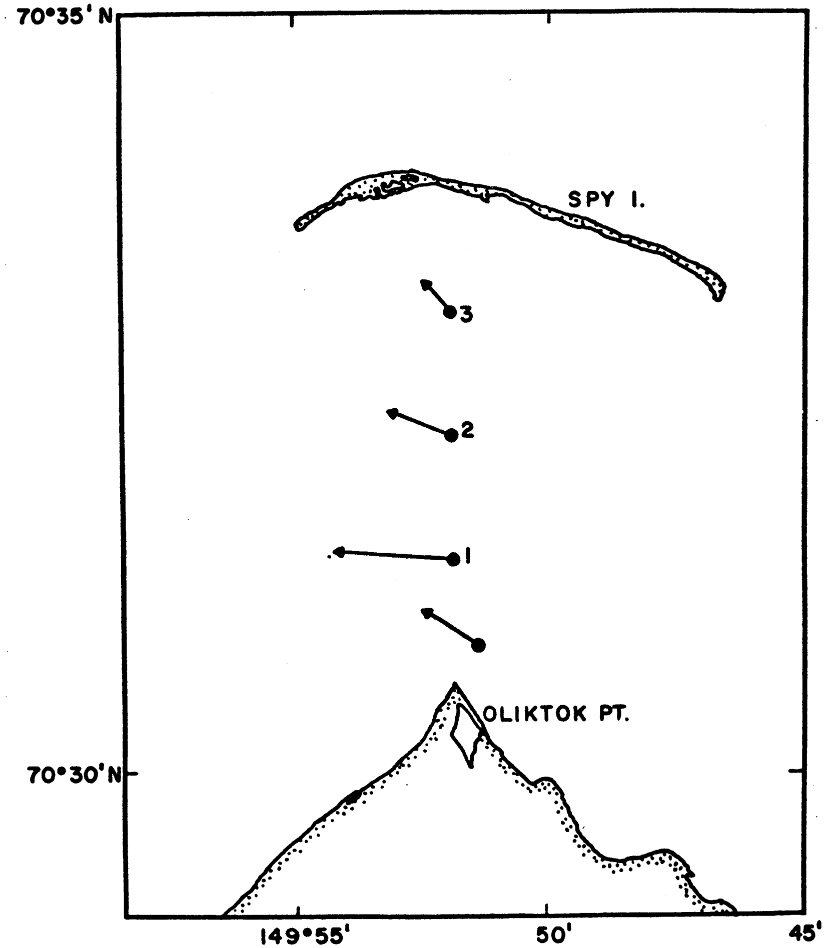


Figure 2 Typical Nearshore Current Pattern



10 cm/sec velocity

Figure 3 Current Transect; Northwest Winds



10 cm/sec velocity

Figure 4 Current Transect; Northeast Winds

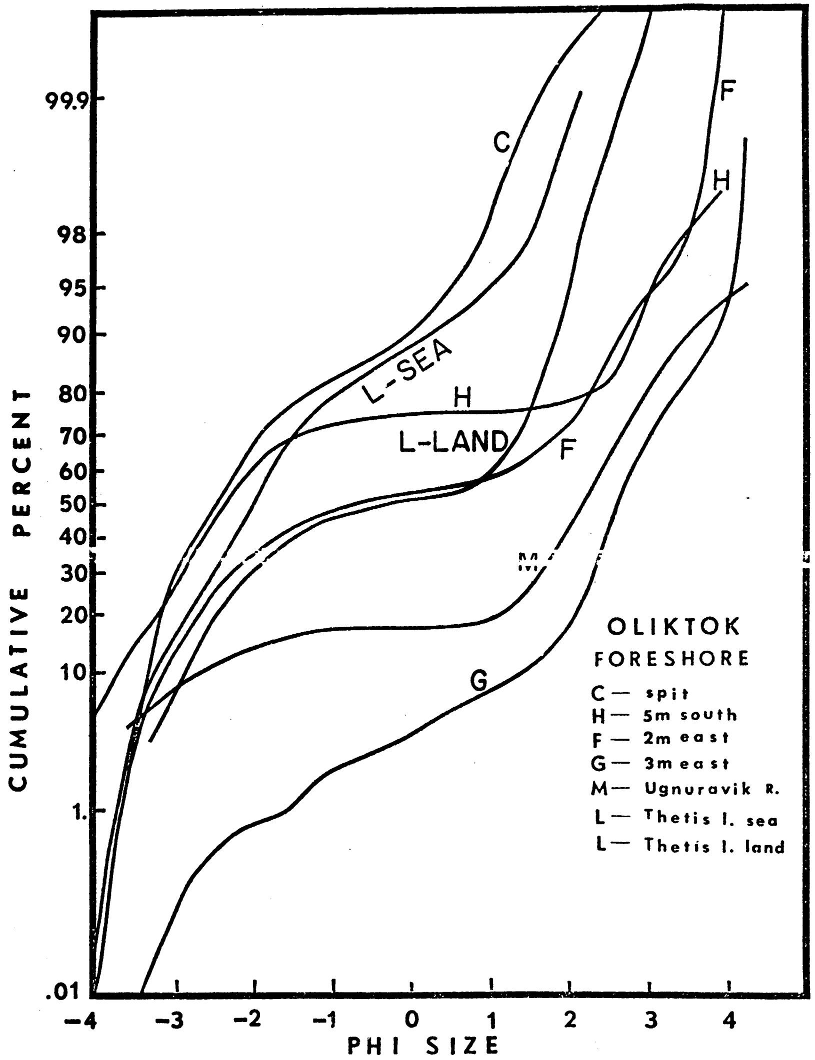


Figure 5 Beach Sediment Sizes, Foreshore

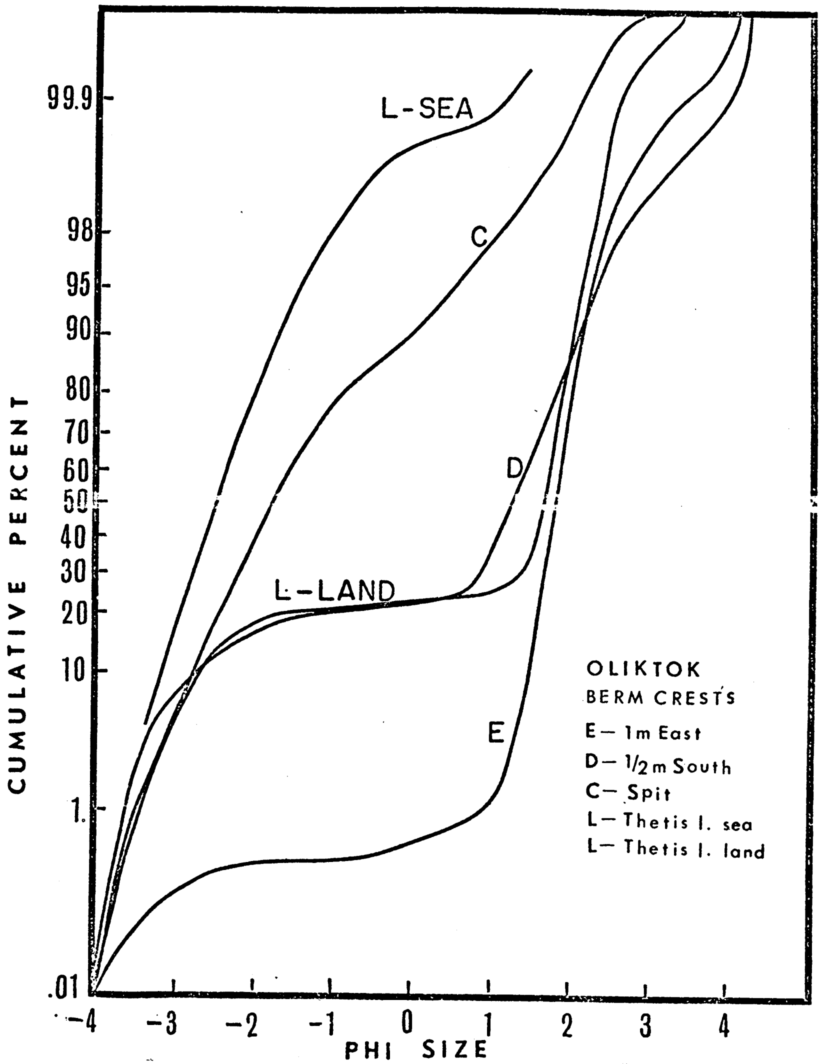


Figure 6 Beach Sediment Sizes, Berm

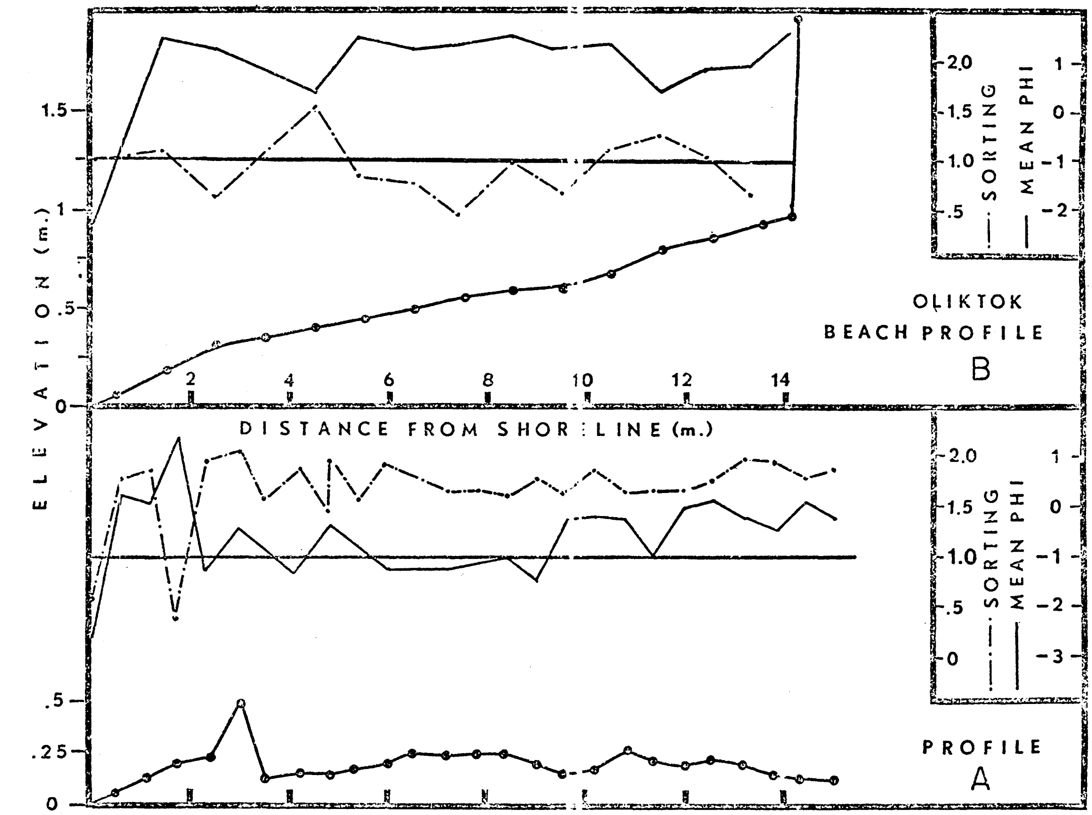


Figure 8 Beach Profiles

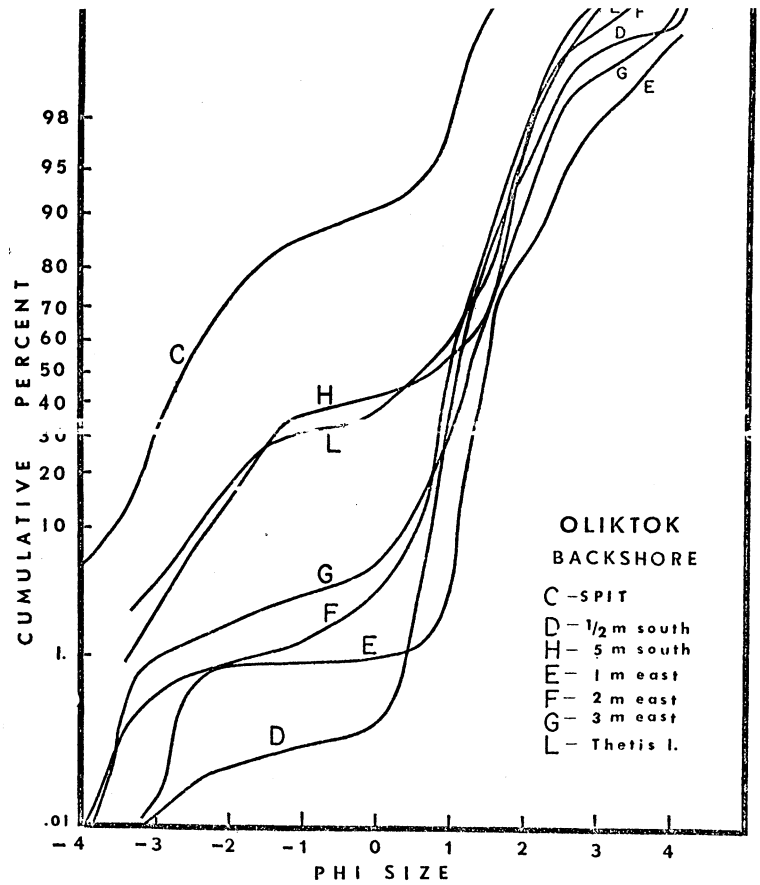


Figure 7 Beach Sediment Sizes Backshore

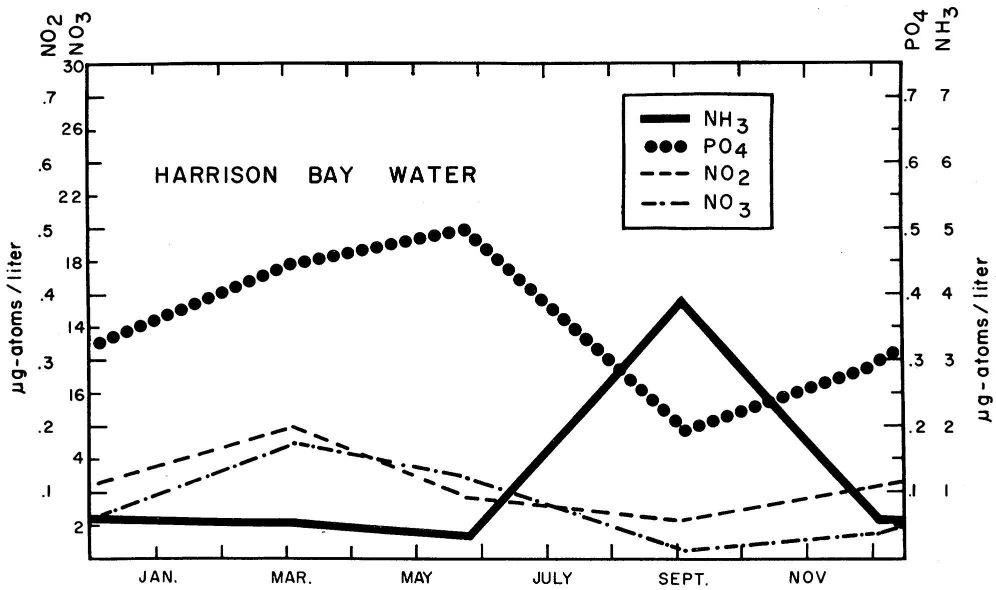


Figure 9 Harrison Bay Water Chemistry

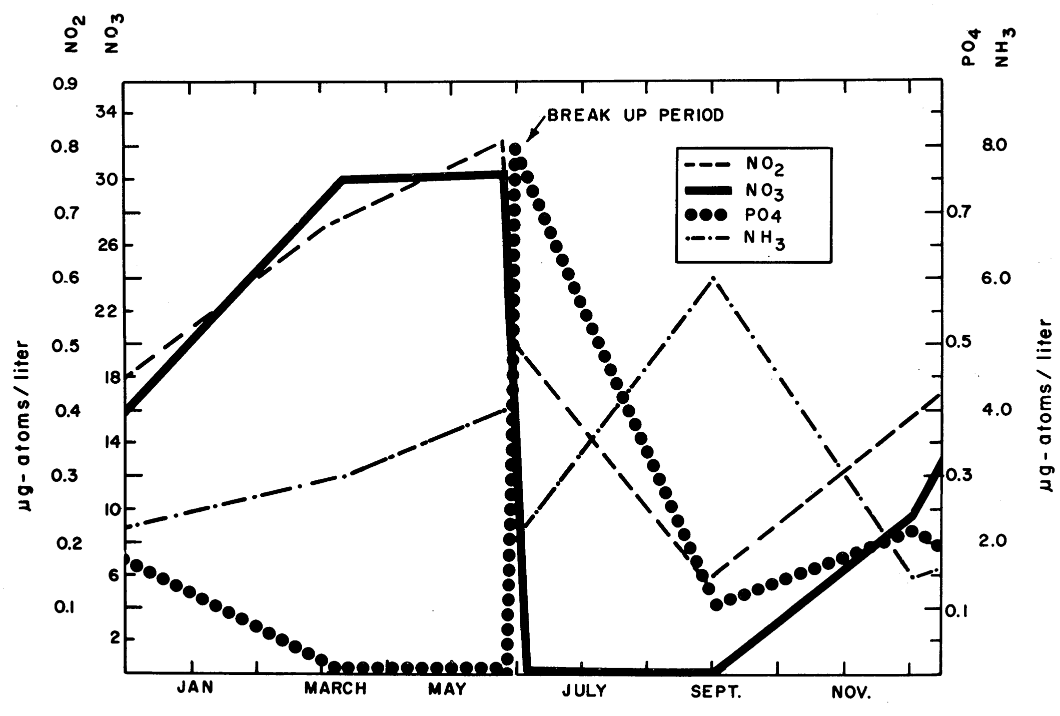


Figure 10 Colville Delta Water Chemistry