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THE ALASKA ARCTIC COAST: WETLAND OR DESERT?

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ABSTRACT. The Arctic coastal zone of Alaska is similar to deserts in many respects. The Alaskan Arctic coast receives approximately 18 cm (7 in.) of precipitation annually and for 8 months of the year there is an absence of liquid water. However, permafrost and low vertical relief combine to limit vertical and horizontal drainage, resulting in appropriate conditions for wetland formation. By the end of August, the surface layer of thawed soil may be only 0.5 m (1.5 ft) deep. The ground water present in the active layer undergoes almost no lateral movement. Most of the surface flow occurs during a very brief spring "breakup" period when the snow melts. Arctic tundra wetlands are found in a mosaic of different landforms: e.g., high and low centered polygons, strangmoor, patterened and non-patterned ground. As is true for deserts, Arctic wetlands are deficient in many of the functional values expected of wetlands: groundwater recharge and discharge, flood storage and desynchronization, dissipation of erosion forces, sediment trapping, nutrient retention and removal, and habitat for fisheries. Arctic wetlands do provide food chain support and habitat for wildlife. Although the amount of wetlands on the Arctic coastal plains is large, equivalent in size to the state of North Carolina, breeding densities of migrating birds are generally low, so habitat is not limiting.

The primary engineering problems involve climate, permafrost, and other environmental considerations. To avoid melting permafrost, roads and building pads are insulated with three to five feet of gravel, and pipelines are insulated and raised above the tundra. Consolidation of facilities reduces surface impacts. For example, as many as 32 wells are directionally drilled from one drill site. There is some flexibility in locating drill sites and roads to avoid valuable wetlands. Culvert locations in roads can be a critical wetlands concern to prevent formation of impoundments or drainage of ponds.

Regulations developed to protect wetlands in the lower 48 states are often inappropriate in the Arctic because of the tremendously different conditions between these areas. A valuable conclusion of 20 years of oilfield experience on the North Slope is that if one is fully aware of appropriate environmental considerations, methods exist for development in an environmentally sound manner.

INTRODUCTION

Question: Is the Arctic coastal zone of Alaska a wetland or a desert?
Answer: Yes.

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Deserts can be defined by low precipitation and lack of surface water. The Alaskan Arctic coastal zone conforms to the first half of the definition and, for 8 months of the year, to the second half as well, for there is an absence of liquid water. Yet, during the brief summer, ponds and lakes abound; waterfowl and shorebirds flock to the area to breed.

Wetlands have been considered important because of the various, significant functional values they have, for example their utility in coastal storm shielding, floodwater storage, groundwater recharge, water purification, and their habitat value. The hydrologic regime of most deserts does not lend itself to fulfillment of many of these functions. The same is true of Arctic wetlands.

To properly regulate industrial development in the Arctic coastal zone, the nature of the wetlands there must be understood: what causes them to exist; what functional values they have; what their features are, what animals use them; and finally what some of the developmental considerations are.

DESCRIPTION

The combination of two ingredients make the arctic form of wetlands possible: climate and topography. The amount of precipitation in the area is relatively unimportant. In fact, when compared to the vast arid areas of the western contiguous United States (Fig. 1), the North Slope of Alaska receives sufficiently low annual precipitation to justify its being classified as a desert (Fig. 2). Annual precipitation along the Beaufort Sea coast (e.g. Barrow, Prudhoe Bay, Barter Island) averages approximately 180 mm (7 in.) (Dingman et al 1980; Walker et al. 1980). Sixty-five percent of the precipitation occurs during the winter as snow, and approximately 35% occurs during the summer as light rain and drizzle. The historical record of snowfall in the arctic may be unreliable due to the influence of wind and deficiencies in collection techniques (Walker et al. 1980). The exact amount of winter snowfall is essentially immaterial because, as will be explained shortly, little of this water becomes available to the wetlands.

Freezing temperatures dominate the yearly cycle on the North Slope (Fig. 3). The annual mid-winter low temperature averages -44°C (-48°F) and has reached -50°C (-58°F). Wind chill can lower the temperature an additional -30°C (-50°F) or more (ARCO records from Prudhoe Bay). Mid-summer high temperatures average 18°C (66°F) and may reach higher than 27°C (80°F). Summer and winter are essentially the only two seasons in the Arctic coastal plain. These are separated by brief periods (potentially as short as 1 or 2 weeks) of "break-up" in late May or early June and freeze-up in mid to late September.

These long, cold winters over thousands of years have resulted in a zone of permafrost that extends as deep as 660 m (2165 ft) (Gold and Lachenbruch 1973). Ground that has remained frozen for two or more years is defined as permafrost (Lachenbruch et al. 1962). It may or may not contain ice. The surface zone that alternately freezes during the winter and thaws during the summer is defined as the active-layer. In the Arctic coastal zone the active-layer is generally very thin; typically, 0.5 m (1.5 ft) is the maximum depth of thaw by the end of the summer. The presence of permafrost prevents surface water from percolating very deep into the ground. This is an essential factor in the formation of wetlands in the Arctic.

When the winter-accumulated snow melts at break-up, surface water briefly covers most of the landscape. This drains as sheet flow over the flat terrain to

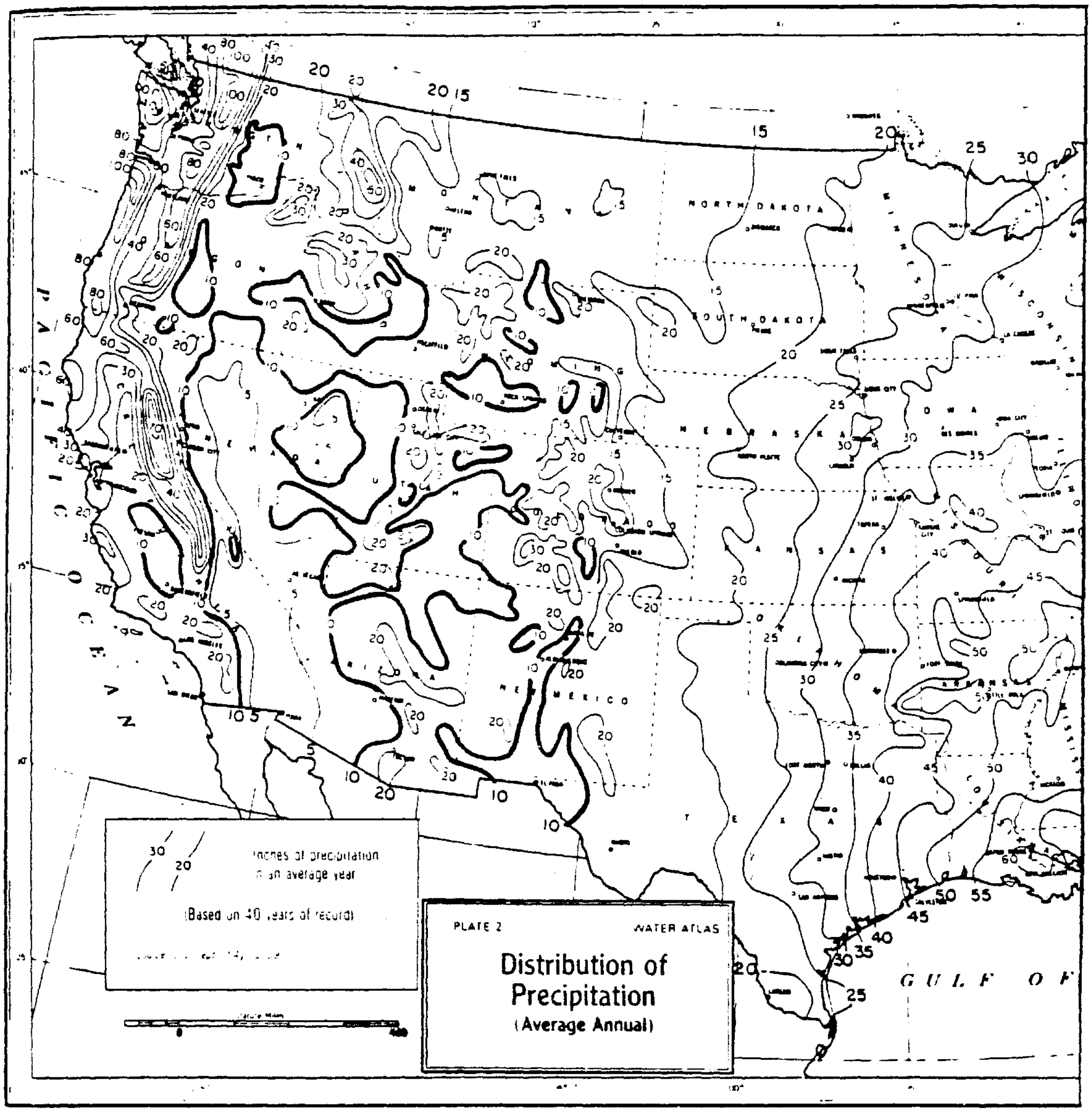

Figure 1. Distribution of precipitation in the contiguous United States. (Geraghty et al. 1973, used by permission)

the streams and rivers. These arterials fill to their banks and discharge volume rates are very high during this brief period. After break-up discharge rates are low in the tundra rivers (Fig. 4) and may be non-existent in many smaller streams (Fig. 5) (P N & D 1985). Little of the break-up flow of water seeps into the ground because the ground itself is still frozen at that time. Thus, precipitation during the winter, which is most of the annual total, contributes little to the wetlands of the area.

Since there is little vertical relief (the landscape can be classified as flat or gently rolling plain) after the high volume flows of break-up there is little horizontal movement of water. Thus, water left from the melting snow and the scant rainfall during the summer does not drain away and is sufficient to create the abundant wetlands. Water loss through evapotranspiration is similar to the quantity of summer precipitation (Bunnell et al. 1975).

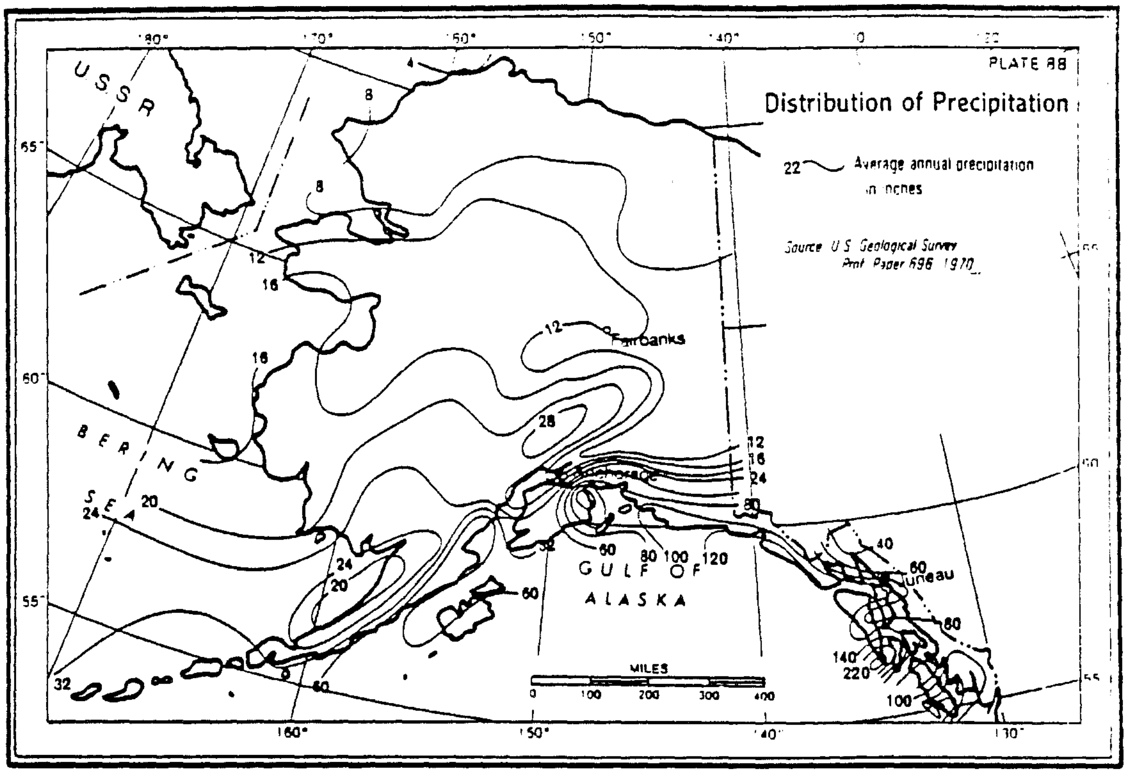

Figure 2. Distribution of precipitation in Alaska. (Geraghty et al. 1973, used by permission)

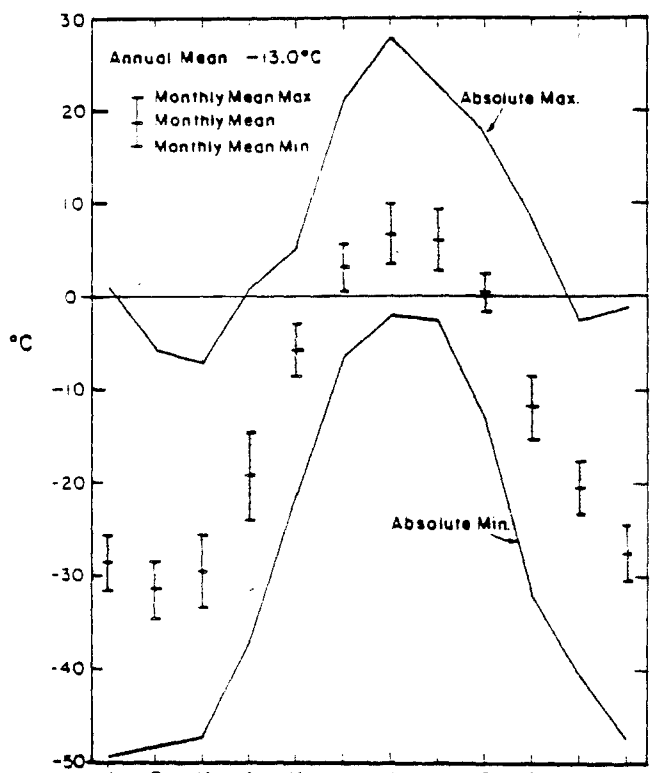

Figure 3. Annual distribution of monthly ranges of air temperature for the Prudhoe Bay region based on an eight year record, 1970-77. (Walker et al. 1980)

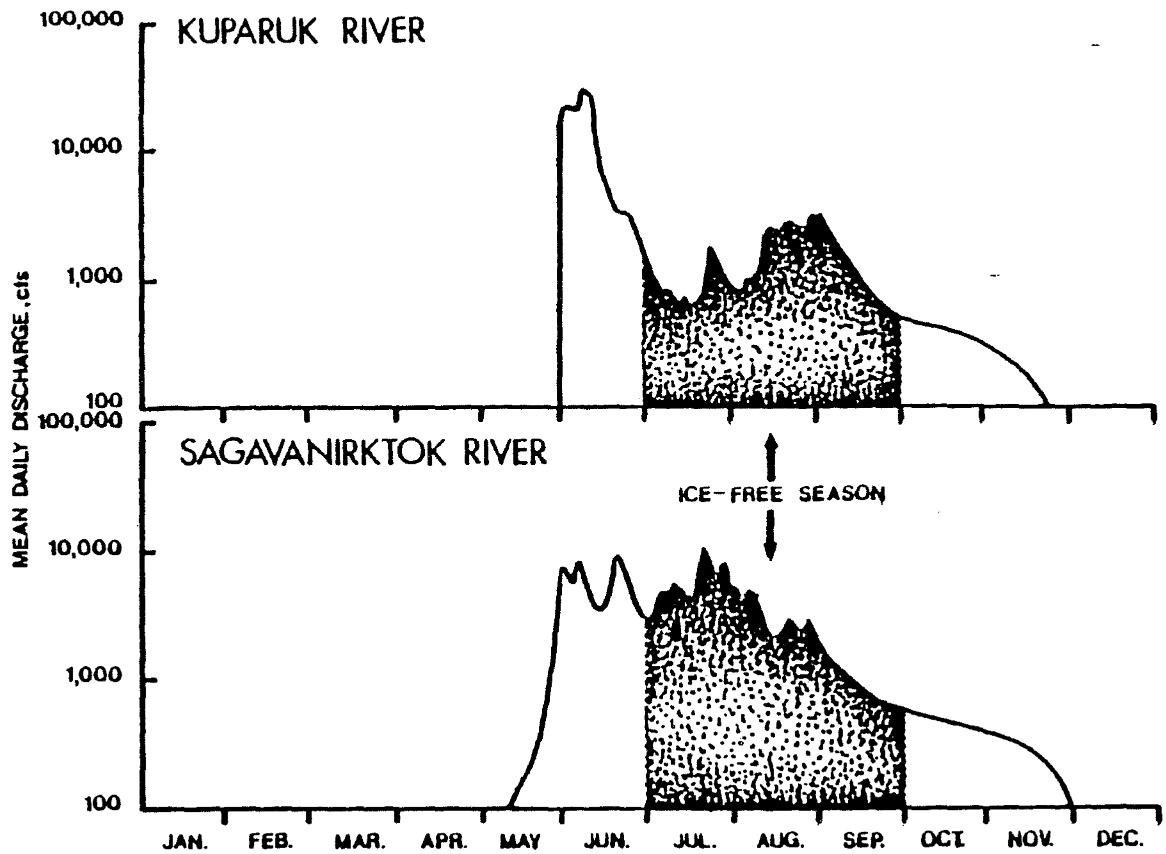

Figure 4. Annual discharge rate distribution of the Kuparuk River, a large tundra river, and the Sagavanirktok River, a large mountain-fed river. (Adapted from Carlson et al. 1977 by Griffiths and Gallaway 1982)

After break-up most of the ponds and lakes do not have a surface hydrologic connection to distinct drainage channels (Lewellen 1972). Surface discharge during the summer occurs primarily as seepage into the soil of the active layer (Ryden 1981).

Groundwater is present only in the thawing active layer. Although this soil is generally rich in organic material and is therefore very porous and permeable, groundwater movement is limited because the topographic relief is so slight. Flow is typically downward in drier (raised) sites, horizontal from drier to wetter sites, and practically stagnant in lower wet sites (Ryden 1981).

The upper 5 to 10 m of many permafrost areas contain relatively large amounts of ice (Brown and Sellmann 1973). This ice can occur in pure forms as horizontal lenses and vertical wedges. Wedges grow annually as new water accumulates during the summer, trickles down thermal shrinkage cracks and freezes in the colder soil below the surface. Ice wedges viewed from above form a network of polygonal patterns that strongly influence the micro-topography of the land.

The mosaic of land forms found in Arctic tundra is a function of the drainage and the freeze-thaw processes just described. Often, small differencesin elevation are created that result in large differences in the moisture content of

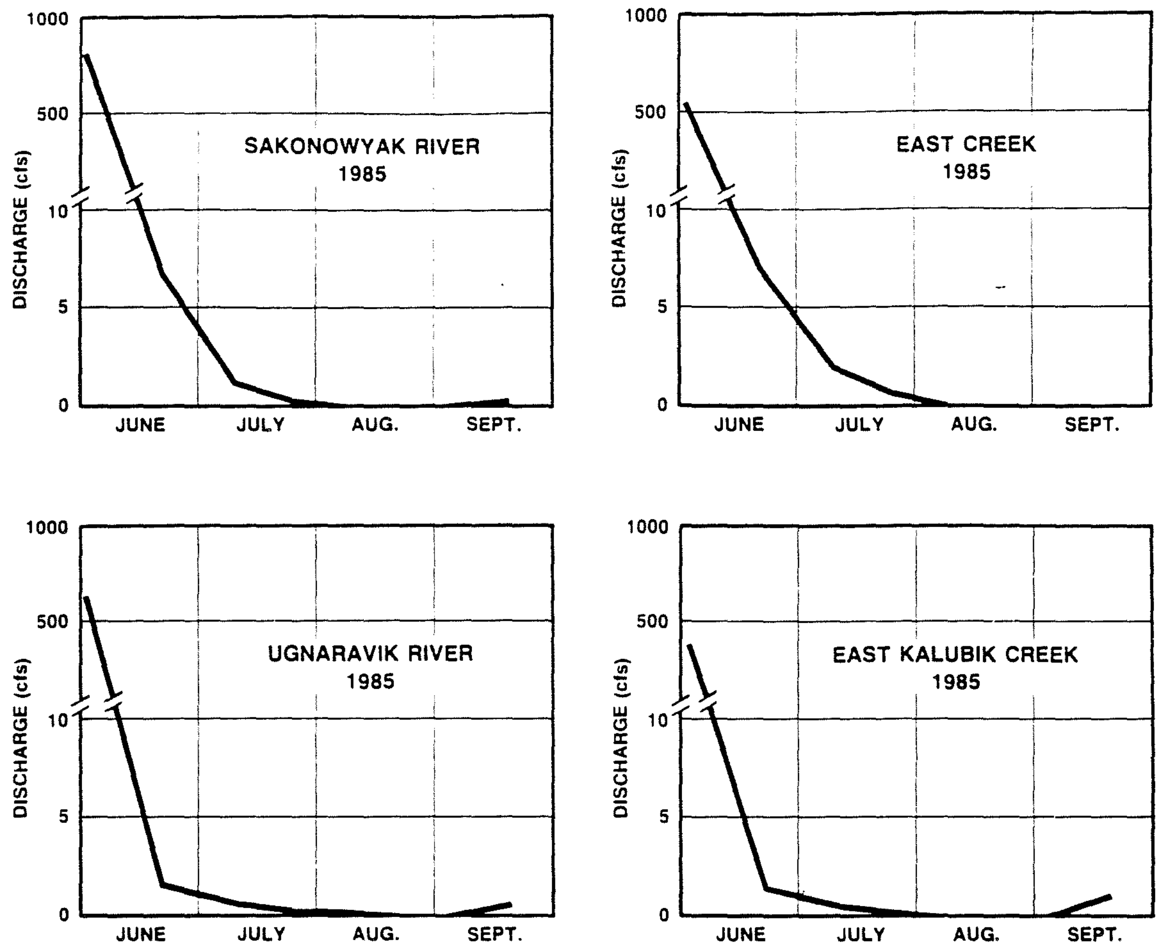

Figure 5. Discharge rates of four drainages during 1985. The drainage areas upstream of the summer measurement stations were Sakonowyak River: 148 km^2 (57 mi^2), East Creek 132 km^2 (51 mi^2), Ugnaravik River 85 km^2 (33 mi^2), and East Kalubik Creek 72 km^2 (28 mi^2). Note the two-orders-of-magnitude change in scale on the discharge axis. Precipitation during most of the summer was below average. (Data from P N & D 1985)

the soil. Low-centered polygons often remain wet in the middle through the summer while the raised rims (up to 0.5 m high) are better drained and drier. Polygons may be several meters across. A frequently occuring land form in very wet areas is strangmoor, in which discontinuous ridges, similar to the edges of low-centered polygons, are found. High-centered polygons are dry in the middle and the cracks or edges between them are wet. Hummocky terrain (up to 0.5 m diameters) is common on well drained slopes. Non-patterned ground exists in areas where there has been relatively little exposure to separated frost cycles, such as in recent drained lake basins.

Drained-lake basins are part of a thaw lake cycle. Arctic lakes can grow from thermal erosion of their banks. If low banks are ultimately breached or adjacent streams are contacted the lake will drain. In time, formation of ice wedge polygons occurs and a new mosaic of dry and wet areas is created. If thawing occurs in ice wedges or ice lenses then subsidence of the ground follows. The subsequent accumulation of water allows further thawing and subsidence and the growth of ponds. Then ponds may connect and form lakes, continuing the process. Most of the Arctic lakes are shallow, frequently less than 2 m in depth, and therefore freeze to the bottom during winter. It may take hundreds of years for thaw-lake cycles to repeat themselves.

Pingos are another feature of the Arctic landscape. They are conical or dome shaped hills up to 15 m high. They are formed by the freezing and expansion of water saturated ground such as in recent drained-lake basins, and have a very ice-rich core.

The processes described here result in a mosaic of land forms where dry soil is frequently interspersed with wet. Areas of low centered polygons and drained lake basins of intermediate age with a high morphological diversity are examples of the mosaic nature of Arctic tundra.

As is true elsewhere, tundra vegetation is very much a function of the moisture content of the soil. Because of varying moisture content, small differences in microtopography can result in abrupt changes in vegetation, as for example, at the centers vs. the rims of low-centered polygons (Wiggins 1951; Britton 1957; cited in Webber et al. 1980). Shallow-lakes may contain the pendant grass, Arctophila fulva; very wet soils support the sedges Carex aquatilis or Eriophorum angustofolium (cotten grass); and drier areas may host the forbs, whose flowers brighten the Arctic summer landscape, and woody plants such as willows. Mosses and lichen can be found on wet, moist, or dry ground.

WETLAND FUNCTIONS

The functional values of wetlands are many. The uniqueness of Arctic wetlands can be illustrated by evaluating how well they perform the functions expected of other wetlands. Adamus and Stockwell (1983) presented a comprehensive list of functions that will serve as the basis for discussion.

Groundwater recharge. The presence of permafrost, a mere 0.5 m (1.5 ft) below the surface effectively limits this function. The only aquifers that would be candidates for recharge exist over 600 m (2000 ft) deep, below the permafrost, and are thus unavailable for recharge.

Groundwater discharge. As has been stated previously the only "groundwater" present is in the active layer, during the summer, and is the moisture of the wetland soils themselves. Movement of this water is very localized, flowing generally from dry (raised) sites toward wet (depressed) sites. Discharge to a tundra stream, therefore, is primarily from only the soil along its banks. This can lead to a situation in which by mid-summer many tundra streams may cease flowing entirely (P N & D 1985).

Flood storage and desynchronization. This function is not fulfilled in Arctic wetlands. During the period when flooding occurs (i.e. spring "breakup") the ground is still frozen and unable to absorb any of this flow. No flooding occurs during the summer due to the very low amounts of precipitation. Even if flooding during the summer did occur, the active layer is so thin, in addition to frequently being saturated, the storage function would not be fulfilled in any case.

Shoreline anchoring and dissipation of erosion forces. When river and stream flows are highest during breakup, the ground is frozen and is protected from erosion whether it is vegetated or not. The soil is loose and organic and the roots of vegetation, while not penetrating deeply are sufficient to protect against the very small erosive forces that exist during the summer flows. The larger rivers, after their peak flows have abated, meander in braided beds that are unvegetated along their banks and thus get no benefit from this wetland function. Erosion in the Arctic, including on the coastline, is largely thermal. The organic mat may provide protection from above but not along exposed edges. Rates of marine shoreline erosion, as a result of wave action (which can enhance thermal erosion), has been found to range to over 2.5 m per year, with averages of 1 m per year (Barnes et al. 1977). Arctic tundra is of little value in performing the function of erosion reduction.

Sediment trapping. Tundra streams are very clear and contain little sediment to be trapped. Rivers on the North Slope, on the other hand, are very turbid with high sediment loads. When they are at peak flows the tundra covered areas of the river beds are still frozen, and at later, lower, flows the rivers are in unvegetated portions of their beds. Arctic wetlands, therefore do not fulfill this wetland function.

Nutrient retention and removal. Arctic wetlands, in general, do not result from water flowing in from an upstream source; they, therefore, do not perform the function of removing and retaining nutrients from an incoming stream. Water purification, which includes this and the previous category, is consequently also not a functional value of Arctic wetlands. Growth of Arctic plants is limited by available nutrients because over 99% of the phosphorous and nitrogen in the soil is in organic forms and is largely unavailable to the tundra plants. Decomposition, which would release the nutrients in inorganic form proceeds very slowly in the Arctic (Chapin et al. 1980). Input of inorganic nitrogen and phosphorous is from precipitation. The losses of these nutrients, primarily organic forms, that result from runoff exceed the gains from precipitation. There may, however, be a net gain of nitrogen due to nitrogen fixation in the soil (Gersper et al. 1980). Plant physiology and fertilization experiments indicate that phosphorous is more of a limiting factor on primary production than are other nutrients (Bunnell et al. 1975).

Food chain support. Migratory birds are the primary beneficiaries of the wetland-based arctic food chains. Geese (e.g., black brant, greater white-fronted geese) tundra swans, and some ducks (e.g., pintail) feed directly on the vegetation, while other ducks (e.g., oldsquaw, eiders) feed largely on the invertebrates (e.g., oligocheates, anostracans, notostracans, cladocerans, chironomids, trichopterans; i.e., various life stages of earthworms, fairy shrimp, tadpole shrimp, water fleas, midges, caddis flies). Shorebirds (e.g., phaloropes, sandpipers) feed exclusively on invertebrates. Loons eat marine and freshwater fishes as well as invertebrates. Terrestrial invertebrates (e.g., arachnids, tipuds; i.e., spiders, crane flies) are also important to many of the invertebrate-eating birds as well as to the young of herbivorous birds such as geese (Bergman et al. 1977; Derksen et al. 1981). Many of the aquatic invertebrates utilize peat as their primary carbon source. Thus their predators, especially diving birds and fishes in rivers, are part of a food chain based on primary production that occured several thousand years ago rather than on modern production (Schell 1983). Although the quantity of river-borne peat present in the estuarine-like nearshore waters of the Beaufort Sea may be similar to or greater than the amount of living algae (phytoplankton and macroalgae) present, the main carbon source for marine invertbrates, and subsequently their predators, is from the modern primary productivity of the marine algae (Schell 1983). While many mammals (e.g., caribou) will feed on wetland vegetation because it is available, they are not dependent on it; that is, they eat it because it happens to be among the kinds of food that are present, not because a particular need for wetland vegetation per se.

Habitat for fisheries. There are no fish from Arctic wetlands that are suitable for commercial or sport fisheries. Commercial and subsistence fisheries that do exist are in large rivers such as the Colville River. Some sport fishing on a very limited scale, is done from the shores of the Beaufort Sea and tundra rivers. Target species for these fisheries include northern form Dolly Varden (frequently but mistakenly called Arctic charr to which it is closely related; Morrow 1980), Arctic cisco, least cisco, whitefishes, burbot, and Arctic grayling. All but the last two of these are anadromous fish that annually overwinter in the major rivers. All of these fishes spawn in relatively swift moving water in streams or rivers (Morrow 1980) and do not rely on wetlands as nurseries. This is primarily because most of the Arctic wetlands do not have an open water hydrologic connection with the rivers and are completely frozen during the winter.

Habitat for wildlife. A wide variety of animals are found on the Arctic coast zone of Alaska. The resident and migratory mammals (e.g., Arctic foxes, lemming, and caribou) are not dependent on wetlands; nor are the resident species of birds (e.g., snowy owls, ravens) (the resident predators may prey on waterfowl when present but rely more on mammals such as lemmings as a year-round food supply). On the other hand, most of the migratory waterfowl and shorebirds that come to the area during the summer, utilize the many wetland habitats available. Among the waterfowl that nest in the Arctic are the tundra swan, black brant, greater white-fronted goose, Canada goose, eiders, oldsquaw, and loons. Representative shorebird species include the red and red-necked phalorape, long-billed dowitcher, pectoral sandpiper and dunlin. The morphological diversity of some drained-lake basins make them especially attractive to waterfowl and shorebirds. Habitat preferences change through the summer as the birds progress from nesting, through broodrearing, to staging for the migration south. Feeding (see above) and protection from predators are the guiding criteria for habitat selection during the different life stages. Depending on the species and the stage, preferences can switch between terrestrial and wetland habitats. Although these habitats are valuable to the birds that use them, compared to more productive Alaskan wetlands farther south, the Arctic coastal plain supports relatively low breeding densities of most water birds (King 1970; Bergman et al. 1977; Derksen et al. 1981). The area available, however, is extremely large. Seventy two percent of the area north of the Brooks Range (the North Slope) is classified as wetlands (Epps in press). This 125,000 km^2 (48,000 mi^2 or 31 million acres) of wetlands is equivalent in size to the state of North Carolina.

Active recreation. Arctic wetlands do not support active water-dependent recreation. There may be some use of rivers or streams for canoeing or kayaking but even this is rare.

Passive recreation and heritage value. During the summer, especially when the migrating birds and caribou are present and the wildflowers are blooming, Arctic wetlands have value in terms of aesthetic enjoyment, nature study, and scientific research. It is satisfying observing the diversity of life in an environment that is so flat and so harsh.

Summary. The foregoing illustrate that Arctic wetlands perform few of the functions expected of wetlands. In this regard Arctic wetlands are quite similar to deserts (Table 1). The positive attributes that do occur in the Arctic are related to utilization of habitat. The deserts too provide habitat for appropriately adapted animals (although obviously not the same ones found in wetlands). The one area where deserts and arctic wetlands differ in the presence or absence of a function is in the minor attribute of active recreation (e.g., off-road vehicles).

Table 1. Comparison of the functional values of Arctic wetlands and deserts.

Function	Arctic Wetlands	Desert
Groundwater recharge	-	-
Groundwater discharge	-	-
Flood storage & desynchonization	-	-
Erosion protection	-	-
Sediment trapping	-	-
Nutrient retention & removal	-	-
Food chain support	+	+
Habitat for fisheries	-	-
Habitat for wildlife	+	+
Active recreation	-	+
Passive Recreation	+	+

- = little or no occurence of this function
+ = this function occurs

DEVELOPMENT

Engineering constraints in the arctic are a function of the same features that create wetlands in the arctic: temperature, permafrost, and topography. Petroleum development in northern Alaska has to consider many environmental factors, which are briefly summarized here (see Smith and Robertson, in press, for a more thorough review). Care must be taken to thermally insulate facilities from the ground for if the permafrost was allowed to thaw, thermal erosion and subsidence (thermokarst) could occur resulting in sinking, twisting, and damage to these facilities. Five feet of gravel is sufficient insulation for roads and building pads. In addition, heated facilities are generally elevated on piles placed through the gravel pad. Oilfield pipelines are insulated and raised above the tundra rather than lying on or under the surface. This also reduces surface impacts.

In addition to considering the impact of the environment on facilities, designs must consider the impact of facilities on the environment. One way in which surface impacts to Arctic tundra are reduced is using a single gravel pad to drill several wells. By employing directional drilling, as many as 32 wells can be based on one pad. Directional drilling also allows some flexibility in locating drill sites so valuable wetlands can be avoided.

Drainage pattern maintenance is another important consideration. Culverts in gravel roads must be sited to allow continued flow at tundra streams and other obvious drainage points as well as at less obvious low areas where sheet flow occurs. Culverts must be sized to handle the peak flows of break-up. Design and placement is engineered to avoid alteration of habitats (e.g., drainage of ponds and lakes or creation of impoundments).

We have found that if the habitats are not significantly altered, wildlife continue to use the oilfield. Alteration of habitat can cause a change in bird usage. For example an impoundment alongside a gravel road may cause some birds to no longer use that area, while other species of birds are attracted to it (Troy 1986). In general birds continue to use the oilfield just as they always have. Likewise small mammals such as lemmings, ground squirrels, and Arctic foxes are common in the area. Special action must be taken to ensure that large mammals such as caribou are able to continue their traditional use patterns. The Central Arctic Herd (CAH) of caribou is a regular, summer visitor to the Kuparuk oilfield (Keene and Gavin 1987). We have found that elevating pipelines 1.5 m (5 ft) above the tundra and separating pipeline 120 m (400 ft) from busy roads allows caribou to move about freely in the oilfield (Robertson and Curatolo 1987). The CAH has tripled in size (approximately 5,000 to 16,000 animals) in 11 years (1975 to 1986), during which time the Kuparuk development has grown from being nothing more than the plans to develop the 1969 discovery, to being the second largest producing oilfield in the United States.

CONCLUSION

Arctic wetlands, in terms of precipitation and degree of fulfillment of wetland functions, are very similar to deserts. Nevertheless, permafrost and topography combine to create conditions conducive to creation and maintenance of true wetlands. These wetlands are of great value to migrating waterfowl and shorebirds. However, because of the relatively low densities of birds that use Arctic wetlands, and the huge expanse of land available, habitat is not limiting.

By virtue of their extent, structure, and function Arctic wetlands are quite different from wetlands in the lower 48 states. These latter wetlands are disappearing at the rate of over 1400 km^2 (350,000 acres) annually. The laws and regulations that are in place for wetland protection are indeed needed to halt this loss. Because, if these wetlands disappear, the habitat values of the Arctic wetlands, however vast they are, become moot for those waterbirds that rely on both areas. However, the concerns and degree of regulation justifiably developed for the lower 48 wetlands are inappropriate for arctic wetlands. Permafrost-based wetlands need to be recognized as uniquely different from other kinds of wetlands and therefore, exceptions may need to be made in how they are treated regulatorily (Epps in press).

The principle regulations for wetlands protection in the United States stem from Section 404 of the Clean Water Act. The program is administered by the U.S. Army Corps of Engineers with guidance provided by EPA's 404(b)(1) Guidelines. Projects requiring a 404 permit may also be required to include some form of mitigation to ameliorate or lessen the impact of that project. The Corps, EPA, and U.S. Fish and Wildlife Service have mitigation policies for guidance, although in practice these frequently become de facto regulations.

Avoidance and minimization are the only practical forms of mitigation in the Arctic. This is accomplished by consolidation of facilities and siting facilities and road routes to avoid, to the extent practical, "sensitive" areas, such as drained-lake basins. This maximizes the amount of available habitat by keeping surface impacts of the oilfield to a minimum. Petroleum development on the North Slope, for example, has impacted less than 1% of the surface area in the oilfields. Proper design and construction of facilities on the Arctic coastal plain ensures minimal impact of the environment on the activities, and of the facilities on the environment. This proper design also minimizes impacts to the other users of the environment: the wildlife. Because of the almost ubiquitous distribution of wetlands in the Arctic coastal plain the concept of development with no net loss of wetland is not achievable. However, the de-minimus level of impacts from properly designed Arctic oilfields should be recognized as acceptable.

Absence of regulation is not being advocated here; rather, that the rules set in place to protect other wetlands may not apply in the Arctic, and we may need a different set of rules. We have seen that environmentally conscientious, large scale petroleum development has occurred in the Arctic coastal plain without significant impact to wildlife populations or the habitats that they use. This experience should serve as the basis for regulations pertaining to development activities in Arctic wetlands.

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