FORM 10-3

EL PASO NATURAL GAS COMPANY

Memorandum

	Distribution	Date:	December 12, 1975
From:	H. Reiquam	Place:	Environmental Affairs

Re: Comparison of Water Availability . . . on the Alaskan North Slope

Attached is a draft report prepared for El Paso by Alaskan Biological Consultants. It has been substantially revised from the first draft, with the collaboration of the authors. Our intent, in all cases, has been to improve the clarity. Your review and comments are solicited.

We expect that the report will find its principal application in the Arctic Gas Construction Evaluation in which certain aspects of the Arctic Gas proposal are being evaluated, and in the "Alyeska Work Pad Feasibility Study."

Howard Reiquam

HR:ljc

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COMPARISON OF WATER AVAILABILITY FOR USE IN CONSTRUCTION OF PROPOSED GAS PIPELINE ON THE ALASKAN NORTH SLOPE

Abstract

This report assesses potential winter water sources on the North Slope in Alaska, the biological characteristics of these waters, and the impact of water withdrawal upon aquatic biota. Based upon this assessment, water availability along the proposed El Paso and Arctic Gas gas pipeline routes is compared.

Groundwater, spring, river, and lake sources were considered. Groundwater will generally not provide reliable sources of water; most springs are critical to overwintering fish and should not be utilized as water sources; rivers will provide unlimited quantities of water until freezing restricts discharge, usually in October or November. Lakes are the single most reliable source of water during the winter. Most shallow lakes on the Arctic Coastal Plain will be capable of providing large quantities of water, but only until late November or December. Lakes in the Foothills and Brooks Mountains Province are deeper than those on the Coastal Plain and will be excellent year-round sources.

Water will be available in quantities sufficient for snow/ice road construction in close proximity to the proposed El Paso alignment. However, the proposed Arctic Gas alignment does not have water in quantities sufficient for snow/ice road construction. Approximately 100 miles of the 195 miles of this pipeline route are deficient in water supplies.

Over-tundra travel restrictions imposed by state and federal regulatory agencies will likely delay the Arctic Gas snow/ice road construction schedule, thus affecting the construction schedule of the entire project. This delay could be as much as two and one-half months during any construction year.

COMPARISON OF WATER AVAILABILITY FOR USE IN CONSTRUCTION OF PROPOSED GAS PIPELINE ON THE ALASKAN NORTH SLOPE

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COMPARISON OF WATER AVAILABILITY FOR USE IN CONSTRUCTION OF PROPOSED GAS PIPELINE ON THE ALASKAN NORTH SLOPE

1.0 Introduction

El Paso Alaska Company (El Paso) and Alaskan Arctic Gas Pipeline Company (Arctic Gas) have independently proposed to construct natural gas pipelines on the North Slope of Alaska. El Paso proposes to construct a line, generally paralleling the Trans-Alaska Pipeline System (TAPS), from Prudhoe Bay south to a terminus at Gravina Point, Alaska. El Paso proposes to utilize the existing gravel "haul road" built by Alyeska for high speed, high volume traffic and to construct a snow/ice work pad for low speed pipeline construction equipment. Arctic Gas proposes to transport the same gas in an easterly direction across the Arctic Coastal Plain into Canada. In order to utilize that route, Arctic Gas proposes to construct a snow/ice work pad for winter construction activities. Because of the absence of other roads, Arctic Gas will need to construct an additional heavy duty snow/ice haul road. Both companies propose to begin snow/ice road construction in September, completing them in December. Actual pipeline construction is proposed to begin in October.

Snow/ice road construction requires large volumes of water to provide the necessary strength to support heavy equipment. Since both projects are premised on the assumption that this construction technique will be feasible during the proposed construction period, it is necessary to assess the water resouces, availability, and impacts of withdrawal along each route. Thus, the major purposes of this report are: (1) to assess potential water sources along both routes, (2) to assess biological use and importance of these potential sources, and (3) to determine if sufficient volumes of water are available during the proposed construction periods.

Three physiographic provinces have been described on the North Slope (Spetzman, 1959). The Coastal Plain Province extends approximately 500 miles east and west and up to 100 miles inland. It ranges from sea level to 500 to 1,000 feet in elevation. Small shallow lakes are numerous in this region and generally do not support resident fish populations. The Foothills Province ranges from 10 to 100 miles in width and 500 to 2,500 feet in elevation. Lakes are both deeper and less numerous than those in the Coastal Plain Province and tend to support varied fish fauna. The Brooks Mountain Province extends from the Foothills Province south to the crest of the Brooks Range. Lakes are less numerous in this area than in the other two provinces, but are considerably larger. Schrader Lake, located in the eastern end of this province, is 10 to 12 miles in length with water depths in excess of 180 feet. Lakes in this region commonly support arctic char, grayling, whitefish, and lake trout, as well as other species.

This report is restricted to those portions of the proposed El Paso and Arctic Gas routes on the North Slope of the Brooks Range, Alaska. The proposed El Paso route traverses all three physiographic regions including the Coastal Plain, the Foothills, and the Brooks Mountain Provinces. The Arctic Gas routing is confined to the Coastal Plain Province.

2.0 Historical Overview

Attempts to locate and develop supplies of potable water in Arctic Alaska during the winter have been difficult, and often unsuccessful (Alter, 1969; Feulner and Williams, 1967; Greely, 1886; Sherman, 1973). The limited water sources which have been developed are generally unreliable in late winter and have proven to cost as much as one dollar a gallon (Alter, undated).

At Prudhoe Bay, the search for water has encompassed groundwater aquifers, shallow lakes, and isolated pools in the Sagavanirktok River. To date, few of these sources have proven to be dependable (Sherman, 1973). Although accurate figures on total quantity of water consumed on the North Slope are not available, it has been estimated that water use at Prudhoe Bay between October 1974 and May 1975 was in the range of 16,000 to 35,000 gallons per hour. Although water consumption at Prudhoe is small, it appears to be sufficient to dewater the mouth of the Sagavanirktok River.

Other methods of winter water supply have been explored, including increasing storage capacity. During the summer of 1975, the Atlantic Richfield Company (ARCO) drained and deepened a lake in an attempt to increase reservoir storage capacity to help alleviate winter water supply shortage.

Other areas on the North Slope have also suffered water shortages in late winter. Historically, it has been difficult to supply Alyeska's Happy Valley Camp with water from the Sagavanirktok River, even as early as March 1971 when water demand was very small (McDonald, 1971). During the 1974-1975 winter, Happy Valley Camp utilized the Sagavanirktok River thaw bulb for water supply. A well was installed approximately 10 feet beneath the riverbed and produced in excess of 1,000 gallons per hour (gph) until late winter when it went dry.

Thaw bulb water beneath the Atigun River has been utilized by Alyeska's Atigun Camp. Camp water supply during the 1974-1975 winter consisted of a 40 to 50 foot cistern and a 150 foot well. These sources produced well over 1,000 gph until late November or December, when production dropped to approximately 500 gph. Two other wells were drilled near Atigun Camp in March and April, but they were dry. A new 180 foot well was drilled in late spring which produced more than 1,000 gph.

One of the ecological problems created by winter water withdrawal is the potential for severely damaging aquatic resources. During past years, withdrawals in the lower stretches of the Sagavanirktok River for Prudhoe Bay camps have dewatered isolated pools of water important to overwintering fish (Alaska Water Study Committee, 1975). It has been reported that small fish clogged the water pump at a location approximately 15 miles south of Deadhorse (Ward and Craig, 1974). The winter of 1974-1975 has brought into focus the scope and nature of these problems.

During March, April and May 1975, reports from the Prudhoe Bay Area indicated that the removal of water from isolated pools in the Sagavanirktok River was having a severe adverse impact upon large numbers of overwintering fish. As a result, state regulatory agencies initiated a procedure to require water use permits designed to regulate industrial winter water removal on the North Slope.

Alaska Statute Title 16.05.870 - The Anadromous Fish Act, delegates the authority to issue and enforce water use permits to the Department of Fish and Game. Permit stipulations include immediate cancellation if withdrawal of water threatens to damage the fishery resource. By this authority, the regional supervisor for the Alaska Department of Fish and Game, Habitat Protection Division, recently issued a directive to all North Slope lease holders and operators (Grundy, 1975). In part, this directive states:

> "Earlier this summer you received a notice from the Water Resources Section, Alaska Division of Lands, Department of Natural Resources, stating you must apply for water appropriation on the North Slope. Concomitantly this Department will review your application and issue our authorization pursuant to AS 16.05.870 to protect the fishery resources in the area. Because of the adverse impact of water use during the winter months to fishes overwintering in the major tributaries, it is our objective to encourage use of water from the upland lake areas to the greatest extent, and to encourage you to either singly or collectively devise a system (reservoir, etc.) where dewatering a major tributary will not occur".

Winter water removal has become a major environmental consideration on the North Slope. Quantities of water withdrawn for camp use in the past have been insignificant when compared to those apparently required for snow/ice road construction. For instance, Arctic Gas (1974) states that between 250,000 and 900,000 gallons of water will be required per mile of construction for haul roads and work pads. Beyond the initial quantities of water required for snow/ice road construction will be water requirements for camp supply and for daily road maintenance programs. These requirements will extend over the proposed two or three year construction period.

3.0 Potential Water Sources During Winter

This section outlines the general nature of potential winter water sources on the Arctic North Slope. Availability of these sources is discussed in broad terms, then the availability of water along the proposed El Paso and Arctic Gas routes is examined. Discussions are focused on areas five and ten miles wide on either side of, and adjacent to, the proposed alignments.

3.1 Groundwater

3.1.1 General

Groundwater in permafrost regions has been defined as "suprapermafrost water (water above the permafrost), intrapermafrost water (water within the permafrost), and subpermafrost water (water beneath the permafrost)" (Muller, 1945). Other sources discussed in this section include bedrock aquifers and groundwater in thawed alluvium under major rivers and large lakes.

Suprapermafrost water is highly seasonal, its sources being rain and/or snow melt (Alter, 1969). The seasonal nature and the quantity of water in this layer are dependent on the depth of the active layer. Suprapermafrost aquifers are frozen between mid-September and June and thus, are unavailable as sources of water during winter.

Intrapermaforst water finds its sources in the downward percolation of surface water or pressurized upwellings from subpermafrost reservoirs. Since the North Slope is underlain by continuous permafrost ranging from 600 to 1,800 feet; intrapermafrost flows are probably negligible (Dingman, 1973).

Subpermafrost water reserves are generally not considered as water sources. Thick continuous permafrost reduces potential recharge from surface waters. In many regions, permafrost extends down to bedrock which, in fact, may eliminate any subpermafrost flow (Alter, 1969). Subpermafrost areas, both above and within bedrock, have been shown to contain limited quantities of highly saline water (Sherman, 1973). Flow rates near Umiat have been measured at ten gph (Williams, 1970a). Low flow and high chloride concentrations would eliminate consideration of subpermafrost water as potential sources of water. Finally, subpermafrost reserves would require pumping up through 600 to 1,800 feet of continuously frozen ground. Such water is therefore subject to freezing. Freezing may also be induced by over-pumping an aquifer (Clark and Alter, 1956).

Groundwater from thawed alluvium beneath large arctic rivers and lakes may provide the single reliable supply of groundwater on the North Slope. Ponds and lakes which freeze to the bottom are underlain by permafrost (Brewer, 1958a). However, large lakes that do not freeze to the bottom and exceed 2,000 feet across are commonly underlain by a zone of unfrozen alluvium due to heat loss from the lake water (Brewer, 1958a and 1955; Hobbie, 1973; U. S. Geological Survey, 1969a). The thickness of this zone, sometimes referred to as a "talik", varies with the area and depth of the water body and with the composition of sediments and underlying formations. Beneath Imikpuk Lake, Brewer (1958a) measured a talik that was 190 feet in depth. Williams (1970a) suggests that the talik of Umiat Lake is a minimum of 103 and a maximum of 345 feet in depth, and that the water stored within thawed alluvium beneath a lake may considerably exceed the volume of the aboveground water stored in the lake basin.

The recharge of unfrozen alluvium beneath lakes is unstudied at this time. However, winter recharge to the alluvial aquifer is probably limited to surface water in the lake. The rate at which lake water would replenish a pumped aquifer would depend upon the thickness and permeability or organic material and silty bottom sediments that separate the lake from the underlying alluvial aquifer.

The talik beneath lakes is considered to be a feasible source of water. Williams (1970a) states that the unfrozen alluvium beneath deep lakes in the Colville River Valley "will yield abundant year-round supplies of ground water".

Thaw bulbs under abandoned oxbow channels and gravel beds under standing water and/or south facing slopes may also provide water during North Slope winters (Williams, 1970b).

3.1.2 El Paso Alignment

Groundwater sources including supra-, intra-, and subpermafrost regions, will not produce sufficient water for construction of roads and work pads. Thawed alluvium under lakes and large rivers, however, may produce usable water throughout most of the year.

El Paso's route parallels the Sagavanirktok River for a distance of approximately 130 miles (milepost [MP] 00 to 130). One hundred twelve miles of the proposed route, between MP 18 and 130, lie within five miles of the River (Figures 1,2, & 3). North of MP 18, the Sagavanirktok River is presently accessible by existing road networks.

Alluvial groundwater in the Coastal Plain Province (MP 00 to 60) has not provided a reliable winter source of water. Alluvial groundwater wells in the Foothills Province (MP 60 to 130) have produced in excess of 1,000 gph but may have to be relocated in late winter due to depletion or freezing of the aquifer. Site specific alluvial gravels beneath the Atigun River in the Brooks Mountain Province may produce similar quantities in early winter. These sources may drop to approximately 500 gph or less in late winter.

3.1.3 Arctic Gas Alignment

Since the Arctic Gas Route lies entirely within the Coastal Plain Province, thick continuous permafrost and hence, low yield of saline groundwater can be expected. Exploratory drilling along coastal regions has encountered saline water at 100 to 200 feet below the active layer (McCarthy, 1952).

Within the 195 mile Alaska segment of the Arctic Gas route, four major drainages are crossed (Figures 4 through 7). These rivers are the Sagavanirktok, crossed at MP 8 and 18, Canning, at MP 62.5, Hulahula, at MP 117.5, and Kongakut, crossed at MP 173. Numerous other small Alaskan streams are crossed by this routing. Some groundwater may be available in the thawed alluvium of the larger rivers.

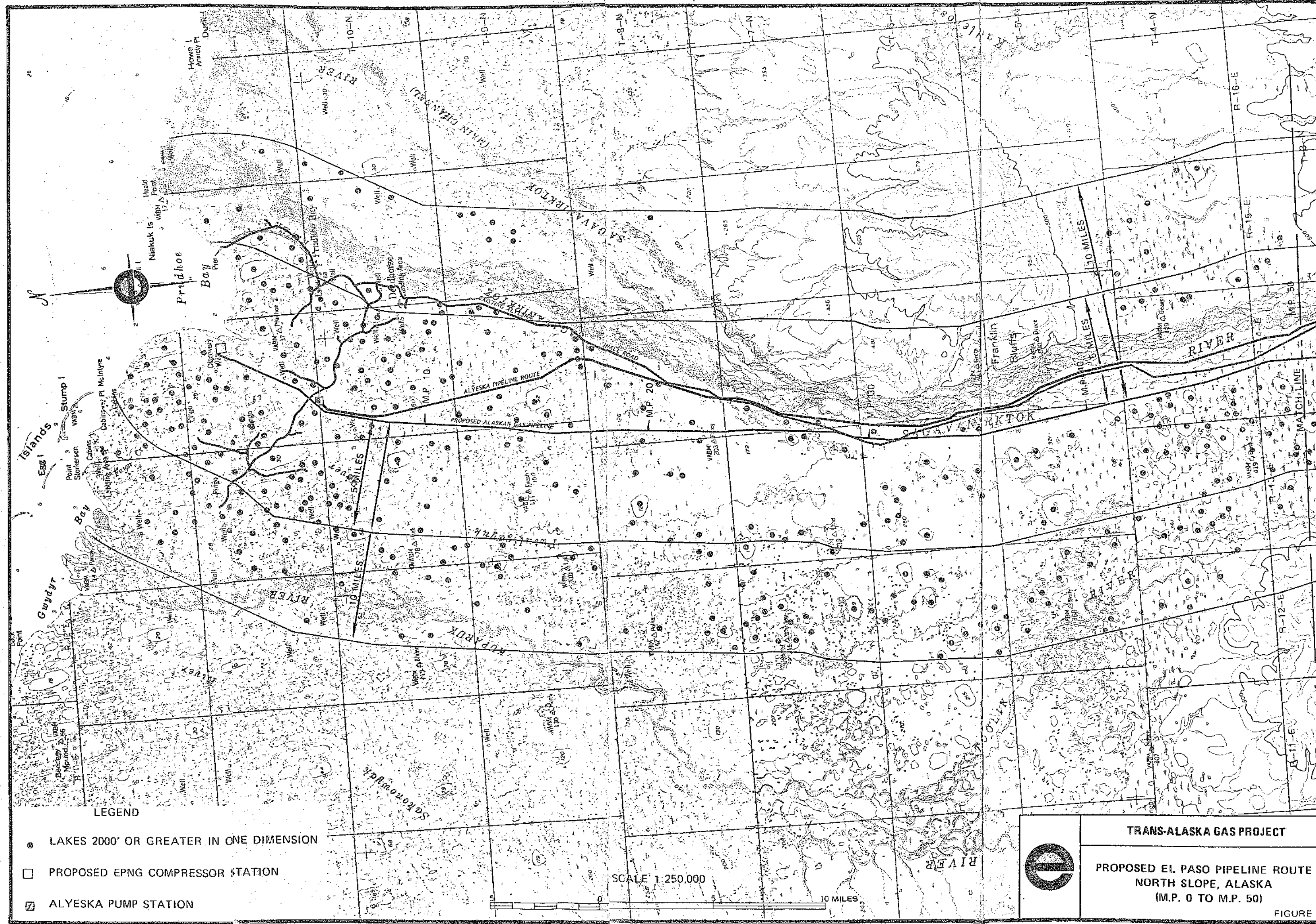
Thawed alluvial gravels underlying large lakes between MP 0 and 62 may have some development potential. However, these areas will require site specific investigation to determine if water is available and if so, in what quantities. Lake alluvium offers much less potential beyond MP 62. This is due in part to the greater sparsity and smaller size of lakes. In addition, restricted access in the Arctic Wildlife Range has precluded groundwater investigations.

3.1.4 Summary

A summary comparison of groundwater sources near the routes proposed by El Paso and by Arctic Gas on the Alaskan North Slope is shown in Table 1.

Groundwater aquifers are generally unsatisfactory water sources during winter because of continuous permafrost, low yield, predominance of saline water, and the expense and difficulty of development. Thawed alluvium under major rivers and lakes, however, may provide limited quantities of water. Thaw bulbs under major rivers should provide reliable sources of water for limited camp use during late fall and early winter. Along the proposed El Paso pipeline route, alluvial sources exist under major rivers and lakes in the Foothills and Brooks Mountain Provinces. Wells tapping river thaw bulbs have produced 500 to 1,000 gph during winter. These wells sometimes failed during late winter, due to insufficient depth, and were relocated.

The Arctic Gas route lies entirely within the Arctic Coastal Plain. Possible groundwater supplies in the Foothills and Brooks Mountain Provinces are some 30 to 100 miles from the route. Thawed alluvium in the Coastal Plain Province has proven to be an unreliable source of water for camp supply. This route crosses four major drainages in the Arctic Coastal Plain including the Sagavanirktok, Canning, Hulahula, and Kongakut Rivers. Alluvial groundwater may exist under these rivers, but will probably be difficult to locate and be restricted to low volume production. There is some potential for alluvial groundwater beneath lakes within five miles of the Arctic Gas route between MP 00 and 70.



TRANS-ALASKA GAS PROJECT
PROPOSED EL PASO PIPELINE ROUTE
NORTH SLOPE, ALASKA
(M.P. 0 TO M.P. 50)
FIGURE 1
LEGEND
LAKES 2000' OR GREATER IN ONE DIMENSION
PROPOSED EPNG COMPRESSOR STATION
ALYESKA PUMP STATION
SCALE 1:250,000
10 MILES
ALYESKA PIPELINE ROUTE
PROPOSED ALASKAN GAS PIPELINE
MATCH LINE
Prudhoe Bay
Gwydyr Bay
SAGAVANIRKTOK
RIVER
KUPARUK
Franklin Bluffs
Niakuk Is
Heald Point
Stump I
Point Storkersen
Egg I
Beechey Point
M.P. 10
M.P. 20
M.P. 30
M.P. 40
M.P. 50
5 MILES
10 MILES
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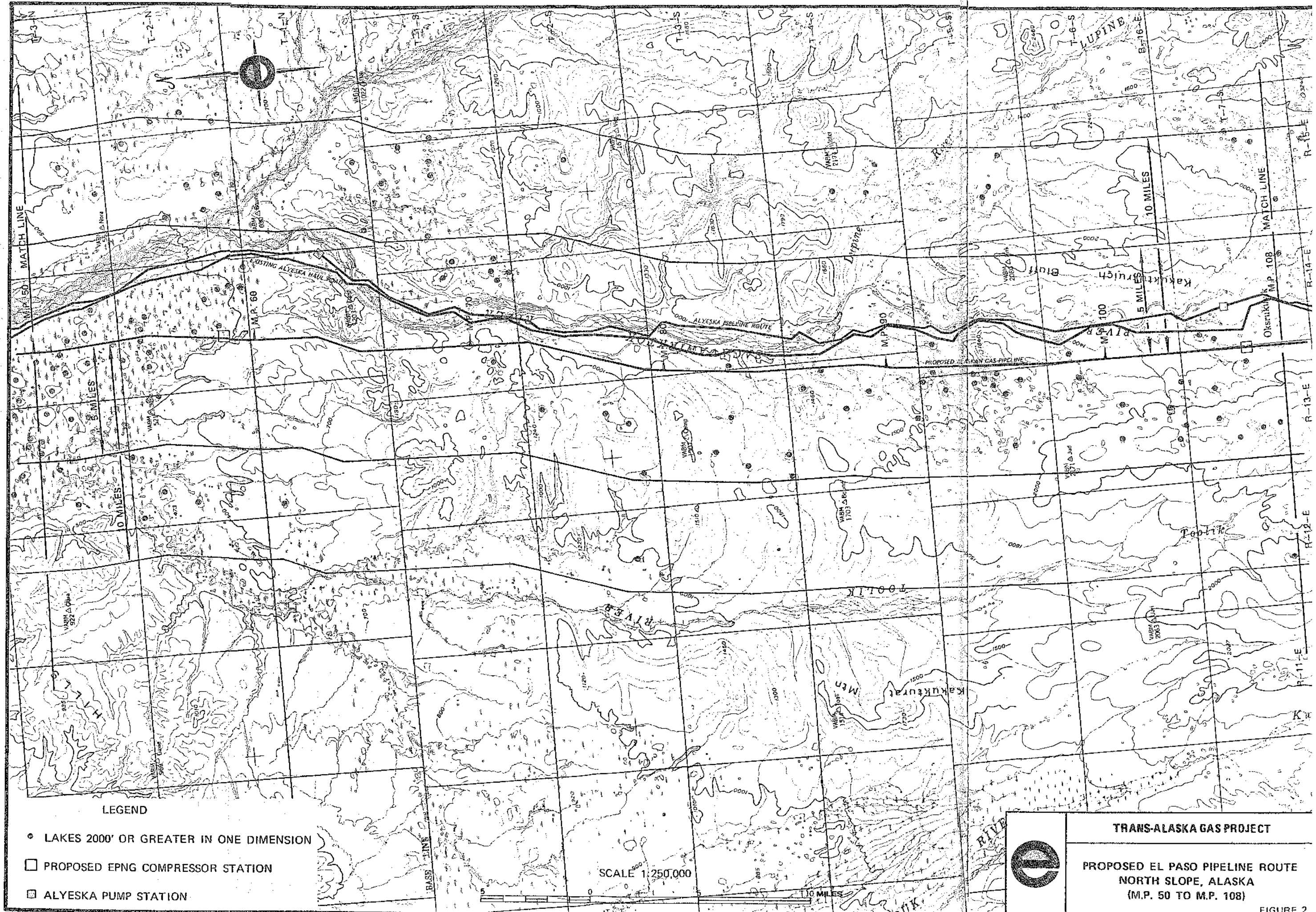


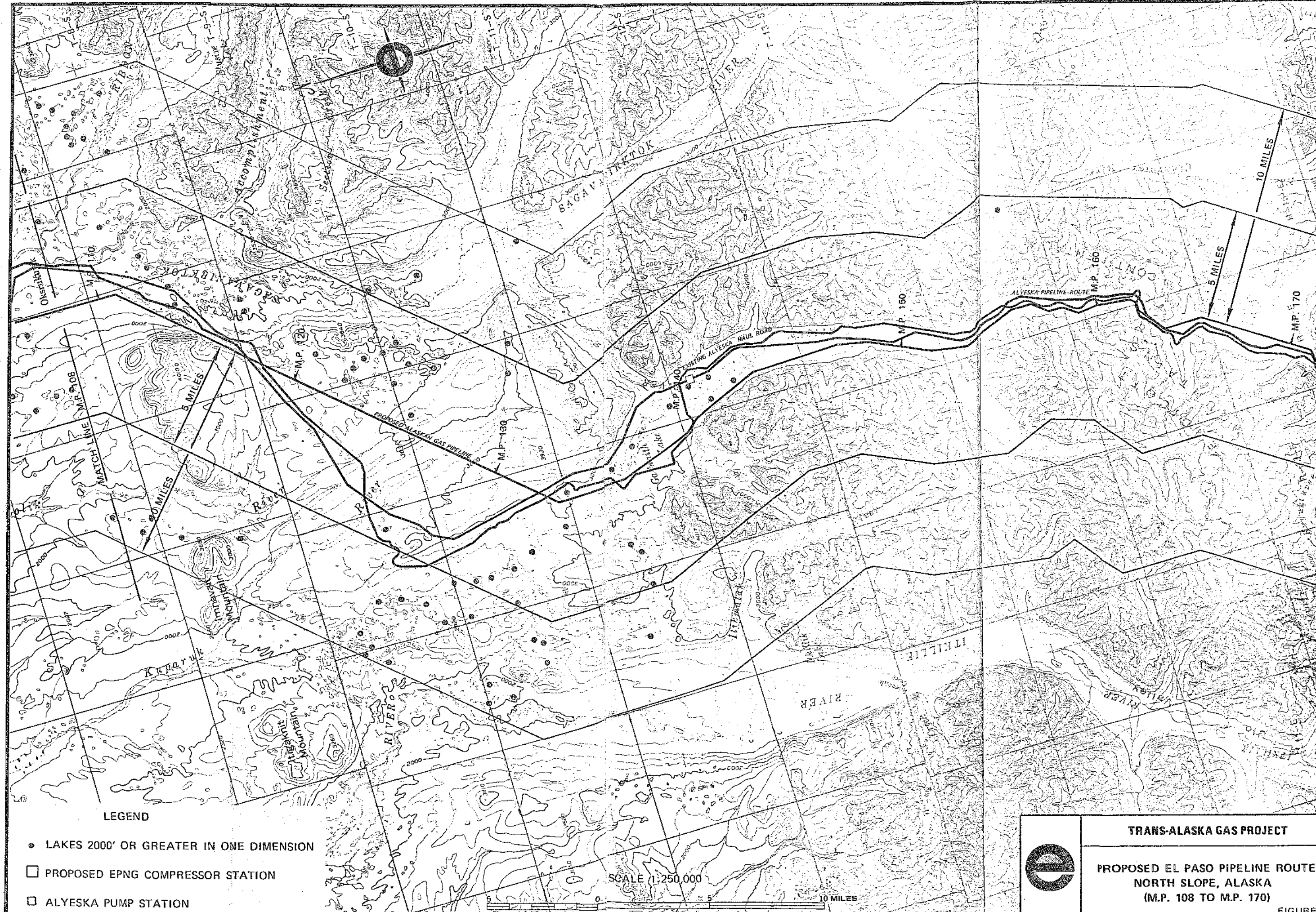
LEGEND

- LAKES 2000' OR GREATER IN ONE DIMENSION
- PROPOSED EPNG COMPRESSOR STATION
- ALYESKA PUMP STATION

TRANS-ALASKA GAS PROJECT

PROPOSED EL PASO PIPELINE ROUTE
NORTH SLOPE, ALASKA
(M.P. 50 TO M.P. 108)

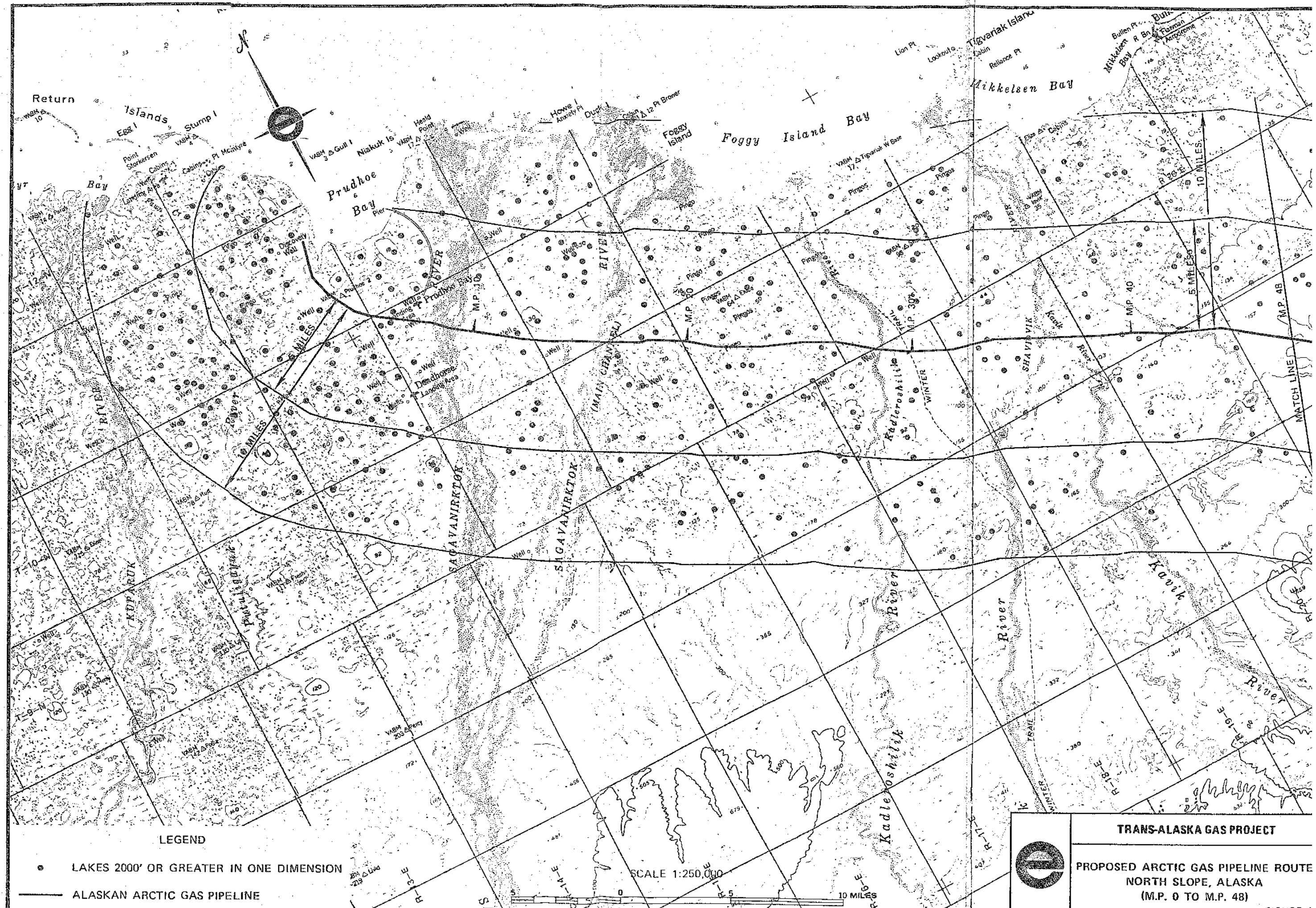
FIGURE 2



TRANS-ALASKA GAS PROJECT

PROPOSED EL PASO PIPELINE ROUTE
NORTH SLOPE, ALASKA
(M.P. 108 TO M.P. 170)

FIGURE 3



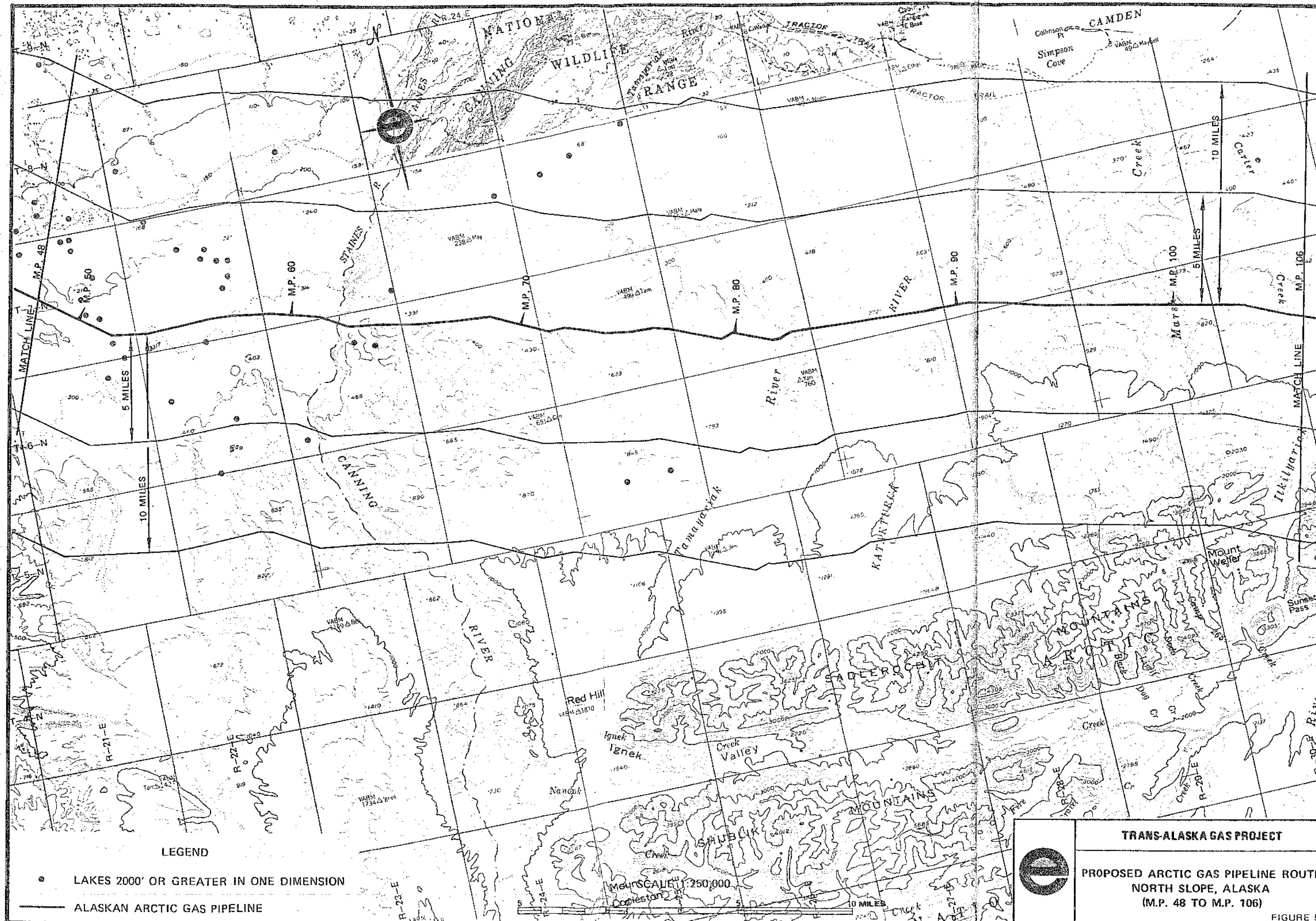
LEGEND

- LAKES 2000' OR GREATER IN ONE DIMENSION
- ALASKAN ARCTIC GAS PIPELINE

TRANS-ALASKA GAS PROJECT

PROPOSED ARCTIC GAS PIPELINE ROUTE
NORTH SLOPE, ALASKA
(M.P. 0 TO M.P. 48)

FIGURE 4



TRANS-ALASKA GAS PROJECT

PROPOSED ARCTIC GAS PIPELINE ROUTE NORTH SLOPE, ALASKA (M.P. 48 TO M.P. 106)

FIGURE 5

TRANS-ALASKA GAS PROJECT

PROPOSED ARCTIC GAS PIPELINE ROUTE
NORTH SLOPE, ALASKA
(M.P. 106 TO M.P. 163)

FIGURE 6

LEGEND

- LAKES 2000' OR GREATER IN ONE DIMENSION
- ALASKAN ARCTIC GAS PIPELINE

TRANS-ALASKA GAS PROJECT

PROPOSED ARCTIC GAS PIPELINE ROUTE
NORTH SLOPE, ALASKA
(M.P. 163 TO M.P. 219)

FIGURE 7

Table 1. A COMPARISON OF POTENTIAL GROUNDWATER SOURCES WITHIN FIVE MILES OF THE EL PASO AND ARCTIC GAS PIPELINE ROUTES, NORTH SLOPE, ALASKA.

	EL PASO			ARCTIC GAS	
	Coastal Plain	Foothills	Brooks Mountain	Coastal Plain	COMMENTS
Suprapermafrost	No	No	No	No	Shallow nature and seasonal flows in this aquifer eliminate consideration as a water source.
Intrapermafrost	No	No	No	No	Water is generally not present in this layer. If found, it is usually saline.
Subpermafrost	No	No	No	No	Any water found in this aquifer is usually saline, difficult to locate, costly to develop, and not reliable as a water source. Flows of 10 gph have been recorded.
Bedrock Water	No	No	No	No	Limited quantities have been found between 1,693 and 2,894 feet below the land surface. Water is saline.
Thawed Alluvium Under:					
Rivers	Yes Limited quantity June to December	Yes 500-1000 gph* 12 months in some locations	Yes 500-1000 gph* 12 months in some locations	Yes Limited quantity June to December	El Paso route parallels the Sagavanirktok River for 130 miles. This allows potential tapping at any location. Arctic Gas is confined to crossings of four possible sources on the Arctic Coastal Plain. Alluvium on the Coastal Plain Province is not reliable water source.
Lakes	Yes Unknown quantity	Yes Unknown quantity	Yes Unknown quantity	Yes Unknown quantity, MP 00-70 only	

*Volumes quoted in this section are per site.

3.2 Springs

3.2.1 General

Springs are reported to be the single sources of free flowing water during winter on the North Slope (Craig and McCart, 1975a; McCart, *et al*, 1974). Although few quantitative data are available, Leffingwell (1919) first described spring sources near the proposed Arctic Gas pipeline route.

The most current description of springs is presented by Craig and McCart (1975a). These springs are perennial in nature and are tributary to mountain streams. Most are generally less than one mile in length and only a few feet wide. Flows are reported to be relatively stable, with summer discharge of North Slope springs ranging from 3.5 to 53 cubic feet per second (cfs).

3.2.2 El Paso Alignment

No known springs are located near the El Paso route as it traverses the Coastal Plains and Foothills Provinces. Some upwellings do occur in the Sagavanirktok River channels in the Coastal Plains Province; in the Foothills Province, many upwellings, as evidenced by icings, occur in the Sagavanirktok.

One spring is known to occur in the Brooks Mountain Province near MP 140 of El Paso's proposed route. This spring is utilized as a supplemental water source by Alyeska's Atigun and Galbraith Camps and Pump Station 4. Quantities of water supplied by this spring are not known.

3.2.3 Arctic Gas Alignment

Seven of the 120 streams crossed by the Arctic Gas route are reported to have spring sources within 16 miles of the proposed alignment (Alaskan Arctic Gas, 1974; Ward and Craig, 1974). These drainages include the Shaviovik, Katarkturuk, Hulahula, Ekalukat and Kongakut Rivers, and Sadlerochit Springs (Figures 4 though 7). Additional springs are located 25 to 100 miles south of the proposed alignment, but are not considered as potential sources due to the distances from the pipeline route.

Flow measurements are available from four of the eight springs characterized in Table 2. Recorded volumes ranged from 10.5 cfs from the Okerokovik Spring to 48 cfs from the Hulahula Spring.

The distances from the proposed pipeline to these eight springs range from 1 to 16 miles. An additional 40 miles or more of access road would be required to tap all of them. Six of these eight springs, however, are reported to be major fish overwintering and spawning sites and will probably not be used as sources of water (Ward and Craig, 1974). The remaining two springs, namely the Okerokovik and Katakturuk, apparently do not support major fish populations and may provide a winter source of water.

Table 2. POTENTIAL SPRING SOURCES AND AVAILABILITY NEAR THE PROPOSED EL PASO AND ARCTIC GAS ROUTES, NORTH SLOPE, ALASKA.

EL PASO

Milepost	Spring Source	Distance From Centerline (miles)	Flow (cfs)	Availability
00-20	None			
20-40	None			
40-60	None			
80-100	None			
100-120	None			
120-140	Near Atigun River	Approx. 1 west MP 140	0.01	Yes. Presently used by Alyeska Camps. Fisheries utilization unknown. Requires site specific evaluation.
140-160	End North Slope Route			
160-195				

ARCTIC GAS

Milepost	Spring Source	Distance From Centerline (miles)	Flow (cfs)	Availability
00-20	Shaviovik	16 south MP 36.5	28.6 (11/3/73) 17.0 (4/11/73)	No. Major fish overwintering area.
20-40	None			
40-60	None			
80-100	Katakturuk	7-8 south MP 87.5	not measured	Yes. No fish reported in this area. Requires site specific evaluation.
100-120	Sadlerochit	1-6 south MP 113	22.0 (5/19/72) 45.0 (4/12/73) 27.0 (11/7/73)	No. Arctic char overwintering site.
	Hulahula	2 north MP 117.5	48.0 (11/5/73)	No. Arctic char spawning and overwintering site. Also native subsistence fishing site.
120-140	Okerokovik	1 south MP 139.4	10.0 (11/7/73)	Yes. No fish seen in this area. Requires site specific evaluation.
140-160	Egakshrak	5 south MP 166	not measured	No. Arctic char spawning and overwintering site.
	Kongakut	5-25 south MP 173 5-10 north MP 173	not measured not measured	No. Arctic char spawning and overwintering sites.
160-195	End Arctic Gas Route MP 195			

Source: Ward and Craig (1974), pp. 91-147.

3.2.4 Summary

Few spring sources are present along the El Paso or Arctic Gas routes. One is known near MP 140 of El Paso's route. This spring is being used as a source of winter supply by Alyeska's Atigun and Galbraith Camps and Pump Station 4.

Eight springs are located within 16 miles of the Arctic Gas route. All but two of these have been reported to support spawning and overwintering fish. The first is the Katakturuk River Springs seven to eight miles south of MP 87.5; discharge has not been measured. The second, Okerokovik River Spring, where flow has been measured at 10 cfs, is located one mile south of MP 139.4. These two springs may supply water during winter but will require site specific evaluation prior to utilization.

3.3 Flowing Surface Waters

3.3.1 General

Hobbie (1973) notes that "there is almost nothing known about the limnology of flowing water in the Arctic". He classified Arctic flowing waters as large rivers, small rivers, streams and springs. These definitions are poorly developed, however. According to Hobbie, "large rivers contain water throughout the year, and have unfrozen holes where fish can overwinter. Small rivers flow all summer, while streams are intermittent and contain water only during snowmelt or after an especially big rain".

Since Hobbie's review, another classification of Arctic flowing water has been published by Craig and McCart (1975a). This work classifies stream types between Prudhoe Bay and the MacKenzie River Delta based primarily upon the origin of the stream and, to some extent, its temperature, chemical properties, and biological characteristics - mainly benthic invertebrate densities. It classifies streams into three broadly-based categories: Mountain, Spring and Tundra Streams. A synoptic description of these three stream types is presented in Table 3. To a large degree, this classification correlates specifically with the delineation of the physiographic provinces, Coastal Plain, Foothills, and Brooks Mountains. Since each of these provinces "has a unique topography, geology, soil, and vegetation" (Spetzman, 1959), it is generally accepted that these differences among provinces are reflected in differences among the waters of each.

According to Alter (1969), few rivers in the cold regions are large enough to maintain an appreciable flow throughout the winter. Most streams in Arctic Alaska freeze solid during the winter (Alaska Water Study Committee, 1975; Hopkins, *et al*, 1955; Sherman, 1973). The actual date that flow cessation occurs is variable, depending upon the stream type and climatic conditions during a particular year.

In general, tundra streams are relatively small in terms of both drainage area and total discharge. Virtually all flow derives

Table 3. SYNOPTIC DESCRIPTION OF ARCTIC STREAM TYPES.

	MOUNTAIN STREAMS	TUNDRA STREAMS	SPRING STREAMS
Origin	Arctic Mountain Province	Foothills and Coastal Province	Mountain and Foothills Province
Size	Largest in area	Moderate	Small to moderate
Temperature	Cold, usually less than 10°C	Summer temp. may exceed 16°C	Usually 3 to 7°C
Duration of Flor	5 months, June to October	3-1/2 to 4-1/2 months, June to to October 15	Perennial
Fish Species	Arctic char, grayling, other	Mostly spawning and rearing; grayling	Spawning, over-wintering and rearing; Arctic char, grayling, other
Benthic Density	Low (100 organisms/m^2)	Intermediate	High (10,000 organisms/m^2)

Source: Craig and McCart, (1975a).

from surface runoff, so it ceases at freeze-up, usually in mid-September. In some years, however, tundra streams continue to flow until mid-October (Craig and McCart, 1975a; Watson, *et al*, 1966).

Mountain streams have been described in considerable detail by Craig and McCart (1975a). They report that flow in mountain streams is derived principally from surface runoff which ceases by mid-October, and from spring sources. Large mountain streams occasionally continue to flow as late as November (Yoshihara, 1972). Data available for the two largest rivers in Arctic Alaska, the Colville and Sagavanirktok Rivers, will serve to establish maximum winter discharge characteristics.

The Colville River is the largest river in Arctic Alaska, nearly 150 miles in length with a drainage area of 24,000 square miles (Table 4) and recorded peak discharge of 1,578,000 cfs (Arnborg, *et al*, 1966). In 1962, discharge dropped rapidly after September 8, the date when average air temperature dropped below 32°F. By the end of September, discharge had dropped from 368,200 cfs to 26,300 cfs. Ice began to form on the river September 30 and ice cover was complete by October 15. Discharge may cease during some winters, but the exact date is unknown (Arnborg, *et al*, 1966; Williams, 1970a). Perennial flow has been reported for certain years. It has been reported that the Indigirka (a Siberian river), which drains an area approximately seven times larger that the Colville, has no discharge from November through April (Suslov, 1961).

The Sagavanirktok River is the second largest in discharge (Schallock and Lotspeich, 1974) and drainage area (Table 4). Peak discharge occurs during spring runoff, normally in the last week of May or first week of June. Surface water records for 1971 indicate that peak discharge in the Sagavanirktok River reached 22,200 cfs on June 2. Discharge fluctuates greatly during the summer until the first of September when it begins to drop steadily. Measurements made at the Lupine Gaging Station show a drop in discharge from 6,050 cfs on September 1, to 900 cfs on September 30, 1971 (U. S. Geological Survey, 1972b).

Table 4. DRAINAGE ARE FOR THE FIVE LARGEST RIVERS ON THE ARCTIC NORTH SLOPE EAST OF BARROW, ALASKA.

River	Drainage Area	
	Square Miles	Acres
Colville	24,000	15,360,000
Sagavanirktok	5,360	3,430,000
Canning	2,106	1,348,200
Hulahula	1,503	962,400
Kongakut	778	497,900

Ice begins to form on the river during the latter part of September, and increases rapidly after that date. For instance, ice depth near the river's mouth at Prudhoe Bay was measured at 1.5 feet on November 6, 1973, while a measurement of 3.0 feet was made near the same location on November 20, 1970 (Ward and Craig, 1974). Ice depths 30 to 50 miles further upstream on November 15 to 22, 1971, ranged from 1.0 to 2.2 feet (Yoshihara, 1972). These data indicate that ice formation is probably greater at the mouths of arctic rivers for any particular date than at locations further upstream.

The Sagavanirktok River is a source capable of providing large quantities of water until flow ceases and pools become isolated. At that time, most of the Sagavanirktok River is frozen to the bottom. The remaining free-water under ice is limited to isolated pools in deeper holes. As a result, free-water becomes difficult to locate and undependable as a water source. Experiences at Prudhoe Bay, Franklin Bluff Camp and Happy Valley Camp have verified this situation. The importance of these isolated pools to fish is discussed later.

According to Schallock and Lotspeich (1974), severe dissolved oxygen depletion during winter has been found in many river systems large and small in Alaska. Their data indicate that this dissolved oxygen depression begins in October and continues into February. Oxygen concentrations measured at stations near the mouth of a river were generally more depressed than at upstream stations. There are few winter oxygen measurements from arctic rivers and fewer yet from isolated pools under ice. Two measurements in the Sagavanirktok River during April recorded dissolved oxygen concentrations of less than 2.0 parts per million (ppm). Four additional measurements taken from sites near Franklin Bluff and Sagwon Bluff found dissolved oxygen values of 4.8 ppm and 1.6 ppm, respectively (Furniss, 1975).

Schallock and Lotspeich (1974) concluded that "The depressed winter dissolved oxygen concentrations and low winter discharge in many Alaskan rivers are more severe and widespread than present literature indicates".

Groundwater in the unfrozen alluvium of the Sagavanirktok River surfaces in the riverbed at numerous locations identified by the presence of "icings" or "aufeis". These sites are potential sources of winter water and should be investigated. All known icings in the Sagavanirktok River have been mapped by Sloan, *et al* (1975), and are shown in Figures 8, 9, and 10.

3.3.2 El Paso Alignment

Within the Arctic Slope drainage, the proposed El Paso pipeline will cross parts of four drainage basins: the Sagavanirktok River, Kuparuk River, Putiligayuk River, and Colville River. Approximately 135 streams including a number of intermittent watercourses, will be crossed (El Paso Alaska, 1974). The vast majority of the streams crossed conform to the definition of Tundra Streams presented by Craig and McCart (1975a); thus, flow in most of these streams from surface runoff, so it ceases at freeze-up, usually in mid-September. In some years, however, tundra streams continue to flow until mid-October (Craig and McCart, 1975a; Watson, *et al*, 1966).

Mountain streams have been described in considerable detail by Craig and McCart (1975a). They report that flow in mountain streams is derived principally from surface runoff which ceases by mid-October, and from spring sources. Large mountain streams occasionally continue to flow as late as November (Yoshihara, 1972). Data available for the two largest rivers in Arctic Alaska, the Colville and Sagavanirktok Rivers, will serve to establish maximum winter discharge characteristics.

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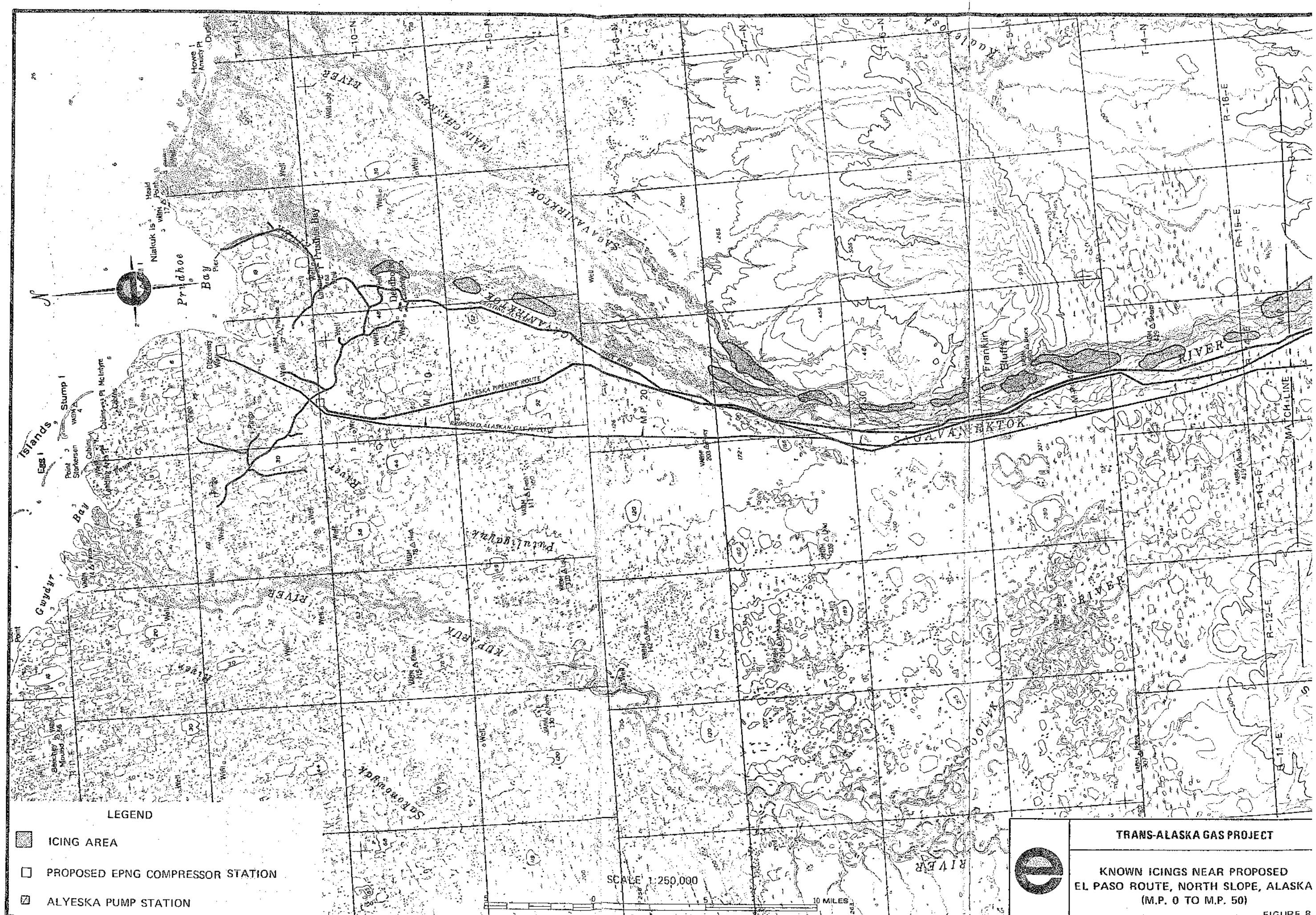


TRANS-ALASKA GAS PROJECT

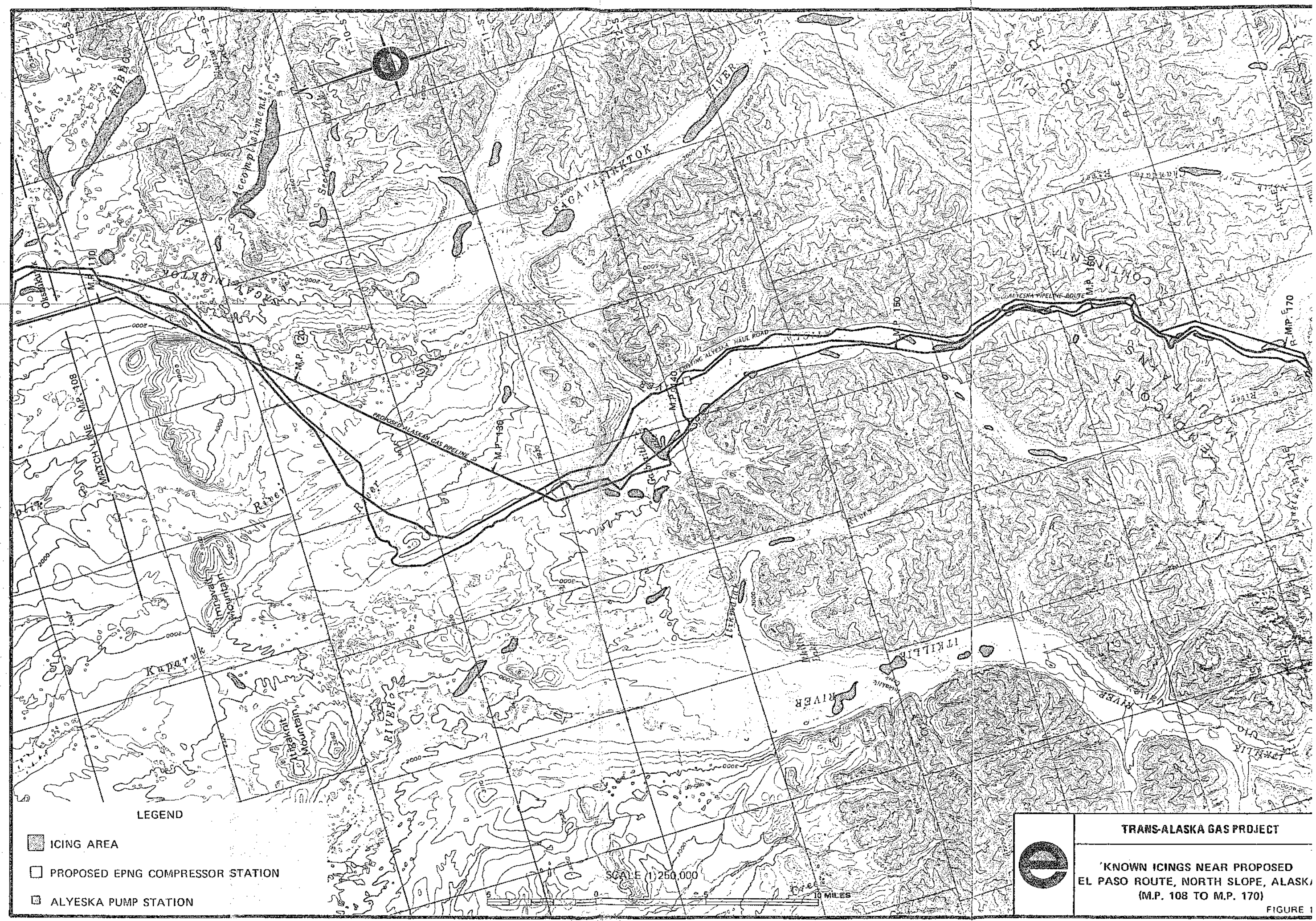
KNOWN ICINGS NEAR PROPOSED EL PASO ROUTE, NORTH SLOPE, ALASKA (M.P. 0 TO M.P. 50)

FIGURE 8

TRANS-ALASKA GAS PROJECT

KNOWN ICINGS NEAR PROPOSED EL PASO ROUTE, NORTH SLOPE, ALASKA (M.P. 50 TO M.P. 108)

FIGURE 9



TRANS-ALASKA GAS PROJECT

KNOWN ICINGS NEAR PROPOSED EL PASO ROUTE, NORTH SLOPE, ALASKA (M.P. 108 TO M.P. 170)

FIGURE 1

should cease in late September or early October and they will be unavailable as winter water sources.

The El Paso alignment parallels the Sagavanirktok River which is a potential source of water during certain times of the year. Between MP 20 and 120, the alignment is usually two to three miles west of the Sagavanirktok River. The single exception to this is between MP 57 and 63, where the alignment skirts west of Sagwon Bluffs and is as much as five miles west of the river. Along this segment of the proposed pipeline, the Sagavanirktok River will be capable of providing large quantities of water through the late fall and early winter until isolated pools of water begin to form under ice. Groundwater upwellings in the river channel are also potential sources of water.

Another potential water source is the Atigun River, a small tributary of the Sagavanirktok. The proposed alignment between Galbraith Lake and Atigun Pass is parallel and in close proximity to this stream. The Atigun River is known to freeze to the bottom during the winter (McDonald, 1971) although the exact date this occurs is not known and certainly varies from year to year. Observations made during fall indicated that freeze-up probably occurs during late September or early October. Consequently, water from the Atigun River will be available only during the early part of the proposed construction schedule.

3.3.3 Arctic Gas Alignment

Arctic Gas reports that about 120 streams are crossed by their Arctic Coastal Plain alignment between its origin at Prudhoe Bay and the Canadian Border. Nineteen of these are Mountain Streams and the remainder are Tundra Streams (Alaskan Arctic Gas, 1974).

As discussed earlier, Tundra Streams often cease flowing in mid-September and do not begin flow again until late May (Craig and McCart, 1975a). Thus, they will not be available as sources of water during that period.

East of the Sagavanirktok River most of the Mountain Streams crossed by the proposed Arctic Gas pipeline are small in drainage area and probably in discharge. Fall surveys conducted by Ward and Craig (1974) indicate that most of these cease flowing shortly after surface ice forms and thus are not potential surface water sources.

The only significant Mountain Streams east of the Sagavanirktok River crossed by the proposed pipeline are the Canning, Hulahula and Kongakut Rivers; none of which are as large as the Sagavanirktok River (Table 4). Although they are not gaged, it is likely that discharge is proportional to drainage area.

Ward and Craig (1974) reported that the Canning River was dry at the pipeline crossing on November 5, 1973 and that the Hulahula River crossing was dry November 7, 1973. The Kongakut River was reported dry at the pipeline crossing on November 5, 1972 (Alaskan

Arctic Gas, 1974). These data indicate that surface flow probably ceases in these rivers sometime during the last part of October, earlier than is the case in the Sagavanirktok River. As a result, surface water sources in rivers will be restricted to low volume pools isolated by ice formation sometime at the end of October. Until then, surface flow under ice will provide a water source in these three rivers.

3.3.4 Summary

The proposed El Paso pipeline parallels the Sagavanirktok River between MP 20 and 120. It could provide large volumes of water until discharge ceases sometime between mid-October and late November. Water should not be taken from the Sagavanirktok after discharge ceases due to potential fisheries utilization. The Atigun River could provide water for construction activities between MP 140 and 160 until freeze-up.

The proposed Arctic Gas pipeline crosses approximately 120 streams between MP 00 and 195. Most of these are Tundra Streams which freeze solid in late September or early October. Prior to early November, water may be available from the Canning, Hulahula and Kongakut Rivers. These sources are reported to have been frozen to the bottom in some locations by early November. The Sagavanirktok River will probably be a reliable water source until later in November, due to its greater flow.

3.4 Standing Surface Water

3.4.1 General

Most arctic lake basins were created by various types of glacial activity or by the effects of permafrost (Hobbie, 1973). As a result of different physical and geological processes, the characteristics of standing water in the three Arctic Slope Provinces are somewhat different.

On the Alaskan North Slope, standing water bodies are generally most abundant in the Coastal Plain Province, uncommon in the Brooks Mountain Province and intermediate in number in the Foothills Province. In the western portion of the Coastal Plain, standing water covers 50 to 75 percent of the land surface area and as high as 90 percent in some regions (Black and Barksdale, 1949). The number and total surface area of these lakes decline toward the east. They are relatively sparse on the Arctic Slope between the Canning River and the Alaska/Yukon Border. The distribution of lakes within ten miles of the proposed El Paso and Arctic Gas alignments is shown in Figures 1 through 7.

Hobbie (1973) has classed standing bodies of Arctic water into three types: ponds, shallow lakes, and deep lakes. Ponds are defined as standing water less than 6.6 feet deep, which freeze solid during the winter, thus preventing the establishment of permanent fish populations. Most shallow lakes are seldom greater than 16.4 feet in depth; fish populations may or may not be present depending on specific situations. Deep lakes exceed 16.4 feet in depth, and usually, but not necessarily, are inhabited by fish.

The most abundant water body on the Coastal Plain Province is the pond; millions have been counted (Briton, 1957). Water seeping through cracks in the ground forms ice wedges in the permafrost, eventually creating a polygonal ridge network that fills with water. This action results in rows of ponds usually less than 200 feet in diameter. These shallow ponds quite often coalesce into larger ponds.

Formation of most shallow lakes on the Coastal Plain is a result of the thawing of large masses of ground ice - the so-called thermokarst process (Black and Barksdale, 1949; Hopkins, *et al*, 1949; Wallace, 1948). These large, shallow lakes become oriented as a result of wind-generated currents (Livingstone, 1963; Carson and Hussey, 1969), and their number has been estimated at tens of thousands in some North Slope areas (Black and Barksdale, 1949). These "thaw" lakes are characterized by elliptical basins with regular bottoms (Hobbie, 1973; Livingstone, *et al*, 1958; U. S. Geological Survey, 1969a). Some of these shallow Coastal Plain lakes are brackish due to salt water intrusion; however, the extent of this condition is not known for the area between Prudhoe Bay and the Alaska Border. Doran (1974) reports that lakes in the MacKenzie River Delta are "often brackish". Obviously, lakes in close proximity to the Beaufort Sea are most likely to be saline.

Another type of shallow lake, termed an "oxbow" lake, is formed by the movement of river channels. These are common along many major arctic rivers. Characteristics of standing water sources near the El Paso and Arctic Gas alignments are given in Tables 5 and 6. Investigations verify that the vast majority of standing waters on the Coastal Plain are shallow (British Petroleum Company, unpubl.; Ward and Craig, 1974). Lakes of the Foothills Province are generally less numerous, smaller in surface area and deeper than those on the Coastal Plain. Lakes on the low ridges originated primarily from thawing or glaciation, but in the river bottoms oxbow ponds are most numerous (Livingstone, *et al*, 1958). In the Brooks Mountain Province, lakes are relatively uncommon (Ward and Craig, 1974). The majority of these result from glaciation and are deep, occurring where a glacial moraine blocks a narrow valley (Hobbie, 1973). Examples of these include Lake Peters, Lake Schrader, Elusive and Chandler Lakes.

Ice begins to form on arctic lakes sometime during September, but as is the case with temperate lakes, the exact date of freezing depends upon the seasonal weather, including temperature, wind, and cloud cover. Other factors determining freeze-up are summer heat income, the variable lengths of time different lakes require to cool sufficiently, and lake depth (Hobbie, 1973). At Barrow, lakes 8.2 to 9.8 feet deep may freeze over anytime after September 1 (Brewer, 1958a). The average freeze date is September 15 to 20, but open water may extend until September 30 (Hobbie, 1973). Arctic Gas (1974) states that freeze-up of Coastal Plain lakes "generally . . . is complete by early October".

Table 5. DEPTHS OF SOME POTENTIAL STANDING WATER SOURCES NEAR THE PROPOSED EL PASO ROUTE, NORTH SLOPE, ALASKA, GROUPED BY PHYSIOGRAPHIC PROVINCE.

Name/#	Location	Surface Acreage	Water Depth (ft.) Maximum	Water Depth (ft.) Mean	Fish Present	Information Source
COASTAL PLAIN PROVINCE						
ME-1	Prudhoe		6.6	--		1
ME-2	Prudhoe		6.6	--		1
ME-3	Prudhoe		8.2	--		1
ME-4	Prudhoe		11.5	--		1
BP-1	Prudhoe		2.8	2.1		2
BP-3	Prudhoe		3.7	3.3		2
BP-4	Prudhoe		3.7	2.7		2
BP-5	Prudhoe		3.0	2.4		2
BP-6	Prudhoe		5.1	4.4		2
BP-7	Prudhoe		5.8	4.2		2
BP-8	Prudhoe		3.0	2.4		2
BP-9	Prudhoe		4.1	3.3		2
BP-10	Prudhoe		6.0	4.9		2
BP-11	Prudhoe		4.3	3.2		2
BP-16	Prudhoe		5.0	3.7		2
BP-17	Prudhoe		3.7	2.7		2
BP-18	Prudhoe		4.8	3.5		2
BP-19	Prudhoe		5.3	4.2		2
BP-21	Prudhoe		4.5	3.0		2
"Oil Drum"	69°47'N, 148°55'W		5.0	--		3
FOOTHILLS PROVINCE						
Sagwon Lake	69°20'N, 148°35'W	400	14	--	Yes	3
Cache 1	69°17'N, 147°28'W	--	25	--	Yes	3
Island Lake	69°15'N, 148°58'W	470	12	6	Yes	4 & 5
Unnamed	69°02', 148°15'	200	87	36	Yes	4 & 5
Unnamed	69°01', 148°54'	300	20	8	Yes	4 & 5
Unnamed	68°50', 148°13'	300	33	19	Yes	4 & 5
Murphy (Toolik)	68°38', 149°35'	--	28	--	Yes	3
Campsite Lake	68°35', 149°13'	--	95	--	Yes	4
BROOKS MOUNTAIN PROVINCE						
Itkillik Lake	68°25'N, 149°55'W	1,330	43		Yes	6
Elusive Lake	68°40'N, 148°30'W	920	55		Yes	6
Galbraith Lake	68°27'N, 149°20'W	1,540	25		Yes	4

1 - Sherman (1973).
2 - British Petroleum Company (unpubl. data).
3 - Edgington (unpubl. data).
4 - McCart, *et al*, (1972).
5 - Yoshihara (1973).
6 - Furniss (1974).

Table 6. WATER AND ICE DEPTH MEASUREMENTS OF STANDING WATER NEAR THE PROPOSED ARCTIC GAS ROUTE, NORTH SLOPE, ALASKA.

Ident.#	Location	Date	Depth (ft.) Water	Ice	Fish Present
COASTAL PLAIN PROVINCE					
#456	Between Sag. & Canning R. 69°54'N, 146°36'W	5/31/73	4	4	No
CT-1	11 mi. south of MP 59 69°41'45"N, 146°21'W	---	15	---	Yes
CR-22-1	69°53'30", 146°20'	4/18/73	8	7-8	Yes
BROOKS MOUNTAINS PROVINCE					
C-1	60°15'45", 145°58'	4/19/73	26	6	Yes
None	Porcupine Lake 68°47'15"N, 146°26'W	4/ 3/73	7	5	Yes
None	Eagle Creek Lake - 1 69°23'45"N, 145°53'W	4/10/73	50	4	Yes
None	Big Lake - 1	---	135	4	Yes
CT-28	60°26'30"N, 146°00'30"W	4/12/73	41	3	Yes
None	Lake Peters*	6/ 8/52	164	4	Yes
None	Lake Schrader*	---	187	---	Yes

*Source: Ward and Craig (1974).
*Depth data measured by Hobbie (1973).

Some very deep lakes in the Brooks Mountain Province sometimes remain open into early October (Hobbie, 1962), but this is unusual.

Ice depth normally reaches two feet sometime between November 7 and 30 (Table 7). A maximum ice depth of from six to seven feet is attained in the late winter (Billello and Bates, 1975; Brewer, 1958b; Kalff, 1968). Ice depth measurements encompassing most of the ice covered period for a typical shallow lake on the Arctic Coastal Plain have been made by Bilello and Bates (1971, 1972, 1975). Their data for October and November are listed in Table 7.

Arctic lakes are generally ice free for two to three months (Boyd, 1959; Brewer, 1958b; Hobbie, 1961; Kalff, 1968). Only a few arctic lakes retain a permanent ice cover; a few in the Canadian High Arctic are open most years, but the majority are completely open every year. Deep lakes are usually clear of ice by mid to late July (Brewer, 1958b). A deep lake, however, can retain its ice cover into August depending on winter ice thickness and cold weather during June and July. Lake Schrader, for example, usually loses its ice cover by July 15. Extreme dates reported by Hobbie (1962) are June 28, 1958, and August 1964 (1973).

The extended duration of the ice cover in the Arctic means that ponds and lakes become ice free after the isolation peak. After that, the generally cloudy weather of July and August reduces the amount of solar radiation available throughout the summer and ensures that water temperatures of lakes seldom exceed 15°C. Smaller ponds, however, may warm to 18°C. Temperature stratification occurs infrequently in arctic standing waters during ice free periods (Hobbie, 1973; Livingstone, *et al*, 1958). Deeper lakes warm slowly and are generally subjected to frequent winds. These conditions prevent establishment of density gradients in the form of thermoclines. However, lakes sheltered from wind and with adequate exposure to sunlight may stratify for brief periods. Hobbie (1961) has observed stratification in Lake Schrader.

During ice free months, arctic lakes are almost always close to complete saturation of oxygen. Oxygen saturation in Lake Peters, for example, ranged from 95 to 100 percent during a summer season. The saturation value decreased to 88 percent as the lake cooled in early September. In February, the top of the water column was at 100 percent saturation, probably due to exclusion of the gases during freezing, and the rest of the water down to about 100 feet was in excess of 90 percent saturation. Water was deoxygenated in both Lake Peters and Lake Schrader at greater depths (Hobbie, 1973).

Shallow lakes may be severely deoxygenated in the winter. For example, oxygen concentrations in Lake 5 (9.8 feet deep) at Cape Thompson were measured at 5 ppm of oxygen at the end of January 1961, and 0 ppm on April 10 (Tash and Armitage, 1967). A second lake near Sagwon (Sagavanirktok River Lake #730) was devoid of oxygen on April 23, 1971 (Edgington, unpubl.). The latter measurement was made when one foot of free-water remained under six feet of ice cover.

Table 7. ICE DEPTH MEASUREMENTS FOR A SHALLOW FRESH WATER LAKE ON THE COASTAL PLAIN PROVINCE APPROXIMATELY 1 MILE S. OF D.E.W. LINE STATION, BARTER ISLAND, ALASKA, 1966-1972.

		Ice Depth (Feet)					
	Year	66/67	67/68	68/69	69/70	70/71	71/72
Month	Day						
Oct.	3	---	---	---	---	0.8	---
	4	---	---	---	0.4	---	---
	10	---	---	---	---	1.0	---
	11	---	---	---	0.6	---	---
	14	---	0.8	---	---	---	---
	15	0.8	---	---	---	---	---
	17	---	---	---	---	1.1	---
	18	---	---	---	0.7	---	---
	21	---	0.9	---	---	---	---
	22	1.0	---	---	---	---	---
	24	---	---	---	---	1.3	---
	25	---	---	---	0.9	---	---
	28	---	1.0	---	---	---	1.2
	29	1.0	---	---	---	---	---
	31	---	---	---	---	1.6	---
Nov.	1	---	---	---	1.1	---	---
	2	---	---	0.5	---	---	---
	3	---	1.7	---	---	---	---
	5	1.8	---	---	---	---	1.3
	7	---	---	---	---	1.8	---
	8	---	---	---	1.4	---	---
	9	---	---	0.7	---	---	---
	11	---	2.2	---	---	---	---
	12	---	---	---	---	---	1.4
	13	2.2	---	---	---	---	---
	14	---	---	---	---	2.0	---
	15	---	---	---	1.8	---	---
	17	---	2.4	---	---	---	---
	18	2.5	---	1.0	---	---	---
	19	---	---	---	---	---	1.6
	21	---	---	---	---	2.0	---
	22	---	---	---	2.3	---	---
	23	---	---	1.4	---	---	---
	26	---	2.6	---	---	---	2.2
	27	2.8	---	---	---	---	---
	29	---	---	---	2.7	---	---
	30	---	---	2.0	---	2.3	---

Sources: Billelo and Bates (1971, 1972, 1975).

Another feature of arctic hydrology is the natural, continued loss of water from some large lakes during the winter. In most cases, flow into arctic lakes ends during September, except from some subsurface flow, yet the rivers draining those lakes continue to flow and the lake level falls (Hobbie, 1973). Greely (1886) noted that during winter the water level of Lake Hazen fell 9.8 to 13.1 feet which created a sagging effect on surface ice. Hobbie (1973) reported that Lake Peters and Lake Schrader have dropped about 3.3 feet during winter months. He estimated that this overwinter loss was equivalent to 6 percent of the total runoff in the drainage basin. As a result of this water loss, ice falls onto the lake bed along the shore, scouring the upper several feet of the littoral zone. This may account for the poorly developed aquatic community along the shores of many arctic lakes.

Although arctic ponds and lakes exist in a region that receives little precipitation, the long winters, low evapotranspiration, and continuous permafrost ensure that 50 to 85 percent of the precipitation runs off the tundra and is available for replenishment (Hobbie, 1973). As a result, the normal overwinter loss of water is easily replaced during spring runoff.

Large volumes of water are available in the winter from lakes that do not freeze solidly to the bottom. As an example of available water quantities which might be expected under the ice in lakes such as those described in Tables 5 and 6, a calculation for a hypothetical lake is useful. Assume a lake with 1,000 acres surface area and a mean depth of four feet. From the data of Bilello and Bates in Table 7, the ice thickness can be expected to reach about two feet by mid to late November. Thus, by that time, half of the water in such a hypothetical lake would be locked up as ice but some 2,000 acre-feet (over 650,000,000 gallons) of water would remain.

Quantities of water in typical Coastal Plain lakes can be more closely approximated by using the average of mean depths of lakes in the Prudhoe Bay area. The average depth of 15 Coastal Plain lakes as shown in Table 5 is approximately 3.3 feet. Using that mean depth and freeze-down data developed by Bilello and Bates, approximate quantities of water remaining under ice at an average date may be calculated for lakes on the Arctic Coastal Plain.

Since ice depth in early to mid November is on the order of a foot, approximately 2.3 feet of water remains unfrozen in Coastal Plain lakes and a loss of about 30 percent of the water has occurred. At least two feet of ice are expected to have formed by the end of November, leaving 1.3 feet of water under ice. This results in a minimum estimated loss of 60 percent of the total available water by that date. Thus, ice thickness is sufficient to lock up most, if not all, available standing water by mid-December.

Freeze-down modification via insulation of standing water to inhibit freeze-down has been attempted in Prudhoe Bay in the past. However, it is costly and has not been evaluated and reported upon at this time, so is not considered in this report.

The marked reduction of free-water in November and December is a factor which must be considered in planning construction methods and schedules. The increase in the number of sources necessary to obtain a given volume of water as winter progresses presents serious ramifications to methods, impact, and feasibility of snow/ice road construction.

3.4.2 El Paso Alignment

In the Coastal Plain Province, approximately 337 standing water bodies have been identified within five miles of the proposed pipeline (Table 8). Of these 337, about 254 are 2,000 feet or larger in one dimension. A minimum of 19 such water bodies are available within five miles of the route between any two 10-mile milepost markers from mile 00 to 60.

Using the mean depth of 3.3 feet for Coastal Plain standing water, and the ice depth data from Bilello and Bates, potentially available water quantities from these 254 lakes can be calculated. The surface area of the 254 standing water sources totals approximately 34,795 acres. Using the average depth of 3.3 feet, a total of 114,824 acre-feet of water, or about 37,000,000,000 gallons, are available before freeze-up begins. Using the earlier approximation of 1.0 foot for ice depth in early to mid November, these lakes can provide approximately 26,000,000,000 gallons of free-water. By the end of November, the total available water can be expected to be reduced to about 15,000,000,000 gallons, or 250 million gallons per mile. By mid to late December, ice thickness can be expected to exceed the mean lake depth, so free-water may not be available at all.

Large volumes of water, in addition to what has been quantified previously, are probably available in the talik underlying these lakes, since they meet the 2,000 foot minimum dimension requirement, provided they are sufficiently deep not to freeze to the bottom. This may provide a late winter source for camps and road maintenance.

The proposed El Paso gas pipeline passes through the Foothills Province between MP 60 and 130. Along this segment, lake abundance, size and distribution are excellent and within close proximity to the pipeline alignment as can be seen from Table 8 and Figures 2 and 3. Depth measurements of standing water in the Foothills Province indicate that such waters are considerably deeper than standing water on the Coastal Plain (Table 5). These waters are sufficiently deep that winter freeze-down will not significantly reduce the volume of water available. Therefore, large quantities of water should be available in the Foothills Province throughout the winter.

The proposed El Paso pipeline alignment passes through the Brooks Mountain Province between MP 130 and 170. Lakes in this Province are sufficiently large and deep (Tables 5 and 8) to provide water throughout the winter. Analysis of lakes in close proximity to the alignment shows that large quantities of water are available during the entire winter, with the exception of the area between MP 160 and 170.

Table 8. NUMBERS OF LAKES AND APPROXIMATE SURFACE AREA OF THOSE GREATER THAN 2,000 FEET LONG WITHIN 5 and 10 MILES OF THE PROPOSED EL PASO ROUTE, NORTH SLOPE, ALASKA.

EL PASO ROUTE	Within 5 Miles			Within 10 Miles		
	Total	Over 2,000 feet		Total	Over 2,000 feet	
Milepost	No. of Lakes	No.	Surface Acreage	No. of Lakes	No.	Surface Acreage
COASTAL PLAIN PROVINCE						
00- 10	140	104	14,326	223	150	19,984
10- 20	61	39	5,176	119	68	8,059
20- 30	26	19	1,495	61	47	4,598
30- 40	23	20	3,000	48	42	6,133
40- 50	49	42	7,327	90	71	11,397
50- 60	38	30	3,471	70	48	5,053
FOOTHILLS PROVINCE						
60- 70	4	2	425	25	11	1,157
70- 80	12	9	819	17	11	1,090
80- 90	15	10	707	20	12	840
90-100	33	15	973	45	19	1,157
100-110	23	14	753	44	22	1,111
110-120	28	7	338	52	19	1,454
120-130	36	14	988	60	30	2,166
MOUNTAIN PROVINCE						
130-140	22	11	1,654	30	14	1,900
140-150	13	4	328	13	4	328
150-160	1	1	51	2	1	51
160-170	0	0	0	1	0	0

3.4.3 Arctic Gas Alignment

The Arctic Gas pipeline alignment lies entirely within the Coastal Plain Province (MP 00 to 195). In terms of standing water abundance, the alignment between MP 00 and 60 is characteristic of the Coastal Plain. Large quantities of water are available in this area until about mid-December. However, east of MP 60, the proposed alignment passes through an area atypical of the Coastal Plain since standing water sources are very limited in number and quantity as shown in Figures 5, 6, and 7. The Environmental Report of Alaskan Arctic Gas Pipeline Company (Alaskan Arctic Gas, 1974) acknowledges this lack of standing water in the eastern portion of the Arctic Coastal Plain, "The vast majority of lakes in proximity to the proposed route are located in the western portion of the region, primarily between the Sagavanirktok and Canning Rivers". From MP 60 to 195 and even further into Canada, few standing water sources exist in reasonable proximity to the pipeline alignment. These few, as shown in Table 9, are poorly distributed for optimum access and use.

There are no large lakes (2,000 feet or greater in one dimension) within five miles of the pipeline between MP 70 and 130 and MP 140 and 180. In addition, only one small lake of 18 acres exists between MP 180 and 190. Within ten miles of the pipeline alignment, a few additional lakes are available; however, none of them occur between MP 80 and 100 and MP 150 and 170.

3.4.4 Summary

Lakes will be the primary source of water for El Paso's proposed winter construction requirements. With five miles of the route, a minimum of 19 lakes, greater than 2,000 feet in length, are available between any two 10-mile milepost markers (MP 00 to 60). Lakes will also provide ample quantities of water between MP 60 and 160. Although less numerous, lakes in this region are generally larger and deeper than those in the first 60 miles.

Until frozen solid, large volumes of water exist in lakes and ponds adjacent to the Arctic Gas route between MP 00 and 60. Lake sources, however, are limited and, in some cases, absent between MP 60 and 195. Between MP 70 and 130 and MP 140 and 180, lakes greater than 2,000 feet in length are absent within five miles of the route. Only one lake of approximately 18 acres is present between MP 180 and 190. As shown in Table 9, lakes are absent from approximately 40 of the total 195 miles of Arctic Gas route.

Table 9. NUMBER OF LAKES AND APPROXIMATE SURFACE AREA OF THOSE GREATER THAN 2,000 FEET LONG WITHIN 5 AND 10 MILES OF THE PROPOSED ARCTIC GAS ROUTE, NORTH SLOPE, ALASKA.

ARCTIC GAS ROUTE	Within 5 Miles			Within 10 Miles		
	Total	Over 2,000 feet		Total	Over 2,000 feet	
Milepost	No. of Lakes	No.	Surface Acreage	No. of Lakes	No.	Surface Acreage
00- 10	106	79	11,351	236	155	20,659
10- 20	65	40	4,117	121	69	6,401
20- 30	74	42	4,434	116	66	6,943
30- 40	49	30	3,333	99	54	6,077
40- 50	43	20	1,638	74	35	2,846
50- 60	46	22	1,167	59	27	1,618
60- 70	6	3	251	15	4	359
70- 80	3	0	0	18	6	292
80- 90	0	0	0	0	0	0
90-100	1	0	0	1	0	0
100-110	0	0	0	2	1	51
110-120	1	0	0	3	1	46
120-130	1	0	0	12	4	307
130-140	5	2	220	17	8	706
140-150	1	0	0	13	6	364
150-160	0	0	0	0	0	0
160-170	0	0	0	0	0	0
170-180	1	0	0	4	1	87
180-190	4	1	18	6	1	18
190-195	14	8	1,388	17	9	1,419

4.0 Biological Importance of Winter Water Sources

As was discussed earlier, unfrozen surface water in the Arctic is significantly reduced due to freezing during the long winter. Consequently, most free-water during this time is critical to the survival of endemic aquatic biota. For instance, the eggs, juveniles, and adults of all freshwater fish are restricted to limited numbers of isolated pools of water under ice in rivers, limited numbers of springs, and some lakes, for eight to nine months of each year.

This section presents an expository analysis which describes winter utilization of free-water sources by aquatic biota.

4.1 Groundwater

4.1.1 General

The biological importance of groundwater upwellings in river channels as fish spawning and overwintering areas is documented for some upstream areas (Craig and McCart, 1974; Furniss, 1974, 1975; Yoshihara, 1972, 1973). During winter, groundwater supplies a continuous flow of well oxygenated water to these overwintering sites. Some of these upwellings are, of themselves, small spring streams which were discussed separately earlier.

The importance of groundwater upwellings to endemic biota in the main stem and delta areas is not understood as well as in the case of upriver areas. Within the main stem and delta areas of large arctic rivers such as the Sagavanirktok, Canning, and Kongakut, groundwater upwellings are not generally utilized by Arctic char for spawning; however, data indicate they are probably important for grayling overwintering and round whitefish spawning and overwintering.

All known fish overwintering areas in the main stem of the Sagavanirktok River are located in the vicinity of aufeis areas. Furniss (in prep.) found grayling and round whitefish overwintering in the Sagavanirktok River at Franklin Bluff in close proximity to an icing. Craig and McCart (1974) report a similar situation in the Brooks Mountains, along the mountain front and in the nearby foothills adjacent to the Arctic Gas pipeline alignment. According to these authors, "Arctic char typically spawn and overwinter in braided, gravel-bottom stream channels in the vicinity of aufeis".

4.1.2 El Paso Alignment

Groundwater appears to be biologically important in the Sagavanirktok River.

4.1.3 Arctic Gas Alignment

Groundwater is probably biologically important in the Canning, Hulahula and Kongakut Rivers and may be important in others.

4.1.4 Summary

The correlation of groundwater (as identified by icings) and fish overwintering areas may be significant. Additional biological investigations are necessary to establish the importance of groundwater in river channels to aquatic biota. Caution should be exercised with respect to water removal in these areas until further information is available.

4.2 Springs

4.2.1 General

The following description of the biological characteristics of spring streams is excerpted from Craig and McCart (1975a):

> "The Spring Stream habitat is one of relative stability and this appears to have a profound biological influence. Kalff and Hobbie (1973) have described these areas as 'green oases in the polar environment'. Streambanks are often overground with vegetation and the streambed is covered in most places with a heavy growth of moss or algae.
>
> Echooka Spring is primarily a spawning area for anadromous char and a rearing habitat for their young. This situation appears to be typical of those springs with easy access to Mountain Streams and the Beaufort Sea".

Approximately 36 spring areas have been located along the Coastal and Foothills Provinces of the North Slope between the Sagavanirktok River and the Canadian border. Of these 36 springs, 34 are known spawning and overwintering areas for anadromous Arctic char, and overwintering sites for lesser numbers of grayling and other species (Craig and McCart, 1974; Furniss, 1974 and in prep.; McCart, *et al*, 1972; Ward and Craig, 1974; Yoshihara, 1972 and 1973). As early as mid-August, Arctic char begin to gather in the vicinity of spring streams to spawn. Spawning peaks September 15 to November 15, although some spawning continues into December (McCart, 1975; McCart, *et al*, 1972; Yoshihara, 1972 and 1973).

Craig and McCart (1975a) report that char eggs cannot tolerate freezing. As a result, most if not all spawning takes place in springs because "these are the only stream areas in which winter flow is assured". The eggs begin to hatch in mid-April and fry emerge during mid-June (Yoshihara, 1973). Through the year fry and juvenile char are abundant in the vicinity of spring water sources (Craig and McCart, 1975a; Furniss, 1975 and in prep.; McCart, *et al*, 1972; Yoshihara, 1972 and 1973).

In springs where conditions are favorable, fish densities are often high. According to Craig and McCart (1975a), "At Echooka

Spring, densities of 5.2 and 3.4 fish/m^2 were recorded (July 20, 1971). In many other spring areas, values ranged from 0.1 to 3.1 fish/m^2".

Spring areas provide some but not all of the overwintering habitat for Arctic char. After studies of the Sagavanirktok River drainage, Yoshihara (1972) concluded "Spring areas at the headwaters of most tributaries provide some overwintering capabilities but it is believed the total fish population is not contained within these restricted areas". Evidently most char spawners move out of the open water areas of springs, presumably to the shelter of ice cover up or downstream (Furniss, 1975 and in prep.; Yoshihara, 1972). The distance char move away from the spawning bed to an overwintering site has not been determined. However, it is likely that char spawners overwinter in the area of spring influence adjacent to their spawning site since spawning activity extends beyond the date when portions of the river freeze to the bottom.

Springs are also important to other forms of aquatic biota, such as insects. The density of benthic organisms in springs often far exceeds that found in other stream habitat types on the North Slope (McCart, *et al*, 1972). In most cases, biomass is also greater in springs. Density and biomass of benthic invertebrates in Spring, Foothill (Tundra) and Mountain Streams are ranked in Table 10. The highest density of benthic macroinvertebrates recorded in one of these springs was more than 84,000/m^2; by contrast, benthos densities in open water areas of Mountain Streams were reported to be as low as 22/m^2.

4.2.2 El Paso Alignment

One spring is reported approximately one to two miles west of MP 140. This spring has not been studied. Surveys will be necessary to determine whether or not others occur in the vicinity of the proposed route.

4.2.3 Arctic Gas Alignment

Eight spring areas are located within 16 miles of the Arctic Gas route. Existing information for these springs is summarized in Table 11.

4.2.4 Summary

Thirty-four of the 36 known springs in the Coastal Plain and Foothills Provinces on the North Slope support overwintering and spawning populations of char. Of the 36 springs, none are found near the El Paso route. One additional unsurveyed spring is located one mile west of El Paso MP 140 in the Brooks Range. Eight of the 36 springs are within 16 miles of the Arctic Gas alignment. Two of the eight may not support overwintering fish populations.

Springs are biological "oases" of the arctic aquatic environment. Various life stages of Arctic char utilize spring areas year-round. Diversity and density of benthos are reported to be greater in

Table 10. RANKED DENSITIES AND BIOMASS (FROM GREATEST TO LEAST) OF BENTHIC INVERTEBRATES IN TWELVE STREAMS ON THE ARCTIC NORTH SLOPE, ALASKA.

	DENSITY		
Rank	Spring Streams	Foothills Streams	Mountain Streams
1.	Echooka Spring		
2.	Ribdon Spring		
3.	Lupine Spring		
4.		Section Cr. (upper)	
5.		Kuparuk River	
6.		Toolik River	
7.		Happy Valley Creek	
8.			Accomplishment Cr.
9.			Ribdon River
10.			Ribdon Tributary
11.			Echooka River
12.			Lupine River

	BIOMASS		
Rank	Spring Streams	Foothills Streams	Mountain Streams
1.	Echooka Spring		
2.		Kuparuk River	
3.	Lupine Spring		
4.	Ribdon Spring		
5.		Toolik River	
6.			Echooka River
7.		Section Cr. (upper)	
8.		Happy Valley Creek	
9.			Accomplishment Cr.
10.			Ribdon River
11.			Lupine River
12.			Ribdon Tributary

Source: McCart, *et al* (1972).

Table 11. SPRINGS LOCATED ALONG THE PROPOSED ARCTIC GAS ROUTE, NORTH SLOPE, ALASKA.

Spring Source	Fish Present	Comments
Shaviovik River	Grayling, Char	A single overwintering area is located approximately 16 miles south of milepost 36.5.
Katakturuk River	--	No fish were seen or caught in these springs. Located 7-8 miles south of milepost 87.5.
Sadlerochit Springs	Grayling, Char	Spring supports lush growth of aquatic vegetation. Benthic densities are high (3,200 - 10,000/m^2). Anadromous char were not caught. However, it is utilized as a juvenile char rearing ground, and possibly as spawning grounds for dwarf Arctic char.
Hulahula	Grayling, Char	Overwintering ground 2 miles north of crossing. Subsistence fishery for Barter Island natives.
Okerokovik	--	Although no fish were observed in November 1973, it is a possible overwintering site for fish.
Ekalukat	Char	This river supports a large population of Arctic char. A spawning and overwintering area is located approximately 5 miles upstream of the crossing.
Kongakut	Char	The Kongakut River is probably one of the most important Arctic char streams in this region. Major spawning and overwintering areas are located 5-10 miles both upstream and downstream of the crossing.

Source: Ward and Craig (1974), pp. 91-148g.

springs than in other North Slope waters. Because of use by aquatic biota, springs are high environmental risk areas in that any utilization of springs, such as withdrawal of water, constitutes a risk in terms of biological impact.

4.3 Flowing Surface Water

4.3.1 General

Rivers and streams in the Arctic are seasonally important to fish and other endemic biota for spawning, rearing, feeding and as migratory routes.

Tundra streams are primarily important to grayling for spawning in the spring, and rearing and feeding in the summer (Craig and McCart, 1975a; Craig and Poulin, 1974; Furniss, in prep.; McCart, *et al*, 1972; Yoshihara, 1972 and 1973). Low flow and freezing prohibit fish use during the late fall and winter. Char and other species use is infrequent. For example, at "Weir Creek", Craig and Poulin (1974) report that "only one percent of the 18,000 fish enumerated at a fish weir were char, the rest were grayling". The ninespine stickleback becomes more abundant in Tundra Streams closest to the Beaufort Sea (Craig and McCart, 1975a).

The Arctic char is the characteristic species in Mountain and Spring Streams, according to Craig and McCart (21). Char use Mountain Streams for migratory paths during late spring as they move from overwintering sites to summer feeding areas in the Beaufort Sea and again in August to mid-September when returning to spawning and overwintering sites (33,34,83,84).

Shallow areas of major North Slope rivers usually freeze to the bottom in October or November, restricting the availability of free-water to isolated pools under river ice. As winter progresses, these isolated pools continue to diminish in size.

Alaska Department of Fish and Game surveys have indicated that fish may overwinter in pools greater than six feet in depth in the Sagavanirktok River (Furniss, 1974 and 1975; Yoshihara, 1972). Investigations conducted by Furniss (in prep.) during 1974-1975, found two isolated pools of water within the Sagavanirktok River. One of these sites is near Franklin Bluffs. The pool, approximately 1,500 feet long and 60 feet wide, was covered by 9 feet of ice. Dissolved oxygen was measured at 4.8 ppm (April 10, 1975). Maximum water depth was about 5.5 feet. Hook and line techniques failed to capture fish, but a gill net placed under the ice caught 28 grayling and 7 round whitefish in 20 hours. Grayling stomachs contained eyed fish eggs, presumably those of whitefish, indicated that this isolated pool is a spawning area for whitefish as well as an overwintering site. A second, smaller, isolated pool was located near Sagwon. Dissolved oxygen was measured at 1.8 ppm (April 9, 1975). Maximum water depth was approximately 2 feet. Hook and line techniques failed to capture fish. A gill net was not set.

Data along the Arctic Gas route indicate that most stream crossings are frozen in winter months (Ward and Craig, 1974). Four fish overwintering areas have been located; the first two are in the Hulahula River approximately 20 miles south of the proposed alignment. Both pools are known Arctic char overwintering sites and are also utilized as annual subsistence fishing grounds by Kaktovik (Barter Island) villagers. The other two sites are in the Canning river approximately 25 miles south of the proposed alignment.

Deltas of large arctic rivers are probably important to overwintering of fish (Furniss, 1975), although data on these areas are sparse (Craig and McCart, 1975b). Encroachment of salt water from the Beaufort Sea may create a brackish area in the winter which is well upstream in the delta regions (Kogl and Schell, 1974; Walker, 1973). Fish species composition and distribution may be altered in these areas due to salt water invasion. Not enough is known at this time about fish utilization of delta areas to identify the importance of this habitiat during the winter.

4.3.2 El Paso Alignment

Along the proposed route, the Sagavanirktok River is the only major flowing water where fish overwinter in isolated pools. This river can be used as a water source without damaging endemic biota until isolated pools begin to form under ice, probably in October or November. Since this date is variable, determination will require field investigation.

4.3.3 Arctic Gas Alignment

Along this route, the Sagavanirktok, Canning, Hulahula and Kongakut Rivers are considered large enough to overwinter fish in isolated pools. Investigations so far verify that fish overwinter in isolated pools in three of these rivers. The Kongakut has not been investigated, although springs both upstream and downstream of the Arctic Gas crossing are utilized for spawning and overwintering (Table 11).

All four rivers can be utilized as water sources without damaging endemic biota until freezing begins to isolate pools under ice. Since this data varies from year to year and from river to river, determination of water availability will require field investigation.

4.3.4 Summary

In the past, some isolated pools of water have been utilized as water sources in the Prudhoe areas, at Franklin Bluff and at Happy Valley. Ward and Craig (1974) report that fish have been sucked into pumps during water removal. Other reports detail instances of isolated pools being pumped dry, with obvious consequences for fish fauna. These reports have prompted regulatory agencies to control and monitor water removed from isolated pools in the Sagavanirktok River near Prudhoe Bay.

Evidence indicates that many of these areas are important to fish fauna. Six isolated pools have been located by various study groups. Five of the six are known to contain fish during winter. Two of these, located on the Hulahula River, are also subsistence fishery sites utilized by Eskimos. Two others are known to occur on the Sagavanirktok River near the proposed El Paso route. The Franklin Bluff site has been shown to support overwintering populations of grayling and round whitefish. Fish have not been found at the Sagwon site. The remaining two pools which have been located, both on the Canning, are known to contain fish.

4.4 Standing Surface Water

4.4.1 General

Arctic freshwaters are generally low in nutrients, receive little direct sunlight, rarely exceed 10°C, and seldom stratify. In response to these environmental factors, the number of floral and faunal species inhabiting standing waters is low, with the resulting food chain being relatively simple (Hobbie, 1973). Although arctic ecosystems are simplified in terms of species diversity, the interrelationships of organisms are still extremely complex and difficult to understand.

"The most striking biological characteristic of arctic Alaskan lakes is the absence of a well-developed shore community," note Livingstone, *et al* (1958). They further observe, "The lack of a shore community, combined with the scars of heavy ice-push, gives to even the most permanent arctic lake a barren, raw, and temporary aspect. The shoreline looks like that of a spring puddle or temporary ditch rather than a lake." Although lack of a shore community is characteristic of most lakes on the tundra, it cannot be said with certainty that all lakes will be without one.

According to Spetzman (1959):

> "Very few kinds of higher aquatic plants grow on the Arctic Slope, and their distribution is erratic. Almost all aquatic vegetation of the Arctic Slope occurs in lakes. Plant communities in each lake are usually arranged in concentric bands, corresponding to depth of water. Most vegetation is limited to water less than 4 feet deep, and the depth preferred by any given species decreases from the foothills northward into the more severe climatic conditions of the coastal plain. Each species forms an extensive colony, mostly by vegetative means, once it becomes established, thus excluding other species. Two ecologic life forms occur, rooted submerged and rooted emergent aquatics. The former are relatively unimportant and usually lacking; the latter play an important part in the obliteration of lakes through the

accumulation of peat. In small lakes, the remains of emergent aquatics from the lake margins accumulate, with the result that the water is gradually replaced by fibrous organic debris and the bottom gradually freezes to higher levels, which eventually permits the development of a mat of vegetation over the lake bed. Thus, a wet sedge meadow is finally formed."

Spetzman goes on to list a total of only thirteen species of aquatic vascular plants on the North Slope. Livingstone, *et al*, (1958), report that in the smaller lakes there is sometimes a good stand of *Arctophila fulva*, a coarse aquatic grass, and in the shallow ponds there is often a good growth of *Hippuris vulgaris* or *Ranunculus pallasii*. Hobbie (1973) has reported phytoplankton production to be low in arctic ponds and lakes.

Surprisingly, quantities of algae are greater in arctic lakes than subarctic or alpine lakes. Hobbie (1973) attributes this to the fact that snow does not build up on ice-covered lakes in the Arctic, allowing light penetration to occur through the ice during long days in the late winter and early spring which results in considerable algal photosynthesis at this time. Photosynthetic rates are mainly limited by the low nutrients of arctic lakes.

Howard and Prescott (1971) report, "Primary production studies of tundra lakes of the Brooks Range and coastal plain reveal two production types. Most lakes had a very low mean rate (20-44 mg C/m^3/24hr.), whereas shallow (ca. 1 m max. depth) lakes of the coastal plain had very high values (223-285 mg C/m^3/24hr.)." All but two of the tundra lakes were classed in the low primary productivity category. They also report that primary productivity was variable. When compared to temperate lakes, most arctic lakes are oliogotrophic.

Two International Biological Program (IBP) studies - at Char Lake and Barrow ponds - have shown that primary production of aquatic plants is many times greater than production of the phytoplankton (1973). The study of ponds at Barrow indicates that sediments derived from vascular aquatic plants dominate the energy and nutrient flow and nutrient release from these sediments controls phytoplankton productivity (Hobbie, *et al*, 1972).

The biomass of the zooplankton in arctic waters is low but comparable to winter zooplankton quantities in temperate lakes. In spite of the low production, the biomass of zooplankton almost always far outweighs that of the phytoplankton (Hobbie, 1973).

The dominant group of benthic animals in arctic water is the chironomid larva. They dominate northern Alaskan lakes (Livingstone, *et al*, 1958), and make up 75 to 95 percent of total numbers and biomass in five ponds at Barrow and five lakes at Prudhoe Bay (Bierle, 1972). Chironomids are most abundant in shallow ponds with organic sediment; in the Barrow ponds their number may reach 9,000 per m^2 (Bierle, 1972).

Shallow ponds near Cape Thompson contained up to 40,000 per m^2 (Watson, *et al*, 1966). Deeper lakes support less biomass than shallow ponds. For example, Chandler Lake is reported to support approximately 1 gm per m^2 as compared to 36 gm per m^2 found in the Barrow ponds (Livingstone, *et al*, 1958).

Hobbie (1973) states that chironomids "are also the most important food for fish and shore birds". Tundra ponds have about 10 species of chironomid larvae, while similar ponds and shallow lakes in temperate areas will have 60 to 160 different species.

In the Arctic, there is not the great variety of animals which usually inhabit the shore zone of more temperate lakes. There appear to be no freshwater sponges, no Notonectidae, Corixidae, Gyrinidae, Dytiscidae, and no Amphibia north of the Brooks Range (Livingstone, *et al*, 1958).

Whether or not a lake freezes to the bottom in winter is, of course, very important biologically. In the experience of Livingstone, *et al* (1958), "fish are to be found only in lakes that are deep enough to have a considerable body of water under the ice in winter, or else in lakes that are connected with deep lakes, rivers, or the sea".

Fish species known to occur in standing waters in the eastern portion of the Arctic Coastal Plain include Arctic char, lake trout, grayling, ninespine stickleback, round whitefish and four-horn sculpin (Ward and Craig, 1974). Least cisco are resident to Elusive Lake (Furniss, 1974) but unknown in other lakes in the area.

Lakes of the Arctic Coastal Plain are characteristically shallow and subject to total or near total freeze-down. Consequently, the majority are not capable of supporting resident fish populations (Ward and Craig, 1974). Some are utilized during ice-free periods and a few support resident populations of ninespine stickleback (Alaskan Arctic Gas, 1974).

Based on existing information, the standing freshwaters of the Arctic Coastal Plain are little utilized by fish and can be considered as areas of low environmental risk.

Most standing waters of the Foothills Province are considerably deeper than those of the Coastal Plain, and are capable of supporting fish fauna. Surveys in the Sagavanirktok River drainage and in the Arctic National Wildlife Range indicate that most Foothills lakes support limited fish populations consisting primarily of lake trout and grayling with populations of Arctic char, round whitefish, and burbot occurring less frequently (Furniss, in prep.; Kogl and Schell, 1974; McCart, *et al*, 1972; Ward and Craig, 1974; Yoshihara, 1972).

Within the Brooks Mountain Province, lakes are deep and generally support resident populations of fish, including lake trout, grayling, Arctic char, and round whitefish (Furniss, 1974; Hobbie, 1960; Kogl and Schell, 1974; McCart, *et al*, 1972; Ward and Craig, 1974).

Although fish in these lakes are characterized by slow growth, they may attain large size and live to ages exceeding 40 years.

4.4.2 El Paso Alignment

The proposed route passes through the entire spectrum of standing water environments: Coastal Plain ponds and shallow lakes, Foothills lakes, and Mountain lakes. Some of these lakes have been surveyed by various agencies and organizations as a result of the North Slope hydrocarbon exploration and the construction of the Trans-Alaska Pipeline System. Lakes surveyed were limited to waters potentially impacted by oil pipeline construction or to those with particularly interesting characteristics or potential importance.

Although some standing water sources are biologically important, especially to fish fauna, many are relatively unimportant. The abundance of lakes along this alignment, their low degree of productivity and the non-use of many of them by game species indicate that large numbers of lakes will be available as water sources. Site specific investigations will be necessary to identify sources with minimal biological importance.

4.4.3 Arctic Gas Alignment

This proposed alignment passes through a region of the Coastal Plain where lakes are relatively unimportant biologically. Studies show that up to 50 percent of the Coastal Plain lakes surveyed do not support resident populations of fish (Ward and Craig, 1974). As with the El Paso route, when lakes are found, they will likely be suitable as water sources. Some information is now available but additional site specific investigations will be necessary to identify specific sources and to assure minimal impact.

4.4.4 Summary

Few of the total standing waters which are potential water sources have been surveyed for fish utilization. Available data, however, indicate that most lakes on the Coastal Plain and a few in the Foothills are probably unimportant to fish production. The majority of Brooks Mountain lakes support lake trout, char, and grayling, which are the only sport fish species occurring in abundance on the Arctic North Slope.

Site specific investigations are necessary to identify the relative importance of a particular lake and to identify acceptable locations for water withdrawal.

5.0 Problems of Winter Water Use Along Both Proposed Routes

5.1 Timing of Construction as Related to Water Source and Availability

Water sources capable of meeting proposed construction requirements are seldom located immediately adjacent to the proposed routes. Utilization of most sources will require additional access roads across delicate tundra. Due to federal and state regulations concerning over-tundra travel, it may not be feasible to construct access roads to water sources during much of the snow/ice road construction period, September to December, which has been proposed by both El Paso and Arctic Gas.

The State of Alaska regulates tundra travel on state land, the Park Service for National Park lands, the Bureau of Land Management for unappropriated Federal Public Domain lands, and the Wildlife Service for Wildlife Refuge lands. These agencies determine when conditions are adequate to support over-tundra vehicular traffic so that tundra damage is minimized. The main requirements are sufficient snow depths (six to eight inches) and completely frozen tundra. The date over-tundra travel is authorized varies widely from year to year; authorization from the State Division of Lands to begin over-tundra travel has varied from October 1 into December. Cross country over-tundra travel on state lands in 1974 was not permitted until December due to insufficient snow depths. In 1975, approvals had not been issued on October 26, 1975, due to unfavorable conditions.

Dates of past permits provide a guideline for evaluation the feasibility of snow and ice road construction between September and December. If mobilization during the proposed three winter construction seasons is delayed beyond late September, due to restricted over-tundra travel to water sources, the quantities of water available will be reduced, access road requirements increased and the construction period shortened.

Utilization of the ditch centerline as access across tundra areas has been proposed (Dau, 1975b) to compensate for late freeze-up or insufficient snowfall. This is not practical for the Arctic Gas proposal because the remote location of most water sources will require numerous and lengthy access roads, across tundra, north and south of the pipeline right-of-way. The El Paso proposal is not contingent upon regulatory agency tundra-travel permitting to the extent of the Arctic Gas proposal. El Paso can utilize the existing Alyeska haul road and access roads to develop water at certain lakes and along the Sagavanirktok River without crossing tundra. Thus, early access to water is assured along the El Paso route.

5.2 Impact of Withdrawal Upon Aquatic Biota

One of the critical biological problems created by proposed gas pipeline construction in the Arctic is the conflict between large volume water removal and use by endemic aquatic biota during the winter.

Water withdrawals during late fall may seriously impact spawning fish; in winter and early spring, it may have deleterious effects on hatching and overwintering fish.

Large volume removal of water from the thawed alluvium beneath large arctic rivers could reduce surface flow at groundwater upwelling sites. Partial and/or total dewatering of isolated pools under ice may result.

As shown earlier, spring areas in arctic streams are extremely important to aquatic biota and especially to anadromous fish species. Human activity in and around spawning areas will probably disturb Arctic char and may reduce spawning success. The period of sensitivity for spawning Arctic char is late August to mid-December, with a highly critical period during the peak of spawning activity September 15 to November 15.

Another potential impact of water removal from springs is the reduction of flow below a minimum necessary for survival of overwintering fish and survival of eggs deposited in the gravel. As flow decreases, marginal areas will become dewatered. Since char spawn in shallow pools and riffles which are constantly fed by spring flow, a reduction in flow may expose eggs to freezing and reduce survival.

It is suspected that adult char overwinter in spring influenced areas in the vicinity of spawning grounds. Flow reduction will reduce the amount of overwintering habitat available to fish and other biota.

Due to the importance of spring areas to aquatic biota, withdrawal from them is not recommended. It is not likely that the Alaska Department of Fish and Game will issue water withdrawal permits for North Slope springs important to fish.

Prior to cessation of flow, water removal from large arctic rivers will not be harmful to endemic biota. However, flow in most arctic rivers ceases in the late fall or early winter. At that time, isolated pools of water remain which are evidently important as overwintering areas for Arctic grayling and round whitefish and may be spawning areas for the latter. Direct removal of water from isolated pools has killed fish in the Sagavanirktok River near Prudhoe Bay. Removal short of complete dewatering may adversely affect overwintering fish by concentrating already dense populations into even smaller areas; the resultant over-crowding may create serious dissolved oxygen depletion, since dissolved oxygen is low at those locations and times. According to Schallock and Lotspeich (1974) low winter dissolved oxygen levels in arctic rivers, particularly near the mouths, may normally be a limiting factor for aquatic biota. Any activity which compounds this problem has the potential for seriously affecting aquatic biota and should not be considered. For this reason, although existing biological information is scarce, isolated pools should probably not be considered as water sources at this time.

Standing water appears to be the single most reliable source of water in the Arctic during winter. The Habitat Protection Section of the Alaska Department of Fish and Game has encouraged all North Slope lease holders to use lake sources rather than river sources whenever possible (Brooks, 1975). Although lakes are the preferred water source, they will require site specific investigation. This is necessary because reduction of water volume may adversely affect fish populations through dewatering of the lake or shoreline spawning areas, or by concentrating fish in a small volume of water that cannot supply sufficient dissolved oxygen for their survival.

5.3 Mitigation of Damage to Aquatic Resources

Site specific consideration of each water source will be necessary during the final design phase of the proposed projects to ensure minimal impact.

The aquatic habitat can be divided into two broad categories: flowing water and standing water. Lakes capable of supporting fish are generally closed systems and are not utilized by anadromous species. Closed systems with resident fisheries offer several rehabilitative advantages over flowing water habitats with migratory populations. These advantages include: (1) pre-impact conditions are most easily assessed; (2) extent of impact is more predictable; (3) damages to a discrete area are usually less; (4) assessment of damages can be done more accurately; and, (5) more is known and published concerning lake fishery restoration (Hammarstrom, 1975; Kalb, 1974; Kramer, 1975; Peckham, 1974; Watsjold, 1973 and 1975; Williams, 1975). Results of those fishery restoration programs have shown that they are successful in Alaska.

6.0 Summary Comparison of Winter Water Availability Adjacent to Proposed Routes

This section summarizes the comparisons of available sources and quantities of water along the proposed El Paso and Arctic Gas pipeline routes. For summary purposes, discussions are limited to areas within five miles either side of the proposed pipeline alignments on the North Slope of Alaska.

Availability of water from sources characterized as groundwater, springs, flowing water, and standing water, near the El Paso and the Arctic Gas routes is shown in Tables 12 and 13, respectively. Calculated volumes of water shown are based on assumed ice thickness in late November, the mean lake depth from data shown in Table 5, and lake surface areas given in Tables 8 and 9.

The "availability" of water, for the purpose of this section, means large volumes of free-water (2×10^5 to $1,500 \times 10^5$ gallons) which may potentially be utilized for snow/ice road construction and are not critical to fisheries. For example, springs known to support spawning and overwintering fish are not discussed as a possible source in this section because of their high fishery value. Isolated pools of river water are also deleted from this section due to their importance to overwintering fish. All lakes of a minimum size, however, are included since most can support withdrawal of large volumes of water, may support only limited fisheries, and/or are shallow enough to freeze solid during winter, thus eliminating fish considerations entirely.

Comparative data included in this section have been prepared on the basis of water availability during fall and early winter. The availability of water during this period is dependent upon two factors: general freeze-up conditions and starting dates for tundra travel.

Comparison of all potential water sources within five miles of either route indicate that water is present in sufficient quantities to meet substantial winter requirements along the El Paso route but not sufficient to meet requirements of Arctic Gas.

Lakes appear to be the primary source of water along both routes during proposed construction seasons. In late November 700,000 to 186,000,000 gallons of water are available from lakes between any two 10-mile milepost markers along El Paso's route from MP 00 to 160 (Table 12).

Although 3,300,000 to 147,600,000 gallons of water are available within any ten-mile segment of the Arctic Gas route between MP 00 and 70, and 2,900,000 gallons are estimated to be available between MP 130 and 140, no standing water sources appear to be available between MP 70 and 130, nor between MP 140 and 180 (Table 13).

Table 12. ESTIMATED QUANTITIES OF WATER AVAILABLE WITHIN FIVE MILES OF THE PROPOSED EL PASO ROUTE, NORTH SLOPE, ALASKA.

Milepost	Groundwater	Springs	Flowing Water	Standing Water (gal.)
00- 10	very limited quantities; unreliable	No	unlimited quantity from the Sagavanirktok River until freeze-up.	1862×10^5
10- 20	"	No	"	673×10^5
20- 30	"	No	"	194×10^5
30- 40	"	No	"	390×10^5
40- 50	"	No	"	953×10^5
50- 60	"	No	"	451×10^5
60- 70	Alluvium; 24,000+ gpd	No	"	55×10^5
70- 80	"	No	"	106×10^5
80- 90	"	No	"	92×10^5
90-100	"	No	"	126×10^5
100-110	"	No	"	90×10^5
110-120	"	No	"	44×10^5
120-130	"	No	"	128×10^5
130-140	No	No	No	215×10^5
140-150	Alluvial gravel; 12-25,000 gpd	1 spring, 2 miles west, 8-13,000+ gpd	unlimited quantity from the Atigun River until freezeup.	43×10^5
150-160	possibly 12-25,000+ gpd	No	No	7×10^5
160-170	No	No	No	-0-

Table 13. ESTIMATED QUANTITIES OF WATER AVAILABLE WITHIN FIVE MILES OF THE PROPOSED ARCTIC GAS ROUTE, NORTH SLOPE, ALASKA.

Milepost	Groundwater	Springs	Flowing Water	Standing Water (gal.)
00- 10	very limited quantities; unreliable	No	unlimited quantity from the Sagavanirktok River until freeze-up.	1476×10^5
10- 20	No	No	No	535×10^5
20- 30	No	No	No	576×10^5
30- 40	No	No	Shaviovik River MP 31 until freeze-up.	433×10^5
40-50	No	No	Kavik River MP 49.5 until freeze-up.	213×10^5
50- 60	No	No	No	152×10^5
60- 70	very limited quantities; unreliable.	No	Canning River MP 62.5, unlimited until freeze-up.	33×10^5
70- 80	No	No	No	-0-
80- 90	No	No	No	-0-
90-100	No	No	No	-0-
100-110	possibly very limited quantities; unreliable	No	Hulahula River MP 117.5 until freeze-up.	-0-
110-120	No	No	No	-0-
120-130	No	No	No	-0-
130-140	No	MP 139.4; spring flow approximately 79 gps	No	29×10^5
140-150	No	No	No	-0-
150-160	No	No	No	-0-
160-170	No	No	No	-0-
170-180	possibly very limited quantities; unreliable	No	Kongakut River MP 173 until freeze-up.	-0-
180-190	No	No	No	2×10^5

Appendix A. LIST OF FISH SPECIES KNOWN TO OCCUR ON THE NORTH SLOPE AND IN THE BEAUFORT SEA DRAINAGES.

Common Name	Scientific Name
Arctic char	*Salvelinus alpinus*
Grayling	*Thymallus arcticus*
Lake trout	*Salvelinus namaycush*
Round whitefish	*Prosopium cylindraceum*
Broad whitefish	*Coregonus nasus*
Humpback whitefish	*Coregonus pidschian*
Longnose sucker	*Catastomus catastomus*
Arctic cisco	*Coregonus autumnalis*
Least cisco	*Coregonus sardinella*
Four-horned sculpin	*Myoxocephalus quadricornis*
Burbot	*Lota lota*
Ninespine stickleback	*Pungitius pungitius*
Northern pike	*Esox lucius*
Arctic cod	*Boreogadus saida*
Slimy sculpin	*Cottus cognatus*
Pink salmon	*Oncorhynchus gorbuscha*
Chum salmon	*Oncorhynchus keta*
Arctic flounder	*Liopsetta glacialis*

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