United States
Environmental Protection
Agency

Region 10
1200 Sixth Avenue
Seattle WA 98 01

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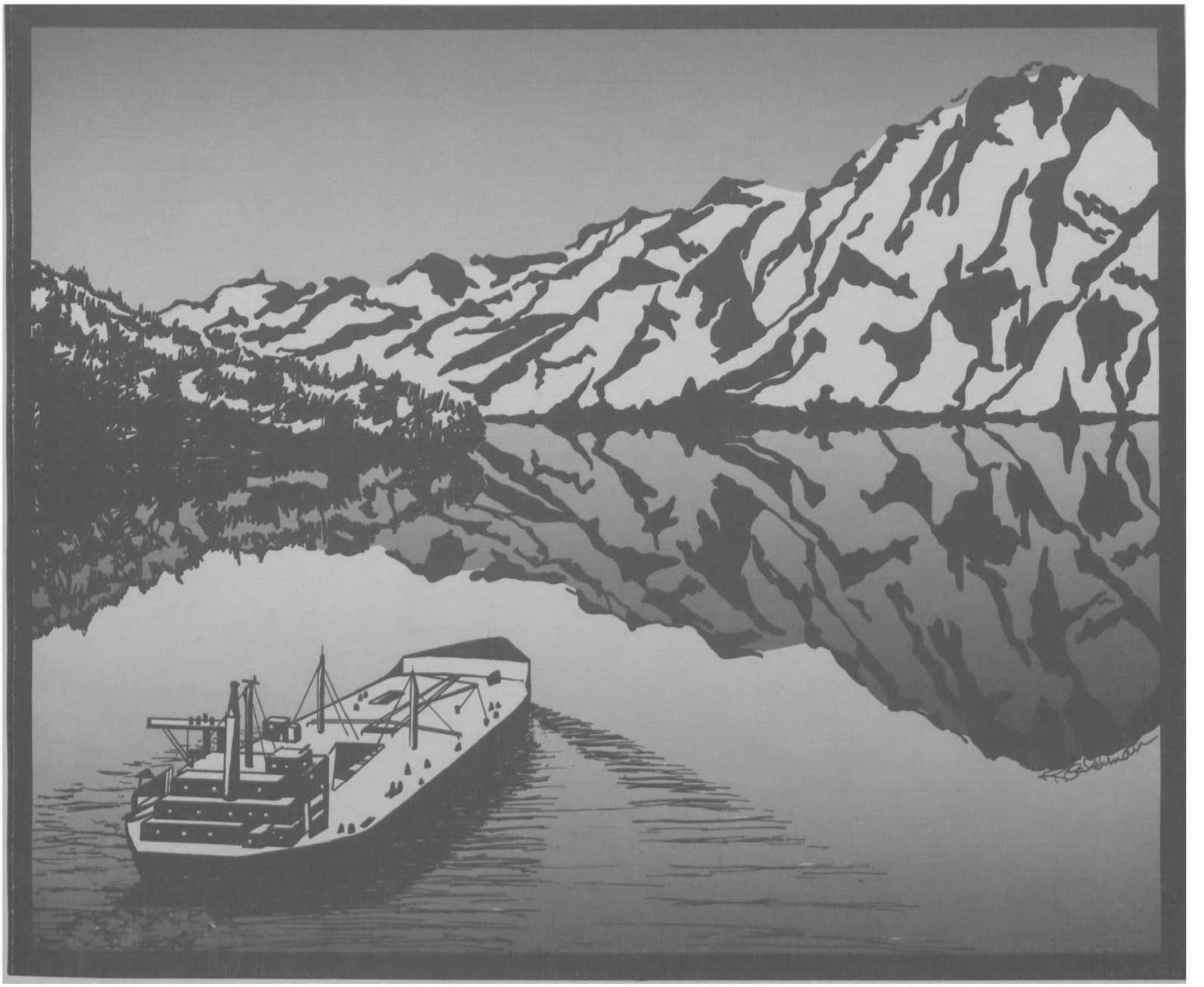
December 1979
EPA 910/9-79-064

Environmental Impact Statement

Alaska Petrochemical Company

Refining and Petrochemical Facility
Valdez, Alaska



ENVIRONMENTAL IMPACT STATEMENT

Alaska Petrochemical Company

Refinery and Petrochemical Facility

Valdez, Alaska

APPENDIX VOLUME I

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If an inconsistency appears between information in the Draft Environmental Impact Statement and Volumes I and II of the Technical Appendices, the DEIS represents the most current information. The technical reports in the Appendices were prepared over a period of several months, concurrent with Alpetco's design development activities. There were completed prior to preparation of the DEIS and as a result may not reflect minor project description changes that occurred subsequent to completion of the reports. The latest available information has, however, been considered in the main text of the DEIS.

Geotechnical

GEOTECHNICAL

GEOLOGY

Regional Prince William Sound

The proposed petrochemical refinery site is located on the east end of Port Valdez, the northeastern most extension of Prince William Sound. Prince William Sound is an extensive northerly embayment near the center of the Gulf of Alaska (Figure 1).

Prince William Sound is separated from the valleys of interior Alaska by the steep slopes of the Chugach, Kenai and St. Elias Mountains. These mountains are progressively higher in elevation from west to east, with numerous peaks in the Kenai Mountains ranging in height from 1,200 to 2,100 meters (4,000 to 7,000 feet), in the Chugach Mountains from 2,100 to 4,000 meters (7,000 to 13,000 feet), and in the St. Elias Mountains from 3,000 to 5,000 meters (10,000 to 18,000 feet).

The mountains surrounding Prince William Sound are youthful (rugged) in form and contain the most extensive system of valley glaciers in North America. Only at lower elevations do the rugged mountain features disappear and rounded glacial carved valleys dominate. (Islieb and Kessel, 1973).

The shoreline of the sound is intricately incised by numerous long, narrow fiords and by many lesser bays and coves. The coastline is generally accented by the abrupt rise of mountains from the shore. The shoreline of Prince William Sound is approximately 4,888 kilometers (3,000 miles) in length, including the shorelines of 34 major and 150 lesser islands which dot the sound.

The present day geomorphology of Prince William sound is extremely complex and is a result of extensive tectonic forces and later by massive glaciation. The folding, buckling and shearing of the strata are the result of these tectonic forces, that have acted since the end of Mesozoic time (past 70 million years). Regional uplift and intrusion of igneous rocks also shaped the topography. Later extensive glaciation carved out U-shaped valleys, hanging valleys, and horns. Since the periods of glaciation, the major geomorphic agents have been the area's heavy precipitation and receding glaciers.

The rocks of the Prince William Sound region are dominantly sedimentary deposits of late Mesozoic Age. The rocks of the sound also include some altered lava flows and granite intrusions.

The bedded sedimentary rocks of the sound are subdivided into two major groups: the Orca and Valdez Groups. The sedimentary beds that comprise these two groups are

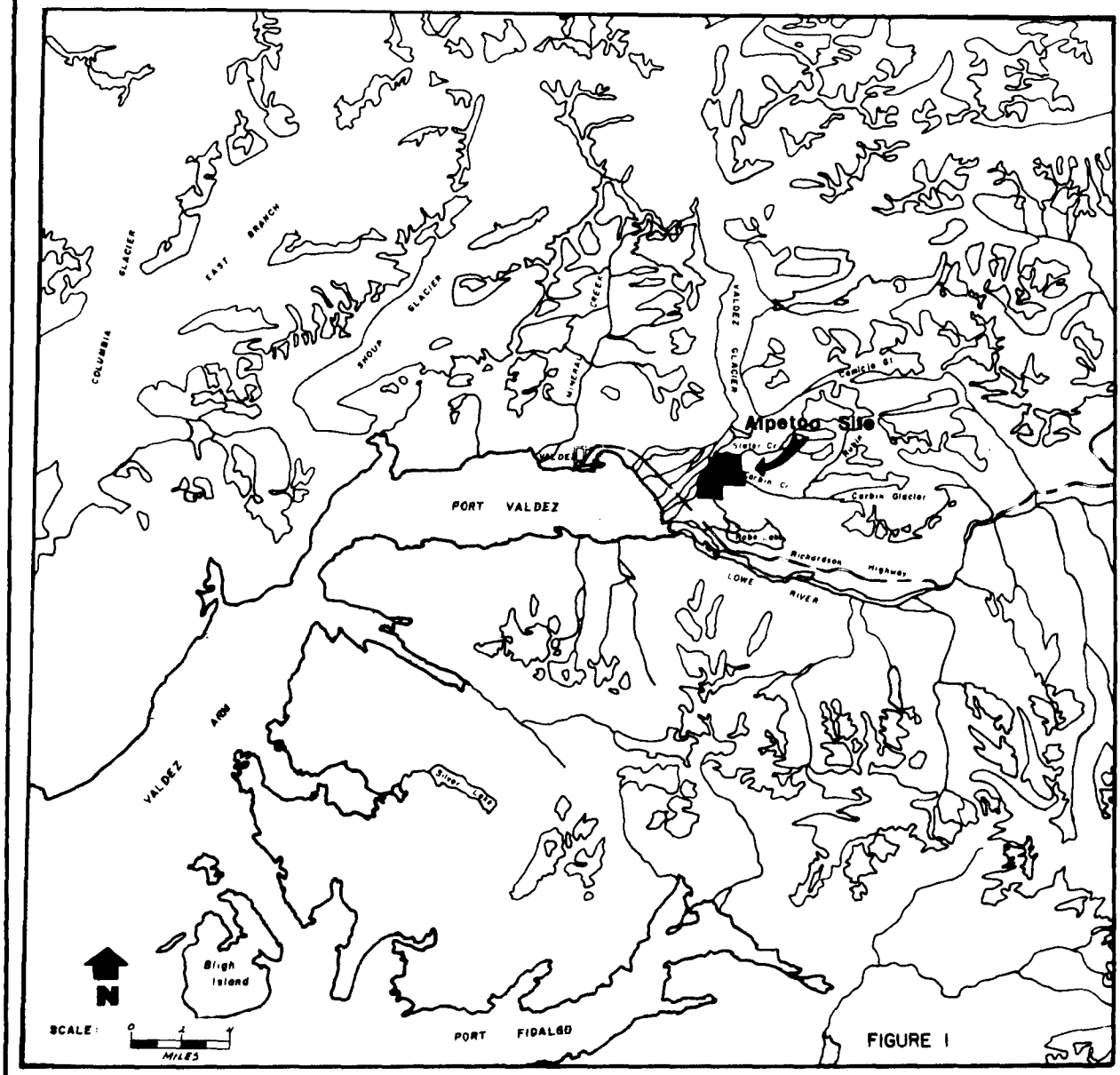


Figure 1	Site Location Map

intensely folded and metamorphosed (Moffit, 1954) (Plafker and MacNeil, 1966). The older group--the Valdez Group--is exposed on the northern and western sides of the sound while the younger Orca Group is exposed on the islands and mainland of the southeastern portion of the Sound (Figure 2).

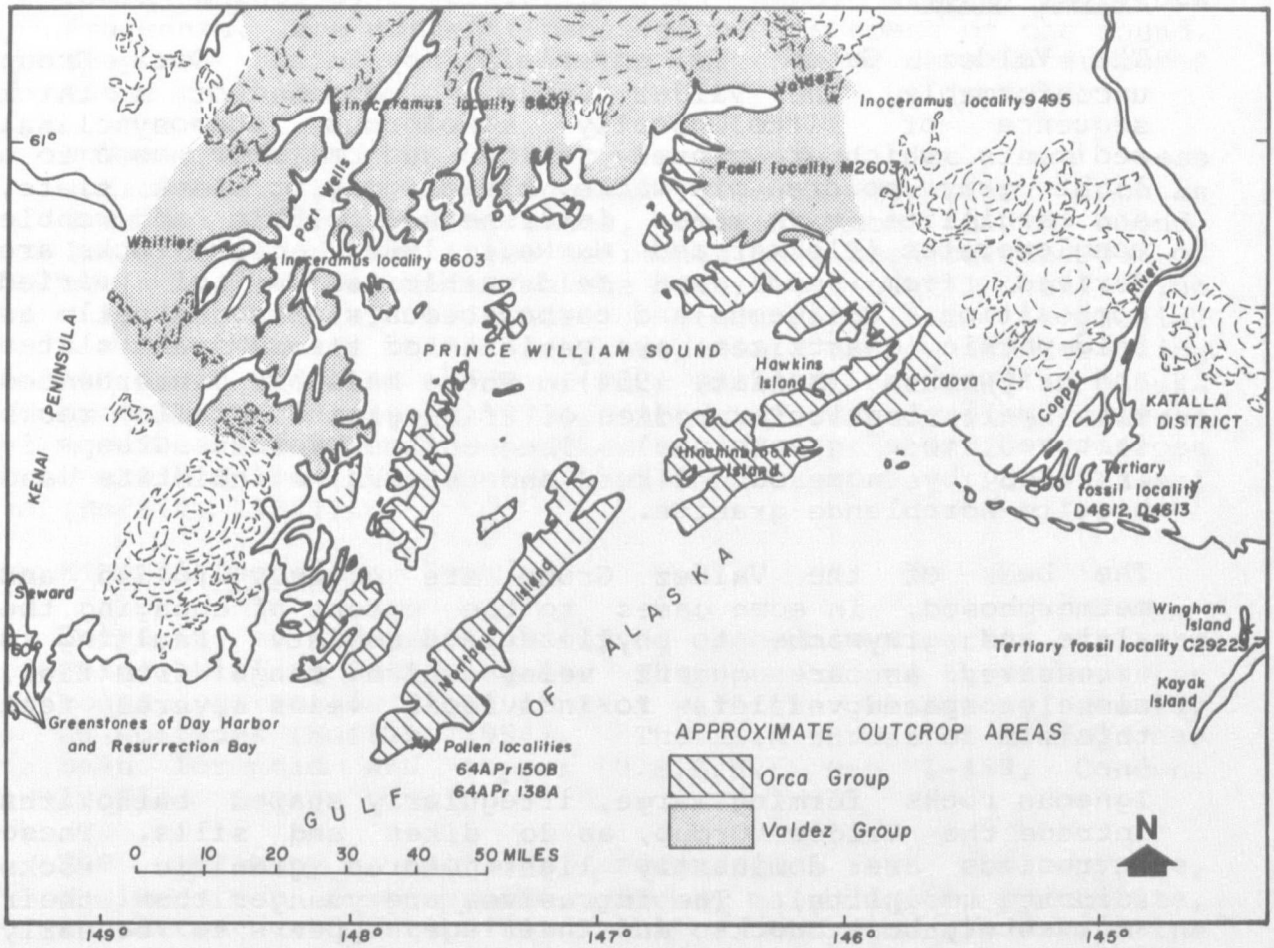
Orca Group

The Orca Group is distinguished from the older Valdez Group primarily by the abundant volcanic rocks and a lesser degree of metamorphism. It also has the typical graywacke and slates of the Valdez Group. In addition, it contains beds of conglomerate and limestone; however, these are limited in occurrence.

The Orca Group is divided into two main units. The lower unit is comprised primarily of dark graywacke and argillite with volcanic and conglomeratic rocks. The volcanic rocks, often termed greenstones, are intensely altered flows, flow breccias, and intrusive sills and dikes. The flows are primarily basalt and diabase (altered to a green color, i.e., greenstone) and are generally found in distinctive pillow structures, suggesting submarine extrusion. These greenstones are considered to be the most characteristic unit of the Orca Group. The conglomerate is poorly sorted and contains lithic clasts with a hard matrix of dark gray argillite (Plafker and MacNeil, 1966).

The upper part of the Orca Group consists primarily of "sandstone and argillite or hard siltstone with minor amounts of volcanic and conglomeratic rocks" (Plafker and MacNeil, 1966). The sandstones are primarily graywacke; however, arkosic and minor carbonaceous, tuffaceous and calcareous sandstones do occur. The upper unit of the Orca Group also includes thin beds of light gray-weathering limestone and reddish-brown shale or siltstone.

The age of the Orca Group has been estimated as early Tertiary (Plafker and MacNeil, 1966) rather than the Mesozoic Age previously assigned (Moffit, 1954). The lower age limit is probably late Eocene. This age was determined by the fossils *Raninoides vaderensis* Rathbun (crab), *Acila decisa* Conrad and *Periploma eodisucs* Vokes (pelecypods) found in a lower volcanic unit. The upper age limit of the Orca Group has not been determined because of scarcity of diagnostic fossils (Figure 2). The complex structure and absence of keybeds makes an estimate of the thickness of the Orca Group difficult.



(Plafker, G. and F.S. MacNeil, 1966)

Figure 2

Prince William Sound Outcrop Areas and Fossil Locations

GEOLOGY

Valdez Group

The Valdez Group is overlain by the Orca Group unconformably. The Valdez Group is composed of a thick sequence of lithologically monotonous eugeosynclinal sediments which are closely folded and metamorphosed to a light gray colored graywacke, bluish-gray or black slate, and argillite with minor interspersed pebble and cobble conglomerates (Plafker and MacNeil, 1966). These rocks are derived from muds and feldspathic sands of varied composition. Siliceous and carbonaceous slates, as well as feldspathic quartzites are variants of the dominant slates and graywackes (Moffit, 1954). These beds are interbedded with small lenticular bodies of fine-grained (mafic) rocks (altered to a greenstone). The entire Valdez Group is intruded by numerous dikes and stocks of biotite and biotite-hornblende granite.

The beds of the Valdez Group are closely folded and metmorphosed, in some cases to the extent of changing the slate and graywacke to phyllite and schist. Faulting is extensive, as are quartz veins which range from fine, closely spaced veinlets to individual veins several feet thick.

Igneous rocks forming large, irregularly shaped batholiths intrude the Valdez Group, as do dikes and sills. These intrusives are dominantly light-colored granitic rocks (diorite to aplite). The intrusives are younger than their sedimentary host rocks and their age appears to be early Oligocene or late Eocene. The Valdez Group is presumed to be of Mesozoic Age (30 to 225 million years ago). Diagnostic invertebrate fossils (*Inoceramus*) were collected near the moraine of the Valdez Glacier, among other places, compared with species from Wyoming and Utah, and assigned a Jurassic (135 to 180 million years ago) to Cretaceous Age (70 to 135 million years ago).

Unconsolidated Quaternary Deposits

The unconsolidated Quaternary deposits include stream, beach, and glacial deposits. The majority of stream deposits within the sound are deposits of streams flowing from glaciers. The largest area of stream deposits are at the head of fiords where glaciers no longer meet tidewater, for example at the mouth of the Valdez Glacier Stream and the Lowe River. In some places these streams have built extensive deltas, which include mudflats. Such a mudflat is found at the mouth of the Valdez Glacier Stream. High bench deposits are rare; however, benches cut in the bedrock are noticeable in the mountains around Port Valdez.

Beach deposits, consisting of sand, gravel and rock fragments, are not continuous along the coast of the sound. They are absent where strong currents or deep water comes close to land.

Moraine deposits, left by retreating ice, are less noticeable. In fact, typical glacial deposits, such as terminal and lateral moraines, are uncommon in the sound. It is believed that these sediments have been carried out of the sound and deposited on the outer continental shelf. The only substantial evidence of this deposition is glacial marine sediments which are present in a narrow arc bordering the north and west side of Tarr Bank in the Gulf of Alaska (Molnia and Carlson, 1975). Areas where submarine terminal moraines have been deposited include the barriers across Unakwik Inlet (above Jonah Bay) and Shoup Bay (Port Valdez) (Moffit, 1954).

Mineral Deposits

There is an abundant variety of economic minerals in the Prince William Sound region. They are found throughout the sound in areas in close contact with the greenstone, usually as sulfides (Moffit, 1954). The main thrust of mining has been for gold and copper (U.S.G.S. Map I-453, Condon, 1965).

The primary sulfides recovered are chalcopyrite, chalmersite, arsenopyrite, galena, molybdenite, pyrrhotite, sphalerite and stibnite. All of the minerals except the molybdenite and chalmersite are found in the Valdez gold/quartz district (Moffit, 1954). Silver has been mined throughout the Prince William Sound as a by-product of the copper and gold mining.

The copper deposits are generally associated with the greenstone. The ore is not necessarily found directly in the greenstone, but rather in the graywackes and slates that are adjacent to it (Moffit, 1954). Mining of copper deposits occurred during the early 1900s when nearly 97 million kilograms (214 million pounds) of copper was produced by 15 operating companies, of which 96 percent was produced at LaTouche Island and Ellamar by Kennecott Copper Corporation and Ellamar Mining Company respectively (Moffit, 1954).

Gold, and associated silver, are found in both gold-bearing quartz lodes and placer deposits; the gold-bearing quartz lode being primary in importance and productivity. The most significant gold-bearing lodes are found in the northern part of Prince William Sound from Valdez Glacier to Passage Canal. The gold deposits are associated with intrusions of

igneous rocks. Placer deposits have not been extremely successful. Most of the gold recovered from placer deposits was obtained from streams flowing into Port Valdez, including Mineral Creek (the site of New Valdez) and Gold Creek (Moffit, 1952).

Regional Structure

Prince William Sound lies in part of the North American tectonic plate (Hamilton, 1976). Its location is very close to the boundary of the Pacific and North American plate. It is this close proximity to a plate boundary, and more specifically its nearness to the Aleutian Arc subduction zone, that has subjected it to the severe tectonic forces that have shaped the structure of the region's geology and caused the region's high seismicity (Figure 3).

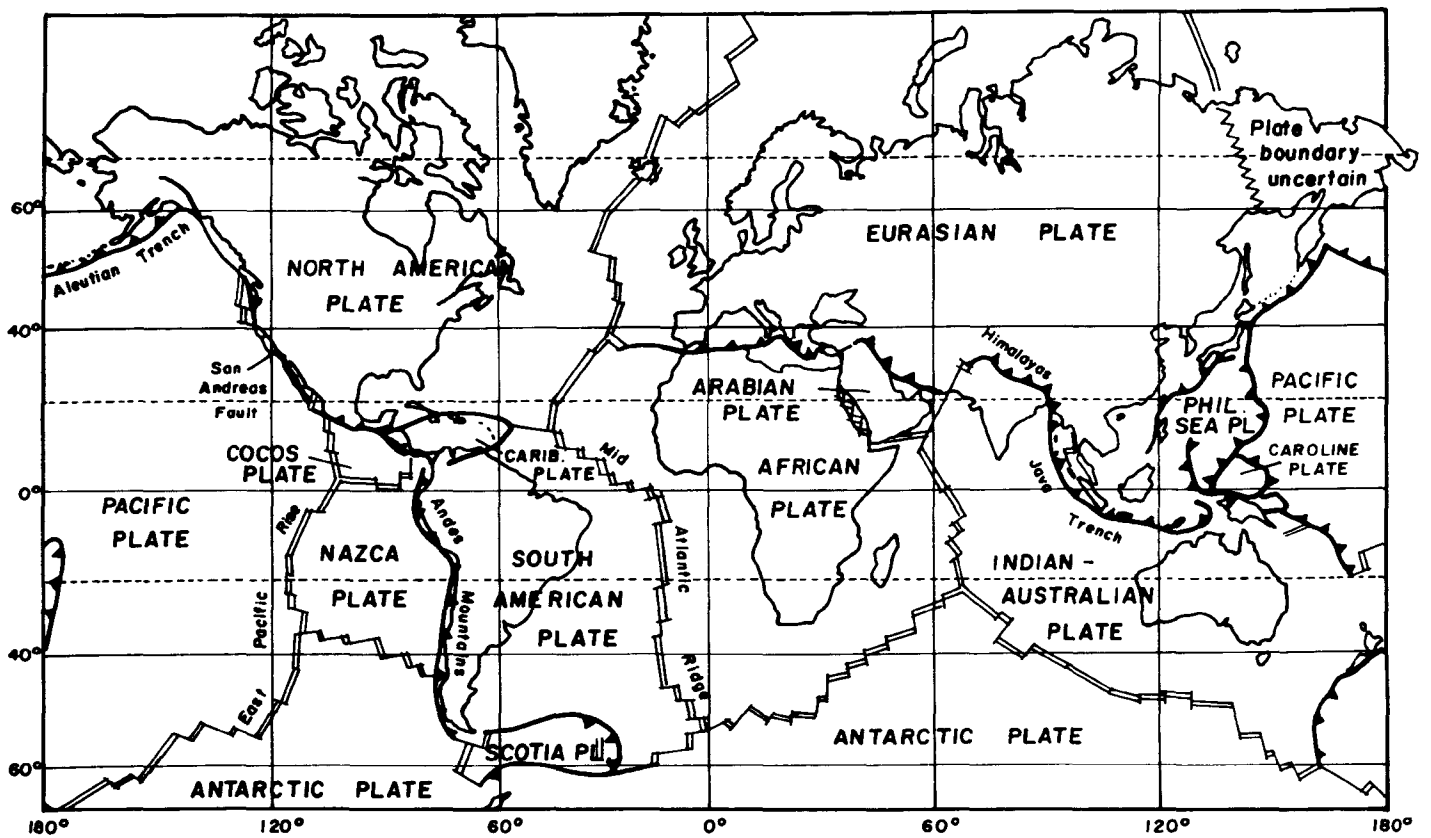
Prince William Sound lies in the Chugach Mountains Geosyncline. This geosyncline has an undetermined initial age of depositional filling. However, the filling of its basin probably concluded by the end of the Mesozic Era (70 million years ago) (Gates and Grye, 1963).

The present day structure of the geosyncline is a result of at least four orogenic events (Plafker, 1969). Each of these orogenic events caused folding and faulting as a result of a north-south compressional force and regional uplift. The regional tectonic history has been discussed extensively by Payne (1955), Gatin and Gyre (1963), and Grantz (1966).

The compressive stresses resulting from these orogenies have created the intensive folding in the region. The intensity of folding increases as one goes south into the Orca Group. Here the folds are of small amplitude and lateral extent. They are complicated by intricate drag folds and minor thrust faults (Plafker and MacNeil, 1966).

With the exclusion of one area on the east side of the Prince William Sound just northeast of Hawkins Island, the west side of the sound has the only evidence of large scale plutonic intrusion. The plutons are primarily granitic in composition. They intrude the Valdez Group on the west side of the sound and the Orca Group on the east side. The period of igneous activity that intruded these plutons concluded during the Eocene Period, approximately 36 million years ago (Figure 4) (Plafker and MacNeil, 1966).

The region is densely faulted. Normal, reverse, and thrust faults exist throughout much of the sound (Figure 5). These faults are identified on several U.S.G.S. and State of Alaska maps. Their confirmation is by field investigation



LEGEND

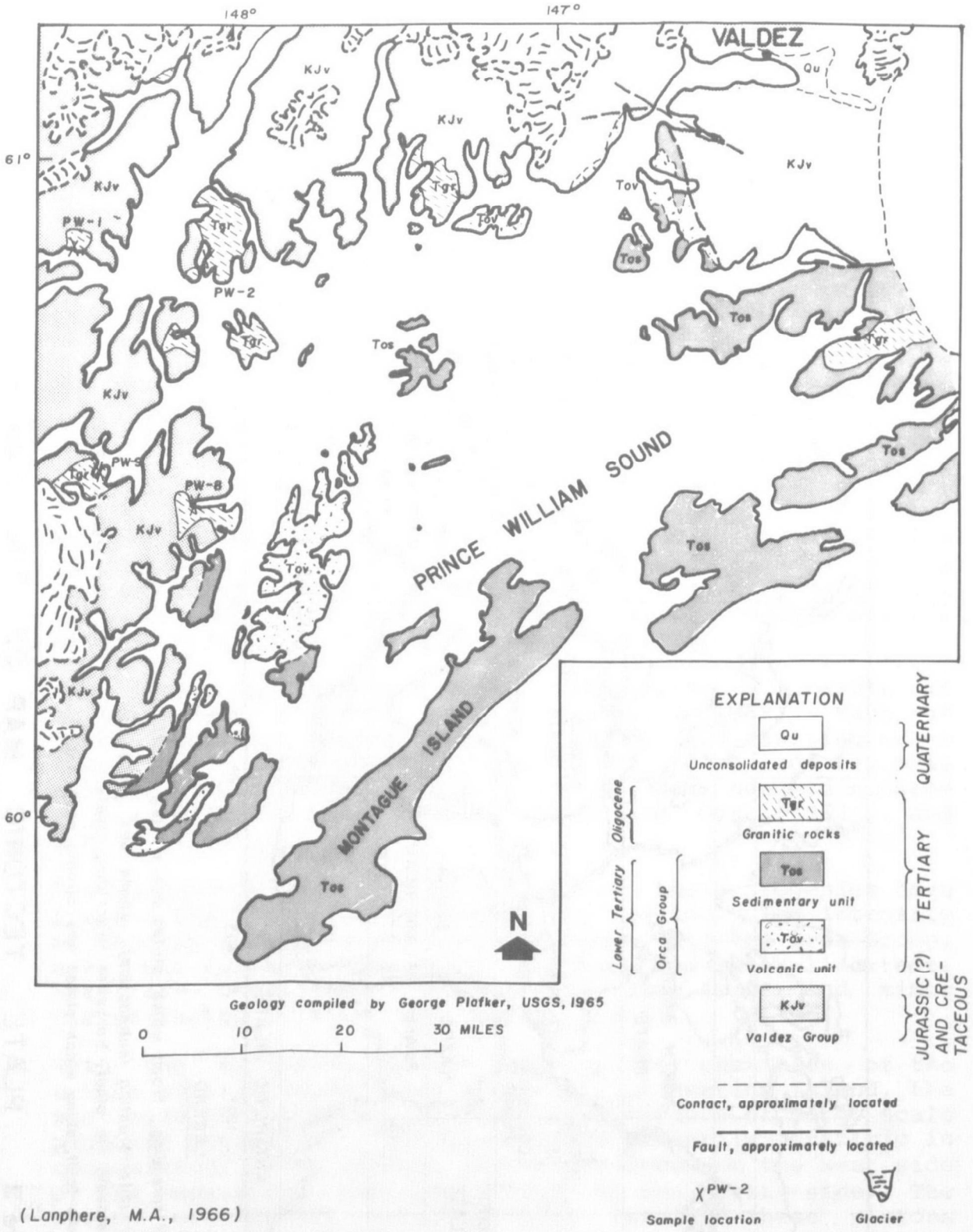
Zone of spreading, from which plates are moving apart.

Zone of underthrusting (subduction), where one plate is sliding beneath the other; barbs on overriding plate.

Strike-slip fault, along which plates are sliding past one another.

Lithosphere plates of the world, showing boundaries that are presently active. Compiled and adapted from many sources; much simplified in complex areas. (Hamilton, W, 1976)

Figure 3 PLATE TECTONIC MAP OF THE EARTH



(Lanphere, M.A., 1966)

Figure 4
Location of Different Rock Types in Prince William Sound

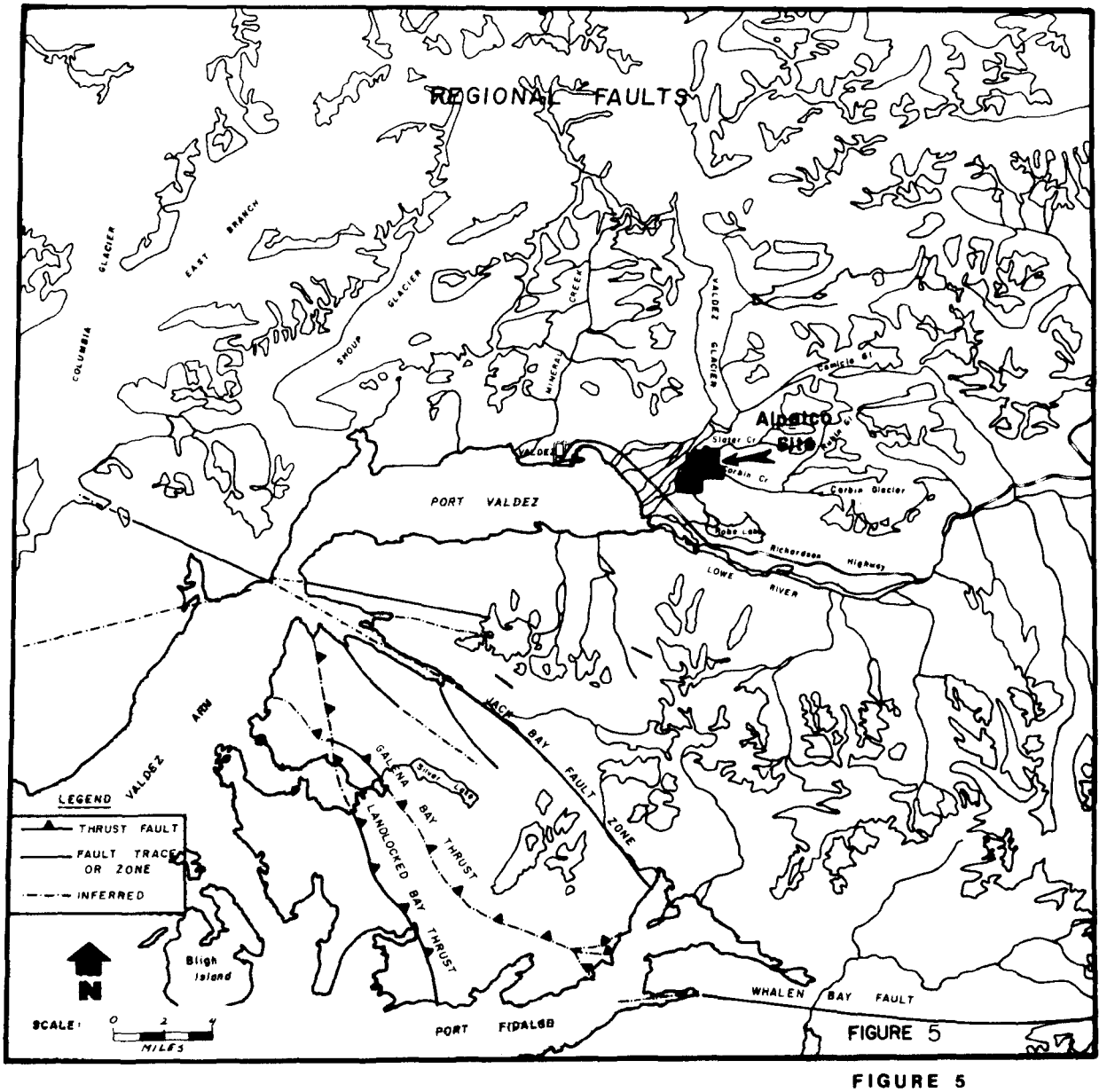

REGIONAL FAULTS
COLUMBIA GLACIER
EAST BRANCH
SHOUP GLACIER
MINERS CREEK
VALDEZ GLACIER
Gemicie Gl
Alpetco Site
Slater Cr
Corbin Cr
Corbin Glacier
VALDEZ
PORT VALDEZ
Robe Lake
Richardson Highway
LOWE RIVER
JACK BAY FAULT ZONE
GALENA BAY THRUST
LANDLOCKED BAY THRUST
Silver Cliff
VALDEZ ARM
LEGEND
THRUST FAULT
FAULT TRACE OR ZONE
INFERRED
N
Bligh Island
SCALE: 0 2 4 MILES
PORT FIDALGO
WHALEN BAY FAULT
FIGURE 5

FIGURE 5

and aerial photographic interpretation.

Prince William Sound is also densely covered with linear features. These linements are identifiable from the interpretation of maps and air photos. A preferred orientation is apparent for a majority of the linements, grouping them into sets.

South of the inferred Whalen Bay Fault, the predominant set trends northeast. This set is identified as the Hinchenbrook set. North of the Whalen Bay Fault the dominant set trends northwest and is identified as the Valdez set (Condon, 1965). The Valdez set extends through Port Valdez and around the proposed Alpetco site.

No direct evidence suggests that the Valdez set or other apparent linear features are faults. They appear to be massive joint sets that have undergone differential weathering with respect to the surrounding intact bedrock.

South of the Jack Bay Fault, W. H. Condon of U.S.G.S. (Map I-453) suggested the possibility of offset along the linements. This statement is inferred from aerial photographic interpretation of splits in the possible thrusts (Condon, 1965). While conducting an economic geology survey of Prince William Sound, Gary Winkler of U.S.G.S., Menlo Park, California, observed that many of the joints, i.e., linear features, are cut by large quartz veins which show no visible evidence of offset (personal communication, August, 1979). The quartz veins probably originated during the last active period of intrusion which ended 36 million years ago (Plafker and MacNeil, 1966).

Prince William Sound was heavily impacted by the 1964 Great Alaska Earthquake, resulting in extreme tectonic uplift and subsidence throughout the region. The tectonic origin of the Good Friday Earthquake can be directly attributed to violent movement of the subduction zone underlying the Aleutian Arc (Plafker and Mayo, 1965). The axis for uplift and subsidence approximately follows the northern contour of the sound. Subsidence was north of this axis and uplift south of it. Approximate estimates of surface tilting are 4 cm/km to the north, and 2 cm/km to the west. These values are derived from Figure 3 of George Plafker's U.S.G.S. Professional Paper 543-I, "Tectonics of the March 27, 1964, Alaska Earthquake". The maximum uplift observed was in Montague Island where it reached 10 meters (33 feet). Subsidence was as great as 2.4 meters (8 feet) in the extreme north part of the region. The regional tilting could have had an effect on the aggradation or degradation of Valdez Glacier Stream. Faulting as a result of the earthquake was found only on Montague Island. Two faults

were identified, the Potter Bay and Hanning Bay. They appear to have existed before the earthquake and were reactiviated by it. No faulting or offsets were observed or reported along the Walen Bay or Jack Bay Fault Systems as a result of the 1964 event.

Geology of Port Valdez and Proposed Plant Site

Port Valdez is a subarctic marine fiord and embayment in the northeast corner of Prince william Sound. It is approximately 21 kilometers (13 miles) long and 4.5 kilometers (2.8 miles) wide with a maximum depth of 240 meters (787 feet). The alignment of the Port is controlled by the steeply north dipping foliation of the rocks of the Valdez Group. The Port is surrounded by steep mountain walls rising to altitudes of 900 meters to more than 1500 meters (3,000 to 5,000 feet). These steep valley walls continue beneath the water to form a steep-sided, flat-bottomed trough with a narrow shallow entrance (Figure 6).

Port Valdez lies within the outcrop belt of the Valdez Group. The Valdez Group, as stated earlier, is comprised of thick beds of interbedded slate and graywacke. It also includes small amounts of argillite, siltstone, arkosic sandstone and conglomerate, all of which are folded and metamorphosed.

Extensive recent deposits of sediment can be found at the mouths of various streams in Port Valdez. At the eastern end of the fiord, the Robe River, Lowe River and Valdez Glacier Stream join to form a large, broad delta with unconsolidated sediments upwards of 183 meters (600 feet) thick. These sediments are primarily poorly consolidated silt, fine sand and gravel. The Mineral Creek alluvial fan west of the Lowe River Delta is also a source of sediment deposition. Broad tidal flats are being deposited at the seaward edge of the Valdez Glacier Stream/Lowe River outwash delta and the Mineral Creek alluvial fan. These deposits are composed primarily of silt, fine sand and organic muds.

Site

The 7.7 square kilometers (1,900 acres) proposed plant site is about 9.5 kilometers (6 miles) from the city of Valdez (New Valdez). The site is located 1.6 kilometers (1 mile) south of Valdez Glacier. Valdez Glacier Stream borders the site on the west. It is bordered on the east by steeply rising mountains, on the north by Slater Creek, and on the south by Corbin Creek (Glacier) (Figure 6). The site is relatively flat, and grades 1.5 percent from the north.

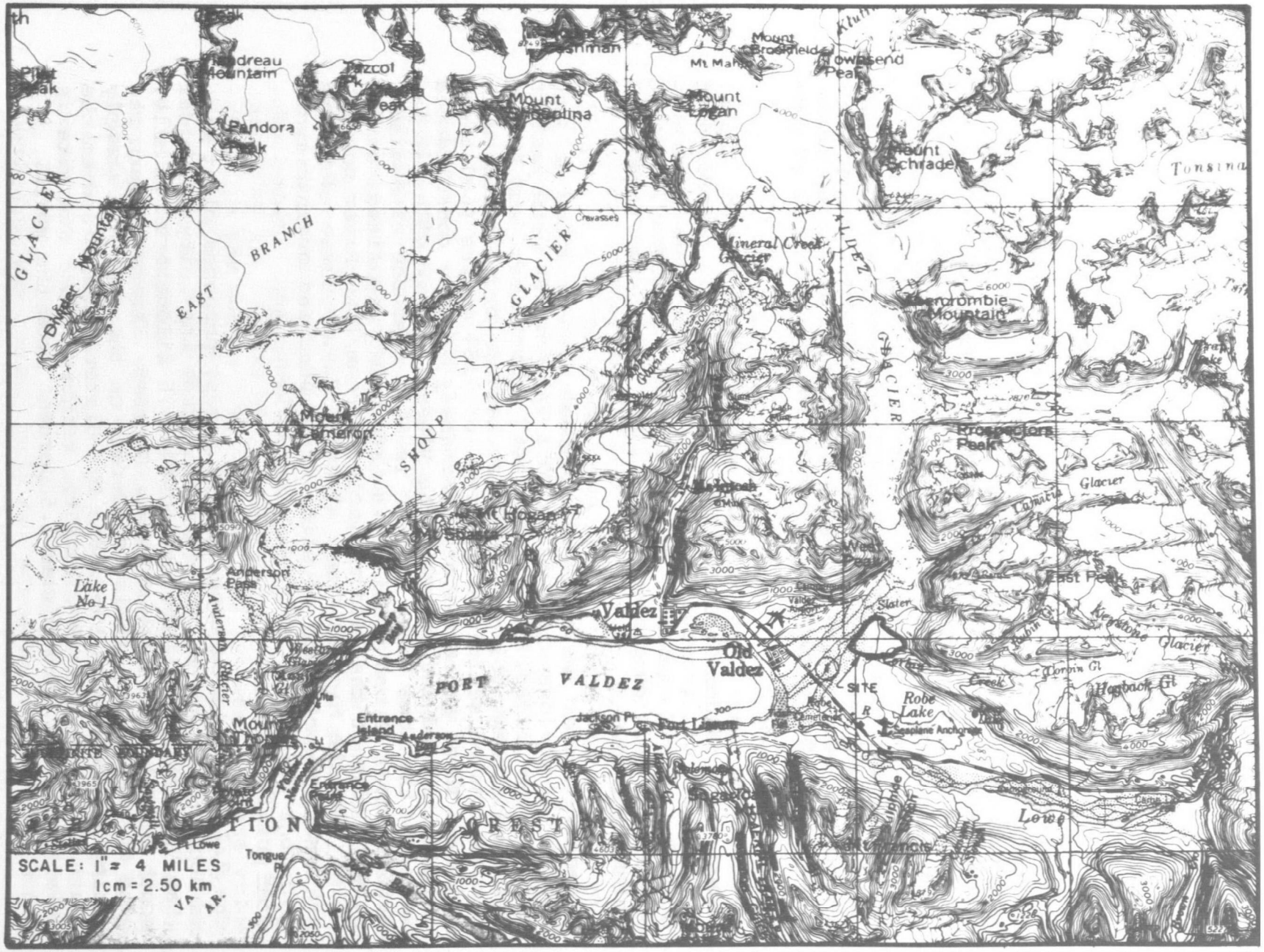


Figure 6 Port Valdez Area

GEOLOGY

About 2/3 of the site is covered with coarse glacial granular soils. The unconsolidated surface sediments (lag gravels) on the site are part of the alluvial fan from the outwash of Valdez and Corbin Glaciers. Drilling has detected that deposition gets finer with depth. The eastern edge of the site also has fine grained colluvium derived from Corbin Valley.

Drilling and a seismic refraction study (May to August 1979) revealed the depth of on-site overburden ranges from 90 meters (300 feet) to greater than 210 meters (700 feet) (Figures 7 and 8). The data indicates that the site is the result of glacial scouring of bedrock by Corbin and Valdez Glaciers. The seismic refraction data showed no sharp drop in the bedrock to suggest that Corbin Glacier acted as a hanging valley in the past. The great depth to bedrock and shape of the valley floor indicates the Valdez and Corbin Glaciers were contemporaneous in advancement and Corbin Glacier did not ride over Valdez Glacier. Tarr (1914) gave a similar hypothesis based upon his analysis of the topography and visual evidence of glacial advances.

Outcrops

Outcrops which border the alluvium of the site are, clean to dirty, siltstones in slightly varying degrees of metamorphism. Of these outcrops on the southern edge of the site appear to be steel grey, calcareous, slates and phyllites. On the extreme eastern edge of the site, partially up Corbin Valley, the rocks are steel grey, high grade, slate. The outcrops on the northern edge of the site are steel grey, highly indurated calcareous siltstone to calcareous argillite with quartz veinlets and calcite bedding veinlets. Bedrock cuttings taken from the drilling program indicate the bedrock below the unconsolidated material of Drill Pad D-1 is a steel grey calcareous rock probably midway between a slate and phyllite in degree of metamorphism. (Figure 9)

The following are the data for the field stations Refer to Figure 10 for their topographic location and Figure 11 for field data presentation.

STATION A:

Lithology:	Highly weathered steel grey slate laminations less than 1 cm.
Beds:	Strike N65°W Dip 68°N

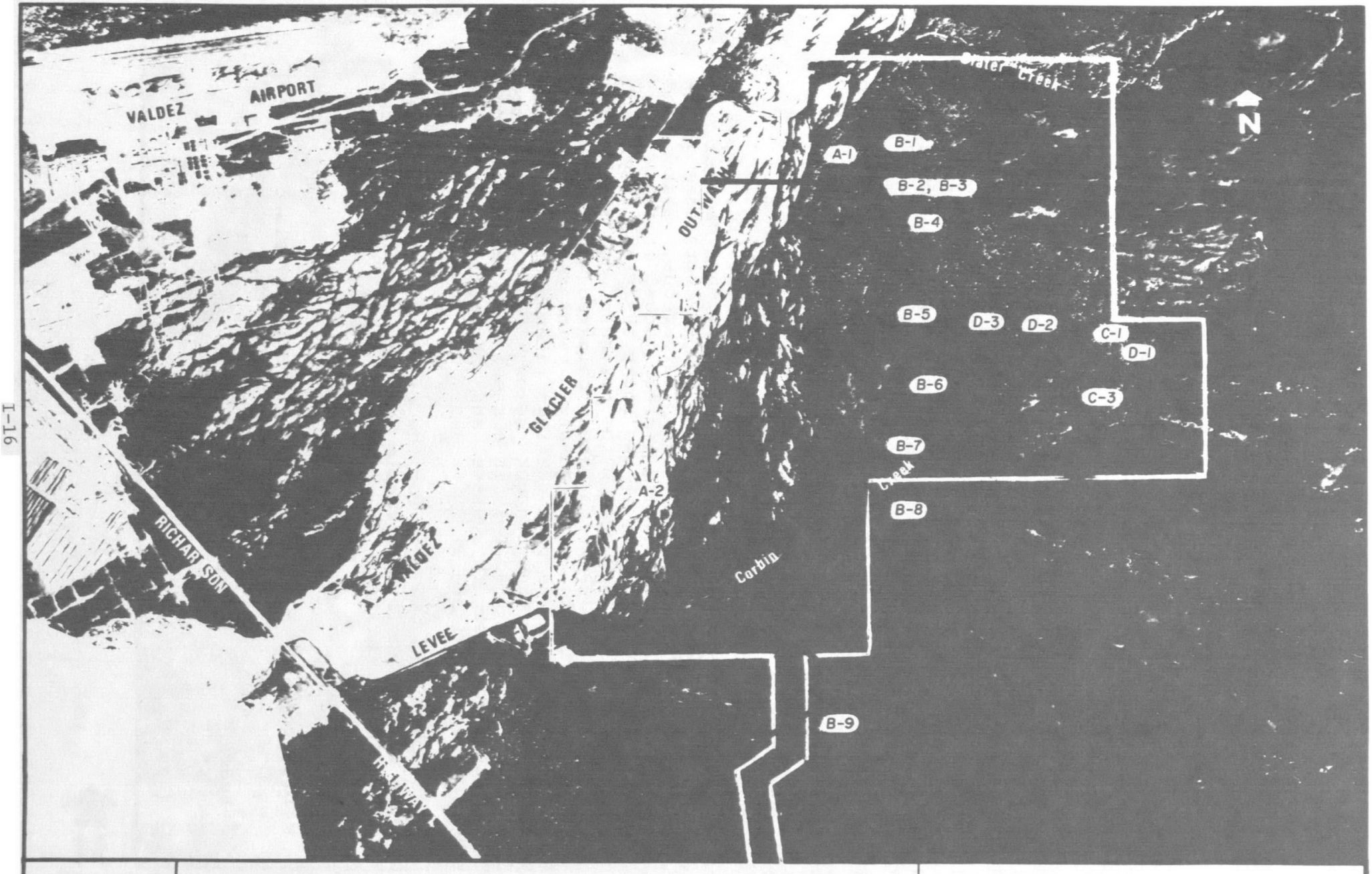
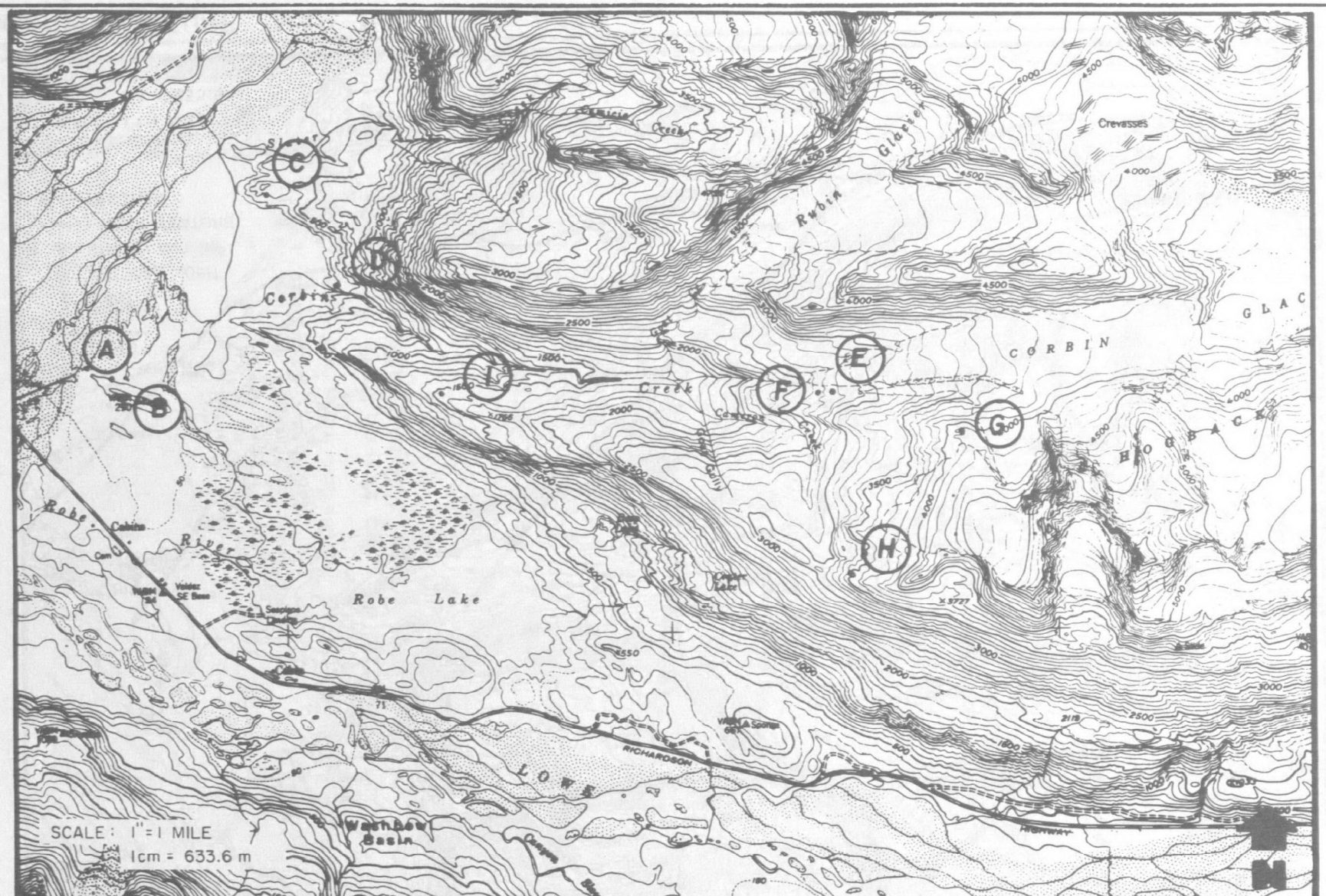


Figure 9

1000 0 2000 4000 feet

200 0 500 1000 meters

SEISMIC LINE AND DRILLING LOCATIONS


A
B
C
D
E
F
G
H
Robe River
Robe Lake
Corbin Creek
Rubin Glacier
CORBIN
GLAC
HOGBACK
Crevasses
Valdez SE Base
Sawmill Landing
Cabins
Cabin
Valdez Glacier
Valdez Glacier Lake
Valdez Glacier Gully
Valdez Glacier Camp
Valdez Glacier Cabin
Valdez Glacier Camp
Valdez Glacier Camp
Valdez Glacier Camp

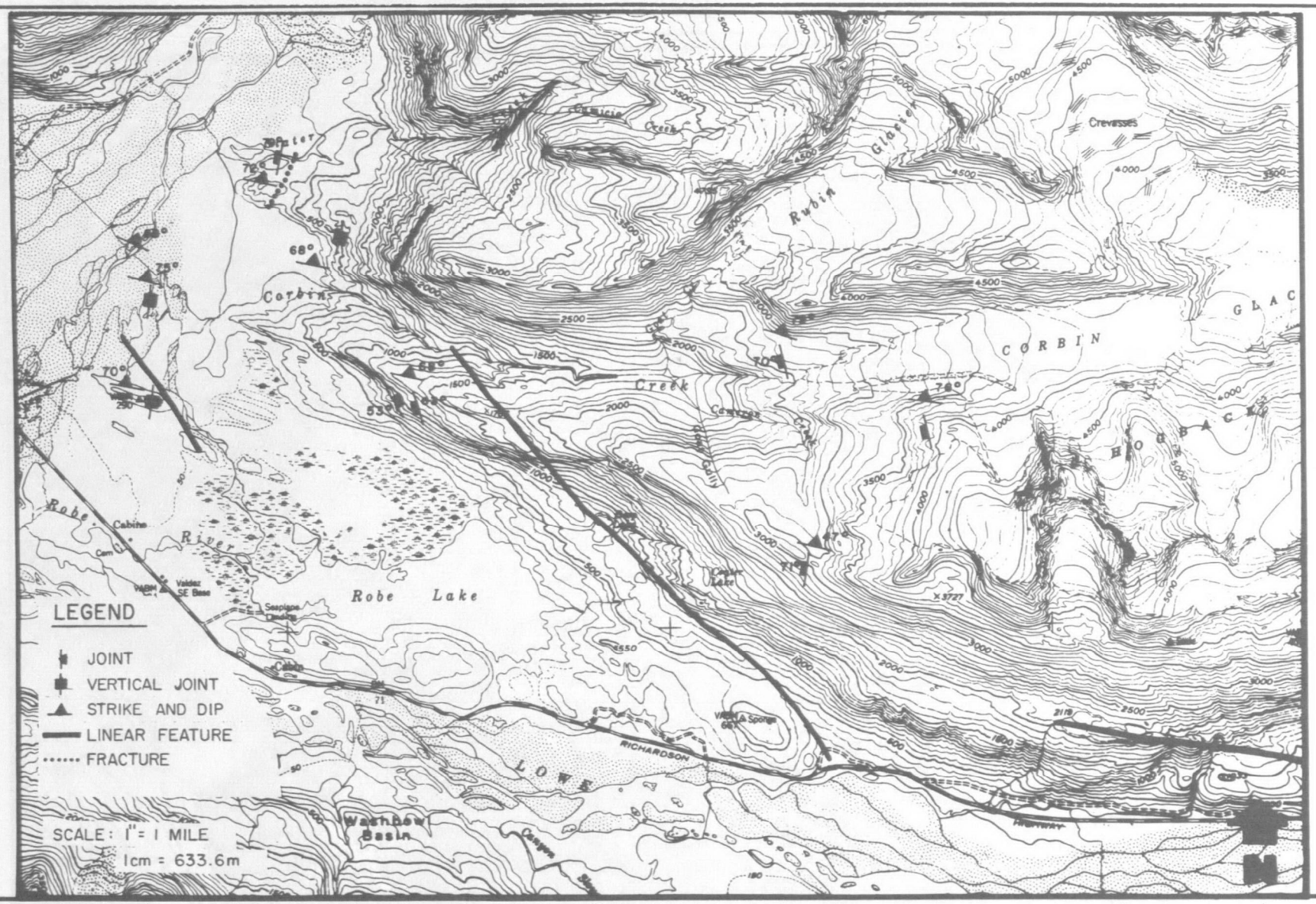


Figure 11 STRUCTURE MAP OF FIELD DATA

GEOLOGY

STATION B:

Lithology:	Steel grey phyllite with lamination varying from 1mm to 5mm.	
Beds:	Strike	N78°W
	Dip	75°N
Joints:	Strike	N5°E
	Dip	90°

STATION C:

Lithology:	Steel grey indurated siltstone with quartz and calcite veinlets.	
Beds:	Strike	N78°W
	Dip	72°N
Joints:	Strike	N10°E
	Dip	79°W

Blocky fracture, 1 meter (3 foot) blocks

STATION D:

Lithology:	steel grey high grade calcareous slate	
Beds:	Strike	N80°W
	Dip	60°N
Joints:	Strike	N10°E
	Dip	90°

STATION E:

Lithology:	steel grey fissile slate with quartz bedding veinlets.	
Beds:	Strike	N72°W
	Dip	79°N

STATION F:

Approximately 100 meters west of Station E.

Lithology:	Same rock type as Station E with higher density of quartz veinlets
Beds:	Strike N68°W Dip 48°N
Joint:	Strike N15°W Dip 70°W

STATION G:

Lithology:	Interbedded units of steel grey fissile slate and light grey arkosic sandstone with quartz veinlets. The alternating rock types vary from 5.1 cm to 21.2 cm (2" to 6") in unit thickness.
Beds:	Strike N83°W Dip 76°N
Joints:	Strike N14°W Dip 14°N

STATION H:

Lithology:	Dirty grey indurated siltstone.
Beds:	Strike N80°W Dip 47°N
Joints:	Strike N7°E Dip 71°W

STATION I

Lithology:	Steel grey fissile slate with quartz bedding veinlets	
Beds:	Strike N82°W Dip 68°N	
Joints:	Set I Strike N16°W Dip 63°W	Set II Strike N32°W Dip 53°NE

No fossils were discovered in our field program.

The foliation and bedding strike approximately east-west and

dip steeply to the north (Figures 12, 13 and 14). Field mapping has identified only two anomolous dip reversals both of which are several kilometers from the site (U.S.G.S. Map I-356). One reversal exists approximately halfway up the west side of Valdez Glacier. Here the rock strikes northeast and dips steeply to the south (Figures 12 and 13). Associated with this anomolous strike and dip is a linear feature identified from aerial photographs and helicopter reconnaissance. The other identified dip reversal lies approximately 32.2 km (20 miles) west of the site just south of Ptarmigan on the Richardson Highway. This dip reversal is also near an air photo identified linear feature (Coulter and Coulter, 1962).

Linements

Linear features identified from aerial photographs and helicopter reconnaissance run close to the site (Figure 11). There appears to exist two different sets of features, a dominant northwest trending set and a subordinate northeast trending set. The northwest trending features probably belong to the Valdez set (Condon, 1965).

Close inspection of these features gave no evidence to suggest they are faults either active or relic. Field examination of the linements is very difficult due to heavy foliage, glacial scouring, weathering, lack of mappable geologic units to identify possible offset, and soil overburden. Indications suggest they are probably major joints that have weathered at a higher rate than the surrounding bedrock.

Air photo interpretation gave no indication of offset. The apparent lack of offset suggests that offset is non-existent or very slight, or that it was pre-glacial, since rock scouring by glaciers was prevalent throughout the region.

Although the linements have not been identified as faults, either active or inactive, they are the zones where differential movement could occur if sufficient tectonic forces were applied to the area. Since differential movement along these features was not observed as a consequence of the 1964 Great Alaskan Earthquake, the probability of sudden realignment of the linement is remote. However, it is not recommended that any construction be undertaken directly upon such features.

Slope Stability

Stability of the rock slopes surrounding much of the site does not appear to present a problem. Rockfalls and talus slopes were not observed on the site. The steep dip of the

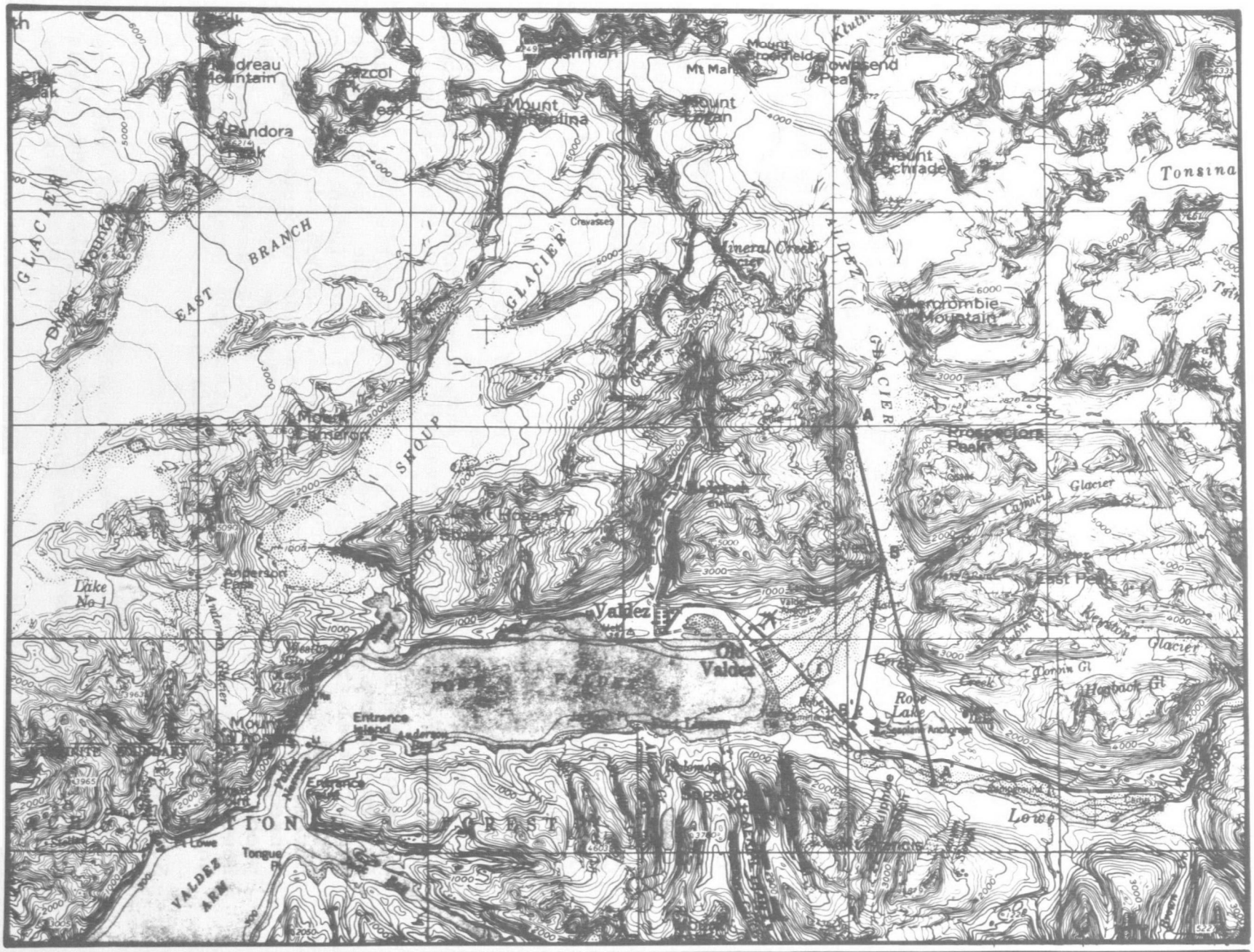


Figure 12 CROSS-SECTIONS

GEOLOGIC CROSS-SECTION A-A′

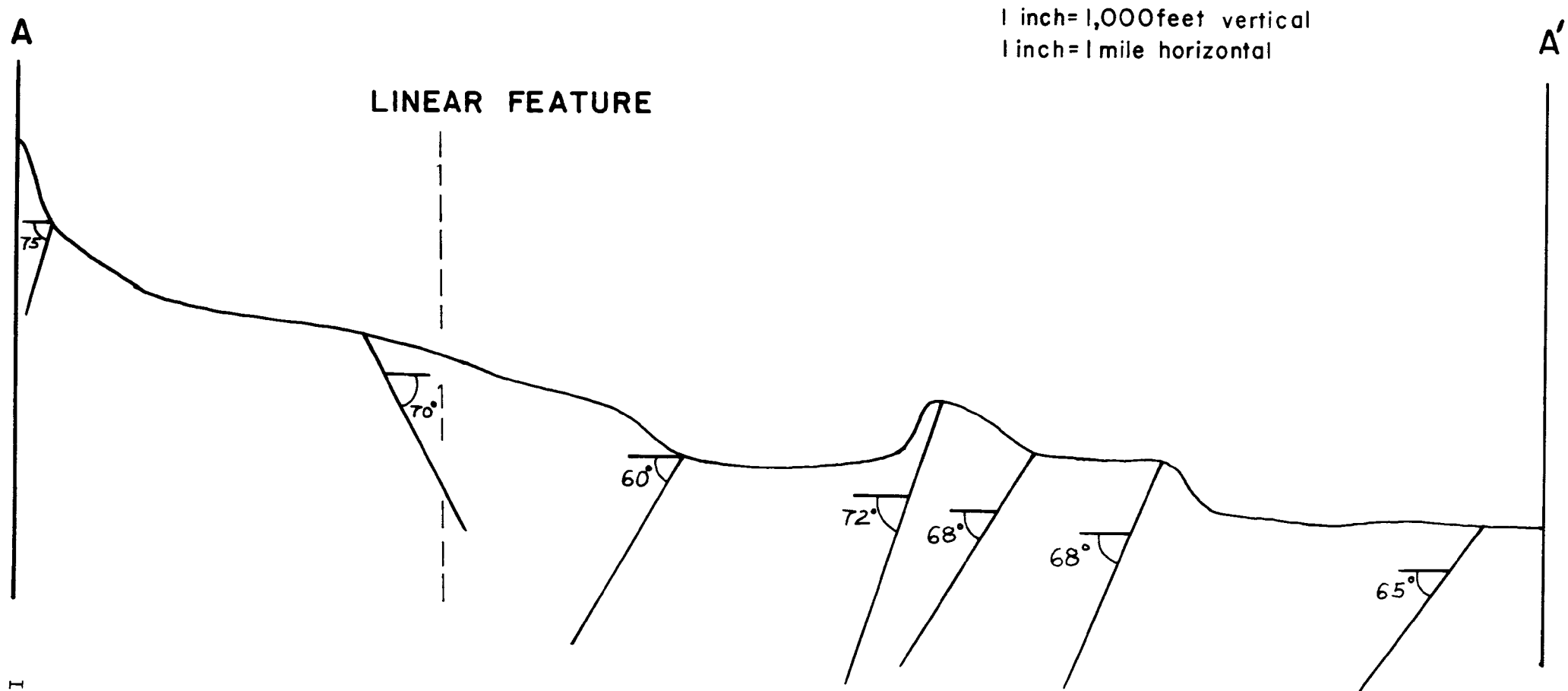


Figure 13

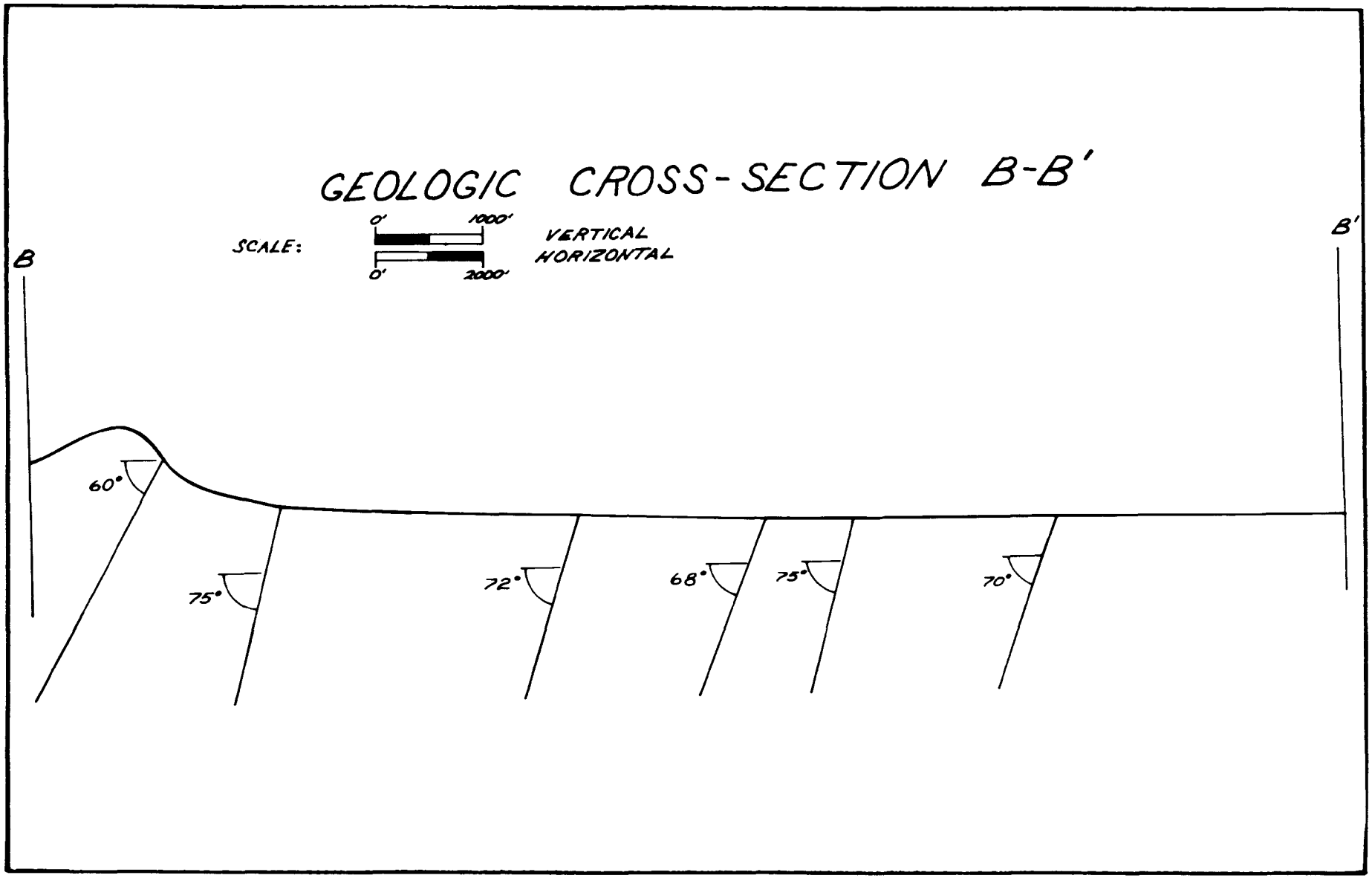

GEOLOGIC CROSS-SECTION B-B'
SCALE:
0'
1000'
VERTICAL
0'
2000'
HORIZONTAL
B
B'
60°
75°
72°
68°
75°
70°

Figure 14

foliation controls the rock's failure planes.

If a large-scale bedding plane failure of a rock slope were to occur, it would probably occur in an area where the strata dips parallel to the face of the slope. Along the south ridge bordering the site, the rock rises approximately 120 m (400 ft) and the strata dips steeply to the north, into the site. Possible failure along bedding planes would most likely occur here. Fortunately, these slopes are not critically steep, nor are there overhanging rock projections that could fail along a bedding plane and slide into the site.

The outcrop ridge on the north edge of the site is a much steeper slope (approximately vertical). However, it has less vertical rise (90 m, 300 ft), and the strata dips to the north (into the face of the slope) so large slope failures along bedding planes is not possible. The possible type of failure would be occasional small blocks falling out of the ridge wall due to weathering along joints and fractures. Construction immediately adjacent to this ridge is not recommended without further investigation into the stability of the rock walls.

The rock outcrop slope on the east edge of the site appears stable. The slope rises approximately 850 m (2800 ft) at approximately 29°, and is heavily covered with foliage. The foliage suggests no recent rock slides and it also provides a protective barrier to occasional loose rolling rocks.

All of the outcrops surrounding the site have been carved by glaciers until they were quite smooth. Lack of ragged uneven slopes suggests little possibility of rock slope failure. The heavy foliage over most of the surrounding slopes suggests there has been no recent slope failure and also acts as a control against possible future failure.

Avalanches

The rock outcrops surrounding much of the site are quite steep. The area's heavy snow fall combined with steep slopes would seem to indicate potential avalanche risk. Although conditions seem favorable for avalanches, no evidence of their previous existence appeared on site. There were no apparent natural avalanche chutes and the hillside's foliage and soils appear unscarred.

Riprap

The outcropping rock could be used as a riprap material. The rock is crisscrossed with fractures and joints, and these should aid in ease of excavation. There is a

possibility of finding beds that have very fine laminations. Rock from these beds would not be adequate for riprap. It appears, however, from our observations that the vast majority of outcropping rock would make satisfactory riprap. If on-site riprap is not desired, other sources in the area are of equal rock quality. On the west side of Valdez Glacier Valley, across from the north edge of the proposed Alpetco site, lies a quarry suitable for riprap. Other riprap sources may be available but are not as close or accessible as this one.

Bedrock Foundations

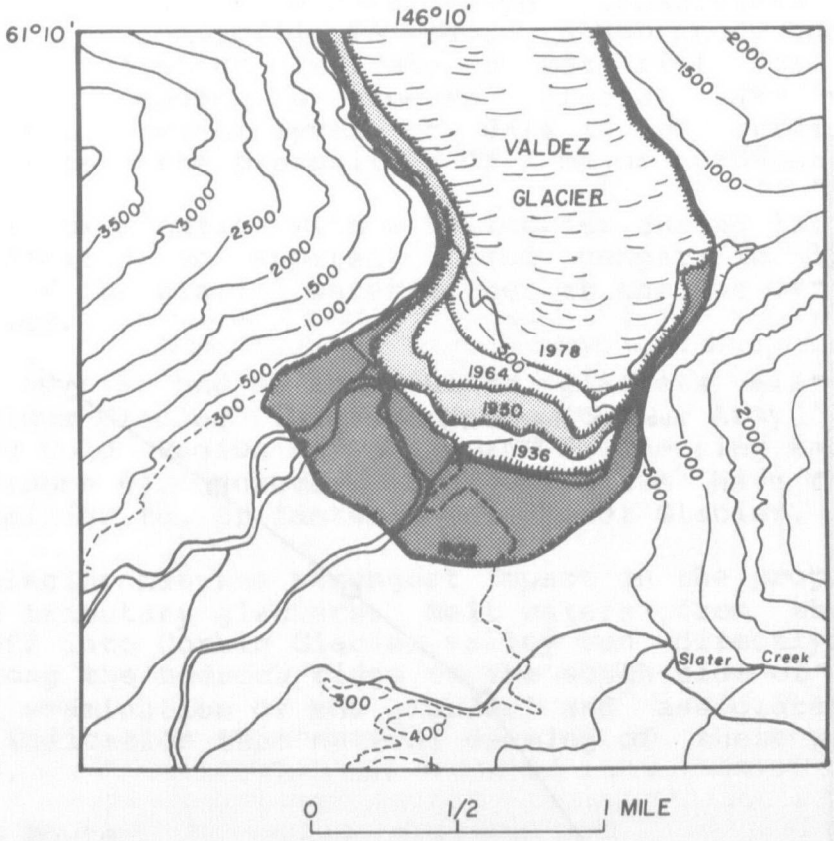
If construction is desired on bedrock, a careful examination of the proposed construction area's bedrock should be undertaken. Careful attention should be given to the possibility of slippage along the steeply dipping bedding planes. Also, a close examination of the joints and fractures should be conducted in any evaluation of the rock as a possible foundation base.

Glaciers

Within the area surrounding the site there are numerous glaciers. Valdez Glacier is the largest of these glaciers and the one with the most significant potential impact upon the site (Figure 6). As shown in Figure 6, Valdez Glacier is a north-south running glacier approximately 32.2 km (20 miles) in length. The surface slope of the glacier is gradual until nearing approximately 305 meters (1000 feet) from the top where it steepens to 15° to 20°. Since it was first observed for movement in 1898, Valdez Glacier has steadily receded except for the year 1906 when it advanced for 76 to 107 meters (250 to 350 feet) (Tarr and Martin, 1914). The rate of recession has varied from 11 to 20 m/year (39 to 74 ft/year) (Figures 15 and 16). No explanation has been hypothesized for the one year of advancement. However, the predominance of years having recession suggest that the Glacier will continue to recede for the foreseeable future (U.S. Army Corps of Engineers Cold Region Research and Engineering Laboratory, 1975).

The Great Alaska Earthquake of 1964 had no apparent effect on the rate of the movement of Valdez Glacier. The only impact the earthquake had on the glacier was a few minor rockslides (U.S. Army Corps of Engineers Cold Region Research and Engineering Laboratory, 1975).

Valdez Glacier has historically experienced some thaw water accumulation along its sides and near its front. These lakes are a result of temporary ice dams blocking the flow



Recorded positions of the terminus of Valdez Glacier since 1909.

(Coulter, H.W. and R.R. Migliacco, 1966)

Figure 15

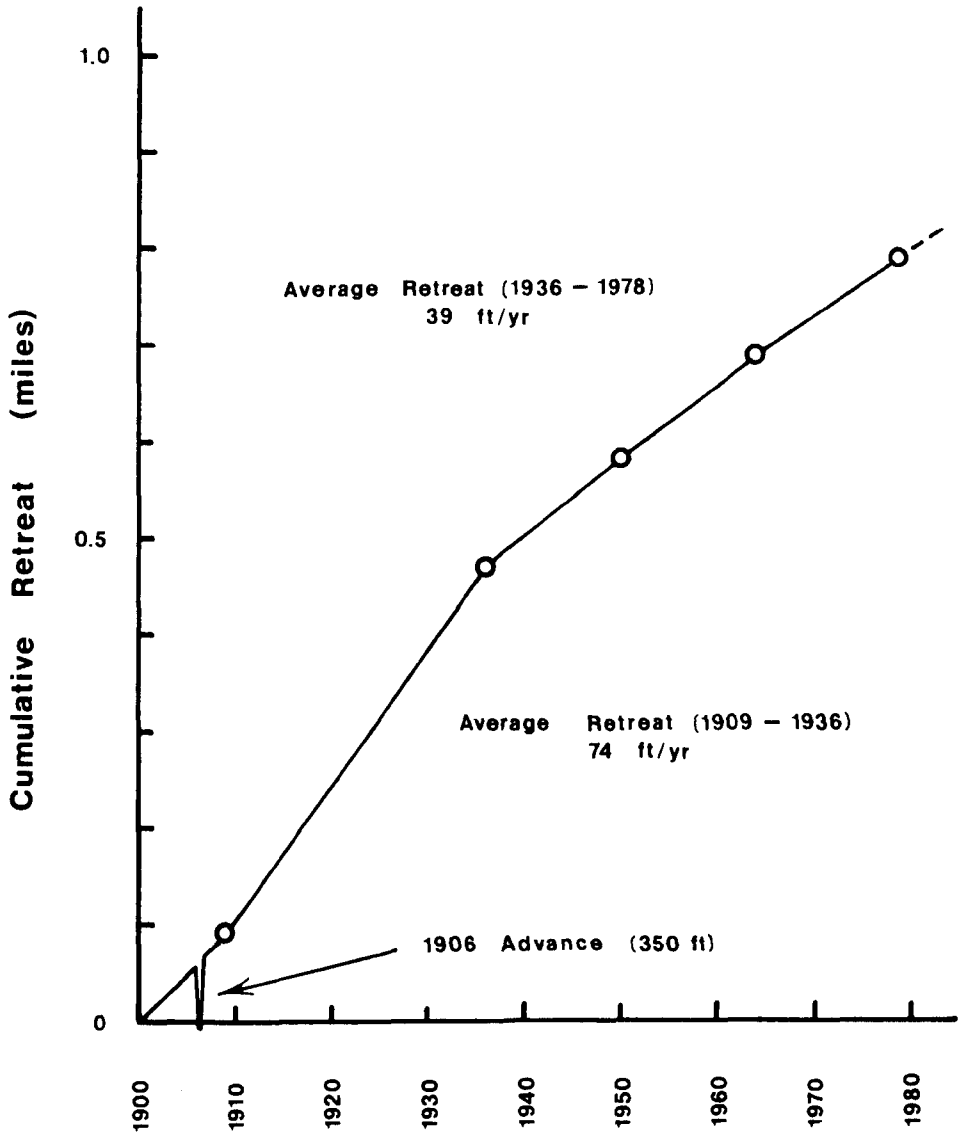


Figure 16 Valdez Glacier Retreat

of water downslope. They appear to thaw often and drain.

A study of the Valdez Glacier lake damming phenomenon is being conducted by Woodward-Clyde Consultants and is scheduled for completion in 1980. A HUD study and earlier geologic information indicate a potential for possibly significant flooding by sudden glacial lake releases. However, the present level of data is not sufficient to support or deny the probability of a major outburst flood.

An aerial examination with a helicopter during late July of 1979 indicated no apparent flood danger, in 1979, from damming of the glacial water either at the toe or edges of the glacier.

Corbin, Camicia and several other glaciers all coalesced with Valdez Glacier in the past (U.S. Army Corps of Engineers Cold Region Research and Engineering Laboratory, 1975) (Figure 6). However, these glaciers have receded at rates similiar to, or faster than, Valdez Glacier.

Corbin Glacier has the strongest impact on the proposed site of these tributary glaciers. Melt waters from the glacier and runoff into Corbin Glacier valley run directly onto the site, along the bedrock ridge on the south side of the site. A visual examination of the glacier and associated terrain gave no indication that natural damming of these waters is possible.

Pipeline Route

The pipeline from the proposed refinery site to the main terminal progresses through two differing geologic conditions.

The first area is that section of pipe beginning at the refinery and continuing until contact with the mountains on the south side of Port Valdez. This section consists of an area of glacial outwash and fluviatile deposits. These deposits include fine grained soils.

Depths to bedrock are probably sufficiently deep in this area to make their influence on construction secondary to soil influences. Estimated depths to bedrock are inferred from the shape of the topography.

Hazards directly related to geology are earthquake associated. Ground cracking and stretching could be factors as suggested by their generation as a result of the Alaska Earthquake of 1964.

The second section exists along the slopes of the mountains

bordering the south side of Port Valdez. Along this section, the pipeline will proceed over alluvial fans and steeply north dipping Valdez group bedrock. Identification of the alluvial fans and bedrock is dependent upon a USGS Open File Map entitled "Preliminary Engineering Geologic Maps of the Trans-Alaska Pipeline Route" by Oscar J. Ferrians, 1971.

Several Linements of the Valdez set run through this area. No exact information has been obtained concerning specific features; however, with the trans-Alaska Pipeline positioned directly upslope from the proposed Alpetco pipeline, a degree of confidence is gained based upon their investigation of the route and subsequent placement of the pipeline. However, certain hazards do exist and should be noted. The possibility of rock slides and avalanches is very real in this area due to the steep slopes. Solid evidence of past avalanches and rock slides are visible in the area.

SEISMIC REFRACTION SURVEY

A shallow seismic refraction survey was undertaken to determine the depth to bedrock in the site area. The instrument used was a Nimbus Instruments Model ES-1200 seismograph. This particular instrument is a 12 channel recorder. Instrument setting can vary both the gain and amplitude of each channel. It also has the capability of stacking several different runs to give an additive composite of the seismic traces. This allows for increased amplitude of character and cancellation of the random noise. The final result being a sharper amplitude break with improved character analysis.

Four seismic roads were cut at the site to shoot the arrays (Figure A). A 335 meter (1100 foot) cable was set out for each set up with the geophones being 30.5 meters (100 feet) apart (Figure B). Shot points distances from the end of the spread varied from 0 to 498 meters (0 to 1600 feet), depending on the predicted depth of bedrock in that area. Explosive charges varying from 0.5 kg to 5 kg (1 lb to 10 lb) were used as energy sources to generate the seismic waves. The type of explosive used was a 0.5 kg (1 lb) container termed a Kinestik. This explosive is a product of Kinepak, Inc., and has a detonation velocity of 5,850 m/s (18,000 ft/s).

To analyze the data from this survey, the first arrival times were picked, and arrival times versus the distance from the shot point were plotted. The slope of the linear segments of the plotted data provided the velocities of the

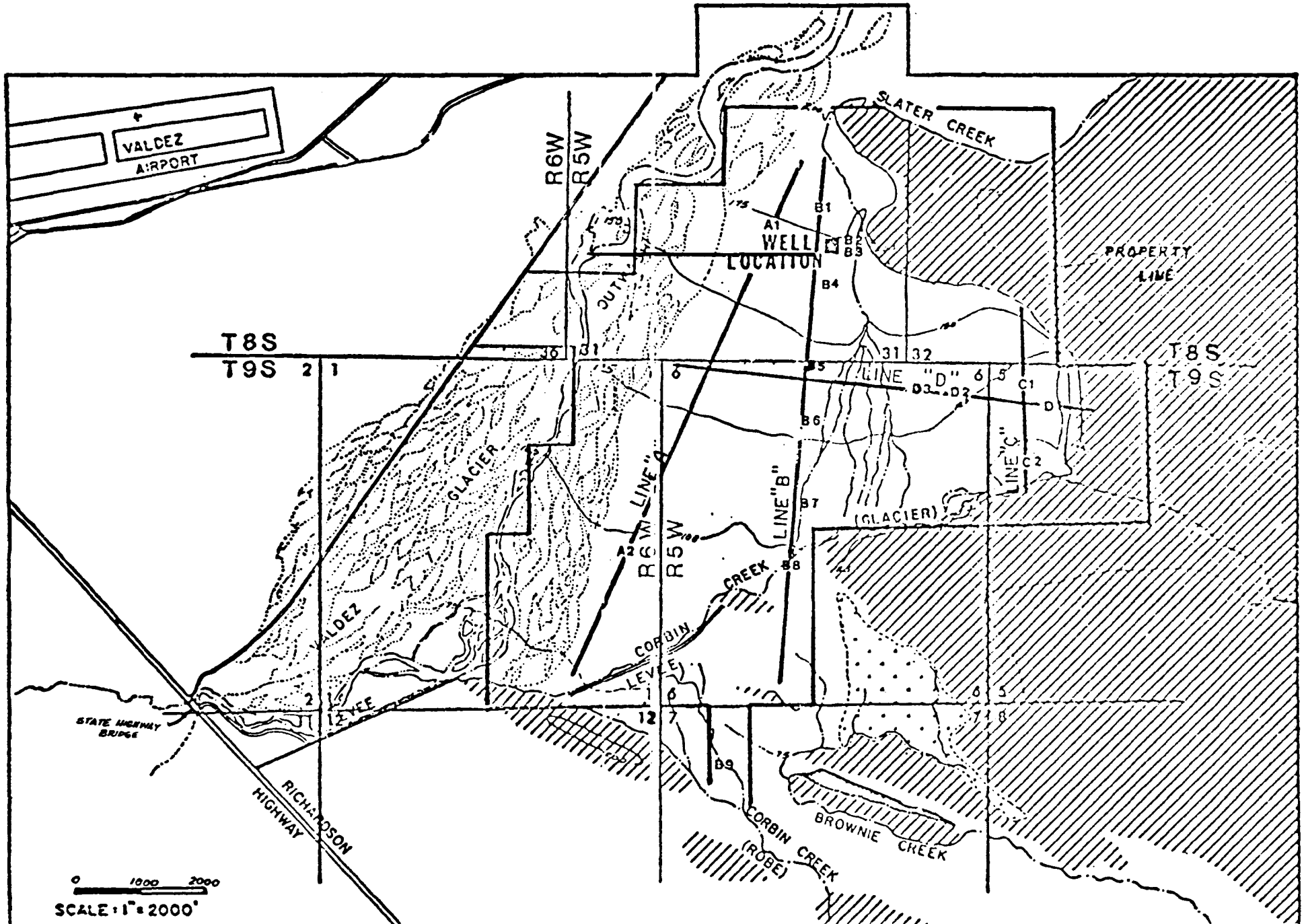
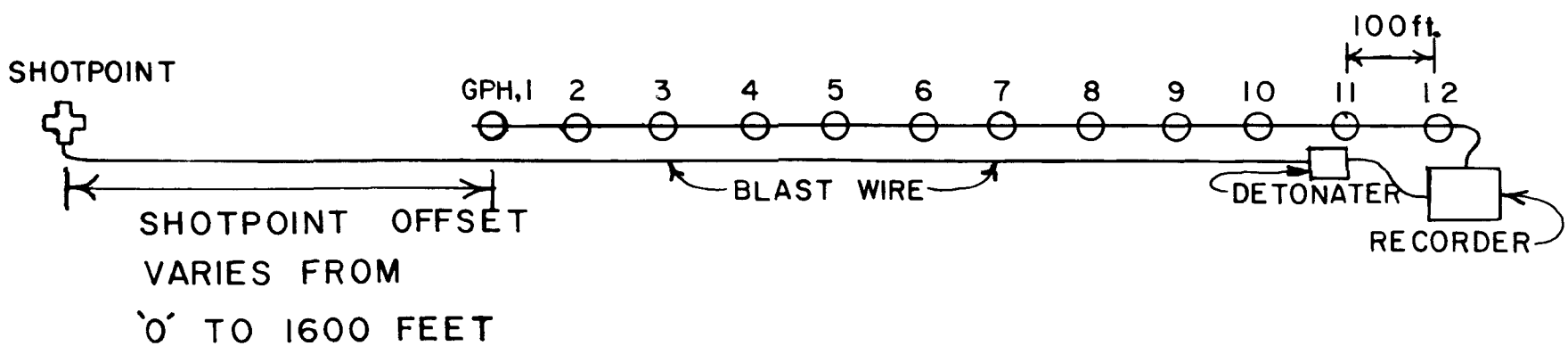


Figure A

1000 0 2000 4000 feet

200 0 500 1000 meters

SEISMIC LINE AND DRILLING LOCATIONS



STANDARD GEOPHONE SPREAD SET-UP FIGURE B

B

soil profile down to and including bedrock.

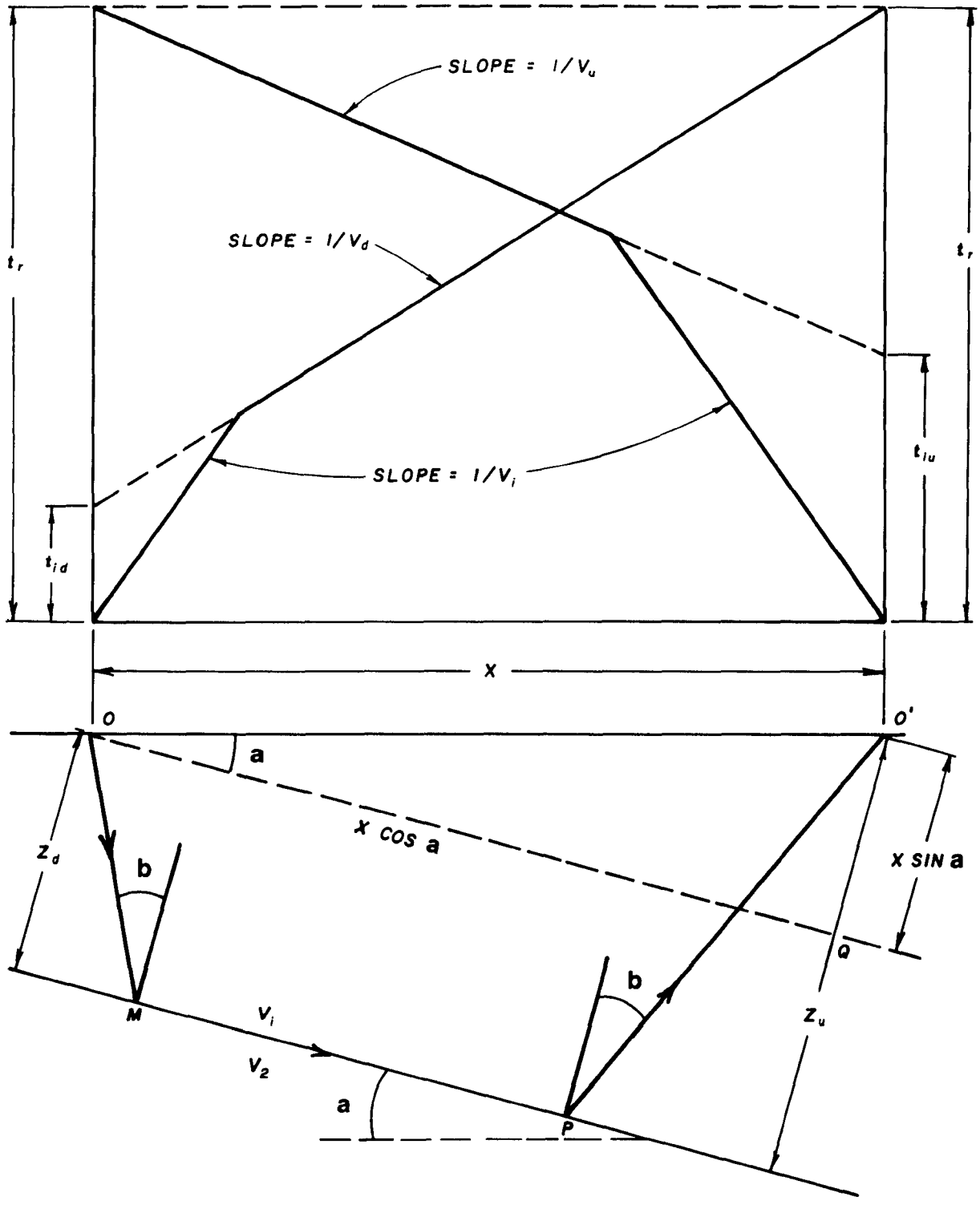
Analysis of the data indicates four soil layers and a bedrock layer within the sensitivity of our seismic equipment and resolution allowed by the geophone spread. The five velocities for the four layers going from the surface to bedrock are approximately: 366 m/s, 1,006 m/s, 1,646 m/s, 2,256 m/s, and 3,668 m/s (1,200 ft/s, 3,300 ft/s, 5,400 ft/s, 7,400 ft/s, and 12,000 ft/s).

We have been unable to tie the calculated velocity interfaces to specific changes in soil type as provided by the drilling logs. The different velocities appear to be tied to the degree of consolidation rather than the specific soil type. The drilling was conducted using an air lift rotary device which is a an indifferent sampling tool and does not give a direct density evaluation.

Based upon the quality of the data, the velocity contrasts, and the multilayer case of depth analysis, the values supplied in the depth to bedrock map are estimated to be plus or minus 10 percent. This confidence level is weakened by the detection of a variable thickness silt layer in the soil profile. This silt was detected by test borings. If the silt layer has a significantly lower velocity than the material overlying it the depth calculation could be in substantial error in areas where the silt layer is thick. The silt layer's velocity probably is not much less, if any less, than the material above it. This assumption is based on our predicted seismic refraction depth versus drilling depths. If the silt's velocity were significantly slower, then our calculated bedrock depth from the refraction survey would be deeper than the true bedrock depths. Our calculated depth for drill hole D-1 was essentially correct. The calculated depth of bedrock at B-3 is 6 meters (20 feet) lower than the drilled depth. We did not encounter bedrock in this testhole. The silt in B-3 was the thickest found on-site, with a thickness of approximately 37 meters (120 feet). If the silt had a slower velocity, we would have had to encounter bedrock at a depth shallower than the drilled depth of 500 feet in order for the slower velocity to have significantly affected our depth calculations.

The methods used to determine the bedrock depths was the intercept time method and a ray path method. Both methods were used to interpret all of the seismic refraction data.

To determine the depth to bedrock, the first interpretation technique used was the intercept time method. This method utilizes the concept of carrying the slope of one particular velocity over to the point where it would intercept the time ordinate on a distance versus time plot (Figure C). Using



RAYPATHS AND TRAVELTIME CURVES FOR A DIPPING REFRACTOR

(Telford, Geldart, Sherriff and Keys, 1976)

FIGURE C

the intercept time in the following equation gives a depth to the interface, at a distance Z cos b tan a from the shot point in the direction of the geophones (b = angle of refraction interface dip).

$$Z = (v_1 t)/2 \cos b$$

Z = perpendicular distance from interface to surface

v_1 = upper layer velocity

v_2 = lower layer velocity

t = intercept time

$b = \arcsin (v_1/v_2)$

(See Figure 3)

To use this method for more than one layer one merely has to subtract the intercept time of the interface above it and calculate a new "b". Adding the previous layer's thickness to each successive layer's will provide a depth to each successive interface until bedrock is reached.

Due to the dip of the refractor's interfaces apparent velocities were obtained from the time-distance plots. To obtain a true velocity, a harmonic mean was taken of the apparent velocities:

$$1/v_t = 1/n\ (1/v_1+1/v_2+1/v_3+\ldots+1/v_n)$$

v_t = true velocity

$v_1, v_2, v_3, \ldots v_n$ = apparent velocities

After analysis with the intercept time method, we refined those calculated depths using a ray path technique. With this method we graphically calculated depths by tracing individual ray paths from shot point to geophone, using total travel time as the criteria of interface placements. The critical angles used to trace ray path angles were the same "b"'s derived for the time-intercept method. As a starting point to determine the depth and dip of each interface, we used the time-intercept calculations. They were moved appropriately to fit the ray path travel time (see Dobrin, 1976 for a detailed explanation of both forms of analysis. Also see Telford, Geldart, Sheriff and Keys, 1976) (Figures D,E,F and G for depth to bedrock cross

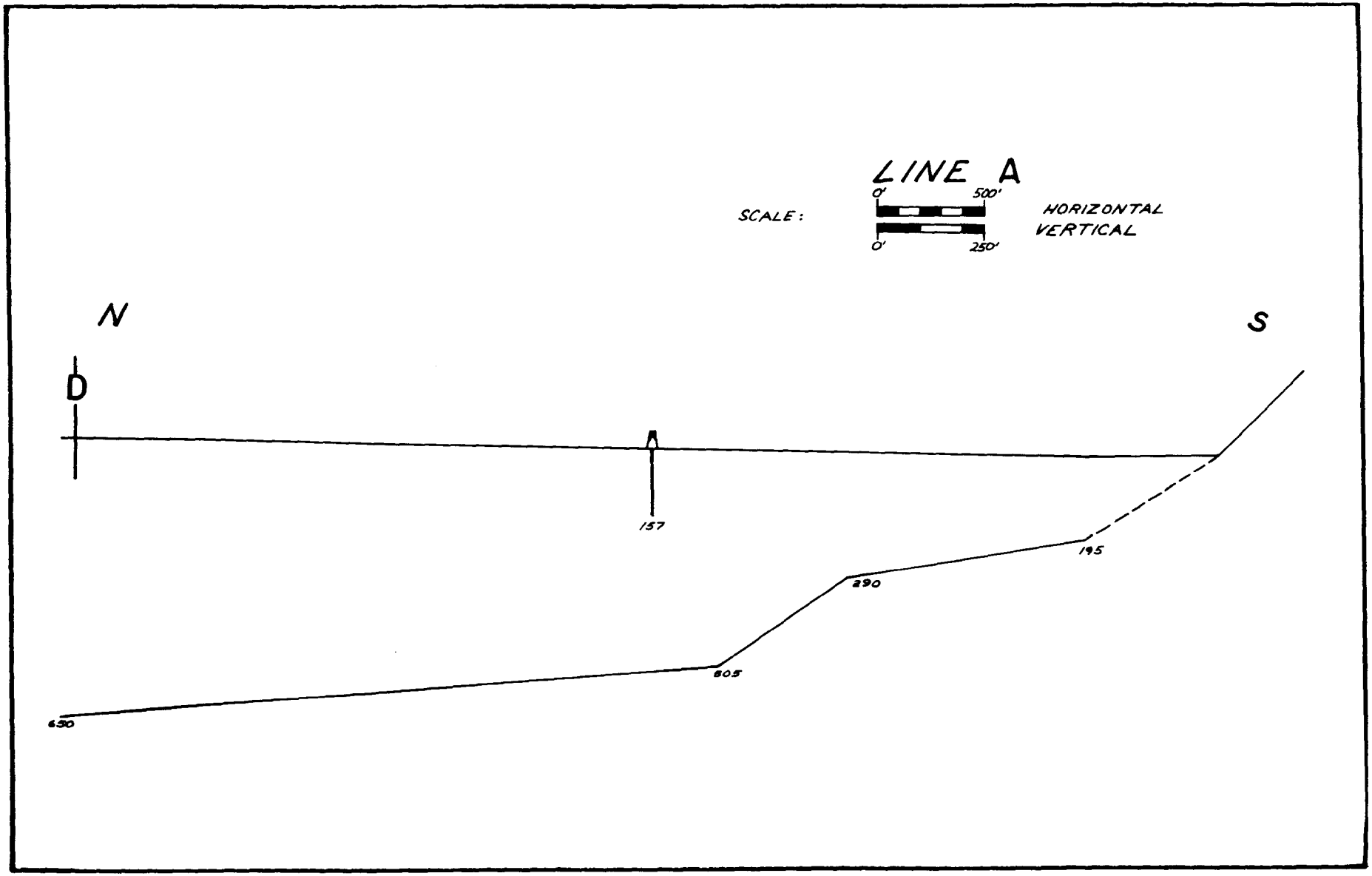


Figure D BEDROCK CROSS SECTION LINE A

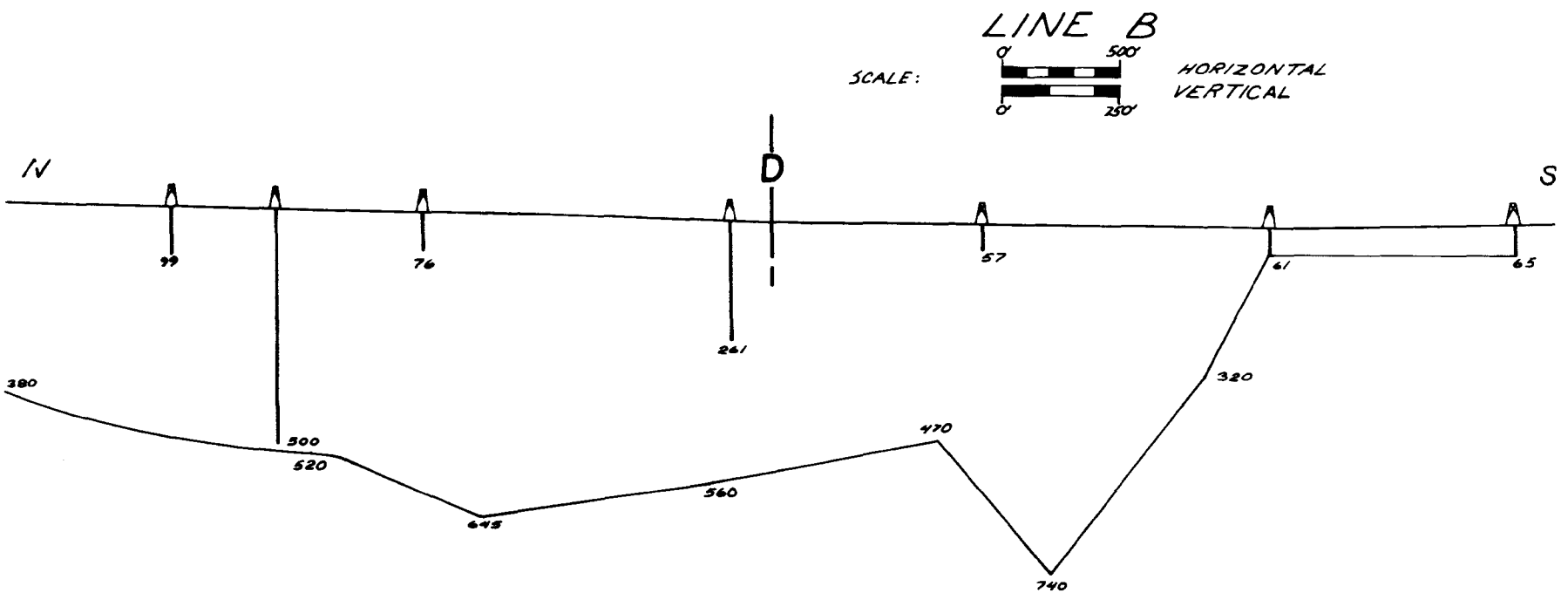


Figure E BEDROCK CROSS SECTION LINE B

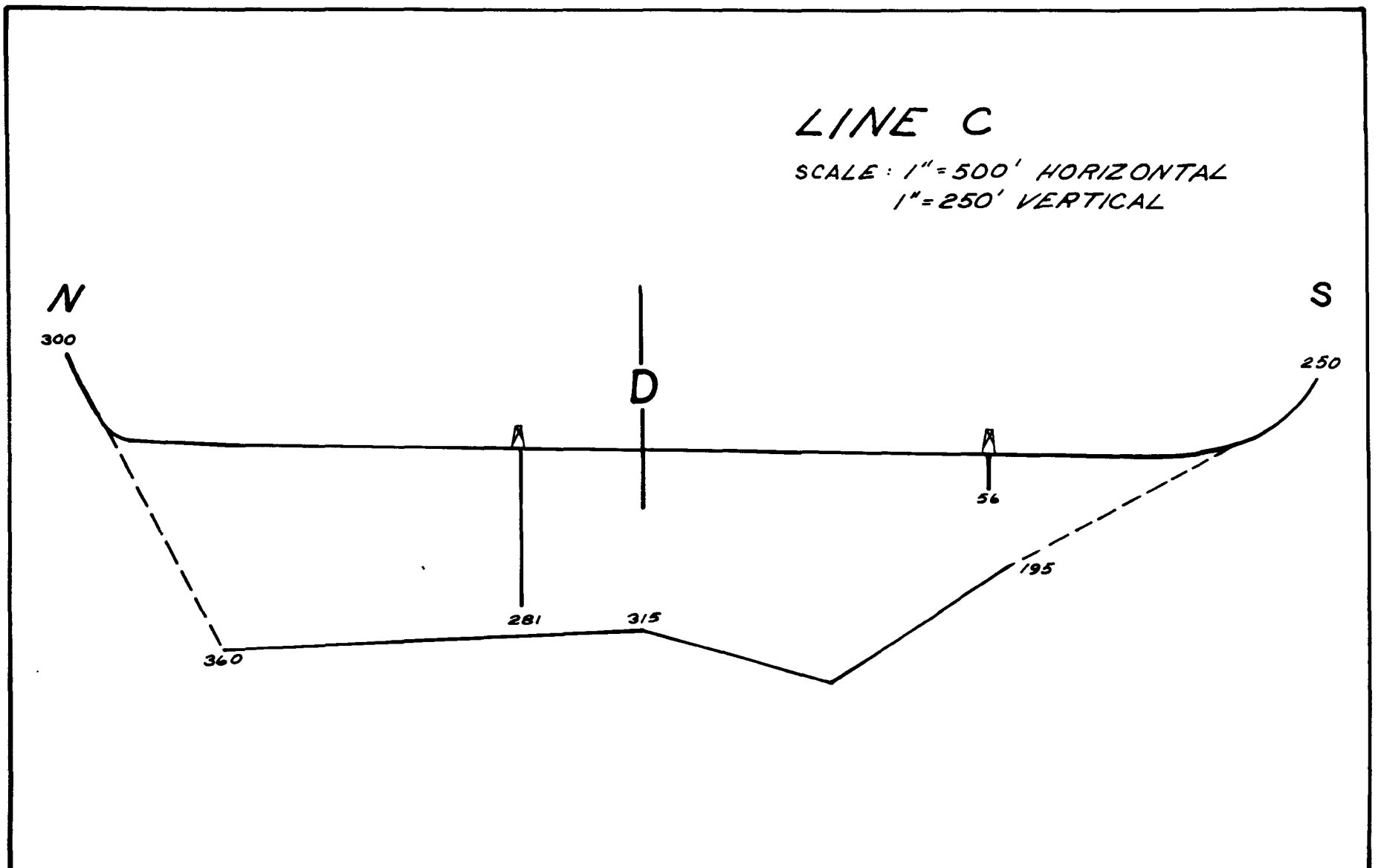


Figure F	BEDROCK CROSS SECTION LINE C

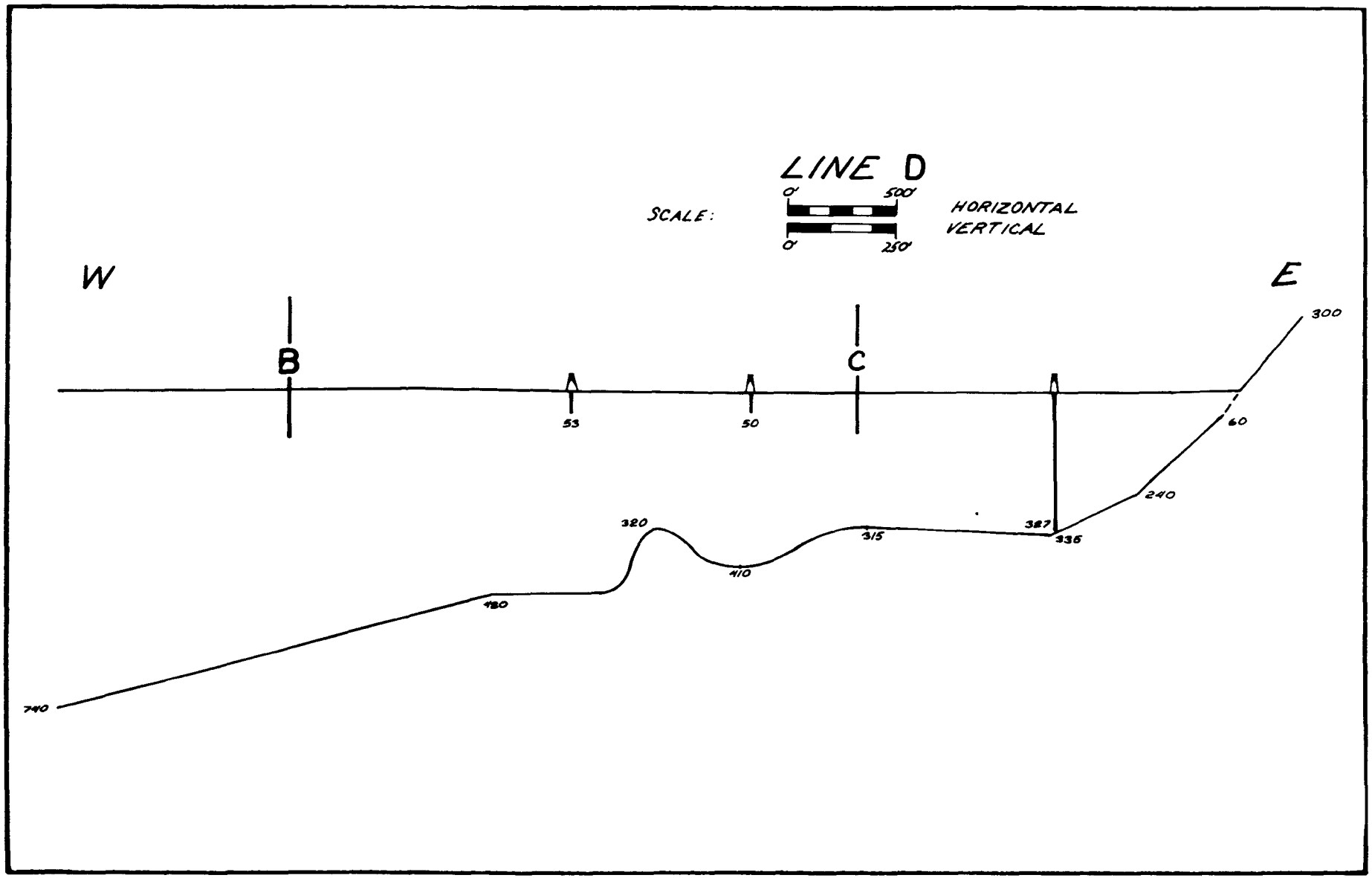


Figure G	BEDROCK CROSS SECTION LINE D

sections).

We ran two downhole velocity surveys to determine interval velocities. This data if precise would have solved our possible lower velocity silt layer question. The downhole survey was unsuccessful.

The downhole survey was run in testholes B-3 and C-1, having 8 inch steel casing with a three dimensional geophone setup. The geophones were lowered downhole and mechanically clamped to the sidewall of the steel casing. Hammer blows were then struck at the surface to generate the signal. Both "S" and "P" waves were generated. The "S" waves were generated for ground response data, while the "P" waves were strictly for interval velocity refraction data.

Analysis of the resultant seismic record gave no interpretable information. Possible explanations for this lack of data could be: 1) interference of the steel casing due to the signal traveling directly to the casing and down it. 2) Poor soil pipe contact. 3) Non-sufficient energy for a high attenuation material such as the cobbly gravels on site. 4) Poor mechanical contact between the geophones and the casing sidewall. We were advised before the survey that the steel casing could prove a problem. Common practice is to use a plastic casing for this purpose. However, the plastic casing was not compatible with the hole's primary function as a test well.

Seismic Reflections

In addition to the refraction survey a small reflection experiment was conducted. Data was recorded with the identical recorder used in the refraction survey. However, the geophone spread was reduced to 20 feet between geophones. A shot point was located at the center of the spread at a depth of 20 feet. Several runs were conducted. We were unable to record any useful data for bedrock profiling. An uneven bedrock surface probably created diffraction to disrupt an interpretable recording. Also, high attenuation due to shooting in gravel probably contributed to a lack of data. This reflection survey was a supplement to our refraction survey and should not be considered as source of poor confidence in our final seismic data evaluation. The instrument used was not ideal for reflection work and the subsurface conditions were adverse for a successful reflection survey.

DEFINITION OF TERMS (FAULTS)

Introduction to the Structure of the Earth, Chapter 7 by Edgar W. Spencer, 1977.

FAULTS-GENERAL CONSIDERATIONS

A fault is a plane or zone in solid rock parallel to which displacement has occurred. Faults occur in many structural situations, varying from minor faults associated with folds to major fault zones which form borders of mountain ranges and others which are major zones of weakness in the lithosphere. Fault zones can be traced to depths of thousands of meters, and their presence to depths as great as 700 km is inferred from the depth of deep-focus earthquakes.

A fault may be smooth, a finely striated or slickensided surface, but more commonly it is a zone ranging from a few to over a hundred meters in width in which the rock has been broken, brecciated, and sometimes ground into a powdery material, called gouge, or crushed and recrystallized into a flinty material called mylonite. Many fault zones are composed of a number of subparallel faults, synthetic faults. The bedding may be systematically displaced as in a step fault pattern, or the sections of rock caught between faults may be folded and rotated, forming a chaotic structural pattern.

Fault nomenclature is complex because the number of variables is great. The fault orientation, the position of the faulted beds relative to the fault, and the amount, direction, and type of movement between the blocks all vary. The movement may be such that adjacent points are displaced by translation, rotation, or both.

FAULT MOVEMENT-DISPLACEMENT, SLIP, AND SEPARATION

The amount and direction of movement between two rock masses separated by a fault is an important aspect of fault problems. Movement may be of critical importance when, for example, the fault involves a severed ore body, a displaced oil-bearing bed, a dam foundation, or a tunnel.

Determination of movement on faults requires thoughtful consideration of what is being measured, even when the fault has essentially planar shape and the movement is translational.

The amount of movement on a planar fault is usually expressed as displacement (syn.: net slip), which is the

distance* between any two originally adjacent points on a fault plane after movement occurs. While this concept is simple its application is difficult or sometimes impossible because relatively few natural features appear as points. Most such points are formed by the intersection of a linear feature, such as those listed below with a fault plane (after Crowell, 1959):

1. Lines formed by intersection of two planes such as the line of intersection of two dikes, a dike with a bed, two veins, etc.

2. Lines formed by the trace of one plane on another:

   a. Trace of a bed below or above an unconformity against the unconformity.

   b. Any older structure terminating against an unconformity or older fault (faults, dikes, sills, veins, sheets, fold axial surfaces, etc.)

3. Linear geology features:

   a. Buried river channels, shoestring sand, attenuated

   Sand lines.

   b. Volcanic necks, ore shoots, etc.

   c. Recent physiographic features along recent faults

4. Stratigraphic lines:

   a. Pinch-out line

   b. Lines formed by facies changes

   c. Shoreline, basin marginal features

*Direction of the slip vector must also be known.

5. Constructed lines:

   a. Isopach lines

   b. Lithofacie lines

   c. Axial and crestal lines

Displacement is but one of a class of terms, called slip, based on the actual relative movement between the fault blocks. Among these terms are:

Net slip: Actual displacement.

Dip slip: The component of net slip measured down the dip of the fault. (Note: Net slip may be equal to the dip slip.)

Strike slip: The component of net slip measured parallel to the strike of the fault.

Oblique slip: A slip which is oblique to the dip of the fault.

When slips cannot be determined, the best way to describe movements is in terms of separations-the distance between any two parts of an index plane disrupted by a fault and measured in some specified direction. Separations may be observed from a geologic map or from subsurface data. Separations are commonly measured:

1. Along the strike of the fault-strike separation.

2. Down the dip of the fault-dip separation.

3. In a vertical line (e.g., a well)-vertical separation.

4. Perpendicular to beds-stratigraphic separation (e.g., the thickness of the beds omitted between units adjacent on opposite sides of the fault).

FIELD PROGRAM

Description

To supplement existing hydrologic and geotechnical information available on the proposed site a field exploration program was conducted. The core of the program was the water well/test hole drilling that occurred during June and July 1979. In addition on-site terrestrial hydrology and geotechnical investigations were conducted on a regular basis from March through August 1979. Monitoring of stream flow and water table data is to continue on a twice-monthly basis from September 1979 into the spring of 1980 to complete a full year of data.

The drilling program consisted of 15 six-inch-diameter holes and one 12-inch-diameter hole that served as a high-volume groundwater test well. Drilling was performed by a private contractor. The work, under contract with Alaska Petrochemical Company, was administered and inspected by DOWL Engineers personnel. Test hole locations were selected to best represent subsurface conditions on the site, particularly with respect to groundwater effects. The 6-inch-diameter holes were drilled with a Koehring Speedstar SS15 rotary drill rig and the 12-inch-diameter hole with a Koehring Speedstar 71 cable tool rig. Steel casing (lining) was installed in all holes and each hole was marked to facilitate winter monitoring of water level and quality and snow depth. Figure A shows the locations of the test holes. Throughout this report are references to an alpha-numeric (e.g., A-2) symbol that identifies each test hole.

Beginning in March 1979 all streams on the proposed project site were monitored regularly for quality and quantity of flow and were further investigated for source. Helicopter and on-the-ground inspections were made throughout the areas to document identifiable conditions and assist in planning the drilling program.

Additional data were obtained from a preliminary site study performed by Northern Technical Services (NORTEC); Alaska State Division of Highway borings; soils studies in the old Valdez townsite; and two existing water wells near the airport.

SEISMOLOGY

I. REGIONAL SETTING

The city of Valdez is situated in that area of southcentral Alaska identified physiographically as the Kenai-Chugach section of the Pacific Border Ranges Province. The Pacific Border Ranges is the southern province of the larger major physiographic division known as the Pacific Mountain System. This system is one of the four major Alaskan physiographic divisions identified as the northwesterly extension of major physiographic divisions of Canada and the western conterminous United States. The Pacific Mountain System includes two dramatic mountain provinces (Alaska/Aleutian and Pacific Border Ranges) separated by an extensive coastal trough (Cook Inlet/Susitna Lowlands) (Figure 1). The Alaska/Aleutian Province is a region of extreme seismic and volcanic activity, which has been identified with the subduction zone formed as the Pacific Ocean plate dips below the North American continental plate. The collision of these two tectonic plates and the resulting subduction zone has formed the Aleutian Island chain and the contiguous Aleutian Range on the Alaskan Peninsula. This volcanic island arc and associated deep ocean trench (Aleutian Trench) are typical expressions of arcuate volcanic island/trench groups found throughout the Pacific. The somewhat regular distribution of the vulcanism around the continental margins of the Pacific have lead to the coining of the popular name "The Ring of Fire" for this region.

Most of the seismic activity of the world takes place along the areas of collision between the continental and oceanic plates. It is, in fact, the mapping of the earth's seismic activity that lead to the recent theory of global plate tectonics. The Aleutian Island Arc and its continued continental expression - the Alaskan Peninsula - form the concave northward expression of orogenisis related to the collision of the North American Continental Plate and the Pacific Ocean Plate. The Alaska Range is the concave southward expression of this same phenomenon. Together these two mountain ranges merge to form an area 5,150 km (3,200 mi) long and 160-480 km (100-300 mi) wide in which approximately 7% of the world's earthquakes occur. The majority of these shallow focus earthquakes (focal depths less than 70 km) occur between the Aleutian Trench to the south, and the volcano chain to the north.

II. MAJOR FAULTS AND FAULT SYSTEMS THAT CAN AFFECT THE SITE

Several major faults or fault systems have been identified which can produce earthquakes that may affect the proposed refinery site (Table 1). Although most of these fault

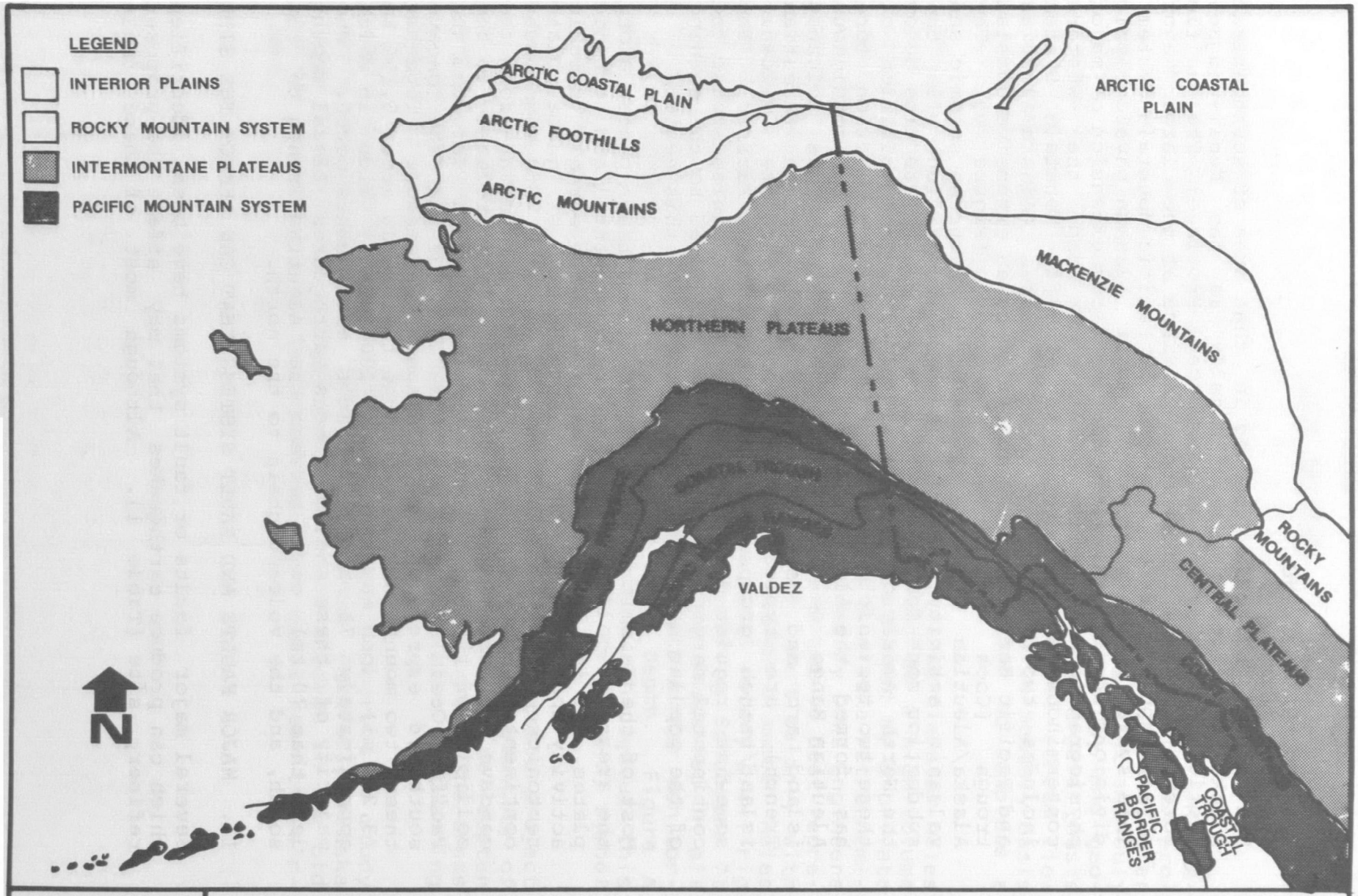


FIGURE 1 PHYSIOGRAPHIC DIVISIONS OF ALASKA

TABLE 1

MAJOR FAULTS THAT CAN AFFECT THE PROPOSED SITE

FAULT SYSTEM	Fault Length (mi)	Nearest Approach To Site (mi)	Maximum Probable Magnitude (M)	Probable Peak Bedrock Acceleration (%g)	Predominant Period of Bedrock Motion (sec)
1. Denali	1600	150	8.5	5	1.1
2. Castle Mountain	350	90	8.0	5	0.7
3. Knik	135	90	7.5	3	0.6
4. Aleutian Megathrust	1800	25	8.6	35	0.4
5. Patton Bay & Hanning Bay	60	90	7.4	3	0.6
6. Chugach - St. Elias	200	80	8.3	6	0.6
7. Ragged Mountain	20	80	6.9	2	0.5
8. Galena Bay	22	18	6.9	24	0.3
9. Jack Bay	32	14	7.1	31	0.3
10. Whalen Bay	12	22	6.6	16	0.3
11. Fairweather	650	150	8.5	5	1.1

systems are a considerable distance away from the site (80 miles or more), they are capable of producing major or great earthquakes that may affect the proposed refinery (Figure 2).

Denali Fault System

The Denali Fault System arcs 1400 km (854 mi) across central Alaska from the Yukon Territory, Canada, to Bristol Bay in the Bering Sea. The fault is divided into three major segments - the eastern or Shakwak Valley segment, the western or Farewell segment, and the two strands of the central segment identified as the Hines Creek Strand and the McKinley Strand. Grantz (1966) suggested that the younger southern strand (McKinley) has "short-circuited" the older, and longer, northern strand (Hines Creek) thus becoming the active section of this portion of the fault system.

The Farewell segment of the Denali Fault System is a complex fault with many strands that exhibit fault scarps of Recent age, wide gouge zones, and evidence of regional drag during late Cretaceous and Cenozoic time. Right lateral slip of up to 100 km (61 mi) has been inferred from reversals of stratigraphic throw and separation of Cretaceous rocks on the western part of the fault. Early or mid-Pleistocene displacements are evidenced in the right lateral offsets of large glaciated valleys at the east end of the fault. Offsets of up to 5 km (3 mi) are inferred (Grantz, 1966).

Fault scarps of Recent age exhibit up to 2.5 m (8 ft) of vertical displacement, and indicate that a large portion of the Cenozoic displacement of the southern section of the fault was up on the south. This displacement has been related to uplift of the Aleutian Island Arc on the mainland. The great lateral extent of this uplifted zone, and its abrupt termination at the Farewell section of the Denali Fault System, reinforces the supposition that this fault zone is a major crustal feature (Van Wormer, et al, 1974).

The Hines Creek Strand in the central portion of the Denali Fault System is the older arcuate connection between the Farewell and Shakwak Valley segments of the fault system. This strand is the northern and more fundamental geologic break of the fault in the central Alaska Range.

Strike-slip faulting is associated with this strand of the fault for continuity with other segments of the fault which reveal evidence of large right-lateral slip. If large horizontal displacement has in fact occurred, it must have

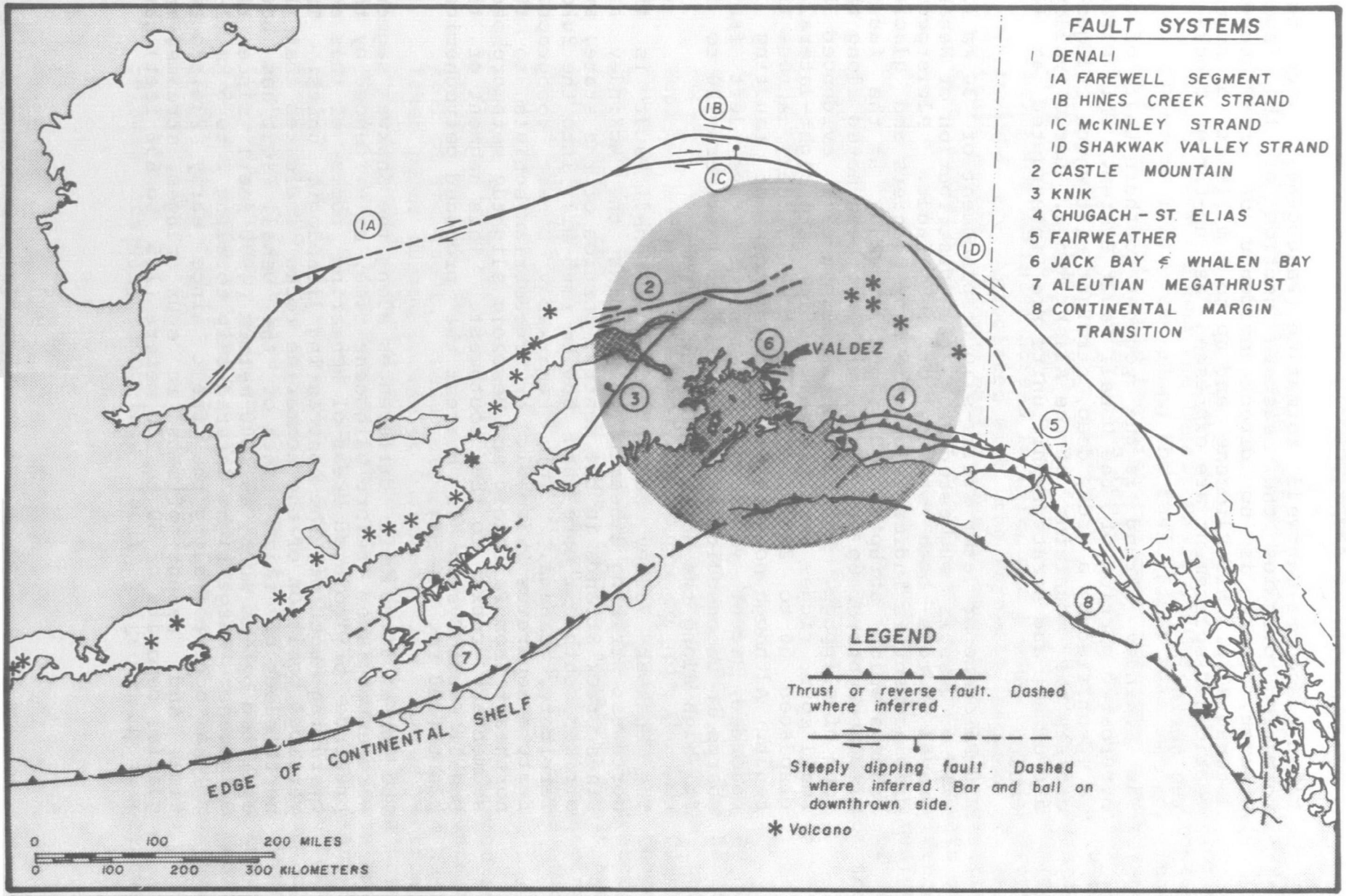


Figure 2 MAJOR FAULTS IN SOUTHCENTRAL ALASKA

taken place pre-Cantwell formation (Paleocene), since this formation overlies the eastern section of the fault. However, there is no direct evidence of pre-Paleocene lateral slip. Mid-Pliocene and up to 6 m (18 ft) of Recent vertical displacement are expressed as up-thrown blocks to the north.

The McKinley Strand is the younger southern half of the bifurcated portion of the Denali Fault System. This strand is identified by a wide, deep, straight rift which obliquely crosses the mountains of the Alaska Range. Large valleys are offset and stratigraphic units are interrupted at the fault.

Mid-Pliocene or later strike-slip displacement of 30 km (18 mi) or less is suggested from the distribution of Nenana gravel across both strands of the fault. Pleistocene displacement is indicated by the many glaciers and glacial valleys which abruptly jog right laterally at the fault. Displacements of up to 7 km (4 mi) have been noted along the zone of slippage. Recent lateral slippage is evidenced by small spur ridges and streams which are right-laterally displaced 50 to 200 meters (165 to 655 feet) across the fault. Although no historic occurrences of faulting is recorded, Recent vertical displacements have left fault scarps in unconsolidated sediments 6 to 15 meters (20 to 50 ft) high along the McKinley Strand.

The Shakwak Valley segment of the Denali Fault is the northwest striking lineament which joins the McKinley and Hines Creek Strands in the central portion of the state, and strikes southeast more than 600 km (365 mi) into the Yukon Territory, Canada. This remarkably linear topographic feature separates Paleozoic or Precambrian schists to the northeast from Paleozoic and Mesozoic slightly metamorphosed sedmentary rocks to the southwest. This segment of the Denali Fault System is nearest the proposed petrochemical plant (200 km, 120 mi).

The great lithologic differences along the Shakwak segment were established before Oligocene time, as evidenced by the presence of isolated areas of nonmarine rocks of this age overlying both of the contrasting lithologic units. The vertical position of the nonmarine rocks indicates that the north block of this branch of the Denali Fault has been uplifted by as much as 1500 meters (4900 feet) since the Oligocene. Large right lateral slip totaling 2 to 5 km (1-3 mi) has occurred along the fault since early Pleistocene time. And, recent offsets in spur ridges, streams, and glacial deposits of 50 to 200 meters (165 to 656 feet) have

been observed along the western portion of the fault (Gantz, 1966).

In spite of the geologic evidence of major prehistoric displacements along the Denali Fault System, the currently measured slip rates along the fault (less than 3mm/yr) (Page and Lahr, 1971), and the historic record of past earthquake activity indicate that this fault system has historically had a low level of seismicity. Only two events with magnitudes larger than 7.0 are believed to be associated with this fault system. A magnitude 7.4 earthquake occurred along the McKinley Strand in 1912, and a magnitude 8.3 event in 1904 are associated with the Farewell segment of the fault system. Eleven earthquakes of magnitude 6 or greater have occurred throughout the central and eastern segments of the system since 1900. Although the historic evidence suggests a moderate magnitude earthquake for design considerations, geologic evidence forces the adoption of a magnitude 8.5 event as the maximum design earthquake for the Shakwak segment of the Denali Fault System.

Castle Mountain Fault System

The Castle Mountain Fault has been classified as a right-lateral strike-slip fault (Grantz, 1966). The fault strikes southwest from the Talkeetna Mountains through the Susitna lowlands where it is thought to join the Lake Clark Fault in the Aleutian Mountains. The continuity of these two faults has not been satisfactorily demonstrated; therefore, the limits of the Castle Mountain Fault are restricted to the Susitna lowlands segment and the Talkeetna Mountains segment. The combined length of these two segments is approximately 350 km (215 mi).

Several kilometers of right-lateral slip have been mapped in Cretaceous and Tertiary lithologic units along the eastern half of the fault. These displacements are believed to have taken place during Eocene to Oligocene time. Large vertical displacements associated with reverse dip-slip faulting have taken place since Miocene time. The vertical offsets are steeply dipping to the north or near vertical. At least 3 meters (9 feet) of Recent dip-slip displacement has been observed along the central portion of the fault; however, no historic fault breaks are known to have occurred. Even the 1964 Prince William Sound earthquake caused no known slippage along the fault, although the Castle Mountain Fault System is within the area of gross tectonic warpage caused by this event (Page and Lahr, 1971).

Seismic activity along this fault is generally associated

with low magnitude (3.0-4.5) shallow events. Only six earthquakes with magnitudes of 6.0 or greater are associated with this fault. Of these six only two were greater than 7.0. The maximum historic event along this fault is believed to be the 1943 magnitude 7.3 earthquake whose epicenter was located just north of the central portion of the fault. Although the two largest recorded earthquakes for this fault system were the 1933 magnitude 7.0, and the 1943 magnitude 7.3 events, it is believed a magnitude 8.0 earthquake is possible along this fault. This assumption is based on known and inferred geologic evidence of past fault rupture and displacement. Therefore, for design purposes a magnitude 8.0 event should be assumed as the maximum earthquake associated with the Castle Mountain Fault System.

Aleutian Megathrust

The subduction zone between the North American and Pacific Ocean tectonic plates is topographically expressed in the North Pacific by the arcuate Aleutian Island chain, the mountains which form the Alaskan Peninsula, and the deep Aleutian oceanic trench. The subduction zone in this area of the Pacific is thought to be a shallow north dipping (reverse fault) thrust zone termed a "megathrust" (Coats, 1962). The unusually shallow angle of thrust is inferred from hypocentral locations and fault plane solutions of the earthquakes that continually express the tectonic realignment along the northern limits of the Pacific Ocean Plate. Although a simplistic interpretation of earthquake epicenters and topographic expression implies the Aleutian megathrust is a smooth circular arc with a radius of approximately 1280 km (800 mi), it is now believed that the arc is composed of relatively short straight line segments joined together at slight angles. It is further thought that these segments are tectonically independent, and may be separated by transverse tectonic features much like the transform faults associated with areas of sea-floor spreading. There has been a tendency for the hypocenters of large earthquakes to occur near one end of these blocks, and the accompanying aftershocks to spread over the remaining portion so that during large events strain is released over an entire segment of the megathrust zone, but stops abruptly at the discontinuity between individual segments (Sykes, 1971).

Nearly the entire Aleutian Arc between 145°W and 170°E has ruptured in a series of great earthquakes since the late 1930s (Keller, 1970). The last great event was the 1964 Prince William Sound Earthquake, which was the largest ever recorded on the North American continent (8.4-8.6). The

epicenter of the event was 65 km (40 mi) west of Valdez. Strain release accompanying this earthquake resulted in gross tectonic warpage of an area of approximately 279,720 sq km (108,000 sq mi). Although Port Valdez was on the "hinge" or line of zero tectonic warpage, Valdez was so severly damaged by a seismically induced submarine landslide and accompanying sea waves (seiches) that the entire townsite was moved to a more stable location.

Because of the high historic seismicity, and the potential area of rupture along the megathrust, a magnitude 8.6 earthquake 40 km (25 mi) from Valdez should be the design earthquake associated with this fault system.

Chugach-St. Elias Fault System

The Chugach-St. Elias Mountain System is thought to be the continental expression of the impingement of the North American and Pacific Ocean tectonic plates immediately north of the Gulf of Alaska. The area is believed to be the zone of transition between dextral tectonic slip along the plate margins southeast of Yakutat Bay and underthrusting along the Aleutian Megathrust. Continuity of relative motion between the two plates implies both dextral and thrust components along the continental margin south of the Chugach-St. Elias Front; however, only thrust displacements are expressed within the fault system (Burns and Plafker, 1975).

The Chugach-St. Elias Fault System is expressed by late Tertiary or early Pleistocene uplift along the southern front of the Chugach and St. Elias Mountains. The faults of this system are high angle north-dipping thrust faults accompanied by intense folding. The relative displacement along the faults, and the intensity of folding increase northward from the continental margin in the Gulf of Alaska toward the mountain front. The main fault of this system, the Chugach-St. Elias Fault, extends a distance of 290 km (180 mi) from the delta of the Copper River eastward to its juncture with the Fairweather Fault at Yakutat Bay.

This fault, which dips northward at an angle of 30° to 60°, is estimated to have a stratigraphic throw of at least 3050 meters (10,000 feet) (Miller, et al, 1959).

Three great earthquakes associated with the Chugach-St. Elias Fault System occurred 80 years ago. A magnitude 8.3 event occurred in September, 1899 followed a week later by a magnitude 7.8 event. Almost one year to the day after the

September event, the area was again rocked by a magnitude 8.3 earthquake. Although the time frame in which these events occurred is generally accepted as that in which lesser earthquakes would be classified as aftershocks of the main 1899 8.3 event, the magnitude of the subsequent events is such that one is forced to view them as independent major earthquakes in their own right (Richter, 1956; Sykes, 1979). Although these earthquakes are "officially" catalogued (NOAA) as having occurred in the same location (142°W60°N), the lack of an extensive array of seismological instrumentation at that time made precise location of these earthquakes impossible. It is probable, however, that release and redistribution of stresses within this very complex "corner" of the regional tectonic environment may have initiated a sudden redistribution of accumulated strain along other adjacent or nearby structural elements of the fault system. Only minor surface expression of fault rupture was reported for these events because of the remoteness of the epicentral area from population centers, inaccessibility of the affected area, and the masking of rupture zones by glaciers and snow fields.

Because of the historic seismicity associated with this fault system, and its potential rupture length, a magnitude 8.3 event occurring 130 km (80 mi) from Valdez should be the design event associated with the Chugach-St. Elias Fault System.

Fairweather Fault System

The Fairweather Fault System approximately parallels the coast of southeastern Alaska from its juncture with the Queen Charlotte Islands Fault off the coast of British Columbia to its inferred joining of the Denali Fault in eastcentral Alaska (Page and Lahr, 1971). The total length of the known and inferred segments of this fault is approximately 1045 kilometers (650 miles). The closest approach of this fault to the city of Valdez is about 240 kilometers (150 miles) to the northeast. Right lateral slip of several centimeters per year has been occurring on this fault through Holocene time and possibly since Miocene time (Grantz, 1966). A major earthquake of magnitude 7.9, which occurred just north of Icy Bay in 1958, caused 6.5 meters of right lateral displacement and 1 meter of vertical slip on this fault.

Several major and great earthquakes have been associated with this fault in the past. The maximum event attributed to this fault is the 1899 Yakutat Bay Earthquake which had an estimated magnitude of 8.6. A magnitude 8.1 earthquake

just north of Queen Charlotte Islands was recorded in 1949. Several major events with magnitudes greater than 7.0 have also been attributed to this fault during the last 70 years.

Because of the historic seismicity associated with this fault, and because of its potential rupture length, a magnitude 8.5 event should be the maximum design earthquake associated with this fault.

Lesser Local Faults

Several minor faults are expressed in Prince William Sound. Those nearest the proposed refinery site (16+ km, 10+ mi) are the Jack Bay, Whalen Bay, Galena Bay and Landlocked Bay Faults. These faults are expressed as steeply dipping normal faults (possibly thrust faults), and are believed to be expressions of orogenisis which took place during late Mesozoic or Tertiary time (Moffit, 1954). The faults are expressed or inferred by deeply weathered zones and straight fiords, which generally follow the strike of the regional major joint sets (Valdez Set and Hinchinbrook Set), and by lithologic unconformities (Condon, 1965).

No direct measurements of slip have been successfully made along these fault systems; however, dextral offsets up to 2 m (6 ft) have been reported along joints in nearby mine shafts (Moffit, 1954).

The seismicity of these faults is unknown due to the "masking" effect caused by the seismic activity of the Aleutian Megathrust, which lies directly below and extends throughout the region. Moreover, no evidence of historic displacement along these faults has been discovered, nor was any offset incurred by the gross tectonic warpage produced in this area by the 1964 Great Alaska Earthquake. Therefore, for design purposes a magnitude 7.1 earthquake should be assigned to these faults based solely on geologic inference of their potential rupture length, and not on historic earthquake activity.

III. EFFECTS OF HISTORIC EARTHQUAKES AT VALDEZ

Six earthquakes are reported to have seriously affected Port Valdez during the period between 1899 and 1979. During each of these earthquakes, events indicating submarine slides or possible liquefaction of the bottom sediments of Port Valdez were reported. During four of these earthquakes, "seismic sea waves" (probably seiching) were reported. The following is a brief summary of the effects of these events at Port Valdez (Coulter and Migliaccio, 1966).

On September 3, 1899 a magnitude 8.3 earthquake occurred near Yakutat Bay (60°N 142°W). Strong ground shaking and "earthquake water waves" were reported in Valdez. It was also reported that a ship, which was anchored in 40 feet of water at the mouth of the Lowe River in 1898, was unable to reach bottom at the same location with 200 ft of cable after the 1899 earthquake. If these reports are factual a massive submarine slide must have occurred in the deltaic sediments at the mouth of the Lowe River. The distance from Port Valdez to the reported epicentral location of the 1899 event (265 km, 165 m) is such that bedrock accelerations were probably on the order of 0.05 g's, and rich with low frequency vibration. Moreover, the depth of the sediments and their probable density leads one to believe the amplitude of shaking exprienced by the soil deposit was also quite small. However, due to the magnitude of this earthquake, the duration of shaking was probably on the order of several tens of seconds. Seismic excitation of this nature is more apt to induce liquefaction in loose fine sand deposits such as that found at the mouth of the Lowe River, rather than slope failure due to over stressing associated with inertial forces generated in the rather flat slope. It is probable that excess pore pressure gradually increased in the fine grain noncohesive sediments during this event until the soil's shear strengh was reduced below that required for stability of the slope, thus precipitating a massive subaquious flow slide.

It is unlikely that the "earthquake water waves" reported in Port Valdez were tsunami waves generated at Yakutat Bay. It is unlikely such waves could propagate from their requisite point of origin near Yakutat Bay and enter the narrow, shallow entrance of Port Valdez in a direction approximately 180° from their direction of travel. It is more likely that the reported waves were slide induced, or the result of seiching within the narrow confines of Port Valdez.

The second reported earthquake to significantly affect Port Valdez occurred on February 14, 1908 just north of Port Fidaigo (61°N 146.25°W). No magnitude has been assigned to this event; however, a Modified Mercalli Intensity of VI is attributed to the assigned epicentral location. Again, violent ground shaking and sea waves were reported at Valdez. Additionally, the submarine cables linking Valdez and Sitka, and Valdez and Seward were broken and buried in several places along the bottom of Port Valdez. No evidence of submarine slides were reported; therefore, faulting was thought to be the culprit. However, no manifestations of faulting could be detected anywhere onshore. It is very unlikely that faulting could have occurred across narrow

Port Valdez, and not left a trace along the shore; therefore, a more probable explanation for burial of several sections of the cable is liquefaction of the sediments in Port Valdez. Liquefaction within these sediments is probable for the same reasons stated for the 1899 earthquake. And, the effects on the cables due to liquefaction would be much like those reported. That is, a complete loss of bearing due to liquefaction of the sediments supporting the cables would cause the cables to sink below the mudline.

If only isolated areas along the continuously supported cable lost all bearing capacity, the cables would sag and stretch between the remaining sections supported on competent soil, break, and be buried by the surrounding sediments as they sunk into the "liquefied" soil. Therefore, it is more probable that liquefaction of the fine sands within Port Valdez was the cause of the cable breaks rather than subaqueous faulting.

On September 21, 1911 a magnitude 6.5 earthquake and three aftershocks occurred between Seward and Whittier (60.5°N 149.0°W). Moderate ground motion was reported at Valdez, and minor talus slides were observed on Valdez Glacier. However, no cracking or distress of the glacier was observed. The submarine cables were again severed as in the 1908 event; however, the separation of the cables did not take place unitl "several seconds" after the earthquake stopped. The severing and burial of the cables was again attributed to faulting at the bottom of Port Valdez; however, no faulting was observed on shore. The fact that the cables were not broken until some moments after shaking had subsided, almost forces one to reject faulting as a cause of the cable breaks, and accept liquefaction and loss of support as the applicable phenomenon. The strongest evidence is that liquefaction quite often is manifested <u>after</u> ground shaking ceases, yet surface faulting must <u>always</u> be accompanied by near-field ground shaking. Non-liquefaction induced subaqueous slides should also be rejected as the cause of cable burial, because the slope of the bottom of the fiord was only 50 feet to the mile (<1%) in the location where the cable was buried. It is very unlikely that accelerations at the mudline of the sediments associated with the magnitude and epicentral distance of this earthquake could have generated appreciable down slope movement of the sediments near enough to affect the cable.

The fourth earthquake known to have affected Port Valdez (January 31, 1912) is not well documented. The earthquake has been assigned a magnitude 7.25 and epicentral location

at 61°N 147.5°W (65 km, 40 mi west of Valdez). Once again the submarine cables were broken in Port Valdez.

The fifth earthquake occurred on February 23, 1925 west of Glennallen and Copper Center. No magnitude determinations were made for this event, but a Modified Mecalli Intensity of VII was assigned at the epicentral location (NOAA). Strong ground shaking caused structural damage to buildings and the dock at Valdez. Power lines were broken, and the submarine cables were severed once more. Seiching in Port Valdez also caused extensive damage to the boardwalk along Water Street.

The last earthquake to affect Valdez was the Great Alaska Earthquake of March 27, 1964. This event was the largest (M=8.4-8.6) ever recorded on the North American continent. The epicenter of the earthquake was approximately 70 km, (45 mi) west of Valdez in Prince William Sound. The earthquake damaged Valdez so severely that the entire city was moved to a new more stable location within Port Valdez (Mineral Creek fan).

The most destructive phenomenon in Port Valdez caused by this earthquake was a massive submarine slide involving approximately 75 million cubic meters (98 million cubic yards) of soil at the face of the Valdez Glacier Stream/Lowe River outwash delta. The slide destroyed the harbor facilities, and many nearshore facilities. Several people were killed by the collapse of the docks and the incoming sea waves generated by the slide. The loss of material at the face of the outwash delta also contributed to a seaward ground stretching and subsidence of part of the shore area to an elevation below high tide level.

Several subordinate phenomena were initiated by the massive slide at the face of the outwash delta. A wave with a reported height of 9 to 12 m (30 to 40 ft) was generated within Port Valdez. The wave traversed the length of the embayment several times at the approximate first mode period of seiching for the "basin". The runup of these waves caused further damage in Valdez beyond that associated with ground shaking. Subsidence, and ground cracking and stretching linked to mass soil loss at the face of the delta also contributed heavily to the destruction within the city. Utilities ("life lines") were especially hard hit by this form of ground failure.

The true cause of the submarine slide, which contributed so heavily to the destruction of old Valdez, and which precipitated ground failure and general seaward progression

of the land mass immediate to the prequake shoreline, is not precisely known. However, both liquefaction of sand layers and lenses, and failure of sensitive fine grain soil (silt, clay) could have produced similar effects as those that were reported to have occurred. According to aerial photo interpretation and published results of ground reconnaissance performed by members of the U.S. Geological Survey soon after the 1964 earthquake, most of the surface distress was generally limited to an area within 1500 m (5000 ft) of the prequake shoreline. The exception to these limits was the area southwest of Knife Ridge along the dike (Dike Road) south of Valdez Glacier Stream (Figure 3). In that area ground cracking and evidence of liquefaction was noted as far as 2450 m (8000 ft) inland from the prequake shoreline.

Surface features accompanying some of the fissures and cracks on the outwash delta were indicative of liquefaction at depth. Sand and occasional gravel particles were ejected as far as 30 m (100 ft) along extensive fissures. Graben-like depressions between fissures were also noted in areas of no reported ground stretching indicating that the loss of ejected material at depth resulted in localized surface depressions of up to 30 cm (12 in) deep. Test borings made by the Alaska Highway Department indicate that the soil fabric in the affected areas was generally more coarse than that which is usually considered to be sensitive to liquefaction. The fact that the ground surface was frozen and, therefore, impermeable when the earthquake struck may have been the important contributing factor which made the critical difference, and allowed a relatively permeable soil to "liquefy." It is, of course, also recognized that the 1964 seismic event was unique in its own right. That is, it was extremely violent and of unusually long duration (4 to 6 min). All of these unusual factors may have combined under just the right circumstances to cause the reported ground failures in and about old Valdez.

IV. SEISMIC GAPS

Kelleher (1970), Sykes (1971) and others have studied the spatial and temporal distribution of great earthquakes (M>7.7) along the Aleutian Megathrust Zone and the major fault systems of southcentral and southeastern Alaska. Although the historic records are somewhat meager for this region, apparent trends suggest the space-time distribution of great earthquakes approaches linearity, and progresses from east to west. Moreover, the aftershock zones of great earthquakes (rupture surfaces) tend to abut one another with very little overlap. Great and large earthquakes do not

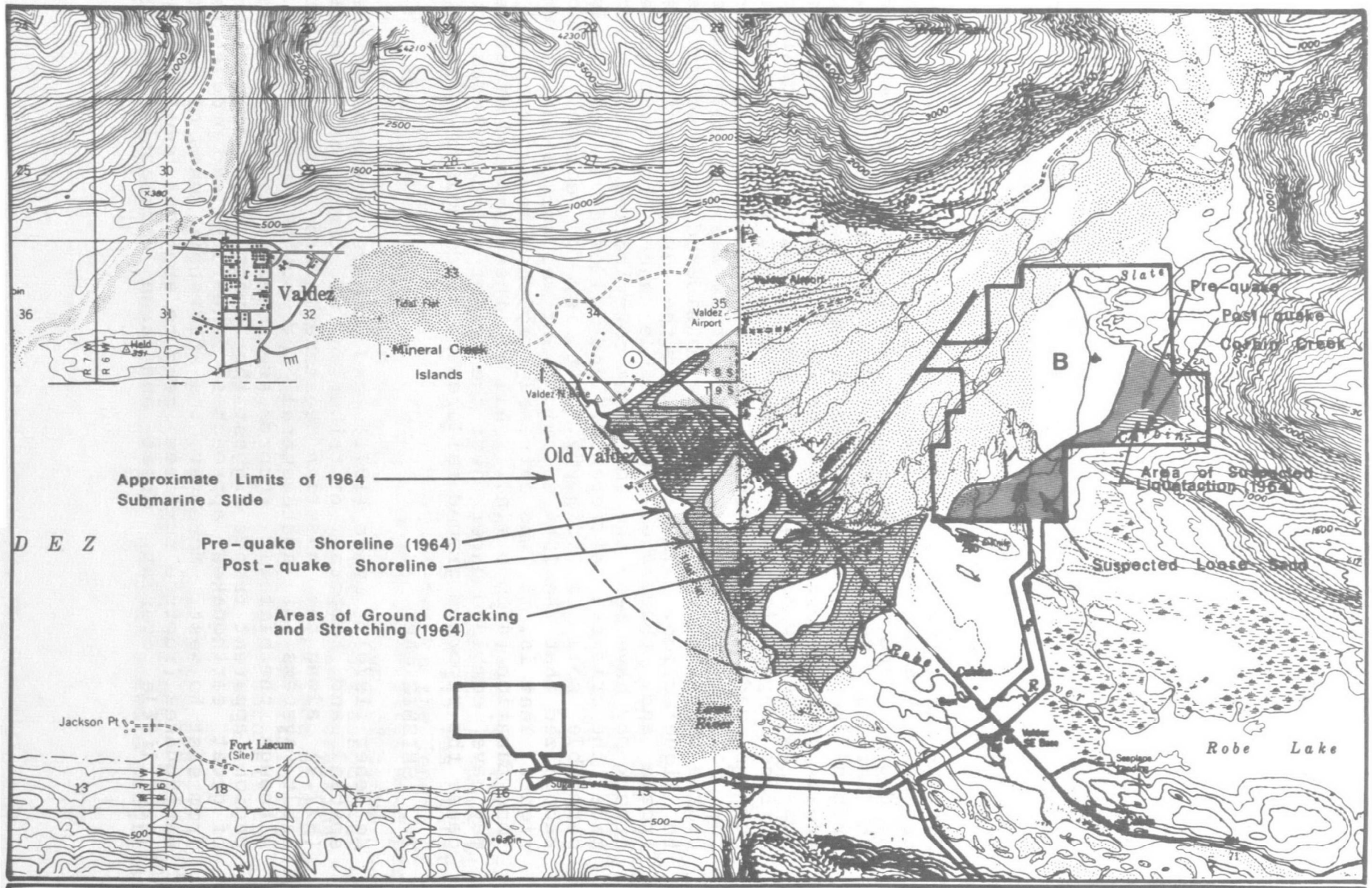


Figure 3 Ground Failure in Valdez - 1964 Earthquake

appear to rerupture the same area within a span of several tens of years. The exception to this "rule" is the sequence of great events which occurred at the turn of the century along the Chugach-St. Elias Fault System.

Areas of seismic quiescence ("seismic gaps") between rupture zones have been observed along the Alaska-Aleutian tectonic boundary as well as other tectonic margins in the Pacific. Observation of the historic space-time sequence of earthquake occurrence has shown that gaps between two rupture zones tend to "fill in" with large or great earthquakes within a few tens of years in the Alaskan region.

A gap of 200 to 300 km (120-180 mi) is evident between the aftershock zones of the 1958 Lituya Bay earthquake (M=7.9) and the 1964 Prince William Sound earthquake (M=8.5). The Chugach-St. Elias Fault System lies within this gap.

Kelleher (1970) postulated this region to be the likely location of a major earthquake within the next 20 years. His hypothesis was born out on February 28, 1979 when a magnitude 7.7 occurred north of Icy Bay (60.62°N141.51°W). This event, and attendant aftershocks, is believed to have released the accumulated strain in the eastern portion of the gap (Lahr, 1979) (Figure 4). Estimates of the seismic moment and accompanying fault slip (approximately 4.5 m) associated with the main shock can account for the strain accumulated in the area since the 1899-1900 series of events, if an average relative motion of 5-6 cm between the Pacific and North American plates is assumed. However, the entire gap was not filled in this tectonically complex "corner" during the rupture sequence (Lahr, et al, 1979); therefore, the probability of a major earthquake occurring within the gap in the near future should still be considered high.

Although advances have been made in the field of earthquake prediction in recent years, the necessary precursory parameters are not yet well defined, nor is the requisite instrumentation deployed regionally to measure and record such data. Therefore, the seismic exposure or seismic risk associated with the proposed refinery should be assessed by the more classic probabilistic approaches, but be tempered with the less rigorous intuitive observations of regional seismic history.

V. SEISMIC RISK

The term "risk" as it applies to earthquake engineering

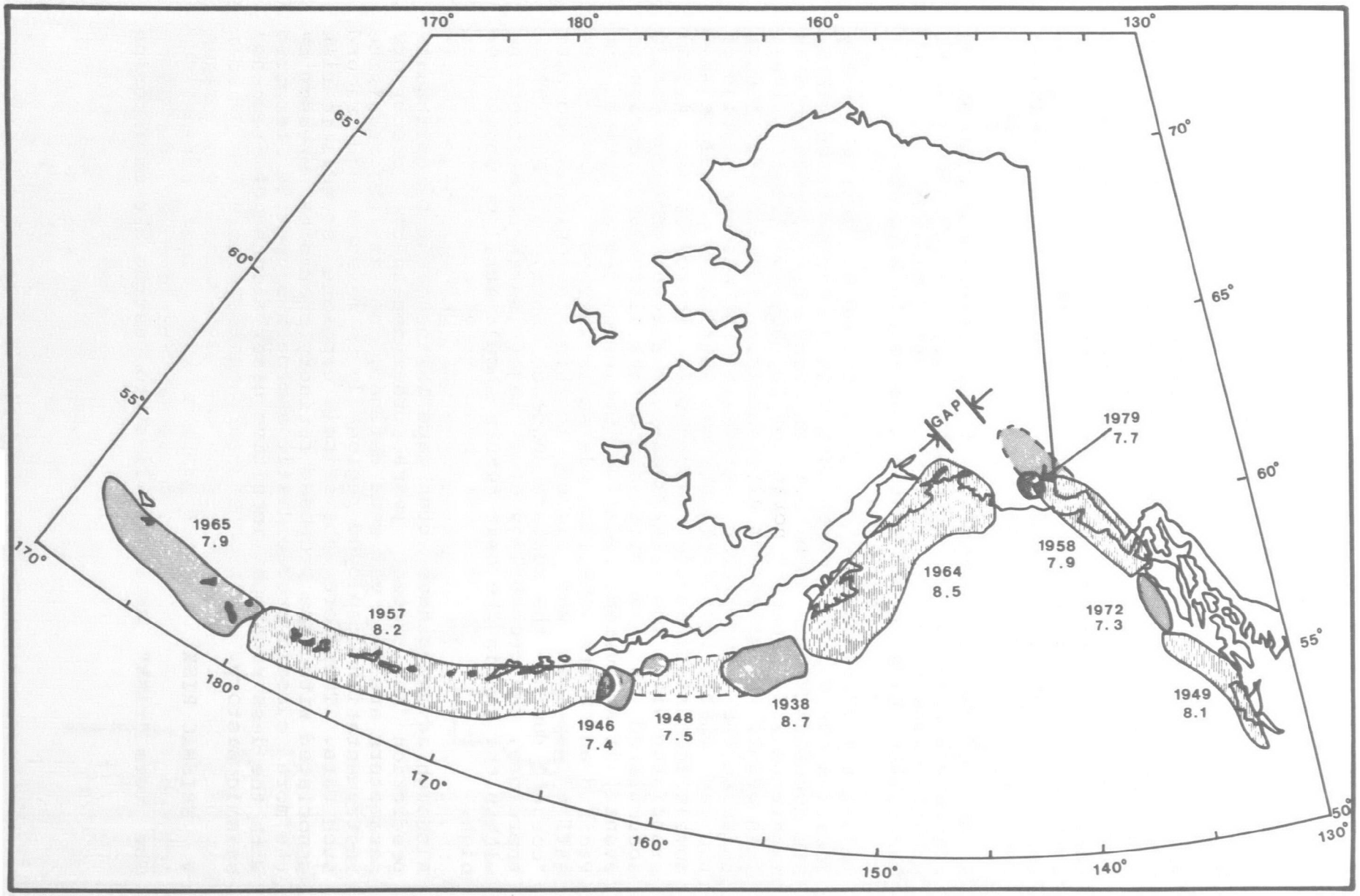


Figure 4 Seismic Gaps in Alaska

might be defined as the probability that a specific site will experience a given level of ground shaking during a specified design period. The design period is usually considered as the socioeconomic life of the structure or system under consideration.

Statistically based seismic risk analyses generally assume that earthquakes occur randomly in space and time within a given area, but with the same average rate of occurrence as that established in the past. A Poisson distribution model, which estimates the probability occurrence of rare events, is used to assess the probability of various levels of ground shaking at a specific site. The model assumes that future events will occur randomly, and independently of past events, but with the same mean frequency distribution of the historic events within the region.

This procedure is based solely on statistical interpretation of the historic seismic activity of the subject region. Little account is given to regional geologic setting, or the geophysical processes that actually produce earthquakes. The recent theories of global plate tectonics, and the continuing expansion of the Worldwide Network of Standard Seismograph Stations have begun to allow significant advancements to be made in the field of regional seismology. However, until more complete seismic source models are developed and the actual earthquake data base is greatly expanded, long range earthquake prediction techniques will continue to rely heavily on statistically based stochastic probability analyses.

Statistical Procedure

The historic distribution of earthquakes (seismicity), according to magnitude, location, and time of occurrence within the Prince William Sound Region was researched through data files obtained from the National Oceanic and Atmospheric Administration (NOAA) Environmental Data Service. These files are updated annually to include the most recent worldwide events.

The historic seismicity of this region was analytically described according to the relationship proposed by Richter (1958). A graph of this relationship is shown in Figure 5. This graph shows the historic frequency distribution, or the mean annual distribution of earthquakes within the Valdez region. The size of the region was determined by selecting a lower limit of bedrock motion that might affect the project site (in this case a bedrock acceleration of 0.05g), and using one of several attentuation relationships

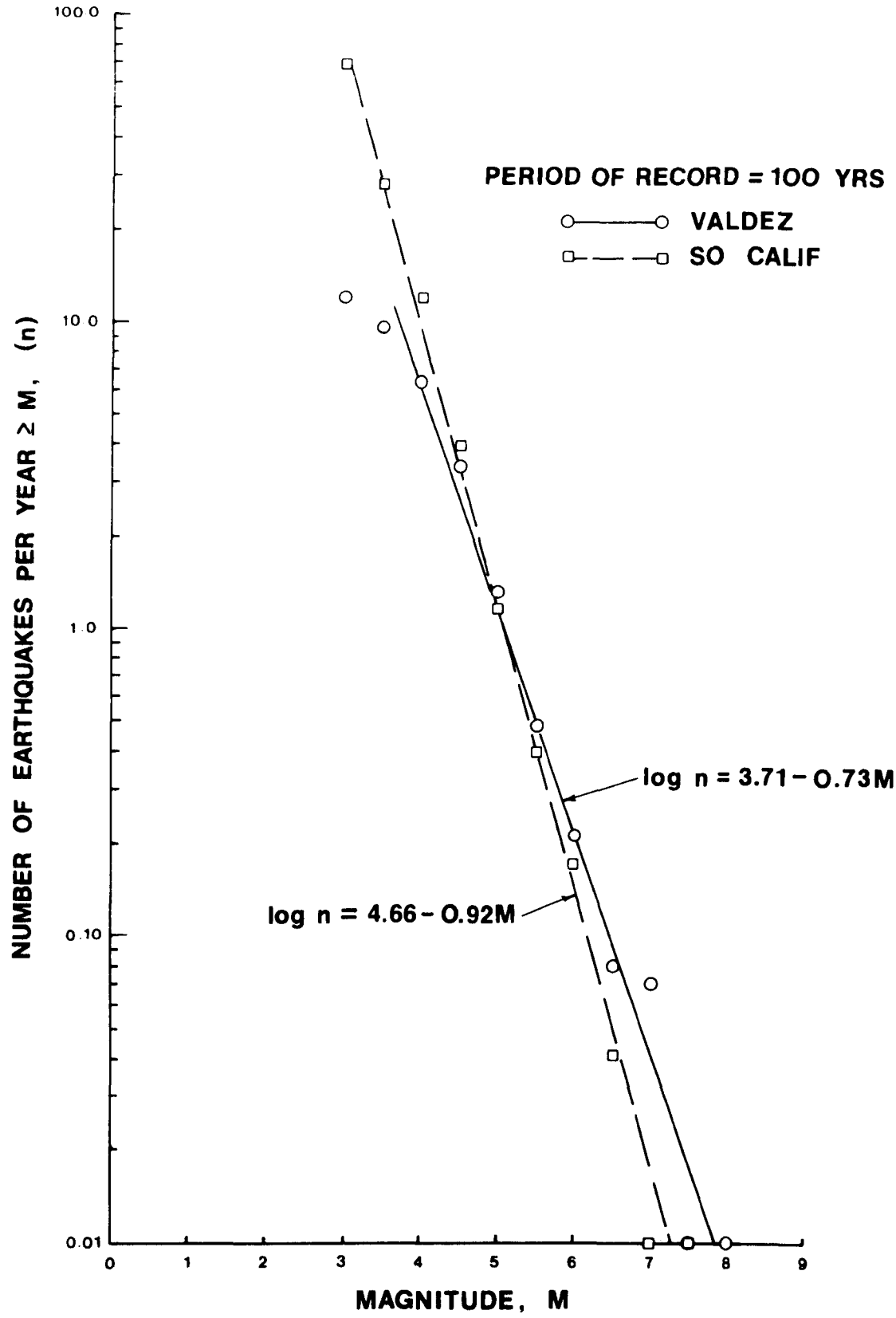


Figure 5
CUMULATIVE MAGNITUDE/FREQUENCY RELATIONSHIP

(Schnabel and Seed, 1972) to determine the maximum distance from the site, an upper bound magnitude earthquake (M=8.6) would produce this level of rock acceleration. The computed distance was used as the "search radius" for this study. All earthquakes known to have occurred within the area circumscribed by this radius were used as the data base.

Spatial Distribution of Ground Shaking

The spatial distribution of various levels of ground shaking for a given magnitude earthquake have been found to be reasonably described by elliptically shaped contours spreading concentrically away from the plane of fault rupture (Housner, 1969, Marachi, 1972). This spatial shape was combined with an appropriate rock acceleration attenuation relationship to estimate the aerial extent associated with specific levels of bedrock motion for various magnitude earthquakes.

Cumulative Seismic Risk

The temporal distribution of earthquakes by magnitude, and the spatial distribution of bedrock acceleration for a given magnitude earthquake, were combined in matrix form to compute the mean annual frequency of occurrence of a given level of bedrock acceleration within the search area.

The spatial and temporal distribution combinations were then used with the Poisson probability distribution to compute the probability of the site experiencing various levels of bedrock acceleration at least once for the design life of the proposed refinery (30 years). The graphical representation of these probabilities is shown in Figure 6.

In general it can be concluded from this graph that the probability that low levels of seismic shaking will be experienced at this site is quite high, and that for substantial shaking is somewhat low. This relationship is, of course, what one would intuitively expect.

Typical aseismic design practice usually includes the selection of a level of acceptable risk, and its associated expected ground motion for an established design period. Structures are then designed to elastically accommodate the resulting ground motion. Elastic design for this level of excitation should keep damage to a minimum during those events likely to occur during the design life of the structure. The more severe ("maximum credible") ground motions with low risk exposure are used as the extreme event survivability loading condition. More refined ductile

analyses using ultimate strength parameters may be employed to economically insure the survivability of structures and plant components, to mitigate loss of life of the refinery personnel, and to reduce unanticipated down-time of the facility during a rare extreme event that may occur during the life of the plant. For example, if it is decided that the proposed refinery should be designed to suffer little or no damage for those ground motions that have a 90% probability of occurring during the design life of the structure, the ground motion that has a 10% chance of exceedence should be chosen as the elastic design motion (Figure 6).

IV. SITE RESPONSE

The response of irregularly shaped alluvium filled valleys to seismic excitation is varied and complex (Seed and Idriss, 1968; Idriss, Seed and Serff, 1974). However, fairly good approximations of the ground surface response are possible with computer modeling techniques presently available. The surface response is represented in terms of the amplification of peak amplitudes and the frequency content of ground motion induced in a soil mass by seismically induced bedrock motion. The more recent and sophisticated finite element computer programs can model the response of two dimensional irregular soil profiles with complex boundary conditions (bedrock profiles) to both horizontal vertical rock motions remarkably well. These programs account for soil parameters such as strain dependent moduli and damping in a way such that strains in all adjacent soil elements are compatible, and are consistent with the dynamic properties of the soil. Similar one dimensional dynamic analyses of horizontally layered soil deposits have been used to model the response of individual "soil columns" within complex profiles. Comparative results between the two methods are consistent; however, the former method is considered to be more representative of the real behavior of the total deposit than is the latter.

Modeling Procedure

The computer program SHAKE 2 (Schnabel, et al, 1972) which models one dimensional wave propagation through a horizontally stratified continuous medium was used during this study to gain insight into the probable response of the proposed refinery site to seismically induced bedrock motion. The rock motion chosen for this study was that which has a 10% chance of occurrence during the design life of the refinery. The method is based on the assumption that

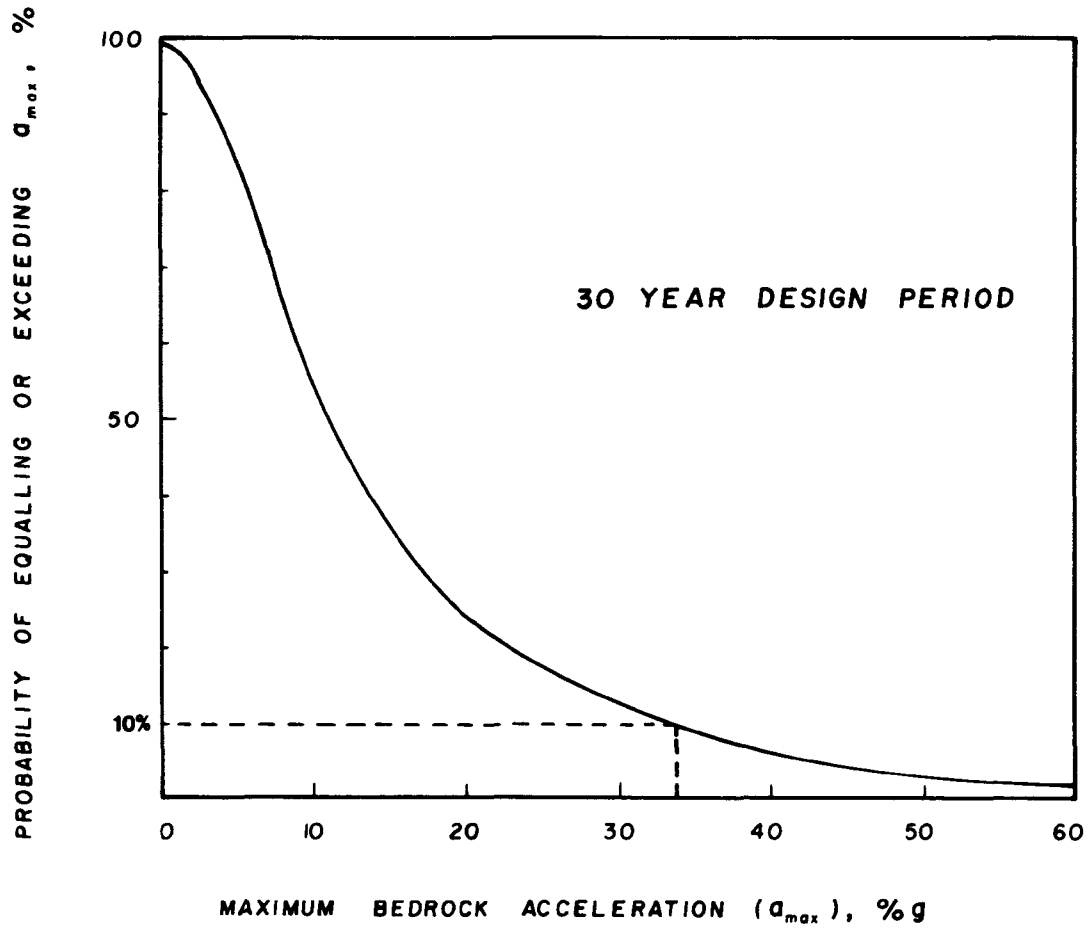


Figure 6 Seismic Risk (Valdez)

the soil deposit responds as a viscoelastic system to the vertical propagation of horizontal shear waves from the underlying rock formation. The soil deposit is idealized by assuming it is composed of homogeneous, isotropic horizontal layers which extend to infinity in the horizontal direction.

Four soil profiles were chosen to model the "limiting", albeit hypothetical, conditions thought to be appropriate for typical locations within the deep alluvial valley of the proposed refinery site - deep stiff, deep soft, shallow stiff, and shallow soft. The terms "deep" and "shallow" describing the depth to bedrock at the study site are used only in a relative sense to describe the depth of soil found below the proposed refinery. They should not be taken in an absolute sense. The soil types encountered during the groundwater study and well development program conducted at the site were used to describe the soil profiles; however, since the in situ soil properties were not measured during this study, typical values of soil density and shear moduli were assigned to the individual soil layers so that both a very dense and a very loose deposit could be modeled. The dynamic properties of the soil deposits were estimated using published average relationships between the dynamic shear moduli and damping ratios of various soils as a function of their shear strain and static properties (Seed and Idriss, 1970).

The depths of the proposed soil deposit in the plant area used in the ground response analysis were those encountered during well drilling and geophysical exploration performed as part of the hydrology/geology/soils investigation program of this study. The depth to bedrock of the "shallow" soil profiles was 90 m (300 ft), and the depth to bedrock of the "deep" deposits was 210 m (690 ft).

The "design earthquakes" selected for the analytical analysis were based on a seismicity study of the 192,000 sq km (74,000 sq mi) area surrounding the site, and on the characteristics of the motions likely to develop in the rock formation underlying the site. Some of the parameters most often used to describe earthquake induced base rock motions are the maximum acceleration, the predominant period of the motion, and the effective duration of shaking. Several studies have produced empirical relationships between these parameters and the distance from the site to the causative fault for earthquakes of various magnitudes (Schnabel and Seed, 1972). Earthquake motions with the requisite characteristics established from the seismicity study performed for the proposed site were selected from existing strong motion accelerograms, or

existing accelerograms were modified to fit the design motion characteristics.

The probable maximum events associated with fault systems both near to and far from the proposed refinery site were modeled in this analysis. Large peak amplitude high frequency rock motions (a[max] = 0.37 g; T = 0.37 sec) were ascribed to the probable maximum event occurring on the Aleutian Megathrust because of its close proximity to the site. Small peak amplitude low frequency rock motions (a[max] = 0.05 g; T = 1.32 sec) used as the design earthquake associated with fault systems at considerable distance from the site (Denali and Fairweather). The effects of these divergent motions on the ground response of the site were investigated to assess the behavior of various types of structures and systems associated with a petrochemical refinery. It is expected that the full range of structural periods common to civil type structures will be present within the refinery complex. That is, structures or structural systems with first mode periods of 0.1 seconds or less (buildings, machine and stiff piping systems, etc.) through 5+ seconds (towers, storage tanks, flexible piping systems, etc.) will be the components of the plant.

Results of Dynamic Response Analysis

Two base rock input motions were selected to model the occurrence of a great earthquake (M = 8.4 - 8.6) both near (<30 km) and far from (>250 km) the site.

The soil profiles modeled in this analysis tended to filter the high frequency components of the input motion, and amplify the low frequency components. This behavior is typical for soil deposits as deep as those considered in this study. The peak bedrock motions generated by large earthquakes near the site were amplified at the ground surface approximately twofold through the shallow stiff soil profile, and peak rock motions produced by distant large earthquakes were similarly amplified at the surface through shallow soft soil deposits. The deep soil deposits (both stiff and soft) generally reduced the surface expression of seismically induced bedrock motions. The reduction was most pronounced for earthquakes occurring near the site.

The behavior of soil above bedrock is greatly influenced by the frequency content of the base motion. As the predominent period of the earthquake motion approaches the fundamental period of the soil mass, large amplifications of the base motion are possible. Furthermore, the magnitude of ground surface spectral values (acceleration, velocity,

displacement), and the period of vibration of a single degree of freedom oscillator for which spectral maxima occur are functions of the frequency content of the computed surface motion. Therefore, the earthquake "source function" (acceleration time history), coupled with the physical characteristics (dynamic behavior) of the soil mass, determines the amplitude and frequency content of the ground surface motion produced by earthquake excitation of the basement rock.

Figure 7 shows the computed response spectra for the various soil profiles and earthquake motions analyzed during this study. Figure 8 shows the suggested enveloping functions associated with the computed response functions. And, Figure 9 compares the results of this study with enveloping functions of the spectra computed from actual recorded earthquake motions modified for use in this study (El Centro, Kern County). The plot of the "worst case" total seismic coefficient suggested by the 1976 Uniform Building Code for determining the base shear for buildings when using the equivalent lateral force design method is also included in this figure.

Figure 8 shows that ground motions associated with those areas of the proposed site underlain by "deep" soil deposits will produce lower spectral values than those areas underlain by "shallow" soil deposits. Moreover, the spectral values associated with the deep deposits are substantially shifted towards the long period portion of the spectrum. Similar relationships can be noted in the spectral response of soft deposits relative to the spectral response of stiff deposits of equal depth.

V. MITIGATION MEASURES (SEISMIC)

The probable behavior of the proposed refinery during earthquakes can best be addressed in a twofold manner - the geotechnical effects (site response) and the structural behavior of refinery elements and systems.

Geotechnical Effects

Although the geotechnical data gathered during this study is not sufficient to make specific predictions regarding the dynamic behavior of the proposed site, some generalities can be drawn and areas in need of further study identified.

The soils in the northwestern and central portions of the proposed site (Area B, Figure 3) appear to be well drained, coarse grain soil (sandy gravel with cobbles and boulders)

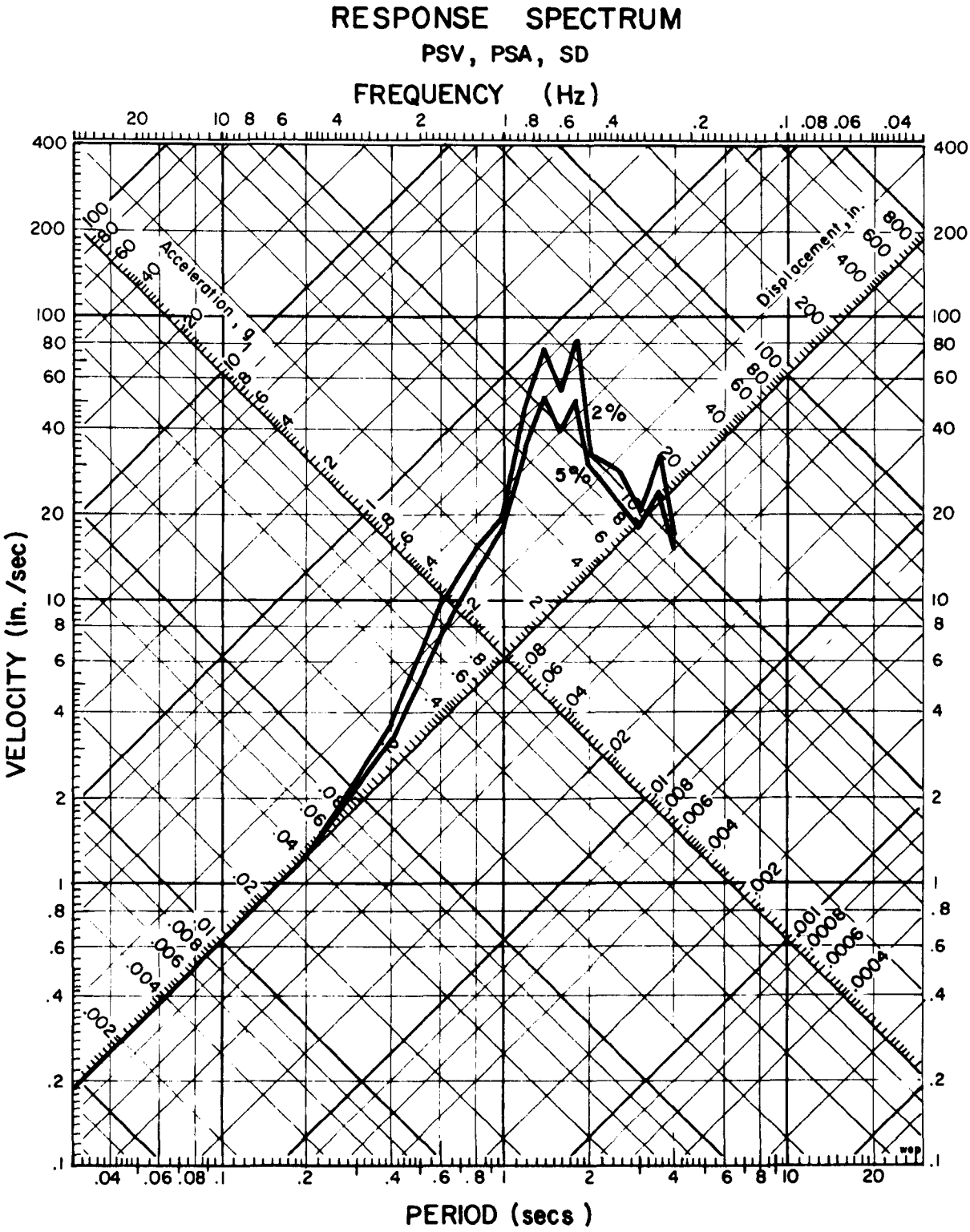


Figure 7a, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
DISTANT EVENT, SHALLOW SOFT SOIL DEPOSIT
MODIFIED RECORD - KERN COUNTY 1952 S69E

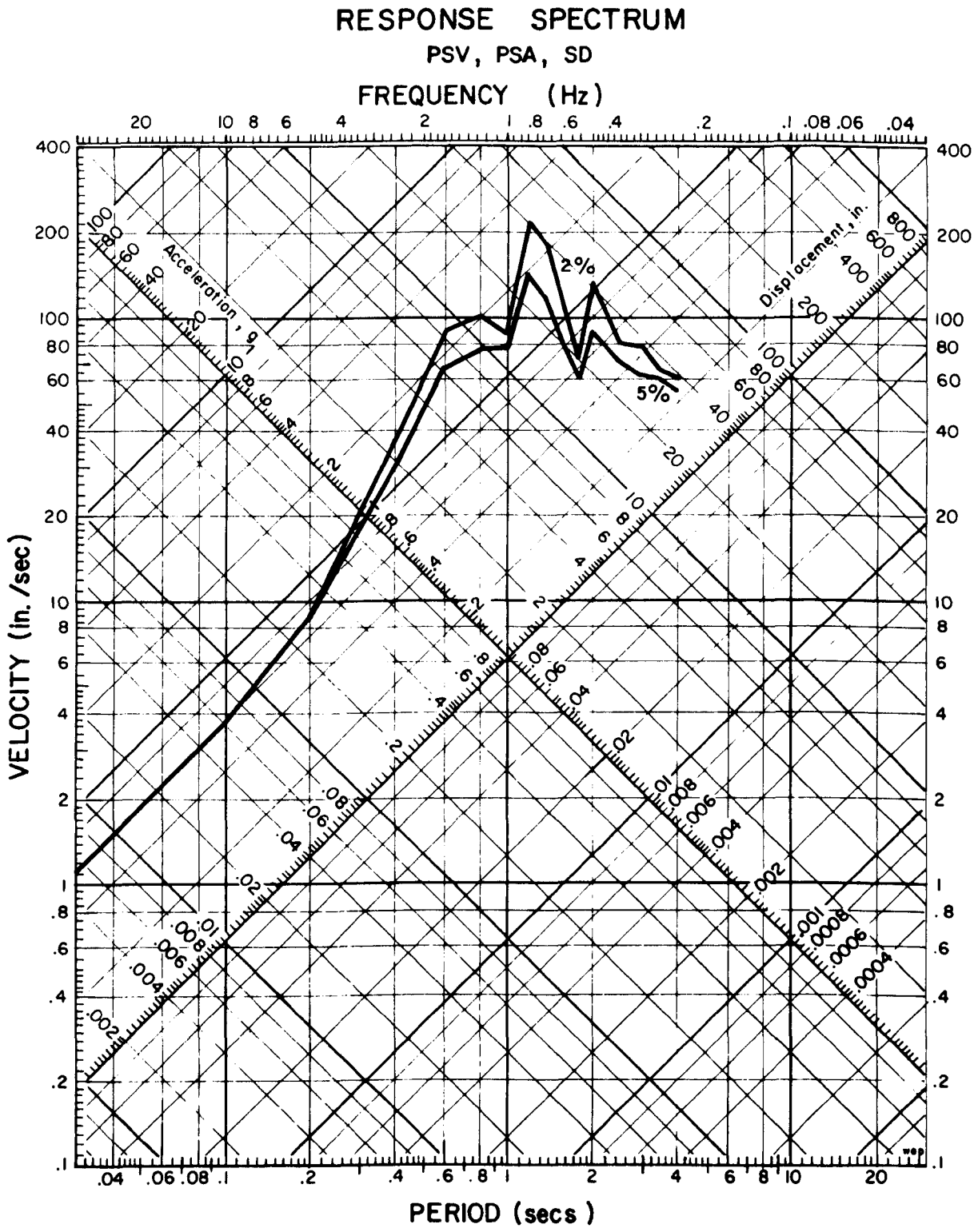


Figure 7b, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
NEAR EVENT, SHALLOW STIFF SOIL DEPOSIT
MODIFIED RECORD - EL CENTRO 1940 S90W

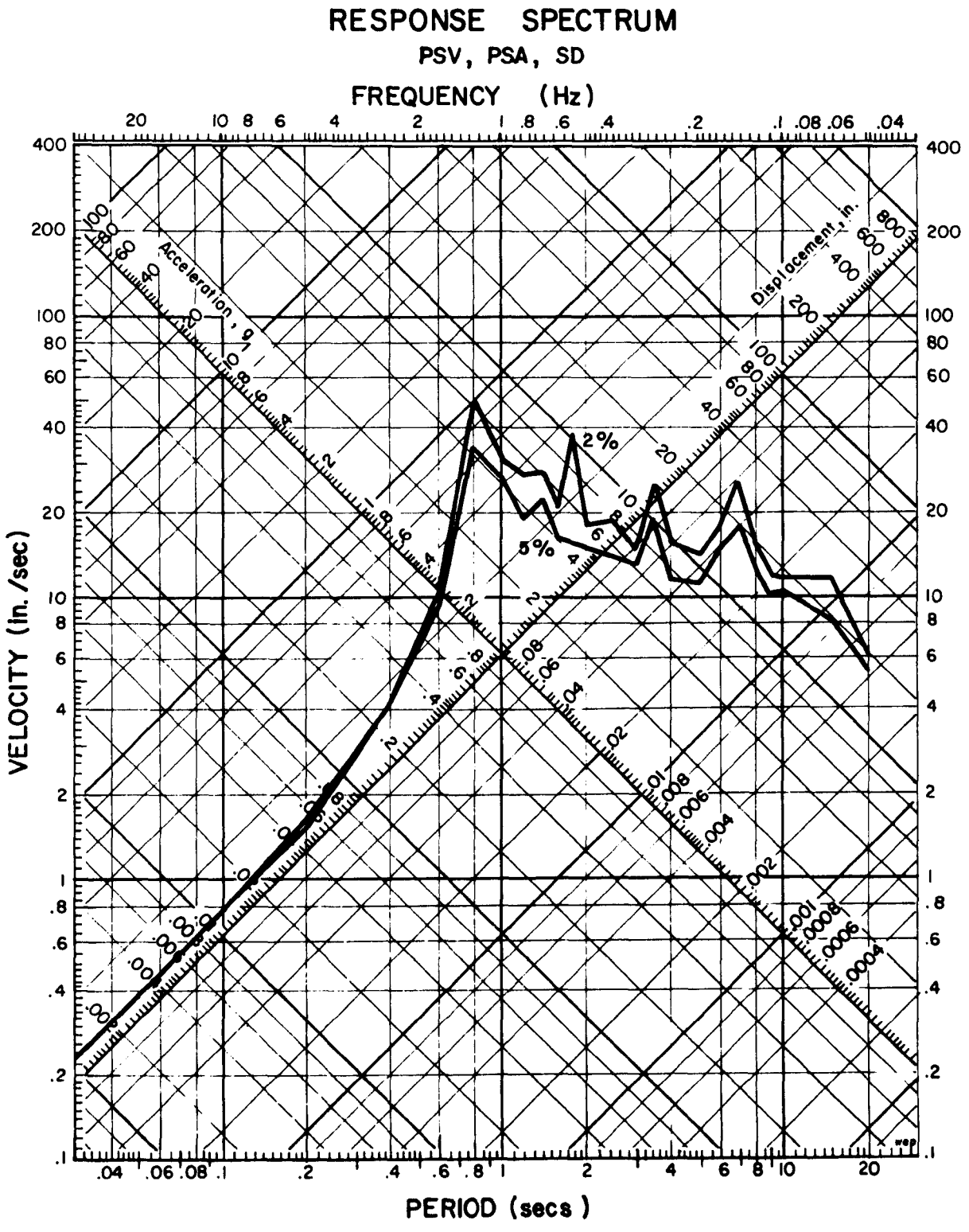


Figure 7c, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
DISTANT EVENT, SHALLOW STIFF SOIL DEPOSIT
MODIFIED RECORD - KERN COUNTY 1952 S69E

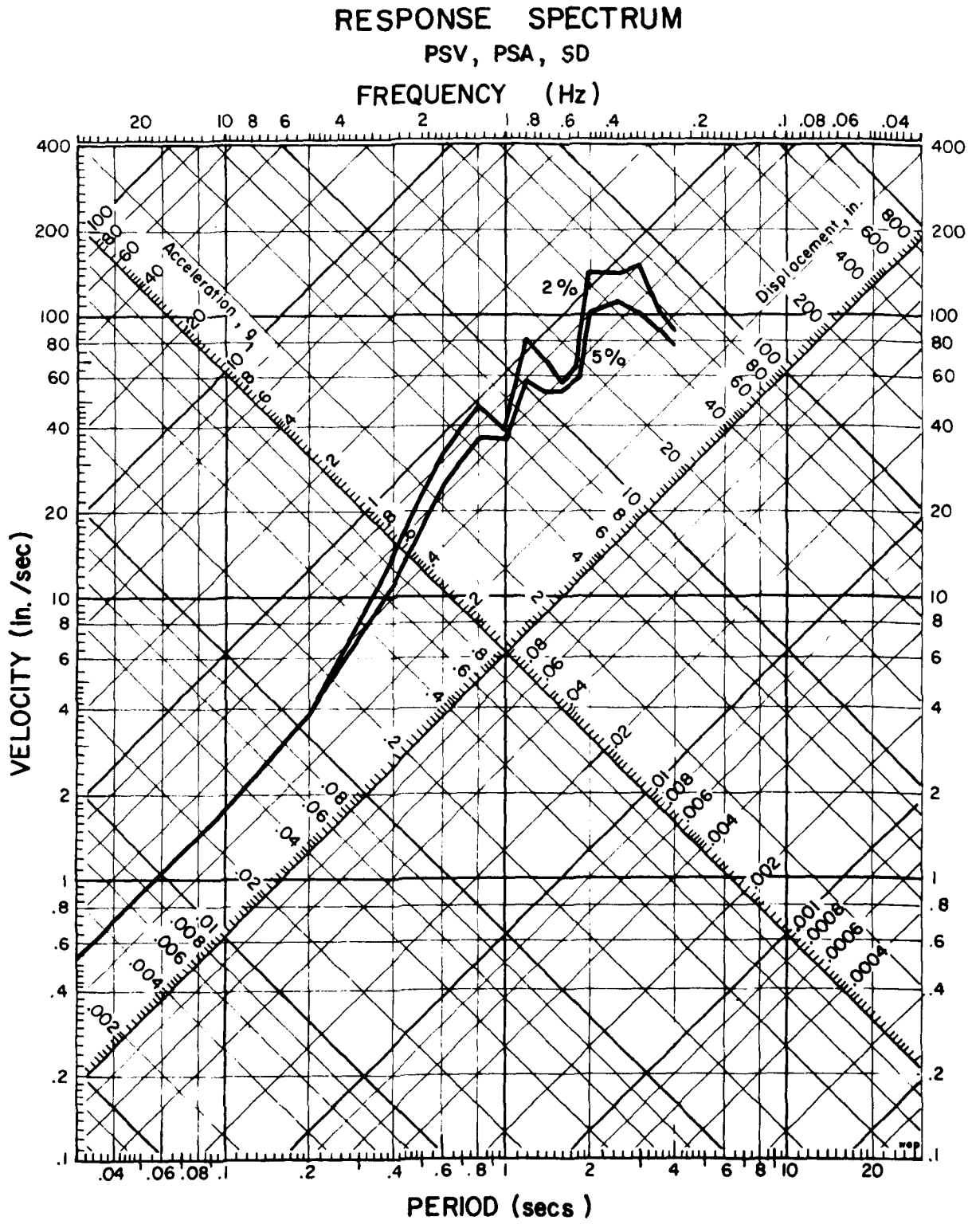


Figure 7d, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
NEAR EVENT, SHALLOW SOFT SOIL DEPOSIT
MODIFIED RECORD - EL CENTRO 1940 S90W

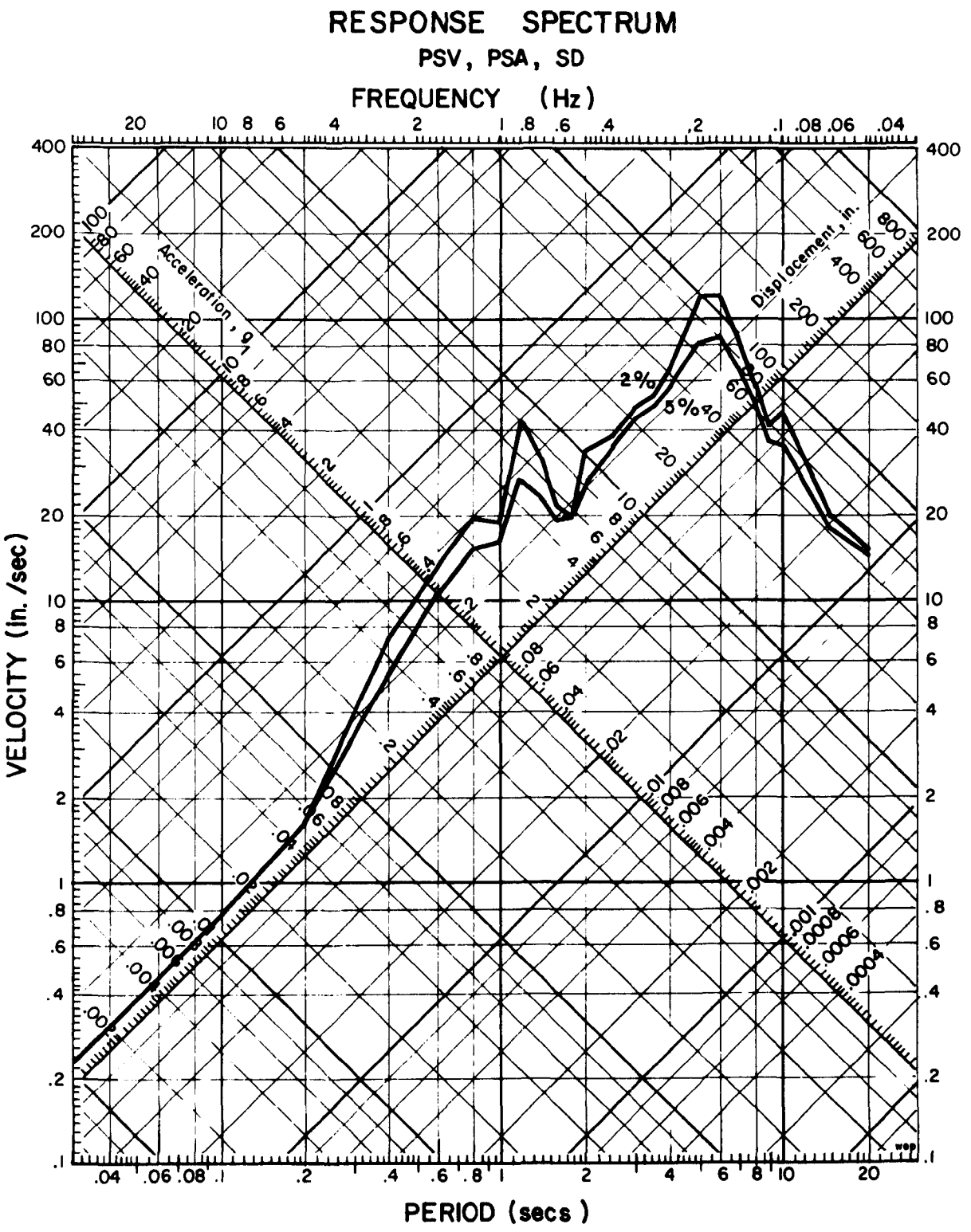


Figure 7e, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
NEAR EVENT, DEEP STIFF SOIL DEPOSIT
MODIFIED RECORD - EL CENTRO 1940 S90W

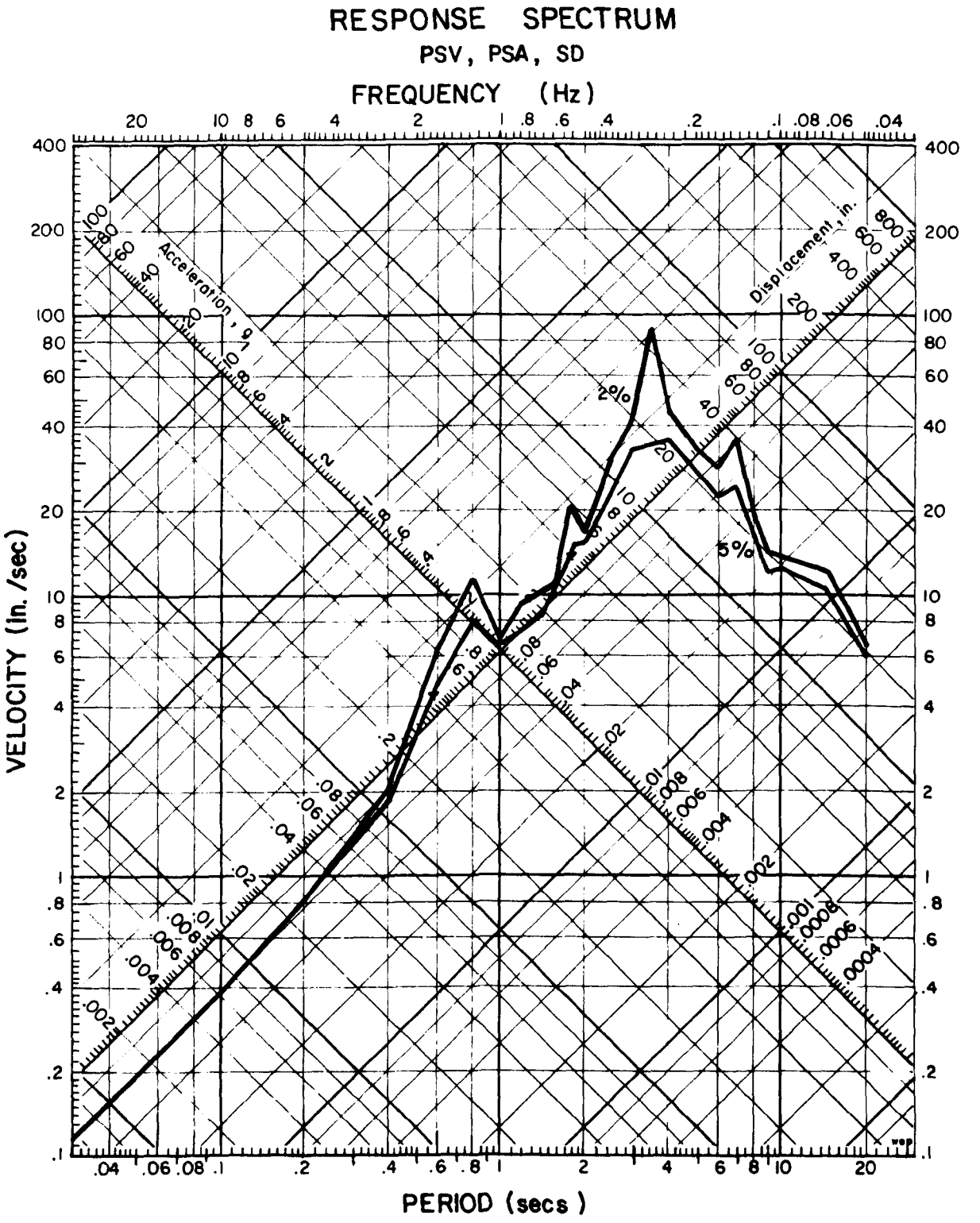


Figure 7f, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
DISTANT EVENT, DEEP STIFF SOIL DEPOSIT
MODIFIED RECORD - KERN COUNTY 1952 S69E

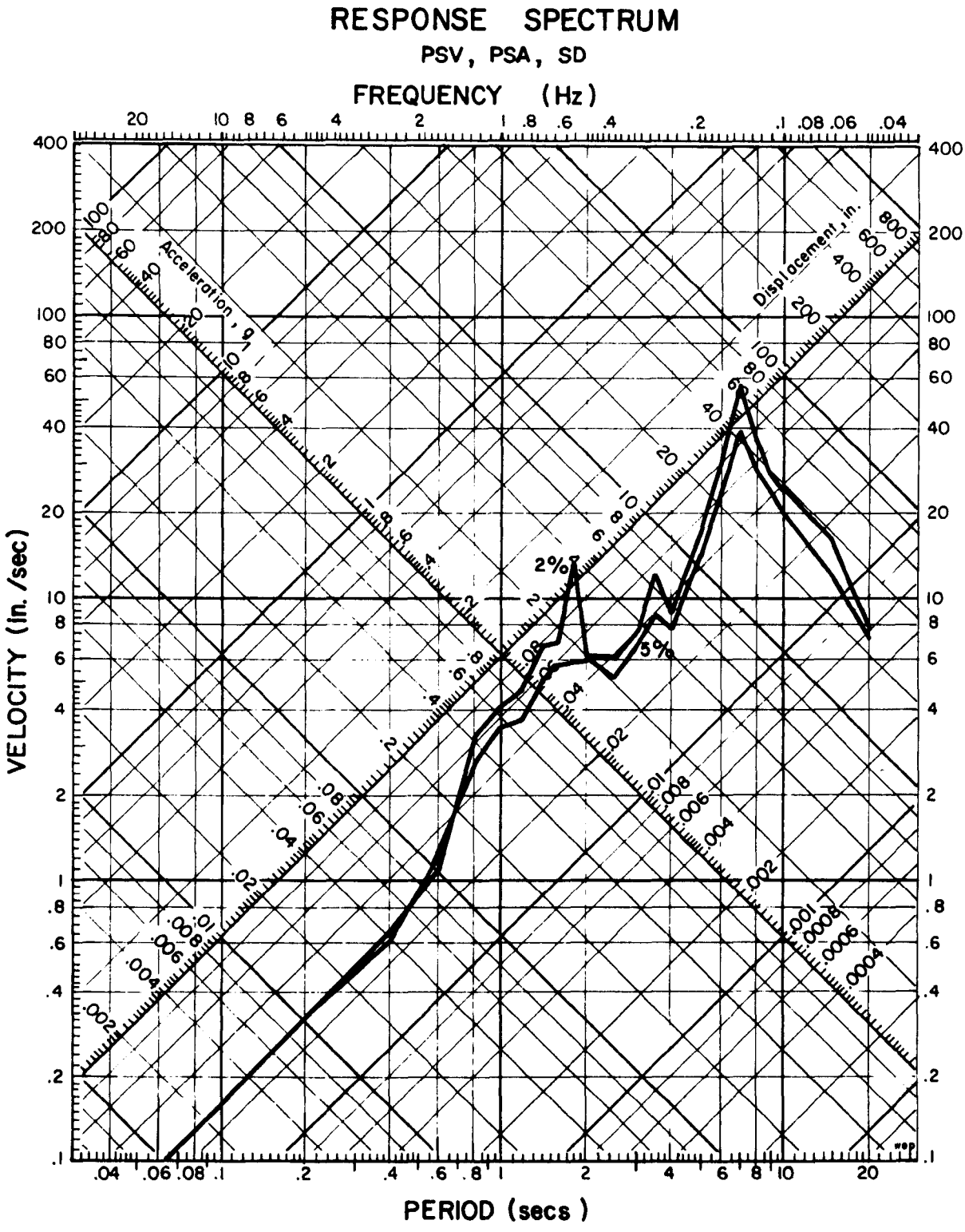


Figure 7g, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
DISTANT EVENT, DEEP SOFT SOIL DEPOSIT
MODIFIED RECORD - KERN COUNTY 1952 S69E

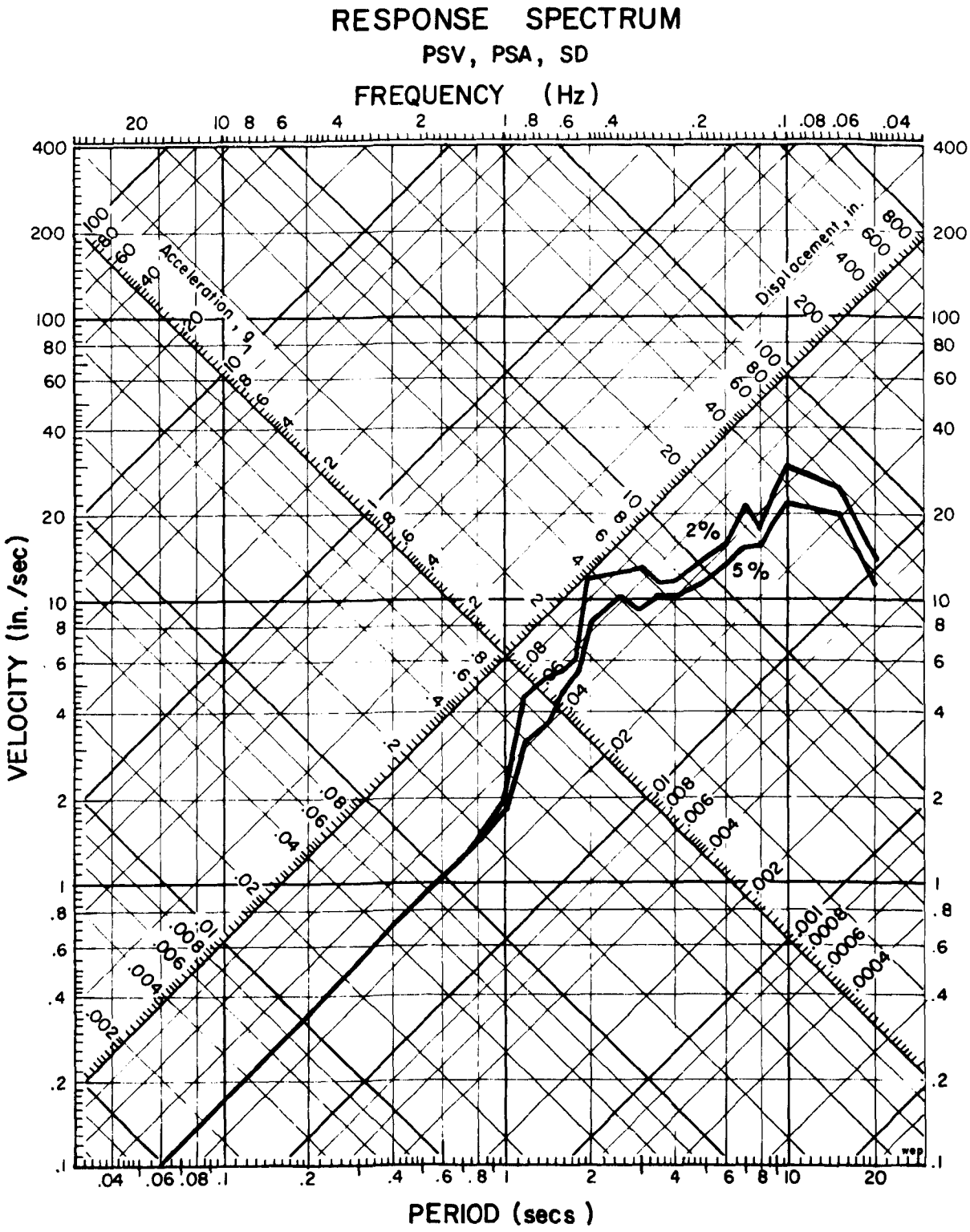


Figure 7h, RESPONSE SPECTRA (Damping = 2% & 5% of Critical)
NEAR EVENT, DEEP SOFT SOIL DEPOSIT
MODIFIED RECORD - EL CENTRO 1940 S90W

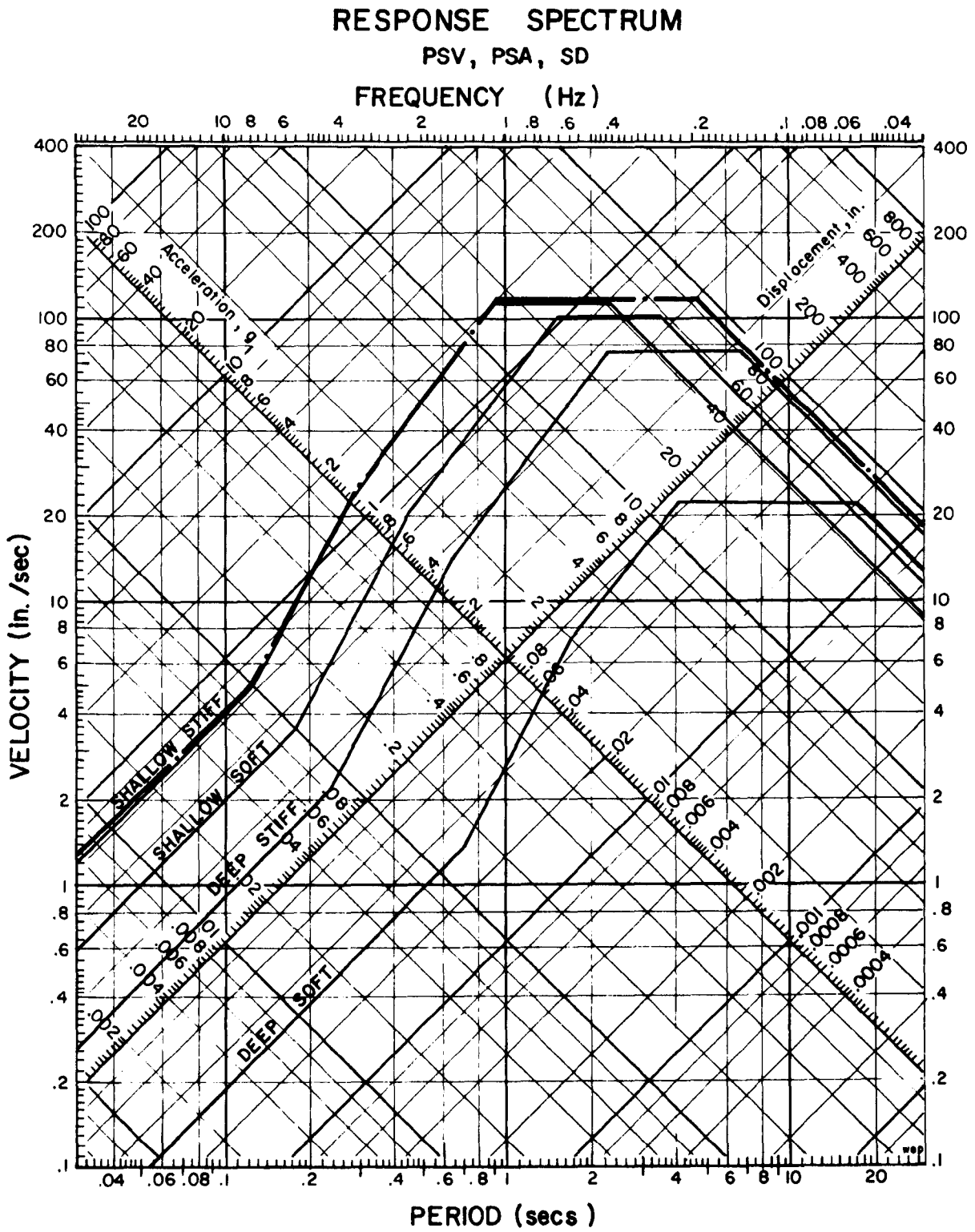


Figure 8, SPECTRAL ENVELOPES
Damping = 5% of Critical

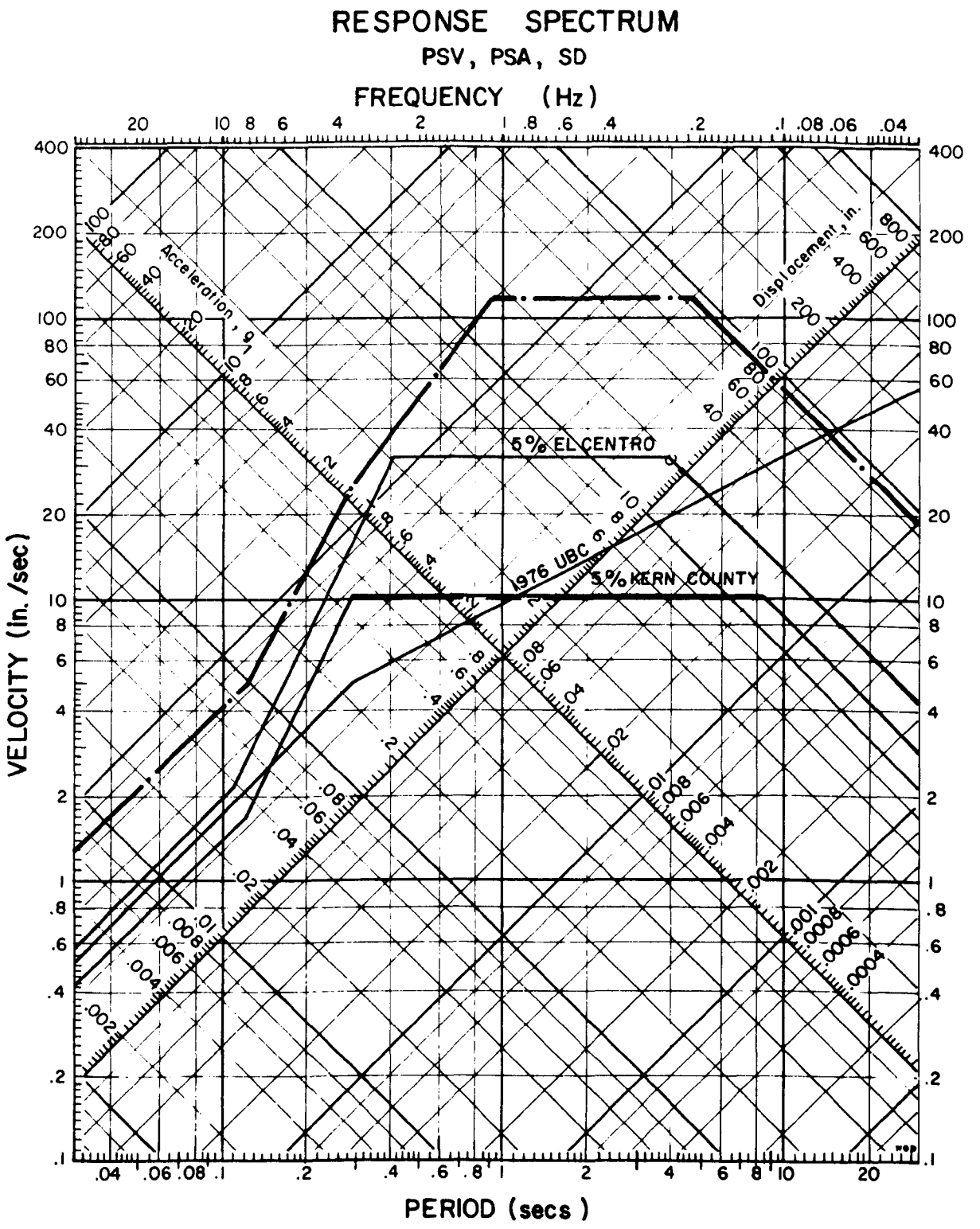


Figure 9, COMPARISON OF SPECTRAL ENVELOPES

of undetermined density. However, reports from the well drilling crew and the field geologist infer the soil in that area of the proposed site is medium dense. The static ground water table was measured at 4 to 18 meters (12 to 60 ft) below the gound surface in that area of the proposed site. If the soil deposit is, in fact, medium dense to dense, no geotechnical hazards related to seismic excitation of the site should exist. That is, liquefaction, or cyclic mobility, is extremely unlikely, as is subsidence due to densification of the soil during ground shaking. If the soil in this area is loose, however, there is a remote chance of a slight amount of seismically induced subsidence due to densification of the loose soil.

The soil encountered during well drilling in the eastern and southern portions (Area A, Figure 3) of the site are finer grain saturated material (sand, silty sand, silt). Here again, the true in situ density of the soil is unknown; however, a few of the Standard Penetration Tests performed during well drilling and the energy required to drive the casing suggest the soil in these areas of the proposed site may be loose. If the formation is as loose as some of the data have indicated, and, if the shallow water table (<5 ft) persists, strong seismic ground shaking may cause liquefaction and ground subsidence within these areas of the site.

It has been theorized that during the 1964 Prince William Sound Earthquake (M=8.4) seismically induced liquefaction resulted in areas of subsidence along Corbin Creek (Glacier) which changed the course of the stream, and permanently flooded a section of the forest. No hard evidence exists to prove this hypothesis; that is, the date the course of the stream was changed is not known, nor is the pre-quake surface elevation of the presently submerged area known. However, aerial photos of the site, and pre-quake (1960) USGS maps do show the creek flowing north of its present course, and the drowned section of forest alive and viable prior to the 1964 earthquake. This combination of facts strongly suggests that subsidence occurred in that area of the site at about the time of the 1964 Great Alaska Earthquake.

In addition to the potentially loose, saturated sand deposit which may be susceptible to liquefaction during strong ground shaking, an area of sensitive "thixotropic" silt was encountered during the well drilling program. Although the phenomenon of thixotropy is usually associated with sensitive clays, the behavior of some of the soil recovered from a depth of about 15 meters (50 ft) in the southwestern

portion of the site was strikingly similar to thixotropic clays. That is, the silt ("rock flour[?]") was extremely sensitive to cyclic loading and lost most of its shear strength during vibratory loading. However, upon cessation of the dynamic load, the silt quickly regained its static shear strength.

It is recommended that before the plant layout has been finalized a detailed subsurface investigation of the site be performed to verify or deny the presence of seismically unstable areas in the site. Should the aforementioned suspicions be verified, the problem areas should either remain undeveloped, and the plant components planned for those areas sited elsewhere on the site, or soil stabilization measures should be undertaken to correct any inadequate condition(s) of the soil. The stabilization method(s) chosen should be predicated on the type of problem found, and what plant components are planned for the affected area(s).

Seismic Effects on Refinery Elements

A specific assessment of the behavior of individual plant components and systems was not within the scope of this study. However, some general behavioral chracteristics of typical refinery structures were examined in light of the "bracketed" ground response performed for proposed site.

The dimensions of the product storage tanks planned for this facility are such that the first mode natural periods of vibration of the fluid/container systems will range from approximately five to ten seconds. That of the tall slender processing towers will be on the order of one to two seconds. And, above ground pipelines may have first mode periods of a few hundredths of a second to several seconds depending on their diameter, free span, and support configurations. The spectral enveloping functions generated for the soil profiles modeled during this study (Figure 8) suggests that spectral displacements should be carefully assessed in the design of storage tanks, containment structures, and long sections of above-ground pipelines, and that spectral accelerations and velocities should be critically assessed for the design of process towers, support buildings, and other short period structures and refinery components.

In general the "mitigating measures" required for structures or elements of structures to insure seismic compliance with a given site simply entails siting structures away from areas of potential ground failure, and designing structural

components to withstand the level of ground shaking considered realistically probable to occur at the site during the life of the structure.

Most structures have a degree of lateral stability inherent in their basic static design. Regular, continuous structures like those found in a petroleum refinery (towers, tanks, pipeline, etc.) have a good deal of inherent seismic stability due to their simple geometry and elasto-plastic material properties. Therefore, adequate design for the interaction of refinery components is apt to be more difficult than design for gross stability of any given element. In this regard an in-depth ground response analysis will be of great value in assessing the probable behavior and interaction of the varied components of the proposed facility. Therefore, a reasonable amount of care employed during design and construction should insure satisfactory behavior of the proposed facility during the probable level of seismic excitation expected at the site during the design life of the proposed facility.

SOILS

Introduction

The purpose of the soils investigation was to identify significant characteristics of the soil system with regard to potential environmental changes which could result from development of the proposed Alpetco facility. In order to achieve an understanding of the soil system's response to the proposed development it is necessary to understand the general area; geology, hydrology and seismicity; the characteristics of the proposed development; and the soil's physical characteristics. Geology, hydrology and seismicity are discussed in detail in separate sections, and are summarized herein as they affect soil characteristics.

Data obtained by NORTEC with a Mobil B-61 drill in 1978 indicated the soil mass generally was composed of fairly large particles, a situation which limits the precision of sampling in the undisturbed state and compromises the results of disturbed sampling such as standard penetration tests. In a formation of this nature samples usually consist of disturbed materials, which provide an understanding of the soil's texture and, indirectly, its physical properties. The subsurface hydrology exploration program was modified to accept occasional standard penetration determinations for sandy soils, and if the occasion developed, thin wall tube samples for soft, fine-grain deposits. Also, the depths and locations of the borings were adjusted to provide both general soils and hydrologic information throughout the site. A general site map, Figure 1, shows the seismic lines, and the drilling pads for the test holes.

Seismic refraction techniques were incorporated into the soils program to improve understanding of the site soils. The seismic refraction program provided an estimate of bedrock depth and of the general layering of the soil systems.

Magnetometer studies were included along the access roads to confirm regional aerial magnetometer studies and as a backup system for the seismic studies. That program was expected to detect gross magnetic anomolies which could influence the water drilling program; however, the data reflected much the same bedrock shape as determined by the seismic refraction data, including an estimate of depth similar to that found in the seismic study at the intersection of seismic lines B and D.

Laboratory testing included identification tests such as: grain size, textural classification, moisture content, Atterberg limits, and consolidation and shear strength data. Salinity tests were included when a massive deep silt layer was encountered.

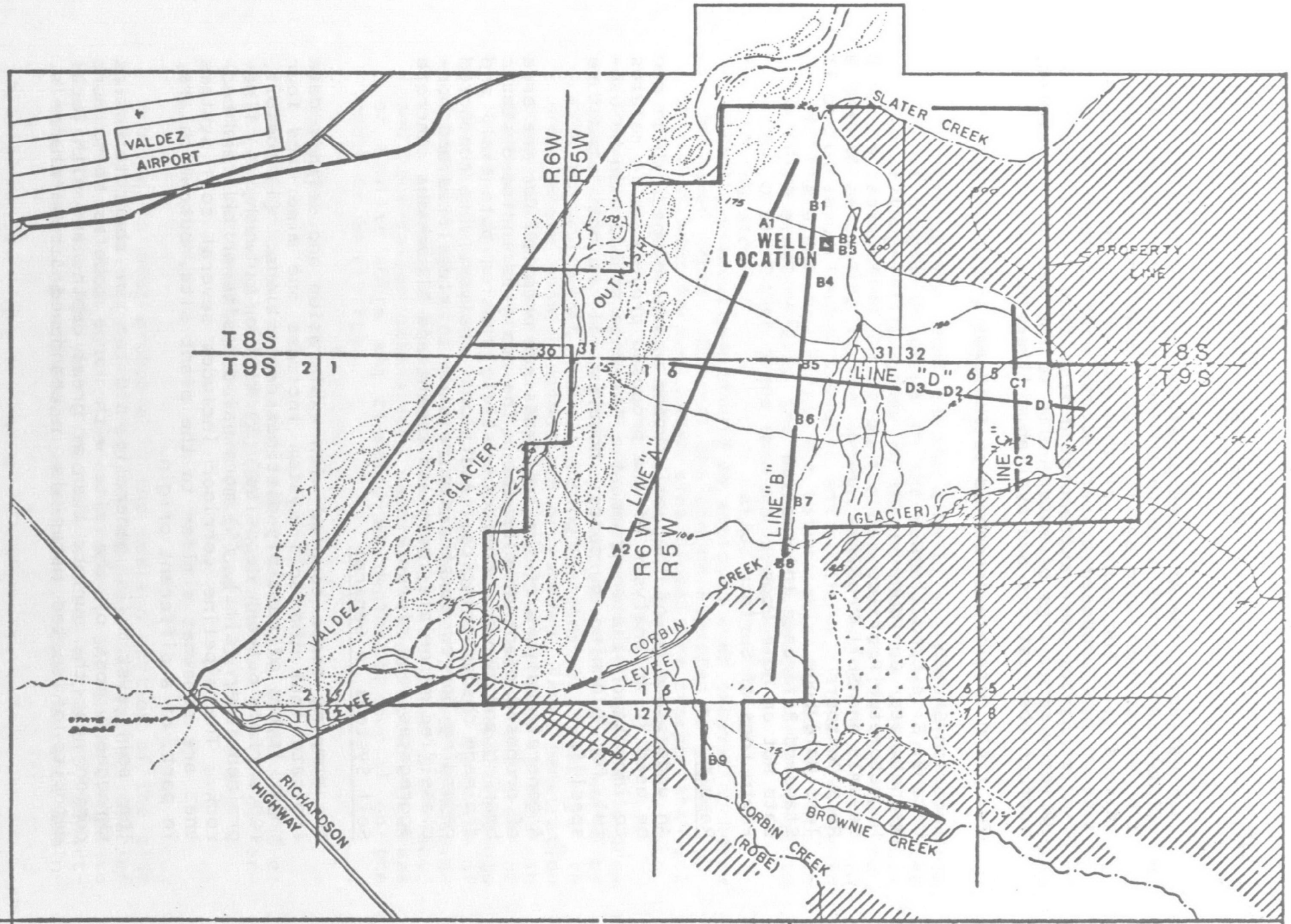


FIGURE 1 LOCATION SKETCH

SOILS

Examination of the proposed pipeline corridor from the southern boundary of the site to the proposed products dock location was accomplished by literature review and surface observations (see Enclosure 1 of this report). The soil properties at the proposed primary access road crossing of Valdez Glacier Stream were extrapolated from data from the proposed refinery site, logs of water wells to the west of the stream, surface observations and available literature.

The field data are presented as follows:

Location Sketch	Figure 1
General Site Conditions	Figure 2
Magnetometer Contours	Figure 3
Magnetometer Profiles	Figures 4 to 8
Seismic and Soil Profiles	Figures 8A and 9
Rock Contours	Figures 10 and 11
Test Hole Logs	Table A
Standard Reference Information	Table B
Data Not on Hole Logs	Table C
Photo Logs of Surface Soils	Table D

Results

An understanding of the soil system was developed, which can be used in an analysis of the proposed project as it relates to impacts on the environment. The data should also be useful for planning purposes; however, it is not "structure specific."

A general analysis of the soil mass was prepared for the area of proposed plant development. The analysis included static bearing and dynamic characteristics, erosion potential, and drainage characteristics. Additional analyses were conducted regarding borrow constraints related to classified and nonclassified materials, portland cement and bituminous concrete aggregates, and riprap.

Soil Systems in General

The pumping tests coupled with exploration and seismic data indicate that the soil system includes one minor and four major layers of possibly distinct depositions: (1) topsoil, (2) surface outwash deposits, (3) till or outwash, (4) fine-grained layer (silt), (5) morainal deposits or till and bedrock. The pipeline corridor includes several soil systems that are somewhat similar to the plant site, but which are, in part, of a different origin.

The soil system is generally similar in characteristics throughout most of the site with large cobbles being more common near the surface than at great depth, and with local deposits of sorted materials in abandoned stream channels.

SOILS

Most of the material appears to be a result of Valdez Glacier action, with local influence of Corbin Glacier along the eastern and southern margins of the site.

There are no bluffs or steep soil slopes subject to failure. There are, however, steep rock slopes along the northern and southern boundaries of the site, and along a portion of the product pipeline corridor.

Groundwater Considerations

The water table depth at the time of exploration ranged from .9m (3 ft) below grade in the south and east, to 18.3m (60 ft) below existing grade in the north. The annual fluctuation is expected to be on the order of 6m (20 ft) with recharge occurring in the spring, summer and early winter. In some areas, toward the east and south, a slight increase in recharge rate may bring the water table to the surface in midsummer. Generally the water table grades from north to south at a flatter grade than the topography.

Standard precautions should be employed when excavating below the water table. Excavations can be expected to slough suddenly without warning, when side slopes are steeper than 1:1 above the water table and 2:1 below the water table.

The water table tends to drop in the winter, thus it is probable that the soils in the seasonal frost zone would be drained and hence stable during periods of freezing. In areas where snow is compacted or removed, frost penetration occasionally may reach 3m (10 ft) and often 1.5m (5 ft). In areas of natural cover, penetration may be on the order of inches. Thus, utilities and pipelines along road crossings should be protected from freezing temperatures by depth of embedment, circulation of the transported fluid, or insulation. Dead-end lines such as static fire lines are risky, and have failed extensively soon after construction in areas of similar soils and climate, at depths of burial on the order of 3m (10 ft).

Hazards

The major potential hazards detected in the plant site are: (A) erosion, (B) flooding, (C) liquefaction, and (D) differential settlement. They are described in detail below.

(A) Erosion

Erosion is most probable in the western portion of the site and mitigation would require control of Valdez Glacier Stream. A dike should be constructed, and proportioned to withstand the 100-year flood envisioned in the U.S. Department of Housing and Urban Development Flood Insurance Admin-

istration (HUD FIA) Valdez Floodplain Study (see Hydrology). Such a dike could be similar to that currently used to contain the stream between the Richardson Highway and Knife Ridge. The core could be composed of unclassified sands and gravels, and should be armored with riprap on the stream side. The armor should extend below present grade to resist erosion at the toe of the levee.

(B) Flooding

The HUD study predicts an average of 1.8m (6 ft) of water could cover the western portions of the site during the maximum possible flood. However, it is projected that high water would last less than 48 hours, thus substantial leakage through the natural foundation soils could be tolerated provided piping of the levee were avoided. Sandy gravel rather than sand would be required along the inboard toe of the dike.

Flooding from Corbin Creek (Glacier) is also a potential problem. The containment dikes proposed around the tankage in that part of the site should restrain the seasonally high water.

(C) Liquefaction

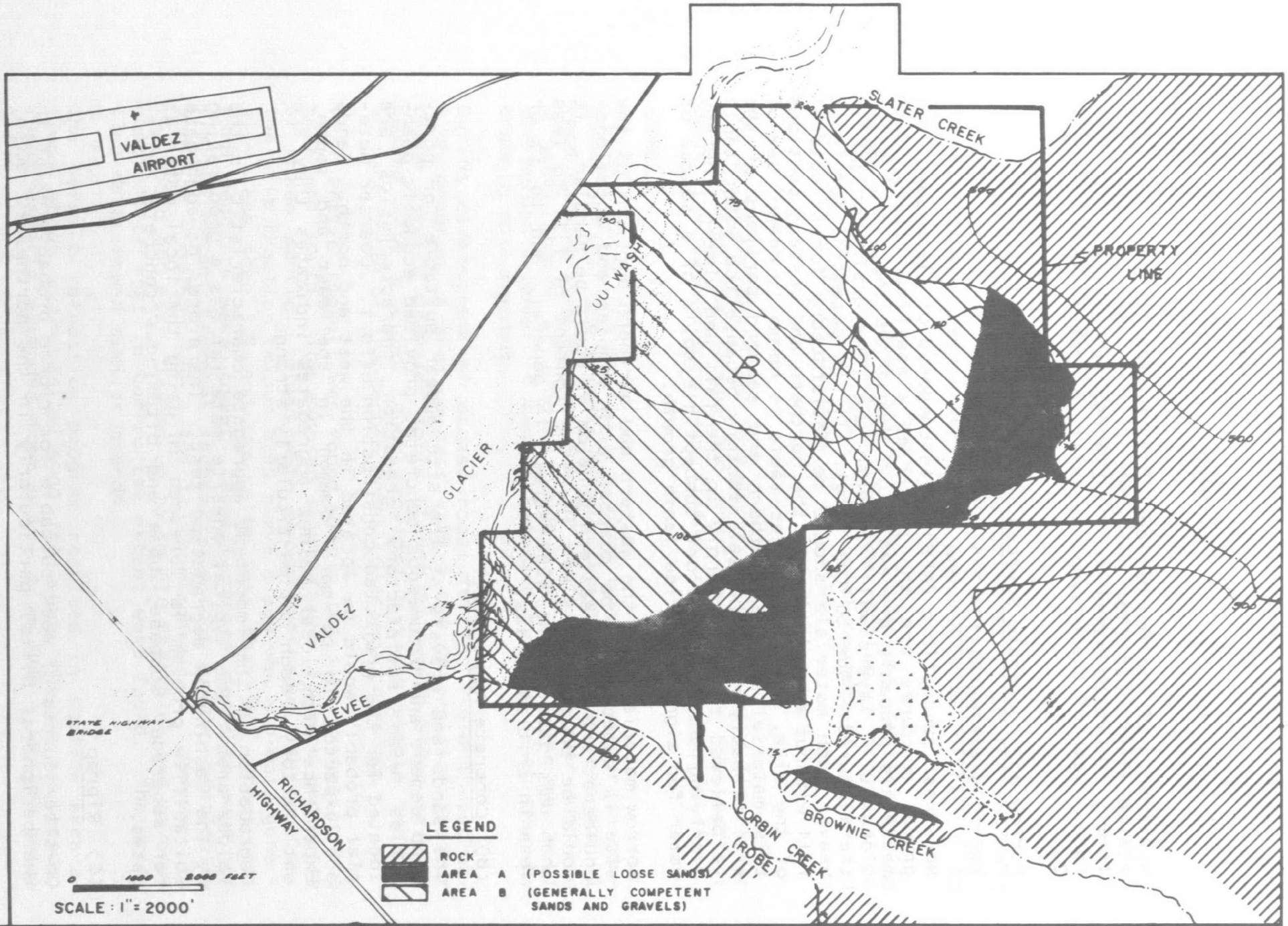
Liquefaction is a potential localized hazard within the proposed site, and may be a hazard along the lowland areas of the proposed products pipeline route. This hazard exists because of the high seismicity of the region, and the loose uniform sands which may exist in the Corbin Creek area and in the southern portions of the site. This hazard is sufficiently probable to require structure-specific exploration to a depth of at least 50 feet in Area A of Figure 2. Development is currently planned to avoid the suspect areas except in the pipeline corridor.

(D) Differential Settlement

Differential settlement may occur due to consolidation of the soil under static loads and liquefaction of loose sands by strong dynamic loads.

Consolidation under the action of static loads should not be a hazard, provided normal design and construction techniques for sub-Arctic climates are followed. Use of moderate bearing values and site-specific exploration to insure that localized soft, fine-grained soils are not within the zone of influence of footings are suggested mitigation measures. The degree of hazard is minimal in the proposed refinery area.

Liquefaction of loose sands can result in the loss of bearing for shallow foundation systems, and can result in large dis-



2 **General Site Conditions** **Figure 2**

placements of the foundations. The hazard is generally associated with loose (low density), fine to medium graded, uniformly saturated sands within 15m (50 ft) of the ground surface. Some of these symptoms exist in Area A shown in Figure 2.

Borrow and Aggregate Sources

(A) Classified Fill

Non-frost susceptible (NFS) soils composed of clean sands and gravel mixtures are the preferred classified fills. Such materials probably are available throughout the site. Occasional silt layers will increase the fine grain content in the mixtures. Due to the relatively low potential for frost heave, such materials should be satisfactory for structural fill without restriction in the northern and western portions of the site, where the water table is normally deep. Use of this material in the southern and eastern portions of the site probably would be satisfactory because the water table is believed to drop sharply in the fall and winter, thereby depriving the mildly frost susceptible soils of a source of water for significant ice lense growth.

Borrow material from the western and northern portions of the site is expected to be coarser with cobbles and occasional boulders, and in the eastern portion it would be sandier. It would be prudent to limit the fine content of fill to less than 10% passing the #200 screen in general, and to 5% or less in critical areas.

(B) Concrete Aggregates

The sands and gravels at the site appear suitable for portland cement and bituminous concrete, provided economic quantities with satisfactory gradation characteristics are located for the projected construction effort. Coarser material probably would be located in the west and north. Sands are expected to be more common in the east and south. Experience with local Valdez aggregates indicates they are satisfactory though not particularly strong.

Degradation is the important aggregate characteristic in the Valdez area. The typical on-site material has a good rating by the Washington degradation test. Therefore, no aggregate suitability problem is foreseen in using the local material for subgrade, subbase, base and bituminous concrete aggregates.

(C) Riprap

On-site sources of rock suitable for riprap probably exist in the peripheral hills, particularly in the northeast. Also,

boulders from borrow sources in the west and north could prove useful for the dike construction. Off-site quarries also exist, such as the commercial source near Valdez Glacier to the northwest of the site.

(D) Impermeable Soil

Small amounts of silt and clay soils exist in the southern part of the site. However, they are in very short supply in an ecologically sensitive area, and would be difficult to handle.

In general, the site soils are satisfactory as engineering materials for inclusion in the construction in a natural or altered state. In addition, commercial sources of borrow and aggregate exist to the west of the site.

Soil Types

The soils are described in a structural sense as a five-layer system with the second and third layers from the surface being the layers most significant to the proposed facility.

Layer 1

Surface Layer (Layer 1) is a thin layer of overburden composed of soil and organic growth extending from less than 1 inch to more than several feet in depth. This layer supports a heavy growth of plants, brush, and trees. The depth of overburden removal is controlled more by root depth than by organic soil content.

During development of access roads for the field investigation program, a shallow pass with a D-8 Caterpillar tractor blade exposed granular soils (Layer 2), which after several passes with a light truck provided a tight stable traffic surface north of the Corbin Creek (Glacier) crossing.

Very little topsoil was found within the site except in the east and south. The exposed soils (Layer 2) were generally of mixed particle sizes with pockets of sand and cobbles. The silt fraction (minus #200 sieve size) was minimal, generally less than 10% and typically less than 5%. Occasional sand deposits were found. Usually these deposits were of limited extent (several inches to a foot or two vertically and 6.1 - 30.5m [20 - 100 ft] horizontally). However, in the south and east, layers up to 3m (10 ft) thick and several hundreds of feet in horizontal extent were found. The drilling data showed similar trends.

The seismic refraction program resulted in shallow excavations about every 15.2m (500 ft) along the access roads. These usually extended from 0.5 - 1.2m (18 - 48 in) below grade.

SOILS

The soils exposed along the roads were photographed uniformly and are shown in the photo logs (Table D). These photos also provide occasional information regarding organic cover.

Layer 2

Layer 2 (as well as much of Layer 3) consists primarily of a material of mixed grain sizes with high permeability rated by the Unified Classification System as GW, GP and GM, occasionally SW, SM and SP. The coefficient of permeability (k) is estimated to be on the order of 10^{-1} to 10^{1} cm/sec. The structural differences between Layers 2 and 3 are generally slight, related to foundation design and seasonal frost heave susceptibilities.

Occasional pockets of sand, cobbles, and silt were observed in these layers. Several thin layers of silt with organic debris were identified at depths greater than 60m (200 ft). The silt layers are 8 - 30cm (3 - 12 in) thick, and are rated as stiff to hard (dense). Their importance is in providing evidence as to how the formation occurred.

The soil's strength is derived from the angle of internal friction and its confining pressure. The angle of internal friction is a function of particle angularity grain size distribution, packing, and hardness. The angle of internal friction was not measured directly, but is estimated to be on the order of 40° based on drilling effort and standard penetration tests (SPT). Compaction of fill is expected to be achieved easily with normal vibratory compaction techniques. The soil should be nearly insensitive to excess water. Nearly all of the Layer 2 soil could be incorporated into structural embankment and aggregate production if required. Limitations are related to maximum particle size.

Layer 3

Layer 3 differs from Layer 2 in that it is below the water table.

The soil mass is rated as medium dense with occasional loose deposits of sand being suspected in the east and south (see Figure 2). The parent material is the graywacke rock common to the local mountains, resulting in angular and subangular particles. Compaction characteristics are good with a fair amount of breakage under moderate compaction loads. This behavior should aid compaction. Degradation testing indicated that after initial compaction, the rate of wear drops off. Dust production from untreated roads in dry weather is moderate with these materials.

Area (A) shown on Figure 2 to the east and southeast may contain loose layers of medium and fine uniform sands, which may

be susceptible to liquefaction. Liquefaction is the descriptive term applied to the state of stress within a soil/water system when the pore water pressure equals or exceeds the intergranular stress. At that point the shearing strength of the soil fabric approaches that of water, essentially zero. This condition is sometimes achieved in nature when a non-cohesive soil is in a saturated, loose (low density) state and is stressed by a dynamic load. In that state, the soil will attempt to densify, and the accompanying volume decrease will cause stress transfer to the pore water. Unless the pore water can escape rapidly the result is a loss in the soil system's ability to accept a load. Thus, conventional bearing and settlement relationships are inappropriate when considering liquefaction.

Zones of potential liquefaction within the proposed site are not clearly defined and in fact may not exist, since the characteristics which indicate liquefaction potential are similar to the characteristics which result from operation of a rotary drill in medium to fine uniform sands which lie below the water table. However, low resolution downhole seismic shear data and observation of shot craters used in the seismic refraction study also indicate that liquefiable deposits may exist near Corbin Creek (Glacier).

In areas subject to liquefaction, shallow spread footing foundation performance during strong seismic loading would be independent of the static bearing value, and could lead to substantial and destructive differential settlement. In these areas deep soil densification is a mitigation measure, and can be accomplished with driven displacement piling or by vibroflotation. Both systems are expensive and justified only if the liquefaction potential is confirmed at the specific structure location.

Deep foundations, driven piling or cast-in-place piling carried below the liquefiable depth could mitigate this hazard.

Layer 4

At a depth of about 70m (230 ft) a thick layer of dense silt was encountered in test hole B-3. The silt layer appears to underlie the entire site. This layer is important to subsurface hydrology, since it appears to separate the subsurface water system into upper and lower water zones as determined by test pumping (see Hydrology report).

The material's physical properties are those of a fine-grained slightly plastic noncohesive soil and are controlled by the angle of internal friction, confinement, density on the order of 103 pcf, and degree of saturation.

Layer 5

The soils below the silt layer appear to be similar to those above (Layers 2 and 3). No specific problems related to settlement or bearing are expected in the deep soils. Examination of the test hole logs indicate a possibility that a portion of the soils may be remnants of moraines. This trend is strongest in the C-line test holes and is compatible with seismic refraction trends in that area. However, whether Layer 5 is a till or outwash is immaterial with regard to foundation considerations, as the layer appears to be structurally adequate.

The test hole logs are shown in Table A, profiles in Figures 8 and 9.

Bedrock

Bedrock is exposed on the site, and bounds the area intended for development on the north, east and south. The bedrock dips below grade to as much as 213m (700 ft), and possibly to much greater depths in the valley of Valdez Glacier Stream to the west of the site. In the area of test hole B-3, which was drilled to a depth of 150m (500 ft), the estimated depth to bedrock is 158m (520 ft). Bedrock was reached in three test holes along the perimeter of the work area, and was in good agreement with the seismic refraction data. Seismic reflection tests has poor resolution and produced no checks of the refraction data. This situation is theorized to be due largely to attenuation of the seismic impulse in the gravelly soils above the bedrock, and defraction along the joints and sets of the bedrock. The bedrock profile is shown on Figures 8 and 9.

Ground Stretching

Ground stretching in the Valdez Glacier Stream and Lowe River valleys was associated with the massive marine slides in Port Valdez caused by the catastrophic 1964 seismic event. The data compiled in the detailed studies related to that event stop short of the proposed refinery site and pipeline corridor areas. Prior to "leaf-out" of the vegetation in 1979, the site was examined for remnant cracks similar to those identified in 1964 aerial photographs of the areas south and west of the project area. None were identified.

The ground stretching as defined by the crack patterns in the 1964 photography was along the axis of the Valdez Glacier Valley toward Port Valdez. The project site is in a side valley more-or-less normal to axis of the Valdez Glacier Valley. The bedrock shape of the site as envisioned from the seismic refraction studies slopes toward and is transverse to the Valdez Glacier Valley.

It is theorized that the stretching was a result of movement of the soil deposits from the Valdez Glacier and Lowe River valleys into Port Valdez. This movement would result in a shearing force rather than loss of restraint across the terminus of the side valleys. Thus, if ground stretching occurred in Valdez Glacier Valley west of the site, much less stretching would have occurred in the site area, since the north-south shearing force across the face of the valley requires very small changes in volume to be accommodated. Thus, in the critical westerly direction, the valley is confined by soils, while the north, east and south sides are confined by rock.

The Lowe River floodplain to the west of the proposed pipeline corridor shows evidence of ground stretching (1964 aerial photographs). The proposed pipeline corridor is about twice as far upstream as the area photographed in 1964. It is possible that the hazard of land stretching is mitigated by distance or soil types at the proposed corridor. The proposed road crossing of Valdez Glacier Stream similarly is well upstream of the areas identified in 1964.

Ground stretching appears to be a potential hazard only to the pipeline corridor. The ability to resist ground stretching is generally beyond an economic soil stabilization program. Therefore, if that hazard is confirmed, the possible mitigation measures would be similar to those used in pipeline construction to accommodate thermal expansion and contraction. Many mechanical methods allow for displacement of pipes; therefore the hazard, while a possibility, appears controllable in a technical and economic context for the pipelines.

Remnant Permafrost

Remnant permafrost was a possibility due to the recent glacial activity in the general vicinity. However, the soil's permeability and obvious groundwater movement would tend to warm the soil mass, and melt buried ice rapidly (in a geologic time frame). Velocity anomolies in the seismic study were conspicuously absent and, hence, tend to support this hypothesis. The magnetometer data are not as sharply defined as the refraction data, and do not support by aerial or ground survey a dipole anomoly, which would be possible for an isolated ice formation. No indicaton of frozen ground was encountered during drilling. During test pumping, the temperature of deep groundwater was 41.5°F. Therefore, there is little likelihood that frozen materials exist within the site except on a seasonal basis.

Drainage

Coarse outwash deposits are vulnerable to stream erosion due

to their general lack of cementing materials (clays, plastic silts and natural cements). Thus, stream erosion can be relatively rapid. The depth of scour generally is shallow in this area due to the flat stream gradient and more-or-less flat topography which encourage the stream to achieve a shallow path of least resistance during rapid fluctuation in flow rates. These flow rates often change as much as 50% in 24 hours.

The site surface gradient typically is 1.5%, which is suitable for general surface drainage. Observations of developed areas in Valdez indicate that walks, roads and similar traffic areas should be slightly raised over the surrounding land if they are constructed of earth to avoid temporary local standing water during periods of thawing or of protracted rain.

Permeability

A soil-related constraint, which is pertinent to the hazard of toxic liquid spills, is the high soil permeability. The coefficient of permeability is on the order of 10^{-1} to 10^{1} cm/sec. During the study period, snowmelt and rain generally were accepted by the soil with little or no surface runoff, except in areas with silty overburden in the eastern and southern portions of the site. Horizontal permeability is probably two to five times as great as vertical permeability due to the nature of deposition, i.e., impermeable, thin horizontal layers along outwash channels.

Mild traffic compaction along the temporary access roads reduced the permeability to possibly 10^{-2} cm/sec., indicating that the blending of relatively small volumes of fines, and the redistribution of the soil particles, result in a less permeable soil structure than the partially sorted natural deposition. Where necessary, the porosity of the soil could be modified, or the soil could be protected by layers of impermeable material.

Field Drilling and Sampling Procedures

The SS15 advanced 15.2cm (6 in) test holes by rotary drilling with airlift of the cuttings. Casing was placed with a vibratory casing hammer. A 20.3cm (8 in)-diameter casing was used to a depth of 9m (30 ft) to allow cementing of the 15.2cm (6 in)-diameter casing to avoid contamination of the water table by surface seepage along the casing.

Soil samples generally were taken at periodic intervals of 1.5m (5 ft) during rotary drilling of the 6 inch diameter holes. The test hole logs are based on the examination of cuttings from the airlift discharge, changes in drill action, and on standard penetration tests (SPT) or thin wall tube samples.

SOILS

The 12-inch production well was drilled with a cable tool drill. Samples were taken from the bailed cuttings. These samples were more precise relative to depth and layering than those obtained from the rotary drill. The soil samples were logged in the field by a geologist. The test hole logs are shown in Table A.

The soils were observed at approximately 1.5m (5 ft) intervals as transported to the surface by the drill's airlift. The examination included: textural classification, particle shape, qualitative degree of saturation, and organic debris. The maximum particle size was estimated by discussion with the driller.

Occasionally, particularly when a loose soil was suspected, the soils were sampled with a standard 5.08cm (2-inch) split spoon. The sample was advanced by a 63.5kg (140 lb.) weight, free-falling 76cm (30 in). The number of blows for each 15.2cm (6 in) increment of advancement is recorded on the hole logs, Table A. In general, the spoon was advanced .6m to 1.2m (2 to 4 ft) beyond the drill bit to insure that blow counts described soils undisturbed by the rotary air drill. It is possible that low blow counts in test hole C-1 indicate a loose soil, or a greater-than-expected disturbed zone. The split spoon was used sparingly due to the large particle sizes expected and the drilling technique. Therefore, this data should be used only with caution for computation of the "standard penetration" (blows to advance the spoon 30cm or 12 in). Thin wall tube samples were taken in the fine grained soils. The sampler is .75m (2.5 ft) long, and has a 7.06cm (2 7/8 inch) inner diameter and a 7.62cm (3.0 inch) outer diameter. The sampler was advanced by driving, due to the nature of the drill steel used and compatibility with the drill's downfeed. The samples were examined in the laboratory for moisture content, vane shear and penetration resistance, and layering, as well as the examination described for the split spoon samples. This data are shown in Table C.

Magnetometer Survey

The magnetometer traverse was made with a Geometric G816 proton magnetometer, which measures total field to 1 gamma. Due to the time of year (summer) with long daylight hours and, hence, strong daily diurnal shifts of up to 50 gammas, and susceptibility to magnetic storms and aural distrubances, the unit was used initially in the back pack mode, a mode which gives a 5 to 10 gamma resolution. The magnetometer data complemented the seismic refraction data and provided a similar estimate of bedrock depth.

In August 1979, a follow-up magnetometer survey was made. The unit was used in the precise mode, and measured the total magnetic field 2.4m (8 ft) above the ground surface to a

resolution of 2 gammas. The data were time-controlled and referenced to a geographic datum. The data were adjusted to the total magnetic field at the Valdez Police Department pistol range southwest of the site. The value used was 56,300 gammas as measured at 3 p.m. on August 21, 1979. That traverse is shown as magnetic contours on Figure 3.

The contours reflect in general the shape of the bedrock in the north, east and south, and possibly the west. The well casings strongly affect the field for several hundred feet. Those areas are adjusted (dashed lines on Figure 3) by the earlier traverse, made prior to the drilling. Profiles of the total magnetic fields along the access roads are shown on Figures 4 to 7. The profiles are smoothed by the running average of five measurements, and are plotted for nominal 30m (100 ft) stations, every third or fourth data point. The survey was made by pacing, thus points between geographic references such as intersections and drill pads are approximate. In general, the work was along the road centerlines with the exception of line D, where a portion of the work was along the roadside berm to avoid standing water in Slater Creek channels.

It is theorized that the magnetic data reflect a homogeneous soil overlying a homogeneous bedrock, with the soil having significantly different magnetic properties than the rock. The magnetic survey data were compatible with and supportive of the seismic refraction, geologic review and drilling data.

Pipeline Corridor

The proposed products pipeline corridor beyond the proposed project site was examined through literature search and by a walk-over inspection in July 1979. The corridor, for the most part, follows the Alyeska pipeline route and should be no more vulnerable to soils-related hazards than is the Alyeska pipeline. The limited soils data along this route indicate the soil mass to be similar, in part, to Layers 2 and 3 with the exception of test hole B-9, which encounters soils which are thought to be old channel deposits of fine grained material. As the corridor approaches the Richardson Highway, it is thought that the upper portions of the soil deposit may be from Valdez Glacier Stream, and from the Richardson Highway south to the foothills, to be deposits from the Lowe River. Ground stretching was identified between the proposed pipeline corridor and Port Valdez in 1964 aerial photos.

Valdez Glacier Stream Main Access Route

The proposed road crossing of Valdez Glacier Stream is near several man-made excavations and natural stream cuts. These exposures follow the trends described for the Layers 2 and 3

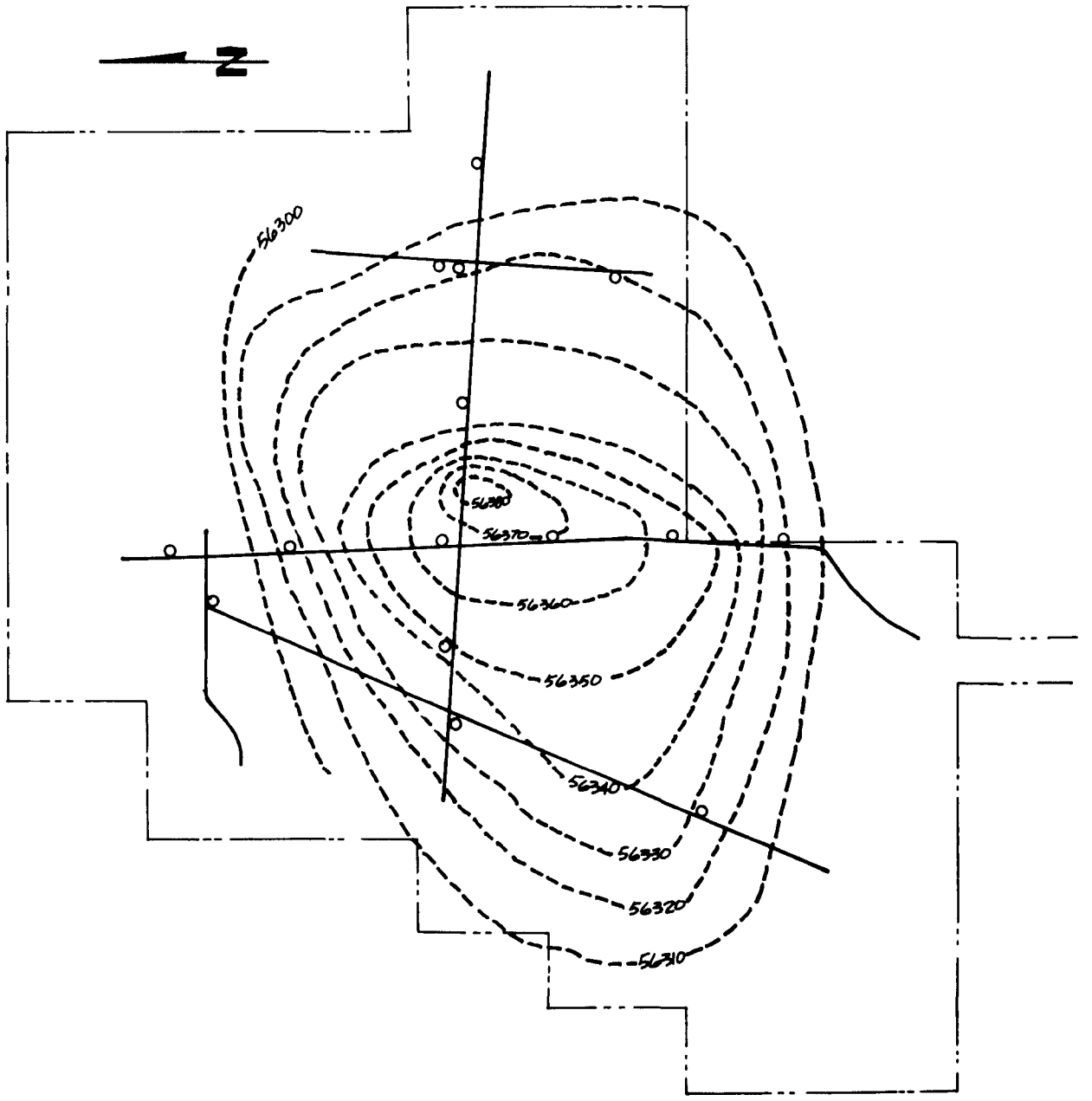
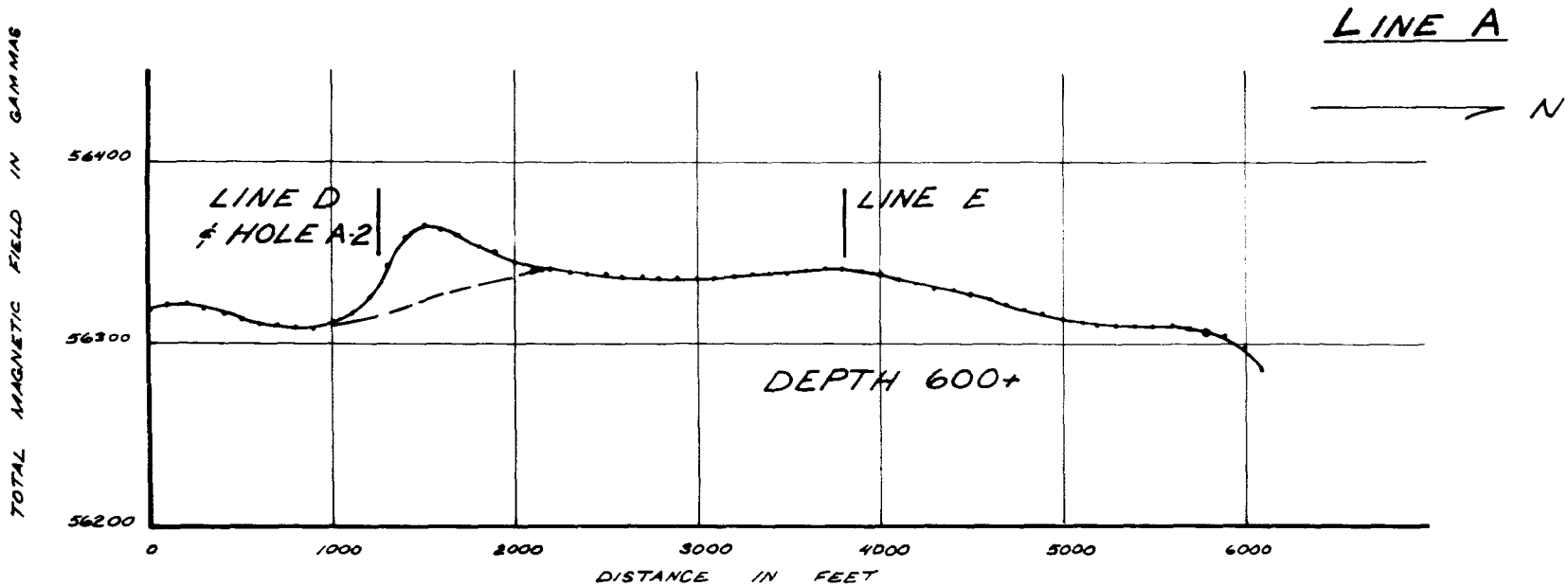
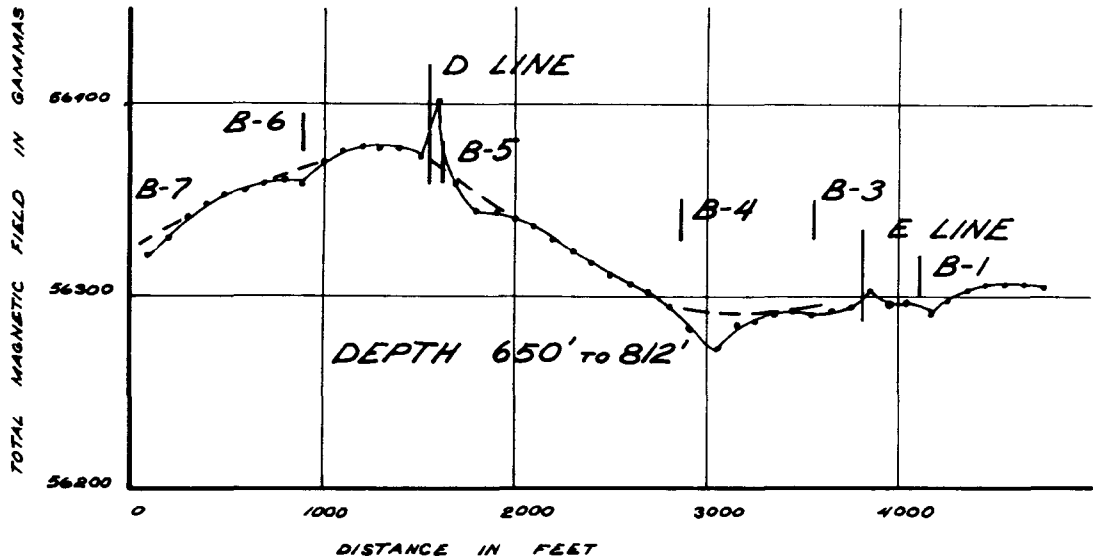


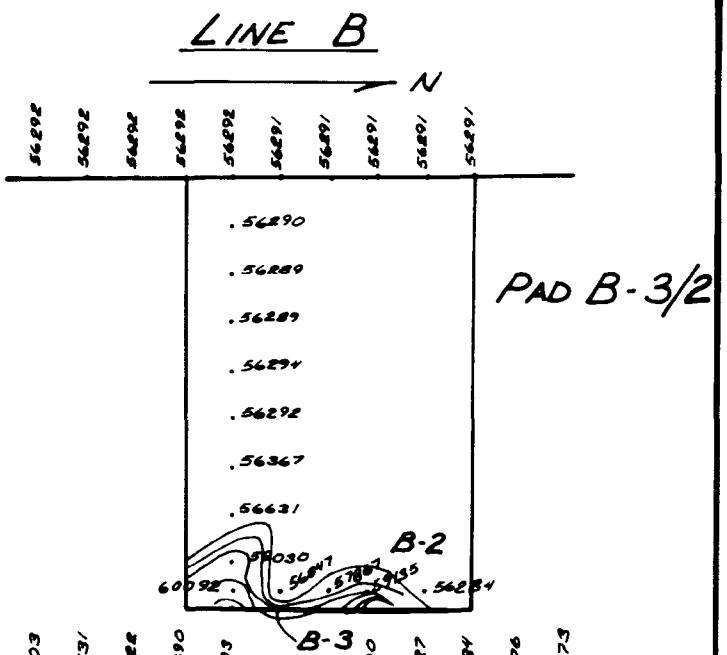
Figure 3
TOTAL MAGNETIC FIELD IN GAMMAS
21 AUGUST 1979
CORRECTED FOR DIURNAL DRIFT AND SMOOTHED FOR CASING EFFECTS
CONTOURS IN GAMMAS

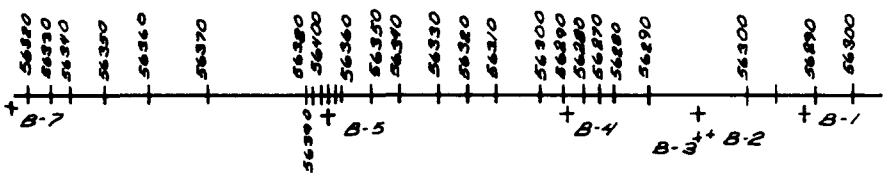


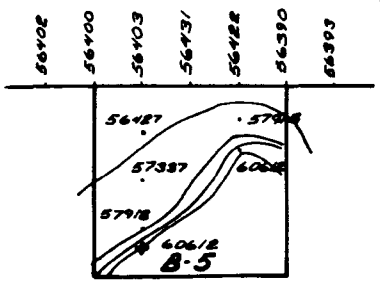
LINE A PLAN

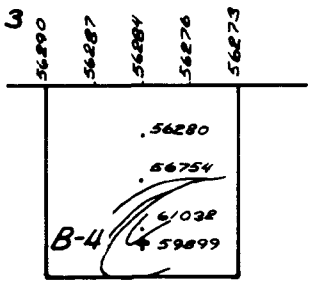
Figure 4	Magnetic Field Survey	Notes: see fig. 5

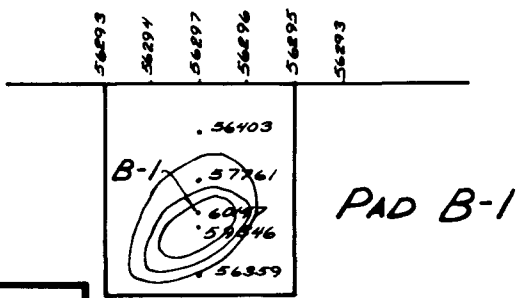






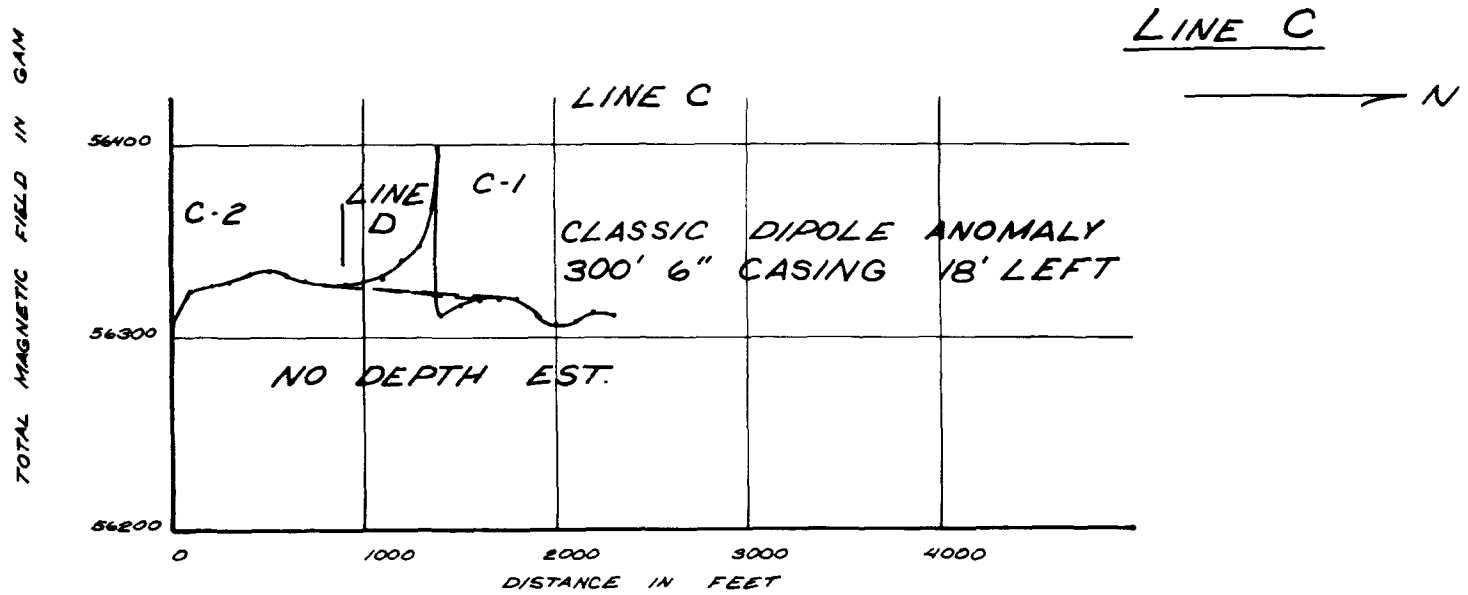






NOTES:
1. PROFILE EVERY 4TH POINT
2. FIVE POINT RUNNING AVERAGE
3. LOCATION BY PACE DATA @ 10 PACES ~ 25' INTERVAL
4. DATA CORRECTED TO DATUM 21 AUG 79

Figure 5 Magnetic Field Survey



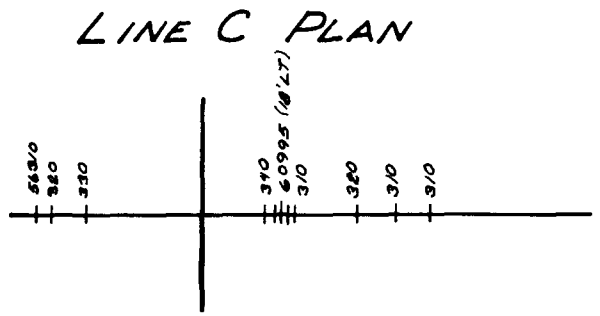


Figure 6	Magnetic Field Survey	Note: see fig. 5

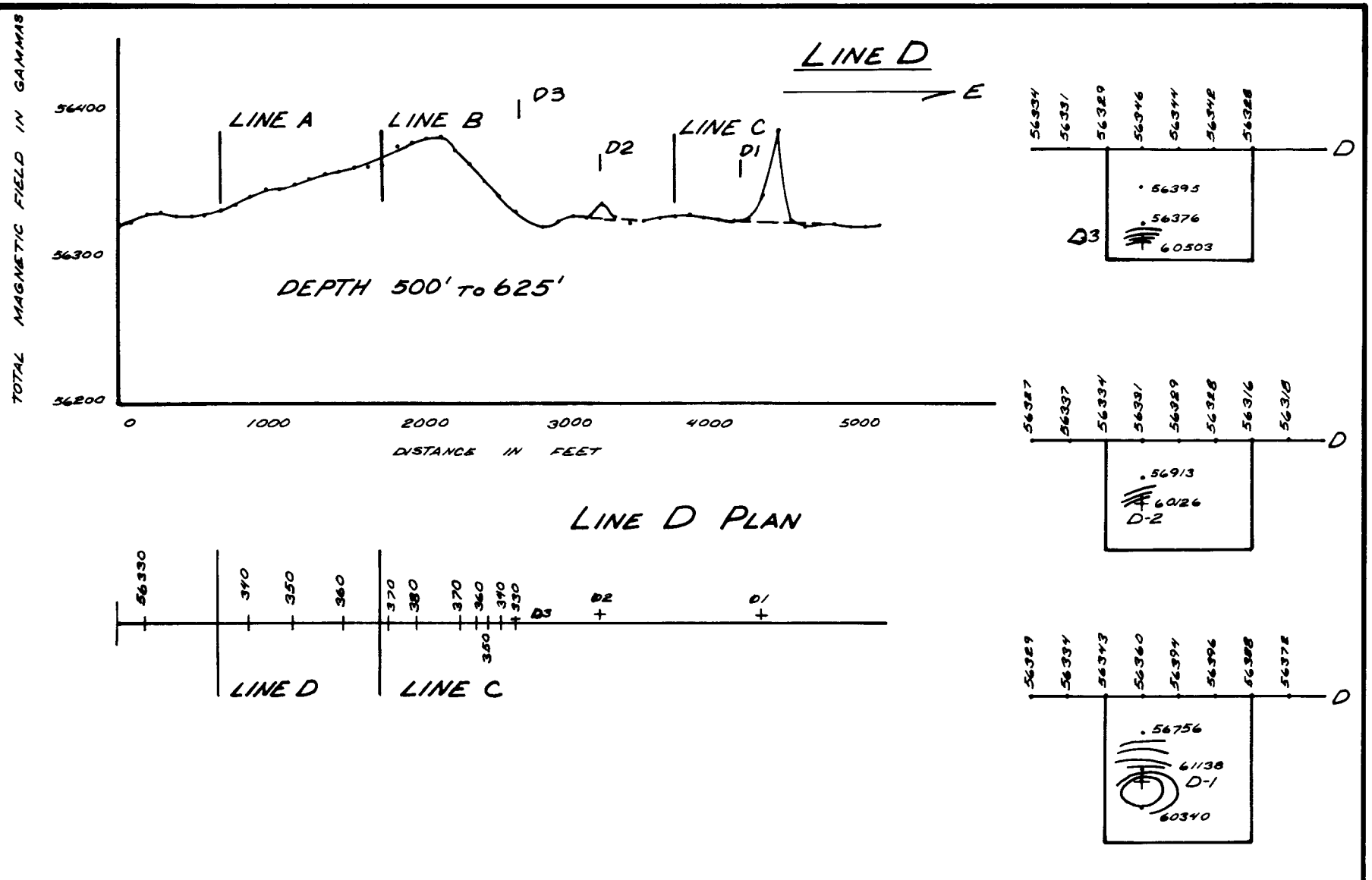
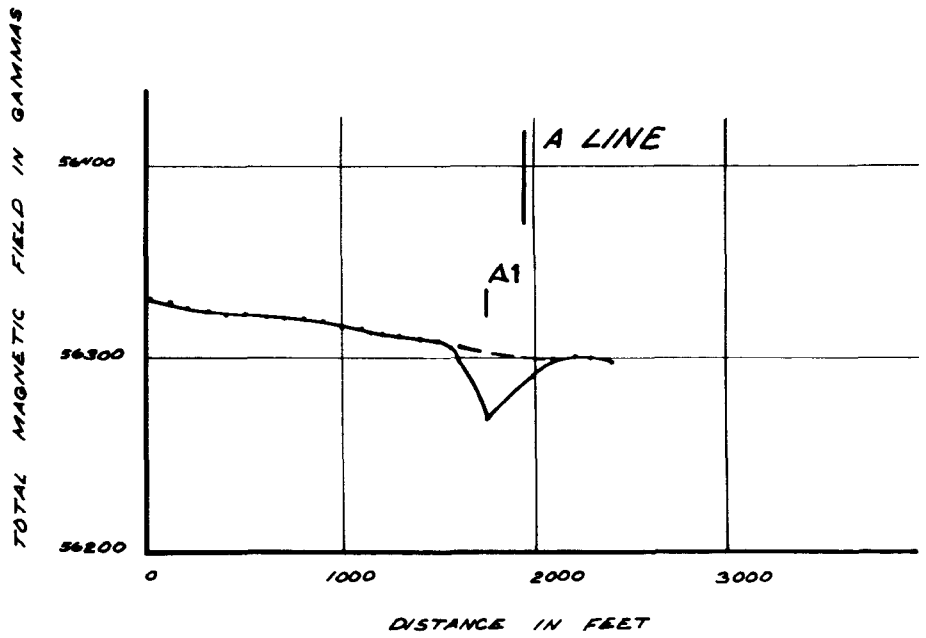


Figure 7	Magnetic Field Survey	Note: see fig. 5



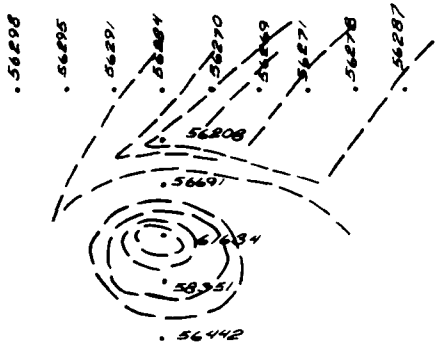


Figure 8	Magnetic Field Survey	Note: see fig. 5

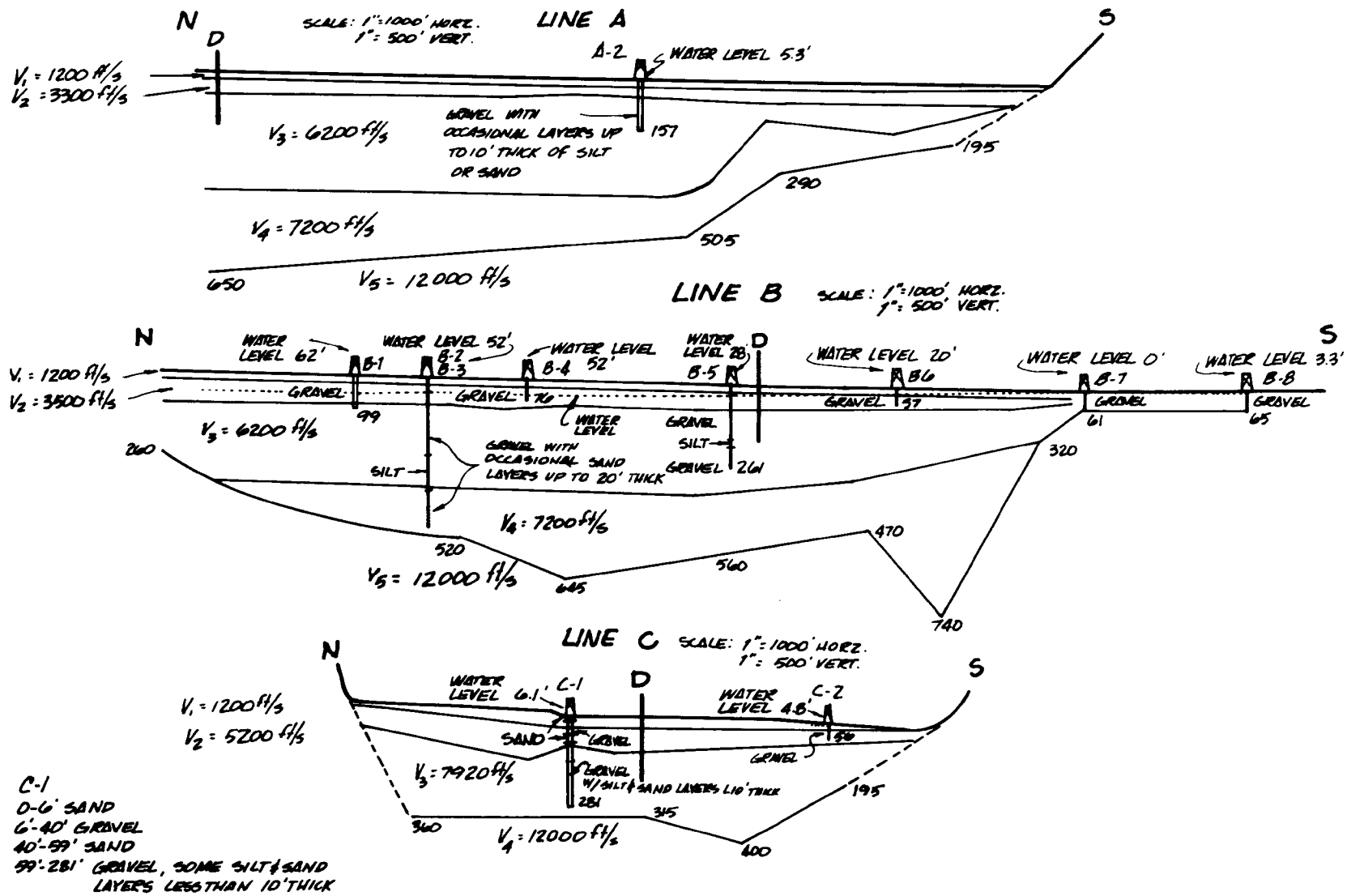


Figure 8A | **Soils & Refraction Seismic Profiles**

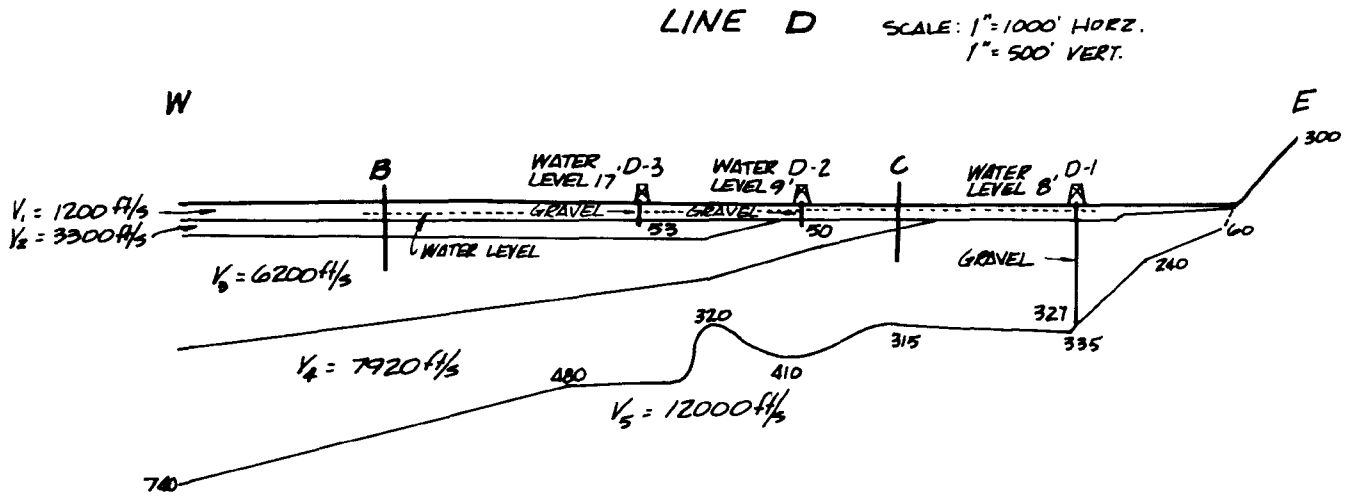


Figure 9 Soils & Refraction Seismic Profiles

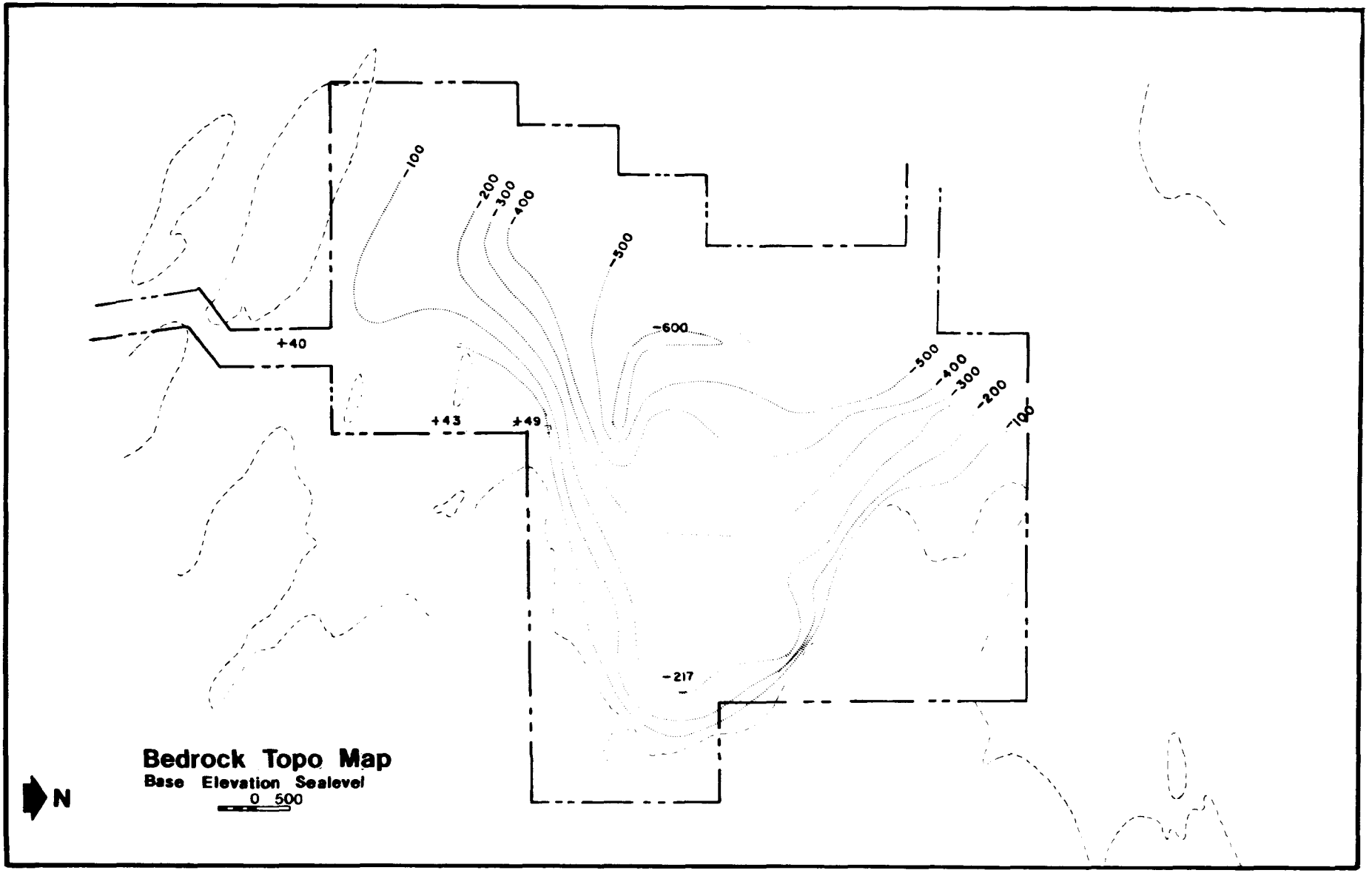


Figure 10	Bedrock Topography

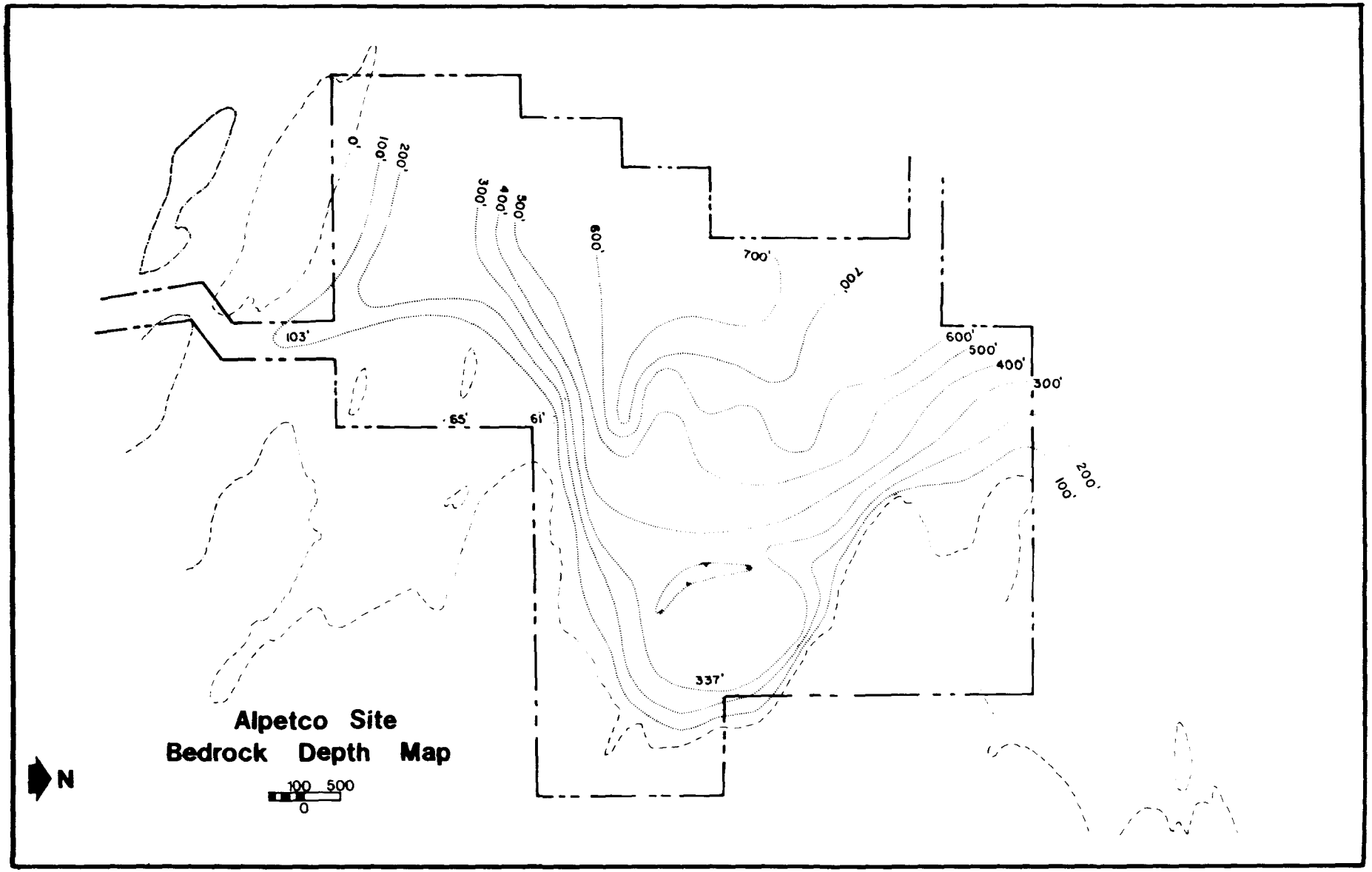


Figure 11 Bedrock Depth Map

soils in the plant site investigation. Use of a temporary Valdez Glacier Stream crossing in June 1979 was discontinued because of erosion. Steep, sharp banks were exposed when the river level dropped in August 1979. At normal summer flow the stream exhibited sufficient velocity to dislodge and transport small to medium boulders. It is expected that particle density and particle size are sufficient to cause pile driving to be difficult. It is theorized that the depth to bedrock is 213 - 274m (700 - 900 ft), based on the seismic refraction studies for the refinery site and the reported depth to bedrock in Port Valdez. State construction of the Richardson Highway bridge across Valdez Glacier Stream revealed no unusual soil conditions which would suggest problems with respect to founding either the bridge or the roadway.

TABLE A

TESTHOLE	PAGE
A1	A-1
A2	A-2
B1	A-4
B2	A-5
B3	A-7
B4	A-8
B5	A-9
B6	A-10
B7	A-11
B8	A-12
B9	A-13
C1	A-15
C2	A-17
D1	A-18
D1	A-19

TABLE A

Test Hole A-1
Date of Drilling 26 June 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 76	Fl Grey Silty Sandy Gravel, damp to saturated, medium density, subrounded particles 6"-, GW/GM

Bottom of hole: 76.9
Water table: 4.6
Frost line: None observed

TABLE A

Test Hole A-2
Date of Drilling 10-11 July 1979

DEPTH IN FEET	SOIL DESCRIPTION
0 to 23	F1 Grey Silty Sandy Gravel (layers silty sand) damp to saturated, dense, subrounded particles, 3"-, GW/GM; sample #1, SPT at 4'-2" to 7'-2", Blows/6" 30/25/23/33/28/34
23-76.5	NFS/F1 Grey Silty Sandy Gravel, saturated, (cleaner with depth) medium density, subrounded particles, +2", GM/GW
76.5-84.5	F1 Brown Silty Sandy Gravel (with organic matter) saturated, medium density, subrounded particles, 12"- (probably a buried topsoil layer included in this interval), GM/GW
84.5-85	F4 Grey Sandy Silt saturated, stiff, nonplastic, ML
85-96	F1 Grey Silty Sandy Gravel, saturated medium density, subrounded particles, +2", GM/GW
96-104	F2 Grey silty Sand saturated, medium density, (heave in hole 30'), SM/SP
104-121	NFS Grey Sandy Gravel, saturated, medium density, subrounded, +2", GM/GW
121-125	F2 Grey Silty Sand, saturated, medium density, SP/SM
125-148	F4 Grey Silt trace gravel, saturated, dilatent, nonplastic, subrounded 3/8"-, ML, sample #2 grab at 128', ML
148-152	F1 Grey Silty Sandy Gravel, saturated, GM/GW
152-154	F4 Grey Silt with trace gravel, saturated, ML

TABLE A

Test Hole A-2 Cont'd.

154-157	Fl Grey Sandy Gravel, saturated, dense subrounded 2"-, SP/SW/SM

Bottom of hole: 156.9'
Water table: 5.3
Frost line: None observed

TABLE A

Test Hole B-1
Date of Drilling July 1979

DEPTH IN FEET	SOIL DESCRIPTION
0-67	Fl/NFS Grey Silty Sandy Gravel, damp to saturated, dense, subrounded particles 6"+, GM/GP
67-76	Fl Grey Silty Sandy Gravel, saturated, dense, subrounded particles, 2"+, GW/GM
76-98.8	NFS Grey Sandy Gravel, saturated, medium density, subrounded particles, 2"+, GP/GW

Bottom of hole: 98'-9"
Water table: 62'
Frost line: None observed

TABLE A

Test Hole B-2
Date of Drilling 30 June-10 July, 1979

DEPTH IN FEET	SOIL DESCRIPTION
0 to 15	F1 Grey Silty Sandy Gravel, damp, dense, subrounded particles, 4"-, GW/GM
15 to 20	F4 Grey Gravelly Sandy Silt, damp dense, nonplastic ML
20 to 47	F1 Grey Silty Sandy Gravel, damp, dense, subrounded particles, 6"+, GM/GW
47 to 50	F4 Grey Gravelly Sandy Silt damp, stiff to hard, nonplastic, ML
50 to 62	F1 Grey Silty Sandy Gravel, saturated, dense, subrounded, 3/4"-, GP
62 to 68	F2/F1 Silty Gravelly Sand and Silty Sandy Gravel, (layered) saturated medium to dense, subrounded particles SW-SM/GW-GM
68 to 80	NFS Grey Sandy Gravel with trace of silt saturated, medium to high density, subrounded, GW/GP
80 to 83.5	F1 Grey Silty Sandy Gravel, saturated, dense, subrounded particles, GP/GM
83.5 to 122.5	NFS Grey Sandy Gravel with a trace of silt, saturated, dense, subrounded, 4"+, GP/GW
122.5 to 125	F1 Brown Sandy Silt with organic debris saturated, stiff, nonplastic, ML
125 to 147	NFS Grey Sandy Gravel, with trace of silt, saturated, dense, subrounded particles, GP (30' of heave)
147 to 147.5	F4 Grey Sandy Silt, with roots, saturated stiff, nonplastic, ML

TABLE A

Table B-2 Continued

147.5 to 157	NFS Grey Sand (with trace of 3/8" gravel), saturated, medium density, subrounded 3/8"-, SP
157 to 166	NFS Grey Sandy Gravel, saturated, medium density, subrounded, GP

TABLE A

Test Hole B-2 Continued

166 to 173	F4/F2 Grey Silt and Silty Sand with layered, saturated, stiff, nonplastic, ML/SM
173 to 177	F1 Grey Silty Sandy Gravel, saturated, medium to high density, subrounded particles, GP/GM
177 to 181	NFS Grey Sandy Gravel, saturated, medium to high density, subrounded particles, GP
181 to 187	F2 Grey Silty Sand, saturated medium density (tends to heave) SM
187 to 195	NFS Grey Sandy Gravel saturated, medium to high density, subrounded particles, GP
195 to 195.6	F4 Brown Silt, with organic debris, saturated stiff, nonplastic, ML
195.6 to 197	F4 Grey Silt and Gravel, saturated, medium density, nonplastic, GM
197 to 199	NFS Grey Sandy Gravel saturated, medium density, subrounded particles, GP
199 to 201	F2 Grey Silty Sand, saturated, medium density, SM

Bottom of hole: 201'
Water table: 50'+
Frost line: None observed

Remarks: 12' Production testwell near B-3

TABLE A

Test Hole B-3
Date of Drilling 15-20 June 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 60	Fl/NFS Grey Silty Sandy Gravel with occasional cobbles, damp to saturated, dense, subrounded particles, 12"-, GW/GM
60 to 142	Fl/NFS Silty Sandy Gravel with occasional cobbles, saturated, dense (becomming finer with depth, subrounded particles, 2"+, GM/GW
142 to 145	NFS Grey Gravelly Sand, saturated, medium to high density, subrounded particles, SW/SP
145 to 171	Fl/NFS Grey Silty Sandy Gravel saturated dense, subrounded particles, 2"+, GW/GM
171 to 176	Fl/NFS Brown Silty Sandy Gravel, saturated (may include a silt layer with organic debris), dense, subrounded particles, 2", GW/GM
176 to 181	NFS Grey Silty Sandy Gravel, saturated dense, subrounded, 2", GP/GW
181 to 213	Fl/NFS Grey Silty Sandy Gravel, saturated, dense, subrounded particles, 2", GW/GM (note sulfurous smell 181'-183')
213 to 231	NFS/F2 Grey Sand with gravel, becomes siltier with depth, saurated, medium density, subrounded 1"-, SP/SM
231 to 343	F4 Grey Sandy Silt, moisture changes from saturated to damp to dry by 269', sample 163' to 165', dense (hard), nonplastic, ML
343 to 460	Fl Grey Silty Sandy Gravel, saturated, subrounded particles, GW/GM
460 to 501	Fl/NFS Grey Silty Sandy Gravel, saturated dense, subrounded particles 2"-, GW/GP

Bottom of hole: 501'
Water table: 52'
Frost line: None observed

TABLE A

Test Hole B-4
Date of Drilling 21 June 1979

DEPTH IN FEET	SOIL DESCRIPTION
0 to 52	Fl/NFS Grey Silty Sandy Gravel, damp to saturated, subrounded particles, 3"-, GW/GM
52 to 76	NFS Grey Sandy Gravel, trace silt, dense, subrounded particles, 2"-, GW, GP

Bottom of hole: 76'
Water table: 52'
Frost line: None observed

TABLE A

Test Hole B-5
Date of Drilling 20-21 June 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 28	Fl/NFS Silty Sandy Gravel with occasional cobbles at 30', damp, medium density, subrounded particles, 12"-, GP/GM
28 to 120	NFS Grey Sandy Gravel, trace silt, saturated, dense, subrounded 2"-, GP/GW
120 to 160	Fl/NFS Grey Silty Sandy Gravel, saturated, dense, subrounded particles, 2"-, GP/GM
160 to 182	Fl Grey Silty Sandy Gravel, (layer of sandy silt 157-159) becomes siltier with depth, (sulfurous smell at 180') saturated, dense, subrounded particles, 2"-, GM/ML
182 to 196	F4 Black-Grey Sandy Silt, saturated, hard, nonplastic, tube sample at 192'-193', ML
196 to 198	Fl Grey Silty Sandy Gravel, saturated, dense, subrounded, GM
198 to 241	Fl Brown Silty Sandy Gravel, saturated, medium density, subrounded particles, 2"-, GM
241 to 160	Fl Grey Silty Sandy Gravel, saturated, dense, subrounded particles, 2", GM/GP

Bottom of hole: 260.5'
Water table: 28'
Frost line: None observed

TABLE A

Test Hole B-6
Date of Drilling

DEPTH IN FEET	SOIL DESCRIPTION
0 to 56.5	Fl/NFS Grey Silty Sandy Gravel with occasional cobbles, damp to saturated, dense, subrounded particles, 6"-, GP/GM

Bottom of hole: 56.5'
Water table: 15.5'
Frost line: None observed

TABLE A

Test Hole B-7
Date of Drilling 3 July 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 30	Fl/NFS Grey Silty Sandy Gravel, with occasional cobbles, saturated, dense, subrounded particles, 6"+, GW/GM
30 to 60	NFS Grey Sandy Gravel, saturated, dense, 3/4"-, GP/GW
60 to 82	Bedrock

Bottom of hole: 82'
Water table: 0'
Frost line: None observed

TABLE A

Test Hole B-8
Date of Drilling

DEPTH IN FEET	SOIL DESCRIPTION
0 to 5	NFS/Fl Grey Silty Sandy Gravel with cobbles at 4', damp to saturated, subrounded particles, 8"-, GP/GM
5 to 22	NFS Grey Sandy Gravel, with occasional cobbles, saturated, medium density, subrounded particles, 2"-, 5'-8', SPT Blows/6" = 16/60/25/24/18/18 10'-13' SPT Blows/6" = 10/23/13/32/13/11 15'-16.9', SPT Blows/6" = 20/14/40/42+ 20'-23', SPT Blows/6" = 7/10/10/11/11/13
22 to 64.9	Fl Grey Silty Sandy Gravel, saturated, dense, subrounded, 1-1/2"-, GM/GP 23-26 SPT, Blows/6" = 11/16/25/15/20/28
64.9-85	Bedrock

Bottom of hole: 85
Water table: 3.3'
Frost line: None observed

TABLE A

Test Hole B-9
Date of Drilling 3 July 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 7.7	NFS Grey Sand, saturated, SW/SP
7.7 to 21	NFS Grey Sandy Gravel layered with Sand, saturated, low to medium density, subrounded particles, 2"-, GP/GW
21 to 28	F4 Grey Sandy Silt, saturated, soft to stiff, nonplastic, ML
28 to 42	NFS/F2 Grey Sand to Silty Sand, (trace gravel) saturated, subrounded particles, 1/2"-. SP/SM
42 to 48	F1 Grey Silty Sandy Gravel, saturated, medium density, subrounded particles, 1-1/2"+, GW/GM
48 to 59	F4 Grey-Brown Silt with wood fragments, saturated, medium density, ML
59 to 60.5	F2 Grey Silty Sand, saturated, medium density, SM
60.5 to 80	F4 Grey Sandy Silt (trace roots) saturated, stiff, dilitant, nonplastic, ML, 60.5' to 62.5', SPT, Blows/6" = 8/8/9/18
80 to 85	F4 Grey Silt, trace sand, saturated, stiff, dilitant, moisture content at or near plastic limit, ML, tube sample 81 to 82.5
85 to 95	F4 Grey Sandy Gravelly Silt, damp, stiff to hard, (at 85' gravelly layer with no water) subrounded particles, 3/4"-, ML
95 to 97	F1 Grey Silty Sandy Gravel, damp to wet, dense, subrounded, 1"-, GM
97 to 105	Grey Silty Sandy Gravel, saturated, dense, subangular particles, 2"-, GM/GP

TABLE A

Test Hole B-9 Continued

105 to 105.9 Bedrock, hard drilling, quartz veined Graywacke

Bottom of hole: 105.9'
Water table: 8' above grade
Frost line: None observed

TABLE A

Test Hole C-1
Date of Drilling 4 July 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 1	F1 Grey, Sandy Silt, damp, soft, nonplastic, ML
1 to 5.6	F2 Grey Silty Sand, trace wood, saturated, medium density, SM
5.6 to 48.8	NFS Grey Sandy Gravel, with trace of silt and with layers of silty sandy gravel, saturated, GP/GM 5.6 to 7, SPT, Blows/6" = 16/20/17 8' to 11' SPT, Blows/6" = 8/8/13/32/15/13 11.5 to 14.5 SPT, Blows/6" = 3/14/24/16/3/20/24 18 to 21 SPT, Blows/6" = 4/6/8/12/4/11/16
39.6 to 48.7	F2 Grey Silty Sand, saturated, loose to medium density, SM 39 to 43 SPT, Blows/6" = 5/4/4/5/5/4/5/6
48.7 to 58.7	F2/F4 Grey Silty Sand and Sandy Silt, saturated (also 6" layer in sample that is damp) loose to stiff, SM/ML 54 to 57 SPT, Blows/6" = 4/4/3/4/6/4/5 55 to 56.5, thin wall tube sample
58.7 to 68	F1/NFS Grey Silty Sandy Gravel saturated, medium density, subrounded particles, 1"-, GP/GM 59.5 to 62 SPT, Blows/6" = 6/9/9/12/35
68 to 78	NFS Grey Sandy Gravel, saturated, medium density, subrounded particles
78 to 117	F1 Grey Silty Sandy Gravel, saturated medium density, subrounded particles, GP/GM
117 to 125	F1 Brown Silty Sandy Gravel, (sulfurous smell) saturated, dense, subrounded particles, GM
125 to 130	F2/F3 Brown Gravelly Silty Sand, saturated, medium density, subrounded particles, 2"-, SM
130 to 135	F4 Brown Sandy Silt, with trace organic debris, saturated, stiff, nonplastic, ML

TABLE A

Test Hole C-1 Cont'd.

135 To 169	F1 Grey Silty Sandy Gravel, saturated, dense, subrounded particles, GM
169 to 177	F2 Grey Silty Sand damp, dense, SM 171-172, SPT Blows/6" = 4/9/46/53/58+
177 to 216	F1 Grey Silty Sandy Gravel with cobbles, damp, dense, subrounded particles, 6"-, GM
216 to 281	F1 Grey Silty Sandy Gravel, saturated, dense, subrounded particles, 2"-, GP/GW

Bottom of hole: 281'
Water table: 6.1'
Frost line: None observed

TABLE A

Test Hole C-2
Date of Drilling 6-7 July 1979

DEPTH IN FEET	SOIL DESCRIPTION
0 to 5	NFS Grey Silty Sandy Gravel, GM/GP
5 to 25	NFS Grey Sandy Gravel, saturated, low to medium density, subrounded particles, 3/4"-, GP/GW (sandier with depth 0.5' to 5' of heave in casing at sampling attempts. 7' To 10', SPT Blows/6" 4/7/5/11/15/9 11.5 to 14.5 SPT Blows/6" 3/3/4/2/6/8/12
25 to 35	Fl Grey Silty Sandy Gravel, trace wood, saturated, medium density, (easy drilling 30'-35') GP/GW 30 to 33, SPT Blows/6" = 4/6/15/18/28/39
35 to 37.5	Fl Brown Silty Sandy Gravel saturated, medium density, sharp particles, GP/GM (casing moved freely after drilling ahead) 37-39 SPT, Blows/6" = 3/6/11/18/22/25 (sample included a thin layer of ash)
37.5 to 40	F4 Grey-Brown Sandy Silt, saturated, stiff, nonplastic, ML
40 to 56	Fl Brown Silty Sandy Gravel, with occasional cobbles, saturated, dense, subrounded particles, GP/GM

Bottom of hole: 56'
Water table: 4.8'
Frost line: None observed

TABLE A

Test Hole D-1
Date of Drilling 22-23 June 79

DEPTH IN FEET	SOIL DESCRIPTION
0 to 1.5'	F4 Grey Sandy Silt, dry, soft, nonplastic, ML
1.5 to 15	F1/NFS Grey Silty Sandy Gravel, damp to wet, medium density, subrounded particles, 1-1/2"-, GP/GM
15 to 40	NFS Grey Sandy Gravel, saturated, dense, subrounded 2"-, GP/GW
40 to 45	F1 Grey Silty Sandy Gravel, saturated, dense, subrounded particles 1/2"-, GP
45 to 59	NFS Grey Sandy Gravel, with cobbles, saturated, dense, subrounded, GP/GW
59 to 93	F1/F3 Grey Silty Sandy Gravel, damp, dense, subrounded particles, GM
93 to 100	F1 Grey Sandy Gravel saturated, dense, subrounded particles, GM/GP
100 to 327	NFS Grey Sandy Gravel with trace of silt, saturated, medium density, subrounded particles, 2"-, GP
327 to 347	NFS Grey Bedrock, Graywacke

Bottom of hole: 347'
Water table: 8.1'
Frost line: None observed

TABLE A

Test Hole D-2
Date of Drilling

DEPTH IN FEET	SOIL DESCRIPTION
0 to 8	NFS/F1 Grey Sandy Gravel with Sandy Silt layers, damp to wet, medium density subrounded particles, GP/GM 5' to 8', SPT Blows/6" = 7/10/10/12/8/10
8 to 39	NFS Grey Sandy Gravel, trace silt, saturated, dense, subrounded particles, GP 10.5 to 13.5, SPT Blows/6" = 9/13/10/17/26/32 16 to 17, SPT Blows/6" = 22/58 17.6 to 18.6, SPT Blows/6" = 18/68
39 to 41	F2 Grey Silty Sand, saturated, dense, SM 40.5 to 43.5, SPT, Blows/6" = 5/8/27/59/26/25
41 to 41.5	F4 Grey Silt with trace organic debris, saturated, nonplastic, ML
41.5 to 50	F1/NFS Grey Silty Sandy Gravel, saturated, dense, subrounded particles, GM/GW

Bottom of hole: 50'
Water table: 9'
Frost line: None observed

TABLE A

Test Hole D-3
Date of Drilling 7-10 July 1979

DEPTH IN FEET	SOIL DESCRIPTION
0 to 13	F-1 Grey slightly Silty Sandy Gravel damp, low density subrounded/rounded particles 1"- SPT at 7.2' to 12' Blows/6" = 2/4/11/9/6/3/5/13/9/9
13 to 36	F-1 Grey Silty Sandy Gravel damp/saturated medium dense, sharp particles SPT at 14.5' to 17.5' and 17.5 and 18.7' Blows/6" = 4/9/27/32/12/13 and 4/10/26/50 in 0.2'
36 tO 36.8	F-2 Grey slightly Silty Sand saturated, low density
36.8 tO 52.7	F-1 Grey slightly Silty Sandy Gravel saturated high density subrounded/rounded 3"+ SPT at 36.8' to 39.8', Blows/6" = 8/20/38/59/63/65

Bottom of hole: 52.7'
Water table: 16.5'
Frost line: None observed

TABLE B

Test Hole Log – Description Guide

ıe soil descriptions shown on the logs are the best estimate of the soil's :haracteristics at the time of field examination and as such do not achieve the precision of a laboratory testing procedure. If the log includes soils samples, those samples receive an independent textural classification in the laboratory to verify the field examination.

The logs often include the following items:

Depth Interval – usually shown to 0.1 foot, within that zone no significant change in soil type was observed through drill action, direct observation or sampling.

Frost Classification – NFS, F1, F2, F3, F4, see "Soil Classification Chart"

Texture of Soil – An engineering classification of the soils by particle size and proportion, see "Soil Classification Chart", note the proportions are approximate and modifications to the soil group due to stratification, inclusions and changes in properties are included.

Moisture Content – this is a qualitative measure:
- dry, no or little apparent surface moisture,
- damp, moisture forms portion of color, less than plastic limit,
- wet, no free water, often soft, if cohesive soil,
- saturated, free water may be squeezed out, if a free draining soil;
- dilatent at natural moisture content, if a non-plastic silt or fine sand. (The moisture content is further defined by reference to Pl, Lw, NP, M% or dilatency.)

Density – refers to more-or-less non-cohesive soils, such as sand gravel mixtures with or without a fine fraction, derived from drilling action and/or sample data; usually described as: very loose, loose, medium dense, very dense. General intent is to portray earthwork characteristics.

Stiffness – refers to more-or-less cohesive soils and fine grained silts of the clay-silt groups. Derived from drill action and/or sample data. Very soft, soft, stiff, very stiff and hard are commonly used terms.

Particle size – The largest particle recovered by the split spoon is 1-3/8", Shelby tube 3", auger flights (minute-man) 2", Auger flights (B-50 hollow stem) 6"-8". Larger particles are described indirectly by action of the drilling and are referred to as cobbles, 3" to 8", or boulders 8"+. Therefore when reviewing the gradation sheets, if any, the description on the hole log must be considered for an indication of larger particles.

Unified Soil Classification – This is a two letter code. See Unified Classification sheet for further definition. In some cases AASHO and/or FAA soil classifications may be shown as well as the unified.

Atterberg Limits – useful for fine grained and other plastic soils.

Pl; natural moisture content believed to be less than plastic limit

Pl+; natural moisture content believed to be between plastic and liquid limits

Lw+; natural moisture content believed to be greater than liquid limit

NP; non-plastic, useful as a modifying description of some silty materials.

Dilatency – is the ability of water to migrate to the surface of a saturated or nearly saturated soil sample when vibrated or jolted – used as an aid to determine if a fine grained soil is a slightly or non-plastic silt or a volcanic ash.

Rock flour – finely ground soil that is not plastic but otherwise appears similar to a clayey silt.

Organic Content – usually described as Peat, PT, sometimes includes discrete particles such as wood, coal, etc. as a modifier to an inorganic soil. Quantity described as; trace, or an estimate of volume, or, in case of all organic, – as Peat. This may include tundra, muskeg and bog material.

Muck – a modifier used to describe very soft, semi-organic deposits usually occuring below a peat deposit.

Amorphus peat – organic particles nearly or fully disintegrated.

Fibrous Peat – organic particles more-or-less intact.

Bottom of Testhole – includes last sample interval.

Frost Line – seasonal frost depth as described by drilling action and/or samples at the time of drilling.

Frozen Ground – other than frost line, described by samples, usually includes description of ice content, often will include modified Unified Classification for frozen soils – this is a special case related to permafrost studies.

Free Water Level – The free water level noted during drilling. This is not necessarily the static water table at the time of drilling or at other seasons. Static water table determination in other than very permeable soils requires observation wells or piezometer installations, used only in special cases.

Blow/6" – The number of blows of a 140 weight free falling 30" to advance a 2" split spoon 6"; the number of blows for a 12" advance is, by definition, the standard penetration.

M% – natural moisture content of the soil sample, usually not performed on clean sands or gravels below the water table.

Type of Sample –
- SP, refers to 2" split spoon driven into the soil by 140 pound weight, a disturbed sample,
- S, thin wall tube, "Shelby" used to obtain undisturbed samples of fine grained soil,
- G, "grab" disturbed sample from auger flights or wall of trench,
- C, cut sample, undisturbed sample from wall of trench.

Dry Strength – a useful indicator of a soil's clayey fraction, N=None, L=Low, M=Medium, H=High

Group – The samples are placed into apparently similar groups based on color and texture and are arbitrarily assigned a group letter. Further disturbed tests including Atterberg Limits, grain size, moisture-density relationship, etc. may be performed on the group and are assumed to reflect the general distrubed characteristics of the soils assigned to the group. This is an important phase of the soil analysis and is used to standardize the various qualitative determinations and to reduce the number of quantitative tests necessary to describe the soil mass.

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

PART 1 DESCRIPTION OF SOIL PHASE (a) (Independent of Frozen State)	Classify Soil Phase by the Univied Soil Classification System							
(1)	Major Group		Sub-Group		Field Identification	Pertinent Properties of Frozen Materials Which May be Measured by Physical Tests to Supplement Field Identification	Guide for Construction on Soils Subject to Freezing and Thawing	
	Description (2)	Designation (3)	Description (4)	Designation (5)	(6)	(7)	Thaw Characteristics (8)	Criteria (9)
PART II DESCRIPTION OF FROZEN SOIL	Segregated ice is not visible by eye (b)	N	Poorly bonded or friable	Nf	Identify by visual examination. To determine presence of excess ice, use procedure under note (c) below and hand magnifying lens as necessary. For soils not fully saturated, estimate degree of ice saturation: Medium, Low. Note presence of crystals, or of ice coatings around larger particles.	In-Place Temperature Density and Void Ratio a. In Frozen State b. After Thawing in Place Water Content (total H_2O, including ice) a. Average b. Distribution Strength a. Compressive b. Tensile c. Shear d. Adfreeze Elastic Properties Plastic Properties Thermal Properties Ice Crystal Structure (using optical instruments) a. Orientation of Axes b. Crystal Size c. Crystal Shape d. Pattern of Arrangement	Usually thaw - stable	The potential intensity of ice segregation in a soil is dependent to a large degree on its void sizes and for pavement design purposes may be expressed as a empirical function of grain size as follows: Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weight are frost-susceptible for pavement design purposes. Gravels, well-graded sands and silty sands, especially those approaching the theoretical maximum density curve, which contain 1-1/2 to 3 percent finer by weight then 0.02 mm size should be considered as possibly frost-susceptible and should be subjected to a standard laboratory frost susceptiblity test to evaluate actual behaviour during freezing. Uniform sandy soils may have as high as 10 percent of grains finer than 0.02 mm by weight without being frost-susceptible. However, their tendency to occur interbedded with other soils usually makes it impractical to consider them separately. Soils classed as frost-susceptible under the above pavement design criteria are likely to develop significant ice segregation and frost heave if frozen at normal rates with free water readily available. Soils so frozen will fall into the thaw-unstable category. However, they may also be classed as thaw-stable if frozen with insufficient water to permit ice segregation. Soils classed as non-frost susceptible under the above criteria usually occur without significant ice segregation and are usually thaw-stable for pavement applications. However, the criteria are not exact and may be inadequate for some structure applications; exceptions may also result from minor soil variations. In permafrost areas, ice wedges, pockets, veins, or other ice bodies may be found whose mode of origin is different from that described above. Such ice may be the result of long-time surface expansion and contraction phenomena or may be glacial or other ice which has been buried under a protective earth cover.
			No excess ice (Well bonded)	Nb - n				
			Excess Ice (Well bonded)	Nb - e				
	Segregated ice is visible by eye (Ice 1 inch or less in thickness) (b)	V	Individual ice crystals or inclusions	Vx	For ice phase record the following as applicable: Location, Orientation, Thickness, Length, Spacing, Hardness, Structure, Color (per Part III below) Size, Shape, Pattern of arrangement Estimate volume of visible segregated ice present as percent of total sample volume.			
			Ice coatings on particles	Vc				
			Random or irregularly oriented ice formations	Vr				
			Stratified or distinctly oriented ice formations	Vs				
PART III DESCRIPTION OF SUBSTANTIAL ICE STRATA	Ice (Greater than 1 inch in thickness)	ICE	Ice with soil inclusions	Ice + soil type	Designate material as ICE (d) and use descriptive terms as follows, usually one item from each group, as applicable: Hardness: HARD, SOFT (or mass, not individual crystals) Structure: CLEAR, CLOUDY, POROUS, CANDLED, GRANULAR, STRATIFIED Color (Examples): COLORLESS, GRAY, BLUE Admixtures (Example): CONTAINS FEW THIN SILT INCLUSIONS	Same as Part II above, as applicable, with special emphasis on Ice Crystal Structure		
			Ice without soil inclusions	Ice				

DEFINITIONS:

Ice Coatings on Particles are discernible layers of ice found on or below the larger soil particles in a frozen soil mass. They are sometimes associated with hoarfrost crystals, which have grown into voids produced by the freezing action.

Ice Crystal is a very small individual ice particle visible in the face of a soil mass. Crystals may be present alone or in a combination with other ice formations.

Clear Ice is transparent and contains only a moderate number of air bubbles (e)

Cloudy Ice is relatively opaque due to entrained air bubbles or other reasons, but which is essentially sound and non-pervious. (e)

Porous Ice contains numerous voids, usually interconnected and usually resulting from melting at air bubbles or along crystal interfaces from presence of salt or other materials in the water, or from the freezing of saturated snow. Though porous, the mass retains its structural unity.

Candled Ice is ice which has rotted or otherwise formed into long columnar crystals, very loosely bonded together.

Granular Ice is composed of coarse, more or less equidimensional, ice crystals weakly bonded together.

Ice Lenses are lenticular ice formations in soil occurring essentially parallel to each other, generally normal to the direction of heat loss and commonly in repeated layers.

Ice Segregation is the growth of ice as distinct lenses, layers, veins, and masses in soils, commonly but not always oriented normal to direction of heat loss.

Well-bonded signifies that the soil particles are strongly held together by the ice and that the frozen soil possesses relatively high resistance to chipping or breaking.

Poorly-bonded signifies that the soil particles are weakly held together by the ice and that the frozen soil consequently has poor resistance to chipping or breaking.

Friable denotes extremely weak bond between soil particles. Material is easily broken up.

Thaw-Stable frozen soils do not, on thawing, show loss of strength below normal, long-time thawed values and/or significant settlement, as a direct result of the melting of the excess ice in the soil.

NOTES:

(a) When rock is encountered, standard rock classification terminology should be used.

(b) Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. However, the impression to the unaided eye is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.

(c) When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt and observing the Quantity of supernatant water as a percent of total volume.

(d) Where special forms of ice, such as hoarfrost, can be distinguished, more explicit description should be given.

(e) Observer should be careful to avoid being misled by surface scratches or frost coating on the ice.

NOTES:

The letter symbols shown are to be affixed to the Unified Soil Classification letter designations, or may be used in conjunction with graphic symbols, in exploration logs or geological profiles. Example — a lean clay with essentially horizontal ice lenses.

or

The descriptive name of the frozen soil type and a complete description of the frozen material are the fundamental elements of this classification scheme. Additional descriptive data should be added where necessary. The letter symbols are secondary and are intended only for convenience in preparing graphical presentations. Since it is frequently impractical to describe ice formations in frozen soils by means of words alone, sketches and photographs should be used where appropriate, to supplement descriptions.

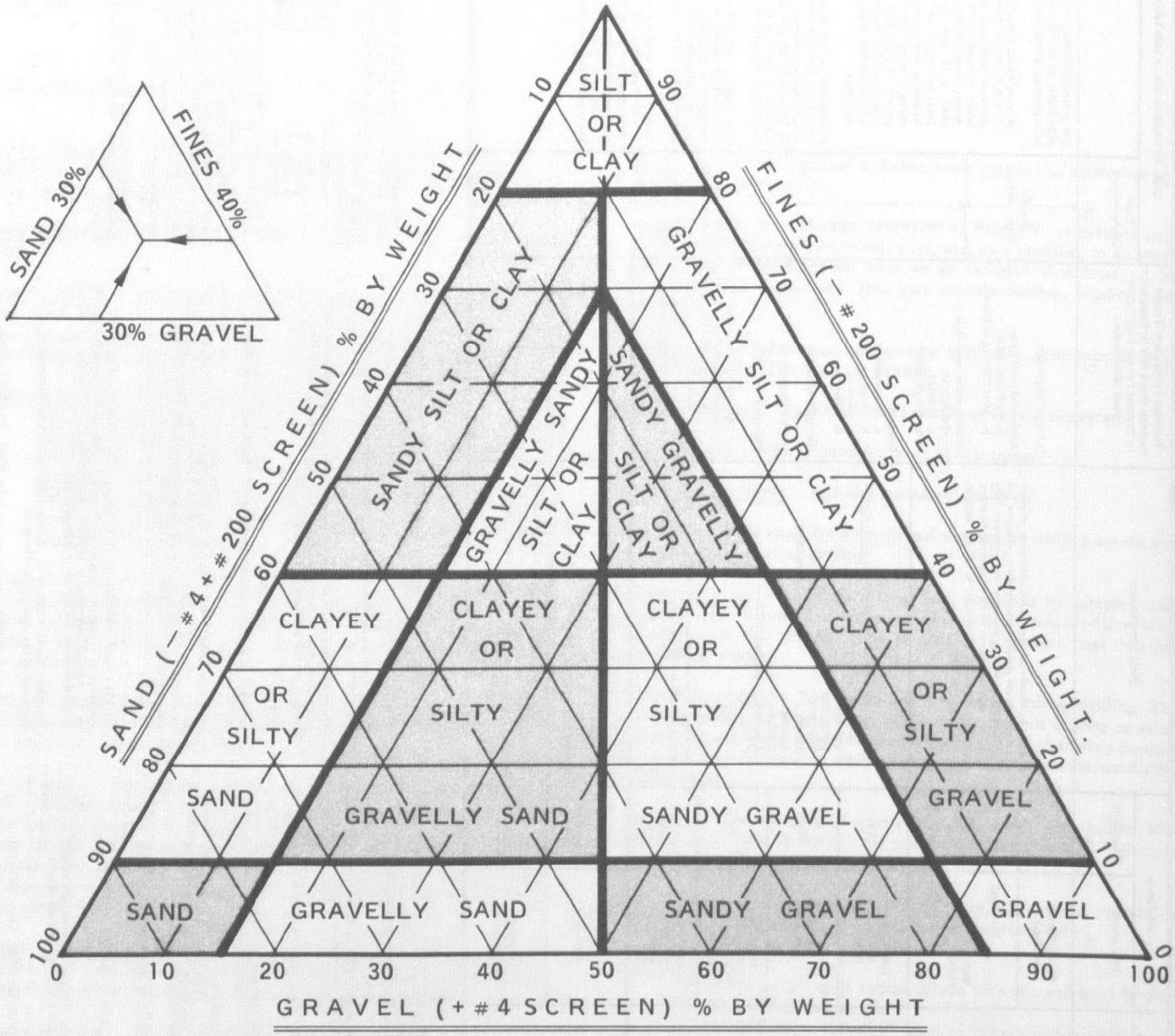
The abbreviation NFS is commonly used to designate non-frost-susceptible materials on exploration logs and drawings.

TABLE B (Continued)

TABLE B

(Continued)

SOIL CLASSIFICATION CHART



NONFROST SUSCEPTIBLE SOILS ARE INORGANIC SOILS CONTAINING LESS THAN 3% FINER THAN 0.02 mm.
GROUPS OF FROST-SUSCEPTIBLE SOILS:

F1 GRAVELLY SOILS CONTAINING BETWEEN 3 AND 20% FINER THAN 0.02 mm.
F2 SANDY SOILS CONTAINING BETWEEN 3 AND 15% FINER THAN 0.02 mm.
F3 a. GRAVELLY SOILS CONTAINING MORE THAN 20% FINER THAN 0.02 mm. AND SANDY SOILS (EXCEPT FINE SILTY, SANDS) CONTAINING MORE THAN 15% FINER THAN 0.02 mm.
b. CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12. EXCEPT VARVED CLAYS.
F4 a. ALL SILTS INCLUDING SANDY SILTS.
b. FINE SILTY SANDS CONTAINING MORE THAN 15% FINER THAN 0.02 mm.
c. LEAN CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12.
d. VARVED CLAYS.

UNIFIED SOIL CLASSIFICATION SYSTEM

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)					Group Symbols a	Typical Names	Information Required for Describing Soils
Coarse grained soils More than half of material is larger than No. 200 sieve size b (The No. 200 sieve size is about the smallest particle visible to naked eye)	Gravels More than half of coarse fraction is larger than No. 4 sieve size (For visual classification, the ¼ in. size may be used as equivalent to the No. 4 sieve size)	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes		GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the course grains; local or geologic name and other pertinent descriptive information; and symbols in parentheses For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics Example: Silty sand, gravelly; about 20% hard, angular gravel particles ½-in. maximum size; rounded and subangular sand grains coarse to fine, about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)
			Predominantly one size or a range of sizes with some intermediate sizes missing		GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see ML below)		GM	Silty gravels, poorly graded gravel-sand-silt mixtures	
			Plastic fines (for identification procedures, see CL below)		GC	Clayey gravels, poorly graded gravel-sand-clay mixtures	
	Sands More than half of coarse fraction is smaller than No. 4 sieve size	Clean sands (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes		SW	Well graded sands, gravelly sands, little or no fines	
			Predominantly one size or a range of sizes with some intermediate sizes missing		SP	Poorly graded sands, gravelly sands, little or no fines	
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see ML below)		SM	Silty sands, poorly graded sand-silt mixtures	
			Plastic fines (for identification procedures, see CL below)		SC	Clayey sands, poorly graded sand-clay mixtures	
Fine-grained soils More than half of material is smaller than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to naked eye)	Identification Procedures on Fraction Smaller than No. 40 Sieve Size						
		Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)			
	Silts and clays liquid limit less than 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)
		Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity	
	Silts and clays liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
		High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays	
		Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity	
Highly Organic Soils		Readily identified by colour, odour, spongy feel and frequently by fibrous texture			Pt	Peat and other highly organic soils	

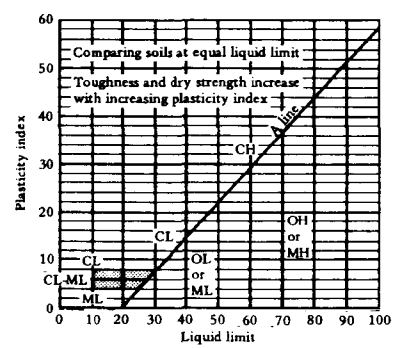
Laboratory Classification Criteria

Use grain size curve in identifying the fractions as given under field identification

Determine percentages of gravel and sand from grain size curve

Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows:
Less than 5% GW, GP, SW, SP
More than 12% GM, GC, SM, SC
5% to 12% Borderline cases requiring use of dual symbols

$C_U = \frac{D_{60}}{D_{10}}$ Greater than 4		
$C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3		
Not meeting all gradation requirements for GW		
Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols	
Atterberg limits above "A" line, with PI greater than 7		
$C_U = \frac{D_{60}}{D_{10}}$ Greater than 6		
$C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3		
Not meeting all gradation requirements for SW		
Atterberg limits below "A" line or PI less than 5	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols	
Atterberg limits below "A" line with PI greater than 7		



Plasticity chart
for laboratory classification of fine grained soils

From Wagner, 1957.
a Boundary classifications. Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW – GC, well graded gravel-sand mixture with clay binder.
b All Sieve sizes on this chart are U. S. standard

Field Identification Procedure for Fine Grained Soils or Fractions

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (Reaction to shaking):

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics):

After removing particles larger than No. 40 sieve size, mould a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit):

After removing particles larger than the No. 40 sieve size, a specimen of soil about one-half inch cube in size, is moulded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eight inch in diameter. The thread is then folded and re-rolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

TABLE B (Continued)

TABLE C

LABORATORY EXAMINATION OF HAND SAMPLES

DEPTH IN FEET	LAB GROUP	FROST CLASS	UNIFIED CLASS	OTHER
TESTHOLE A-1	-----	-----	-----	-----
TESTHOLE A-2				
4.1' to 7.1'	B	F1	GW	
128'	G	F4	CL	
TESTHOLE B-1	-----	-----	-----	-----
TESTHOLE B-2				
142'	G	F4	ML	
TESTHOLE B-3				
280'-281'	G	F4	ML	q_u 3.5+kg/cm^2 V_s 0.9 ksf M=25±1%, Lw=27% P.I.=3, See sample log & gradation sheets C1&L2
TESTHOLE B-4	-----	-----	-----	-----
TESTHOLE B-5				
192.9' to 194.9'	G	F2-F4	SM-ML	M, Silt=15.5%, Lw=24%, P.I.=4, M, Silty Sand= 18.6%, see sample log & gradation sheets C3-C5
TESTHOLE B-6	-----	-----	-----	-----
TESTHOLE B-7	-----	-----	-----	-----
TESTHOLE B-8				
5' to 8'	A	NFS	GW	
10'to 13'	A	NFS	GW	
15'to 16'	A	NFS	GW	
20' to 23'	A	NFS	GW	
23.3' to 25.3'	B	F1	GW	
TESTHOLE B-9				
60.5' to 63.5'	C	F2	SM	
81' to 81.5'	-----	F4	ML	M%=29% to 34% q_u 0.3 to 1.5 kg/cm^2 V_s=0.4 to 1.3 ksf, Lw=30% P.I.=3, see sheets C6&C7

TABLE C (Continued)

TESTHOLE C-1				
4.9' to 7.1'	B	F1	GW	
5' to 6.5'	A	NFS	GW	
11.5' to 14.5'	A	NFS	GW	
18.2' to 27.2'	A	NFS	GW	
43' to 43.5'	C	F2	SM	
54' to 57'	C	F2	SM	
59.5' to 62.5'	G	F4	CL	
170'-8"	E	F2	SP	
170'-8"+	B	F1	GW	
TESTHOLE C-2				
7.1' to 10.1'	B	F1	GW	
36.8' to 39.8'	G	F4	CL	
36.8' to 39.8'	F	F3	GL	
TESTHOLE D-1				
5.7' to 7.8'	-----	F3	SM	Gradation sheet C8
TESTHOLE D-2				
10.4'	A	NFS	GW	
15.9' to 16.9'	B	F1	GW	
40.5' to 43.5'	B	F1	GC	
40.5' to 43.5	G	F4	CL	
45' to 47'	C	F2	SM	
TESTHOLE D-3				
36.9' to 39.9'	A	NFS	GW	

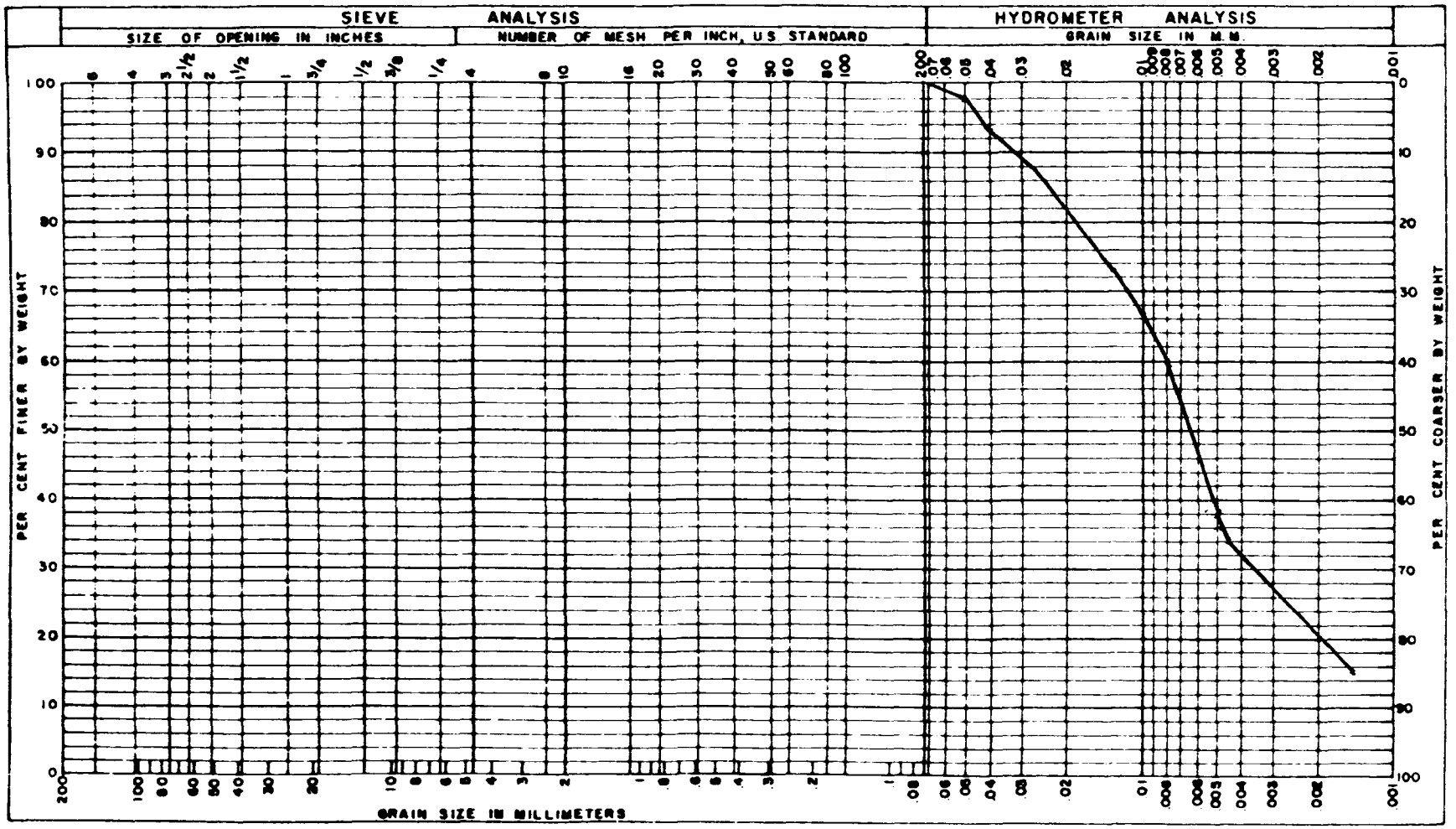
ALASKA TESTLAB

ALASKA TESTLAB
4040 B STREET
ANCHORAGE, ALASKA 99503

Sheet C2 of
W. O. No. D11751
Date 6-25-79
Technician JM

Textural Class SILT
Frost Class F4 Unified Class ML
Plastic Properties L_W = 27 P.I. = 3
Date Received 6-19-79

Client DOWL ENGINEERS
Project ALPETCO EIS DRILLING
Sample Number B3 SA 34
Location 280-281 ft.
Sample Taken By ATL-TB



U.S. STD SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	
1/2	
3/8	
4	
10	
20	
40	
80	
200	100
0.02 MM	80

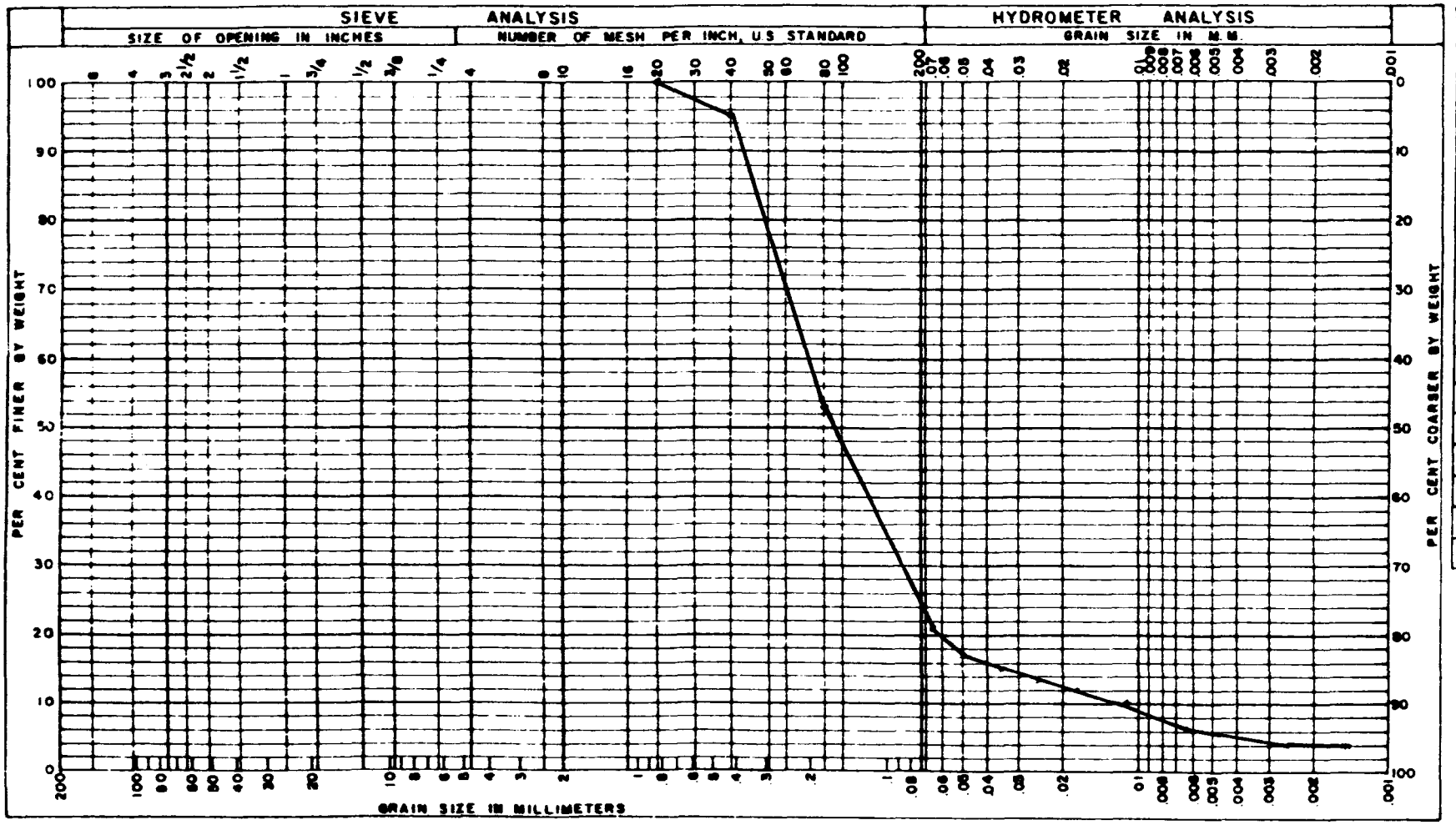
ALASKA TESTLAB

4045 B STREET
ANCHORAGE, ALASKA 99503

Sheet C4 of
W. O. No. D11751
Date 6-26-79
Technician TAS

Textural Class SILTY SAND
Frost Class F2 Unified Class SM
Plastic Properties
Date Received

Client ALPETCO
Project VALDEZ EIS DRILLING
Sample Number TH B-5 192.9 to 194.9
Location -193.5 ft. SA #3
Sample Taken By TB



U.S. STD. SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	
1/2	
3/8	
4	
10	
20	100
40	95
80	53
200	22
0.02 MM	12

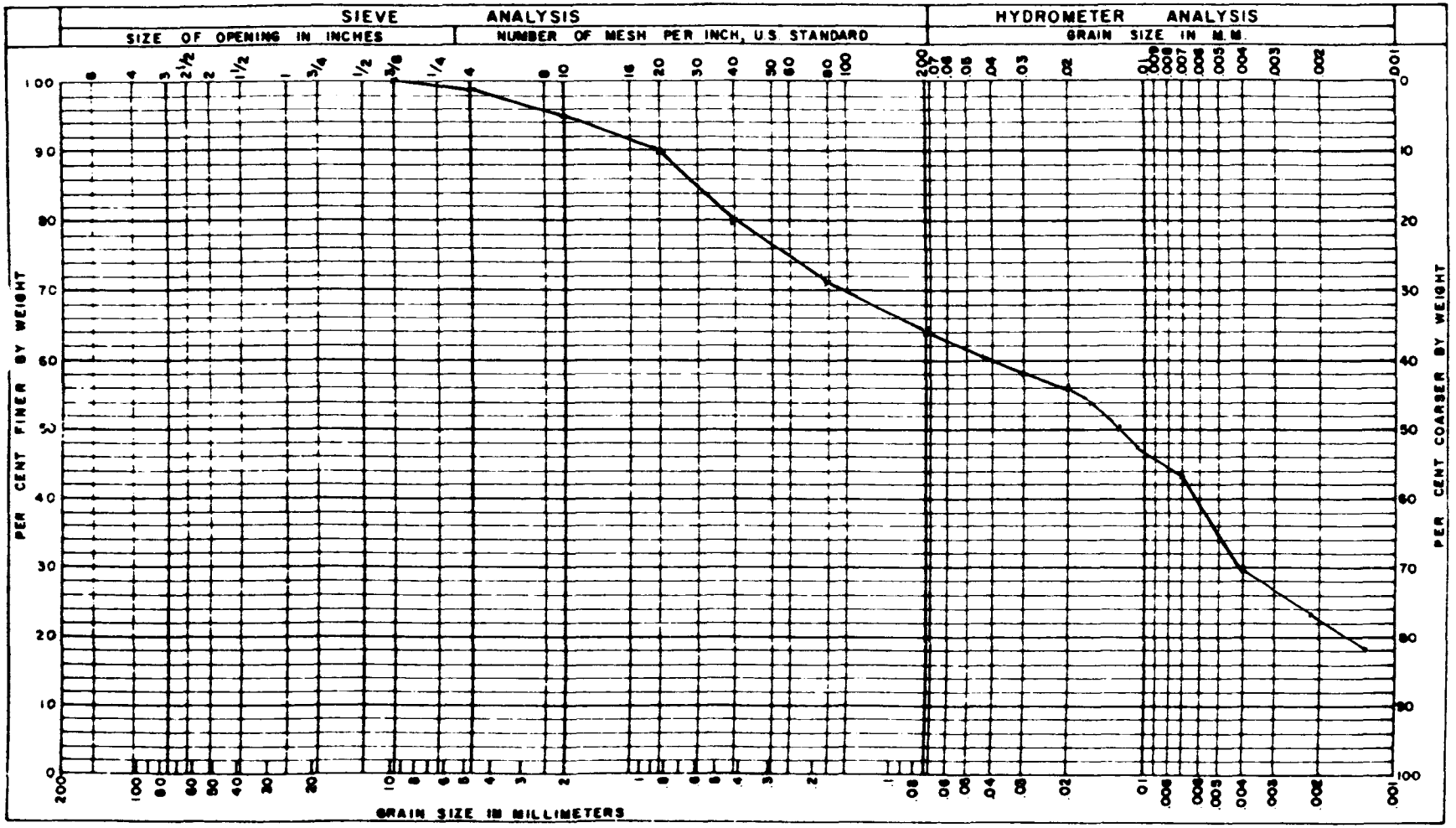
ALASKA TESTLAB

ALASKA TESTLAB
4040 B STREET
ANCHORAGE, ALASKA 99503

Sheet C5 of
W. O. No. D11751
Date 6-26-79
Technician TAS

Textural Class SILT
Frost Class F4 Unified Class ML
Plastic Properties L_w = 24 P.I. = 4
Date Received

Client ALPETCO
Project VALDEZ EIS DRILLING
Sample Number TH B-5 192.9 to 194.9
Location -194.5 ft. SA #1
Sample Taken By TB



U.S. STD. SIEVE	CUM. % PASS
2	
1 1/2	
1	
3/4	
1/2	
3/8	100
4	99
10	95
20	90
40	80
80	71
200	64
0.02 MM	56

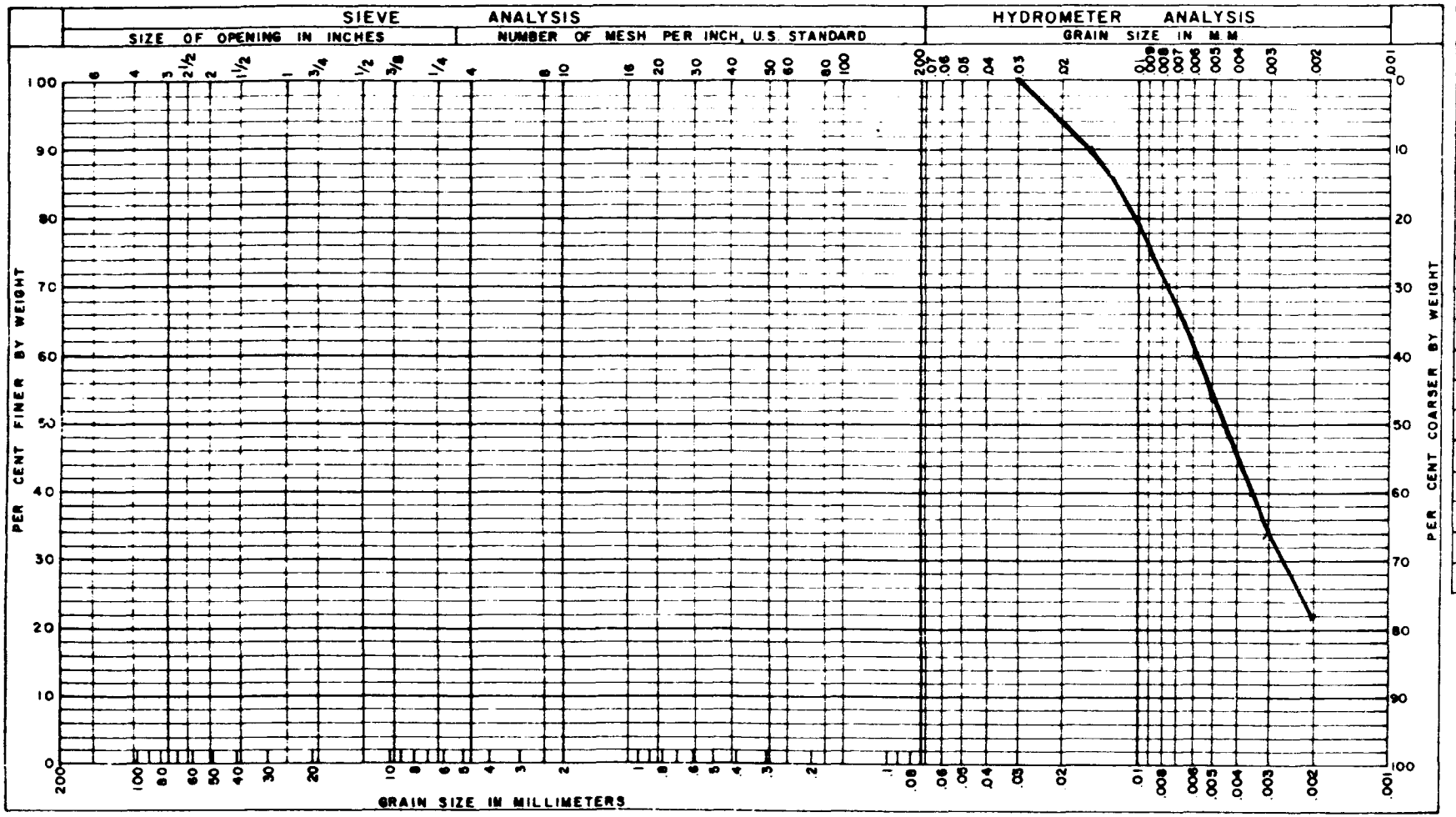
ALASKA TESTLAB

ALASKA TESTLAB

Sheet C7 of
W. O. No. 99999
Date 7-17-79
Technician MS-RLS

Textural Class SILT
Frost Class F4 Unified Class ML
Plastic Properties LL = 30, P.I. = 3
Date Received

Client ALPETCO
Project ALPETCO EIS
Sample Number #1
Location TB B-9 SAMPLE 13 SPEC. #1
Sample Taken By ATC



U.S STD SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	
1/2	
3/8	
4	
10	
20	
40	
80	
100	
200	100
0.02 MM	96.3

ALASKA TESTLAB

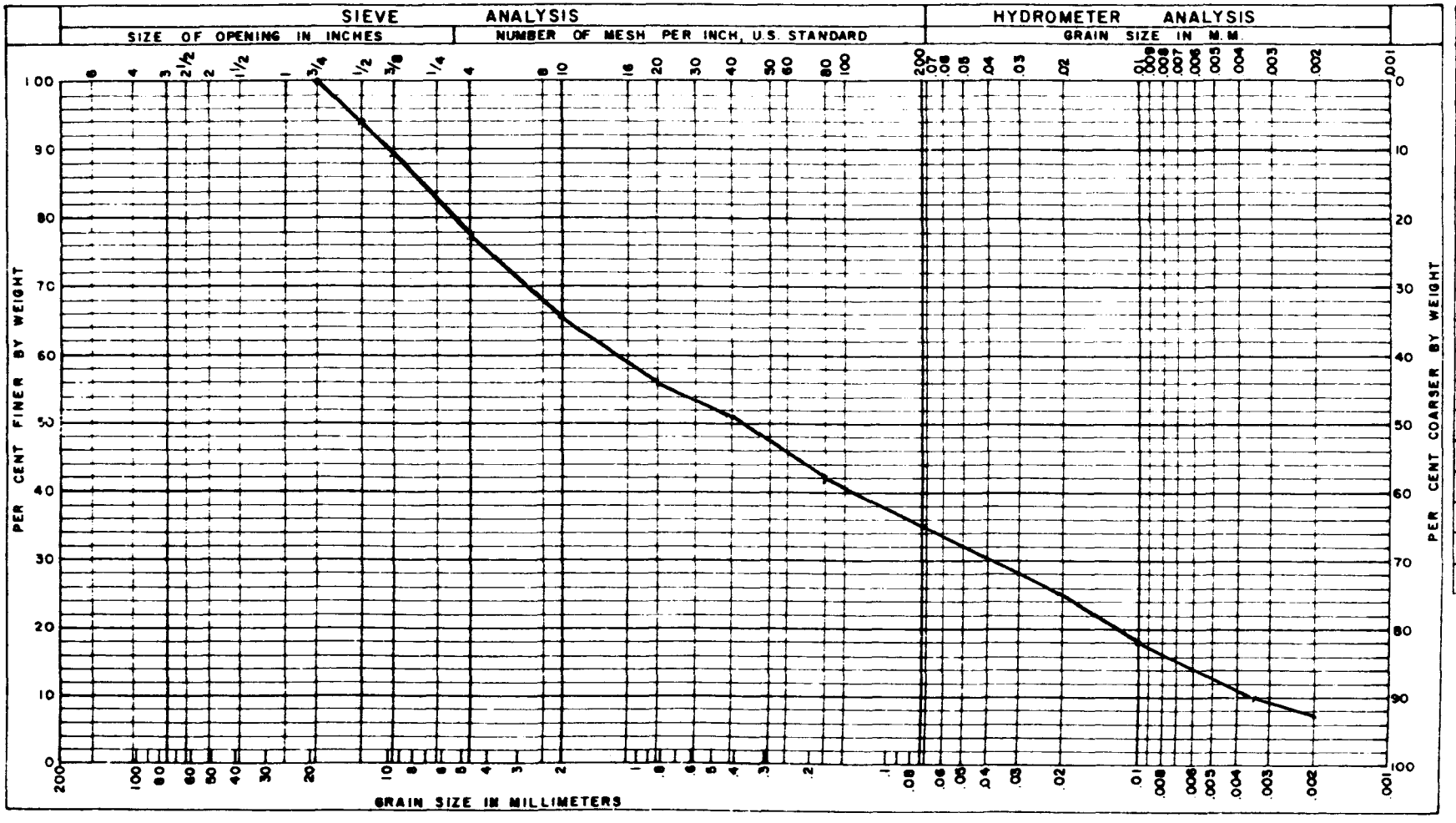
ALASKA TESTLAB

4040 B STREET
ANCHORAGE, ALASKA 99503

Sheet C8 of
W. O. No. D11751
Date 7-9-79
Technician MS

Textural Class SILTY GRAVELLY SAND
Frost Class F3 Unified Class SM
Plastic Properties
Date Received

Client ALPETCO
Project VALDEZ EIS
Sample Number
Location THD-1 68"-93"
Sample Taken By TB



U.S. STD. SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	100
1/2	94
3/8	89
4	77
10	65
20	56
40	51
80	42
100	
200	35
0.02 MM	25.2

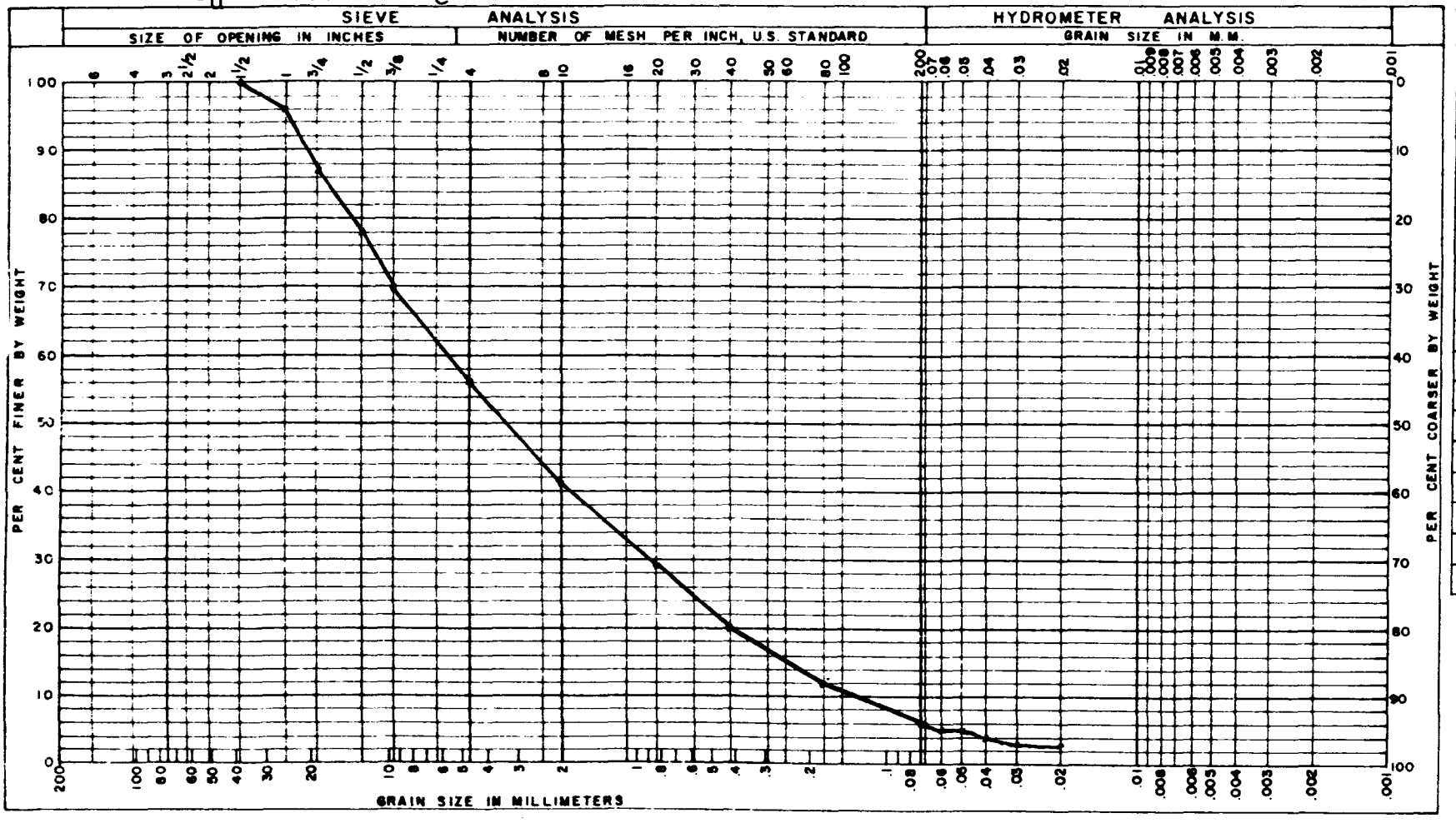
ALASKA TESTLAB

Sheet C9 of
W. O. No. D11751
Date 7-16-79
Technician MS, RS, RM, LS, TK

Textural Class GRAVELLY SAND
Frost Class NFS Unified Class SW/SM
Plastic Properties
Date Received

Client ALPETCO
Project VALDEZ E.I.S.
Sample Number GROUP A
Location
Sample Taken By TB

C_u = 43.8 C_c = 1.0



U.S. STD. SIEVE	CUM % PASS
2	
1 1/2	100
1	96
3/4	87
1/2	78
3/8	70
4	56
10	41
20	29
40	20
80	12
100	
200	66
0.02 MM	2.9

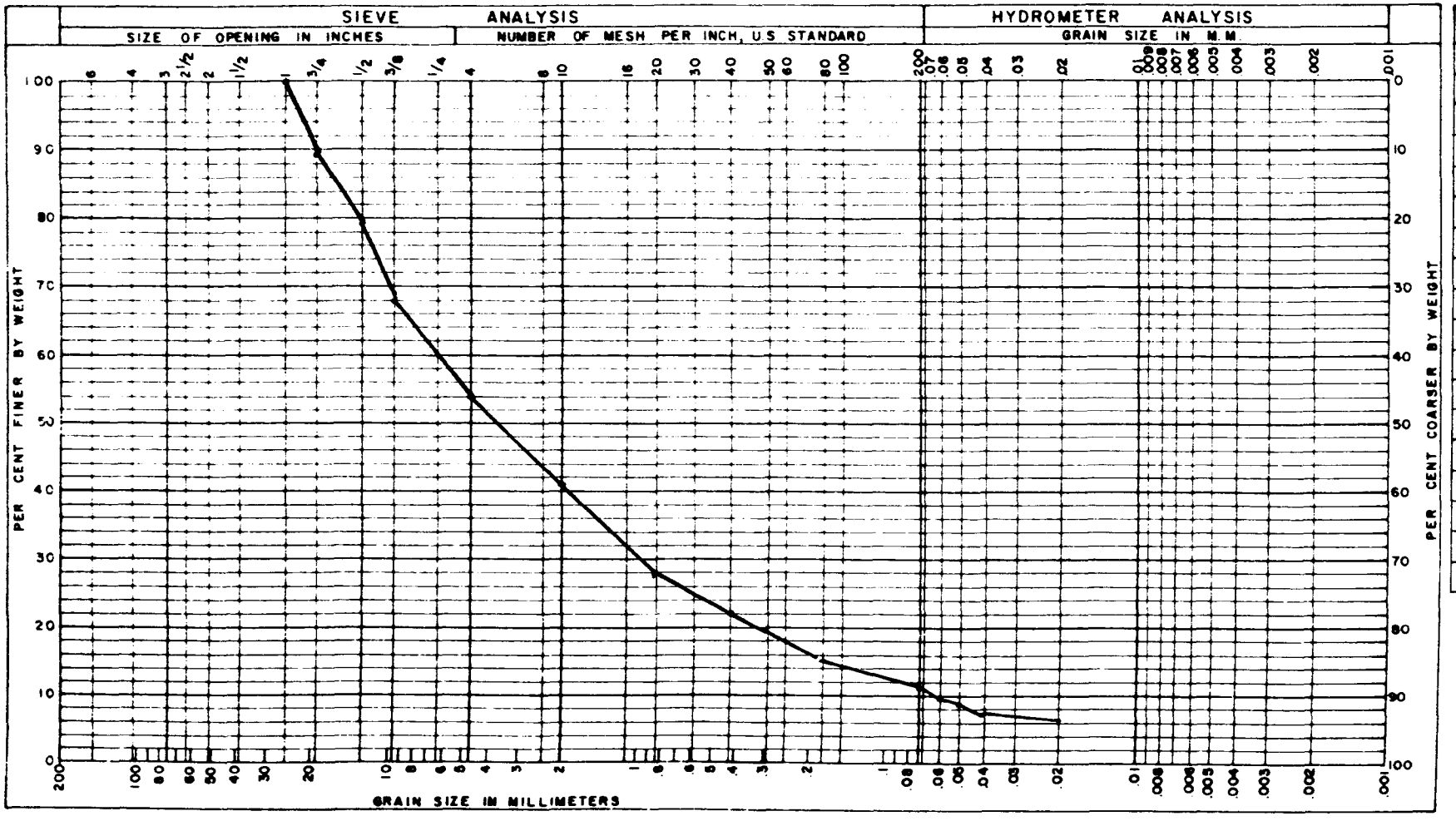
C10

ALASKA TESTLAB

Sheet _____ of _____
W. O. No. D11751
Date 7-16-79
Technician TKK

Textural Class SILTY SANDY GRAVEL
Frost Class F-1 Unified Class GW/GM
Plastic Properties
Date Received
C_u = 96.9 C_c = 2.2

Client ALPETCO
Project VALDEZ E.I.S.
Sample Number GROUP B
Location
Sample Taken By TB



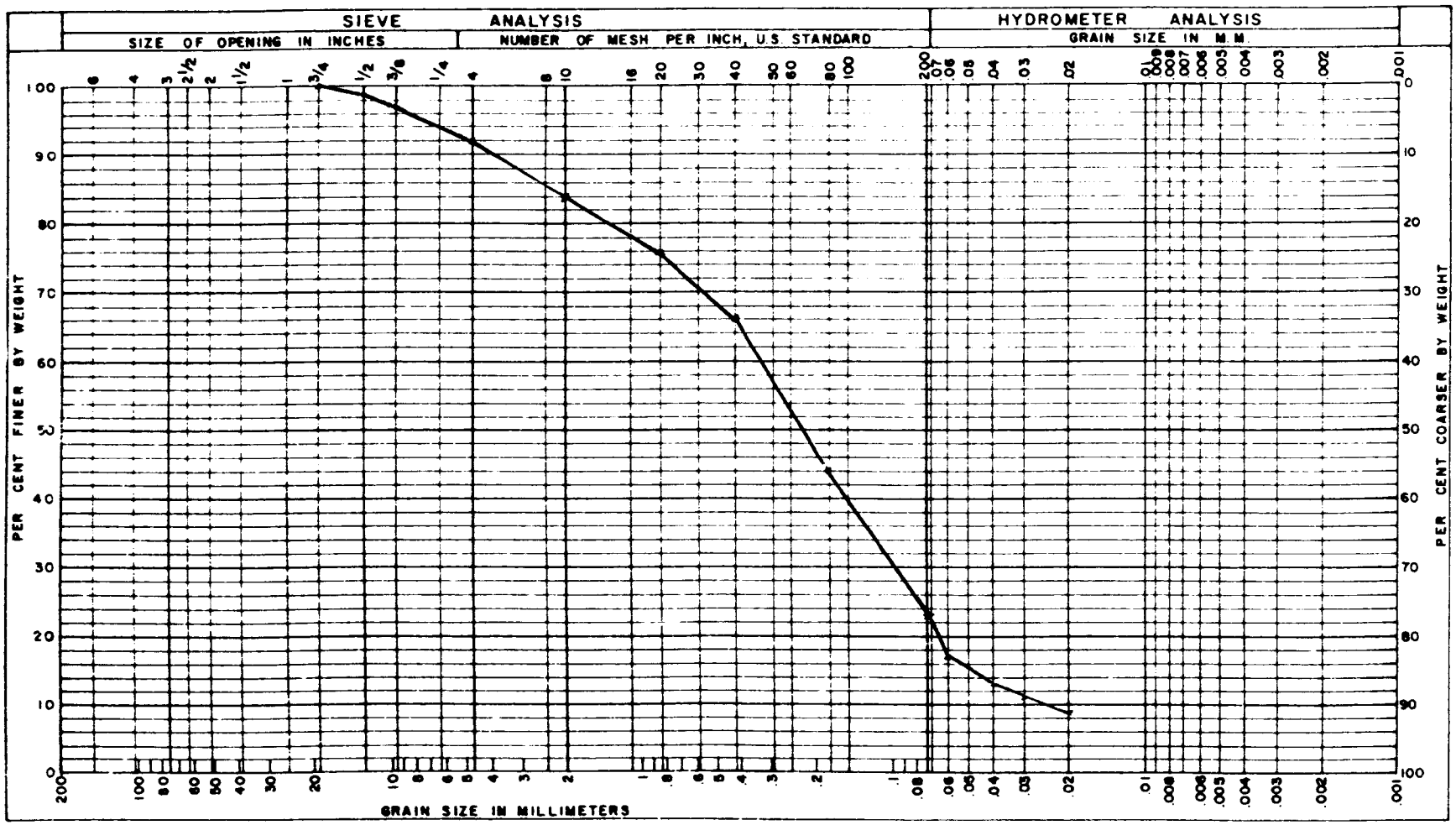
U.S. STD. SIEVE	CUM % PASS
2	
1 1/2	
1	100
3/4	89
1/2	79
3/8	68
4	54
10	41
20	28
40	22
80	15
100	
200	10.8
0.02 MM	6.3

ALASKA TESTLAB

Sheet _____ of _____
W. O. No. D11751
Date 7-16-79
Technician MS

Textural Class SILTY SAND
Frost Class F-2 Unified Class SM
Plastic Properties
Date Received
C_u = 12.2 C_c = 1.12

Client ALPETCO
Project VALDEZ E.I.S.
Sample Number GROUP C
Location
Sample Taken By TB



U.S STD SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	100
1/2	99
3/8	97
4	92
10	84
20	76
40	66
80	44
100	
200	23
0.02 MM	8.2

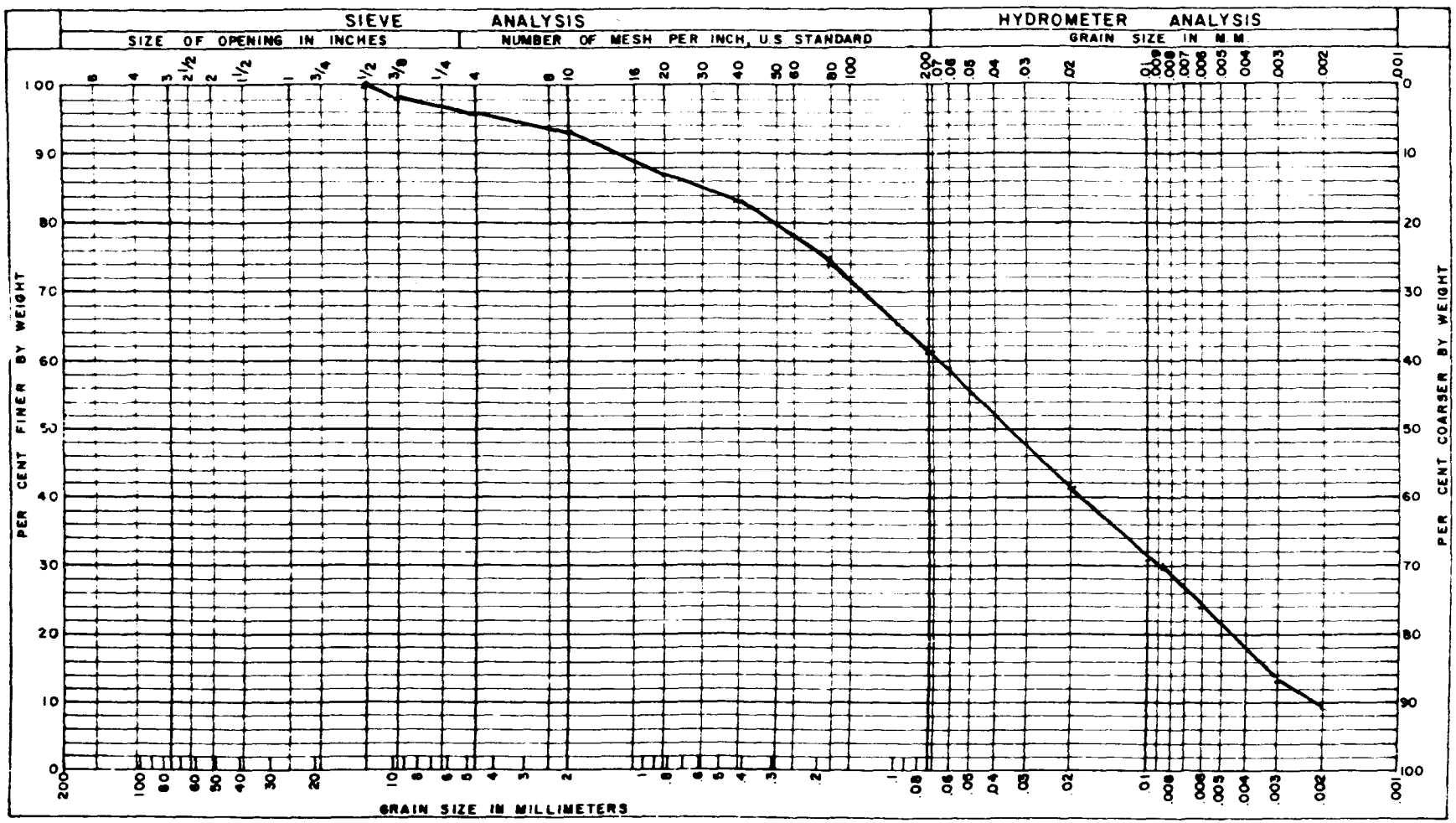
ALASKA TESTLAB

ALASKA TESTLAB

Sheet C 12 of
W. O. No. D11751
Date 7-16-79
Technician MS

Textural Class SANDY SILT (GLACIAL TILL)
Frost Class F-4 Unified Class ML
Plastic Properties LL = 26 PI = 3
Date Received

Client ALPETCO
Project VALDEZ E.I.S.
Sample Number GROUP G
Location
Sample Taken By TB



U.S STD SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	
1/2	100
3/8	98
4	96
10	93
20	87
40	83
80	74
100	
200	61
0.02 MM	43.2

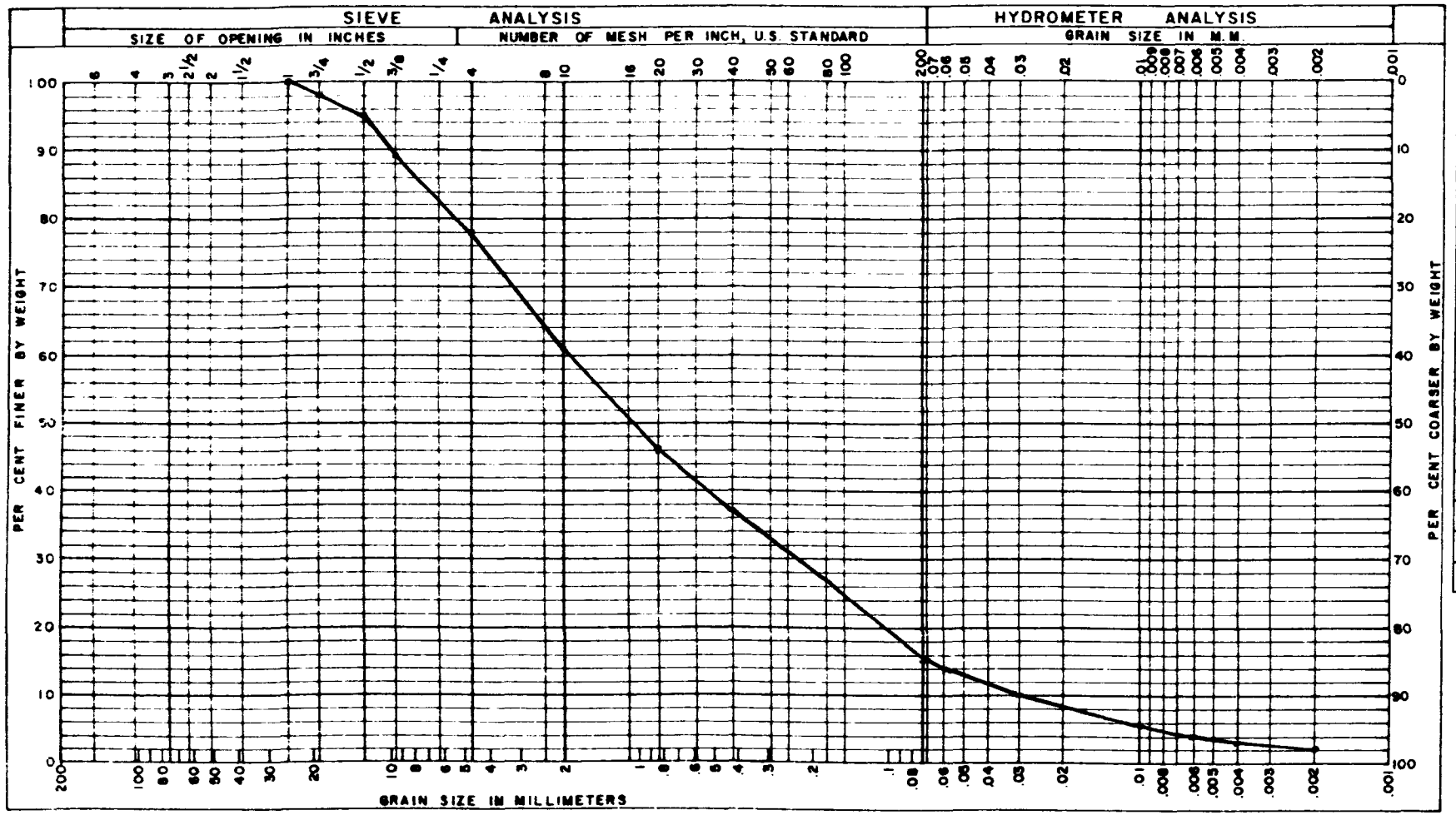
ALASKA TESTLAB

ALASKA TESTLAB

Sheet C 13 of
W. O. No. D11751
Date 7-25-79
Technician LS

Textural Class SILTY GRAVELLY SAND
Frost Class F2 Unified Class SM
Plastic Properties
Date Received 7-22-79

Client ALPETCO
Project ALPETCO EIS
Sample Number #1 PAD C-1
Location TAG DESTROYED
Sample Taken By TB



U.S. STD. SIEVE	CUM. % PASS
2	
1 1/2	
1	100
3/4	98
1/2	95
3/8	89
4	78
10	61
20	46
40	37
80	27
100	
200	15.6
0.02 MM	8.2

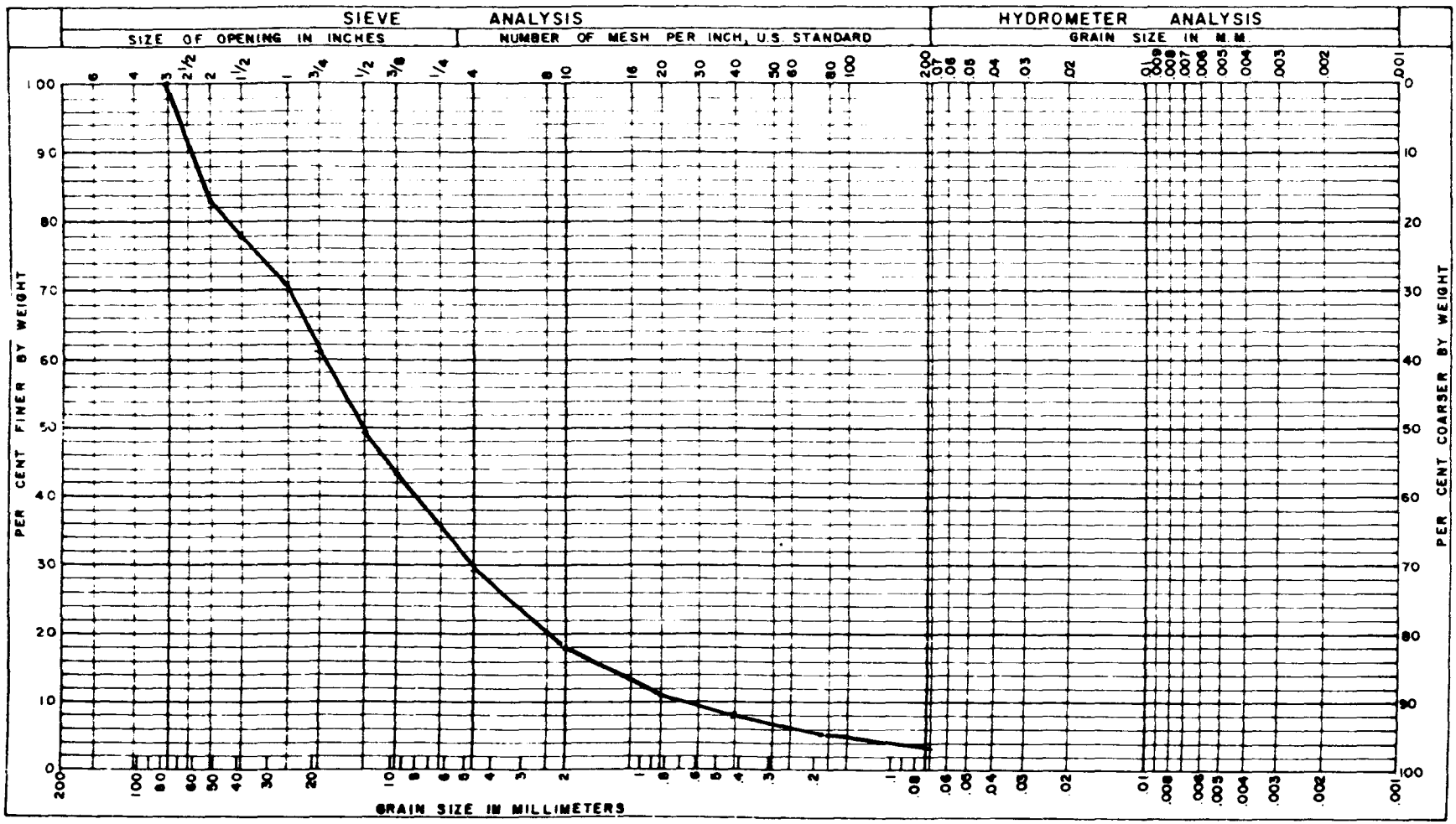
ALASKA TESTLAB

ALASKA TESTLAB

Sheet C 14 of
W. O. No. D11751
Date 7-25-79
Technician LS

Textural Class SANDY GRAVEL
Frost Class NFS Unified Class GW
Plastic Properties NP
Date Received 7-22-79
6" cobble removed from sample; numerous root systems

Client ALPETCO
Project ALPETCO EIS
Sample Number #2
Location 0.1 mile south of A-2
Sample Taken By TB



U.S. STD. SIEVE	CUM % PASS
3	100
2	83
1 1/2	78
1	71
3/4	61
1/2	49
3/8	43
4	29
10	18
20	11
40	8
80	5
100	
200	3.5
0.02 MM	

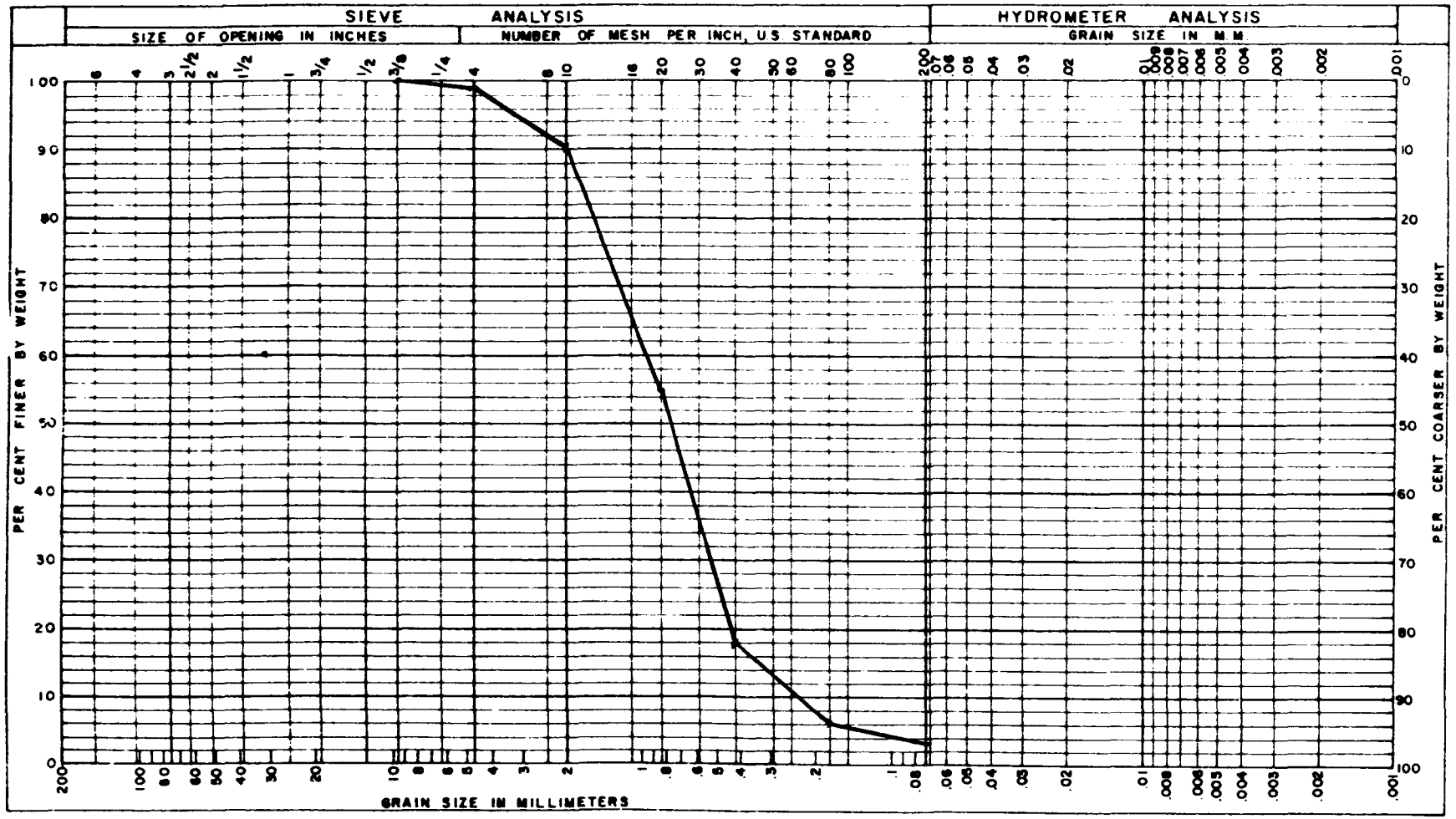
ALASKA TESTLAB

ALASKA TESTLAB

Sheet C 15 of _____
W. O. No. D11751
Date 7-25-79
Technician LS

Textural Class SAND
Frost Class NFS Unified Class SP
Plastic Properties NP
Date Received 7-22-79

Client ALPETCO
Project ALPETCO EIS
Sample Number #3
Location D-9 PAD MA
Sample Taken By TB



US STD SIEVE	CUM % PASS
2	
1 1/2	
1	
3/4	
1/2	
3/8	100
4	99
10	90
20	55
40	18
80	6
100	
200	3.2
0.02 MM	

ALASKA TESTLAB

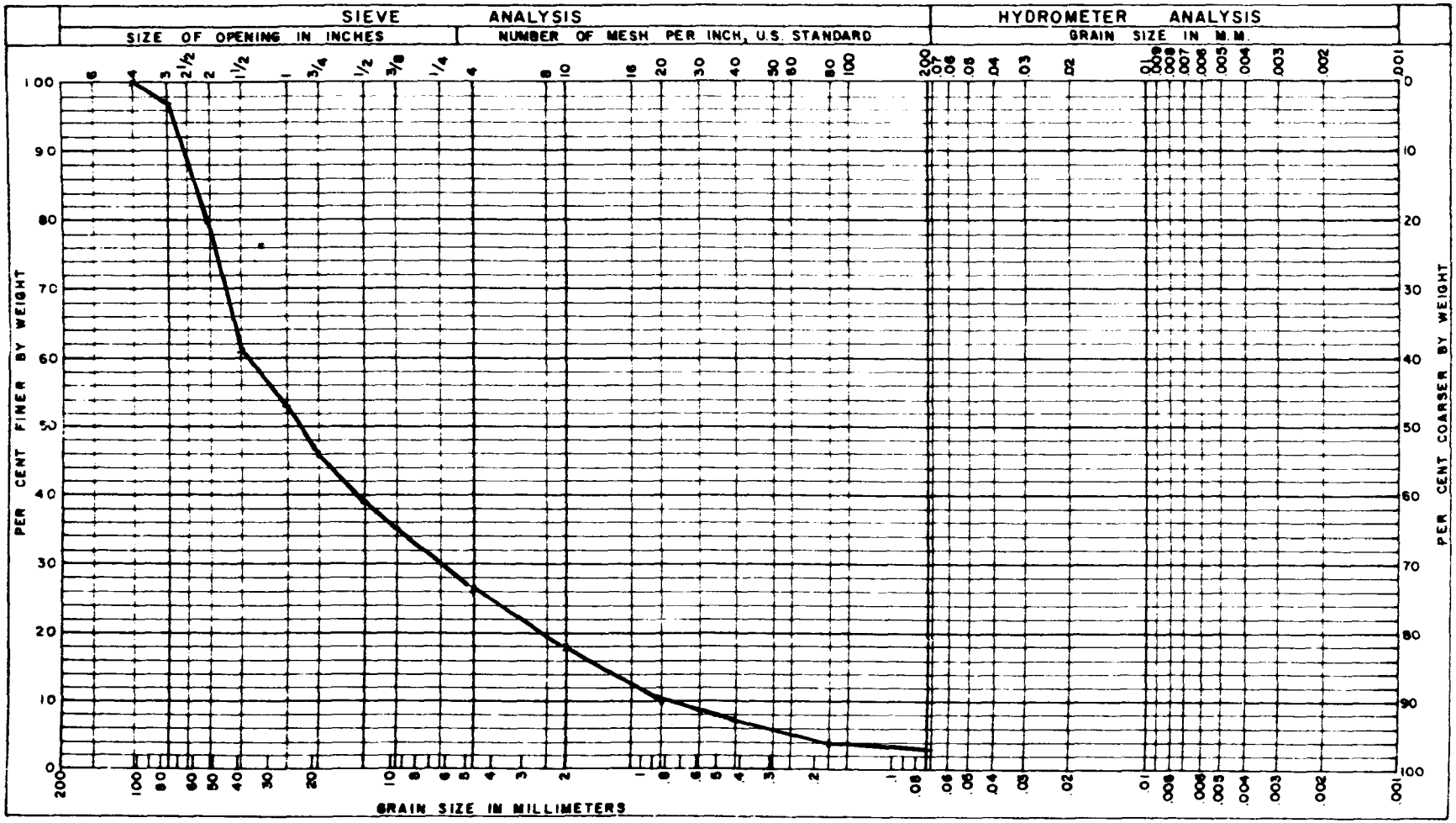
ALASKA TESTLAB

4048 B STREET
ANCHORAGE, ALASKA 99503

Sheet C 16 of
W. O. No. D11751
Date 7-25-79
Technician LS

Textural Class SANDY GRAVEL
Frost Class NFS Unified Class GW
Plastic Properties NP
Date Received 7-22-79
6" & 4" cobbles removed from sample

Client ALPETCO
Project ALPETCO EIS
Sample Number #4
Location PAD B, 2 & 3
Sample Taken By TB



U.S. STD. SIEVE	CUM % PASS
4	100
3	97
2	80
1 1/2	61
1	53
3/4	46
1/2	39
3/8	35
4	26
10	18
20	10
40	7
80	4
100	
200	2.5
0.02 MM	

ALASKA TESTLAB

4040 "B" STREET
ANCHORAGE, ALASKA 99503
(907) 278-1551

August 1,1979
W.O. #D11751

DOWL Engineers
4040 "B" Street
Anchorage, Alaska 99503

Re: Alpetco Project

Attention: Mr. Harry Lee

Dear Harry,

As per your request, we have performed ALASKA METHOD T-13-69, Degradation of Aggregate on the "Large Bag" sample labeled Pad B, 2 & 3 submitted to our laboratory on July 22, 1979.

The degradation factor was determined by the formula:

$$D = \frac{15 - H}{15 + 1.75H} \times 100$$

Where D= Degradation factor
H= Height of Sediment in Tube (inches)

Values may range from 0 to 100, with high values being more suitable material. "H" for this sample was 2.8 therefore:

$$D = \frac{15 - 2.8}{15 + 1.75\ (2.8)} \times 100$$

D= 61

If you have any questions, please do not hesitate to contact our office.

Very truly yours,

ALASKA TESTLAB

Melvin R. Nichols
Laboratory Manager

MPN/11

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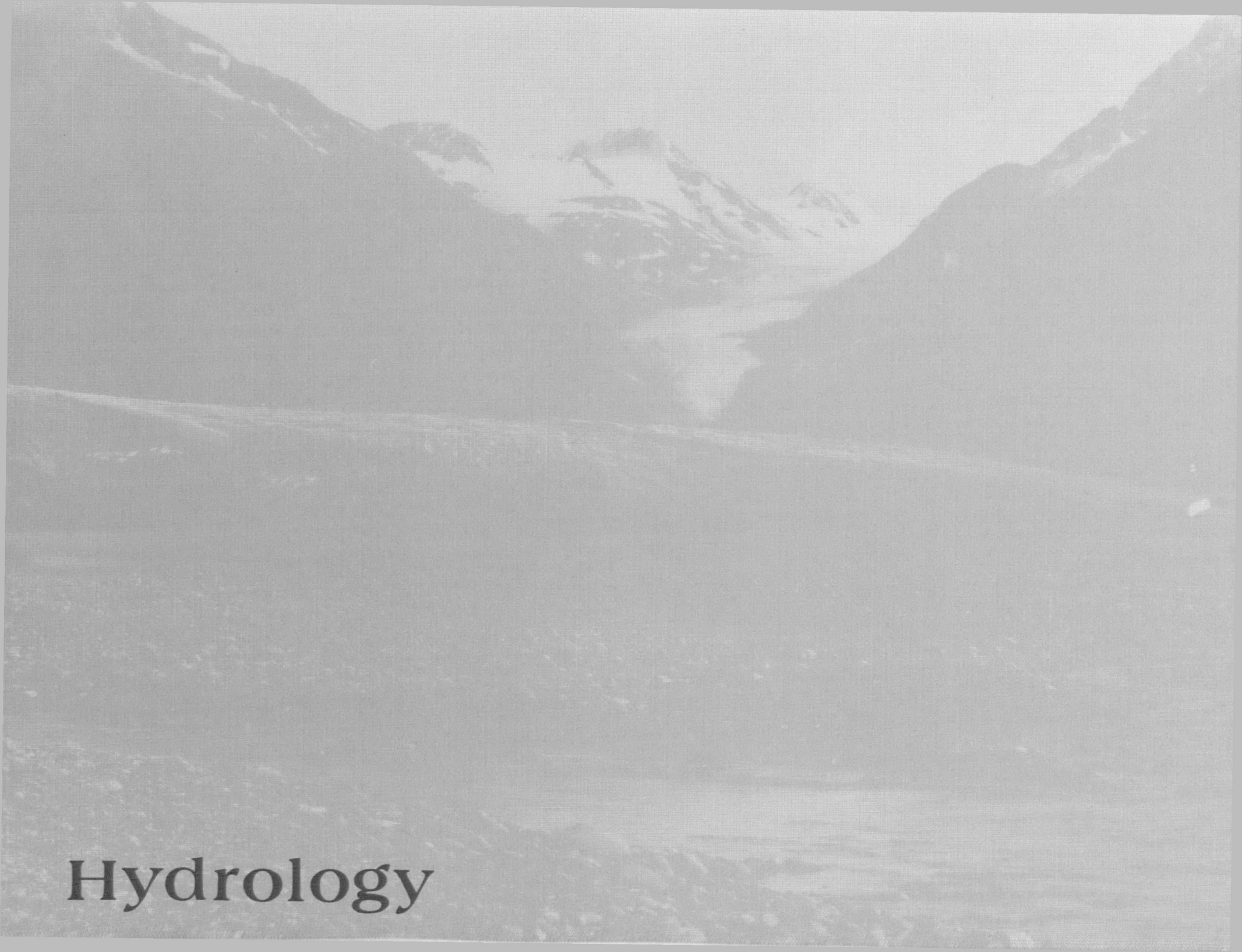

Hydrology

HYDROLOGY

EXISTING CONDITIONS

General

The project site is located east of the Valdez Glacier Stream and generally north of Corbin Creek (Glacier) on the outwash plain created by the Valdez Glacier. The site slopes from north to south at approximately 1-1/2 percent. Over most of the site, the subsurface materials consist of stream deposited gravels, sands, and boulders with some relatively thin interbedded layers of silt. At an elevation referenced to mean sea level, varying from 0 to -19 m (0 to -64 ft), an extensive silt layer was encountered during drilling operations, which apparently extends under the entire project site. This relatively impermeable layer divides the more porous materials above and below into two distinct aquifers.

Upper Aquifer

Over virtually the entire site, the materials in the upper portion of the soil horizon are sufficiently permeable that a water table aquifer situation exists which is capable of quite high production rates. The level of the water table slopes gently from north to south, being 12 to 18 m (40 to 60 ft) below the surface near the north end of the site and at the surface near the southern edge of the site. The winter flows noted in Valdez Glacier Stream, Corbin Creek (Robe) and Brownie Creek are due to the drainage of groundwater into the water courses. It is apparent from the highly permeable nature of the material at the surface, that recharge occurs to this unconfined aquifer, directly from the streams traversing the area. Also, most of the rainfall during the summer months soaks into the ground. Investigations early in the spring of 1979 determined that some year-round flow exists in the Corbin Creek (Glacier) drainage (approximately 5 cubic feet per second) where it enters the outwash plain at the east edge of the site; however, this flow quickly disappears into the gravels of the stream bed during winter months because the remainder of the channel stands dry. Also, melt water and rainfall-fed streams from the mountains around the eastern perimeter of the site are lost in the gravels of the outwash plain. In addition, some snowmelt and winter rains are believed to occur which directly enter the soil with little or no runoff.

As the drilling work on the site occurred during June and July, it was not possible to conclusively verify the possible dynamic seasonal fluctuations of the unconfined

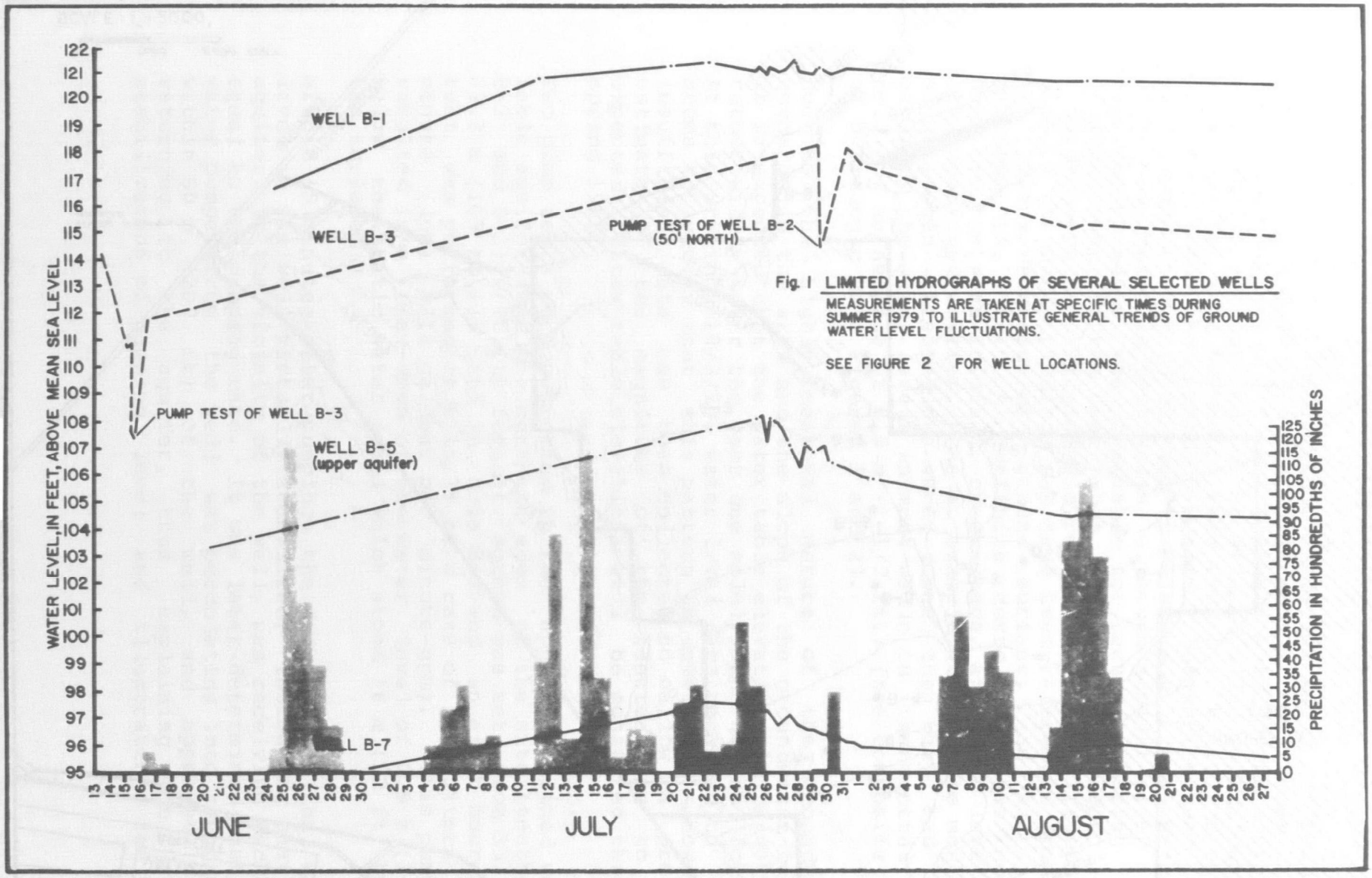

FIGURE 1 LIMITED HYDROGRAPHS OF SEVERAL SELECTED WELLS

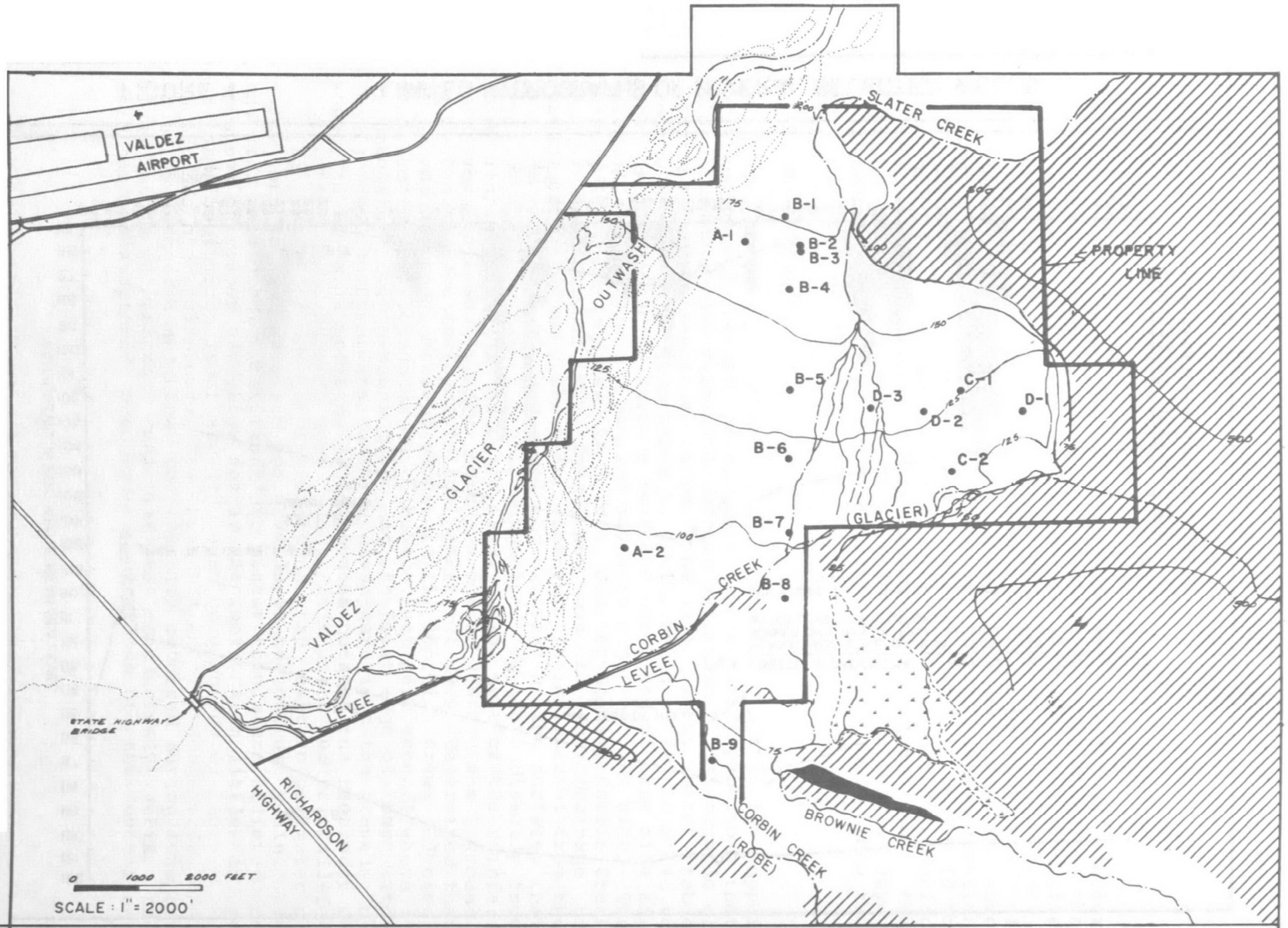

Fig. 2 WELL & TEST HOLE LOCATION MAP

water table. The water table elevation was first read in Well B-3 on 6/14/79, after a large part of the summer stream runoff had already occurred. During the following month the water levels in that and other wells drilled in the central area of the site seemed to rise from 2 to 6 ft., depending on the well and the period of record. During the last half of July and the month of August, relatively little change in level was noted in most wells, although similar creek flows and precipitation was available for recharge during that period. Due to the fact that the earliest water levels recorded were primarily single readings, it is believed that some of the early readings may have been referenced from top of casing instead of ground surface, as all other measurements were. A definite correlation was noted, however, between rainfall, creek stage, and water levels in the unconfined aquifer. As an example, during the month of August, when stream-flows were lower than they had been earlier, the water levels in most wells in the central area fell by an average of 0.5 m (1-1/2 ft.) (see composite plot of hydrologic data Figures 1 and 2).

Due to the highly seasonal nature of the groundwater recharge in the area and the slope of the groundwater table, it is expected that the water table elevation will fluctuate rather widely over the year due solely to natural forces. At this writing, 10/3/79, water level data recorded to date seems to verify that this pattern is developing; however, insufficient data has been collected to allow a precise estimate of the magnitude of the fluctuations to be expected. Water table elevations will be monitored through spring 1980.

Two pump tests were performed in the upper unconfined water table aquifer near the northern edge of the site (testholes B-2 and B-3). Thirty feet of screen was set from 33.2 to 42.3 m (109 to 139 ft) in hole B-3 and an eight hour pump test was performed on 6/15/79 at a rate of 1204 liters per minute (lpm) (318 gallons per minute-gpm). This pumpage resulted in a draw-down of the water level of 0.9 m (3 ft) below the static water level which stood 16 m (52 ft) below the surface.

Within 15 minutes after pumping, the draw-down of the water level in the well virtually stabilized, indicating that the aquifer, in the vicinity of the well, was receiving recharge equal to the pumping rate. It was later determined that the water pumped from the well was percolating into the ground within 60 m (200 ft) of the well, and appeared to be returning to the aquifer, thus explaining the rapid stabilization of pumping level and illustrating the high

permeability of the soils.

In testhole B-2, located 15 m (50 ft) north of B-3, a well screen was installed between 38 and 44 m (125 and 145 ft) below the surface and a 72 hour pump test was performed at a rate of 5,870 lpm (1550 gpm).

In an attempt to prevent the re-circulation of pumped water which had been suspected during the preliminary pump test of well B-3 on 6/15/79, an 8" steel pipeline was assembled 167 m (550 ft) toward Slater Creek. The groundwater level drawdown was about 5.5 m (16 ft) below the static water level of 14.6 m (47.8 ft) below ground surface. Although water levels were monitored at all wells on the site during the pump test, only wells B-3 and B-4, located 15 m (50 ft) and 150 m (500 ft), respectively, south of the pumped well showed water level changes which could be attributed to the pump test. The water level drawdown in well B-3 totaled 1.27 m (4.17 ft) and stabilized within 8-1/2 hr. after pumping began. The drawdown in well B-4 totaled approximately 0.56 m (1.83 ft). The pump test proved inconclusive in accurately defining the aquifer characteristics such as storage coefficient and transmissivity. There may have been some confining aquifer influence that affected the performance. The transmissivity of the aquifer, however, is estimated to be over a million gallons per day per foot.

The quality of the water from the unconfined aquifer is quite good. It is within the limits set by State of Alaska and EPA for all specified contaminants and is only moderately hard (see water analysis report). This could be due to the fact that the valley geology is "new", so the water has not had extensive contact time in which to absorb minerals from the formation. Its temperature at 5.2°C (41.5°F) is relatively warm when compared to most Alaskan groundwaters.

Lower Aquifer

The lower or confined aquifer consists of sandy gravels which lie below the silt layer that blankets the site at depth. Correlation of static water level, or pressure of the water in the formation, in each of the various wells which penetrated below the silt layer, indicates that this lower aquifer is well separated from the unconfined aquifer above. It was determined, however, that in the eastern end of the site, the separation becomes less certain. The static water levels of the lower formation define a much flatter slope from north to south than do the water levels

TABLE 1

Ground water quality data conducted by Chemical and Geological Laboratories of Alaska, Inc., for Test Well B-2 (Upper Aquifer), Valdez, Alaska.

	mg/l		mg/l
Ag, Silver	<0.003	Ti, Titanium	<0.01
Al, Aluminum	0.01	W, Tungsten	<0.01
As, Arsenic	<0.05	V, Vanadium	<0.01
Au, Gold	<0.01	Zn, Zinc	0.006
B, Boron	0.01	Zr, Zirconium	<0.01
Ba, Barium	<0.01	Ammonia-N	<0.02
Bi, Bismuth	<0.05	Nitrate-N	0.9
Ca, Calcium	24	Nitrite-N	<0.01
Cd, Cadmium	<0.0005	Phosphorus-P	0.01
Co, Cobalt	<0.01	Chloride	<2
Cr, Chromium	<0.01	Fluoride	0.6
Cu, Copper	0.003	Cyanide	<0.002
Fe, Iron	0.02	Sulfate	1
Hg, Mercury	0.0003	Total Dissolved Solids	71
K, Potassium	1.4	Hardness as $CaCO_3$	67
Mg, Magnesium	1.6	Alkalinity As $CaCO_3$	62
Mn, Manganese	<0.01	Oil & Grease	<0.1(*)
Mo, Molybdenum	<0.01	Hydrogen Sulfide	<0.003
Na, Sodium	2.2	Iron Bacteria	0
Ni, Nichel	<0.01	mmhos Conductivity	190
P, Phosphorous	0.01	pH Units	6.8
Pb, Lead	<0.02	Turbidity NTU	<1
Pt, Platinum	<0.01	Color Units	<5
Sb, Antimony	<0.01	Drinking Water Analysis for Total Coliform Bacteria	Satisfactory
Se, Selenium	<0.01		
Si, Silicon	3.6	Cation-Anion Balance	+0.08
Sn, Tin	<0.01		
Sr, Strontium	0.16		

(*) Lowest detection limit obtainable with amount of sample submitted.

of the unconfined aquifer. Near the north end of the site (well B-3) the static water level of the lower formation was found to be 8 to 9 m (25 to 30 ft) lower than the unconfined aquifer; and at the south edge (hole B-9) the confined formation had a static level 2.4 m (8 ft) above the ground surface, while the unconfined formation had a level approximately at the surface. For this reason, it appears that the lower aquifer has little connection with the surface drainage, at least within the proximity of the site.

Due to the flatter gradient of the static water level in the lower formation, it is apparent that this aquifer does not exhibit the dynamic fluctuations expected of the unconfined aquifer and is likely recharged at a much slower rate. In fact, the pump test performed on this aquifer at well B-3 indicated that recharge may be nearly non-existent. The recharge which this formation does receive likely has two major components. Firstly, it is possible that it receives a significant portion of its recharge from leakage through minor interconnections with the unconfined system. Also, it is likely that a considerable portion of recharge is contributed from flows through bedrock fissures. This aquifer was test-pumped at well B-3 using a screen installed from 140 to 150 m (465 to 500 ft). It was pumped at a rate of 1230 lpm (328 gpm) for 24 hours (7/25 and 26/79) which lowered the water level in the well 5 m (16.5 ft) below the static water level of 23 m (78 ft) below ground surface. Analysis of the drawdown data did not reveal an indication of any recharge sources within the influence radius of the well. It did, however, indicate the existence of impervious boundaries of the aquifer. All factors indicate that this confined aquifer would not be able to support sustained high pumping rates.

The quality of the water from this aquifer is only slightly lower than that of the unconfined aquifer, but still well within government requirements. Table 2 provides the water quality analyses for the confined aquifer.

Aquifer Interconnection

From the water level observations and pump test data, it appears that, within the vicinity of the wells which were pumped (B-2 and B-3) very little interconnection exists between the aquifers.

EFFECT OF ENVIRONMENT ON PROPOSED PROJECT DEVELOPMENT

General

TABLE 2

Ground water quality data conducted by Chemical and Geological Laboratories of Alaska, Inc., for Test Well B-3 (Lower Confined Aquifer), Valdez, Alaska.

	mg/l		mg/l
Ag, Silver	<0.003	Ti, Titanium	<0.01
Al, Aluminum	<0.01	W, Tungsten	<0.01
As, Arsenic	<0.05	V, Vanadium	<0.01
Au, Gold	<0.01	Zn, Zinc	<0.005
B, Boron	0.01	Zr, Zirconium	0.01
Ba, Barium	<0.01	Ammonia-N	<0.02
Bi, Bismuth	<0.05	Nitrate-N	1.3
Ca, Calcium	36	Nitrite-N	0.02
Cd, Cadmium	0.001	Phosphorus-P	0.06
Co, Cobalt	<0.01	Chloride	<2
Cr, Chromium	<0.03	Fluoride	0.6
Cu, Copper	0.002	Cyanide	<0.002
Fe, Iron	0.03	Sulfate	7.1
Hg, Mercury	0.0008	Total Dissolved Solids	124
K, Potassium	0.8	Hardness as $CaCO_3$	95
Mg, Magnesium	1.2	Alkalinity As $CaCO_3$	117
Mn, Manganese	<0.01	Oil & Grease	<0.1(*)
Mo, Molybdenum	<0.01	Hydrogen Sulfide	<0.003
Na, Sodium	2.7	Iron Bacteria	0
Ni, Nichel	<0.01	mmhos Conductivity	270
P, Phosphorous	0.06	pH Units	7.2
Pb, Lead	<0.02	Turbidity NTU	<0.1
Pt, Platinum	<0.01	Color Units	<5
Sb, Antimony	0.01	Drinking Water Analysis for Total Coliform Balance	Satisfactory
Se, Selenium	<0.01		
Si, Silicon	5.7	Cation-Anion Balance	+0.06
Sn, Tin	<0.01		
Sr, Strontium	0.08		

(*) Lowest detection limit obtainable with amount of sample submitted.

The groundwater environment will have little effect on the majority of the site area. The only exceptions to this statement are the areas adjacent to Corbin Creek (Glacier) along the south edge of the site, and the areas around the headwaters of Corbin Creek (Robe) and Brownie Creek. This area has been ruled out for plant facility locations, due to the fact that these drainages have been identified as salmon spawning streams, and since the high water table in the area would surely be disturbed by any major construction operations in the area. The area along Corbin Creek (Glacier) would be characterized by an extremely high water table elevation, standing at or above the surface during mid to late summer months. This factor could require special measures to prevent flooding of facilities constructed near the stream. In addition, it would be wise to schedule any subsurface excavations in that area to occur during the period between November and May. Water supply for minor and/or short term uses could be withdrawn from either aquifer at virtually any point in the site where it may be desired (see "Proposed Development Approach" section for details on recommended water supply withdrawals).

EFFECT OF DEVELOPMENT ON ENVIRONMENT

General

The proposed site may be safely developed for the proposed purpose without causing significant degradation to the groundwater environment. In order that this may be accomplished, however, certain precautions must be taken in the design of the facility and the subsequent construction and operation. These considerations are concerned basically with three parameters: pumpage, recharge, and contamination. Pumpage and recharge are, of course, interrelated.

Pumpage

The upper, unconfined, aquifer under the site, as mentioned above, appears to be the major source of water for Corbin (Robe), Glacier Creek, and possibly to a lesser extent, Brownie Creek, during winter months. Since Brownie and Corbin (Robe) Creeks have been identified as salmon spawning streams, their flow must be maintained throughout the winter to ensure the survival of the salmon fry. It is conceivable that, should the water table be lowered drastically, the flows in these creeks could be reduced sufficiently to be detrimental to the fish populations. It is estimated that at the proposed demand rate of 1,700,000 gallons per day required for operation of the facility, one could expect the

water table to be drawn down approximately 2 m (6 ft) during the winter months when no appreciable recharge is being received by the water table. It is felt that this magnitude of draw-down would cause little, if any, noticable effects to the stream environment. If, however, the streams begin to be affected by winter water table draw-down, it would be feasible to make up any deficit in stream flow by piping water from the plant water system into the streams. The indications are that adequate recharge will be available during the summer months to provide whatever quantity is reasonably required.

Due to the gradient, or slope, of the water table of the unconfined aquifer, and its significant elevation above sea level, approximately 21 meters (70 feet) on the site, the relatively small drawndown of the water table in the area due to withdrawal of operational quantities of water could not cause infiltration of saltwater into the aquifers. The lower aquifer also has a water pressure level considerably above sea level (approximately 19.5 meters, 65 feet), thus it would be necessary to lower the pressure in that aquifer by nearly 30 meters (100 feet) to provide the elevation difference necessary to allow the possibility of saltwater intrusion into the aquifer.

The lower, or confined aquifer, apparently does not surface in the near vicinity of the project site. For this reason, it is expected that the environmental effect of any pumping from that aquifer would be very small within the area of the proposed site.

Recharge

Although insufficient data is presently available to fully assess the total groundwater recharge capability of the site as it presently exists, it is felt that the combination of highly permeable materials at the surface, abundant precipitation, and close proximity to large streams should provide sufficient recharge to the unconfined aquifer located under the site so that continuous pumpages as high as 3-4 mgd may be safely withdrawn.

Contamination

The porous nature of the surface materials found over the majority of the site area causes the unconfined aquifer to be vulnerable to contamination by spills of petrochemical products on the ground surface. The degree of hazard from this contamination source would be highest for the intermediate specific gravity constituents, such as light

fuel oils, etc. The lighter fractions (gasoline, naptha, etc.) will eventually dissipate from the ground. The heavier materials, such as crude oil, asphalt, etc., would have a better likelihood of being cleaned up before large amounts soaked into the ground to any great depth. The light fuel oils, however, in an underground situation will persist almost indefinitely, and are of a sufficiently light viscosity to soak into the permeable gravels to great depths before cleanup could be effected. In addition, the porous nature of the material will allow leaching of virtually any water soluble contaminant which may be present on the surface in significant quantities.

The lower, or confined, aquifer located under the site, however, is well protected from any accidental contamination from surface.

PROPOSED DEVELOPMENT APPROACH (Mitigation Measures)

General

The environmental effects mentioned above are not of such severity that they can not be accommodated by the design and in the construction of the facility. In fact, for the most part the environmental constraints on the groundwater use and protection will incur very little extra in the way of unusual construction expense.

Water Source Development

Pump tests performed on the unconfined aquifer have indicated that sufficient water is available for the proposed needs of the facility.

Due to the dynamic nature of the recharge/draw down cycles of the aquifer which are expected to occur normally over the various seasons of the year, it is felt that any possible impact on the critical salmon spawning streams near the south edge of the site may be minimized by withdrawal of any large long term quantities from near the northern edge of the site.

Major design features such as air cooling are being planned that would minimize the effect of pumpage on the water table elevations in the south edge of the site. These mea sures should hold the effects on the water table in that area to an acceptable amount. The water levels and flow rates in Corbin Creek (Robe) and Brownie Creek could be monitored during the winter months. If it is found that their flow becomes adversely affected by a declining water table,

sufficient flow from the facility water system or from a well could be supplied to the creek system to make up the flow deficit which develops. This extra pumpage which would likely not be required for more than 2 or 3 months would easily be replenished by the high recharge rates available during summer months. As mentioned previously, small and/or intermittant water demands over the remainder of the site could be withdrawn virtually anywhere they are required without measureably influencing the water table aquifer.

Due to the abundance of water available in the unconfined aquifer, its relatively good quality, and the high recharge capability from the surface streams, it is believed that development of production wells in the deeper, confined aquifer would not be necessary. In order to insure that groundwater recharge within the project site will remain at the present high levels, it is recommended that any channelization of Corbin Creek (Glacier) and Slater Creek be as shallow and broad as possible, roughly approximating the surface area available to groundwater infiltration as it presently exists during average high water periods during the summer.

The proposed diversion of Slater Creek into Valdez Glacier Stream will remove a recharge source from the central protion of the site; it is felt that this will not materially lower the average annual water table level under the majority of the site. In order to partially make up for this loss, it is recommended that the water which runs off of the mountains east and north of the site be allowed to percolate into the ground.

Pollution

The control of pollution to the unconfined water table aquifer is probably the most serious groundwater related design problem presented by the site. As mentioned above, spills of light oils would be particularly damaging to the quality of the water from the unconfined aquifer. For this reason, it is important that all areas in which spills could occur be diked and sealed with a material of sufficiently low permeability that cleanup work would be practical if a spill occurred.

I) GENERAL DESCRIPTION

The proposed Alpetco project site is located approximately five miles east of the City of Valdez, bounded on the west by Valdez Glacier Stream, on the north by Slater Creek, on the south by *Corbin Creek (Glacier), and on the east by bedrock spurs of Chugach Mountains. Figure I.1 shows the location of the study area, and illustrates the important drainage systems within this area. Corbin Creek (Glacier) cuts through the study area discharging into Valdez Glacier Stream. Slater Creek also flows within the study area in a southerly direction, before it drains into Corbin Creek (Glacier). The study area also encompasses Brownie and Corbin Creek (Robe) drainage systems which were originally included within the proposed project bounds.

Principal Streams

Valdez Glacier Stream, draining an area of 157 square miles, is the principal drainage system immediately adjacent to the project site. This stream heads at the foot of the Valdez Glacier on the south slope of the Chugach Mountains. During the summer, it is fed by rainfall and by meltwater from snowfields and glaciers in the high mountains separating coastal zones from interior Alaska. Although snowmelt during the months of June and July provides the first high volume of flow, the maximum discharge generally results from rain run-off and glacier melt during the late summer and early fall. During the winter, low flows will occur when the stream is fed by groundwater contributed by the surface flows in the upper reaches of Corbin Creek (Glacier), although there may be some groundwater feeding at the headwaters of Valdez Glacier Stream itself. Other physical characteristics of Valdez Glacier Stream basin are:

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*Alaska Department of Fish and Game designates Corbin Creek (Glacier) as that part of Corbin Creek from the headwaters to its discharge into Glacier Stream, and Corbin Creek (Robe) as that part of Corbin Creek lying south of the dike and which drains into Robe Lake. This usage will be retained throughout the report.

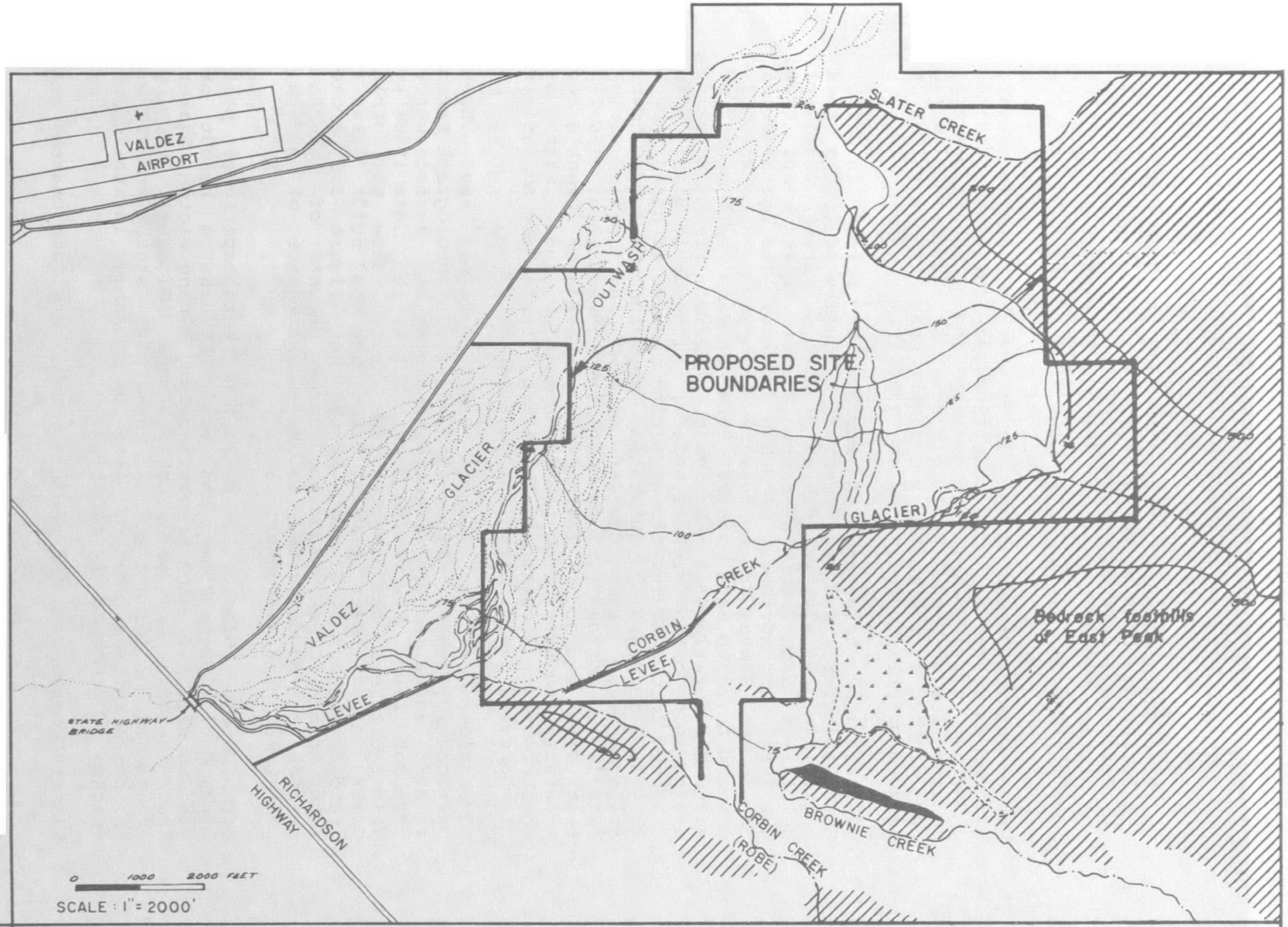


Figure I.1 STUDY AREA

TERRESTRIAL HYDROLOGY

Mean basin elevation	:	3480 ft. Mean Sea Level
Percentage Glacial coverage	:	56
Percentage lake coverage	:	<1%
Stream length	:	24.9 miles
Stream slope	:	252 feet per mile

Valdez Glacier Stream is of glacial origin, and is a swift meandering stream with continuously shifting braided channels. It flows into the eastern end of the Valdez Arm, an extension of Prince William Sound. An alluvial delta has been formed at its mouth, due to the heavy concentration of scoured material supplied by the glacier.

The principal tributary of the Glacier Stream is Corbin Creek (Glacier), and the principal tributary of Corbin Creek (Glacier) is Slater Creek. Corbin Creek (Glacier) originates from Corbin Glacier. Slater Creek heads from glaciers lying northwest of Rubin Glacier. The channels of Corbin and Slater Creeks traverse the study area roughly perpendicular to each other. Both streams have undergone several alterations in the past. Slater Creek normally drains into Corbin Creek (Glacier), although it might have branched into Glacier Stream during periods of high flows. The 1952 U.S.G.S. quadrangle map shows Slater Creek draining into both Glacier Stream and Corbin Creek (Glacier). Currently, a band of high ground about 150-200 feet wide and about 10-15 feet above Slater Creek's bed separates the creek from the floodplain of Glacier Stream at their closest location. Therefore, there is no surface discharge of Slater Creek into Glacier Stream.

Alterations of the Corbin Creek channel have been particularly severe. Figure I.2, an aerial photograph taken in 1950, shows Corbin Creek discharging its surface water into Robe Lake. However, a dike built in the late 1950s by Valdez citizens has diverted the surface flow of Corbin Creek into Glacier Stream. The dike was built after a braided channel of Glacier Stream (see Figure I.2) broke into Corbin Creek, allowing large amounts of glacial sediment to be deposited in Robe Lake (State of Alaska, 1979) causing rapid deterioration.

Both Corbin (Glacier) and Slater Creeks experience peak flows during late summer and early fall as a result of glacial melt and high precipitation. During winter, Slater Creek becomes dry and Corbin Creek (Glacier), fed by groundwater originating in the high steep mountains, maintains surface flows of open water only in its upper reaches adjacent to the foothills.

Slater Creek enters the project site as one main channel but

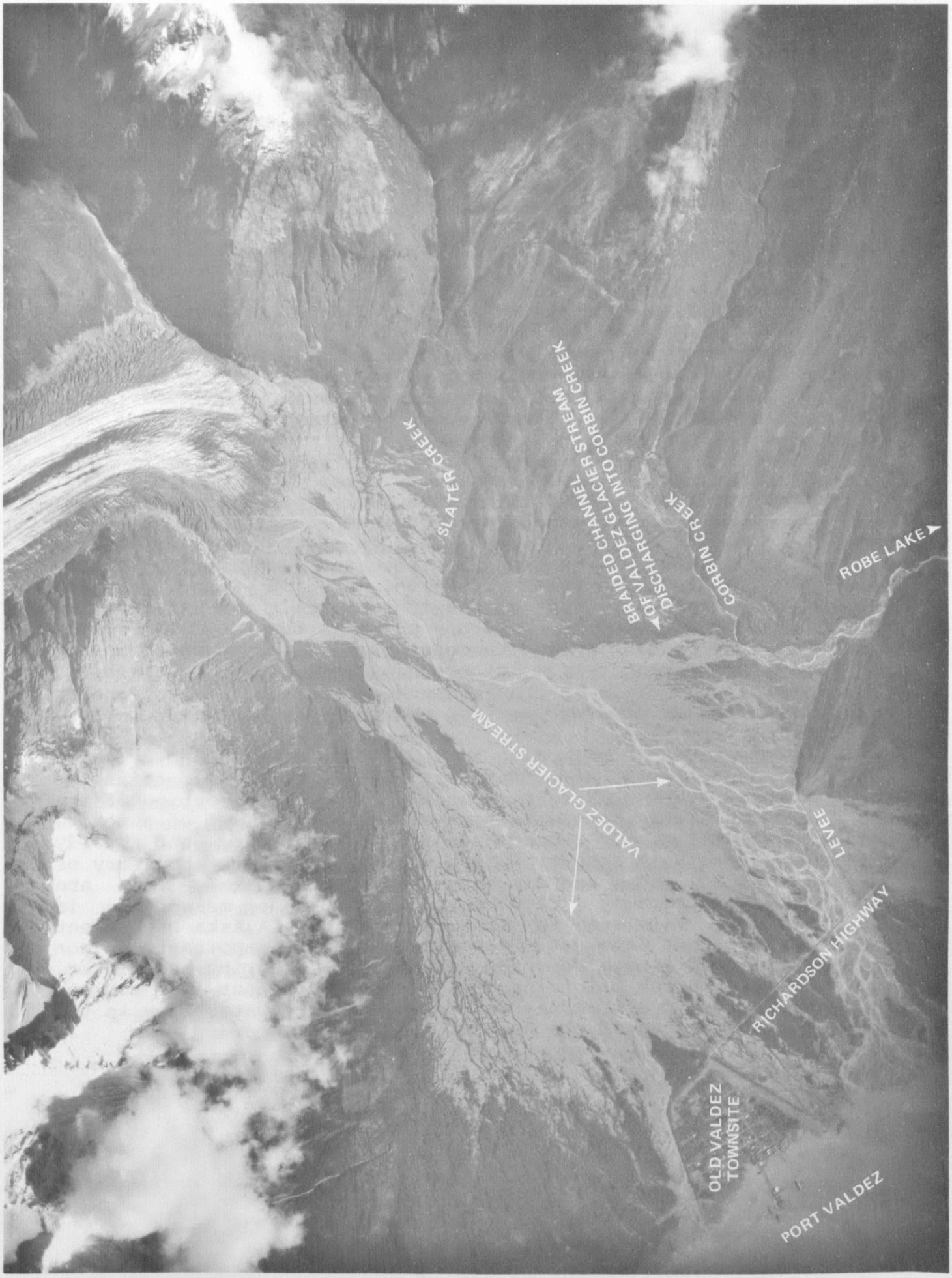

SLATER CREEK
BRAIDED CHANNEL GLACIER STREAM
OF VALDEZ GLACIER INTO CORBIN CREEK
DISCHARGING
CORBIN CREEK
ROBE LAKE
VALDEZ GLACIER STREAM
LEVEE
RICHARDSON HIGHWAY
OLD VALDEZ
TOWNSITE
PORT VALDEZ

FIGURE I-2

braids into five to six channels within the project site, before it drains into Corbin Creek (Glacier). Corbin Creek (Glacier) has braided channels at the flat foothills where the stream emerges from the higher mountains. It forms a small flood plain at this location. The greater drainage basin characteristics include:

	Corbin Creek (Glacier)	Slater Creek
Drainage area (mi^2)	13	6
Percentage glacial coverage	33	15
Percentage lake coverage	0	0
Slope (ft/mile)	407	380
Length (mile)	6.5	4.5

The southern half of the study area occupies the upper drainage basins of Corbin Creek (Robe) and Brownie Creek. The two surface drainage systems seem to be independent of each other. Brownie Creek heads in the wetlands and swamps to the southeast of the plant site and is primarily fed by warm, 40°F, groundwater from this area in winter. During spring break-up, (spring thawing) snowmelt run-off from the high ridge behind the wetlands augments the flow of Brownie Creek by recharging and increasing the level of water in the wetlands. Winter flow of Brownie Creek may be sustained by year-around drainage from bedrock areas to the east and/or from shallow groundwater from north of the headwater area.

Corbin Creek (Robe) also is fed by groundwater and by water seeping through and underneath the dike which contains the Corbin Creek (Glacier) system. The upper portion of the Corbin Creek (Robe) drainage basin is comprised of numerous channels, mostly abandoned and revegetated, and poorly defined. Both streams flow along the southern boundary of the study area and discharge into Robe Lake. They are small, generally slow moving, and some meandering is evident. This area is identified by the Alaska Department of Fish and Game as "an exceptionally important salmon spawning drainage for the Valdez area." During the winter, Brownie Creek maintains open waters throughout its course, and Corbin Creek (Robe) has open surface water flow in the middle reaches of its course.

Figures I.3 and I.4 present the known drainage areas affecting the project site.

Stream-flow records in the area of concern are fragmentary. These records consist principally of miscellaneous discharge measurements on Glacier Stream by the U.S. Geological Survey (U.S. Geological Survey, 1973) and by the Institute of Marine Science of the University of Alaska (University of Alaska, 1973).

II) CLIMATE

The Chugach Mountains present orographic barriers which exert a pronounced effect on the climate of coastal areas. Valdez, located on the coast, reports an average annual precipitation of 62.4 inches, whereas at Copper Center about 80 miles northeast of Valdez, in interior Alaska, annual precipitation is only 9.2 inches. That transition from the wet coastal climate to the dry continental climate occurs within about 20 miles. No climatological observations exist on the mountains to determine the actual boundary of the change, but it would appear to lie on the north side of the Chugach Mountains and parallel to them (Robert W. Retherford Assoc., 1976).

The rainfall intensity is considered to be moderate but of long duration. The maximum recorded 24 hour rainfall in the Prince William Sound area was 9.4 inches, recorded at Cordova on September 9, 1917, as a result of a general storm. Precipitation of 5 inches per day is rare in Valdez, and the maximum observed 24 hour precipitation is 5.10 inches. The mean annual snowfall is 265.9 inches. The maximum annual snowfall of 517 inches occurred in 1928, and the greatest depth at one time was 80 inches in 1949 (Bomhoff, Collie and Klotz Consulting Engineers and Planners, 1971). The seasonal distribution of precipitation is fairly uniform. The maximum precipitation usually occurs in September or October, and the minimum falls in the spring, from April to June.

Snow drifting in the Glacier Stream's floodplain is common and results in drifts of 20 feet near the confluence of Glacier Stream and Corbin Creek. Snow depths in the site area are reported to often be in the order of 6 feet to 10 feet. It is believed that the reported depths are influenced by the heavy brush cover and would generally be less in cleared areas.

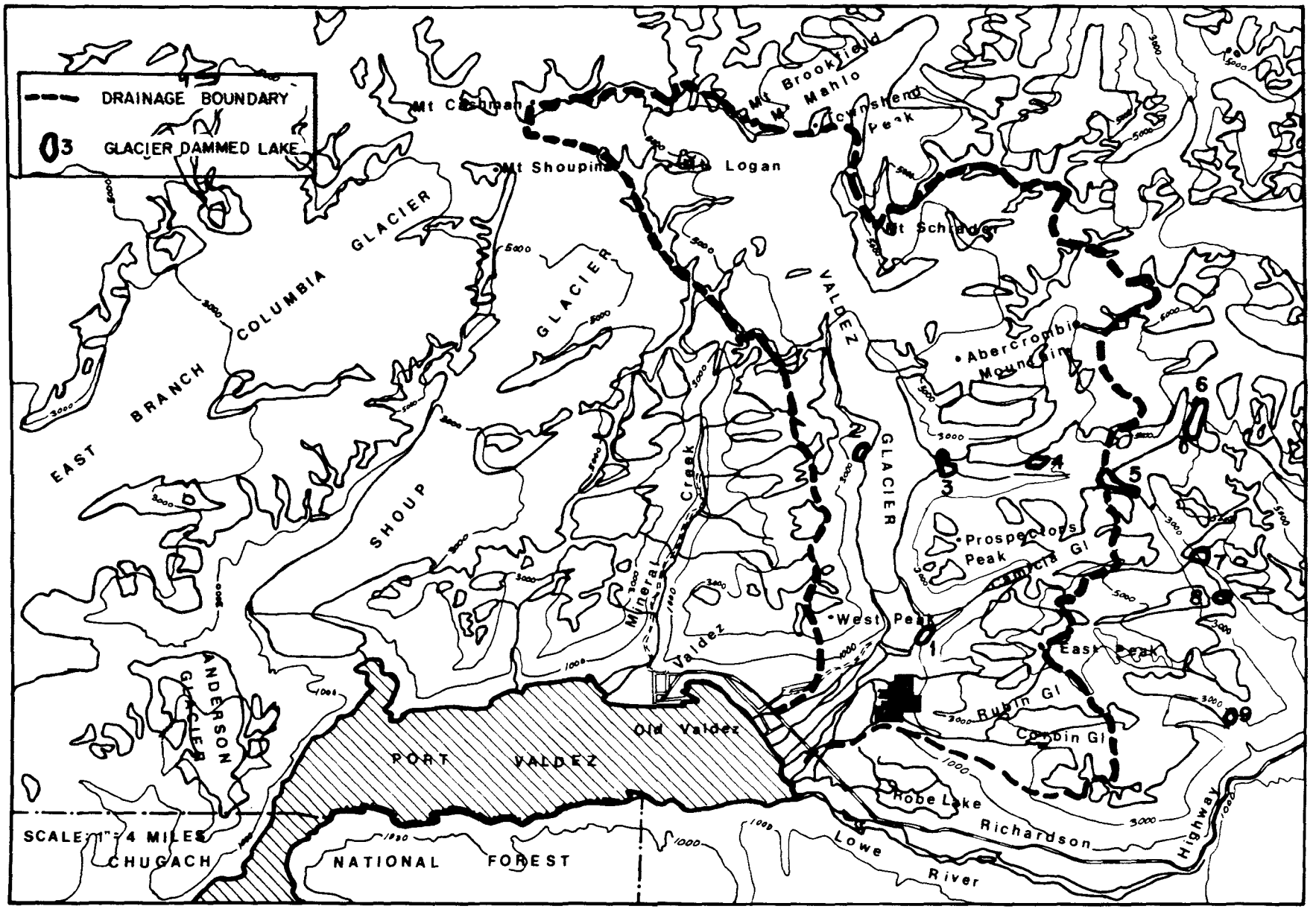


Figure I.3 DRAINAGE AREA FOR VALDEZ GLACIER STREAM AND GLACIER - DAMMED LAKES

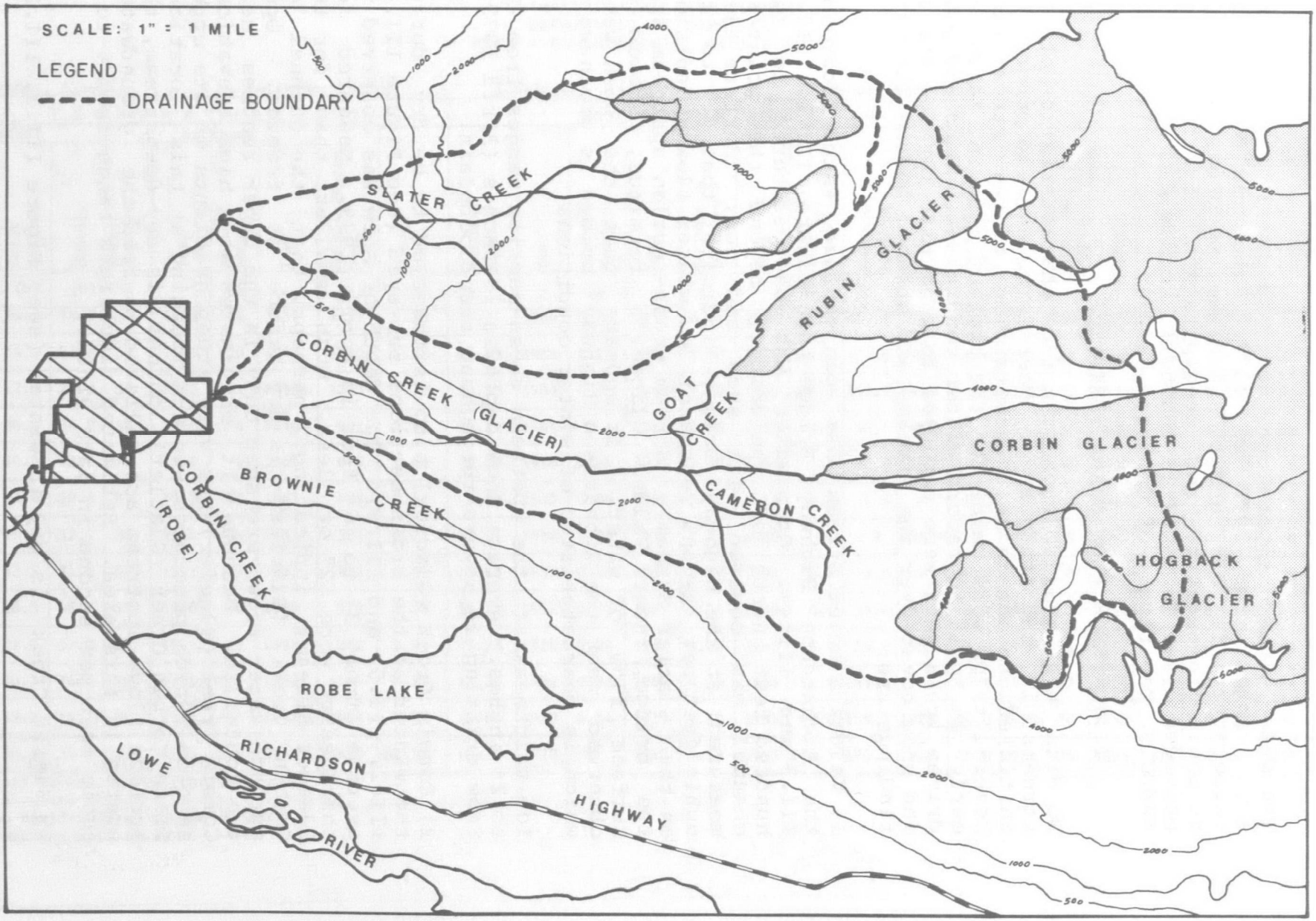


Figure I.4 DRAINAGE BASINS FOR SLATER CREEK AND CORBIN CREEK (GLACIER)

The mean annual temperature near sea level in the Valdez area ranges from 39°F to 43°F. The maximum recorded temperature is 87°F and the minimum recorded is -28°F. Seasonal temperature and precipitation distribution are provided (see Table II-1) (Bomhoff, Collie and Klotz, 1971, and U.S. Department of Commerce, 1907).

III) STREAM FLOW CHARACTERISTICS

No data are available on the flow characteristics of the streams in the study area. Therefore, a field program was initiated to obtain an understanding of the stream flow. Several trips were made to the project site in March and early in April to record winter conditions. Hand and power driven ice augers were employed to penetrate through the ice and snow cover over the streams and stream beds. The major findings are:

1) Valdez Glacier Stream has open surface water flow under the Richardson Highway Bridge (see Figure III.1, III.2, III.3 and III.4). Open water was observed three to four hundred feet north of the bridge, beyond that point the channel was covered with snow and ice. Surface flows measured at the highway bridge indicate that 0.1 to 2.0 cubic feet per second represent low winter flow conditions on the Glacier Stream. Stream cross-section upstream from the bridge, near Valdez Glacier's terminus, showed no surface flow of water. It appears that the open water observed near the Richardson Highway bridge is groundwater which is characteristic of winter conditions.

Ice thickness at the upstream cross-section ranges from 14 to 24 inches. Average snow depth is 19 inches (April 1979). Snow drifting is severe throughout the floodplain.

2) Corbin Creek (Glacier) also is observed to be dry during the winter at the cross-sections surveyed (see Figure III.1, III.2, III.5, and III.6). The depth of snow was observed to average from 3 to 6 feet in April 1979. Measured ice thicknesses were 2" or less, much smaller than for the Glacier Stream, indicating, perhaps, that the channel of Corbin Creek (Glacier) is dry before it freezes. Open surface water flows are seen only in the upper reaches near the foothills. Because it originates at a high elevation, Corbin Creek (Glacier) has very steep gradients in its upper section which precludes winter freezing at this location. Since Corbin Creek (Glacier) channel is dry downstream, the surface flows upstream are believed to feed the groundwater system in this area. Estimated discharges range from 4 to 7 cubic feet per second in late winter.

3) Slater Creek is dry in winter (see Figure III.1, III.2,

CLIMATOLOGICAL DATA SUMMARY
DEPARTMENT OF COMMERCE
ESSA - ENVIRONMENTAL DATA SERVICE

Station: Valdez, Alaska **Latitude:** 61°08' **Longitude:** 146°15' **Ground Elevation:** 60' **Standard Time Used:** AST

Month	TEMPERATURE (°F) Normal: Daily Maximum	Daily Minimum	Monthly	Extremes: Record Highest	Year	Record Lowest	Year	Normal Degree Days	Normal Total	PRECIPITATION TOTALS (Inches): Maximum Monthly	Year	Minimum Monthly	Year	Maximum in 24 Hours	Year	Snow and Sleet: Mean Total	Maximum Monthly	Year	Maximum in 24 Hours	Year	Greatest Depth on Ground	Year	Precipitation .10" or more	MEAN NUMBER OF DAYS: Temperatures: Maximum: 70° and Above	32° and Below	Minimum: 32° and Below	0° and Below	Month
(a)	(b)	(b)	(b)	56	-	56	-	(b)	(b)	54	-	54	-	54	-	48	48	-	48	-		-	14	48	48	55	55	(a)
Jan.	25.3	11.0	18.2	55	1963	-24	1951	1451	5.79	15.17	1949	0.41	1914	3.07	1954	56.3	127.8	1949	32.5	1948	115	1924	9	0	23	31	6	Jan.
Feb.	29.2	14.3	21.8	59	1923	-28	1947	1210	4.88	16.09	1953	0.23	1950	4.00	1928	47.2	174.5	1928	43.0	1928	120	1924	9	0	17	28	3	Feb.
Mar.	34.4	17.6	26.2	57	1965	-11	1918	1203	3.70	13.55	1930	0.40	1943+	3.30	1960	36.7	117.1	1930	25.0	1927	132	1928	8	0	10	31	1	Mar.
Apr.	43.4	26.4	34.9	68	1965	4	1910	903	2.96	10.11	1941	T	1948	2.36	1915	13.1	40.0	1956	17.0	1930	135	1929	8	0	1	26	0	Apr.
May	51.8	34.5	43.1	78	1910	6	1964	679	3.48	8.12	1956	0.36	1920	1.80	1961+	2.1	22.0	1949	12.0	1949	40	1949	8	*	0	9	0	May
June	58.9	42.0	50.4	87	1953	27	1961	438	2.61	6.59	1955	0.46	1934	1.66	1914	0.0	0.0	-	0.0	-	2	1947	8	1	0	*	0	June
July	60.1	45.2	52.7	84	1911	33	1957+	381	4.72	11.51	1958	0.88	1916	2.41	1930	T	T	1953+	T	1953+	0	-	11	2	0	0	0	July
Aug.	59.8	43.5	51.6	84	1911	29	1913	415	6.48	13.63	1939	0.34	1967	2.97	1932	0.0	0.0	-	0.0	-	0	-	13	1	0	*	0	Aug.
Sep.	53.6	38.5	46.0	82	1910	14	1946	570	8.38	18.74	1912	0.71	1967	3.71	1949	0.1	4.0	1956	2.0	1956+	1	1956	13	0	0	4	0	Sep.
Oct.	43.5	31.0	37.2	69	1954	5	1935	862	7.95	17.23	1936	2.22	1947	3.00	1965	8.4	41.0	1956	35.0	1956	35	1956	12	0	1	18	0	Oct.
Nov.	32.1	20.3	26.2	59	1936	-10	1963	1164	6.27	17.38	1952	0.32	1909	4.30	1956	31.0	131.0	1956	26.0	1956	67	1956	10	0	13	29	1	Nov.
Dec.	26.2	13.2	19.7	54	1966	-18	1917	1404	5.15	16.66	1928	0.14	1917	5.10	1955	49.6	150.7	1928	30.0	1955	76	1955	10	0	22	31	4	Dec.
ANL	43.2	28.1	35.7	87	1953	-28	1947	10680	62.37	18.74	1912	T	1948	5.10	1955	244.5	174.5	1928	43.0	1928	135	1929	119	4	87	207	15	ANL

(a) Length of record, years (through 1967)
(b) Climatological Standard Normals (1931-1960)
\+ Also on earlier days, months or years
* Less than one half (0.5)

Average Temperature

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1972	12.0	19.0	20.7	28.8	41.6	49.3	58.8	58.0			28.4	19.2	
1973	13.5	21.2	31.0	38.2	44.0	50.2	53.9	51.3	45.9	36.8	22.8	23.1	36.0
1974	14.6	21.1	26.9	37.5	47.2	52.5	54.7	55.2	49.5	38.1	33.8	25.1	37.7
1975	19.6	21.1	27.8	35.3	44.0	50.2	55.3	54.5	46.5	37.3	23.4	19.7	36.2
1976	22.3	19.4	29.0	36.5	43.6	52.8	55.6	53.6	46.2	36.7	33.7	28.2	38.1
RECORD MEAN	16.4	20.4	27.1	35.3	44.1	51.0	55.7	54.5	47.0	37.2	27.7	23.0	36.6
MAX	22.2	27.0	34.1	42.2	51.2	57.3	62.2	61.0	52.8	41.9	32.1	27.4	42.6
MIN	10.6	13.7	20.0	28.3	36.9	44.7	49.1	48.0	41.2	32.5	23.3	18.6	30.6

TEMPERATURE SUMMARY DATA - Records prior to 1968

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Averages (Oct. 1909 - Dec. 1952. Breaks in the record. About 38 years data.)													
Mean	18.8	21.3	25.7	35.1	42.6	49.9	52.8	51.8	46.1	37.7	26.6	20.2	35.7
Maximum	25.9	28.9	34.1	42.9	51.2	58.4	60.4	59.9	53.5	43.7	32.6	28.8	43.2
Minimum	11.7	13.8	17.3	27.3	33.9	41.4	45.1	43.7	38.6	31.8	20.6	13.6	28.2
Extremes (Oct. 1909 - Dec. 1967. Breaks in the record. About 56 years data.)													
Highest	55	59	57	68	78	87	84	84	82	69	59	54	87
Year	1963	1923	1965	1965	1910	1953	1911	1911	1910	1954	1936	1966	1953
Lowest	-24	-28	-11	4	6	27	33	29	14	5	-10	-18	-28
Year	1951	1947	1918	1910	1964	1961	1957	1913	1946	1935	1963	1917	1947
Average number of days through 1967. Approximately 48 years data for maxima and 55 years for minima.													
Max. 70° & above	0	0	0	0	*	1	2	1	0	0	0	0	4
Max. 32° & below	23	17	10	1	0	0	0	0	0	1	13	22	87
Min. 32° & below	31	28	31	26	9	*	0	*	4	18	29	31	207
Min. 0° & below	6	3	1	0	0	0	0	0	0	0	1	4	15

* Less than one-half

Precipitation

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1972	1.76	2.66	3.61		4.35	2.78	1.44	3.19			6.85	1.52	
1973	4.63	3.07	3.43	3.75	2.51	3.22	1.68	9.35	2.78	4.35	2.43	3.35	44.55
1974	0.01	5.21	1.55	5.93	0.79	2.08	2.34	4.22	7.59	12.90	9.78	6.42	58.82
1975	5.24	3.98	2.00	5.42	1.95	2.74	4.30	3.41	12.83	5.51	0.42	6.36	54.16
1976	7.00	2.27	3.80	5.47	2.53	1.00	1.87	3.03	12.58	9.53	20.59	8.29	77.96
RECORD MEAN	3.73	3.44	2.88	5.14	2.43	2.36	2.33	4.64	8.95	8.07	8.01	5.19	57.17

PRECIPITATION SUMMARY DATA - Records prior to 1968

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean †	5.05	4.62	4.03	2.91	2.90	2.39	3.82	6.27	9.21	7.96	5.85	5.65	60.66
† Oct. 1909 - Dec. 1952. Breaks in the record. Approximately 38 years data.													
Max. %	15.17	16.09	13.55	10.11	8.12	6.59	11.51	13.63	18.74	17.23	17.38	16.66	18.74
Year	1949	1953	1930	1941	1956	1955	1958	1939	1912	1936	1952	1928	1912
Min. %	0.41	0.23	0.40	T	0.36	0.46	0.88	0.34	0.71	2.22	0.32	0.14	T
Year	1914	1950	1943	1948	1920	1934	1916	1967	1967	1947	1909	1917	1948
Max. % 24 Hr.	3.07	4.00	3.30	2.36	1.80	1.66	2.41	2.97	3.71	3.00	4.30	5.10	5.10
Year	1954	1928	1960	1915	1961	1914	1930	1932	1949	1965	1956	1955	1955

% Oct. 1909 - Dec. 1967. Breaks in the record. Approximately 54 years data.

Heating Degree Days

VALDEZ, ALASKA

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1972-73	222	213			1085	1411	1533	1212	1054	795	647	435	
1973-74	332	413	795	863	1258	1302	1558	1226	1176	825	565	369	10682
1974-75	312	298	457	828	1036	1230	1402	1223	1154	887	647	437	9911
1975-76	292	317	548	854	1241	1401	1319	1315	1107	848	655	358	10255
1976-77	285	346	558	873	934	1137							

Cooling Degree Days

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1972	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0	0	0	0	0

Snowfall

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1972-73	0.0	0.0			64.6	23.4	83.2	48.7	46.6	10.1	T	0.0	
1973-74	0.0	0.0	0.0		26.7	40.3	T	77.8	22.4	13.0	0.0	0.0	
1974-75	0.0	0.0	0.0	10.8	38.2	90.6	90.3	65.8	37.4	29.0	1.8	0.0	363.9
1975-76	0.0	0.0	0.0	14.7	6.8	84.1	96.1	33.2	75.5	40.6	T	0.0	351.0
1976-77	0.0	0.0	0.0	25.8	44.7	101.5							
RECORD MEAN	0.0	0.0	0.0	17.1	36.2	68.4	59.1	52.2	45.6	27.1	0.4	0.0	306.1

SNOWFALL SUMMARY DATA - Records prior to 1968 † †

	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
Mean	T	0.0	0.1	8.4	31.0	49.6	56.3	47.2	36.7	13.1	2.1	0.0	244.5
Maximum monthly	T	0.0	4.0	41.0	131.0	150.7	127.8	174.5	117.1	40.0	22.0	0.0	174.5
Year	1953		1956	1956	1956	1928	1949	1928	1930	1956	1949		1928
Max. in 24 hours	T	0.0	2.0	35.0	26.0	30.0	32.5	43.0	25.0	17.0	12.0	0.0	43.0
Year	1953		1956	1956	1956	1955	1948	1928	1927	1930	1949		1928
Greatest on Grnd.	0	0	1	35	67	76	115	120	132	135	40	2	135
Year			1956	1956	1956	1955	1924	1924	1928	1929	1949	1947	1929

† † Oct. 1909 - Dec. 1967. Breaks in the record. Approximately 48 years data.

# Indicates a station move or relocation of instruments. See Station Location table.

Record mean values above are means through the current year for the period beginning in 1972.

Meteorological Data For The Current Year

Station: VALDEZ, ALASKA 8 28442 — RADER BUILDING — Standard time used: ALASKAN — Latitude: 61° 01′ N — Longitude: 146° 02′ W — Elevation (ground): 23 feet — Year: 1976

Month	Temperature °F: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date	Relative humidity, pct.: Hour 02	Hour 08	Hour 14	Hour 20 (Local time)	Wind: Resultant: Direction	Speed m.p.h.	Average speed m.p.h.	Fastest mile: Speed m.p.h.	Direction	Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F: Maximum (b): 90° and above	Maximum: 32° and below	Minimum: 32° and below	Minimum: 0° and below	Average station pressure mb (Elev. 31 feet m.s.l.)
JAN	26.7	17.8	22.3	38	30	-4	8	1319	0	7.00			96.1			77	74	73	76	08	4.4	5.8	23	17	4		6.5	10	3	18	16	15			0	22	31	2	1002.7
FEB	24.4	14.3	19.4	36	1	4	10	1315	0	2.27			33.2			72	67	64	67	06	6.9	8.2	29	34	8		6.6	10	1	18	10	7			0	25	29	0	1006.8
MAR	35.4	22.6	29.0	44	23	9	9	1107	0	3.80			75.5			77	74	70	79				28	36	11						15	14			0	9	30	0	
APR	42.6	30.4	36.5	57	30	22	7	848	0	5.47			40.6			79	69	66					17	11	15						14	9			0	0	21	0	
MAY	49.8	37.4	43.6	65	31	33	17	655	0	2.53			T				78	68					18	27	25						21	0			0	0	0	0	
JUN	59.8	45.8	52.8	70	25	42	2	358	0	1.00			0.0				76	63					14	28	25						8	0			1	0	0	0	
JUL	62.8	48.4	55.6	74	31	41	24	285	0	1.87			0.0				83	71					17	28	9						10	0			4	0	0	0	
AUG	60.0	47.2	53.6	76	22	41	30	346	0	3.03			0.0				89	77					17	28	4						18	0			2	0	0	0	
SEP	51.2	41.1	46.2	63	5	35	30	558	0	12.58			0.0				91	81					18	27	22						25	0			0	0	0	0	
OCT	40.8	32.5	36.7	50	6	16	28	873	0	9.53			25.8				85	81					21	13	30						21	6			0	3	13	0	
NOV	37.4	30.0	33.7	45	12	22	4	934	0	20.59			44.7				88	86					23	11	18						26	10			0	1	23	0	
DEC	31.0	25.3	28.2	38	13	10	9	1137	0	8.29			101.5			87	85	86					23	11	8		9.6	0	3	28	23	17			0	18	31	0	
YEAR	43.5	32.7	38.1	76	AUG 22	-4	JAN 8	9735	0	77.96			417.4				80	74					29	34	FEB 8						207	78			7	78	178	2	

Normals, Means, And Extremes

Month	Temperatures °F: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity pct.: Hour 02	Hour 08	Hour 14	Hour 20 (Local time)	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F: Max. (b): 90° and above	Max.: 32° and below	Min.: 32° and below	Min.: 0° and below	Average station pressure mb. (Elev. 31 feet m.s.l.)
(a)				5		5					5		5				5					1	1				4	4			1	1	1	1	4	4			4	4	4	4	
J	25.0	10.6	17.8	38	1976	-20	1972	1463	0	5.06	7.00	1976	0.01	1974			96.1	1976				74	73				38	01	1975		6.5	10	3	18	11	9			0	26	31	4	
F	29.8	15.0	22.4	46	1973	-3	1972	1193	0	5.30	5.21	1974	2.27	1976			77.8	1974				67	64				32	04	1975		6.6	10	*	18	11	9			0	18	29	0	
M	35.3	18.2	26.8	51	1974	-6	1972	1184	0	4.33	3.80	1976	1.55	1974			75.5	1976				74	70				29	33	1974						16	10			0	11	29	1	
A	44.1	27.1	35.6	61	1974	5	1972	882	0	3.06	5.93	1974	3.75	1973			40.9	1972				69	66				24	36	1975						15	6			0	0	20	0	
M	52.5	35.0	43.8	71	1974	21	1972	657	0	3.20	4.35	1972	0.79	1974			1.8	1975				78	68				21	28	1974						14	*			*	0	1	0	
J	59.6	42.8	51.2	73	1973	31	1972	414	0	2.70	3.22	1973	1.00	1976			0.0					76	63				23	27	1974						12	0			1	0	1	0	
J	61.1	45.5	53.3	80	1975	33	1972	363	0	4.31	4.30	1975	1.44	1972			0.0					83	71				20	22	1975						14	0			3	0	0	0	
A	60.0	44.0	52.0	78	1974	36	1973	403	0	5.80	9.35	1973	3.03	1976			0.0					89	77				24	04	1973						17	0			3	0	0	0	
S	54.2	38.7	46.5	72	1974	27	1973	555	0	7.74	12.83	1975	2.78	1973			0.0					91	81				18	27	1976						20	0			*	0	1	0	
O	44.0	30.9	37.5	56	1975	8	1975	853	0	6.75	12.90	1974	4.35	1973			25.8	1976				85	81				30	12	1975		6.6	6	9	16	17	4			0	2	14	0	
N	32.2	19.9	26.1	45	1976	5	1975	1167	0	5.67	20.59	1976	0.42	1975			64.6	1972				88	86				41	03	1973		6.7	8	5	17	13	7			0	14	26	0	
D	25.9	13.1	19.5	40	1975	-6	1975	1411	0	5.39	8.29	1976	1.52	1972			101.5	1976				85	86				30	12	1975		8.1	5	2	24	18	13			0	21	31	2	
YR	43.6	28.4	34.2	80	JUL 1975	-20	JAN 1972	10545	0	59.31	20.59	NOV 1976	0.01	JAN 1974			101.5	DEC 1976				80	74				41	03	NOV 1973						176	56			7	90	182	6	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 87 in June 1953; lowest temperature -28 in February 1947; maximum monthly precipitation 18.74 in September 1912; minimum monthly precipitation trace (T) in April 1948; maximum monthly snowfall 174.5 in February 1928.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

Summarized temperature, precipitation and snowfall data for the period prior to 1968, on the next page, were compiled from summaries and records on file at the National Climatic Center, Asheville, North Carolina, by J. T. B. Beard, Primary Data Branch, National Climatic Center.

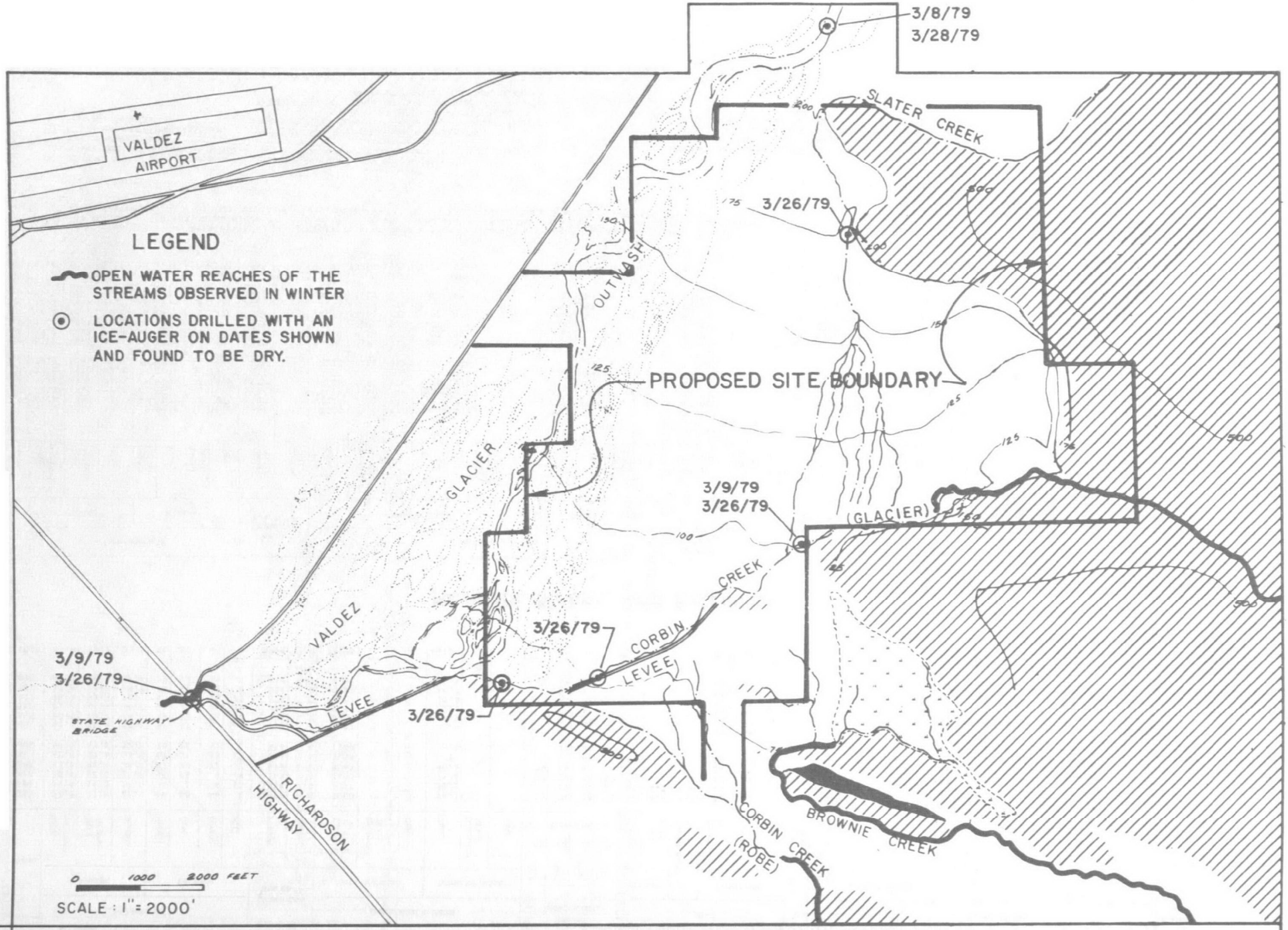


Figure III.1 WINTER CONDITIONS

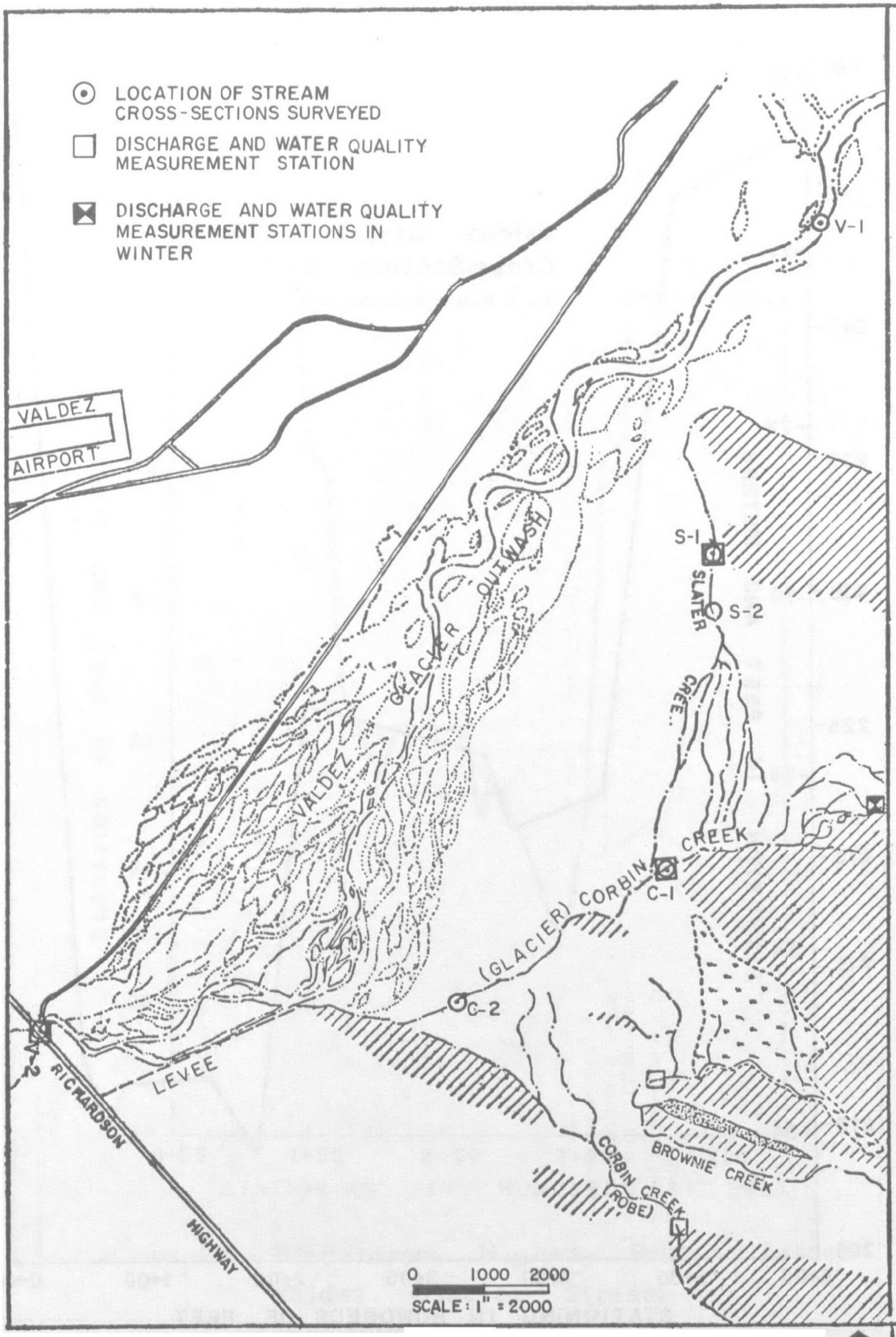


Figure III.2 SAMPLING & SURVEY LOCATIONS

III.2

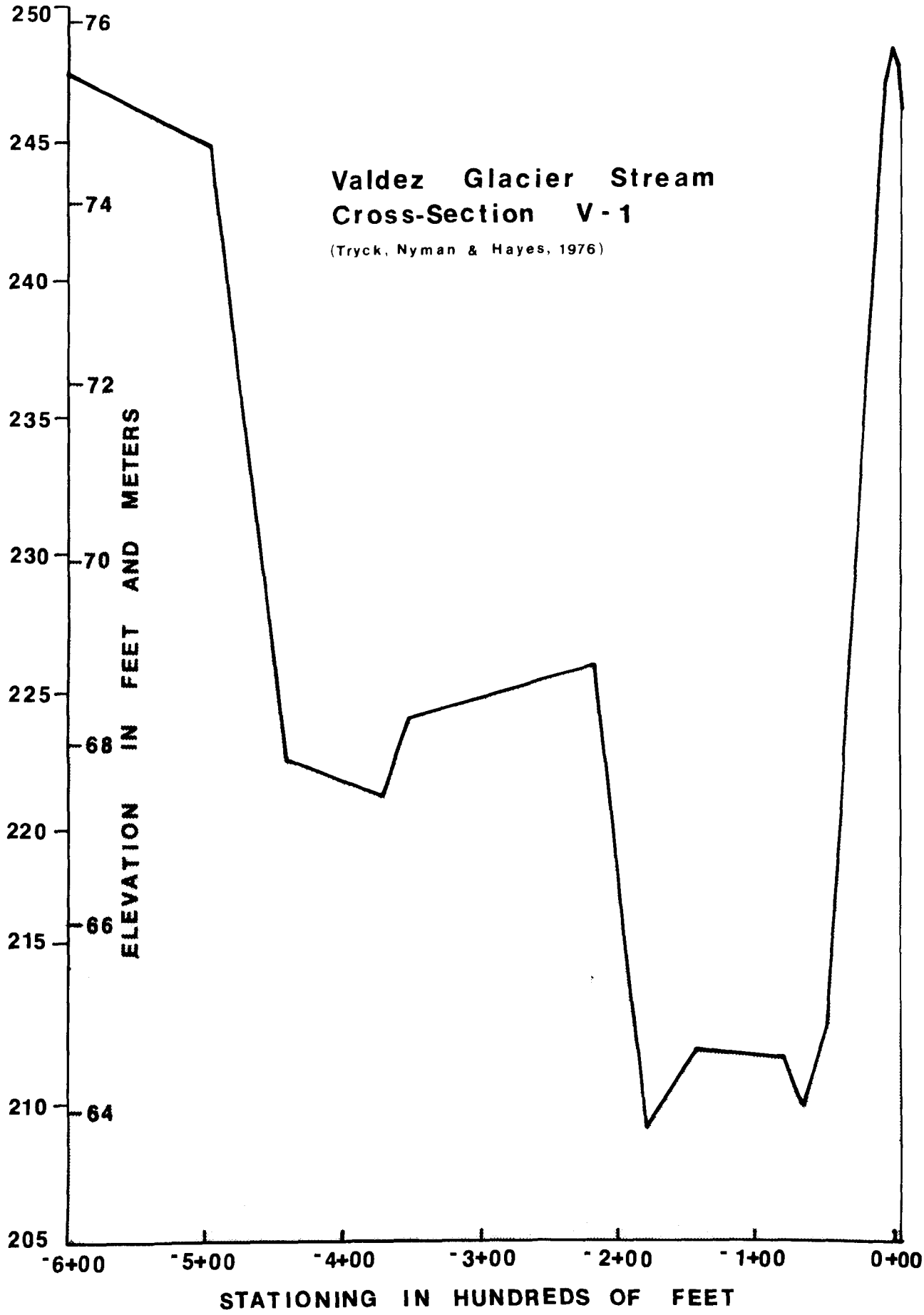
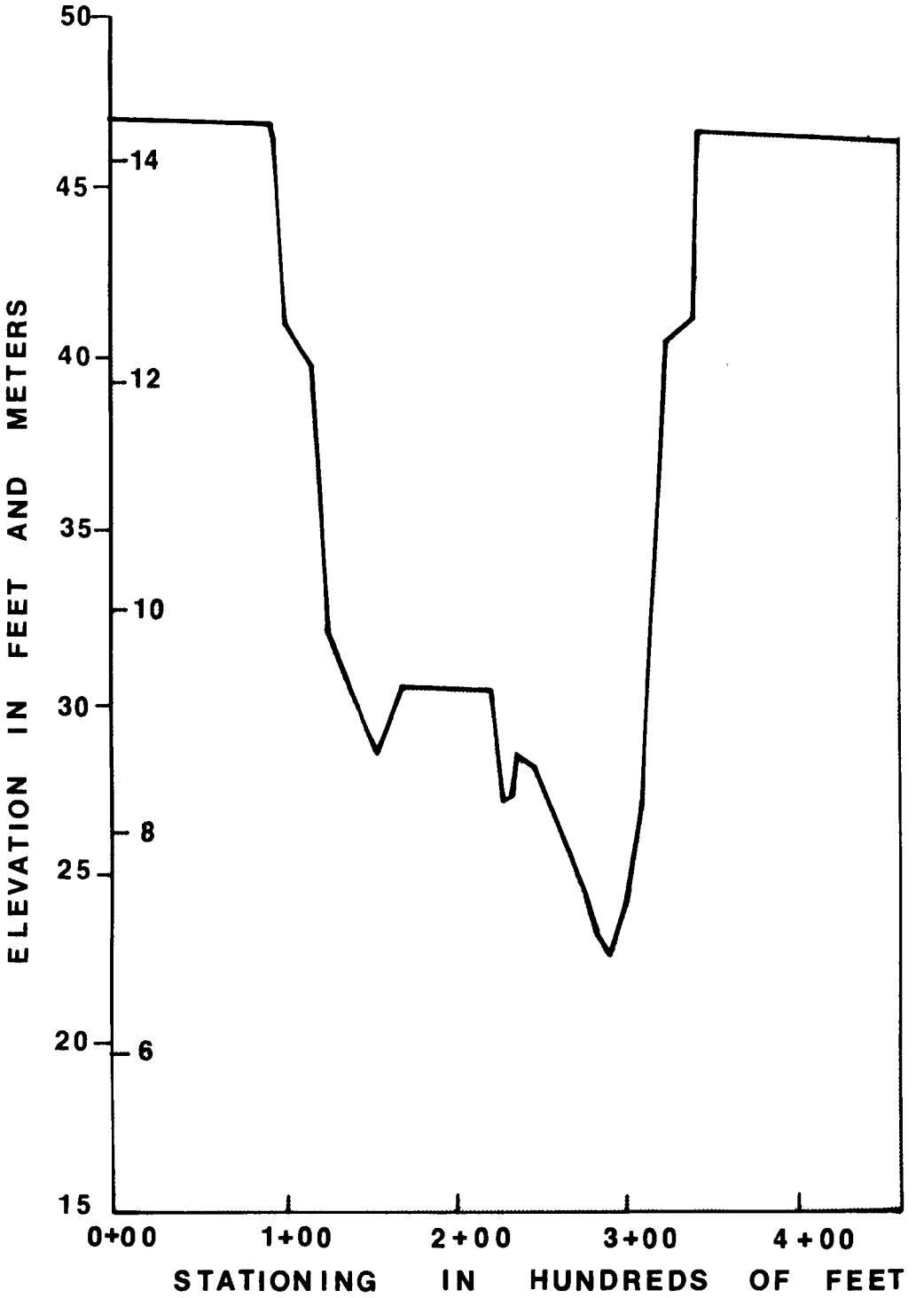

Valdez Glacier Stream
Cross-Section V-1
(Tryck, Nyman & Hayes, 1976)
ELEVATION IN FEET AND METERS
250
245
240
235
230
225
220
215
210
205
76
74
72
70
68
66
64
-6+00
-5+00
-4+00
-3+00
-2+00
-1+00
0+00
STATIONING IN HUNDREDS OF FEET

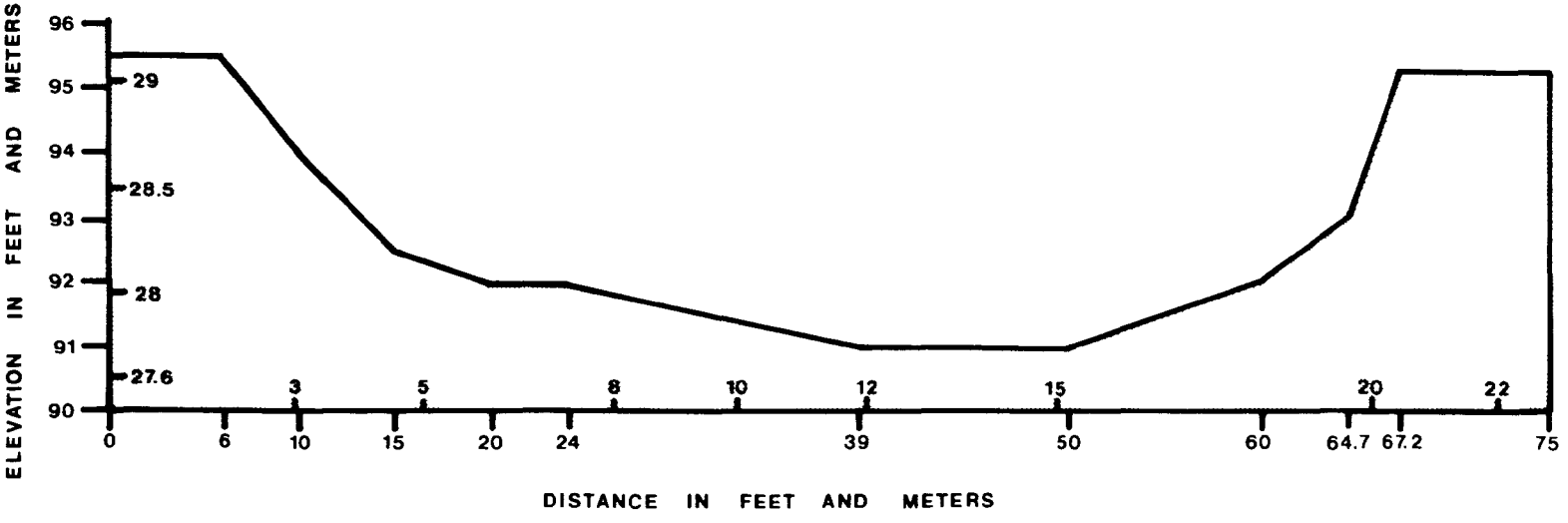
FIGURE III.3



Richardson Highway Bridge Across Valdez Glacier Stream

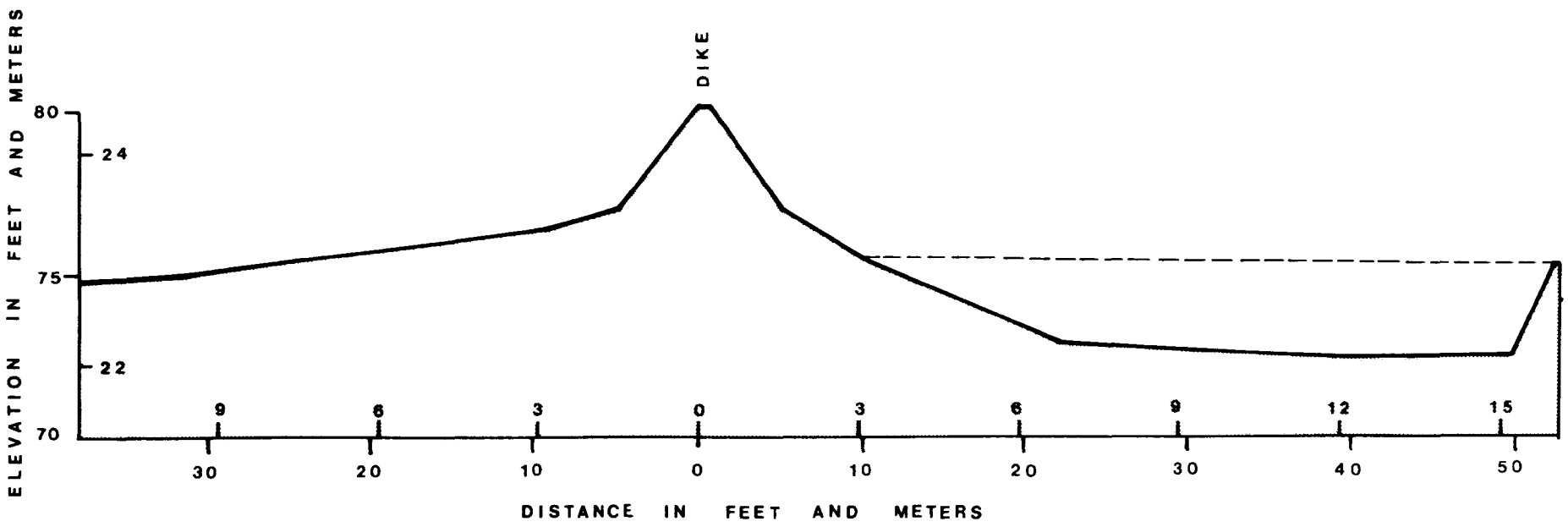
(Tryck, Nyman & Hayes, 1976)

FIGURE III.4



Corbin Creek (Glacier) Cross-section C-1

Figure III.5



Corbin Creek (Glacier) Cross-Section C-2

Figure III.6

III.7 and III.8). Lack of appreciable ice cover indicates that this stream also dries up before the onset of freezing. Depth of snow cover was from 4 to 5 feet in April 1979.

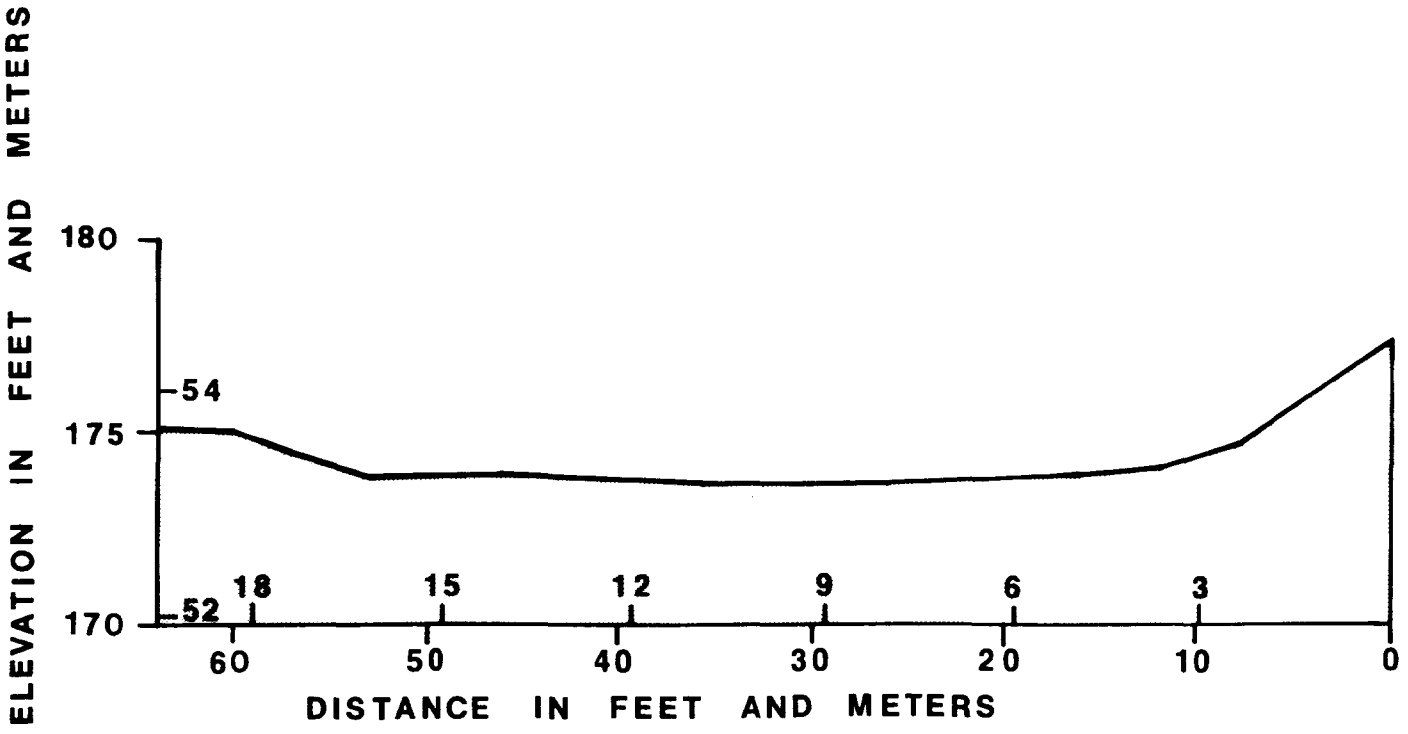
4) Brownie Creek has open surface flow year around. Although it is a small and slow moving stream, it has an unusually high water temperature of 40°F in the winter. This warm water originates in the wetlands and hampers any growth of ice on the stream. A mile downstream of its headwaters, Brownie Creek's water temperatures drop to 33-34°F. In contrast to the clear waters in winter of Corbin Creek (Glacier), Brownie Creek has a particular tea color, perhaps indicative of its origin in the wetlands.

Corbin Creek (Robe) is covered with snow and a thin layer of ice, except for the middle reaches of its drainage channel where open surface water flow was observed. Water temperatures are not as high as on Brownie Creek, ranging from 35°F to 39°F in winter. Its waters are tea-colored and its bed material is coarser than the bed material in Brownie Creek, where the percentage of sands and silts is higher than any other stream in the study area. Estimated discharges of both creeks is approximately 0.5 cubic feet per second in winter.

Collection of baseline data on stream flows has continued to show seasonal fluctuations of water flow. Partial hydrographs of the streams in the study area, Figures III.9 and III.10, have been produced by individual periodic measurements of flow. These hydrographs should not be used for design purposes because the stream flow data do not provide maximum or minimum flow discharges. These results display only the trend of seasonal variations of stream flow during a portion of the 1979 water year.

It appears that Corbin Creek (Glacier) is the principal source of water in winter, by recharging the groundwater system which provides some of the baseflow for the Glacier Stream and Corbin Creek (Robe). Also, the fact that water temperatures in the Glacier Stream and Corbin Creek (Robe) are several degrees higher than Corbin Creek (Glacier) seem to indicate that the surface flows of Corbin Creek (Glacier) which feed the groundwater system remain as groundwater for some time before appearing as surface water again. Examination of hydrographs show the second half of April as the beginning of breakup when the discharge values have started to increase.

Breakup first starts on Corbin Creek (Glacier) as the southern slopes of the East Peak begin melting causing a considerable snowmelt run-off into V-shaped narrow Corbin Creek valley. The advance of the breakup, which is first



Slater Creek Cross-section S-1

Figure III.7

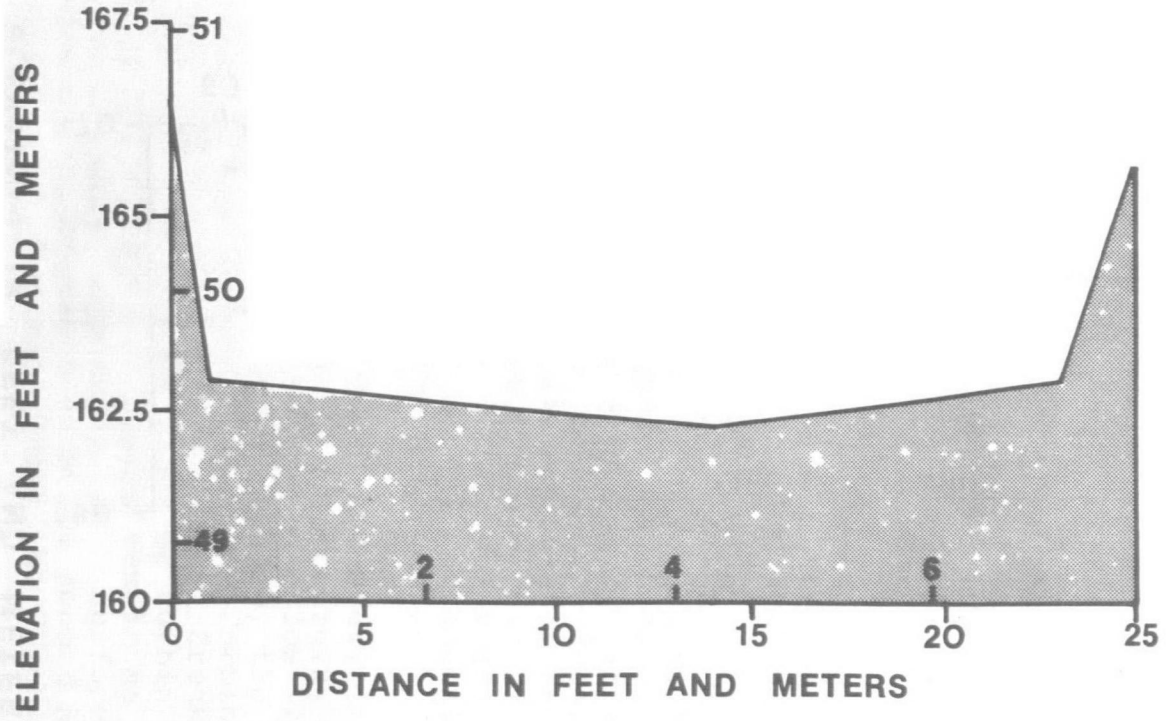


Figure III.8 Slater Creek Cross-Section S-2

FIGURE III.8

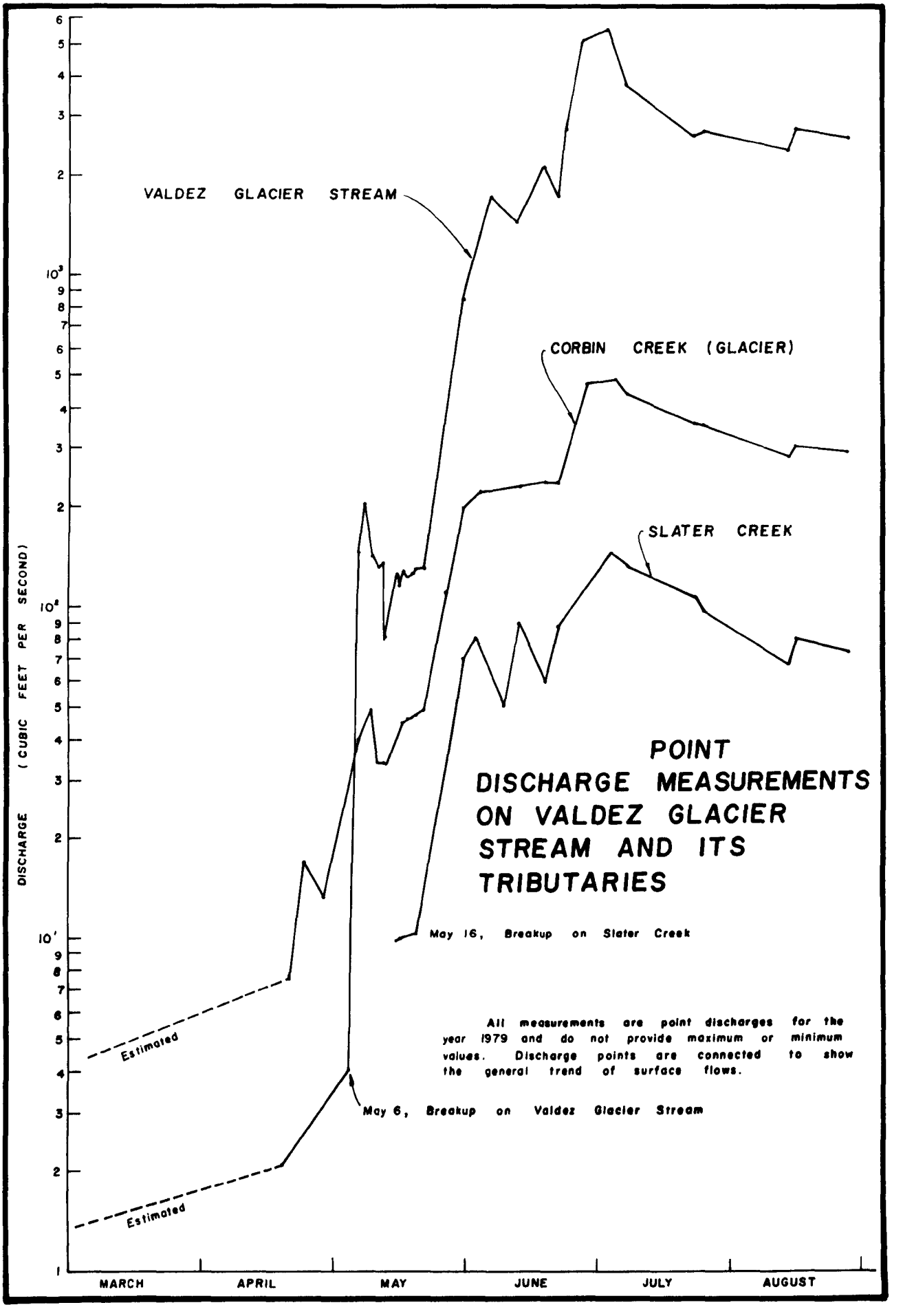

VALDEZ GLACIER STREAM
CORBIN CREEK (GLACIER)
SLATER CREEK
POINT DISCHARGE MEASUREMENTS ON VALDEZ GLACIER STREAM AND ITS TRIBUTARIES
May 16, Breakup on Slater Creek
All measurements are point discharges for the year 1979 and do not provide maximum or minimum values. Discharge points are connected to show the general trend of surface flows.
May 6, Breakup on Valdez Glacier Stream
Estimated
Estimated
DISCHARGE (CUBIC FEET PER SECOND)
MARCH
APRIL
MAY
JUNE
JULY
AUGUST

Figure III.9

POINT DISCHARGE MEASUREMENTS ON BROWNIE CREEK AND CORBIN CREEK (ROBE)

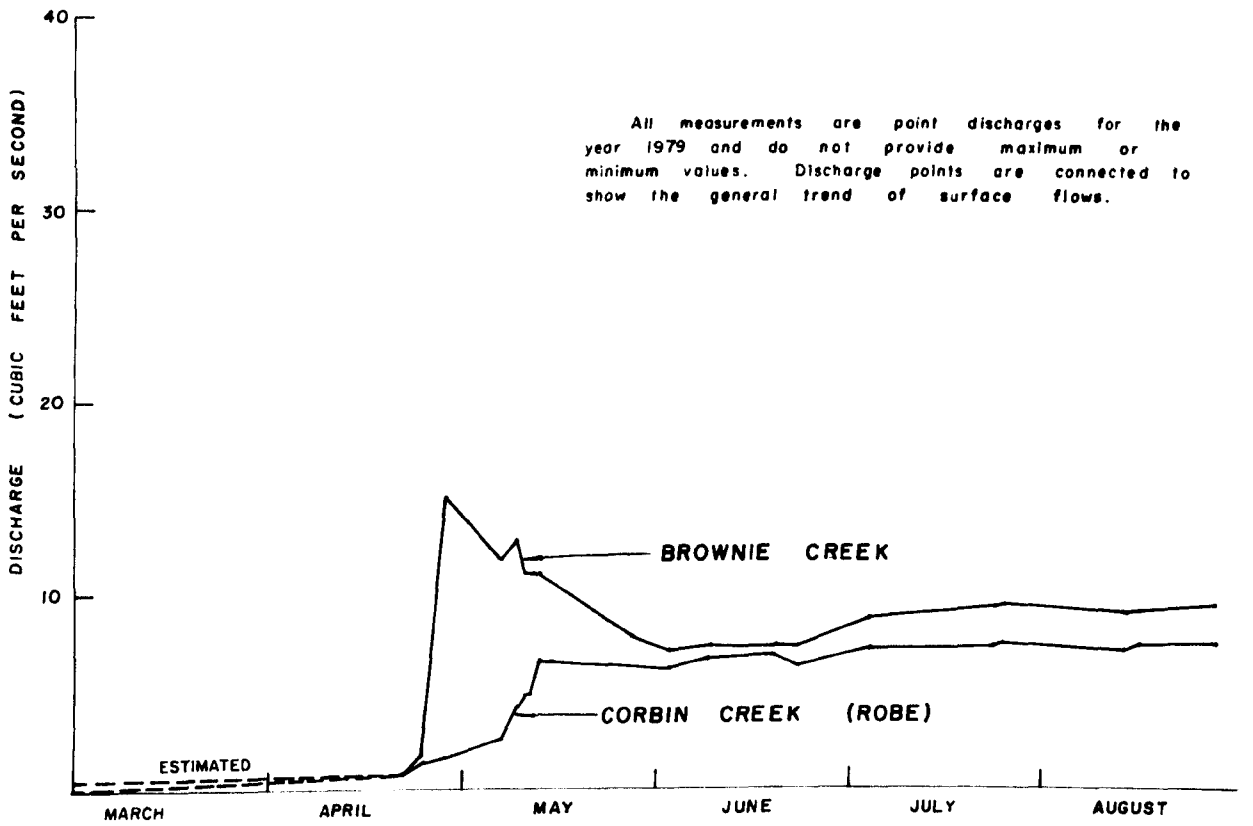


Figure III.10

observed in the foothills, progresses downstream at the rate of 400-500 feet per day. No significant icings or ice jams were observed during breakup except at the confluence of Valdez Glacier Stream and Corbin Creek (Glacier). At this location, drifted and wind-compacted snow reached a depth of approximately 20 feet and there was partial flooding of the area upstream of the confluence.

Breakup, is identified by a sudden increase of discharge and disappearance of ice and snow cover on the surface flow, this occurred on Valdez Glacier Stream and Slater Creek on May 6 and 16, 1979 respectively. The discharge of Valdez Glacier Stream has increased from a winter low of less than 3 cubic feet per second to over 200 cubic feet per second. Floating ice blocks have been observed, yet they have not caused any significant ice jams. The warm Brownie Creek appears to have a separate source of water in the wetlands. Snow melt run-off from the high ridge behind the wetlands has increased the flow discharge of Brownie Creek up to 20 cubic feet per second. At this time, water temperatures of Brownie Creek had dropped to 33°-34°F. Deposition of organic silts along the banks of Brownie Creek has been observed.

Based on Figures III.9 and III.10, which represent partial hydrographs of the streams in the study area and other stream flow records in the Prince William Sound area, the run-off pattern is characterized by a high volume of flow occurring during June and July from snowmelt. Large diurnal fluctuation (as much as 30 or 40 percent of the measured flows) is caused by meltage from glaciers that cover a considerable percentage of the basin. An additional peak volume is expected to occur in August and September resulting from a combination of rainfall and glacier melt.

The monthly distribution of flow should approximately parallel that of Solomon Gulch and Lowe River where records are available. 82% of the Solomon Gulch and 90% of the Lowe River annual run-off occur in the four months from June through September. Monthly percentage of annual run-off for these two streams is as follows (Robert W. Retherford Assoc., 1976):

MONTHLY PERCENTAGE OF ANNUAL RUN-OFF

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solomon Gulch	1	1	1	1	6	21	23	19	19	7	4	1
Lowe River	<1	<1	<1	<1	3.5	20	30	27	13	6	1	<1

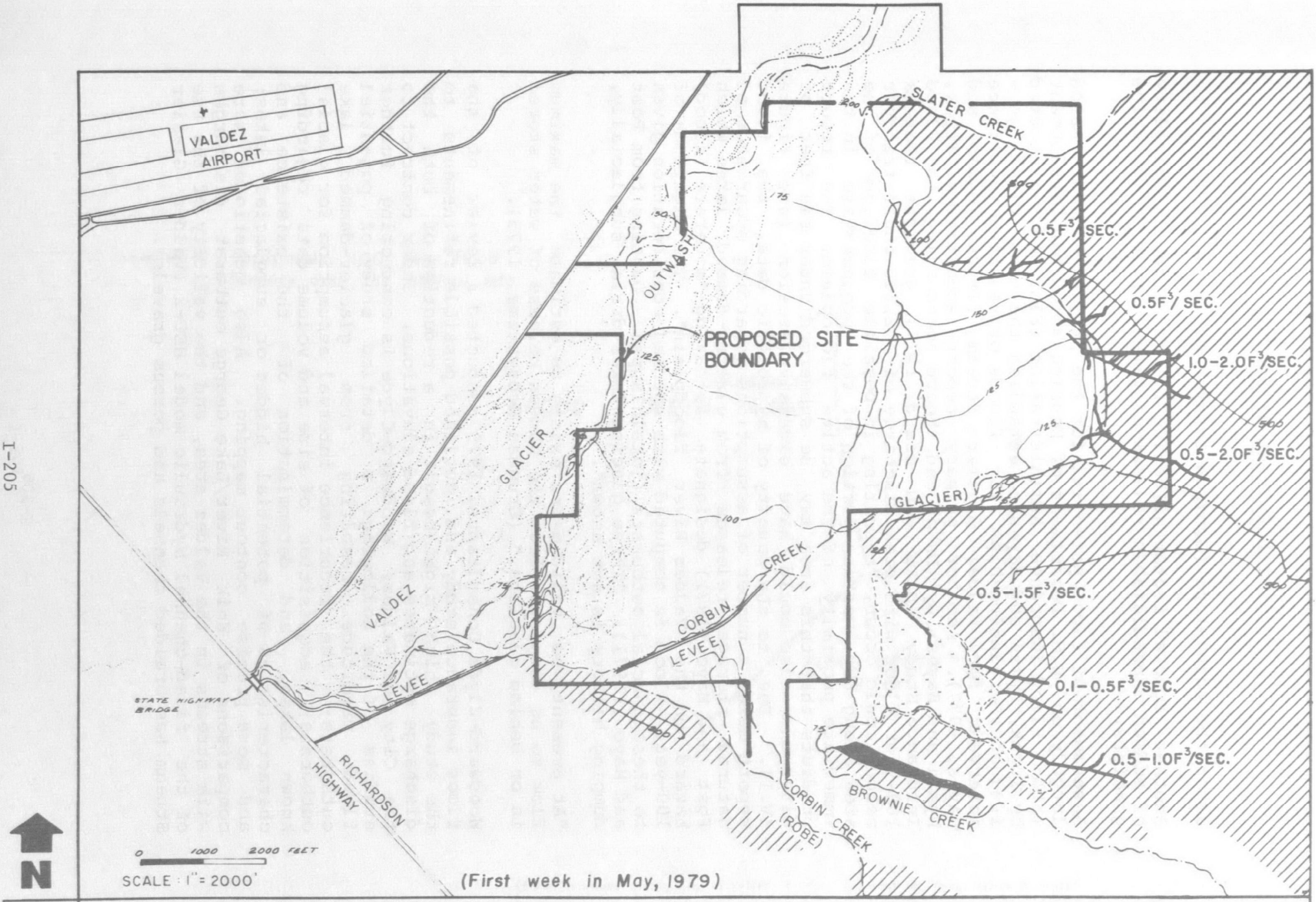
Estimates of average annual run-off for the study area can be made from drainage area relationships. Although precipitation data can also be used as a basis for estimating the variation in annual run-off, lack of climatological stations on the Chugach Mountain barriers restricts its use to the coastal areas. Streams which are partially fed from glaciers have fairly uniform annual run-offs as the glaciers tend to reduce the variations due to annual precipitation. The mean annual run-off ranges from approximately 8 to 10 cubic feet per second per square mile (cfsm). During late summer, as a result of rapid glacial melt and heavy precipitation, mean annual peak run-offs average 80 to 100 cfsm. Mean annual low monthly run-offs, which will occur in late winter, are in the range of 0.5 to 1 cfsm (Grumman Ecosystems Corp., 1975). Wetlands and swamps in the southeast of the study area would probably retain run-off as shallow groundwater.

Corbin Creek (Robe) and Brownie Creek are not directly glacial fed. Average normal flows in both streams are in the range of 6 to 10 cubic feet per second in summer.

Small streams and creeks observed in 1979 that develop only during snowmelt, and later are fed by precipitation run-off, are identified and their locations shown on Figure III.11. Estimated peak discharges are also shown. While some of the snowmelt run-off from these creeks drains into Corbin Creek (Glacier), the rest forms a channel that flows along the perimeter of the foothills recharging the groundwater system. Over the wetlands area, three more snowmelt run-off creeks have been identified. All these creeks discharge into the wetlands where they are drained away by Brownie Creek. With the snowmelt run-off replenishing the wetland's reservoir, areas of open surface water have been observed in the late spring ranging from a depth of 2 to 3.5 feet of standing water. An appreciable increase of the discharge and water velocities of Brownie Creek have also been recorded during that period. Deposits of organic silts on the branches of small brush and on the channel bank were seen after the melt water from the wetlands flooded over the snow in the upper reaches of Brownie Creek.

IV) FLOOD POTENTIAL

The maximum discharge of streams south of the Chugach Mountains generally results from rain run-off and glacier melt during the late summer or fall. Frequent rainstorms along the coast at this time of year dump enough precipitation on the high, steep mountains to produce extremely high discharges. During this type of flood, flows reach their peak within a few hours of the maximum precipitation and recede to the base flow within 2 or 3 days



(First week in May, 1979)

Figure III. II SPRING SNOWMELT CREEKS AND ESTIMATED DISCHARGES

after the rain stops (Grumman Ecosystems Corp., 1975).

Another crucial factor affecting floods is the possibility of sudden unpredictable release of water stored in or behind glaciers.

Assessment of flood potential for the project site is based largely on U.S. Department of Housing and Urban Development (HUD) Flood Insurance Administration (FIA) study conducted by Tryck, Nyman and Hayes to establish the peak discharge - frequency relationships for floods of selected recurrence intervals for Valdez Glacier Stream (Tryck, Nyman and Hayes, 1977). Another primary report submitted to Tryck, Nyman and Hayes by Duke and Beard concerning the Flood Insurance Study (Duke and Beard, 1977) predicts that a 100-year flood with peak discharge of 232,000 cubic feet per second could occur, resulting in possible flooding of the area along the western portion of the project site in the immediate proximity of the active floodplain. The report predicts that this area may be submerged under six feet of water and also could have excessive erosion (see Figure IV.1). Due to the paucity of hydrologic data, the flood report makes a number of assumptions regarding occurrence of natural storage releases from glacier-dammed lakes which Post and Mayo (1971) designate as having "moderate (flood) hazard on the Valdez River floodplain". The magnitude of 100-year flood is computed with special consideration given to these glacial outbursts (jokulhlaups). Quoting from Post and Mayo (1971): "Three glacier lakes drain subglacially, dumping history is not known".

"At present, no valid means exists to estimate the maximum flow to be expected from the sudden release of water stored in or behind glaciers." (Grumman Ecosystems, 1975).

Woodward-Clyde Consultants, 1979 conducted a review of the flood insurance study and outlined possible refinements to the study which might result in a reduction of both the discharge estimates and flood elevations. Under contract to the City of Valdez, Woodward-Clyde is conducting further studies of the following: a detailed study of potential flood magnitude resulting from glacier-dammed lake outbursts; the recurrence interval assumption for glacial outbursts; acquisition of size and volume data regarding known lakes, and determination of the existence and characteristics of potential hidden or subglacial lakes; and more precise contour mapping. Also questioned were comparisons of Knik River/Lake George outburst discharges with streams in the Valdez area, and the validity of the use of the fixed-channel hydraulic model HEC-2 (Valdez Glacier Stream has braided channels and porous gravels).

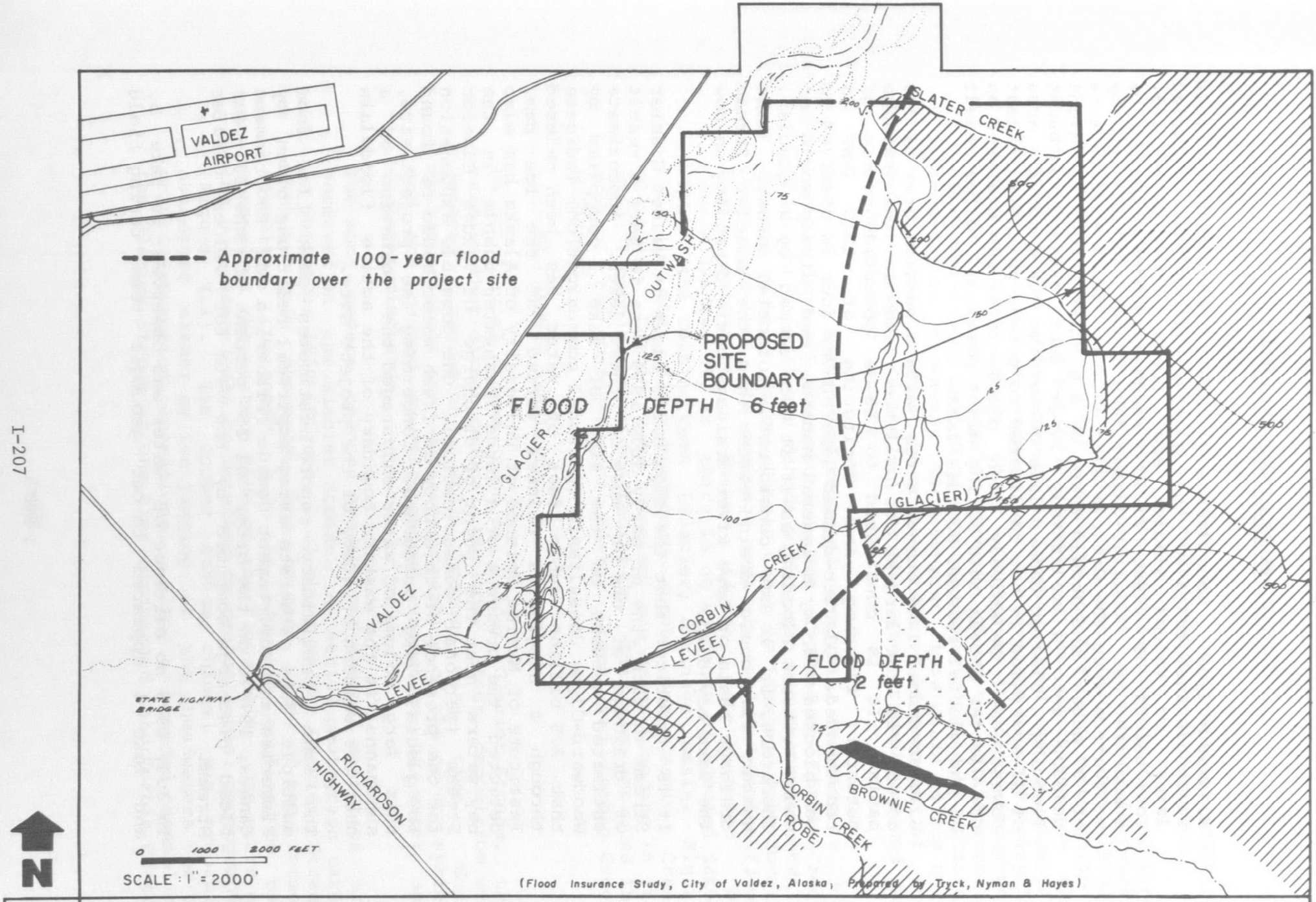


Figure IV.1 APPROXIMATE 100-YEAR FLOOD BOUNDARY FOR ALPETCO SITE

Woodward-Clyde Consultants have conducted field reconnaissance trips to the glacier-dammed lakes. Glacial lakes on Valdez Glacier are shown on Figure I.3. Conclusions of these field reconnaissances could be summarized as: Glacier-dammed lake number one is fed by meltwaters from the Camicia Glacier. It has a surface area of 57 acres, and should there be a glacier surge, it might develop into a relatively large lake causing outburst flooding. Glacier dammed lake number two has a surface area of 31 acres and is not considered to pose a potential threat downstream. Relatively high discharge values measured on the Glacier Stream this spring might possibly be the result of the glacial release of this lake.

Glacier-dammed lake number three, with a surface area of 300 acres, is the largest of all the lakes in the drainage basin. It is considered to be a potential source of outburst flooding, and monitoring of this lake is recommended. Glacier-dammed lake number four is observed to be blocked off by a lateral moraine and likely would not cause outburst flooding as if it were dammed by a glacier. Therefore, it is not considered a potential threat. Lake number five could drain either into the Glacier Stream drainage basin or Lowe River drainage basin depending on how the lake may dump.

It is theorized that the high early flows in Valdez Glacier Stream in late June or early July 1979 were in part a result of drainage of one or more of these lakes. Approximate estimated numbers on the size of lake 3 supplied by Woodward-Clyde Consultants (personal communication) indicate that 2.5 billion cubic feet of water has been relesed through a subglacial channel formed at the ice dam. Institute of Marine Science of University of Alaska has also detected the presence of a large freshwater bubble in the bay waters near the point of discharge of Valdez Glacier Stream (personal communication). One possible explanation for the presence of this body of fresh water could be found in glacial lake outbursts. Concerning the project site, this large volume of water encouraged the formation of a subchannel at the eastern boundary of the active floodplain near the western boundary of the project site.

The same preliminary report estimates peak flow from multiple lake outbursts using empirical relations given by Fisheries and Environment Canada (Fisheries and Environment Canada, 1977) on the order of 25 percent of the 100-year flood discharge computed by the FIA for Valdez Glacier Stream.

In July 1979 no evidence of water was observed in lake 3, and lake 4 appeared to our geologic team during field

reconnaissance by helicopter to be morainal dammed. Geologic team during field reconnaissance by helicopter.

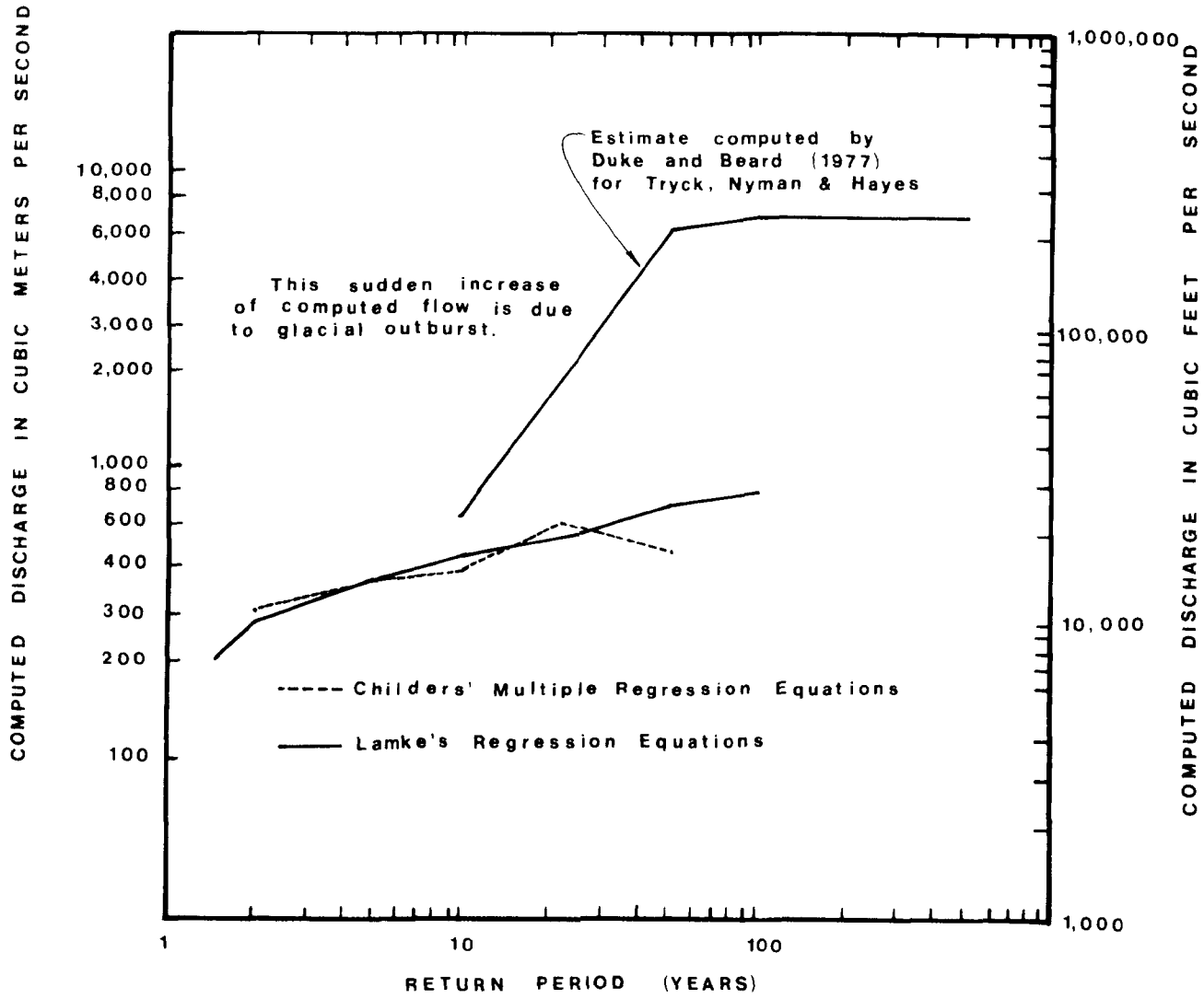
Flood discharge magnitudes also have been computed excluding floods caused by glacier-dammed lake outbursts (Berwick, Childers and Kuentzel, 1964; Childers, 1970; Lamke, 1979). Flood-frequency curves indicate the frequency with which a single flood event will exceed a given discharge on the long-term average. Hence, a 50-year flood can be expected to be equalled or exceeded on the average of once every 50 years. Figure IV.2, which illustrates the flood-frequency curve for Valdez Glacier Stream, shows the difference in flood magnitudes caused by rainfall/snowmelt and by glacier dammed lake releases. The 100-year flood which is due only to rainfall/snowmelt is on the order of 13 percent of the estimate given by the FIA for the same frequency flood due to the glacier outbursts.

Results of a standard regional analysis, assuming a log Pearson Type III distribution, are applied to Corbin Creek (Glacier) to estimate floods with given recurrence intervals (Lamke, 1979). Since Slater Creek is flowing into Corbin Creek (Glacier), its drainage area is included in the flood flow estimates. These floods are caused by rainfall/snowmelt, as there is no evidence of glacial lakes within the Corbin Creek (Glacier) drainage basin. Figure IV.3 is the flood-frequency curve for Corbin Creek (Glacier). Corbin Creek (Glacier) can cause flooding in its small floodplain near the foothills. This also includes the area of the confluence of Slater Creek and Corbin Creek (Glacier).

V) CHANNEL STABILITY

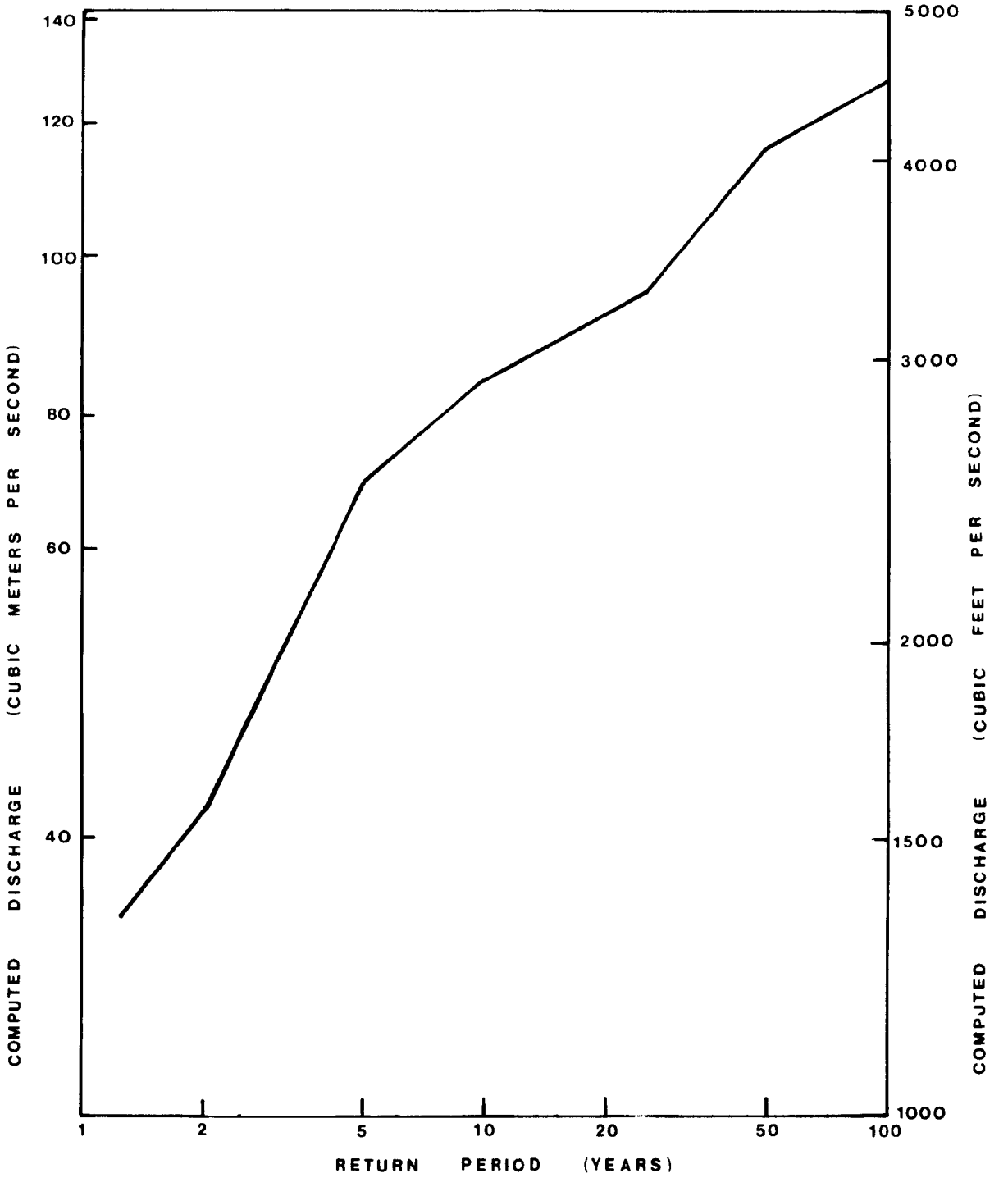
In an alluvial stream such as Valdez Glacier Stream, the rule is that either general or local scour, deposition and lateral migration will occur with time. Such characteristics are dynamic properties of the river system and are caused by independent variables of water and sediment discharge.

The most severe channel erosion and lateral migration are observed on the Glacier Stream. An aerial photograph taken in September 1950 (Figure I.2) shows Valdez Glacier Stream with two main channels, one on each side of the former townsite. Currently, all the flow is confined to one channel on the eastern side of the floodplain. The scars of the old channel can be detected on recent aerial photographs (Figure V.1). The former stream channel was probably abandoned either by ice jamming at the headwaters or by gravel extraction operations. Also, a braided channel of the Glacier Stream at one time discharged into Corbin Creek,



Flood frequency curve for Valdez Glacier Stream.

Figure IV.2



Flood frequency curve for Corbin Creek (Glacier).

Figure IV.3

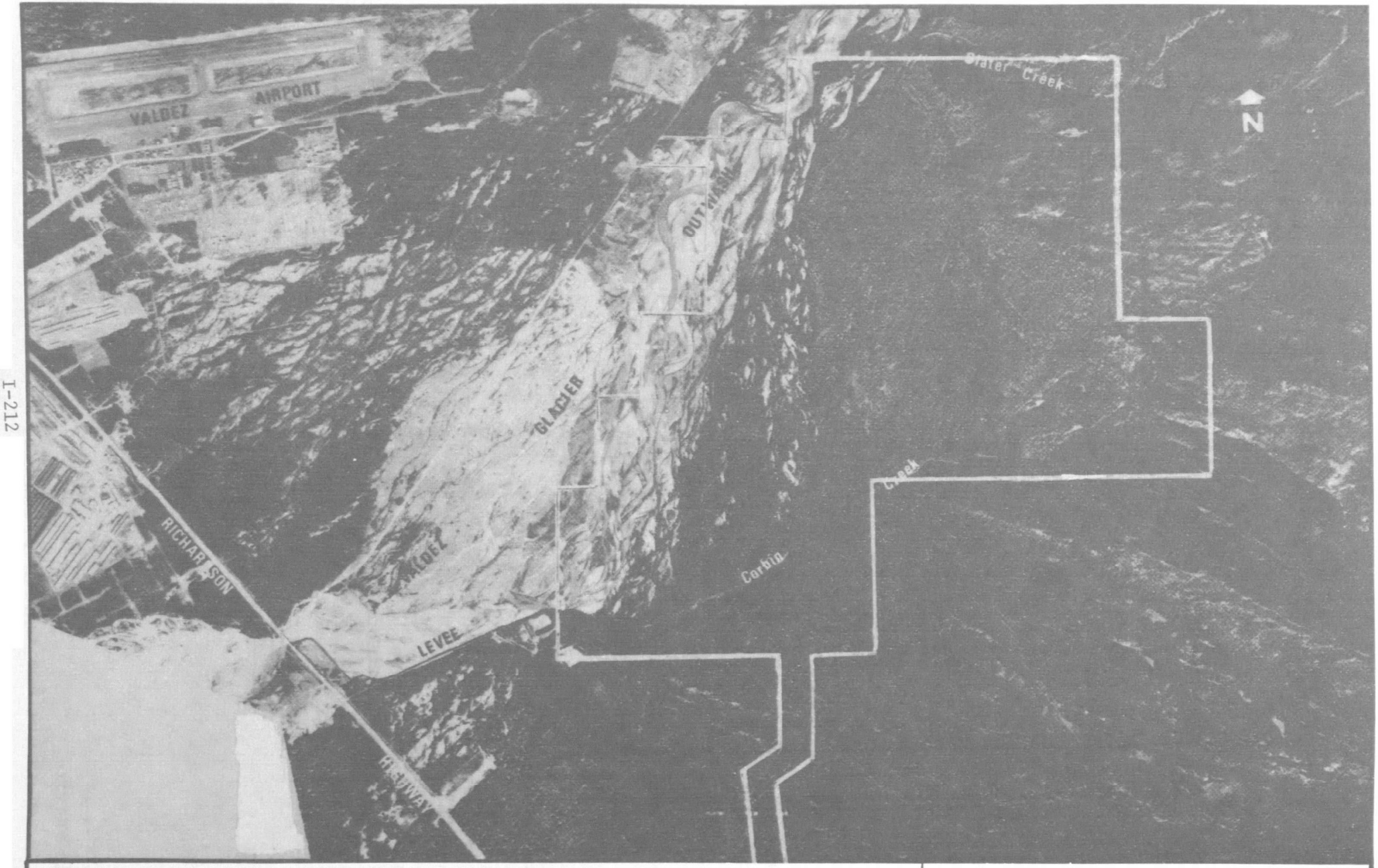


Figure V.1 AERIAL PHOTOGRAPH OF THE SITE AREA TAKEN 9·26·78

1000 0 2000 4000 feet

200 0 500 1000 meters

CCC/HOK – DOWL ENVIRONMENTAL IMPACT STATEMENT ALPETCO	KEY MAP	

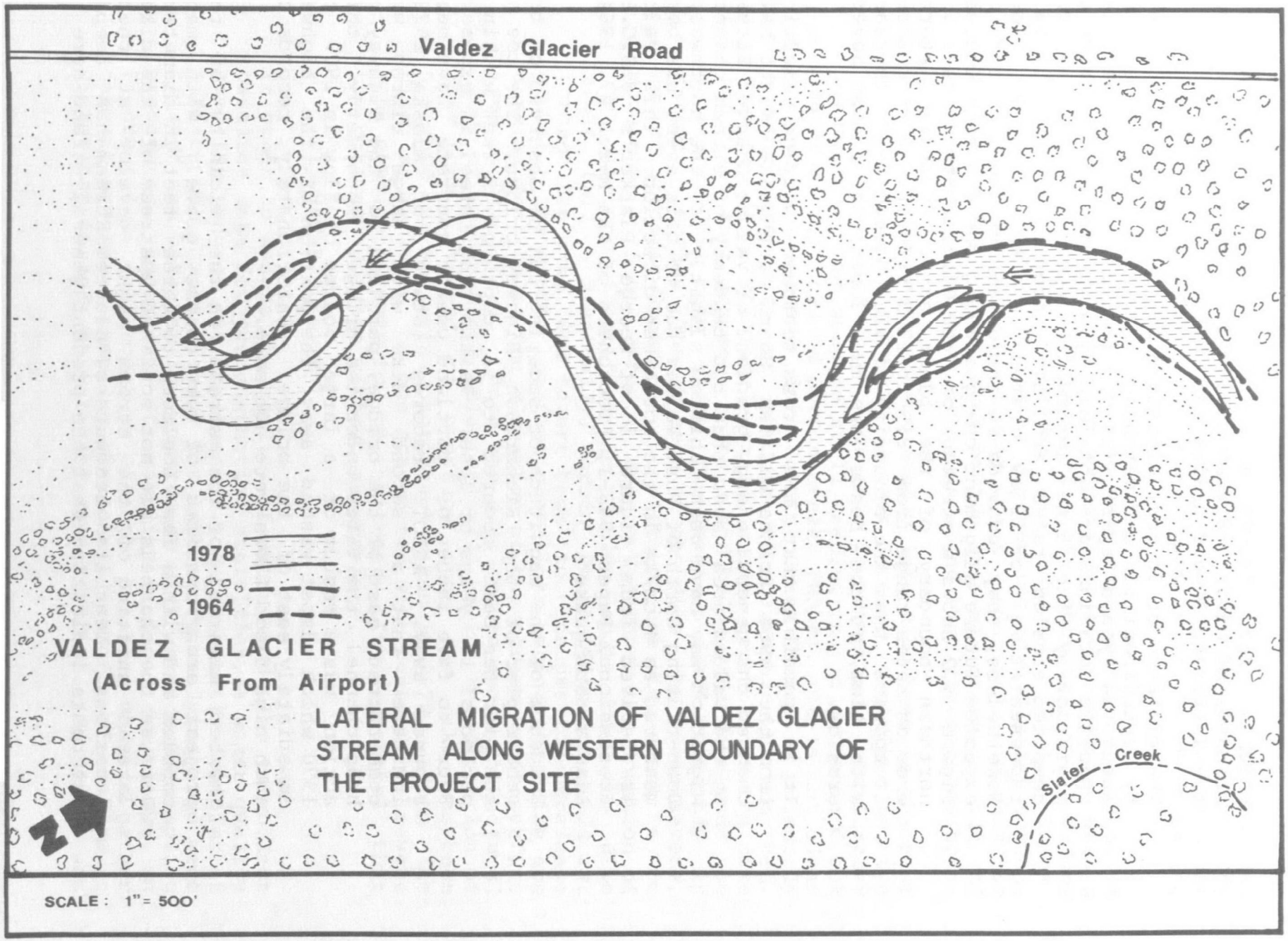

Valdez Glacier Road
1978
1964
VALDEZ GLACIER STREAM
(Across From Airport)
LATERAL MIGRATION OF VALDEZ GLACIER STREAM ALONG WESTERN BOUNDARY OF THE PROJECT SITE
Slater Creek
N
SCALE : 1" = 500'

FIGURE V.2

which in turn flowed into Robe Lake. Today, the braided channels of Glacier Stream still flow into Corbin Creek, but the latter no longer drains into Robe Lake.

The distance of lateral migration by the stream is measured by superimposition and matching of aerial photographs taken about 14 years apart (Brice, 1971). Erosion rates at specific locations are obtained by dividing the distance of migration by the time interval between photographs. The computed erosion rates are not necessarily statistically representative of flow rates either high or low. Nonetheless, they provide an indication of the magnitude of expected future alignment changes along the drainage course. Figure V.2 shows a stretch of the Glacier Stream near the northern boundary of the plant site. Computed lateral erosion rates range from 8.5 to 22.3 ft/year. Furthermore, it appears that the sinuosity of the stream will increase with time, as the bends are the locations of most severe erosion.

It is possible that the gross tectonic warpage resulting from the 1964 Prince William Sound earthquake might have changed the general energy gradient of Valdez Glacier Stream in the Valdez area such that the tendency of stream channel migration may have been shifted slightly to the northwest. Down-tilting north of Port Valdez due to this event has been measured as 4 cm/km in the northwest direction. This value is derived from figure 3 of George Plafker's U.S.G.S. Professional Paper 543-I, "Tectonics of the March 27, 1964, Alaska Earthquake".

Evidence of the magnitude of scouring can be observed on the center pier of the Richardson Highway bridge. The toe of the pier has been scoured to a depth of 3 feet within a period of 14 years or less. Reinforcing steel is exposed. Four to five inches of portland cement concrete have been scoured away. ASDOT records (State of Alaska, 1972) indicate that a second dike with large riprap was constructed east of the bridge, parallel to the highway to help channel the water under the bridge. Apparently, this action was a result of a large volume of flow in 1969 or 1970 which almost washed away the portion of the highway immediately east of the bridge. Unfortunately, records of such high flood flows were not made.

The bed material of the stream in the vicinity of the project area consists of very coarse gravel, with many cobbles and with a few boulders to three feet in diameter. Because the channels are not confined upstream of the dike, lateral shifting of the stream might develop at these locations. Near its headwaters, Glacier Stream has deeply cut banks indicating that the present general trend here is

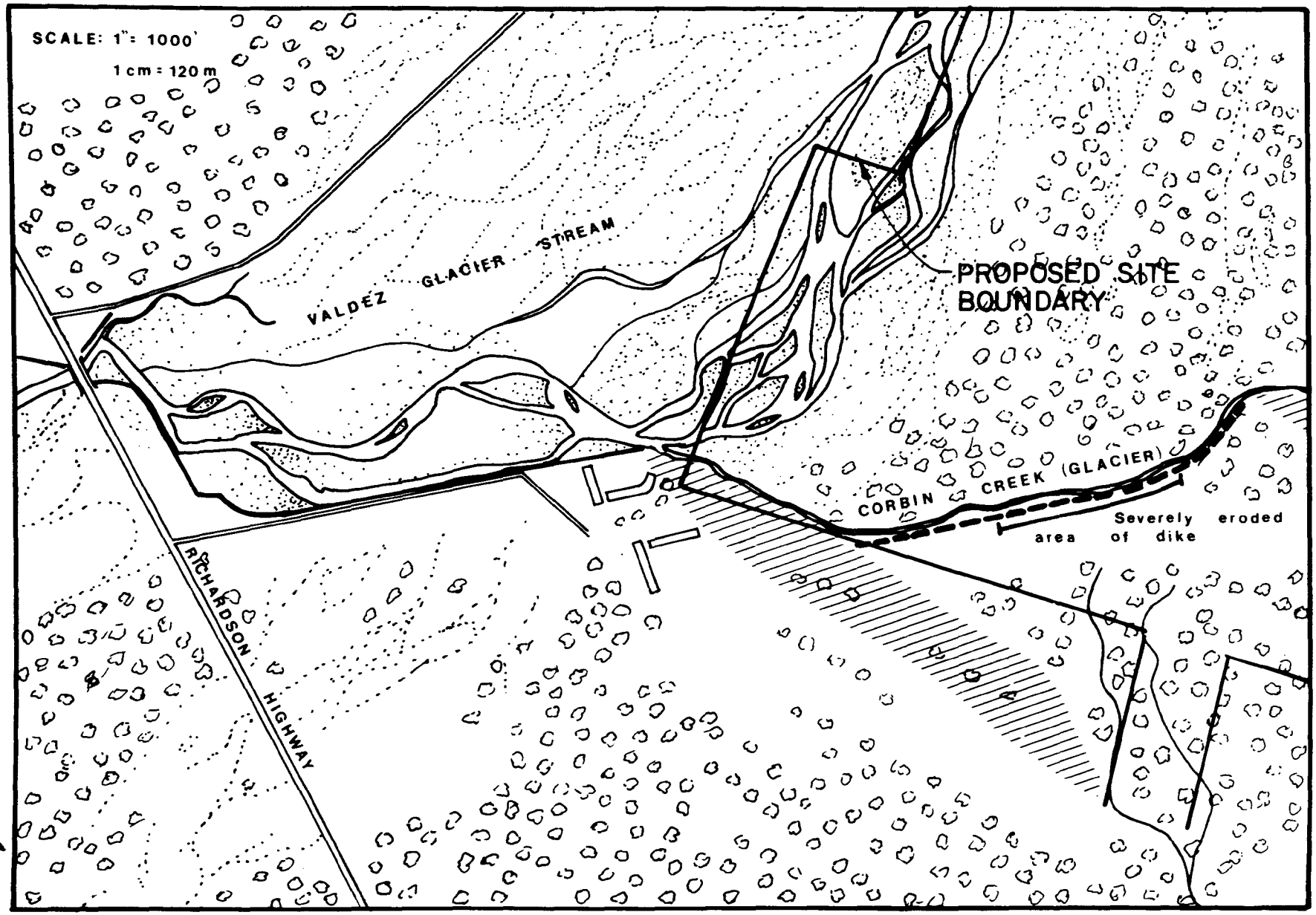
one of scouring of the bed material. Terraces at various levels along the Glacier Stream show that the recent history of the river has been one of degradation rather than aggradation. Thus, the stream is considered to be degrading moderately at present.

Slater and Corbin Creeks also have undergone some changes in recent years. If present conditions are compared with a 1952 U.S.G.S. topographical map showing the Valdez quadrangle, several changes are obvious. Slater Creek, shown at one time partly discharging into Glacier Stream, now drains wholly into Corbin Creek (Glacier). Within the project site, Slater Creek braids into six channels, all of which have undefined, irregular, and highly vegetated beds.

Corbin Creek, which flowed mostly into Robe Lake in the past with some discharge into Glacier Stream, was diked in the late 1950s. Its main flow now is diverted into Glacier Stream with some seepage still feeding the old Corbin Creek channels, now called Corbin Creek (Robe). It is not clear whether the seepage into Corbin Creek (Robe) is primarily through the dike or through the permeable stream bed. However, the relatively small cross section of the dike indicates that seepage through and below the dike must be substantial at this time. The "make-do dike" currently is rather fragile. The erosion of the dike has been severe, and at specific locations the width of the dike crest is no more than 1.5 or 2 feet. Figure V.3 shows the location of the dike and identifies the problem spots where the dike might fail. Eventually, Corbin Creek (Glacier) will cut through the dike and revert back to its previous drainage course. The ground surface elevations behind the dike are several feet below the elevation of the stream water surface (see Figure III.6). Once the dike erodes away, the natural flow of Corbin Creek (Glacier) will be in the direction of Robe Lake. Evidence of overflow over the dike has been observed on an aerial photograph taken in 1978. Along the dike, aggradation of the stream bed with concurrent severe bank erosion appears to be the trend. It is doubtful that the dike can survive without maintenance.

VI) WATER QUALITY

In order to assess the quality of water and also to collect baseline data for preconstuction activities, a water quality sampling program was implemented. Representative samples of surface water were taken for laboratory analyses, and were "fixed" and obtained in accordance with standard sampling procedures. Locations of sampling stations are shown on Figure III.2. Although an attempt has been made to gather data at prechosen sampling stations, lack of surface flow in winter has forced shifting of some stations. No sample was



V.3 Figure V.3 LOCATION OF DIKE ON CORBIN CREEK (GLACIER)

collected from Slater Creek in winter, as it was found to be dry. Some water quality data, such as dissolved oxygen (DO), pH, and temperature, were determined in the field. Water quality analyses, shown in Table VI.1, have been conducted by Chemical and Geological Laboratories of Alaska, Inc.

Dissolved mineral content, suspended sediment, and temperature are important parameters for assessing chemical and physical qualities of surface water as utilized by man, and its suitability as a habitat for fish and other wildlife.

The dissolved-solids content shows seasonal variations and also variations from stream to stream. During the periods of high run-off, the concentration of dissolved substances are low. Hardness of the surface water exhibits the same variability. Total dissolved solids concentration in Valdez Glacier Stream range from 55 mg/l in winter to 39 mg/l in summer, whereas the concentration in Corbin Creek (Glacier) drop from 62 mg/l in winter to 22 mg/l in summer. The run-off from snow and glacier melt accounts for these variations, due to the rejection of impurities in the formation of ice and snow. Surface water in all the streams of the study area have an observed range in dissolved solids content from 18 mg/l in Slater Creek to 137 mg/l in Corbin Creek (Robe). The latter creek is not fed by snow or glacier. Most of the surface water seems to be of the calcium bicarbonate type and is considered medium to hard.

During the winter, the concentrations of all chemical constituents measured are within EPA and State-recommended levels for drinking water (see Table VI.1, EPA, 1975; State of Alaska, 1979). The concentration values of chemical constituents include both dissolved and precipitated forms. Therefore, these values do not represent just the dissolved concentrations in the solution. This is particularly true of iron concentration in the Glacier Stream. The reported iron concentration of 2.2 mg/l for a sample taken in June is much greater than the maximum limit set for drinking water (0.3 mg/l). It is certain that the dissolved iron concentration is much lower than the reported value, which also includes iron in precipitated form. Table VI.2 provides values for some of the chemical constituents in dissolved form which are taken from U.S. Geological Survey records for Valdez Glacier Stream (U.S. Geological Survey, 1973).

The only limitation for utilization of surface water during the periods of high flow is the high suspended sediment concentration and increased turbidity. Table VI.3 shows suspended sediment concentrations and rates of sediment

TABLE VI.1

Surface Water Quality Data

	Brownie Creek	Corbin Creek (Robe)	Valdez Glacier Stream		Corbin Creek (Glacier		Slater Creek
	mg/l	mg/l	mg/l		mg/l		mg/l
	3-29-79	4-10-79	4-11-79	6-13-79	3-29-79	6-13-79	6-13-79
Ag, Silver	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Al, Aluminum	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As, Arsenic	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ba, Barium	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Ca, Calcium	30	53	18	12	21	8.9	6.3
Cd, Cadium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cr, Cromium	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Cu, Copper	<0.006	0.014	0.02	0.008	<0.006	0.003	0.002
Fe, Iron	0.06	0.04	0.015	2.2	<0.05	0.24	0.07
Hg, Mercury	<0.0002	<0.0002	<0.0002	0.002	<0.0002	0.0002	<0.0002
K, Potassium	<1	0.8	0.8	<1	<1	<1	<1
Mg, Magnesium	0.9	1.1	0.76	1.4	0.9	0.5	0.4
Mn, Manganese	0.03	0.01	<0.01	0.05	<0.01	0.01	<0.01
Na, Sodium	1	1.0	0.8	0.8	2	0.4	0.4
Ni, Nickel	0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.01
Pb, Lead	<0.01	<0.02	<0.02	<0.02	<0.01	<0.02	<0.02
Se, Selenium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
V, Vanadium	<0.05	<0.05	<0.05	<0.01	<0.05	<0.01	<0.01
Zn, Zinc	<0.005	0.014	0.005	0.010	<0.005	<0.005	<0.005
Zr, Zirconium	<0.05	<0.05	<0.05	<0.01	<0.05	<0.01	<0.01
Ammonia-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Nitrate-N	<0.1	0.2	0.2	0.2	0.2	0.1	0.1
Nitrite-N	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chloride	2	<2	<2	<2	2	<2	2
Flouride	<0.1	0.2	0.2	<0.5	<0.1	<0.5	<0.5
Sulfate	4	3	7	<1	12	<1	<1
Total Dissolved Solids	78	137	55	39	62	22	18
Hardness as $CaCO_3$	79	137	48	36	57	24	17
Alkalinity as $CaCO_3$	66	130	45	38	40	20	16
Hydrogen Sulfide	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Oil and Grease	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron Bacteria	0	0	0	0	0	0	0
Conductivity (mmhos)	160	260	110	90	120	55	39
Turbidity NTU	1	4	1	250	5	50	5
Color Units	10	10	<10	20	20	10	<5

Source: DOWL Engineers

TABLE VI.2

Surface Water Quality Parameters for Valdez Glacier Stream

Date	Time	Discharge (CFS)	Dissolved silica (SL02) (MG/L)	Dissolved iron (FE) (UG/L)	Dissolved Manganese (MN) (UG/L)	Dissolved Calcium (CA) (MG/L)	Dissolved Magnesium (MG) (MG/L)	Dis solved sodium (NA) (MG/L)	Dissolved Potassium (K) (MG/L)	Bicarbonate (HC03) (MG/L)	Carbonate (C03) (MG/L)
Oct. 13...	1000	257	1.4	240	20	18	1.0	1.5	1.1	44	0
Apr. 05...	1445	.15	--	--	--	--	--	--	--	†57	†1
June 18...	1300	1340	--	--	--	--	--	--	--	†32	†0

Date	Dis solved sulfate (SO4) (MG/L)	Dissolved chloride (Cl) (MG/L)	Dissolved fluoride (F) (MG/L)	Dissolved nitrate (N) (MG/L)	Ammonia nitrogen (N) (MG/L)	Organic nitrogen (N) (MG/L)	Total phosphorus (P) (MG/L)	Dissolved ortho. phosphorus (P) (MG/l)	Dissolved solids (sum of constituents) (MG/L)	hardness (Ca,Mg) (MG/L)	Noncarronate hardness (MG/L)
Oct 13...	11	2.5	.2	.09	.02	.19	.01	.00	59	49	13
Apr 05...	--	--	--	--	--	--	--	--	--	--	--
June 18...	--	--	--	--	--	--	--	--	--	--	--

Date	Specific conductance (micromhos)	pH (units)	Temperature (Deg C)	Color (platinum-cobalt units)	turbidity (JTU)	dissolved oxygen (MG/L)	Carbon dioxide (CO2) (MG/L)	Fecal coliform (col. per 100 ML)	Dis-Streptococci (colonies per 100 ML	Dissolved organic carbon (C) (MG/L)
Oct. 13...	†95	†7.2	1.0	0	--	†12.9	--	--	--	--
Apr. 05...	†115	†8.6	3.5	<5	<1	†12.0	†.4	--	†80	.0
June 18...	†69	†8.0	2.0	5	300	†13.4	.8	†80	†80	2.0

(Source: U.S. Geological Survey, Water Resources Data for Alaska, Part II. Water Quality Records, 1973)

TABLE VI.3

Measured Suspended Sediment Concentrations and Rates

Date	Stream	Suspended Sediment (mg/l)	Discharge (m^3/sec)	Rate of Sediment Discharge (g/sec)
5-15-79	Corbin Creek (Glacier)	24	1.2	28.8
6-12-79	Corbin Creek (Glacier)	138	6.5	897.0
6-12-79	Valdez Glacier Stream	164	45.4	7,445.6
7-14-72	Valdez Glacier Stream*	930	72.0	66,990.0
8-15-79	Corbin Creek (Glacier)	2310	8.9	20,559.0
8-15-79	Slater Creek	17	2.3	39.1
10-30-72	Valdez Glacier Stream*	30	16.8	511.0

*Source: Environmental Studies for Port Valdez, Data Volume One Institute of Marine Science, University of Alaska, 1973.

discharge for Valdez Glacier Stream, Corbin Creek (Glacier) and Slater Creek. It was observed in the field that Corbin Creek (Glacier) did not pick up appreciable quantities of suspended materials during the first two or three weeks of breakup. During this period, heavy snowmelt run-off constitutes a very large percentage of the total flow. Measured quantities of suspended sediments range from 3 mg/l at Glacier Stream after breakup to 930 mg/l in mid-summer.

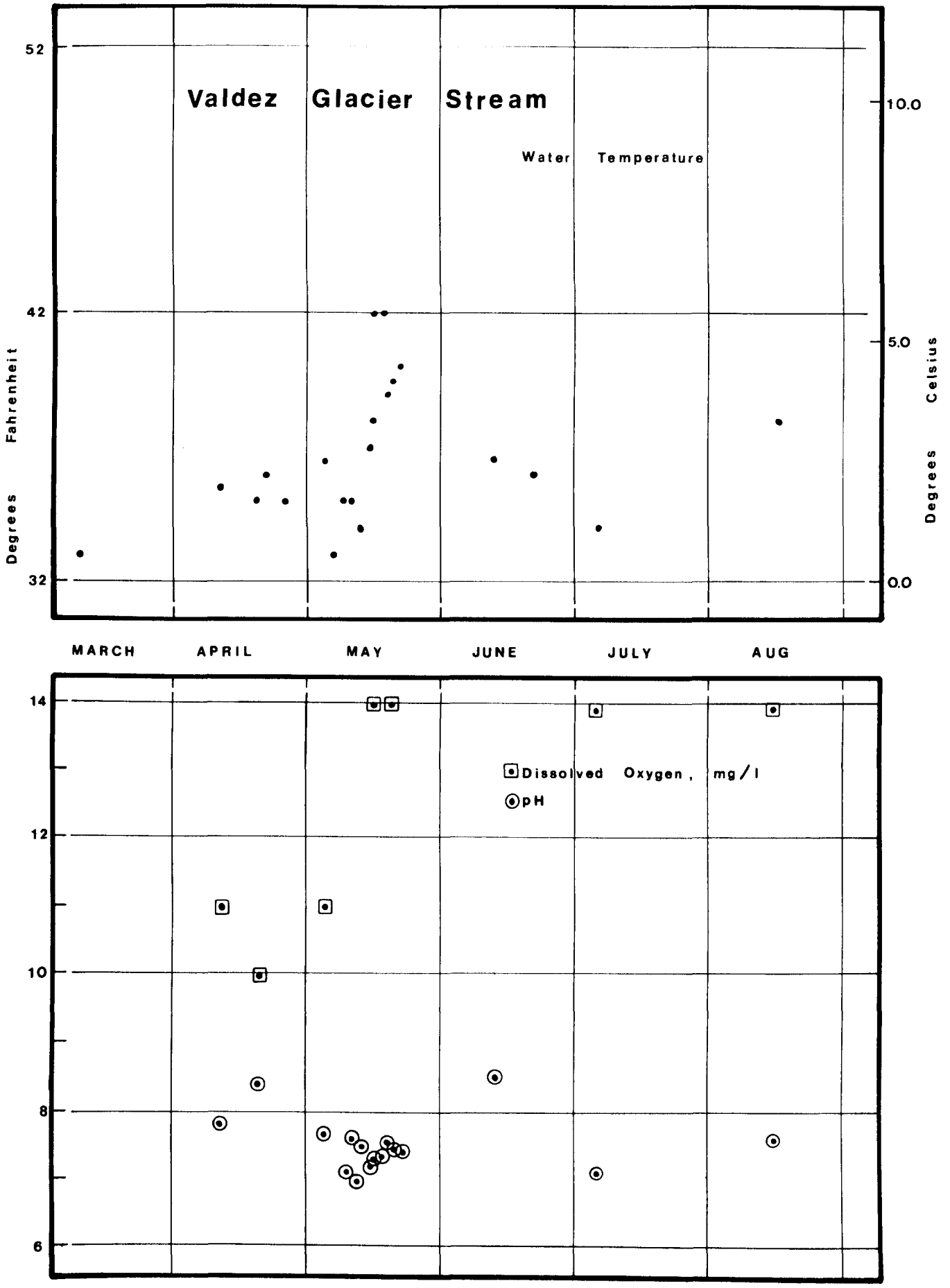
Although the first measured suspended sediment concentration on Corbin Creek (Glacier) is higher than Glacier Stream, this is due mainly to the presence of large, heavy particles (some fine sand) which are carried away by high velocity flow at the sampling point which are trapped in the sample. Otherwise, turbidity values indicate that Corbin Creek (Glacier) is less turbid than Valdez Glacier Stream at the time of measurement. However, heavy glacial melting in mid and late summer has increased suspended sediment concentrations tremendously.

The results of the color determination tests are to be regarded as "true color" or "apparent color." Color values of samples taken in summer are due to substances in solution only; that is, it is the color of the water after the suspended matter has been removed. Winter "apparent color" values include any color produced by substances in suspension and solution.

According to the recently revised edition of Alaska State Water Quality Standards (State of Alaska, 1979), the chemical quality of the surface water within the study area is acceptable in winter for drinking, industrial use, aquaculture, agriculture, and for most other uses. During the periods of high run-off in summer and early fall, however, increased concentrations of suspended sediment and turbidities preclude its use in an untreated state. Corbin Creek (Robe) and Brownie Creek are not directly glacial fed. Both creeks maintain a quality water in the context of national and State of Alaska water quality standards throughout the year. It is theorized that this situation is a result of their being largely fed by groundwater and surface water without glacial suspended solids.

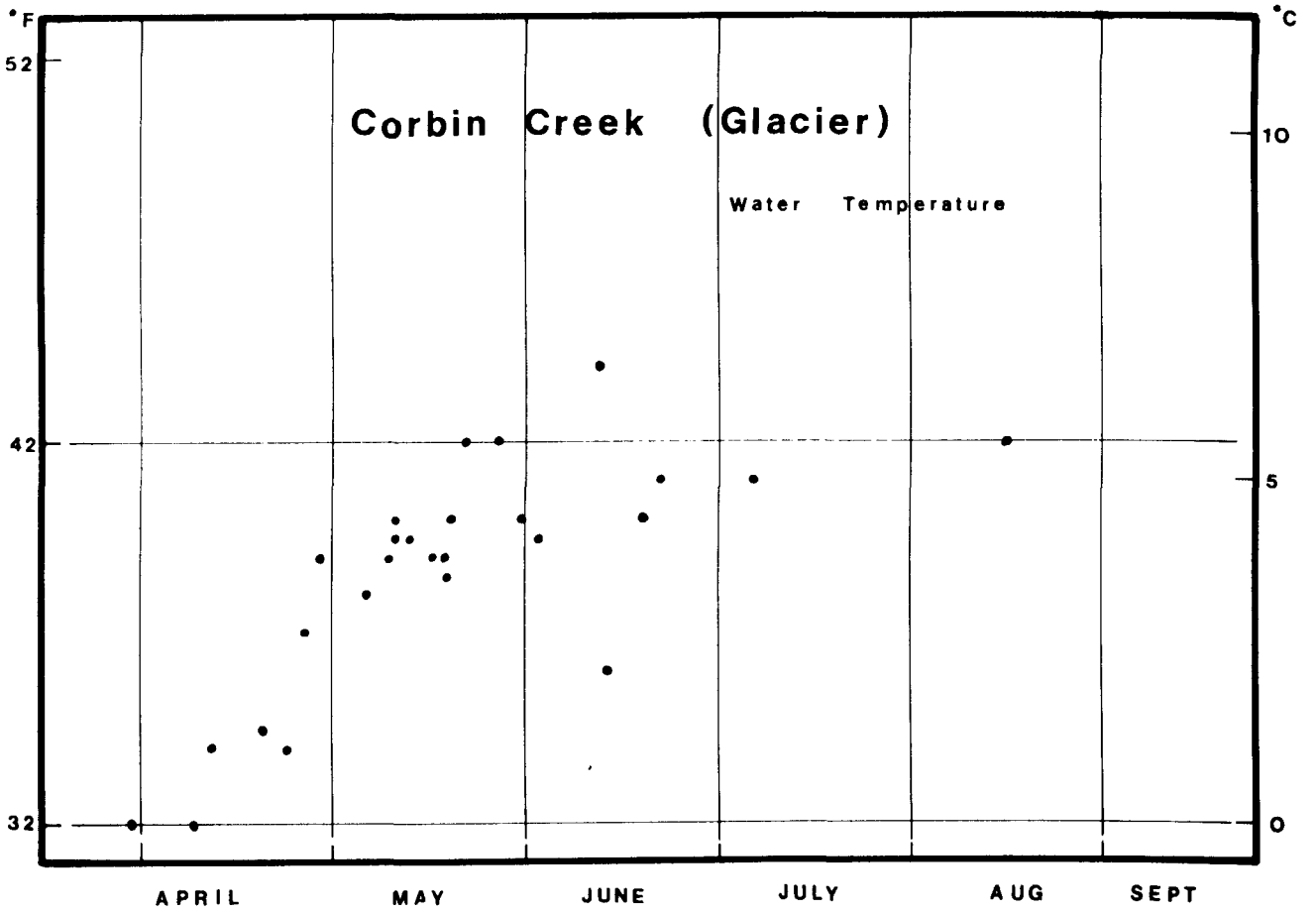
Dissolved oxygen contents range from 8 mg/l, at the headwaters of Brownie Creek, to 14 mg/l in Corbin Creek (Glacier). The low dissolved oxygen reading in Brownie Creek could be attributed to its groundwater character close to its headwaters. Values of pH are well within the recommended values for most uses, ranging from 6.6 to 8.5. The low reading is from Brownie Creek and the high reading is from Valdez Glacier Stream. Winter surface water temperatures range from 32+°F in Corbin Creek (Glacier) to

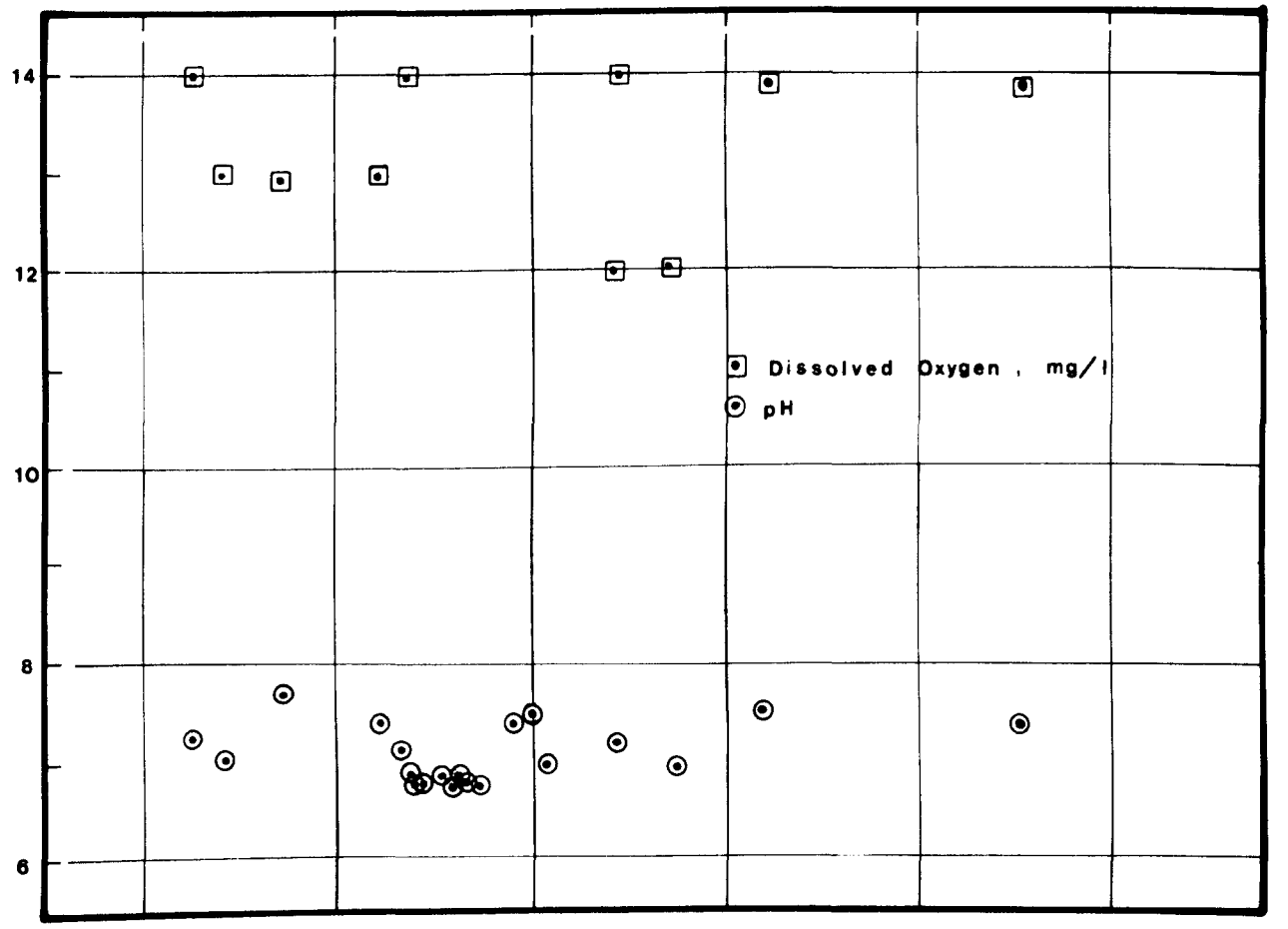
40°F in Brownie Creek. Seasonal variations in surface temperatures are reflected on Figures VI.1 through VI.5. Measured values of pH and dissolved oxygen contents for each stream are given in the same figures.



SURFACE WATER TEMPERATURE, DO, AND pH MEASUREMENTS ON VALDEZ GLACIER STREAM

FIGURE VI. I





SURFACE WATER TEMPERATURE, DO, AND pH MEASUREMENTS

FIGURE VI.2

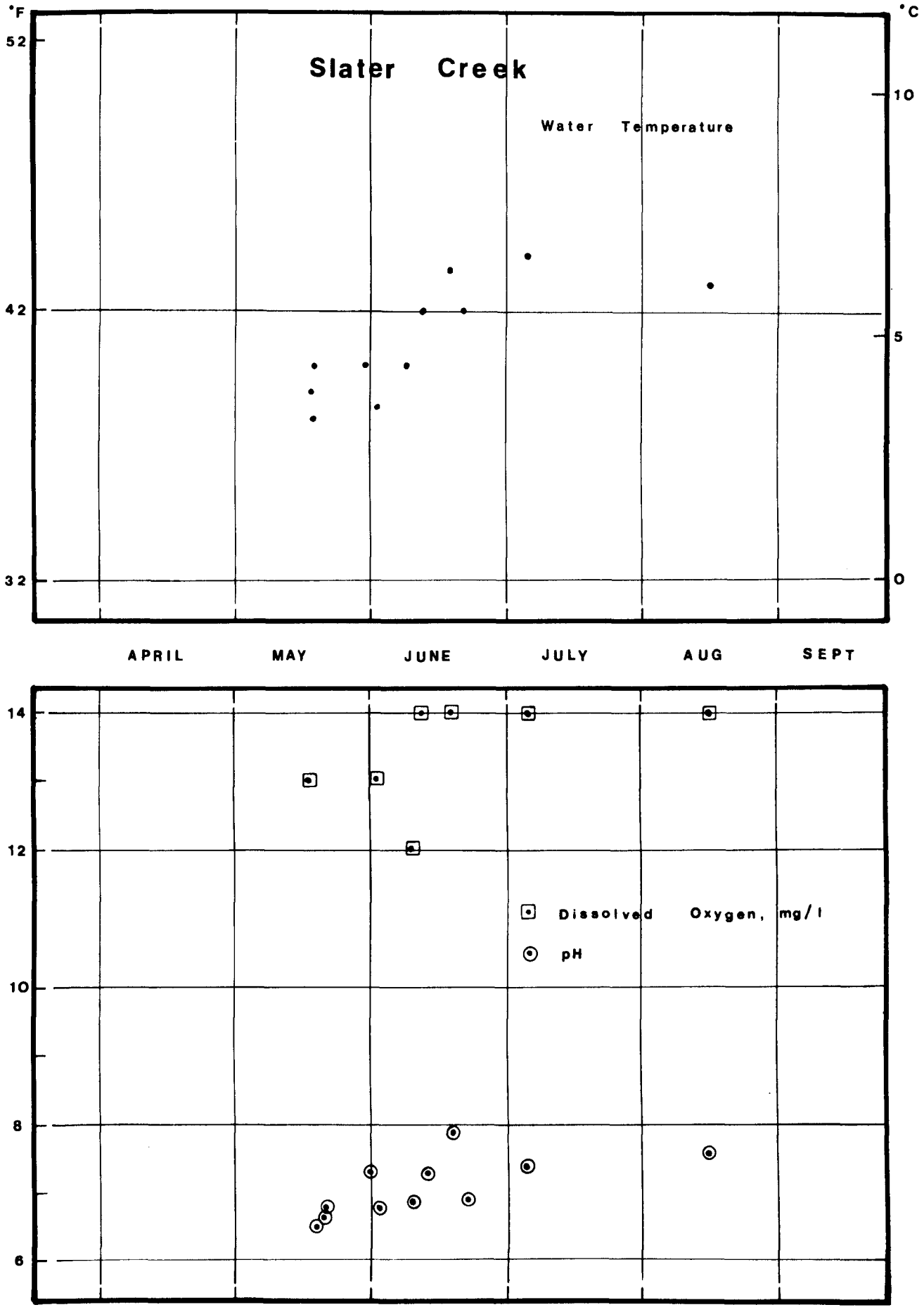
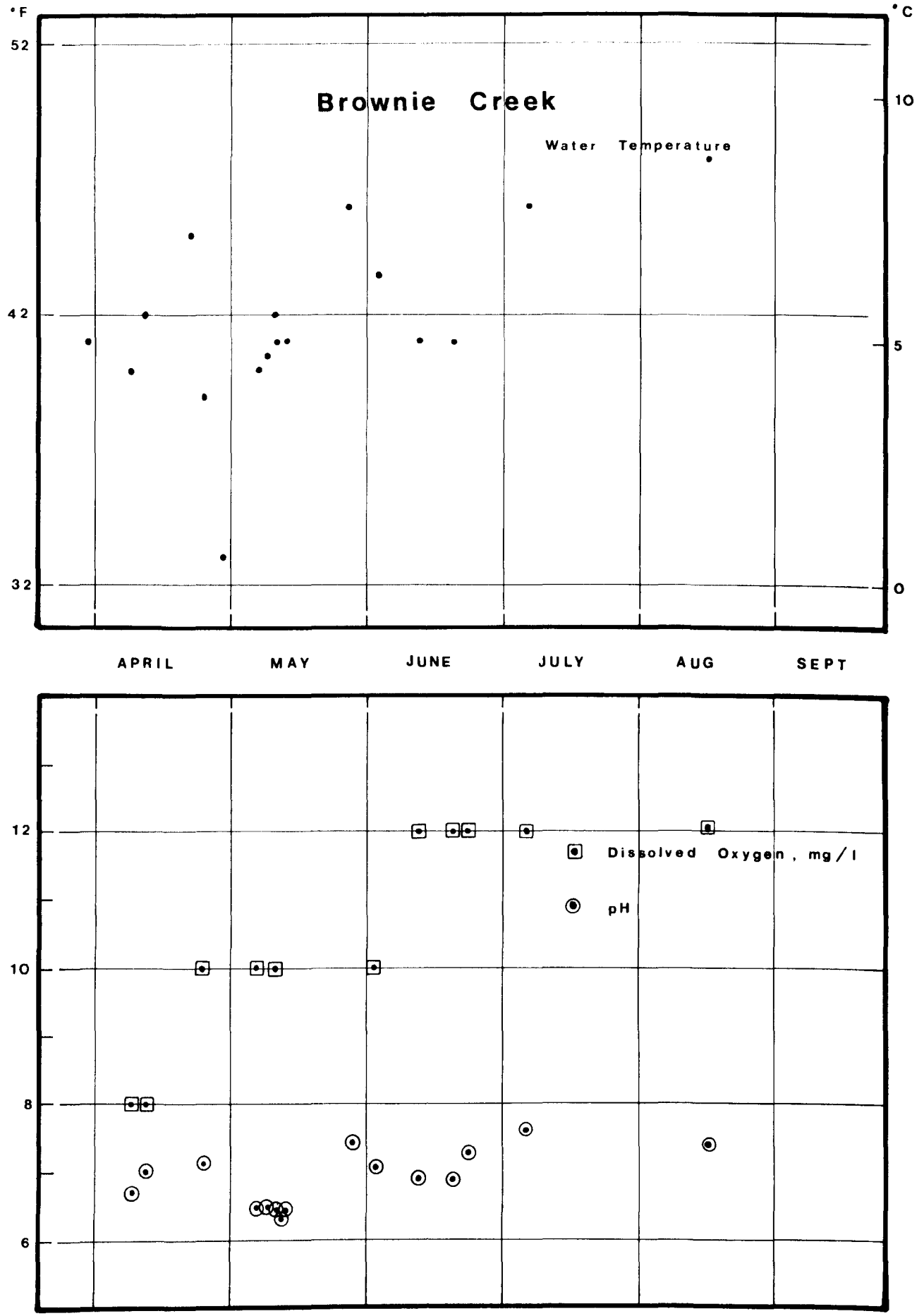


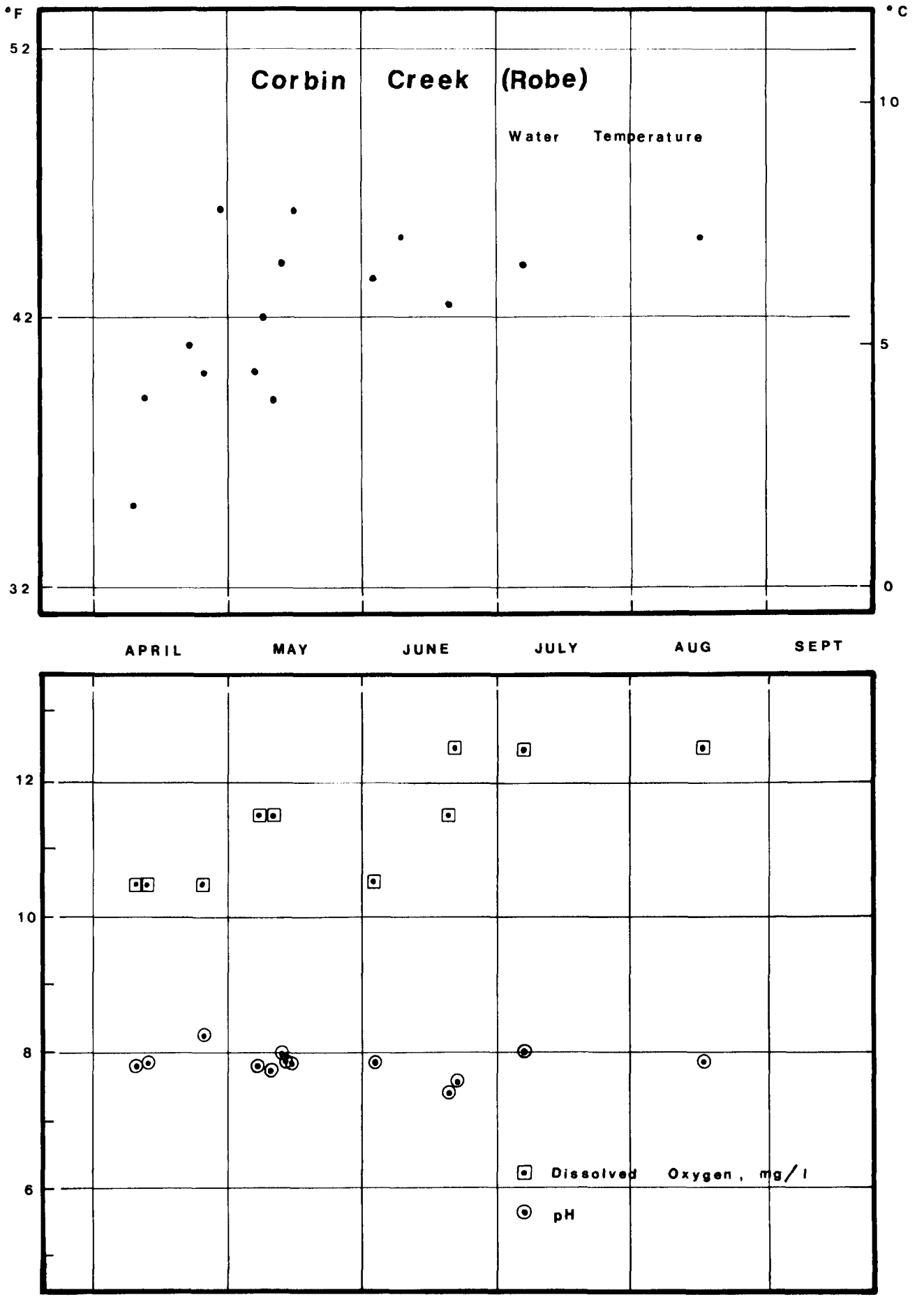
Figure VI.3 SURFACE WATER TEMPERATURE, DO, AND pH MEASUREMENTS

FIGURE VI.3



SURFACE WATER TEMPERATURE, DO, AND pH MEASUREMENTS

FIGURE VI.4



SURFACE WATER TEMPERATURE, DO, AND pH MEASUREMENTS

FIGURE VI.5

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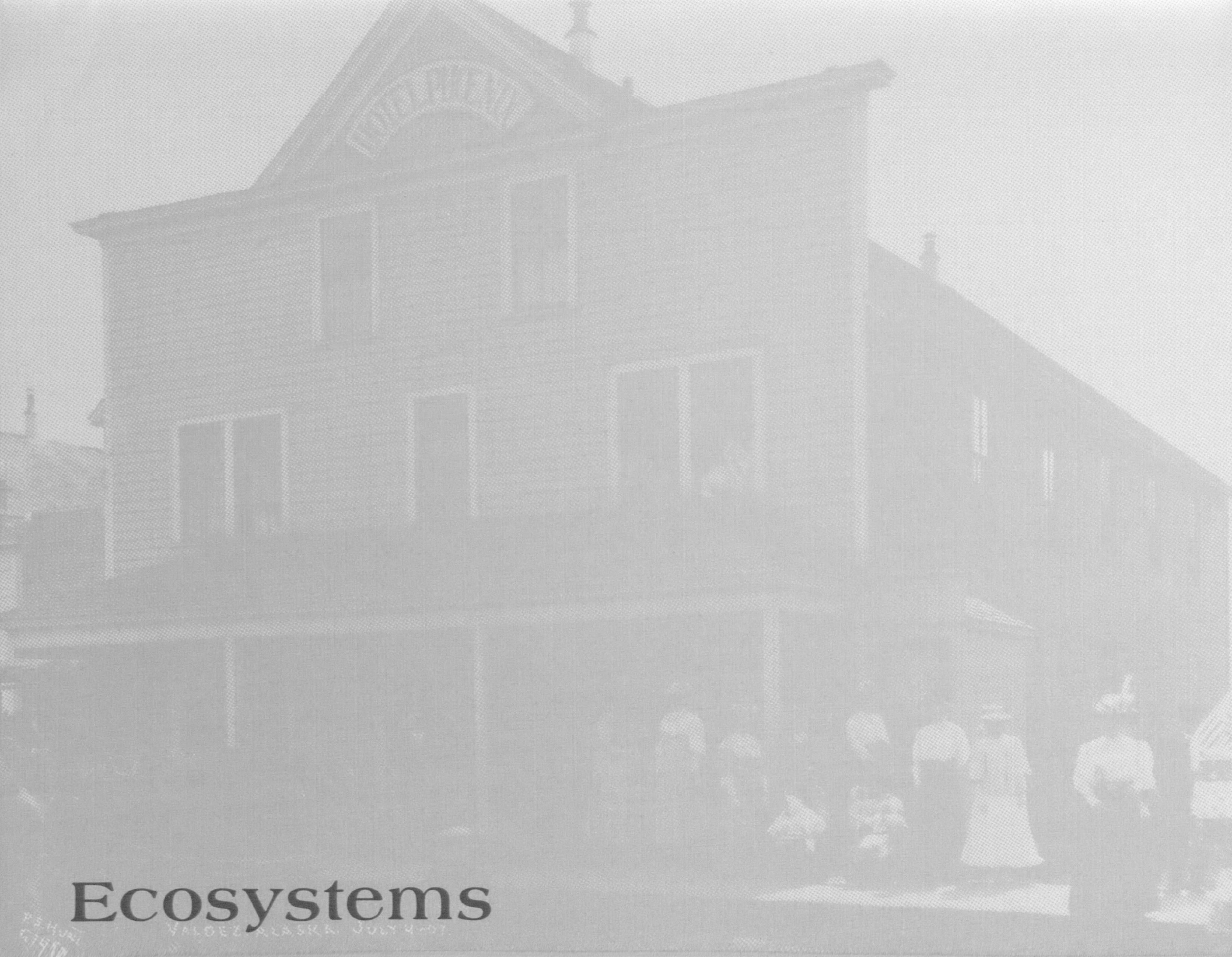

Ecosystems

ECOSYSTEMS

THE BIRDS OF PORT VALDEZ

Prepared for

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INTRODUCTION

The purpose of this study is to describe the occurrence and seasonal abundance of birds in the Valdez area as a basis for measuring the potential impacts of a proposed petrochemical refinery on avian populations or their habitat. The proposed refinery would be located southeast of Valdez Glacier with a complex of crude oil pipelines extending between the trans-Alaska oil pipeline and the refinery and product pipelines from the refinery to a marine terminal facility at the mouth of Solomon Gulch Creek.

Very little ornithological work had been conducted in Port Valdez prior to 1977. However, this study and ongoing studies of waterfowl by the U.S. Fish and Wildlife Service will provide the basis for a comprehensive description of bird distribution.

The study area extends from the Allison Creek delta westward to the Mineral Creek delta including the drainages of Valdez Glacier Stream, Corbin Creek, Brownie Creek, Robe River, and Lowe River (Figure 1).

METHODS

Surveys were conducted monthly from March through August, 1979. Supplemental observations were made during the spring and fall migration period. A variety of transportation methods were used including auto, helicopter, boat, and foot. All species identifications were made with the assistance of binoculars or spotting scope. Special attention was directed to the delineation of sensitive habitat such as nesting, staging, or feeding areas.

Data was recorded on standard forms that included observer, locality, survey methods, species, sex, date, number, habitat type, and remarks. The common and scientific names of birds are from the American Ornithologists' Union (1957, 1973, 1976). Plant names are according to Hulten (1968).

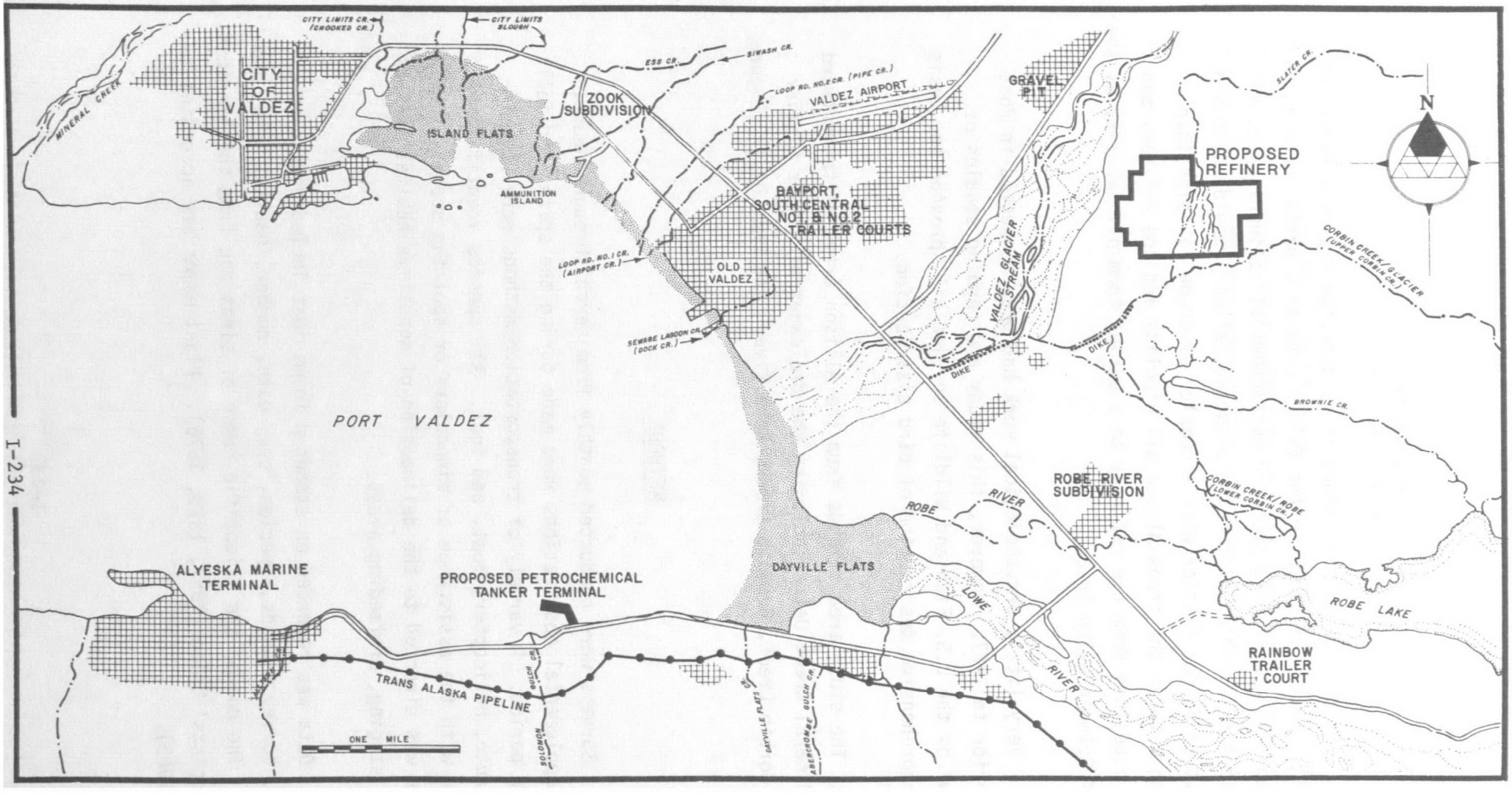

FIGURE 1

STUDY AREA

ECOLOGICAL DISTRIBUTION AND ABUNDANCE

The distribution of birds was determined from a summary of habitat use data from the bird observation forms. The classification system is modified from Dice (1920) and Williamson and Peyton (1962) and includes 12 ecological formations:

Fluviatile Waters	Deciduous Forest
Streamside Alluvium	Grassland
Riparian Woodland	Saltwater Marsh
Freshwater Marsh	Intertidal Flats
Alder Shrub	Marine Littoral Waters
Spruce Forest	Sea Beach

Fluviatile Waters: Includes all flowing waters.

Streamside Alluvium: Floodplain formations consisting of exposed gravel or cobbles with only scattered vegetation including species typical of early plant succession.

Riparian Woodland: A shrub-dominated formation that usually occurs along the margins of streams and lakes. Within the study area this type is dominated by willow (*Salix* sp), alder (*Alnus crispa*), and young cottonwood (*Populus balsamifera*).

Freshwater Marsh: Areas of standing water, lush emergent vegetation, small ponds, and floating mats. The emergent vegetation of the study area is dominated by sedge (*Carex* sp), dwarf birch (*Betula glandulosa*), mare's tail (*Hippuris* sp), and horsetail (*Equisetum* sp).

Alder Shrub: Dense shrub thickets typical of lower mountain slopes. Alder (*Alnus crispa*) interspersed with mountain ash (*Sorbus scopulina*), red elderberry (*Sambucus racemosa*), grasses (*Calamgrostis canadensis*), and various herbacious species. This type occurs on all mountain slopes within the study area.

Spruce Forest: Forests of Sitka spruce (*Picea sitchensis*) with an understory of alder (*Alnus crispa*), devil's club (*Echinopanax horridum*), salmonberry (*Rubus spectabilis*), highbush cranberry (*Viburnum edule*), and a variety of ferns and mosses.

Deciduous Forest: Limited within Port Valdez to stands of black cottonwood (*Populus balsamifera*) of varying age commonly occurring on floodplain sites.

Grassland: Nearly pure stands of grasses but generally of limited extent such as river banks, uplands adjacent to lakes or sea beaches, and mountain slopes near timberline. Species are highly variable but some of the more common representatives include bluejoint (*Calamagrostis canadensis*), lyme grass (*Elymus* sp), and bluegrass (*Poa glauca*).

Saltwater Marsh: Vegetated areas that are periodically flooded by tidal action. Alkali grass (*Puccinellia hultenii*), sedge (*Carex lyngbyaei*), and spike rush (*Eleocharis kamtschatica*) are the primary species of this formation within the study area.

Intertidal Flats: This formation consists of largely unvegetated tidal flats, with scattered patches of rockweed (*Fucus distichus*), scurvy grass (*Cochlearia officinalis*), goose grass (*Puccinellia nutkaensis*), spurry (*Spergularia canadensis*), green algae (*Enteromorpha* sp), and brown algae (*Pylaiella* sp). Scattered clusters of blue mussel (*Mytilus edulis*) occur in rocky and gravel areas along the outer islands and pink shells of the clam (*Macoma balthica*) are conspicuous throughout this formation.

Marine Littoral Waters: Relatively shallow marine waters bordering the shore and extending approximately two miles from land where they merge with pelagic waters. The waters of bays and lagoons even though brackish are included here.

Sea Beach: Sand or gravel areas bordering the ocean. Vegetation is generally sparse but may include species such as lyme grass (*Elymus* spp), bedstraw (*Galium aparine*), seaside avens (*Potentilla anserina*), and goose grass (*Puccinellia nutkaensis*).

The occurrence of birds within the various habitats listed above is included in Table 1.

SENSITIVE AREAS

No endangered species were observed during this study and none are reported in the literature for Port Valdez. However, Isleib and Kessel (1973) cited one unconfirmed record of the endangered American peregrine falcon (*Falco peregrinus anatum*) for Cordova, Alaska in their discussion of the non-endangered Peale's peregrine falcon. The latter species does occur in the Prince William Sound area.

Six bald eagle nest trees were observed during field investigations, but only two were active in 1979 (Figure 2). Three of the inactive nests are adjacent to Dayville Road, an area that has sustained a high level of vehicle traffic since the Alyeska crude oil pipeline and marine terminal were constructed. The fourth inactive nest is next to Corbin Creek (Glacier), an area that probably supported salmon spawning prior to the diversion of the stream by local residents around 1957 (ADF&G 1979).

Bald eagle concentrations have been noted in the Lowe River Valley from early October to mid-November, presumably in response to the late silver salmon run. Fifty-eight eagles were observed from the Richardson Highway between Old Valdez and Sheep Creek on November 3, 1976 (Morsell, personal communication).

Arctic terns and black-legged kittiwakes are the only colony nesting sea birds in Port Valdez (McRoy and Stoker 1969). Shoup Bay supports nesting colonies of both species. Arctic terns also nest near the entrance to Valdez small boat harbor and on Island Flats (Figure 2).

TABLE 1

ECOLOGICAL DISTRIBUTION OF BIRDS OF PORT VALDEZ

	Fluviatile Waters	Streamside Alluvium	Freshwater Marsh	Saltwater Marsh	Riparian Woodland	Deciduous Forest	Spruce Forest	Alder Shrub	Intertidal Flats	Marine Littoral Waters	Grassland	Sea Beach
Common Loon										X		
Arctic Loon										X		
Red-throated Loon										X		
Red-necked Grebe										X		
Horned Grebe										X		
Pelagic Cormorant										X		
Great Blue Heron									X			
Trumpeter Swan				X								
Canada Goose				X					X			
Brant												X
White-fronted Goose				X					X			
Mallard			X	X					X	X		X
Gadwall									X			
Pintail			X	X					X	X		
Green-winged Teal			X	X					X			
Blue-winged Teal				X								
American Widgeon			X	X					X			
Northern Shoveler				X					X	X		
Canvasback			X									
Greater Scaup										X		
Common Goldeneye										X		
Barrows Goldeneye										X		
Bufflehead										X		
Oldsquaw										X		
Harlequin Duck										X		
White-winged Scoter										X		
Surf Scoter										X		
Black Scoter										X		
Common Merganser										X		
Red-breasted Merganser										X		
Goshawk						X						
Sharp-shinned Hawk								X				
Bald Eagle						X			X			
Spruce Grouse							X					

TABLE 1 (Continued)

ECOLOGICAL DISTRIBUTION OF BIRDS OF PORT VALDEZ

	Fluviatile Waters	Streamside Alluvium	Freshwater Marsh	Saltwater Marsh	Riparian Woodland	Deciduous Forest	Spruce Forest	Alder Shrub	Intertidal Flats	Marine Littoral Waters	Grassland	Sea Beach
Willow Ptarmigan					X			X				
Sandhill Crane				X								
Black Oystercatcher												X
Semipalmated Plover		X							X			X
Black-bellied Plover									X			
Common Snipe			X						X			
Whimbrel									X			
Spotted Sandpiper	X			X								
Wandering Tattler									X			
Greater Yellowlegs			X	X								X
Lesser Yellowlegs				X								X
Least Sandpiper				X					X			
Short-billed Dowitcher				X					X			
Long-billed Dowitcher									X			
Semipalmated Sandpiper									X			
Western Sandpiper									X			
Hudsonian Godwit				X					X			
Northern Phalarope			X									
Glaucous-winged Gull	X	X	X	X					X	X		X
Herring Gull		X		X					X	X		X
Mew Gull	X	X	X	X					X	X		X
Bonapartes Gull									X	X		
Black-legged Kittiwake										X		
Arctic Tern		X	X	X					X	X	X	X
Common Murre										X		
Marbled Murrelet										X		
Belted Kingfisher	X	X	X	X	X				X	X		
Rufous Hummingbird							X					
Downy Woodpecker					X	X						
Western Flycatcher						X						
Olive-sided Flycatcher						X	X					
Violet-green Swallow				X								
Tree Swallow			X									
Black-billed Magpie			X	X	X	X	X	X	X			

TABLE 1 (Continued)

ECOLOGICAL DISTRIBUTION OF BIRDS OF PORT VALDEZ

	Fluviatile Waters	Streamside Alluvium	Freshwater Marsh	Saltwater Marsh	Riparian Woodland	Deciduous Forest	Spruce Forest	Alder Shrub	Intertidal Flats	Marine Littoral Waters	Grassland	Sea Beach
Common Raven		X	X	X	X	X	X	X	X		X	X
Northwestern Crow		X	X	X	X	X	X	X	X		X	X
Black-capped Chickadee							X					
Boreal Chickadee							X					
Chestnut-backed Chickadee						X	X					
Brown Creeper					X	X						
Dipper	X											
Robin				X	X	X						
Varied Thrush						X	X					
Hermit Thrush					X	X	X					
Swainson's Thrush						X						
Gray-cheeked Thrush						X						
Golden-crowned Kinglet						X	X					
Ruby-crowned Kinglet						X	X					
Water Pipit				X								X
Bohemian Waxwing							X					
Orange-crowned Warbler						X	X	X				
Yellow Warbler					X	X						
Yellow-rumped Warbler						X		X				
Blackpoll Warbler								X				
Northern Waterthrush					X							
Wilson's Warbler						X						
Red-winged Blackbird			X		X							
Rusty Blackbird					X							
Pine Grosbeak						X						
Common Redpoll					X	X						
Savannah Sparrow					X						X	
Dark-eyed Junco							X					
Tree Sparrow					X							
White-crowned Sparrow					X							
Fox Sparrow					X	X						
Lincoln's Sparrow					X							
Song Sparrow						X						
Lapland Longspur				X								

During the spring and fall migration period, salt marshes at Island Flats and Shoup Bay are used by several hundred Canada geese. The small marsh on Dayville Flats also receives some use. In addition to migrants, smaller numbers of resident geese use the above areas throughout the year.

Nesting habitat for waterfowl is scarce in Port Valdez. The largest area is the freshwater marsh at Robe Lake. Decreasing water levels in the lake have resulted in ever increasing acreage of emergent vegetation. Smaller areas of nesting habitat for dabbling ducks and shorebirds occur on Island Flats, the Mineral Creek delta, and Shoup Bay.

In winter, diving ducks and sea ducks are relatively abundant in Port Valdez. At high tide, Barrow's goldeneye, common goldeneye, bufflehead, harlequin duck, and white-winged scoter move onto intertidal flats to feed on abundant pink shelled clams (*Macoma balthica*). During the winter, near-shore waters are clear and feeding conditions are good. The primary feeding areas are near Solomon Gulch Creek and Island Flats (Figure 2).

SEASONAL OCCURRENCE

WINTER

Winter is a time of clear water conditions in Port Valdez because its glacial tributaries, which carry a large volume of silt to the estuary in summer, are mostly frozen. Marine birds respond to these improved conditions and large numbers of Barrow's goldeneye, mallard, bufflehead, white-winged scoter, common merganser, and oldsquaw forage in the Allison/Solomon Gulch Creek area and at Island Flats. Greater numbers of waterfowl are present in winter than during the summer (Sangster 1978).

Snow accumulations on the lowland river deltas are great and cover much of the shrub vegetation. This condition undoubtedly contributes to the relatively small number of terrestrial birds. The most common species that remain in the lowlands through the winter include:

PAGE NOT

AVAILABLE

DIGITALLY

Downy Woodpecker	Black-capped Chickadee
Steller's Jay	Boreal Chickadee
Black-billed Magpie	Brown Creeper
Common Raven	Pine Grosbeak
Northwestern Crow	Common Redpoll

SPRING

Seasonal visitors arrive on marine wetlands in late April while upland areas are still covered by a heavy blanket of snow. Spring migration peaks around May 10th. It is interesting to note that fewer than 1,000 birds of all species passed through eastern Port Valdez during the spring migration of 1979. Less than 70 miles away on the Copper River delta, shorebird densities alone may exceed 250,000 in early May (Isleib and Kessel 1973). Most of the same species that move through the Copper River delta also pass through Port Valdez but, as suggested above, numbers of each are conspicuously smaller. This supports the data of Isleib and Kessel (1973) that the main migration route for waterbirds is directly across Prince William Sound or up the Copper River Valley rather than across the heads of fjords like Port Valdez.

SUMMER

Waterfowl numbers are lowest during the nesting period (Figure 3). This is perhaps due to the limited amount of nesting habitat available. The deltas of Lowe River, Robe River, and Valdez Glacier Stream, plus Island Flats and Shoup Bay support the only marshes. Receding water levels over many decades in Robe Lake and subsequent emergent vegetation have resulted in the only sizable freshwater marsh in the area. The marsh provides valuable nesting habitat for dabbling ducks, shorebirds, and more unusual species such as the red-winged blackbird.

Extensive cottonwood forests are dominated by Wilson's warbler, hermit thrush, varied thrush, common redpoll, and ruby-crowned kinglet. Adjacent alder-covered mountain slopes are utilized by the yellow-rumped

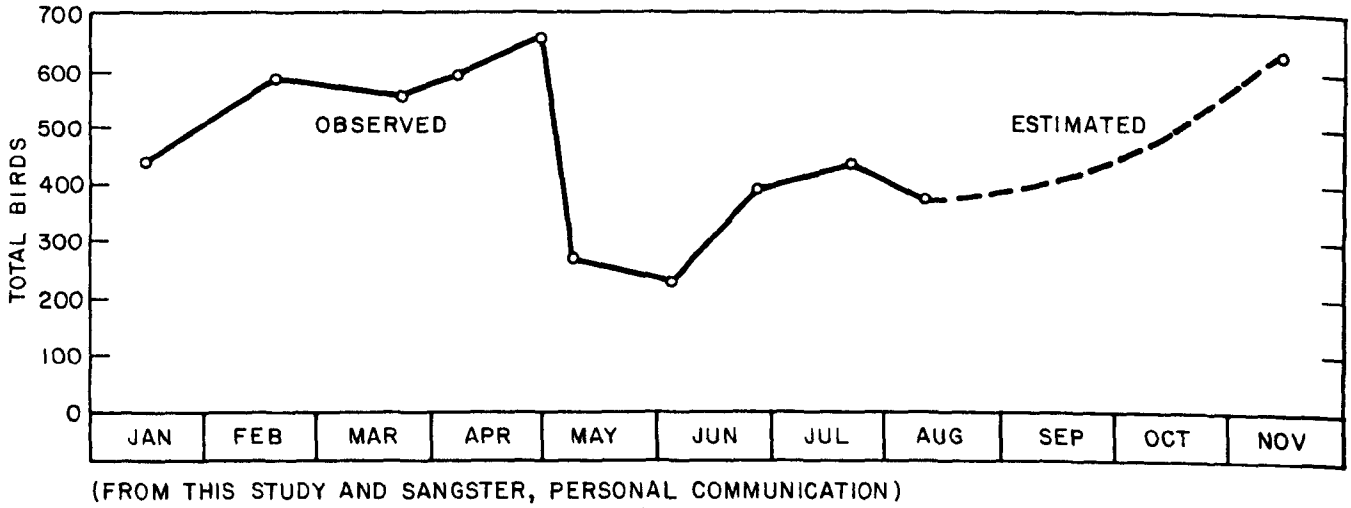

FIGURE 3

SEASONAL ABUNDANCE OF BIRDS IN THE ISLAND FLATS AREA

warbler, blackpoll warbler, and white-crowned sparrow. Open floodplain alluvium along Valdez Glacier Stream provides excellent nesting habitat for semipalmated plovers. In nearby riparian areas the fox sparrow, Lincoln's sparrow and white-crowned sparrow are more typical.

Large concentrations of gulls are attracted to salmon spawning areas particularly during odd years when pink salmon are most abundant. They are also attracted by cannery wastes and the City of Valdez sanitary landfill along with abundant ravens, black-billed magpies, and northwestern crows.

FALL

Fall migration extends from July to November, beginning with shorebirds and passerines followed by a gradual build-up of waterfowl. Ongoing studies by the U.S. Fish and Wildlife Service suggest that somewhat greater numbers of migrants move through the west end of Port Valdez, particuarly the Shoup Bay area, than through the east end of the Port.

As in spring, the Canada goose is one of the more conspicuous fall migrants. However, large numbers of ducks such as mallard, Barrow's goldeneye, bufflehead, harlequin duck, and white-winged scoter also move into the area in autumn.

ANNOTATED LIST OF BIRDS

From March to August 1979, 102 species of birds were observed within the study area. Personal observations by Joan Perkins, a resident of Port Valdez, ongoing studies of the U.S. Fish and Wildlife Service, Sangster (1978), and an earlier survey by McRoy and Stoker (1969) added an additional 11 species.

Common Loon (*Gavia immer*) -- This species was observed regularly in singles and pairs off the mouth of Solomon Gulch Creek, Island Flats, and Old Valdez townsite.

Arctic Loon (Gavia arctica) -- An uncommon visitor in Port Valdez. One bird was seen on June 6, 1979. U.S. Fish and Wildlife Service biologists recorded several arctic loons in May and June of 1979 and Sangster (1978) reported three birds in November 1977.

Red-throated Loon (Gavia stellata) -- Occasional birds were observed throughout the period of study in nearshore waters. Observation of nesting display on June 7, 1979 suggests that nesting occurs on the floating marshes surrounding Robe Lake. This is a common nesting species in the Prince William Sound area (Isleib and Kessel, 1973).

Red-necked Grebe (Podiceps grisegena) -- This species is a common year-round resident. Large flocks were observed frequently throughout the winter period (Sangster, 1978). Following the spring migration period, pairs assumed to be nesters were observed on freshwater marshes at Robe Lake.

Horned Grebe (Podiceps auritus) -- A common winter resident according to Sangster (1978). Many groups were observed on marine littoral waters during the first week of May, but no birds could be located during the nesting period.

Double-crested Cormorant (Phalacrocorax auritus) -- No cormorants of this species were observed during this study, but Sangster (1978) reported eight wintering birds in November 1977.

Pelagic Cormorant (Phalacrocorax pelagicus) -- Occasional individuals were observed throughout the study period and Sangster (1978) found them to be common in Port Valdez from November 1977 to February 1978.

Great Blue Heron (Ardea herodias) -- A lone bird was observed on the intertidal flats near Old Valdez townsite on March 21, 1979. McRoy and Stoker (1969) reported four birds in Port Valdez in August 1969.

Trumpeter Swan (Olor buccinator) -- A rare visitor. One immature swan was observed at close range on the Mineral Creek delta on May 9, 1979 and seven one-year-old birds were found at Robe Lake on June 5, 1979.

Canada Goose (Branta canadenis) -- This species is a common year-round resident of the Prince William Sound area (Isleib and Kessel, 1976). Sangster (1978) reported Canada geese within the study area during each of the winter months. During spring migration, there was a sharp increase in abundance with maximum numbers of 372 recorded on April 30, 1979. The marsh just east of Sontag Spit (immediately east of Ammunition Island) was the primary staging area with lesser use between Sontag Spit and the Old Valdez townsite and on Dayville Flats. Apparently there is only limited use of the Mineral Creek delta. One goose was recorded in the latter area on May 9, 1979 and local residents said that small flocks use the area occasionally during spring migration. All geese were gone from Island Flats by the onset of the nesting period. In late June some birds returned. Large numbers of geese were observed in August 1969 in Shoup Bay (McRoy and Stoker, 1969) suggesting the possibility of nesting in that area.

Brant (Branta bernicla) -- An uncommon summer visitor. Four birds were observed feeding on a gravel bar near the mouth of the Valdez boat harbor on June 4, 1979. Fish and Wildlife Service biologists observed up to 16 birds feeding near the mouth of Valdez Glacier Stream in late May 1979.

White-fronted Goose (Anser albifrons) -- A single bird was observed with a flock of Canada geese on April 30, 1979 and three more were seen on May 1, 1979.

Mallard (Anas platyrhynchos) -- A common year-round resident. Nests were found by Fish and Wildlife Service biologists on West Island and Spruce Island and broods were observed commonly on salt marshes around Island Flats. Nesting was also suspected

on Robe Lake marsh and the marsh at the head of Brownie Creek. Relatively large concentrations of non-breeding males occurred on intertidal flats during the summer. Sangster (1978) found mallards to be one of the most abundant winter species in Port Valdez.

Gadwall (Anas strepera) -- A single gadwall was observed feeding with a mixed flock of pintail and American widgeon on May 7, 1979.

Pintail (Anas acuta) -- A common migrant and summer resident. Nesting was assumed on Robe Lake marsh and two broods were observed on Souwest Cove on June 5, 1979 and one on City Limits Slough on June 6, 1979. Additional broods were observed by U.S. Fish and Wildlife Service personnel in June and July. Non-breeding males were common during the summer.

Green-winged Teal (Anas carolinensis) -- This is a common nesting species. The first spring arrivals were a pair seen feeding in some old sedge on April 25, 1979. Broods were commonly observed on Island Flats in July and one brood was observed on the Mineral Creek delta on July 17, 1979.

Blue-winged Teal (Anas discors) -- A male with conspicuous powder-blue shoulder patches was seen flying with a flock of green-winged teal on May 7, 1979. On May 10, 1979, another bird which most closely resembled a bluewinged teal/cinnamon teal (Anas cyanoptera) hybrid was observed at close range at the edge of a small pond with several green-winged teal. The bird had a powder-blue shoulder, white cresent behind the eye, and black undertail typical of a blue-winged teal, but it had a chocolate-brown head and uniform cinnamon breast with delicate black barring on the flank feathers.

American Widgeon (Anas americana) -- A common migrant and uncommon summer resident. A pair assumed to be nesters were flushed at close range on the Robe Lake marsh on June 5, 1979,

and U.S. Fish and Wildlife Service biologists found three broods on Island Flats.

Northern Shoveler (Spatula clypeata) -- This species was seen regularly during the spring migration on Dayville Flats, from the west side of Island Flats to the Old Valdez townsite, and on Robe Lake.

Canvasback (Aythya valisineria) -- Two pair of canvasbacks were seen in a small area of open water at the outlet of Robe Lake on May 8, 1979. The remainder of the lake was still ice-covered on that date.

Greater Scaup (Aythya marila) -- Feeding scaup were regularly observed at high tide feeding in the Allison/Solomon Gulch Creek area and on Island Flats and at low tide in littoral waters near the outer islands. The species is apparently a year-round resident of the area, but no evidence of nesting was obtained during the study period.

Common Goldeneye (Bucephala clangula) -- In March, April, and May, small numbers of common goldeneye were seen with flocks of Barrow's goldeneye.

Barrow's Goldeneye (Bucephala islandica) -- An abundant winter resident and one of the most common species of diving ducks in the area. Sangster (1978) reported relatively large winter concentrations.

Bufflehead (Bucephala albeola) -- A common winter resident (Sangster, 1978). During this study, no birds were observed after spring migration.

Oldsquaw (Clangula hyemalis) -- Apparently this species is a regular winter visitor to Port Valdez (Sangster, 1978; Joan Perkins, personnal communication), but none were observed during this study.

Harlequin Duck (Histrionicus histrionicus) -- Small flocks were regularly observed feeding in nearshore waters and resting on the rocky shores of the offshore islands.

White-winged Scoter (Melanitta deglandi) -- A common resident. Few birds were present in Port Valdez during the nesting period because, as suggested by Gabrielson and Lincoln (1959), nesting occurs mainly along freshwater lakes and streams of interior Alaska.

Surf Scoter (Melanitta perspicillata) -- A common resident of Port Valdez but somewhat less abundant than the white-winged scoter.

Black Scoter (Melanitta nigra) -- A rare visitor. A lone male was observed just east of the Valdez small boat harbor on May 7, 1979.

Common Merganser (Mergus merganser) -- Small numbers were observed in marine littoral waters throughout the study period.

Red-breasted Merganser (Mergus serrator) -- A common summer resident. Pairs and singles were observed from late April through the summer. Sangster (1978) found none of this species from November through March.

Goshawk (Accipiter gentilis) -- An adult was observed by a geologist working on the proposed refinery site on June 12, 1979.

Sharp-shinned Hawk (Accipiter striatus) -- One immature bird was observed on August 12, 1979 by the study team. Joan Perkins, a resident of Valdez, has observed this species in winter. McRoy and Stoker (1969) observed one bird in August 1969.

Bald Eagle (Haliaeetus leucocephalus) -- A common nesting species throughout the Valdez area. There is one active nest

on the south fork of Siwash Creek about 100 feet southwest of Mineral Creek Loop Road in a live cottonwood and another adjacent to Dayville Flats on the bank of Lowe River. There is one inactive nest in a cottonwood at the point where Corbin Creek (Glacier) leaves the mountains and three adjacent to the Dayville Road (Figure 3).

Spruce Grouse (Canachites canadensis) -- Joan Perkins (personal communication) reported this species to be a resident of spruce forests in the Valdez area, but none were observed by the study team.

Willow Ptarmigan (Lagopus lagopus) -- This species is reported to be a common resident of the Lowe River Valley by Isleib and Kessel (1973). No ptarmigan were observed during the period of study but ptarmigan tracks in the snow were recorded near Slater Creek on April 10, 1979.

White-tailed Ptarmigan (Lagopus leucurus) -- The only record for the Valdez area is cited in Gabrielson and Lincoln (1959) who indicated that G.C. Cantwell collected this species "at Valdez in 1916."

Sandhill Crane (Grus canadensis) -- A lone bird was observed on the Mineral Creek delta around May 20, 1979 by George Perkins (personal communication).

Black Oystercatcher (Haematopus bachmani) -- This species was observed on rocky margins of offshore islands. A single bird, which was very much alarmed and presumed to be nesting, was found on Raspberry Island on June 4, 1979.

Semipalmated Plover (Charadrius semipalmatus) -- A common nesting species in the Valdez area. The earliest spring sighting was on April 30, 1979 when three were found on the intertidal flats. Many individual plovers giving "broken-wing" displays were observed on the alluvium along Valdez Glacier Stream on June 6, 1979.

Black-bellied Plover (Pluvialis squatarola) -- A rare summer visitor. A lone bird was observed at the mouth of the Lowe River on April 28, 1979.

Ruddy Turnstone (Aernaria interpres) -- An uncommon summer resident. The only sightings within the study area were recorded by U.S. Fish and Wildlife Service biologists who found them first on June 26, 1979 with occasional observations through the remainder of the summer.

Common Snipe (Capella gallinago) -- Winnowing birds were common in the Robe Lake/Corbin Creek area in May and June. No snipe were observed on Island Flats but the species was recorded at the mouth of the Lowe River on May 8, 1979.

Whimbrel (Numenius phaeopus) -- An uncommon summer resident. Four birds were seen feeding on the intertidal flats on May 9, 1979 and a pair of whimbrels were recorded on the Island Flats salt marsh on June 4, 1979. A single individual was recorded on Island Flats on July 18, 1979.

Spotted Sandpiper (Actitis macularia) -- A common summer resident along streams and lakes in Port Valdez. The first spring migrant was recorded on June 5, 1979 on the salt marsh of Island Flats and occasional individuals were recorded through the summer. The species appears to be somewhat more abundant on the Mineral Creek delta.

Wandering Tattler (Heteroscelus incanum) -- An uncommon summer resident. Small numbers of birds were observed from time to time on the Solomon Gulch Creek delta, Island Flats, and the outer islands beginning on May 9, 1979.

Greater Yellowlegs (Tringa melanoleucus) -- Spring migrants arrived on April 28, 1979. A few birds were found near Robe Lake during the nesting period and on Island Flats in the late summer.

Lesser Yellowlegs (Tringa flavipes) -- An uncommon migrant. Two were seen on Island Flats and one on the Mineral Creek delta on May 9, 1979.

Rock Sandpiper (Calidris ptilocnemis) -- A common winter visitor in Port Valdez according to Joan Perkins (personal communication) and Sangster (1978). No rock sandpipers were observed during this study.

Pectoral Sandpiper (Calidris melanotos) -- A rare summer visitor. U.S. Fish and Wildlife Service biologists observed two pectoral sandpipers near the entrance to the Valdez small boat harbor on May 21, 1979.

Least Sandpiper (Calidris minutilla) -- A common migrant. Small numbers of this species were observed regularly on Island Flats from May 7 until August. Four were seen on the Mineral Creek delta on May 9, 1979.

Semipalmated Sandpiper (Calidris pusillus) -- This species was not observed in Port Valdez during the usual shorebird migration period. However, an aberrant record was noted on March 21, 1979 when a flock of approximately 300 semipalmated sandpipers was observed at low tide west of Ammunition Island.

Western Sandpiper (Calidris mauri) -- According to McRoy and Stoker (1969), this species is a fall migrant in Port Valdez and a few individuals were reported on the Mineral Creek delta and Island Flats. However, during the current study the only record was a single bird feeding with a large flock of semipalmated sandpipers on March 21, 1979. Greater numbers of this species move through the west end of Port Valdez according to U.S. Fish and Wildlife Service biologists. The 1979 fall migration at Shoup Bay began around July 10, 1979 (Sangster, personal communication).

Short-billed Dowitcher (Limnodromus griseus) -- A common migrant. This species was first observed on April 30, 1979

and small groups were seen feeding in the intertidal zone until May 10, 1979.

Long-billed Dowitcher (Limnodromus scolopaceus) -- An uncommon migrant. A pair of long-billed dowitchers was seen feeding with six short-billed dowitchers and a male Hudsonian godwit on May 9, 1979 near Ammunition Island.

Hudsonian Godwit (Limosa haemastica) -- A male was observed near Bluff Island on May 9, 1979 and the following day a pair was seen on the salt marsh near Ammunition Island.

Northern Phalarope (Phalaropus lobatus) -- This species was assumed to be nesting on Robe Lake marsh. Several pairs were observed in active display in early June.

Glaucous-winged Gull (Larus glaucescens) -- A common resident. This species is abundant in Port Valdez with major concentrations near the City of Valdez sanitary landfill near Sewage Lagoon Creek. Except for the landfill, the greatest numbers of birds were observed on Island Flats in May during the stickleback spawning period, when salmon fry were entering the estuary from adjacent streams, and during the pink salmon spawning season in August.

Herring Gull (Larus argentatus) -- A common resident. Herring gulls are generally less abundant in the study area than glaucous-winged gulls. Sangster (1978) reported this species throughout the winter period.

Mew Gull (Larus canus) -- The most abundant gull in the study area. Large numbers of resting birds were observed along Valdez Glacier Stream, the Lowe River delta, and on the salt marsh surrounding Island Flats. Much feeding activity was observed in intertidal areas. There was a large increase in numbers of gulls in the intertidal zone during the salmon spawning season.

Bonapartes Gull (Larus philadelphia) -- A summer resident. On April 30, 1979, six Bonapartes gulls were seen on the tide flats and occasional birds were seen throughout the summer.

Black-legged Kittiwake (Rissa tridactyla) -- A summer resident. This species arrived on the study area on April 30, 1979 and was seen regularly through the summer. The nearest nesting colonies are in Shoup Bay (McRoy and Stoker, 1969).

Arctic Tern (Sterna paradisaea) -- A common nester. Arctic terns arrived in the study area on April 30, 1979. Approximately 30 pairs nested on the outer islands including Spruce Island, Cranberry Island, and Iris Island (Figure 2). Two or three pairs nested at the base of Sontag Spit (east of Ammunition Island) and about ten pairs nested along the beach outside of the Valdez boat harbor. The latter colony was also identified by McRoy and Stoker (1969). Numbers of Arctic terns build up in late July and the birds leave the Valdez area around August 1 (Mary Sangster, personal communication).

Common Murre (Uria aalge) -- This species is reported to be a winter resident of Port Valdez (Joan Perkins, personal communication). One bird was seen in marine littoral waters on April 25, 1979.

Pigeon Guillemot (Cepphus columba) -- This species is reported to be a winter resident of Port Valdez (Joan Perkins, personal communication), but none were seen during this study.

Marbled Murrelet (Brachyramphus marmoratus) -- An uncommon resident. Occasional birds were seen on marine littoral waters throughout the course of the study.

Great Horned Owl (Bubo virginianus) -- This species is reported to be a resident of Port Valdez (Joan Perkins, personal communication), but none were observed during the course of this study.

Rufous Hummingbird (Selasphorus rufus) -- An uncommon summer resident. A single bird was observed at a hummingbird feeder near Mineral Creek on May 9, 1979. Joan Perkins (personal communication) reported that the birds come to her feeder each summer.

Belted Kingfisher (Megaceryle alcyon) -- A common resident. This species was observed regularly along small streams and in the intertidal zone throughout Port Valdez.

Downy Woodpecker (Picoides pubescens) -- A common resident. One nest was found in a cottonwood tree near Slater Creek on June 20, 1979 and scattered observations were made in forested areas throughout the period of study.

Western Flycatcher (Empidonax difficilis) -- One bird was observed at close range in riparian woodland along Dayville Road on July 18, 1979.

Olive-sided Flycatcher (Nuttallornis borealis) -- One bird was seen in the mixed spruce/cottonwood forest near Robe Lake on July 17, 1979.

Violet-green Swallow (Tachycineta thalassina) -- A common summer resident. Feeding birds in flight were commonly observed from May 1, 1979 through the study period.

Tree Swallow (Iridoprocne bicolor) -- Several were seen feeding over Robe Lake on July 17, 1979.

Steller's Jay (Cyanocitta stelleri) -- This species is reported to be a winter resident of Port Valdez (Joan Perkins, personal communication). One bird was observed during the period of study on August 11, 1979.

Black-billed Magpie (Pica pica) -- A common resident of the Valdez area. This species was regularly observed through the period of study.

Common Raven (Corvus corax) -- A common resident. Dense aggregations were observed at the sanitary land fill at the Old Valdez townsite and smaller numbers were recorded in essentially all habitats elsewhere.

Northwestern Crow (Corvus caurinus) -- A common resident. Individuals and small flocks were regularly observed in the intertidal zone and within the City of Valdez. Nesting was suspected in spruce forests adjacent to Souwest Cove.

Black-capped Chickadee (Parus atricapillus) -- A common resident of the Valdez area. Within the study area this species was observed in forests near Robe Lake, Mineral Creek, and Dayville Road.

Boreal Chickadee (Parus hudsonicus) -- This species is reported to be a winter resident in the Mineral Creek area (Joan Perkins, personal communication). Three were observed on August 11, 1979.

Chestnut-backed Chickadee (Parus rufescens) -- The first sightings were at Robe Lake on May 8, 1979. One bird was seen along Dayville Road on July 18, 1979, and several individuals were observed foraging with boreal chickidees in the Mineral Creek area on August 11, 1979.

Brown Creeper (Certhia familiaris) -- A common resident. Individual birds were observed or heard calling from time to time in mature forests throughout the period of study.

Dipper (Cinclus mexicanus) -- An uncommon resident. Individuals and pairs were observed along City Limits Creek in April 1979 and Joan Perkins reported this species throughout the year in the Mineral Creek area.

American Robin (Turdus migratorius) -- A common summer resident. The first robins arrived on the study area on May 1, 1979 and

the species was observed regularly throughout the summer period.

Varied Thrush (Ixoreus naevius) -- A common summer resident. This species was heard and observed regularly in cottonwood and spruce forests.

Hermit Thrush (Catharus guttatus) -- A common summer resident. One of the most abundant thrushes of Port Valdez. Birds were commonly seen and heard singing in spruce and cottonwood forests.

Swainson's Thrush (Catharus ustulatus) -- One bird was seen near Slater Creek on June 20, 1979.

Gray-cheeked Thrush (Catharus minimus) -- Individual birds were recorded in cottonwood forests in June and July.

Golden-crowned Kinglet (Regulus satrapa) -- A common summer resident. This species was found in spruce forests from Mineral Creek to Robe Lake.

Ruby-crowned Kinglet (Regulus calendula) -- A common summer resident. The distinctive song of this kinglet was heard in forested areas from early May through the summer.

Water Pipit (Anthus spinoletta) -- A common migrant. Small flocks were seen feeding on the Island Flats salt marsh from April 30 to May 7, 1979.

Bohemian Waxwing (Bombycilla garrulus) -- A pair of birds were observed in spruce forests near Robe Lake on July 17, 1979. M.E. Isleib saw small flocks near Valdez Arm during July-August 1972 (Isleib and Kessel 1973).

Orange-crowned Warbler (Vermivora celata) -- A common summer resident. This species was observed in shrub and forest areas throughout the period of study.

Yellow Warbler (Dendroica petechia) -- A lone male was seen in the cottonwood forests along Corbin Creek (Glacier) on June 20, 1979.

Yellow-rumped Warbler (Dendroica coronata) -- This species was common in alder shrub and deciduous forests of the study area.

Blackpoll Warbler (Dendroica striata) -- From June 5, 1979 through August, this species was found in alder shrub on mountain slopes around the study area.

Northern Waterthrush (Seiurus noveboracensis) -- One bird was seen along Dayville Road on July 18, 1979.

Wilson's Warbler (Wilsonia pusilla) -- One of the most common species observed in deciduous forests of Port Valdez.

Red-winged Blackbird (Agelaius phoeniceus) -- A displaying male in brilliant breeding plummage was seen on Robe Lake marsh on June 5, 1979. This species was still present on July 17, 1979.

Rusty Blackbird (Euphagus carolinus) -- Adults feeding young were seen at Robe Lake on June 5, 1979 and a lone male was observed near Siwash Creek on May 6, 1979.

Pine Grosbeak (Pinicola enucleator) -- One male was seen in the cottonwood forest east of Island Flats on May 1, 1979. On July 17, 1978, three males were recorded along Dayville Road. Joan Perkins reported that this species is a year-round resident of the Valdez area.

Common Redpoll (Carduelis flammea) -- A common resident. Redpolls were observed in a variety of habitats throughout the period of study.

Pine Siskin (Carduelis pinus) -- Joan Perkins (personal communication) reported that siskins were common winter re-

sidents of the Valdez area. None were observed by the study team.

White-winged Crossbill (Loxia lencoptera) -- None were observed during the course of the study, but Joan Perkins (personal communication) reported them to be winter residents.

Savannah Sparrow (Passerculus sandwichensis) -- A common summer resident. The earliest spring record was April 30, 1979 near City Limits Creek. Later, singing males were seen in the scattered grasslands on the drier sites bordering Corbin Creek (Robe), Island Flats salt marsh, and the Mineral Creek delta.

Dark-eyed Junco (Junco hyemalis) -- A common summer resident of the Valdez area.

Tree Sparrow (Spizella arborea) -- One bird was seen singing near Robe Lake on May 8, 1979.

White-crowned Sparrow (Zonotrichia leucophrys) -- A common summer resident. Two birds were seen in riparian woodland near Old Valdez townsite on May 7, 1979 and one was seen in the willows along City Limits Creek on June 6, 1979. This is a common nesting species along Valdez Glacier Stream. The species is probably a regular nester in stream valleys adjacent to Port Valdez.

Golden-crowned Sparrow (Zonotrichia atricapilla) -- U.S. Fish and Wildlife Service biologists found one dead golden-crowned sparrow in the Valdez business district on June 10, 1979 and later reported the species to be common in the Mineral Creek canyon.

Fox Sparrow (Passerella iliaca) -- A common summer resident. Beginning on April 29, 1979, fox sparrows were regularly observed in alder shrub habitat. Nesting was suspected on the

islands adjacent to Island Flats, and the alder-covered mountain slopes throughout the study area.

Lincoln's Sparrow (Melospiza lincolnii) -- This species was observed three times in the Corbin Creek (Robe) - Robe Lake area from May 10 to July 17, 1979.

Song Sparrow (Melospiza melodia) -- A common summer resident. Singing was heard regularly in woodland habitats including offshore islands.

Lapland Longspur (Calcarius lapponicus) -- A common spring migrant. Small flocks were observed on the Island Flats salt marsh from April 30 to May 1, 1979.

SUMMARY

One-hundred thirteen species of birds were found to occur in the Port Valdez area from March through August 1979.

In summer, the highest bird diversity and abundance is found in the deciduous forest community. In winter, the marine littoral waters and the intertidal zone suppports the greatest densities.

Seasonal migration patterns are similar to other areas of Prince William Sound but relative abundance of individuals within each species is extremely low.

The Robe Lake freshwater marsh is perhaps the most unusual wildlife habitat in the study area followed by salt marshes at Dayville Flats, Island Flats, the Mineral Creek delta, and Shoup Bay.

No rare or endangered species occur in the area but two active bald eagle nests were present in 1979.

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FRESHWATER AQUATIC HABITATS OF THE VALDEZ AREA

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INTRODUCTION

As part of a general program designed to acquire baseline biological data for the proposed Alaska Petrochemical Company (Alpetco) refinery, freshwater habitats and fishery resources were investigated on and near the proposed refinery site and in the Valdez area. Data were acquired through literature review, interviews with resource agency personnel, and through field surveys conducted in late winter and summer. Additional information pertinent to this study phase was collected in conjunction with sampling done for the salmon fry dispersion studies. Hydrological data collected by DOWL Engineers have been incorporated where applicable to habitat discussions.

FIELD STUDY METHODS

Aerial observations of the proposed refinery site and surrounding area were conducted from a helicopter on March 21, 1979. Areas of open water and potential winter fish habitat were noted. A ground survey of the refinery site area was conducted on April 10. Observations were made on Upper Corbin Creek (Corbin Creek/Glacier), Lower Corbin Creek (Corbin Creek/Robe), and Brownie Creek (Figure 1). A small mesh seine was used to capture fish where feasible. General habitat characteristics were noted and water temperature measurements were made. A second ground survey was conducted on June 20 to 22. Selected portions of the above streams, plus Slater Creek, were sampled for fish presence using a Smith-Root Type VII backpack electroshocker. Each stream's physical characteristics were noted. Total lengths were recorded for all captured fish. Samples of small salmonids were preserved to verify identifications.

STREAM DESCRIPTIONS - REFINERY SITE AREA

Valdez Glacier Stream Drainage

1. Slater Creek - Slater Creek originates in the mountains east of the proposed refinery site. It flows westward to the edge

of the Valdez Glacier Stream floodplain and then southward across the refinery site to its confluence with Upper Corbin Creek (Figure 1). The stream is fed, at least in part, by melt water from two small glaciers. Hydrological investigations indicated that the stream was completely dry during the winter of 1978-79 and did not begin to flow until about mid-May (DOWL Engineers). Flow can be expected to cease in the fall. Within the refinery site, the stream flows in braided channels through densely wooded terrain. Bed materials vary from silt to cobble.

The primary summer sampling effort occurred near the intersection of the stream and the existing east-west construction road (about 550 meters (m) north of the Upper Corbin Creek confluence). At that point, Slater Creek flowed through six separate channels ranging in width from 1.5 to 6 m. Water was milky gray-green but not totally opaque. The stream bottom was visible at depths up to 46 centimeters (cm). Each sub-channel was shocked for a distance of at least 50 m and the main channel was shocked for a distance of about 300 m. One unidentified fish about 15 cm long was observed but not captured. It is likely that the fish was a Dolly Varden (Salvelinus malma).

Slater Creek is not a productive fish stream. Seasonal flow and turbid water prevent extensive use by fish. A few Dolly Varden probably utilize the stream seasonally. These fish either originate in Port Valdez, entering Slater Creek via Upper Corbin Creek and the Valdez Glacier Stream, or overwinter in the open water areas of Upper Corbin Creek, entering Slater Creek when flow begins in the spring.

2. Upper Corbin Creek (Corbin Creek/Glacier) - Upper Corbin Creek originates in the mountains east of the refinery site and flows southwesterly into the Valdez Glacier Stream. Originally Corbin Creek flowed southward into Robe Lake; however, a dike (Figure 1) was constructed in the mid-1950s, which diverted the flow westward (see Robe Lake discussion).

PAGE NOT

AVAILABLE

DIGITALLY

The aerial survey in March revealed an area of flowing open water at the upper end extending about 450 m westward from the base of the hillside (Figure 1). A ground survey of this segment on April 10 (winter conditions still prevailed) revealed a flow of about 0.3 cu. m/sec. (10 cfs). Water was very clear and the substrate was composed of clean gravel, slate, or both. The habitat appeared very sterile with little development of stream invertebrates. No fish were observed in spite of excellent visibility. Hydrological investigations revealed no above-ground flow in the Upper Corbin Creek stream bed a short distance below the open water area during the winter of 1978-79 (DOWL Engineers). Therefore, the flowing water in the upper area was isolated from other waterbodies. The presence of two old bald eagle nests adjacent to the open water section leads to speculation that spawning salmon may have utilized the stream in the past, perhaps before it was diverted from the Robe Lake system. Winter flow and substrate conditions appeared suitable for survival of salmon eggs.

In the summer, Upper Corbin Creek receives glacial melt water from Corbin Glacier. The flow exceeds 11 cu. m/sec. (400 cfs) (DOWL Engineers) and the water is very turbid. Stream conditions prevented effective fish sampling during the summer surveys. Some slough areas were shocked but no fish were observed. The presence of fish in Slater Creek indicates that fish probably are present in Upper Corbin Creek. However, the stream is not productive fish habitat and use is probably limited to a few Dolly Varden during the summer.

3. Valdez Glacier Stream - Valdez Glacier Stream is a short river that originates at the Valdez Glacier and in the summer flows in braided channels across a wide floodplain into Port Valdez. Some winter flow occurs at the lower end of the stream but no above-ground flow was found upstream from the Richardson Highway bridge during the winter of 1978-79 (DOWL Engineers).

Because of the high flow, turbid water, and poor habitat characteristics, the Valdez Glacier Stream was not sampled during this study. The only species reported in the literature to be present in the stream is eulachon, Thaleichtys pacificus (Johnson and Rockwell 1978). These fish undertake spawning migrations from salt water to fresh water in the spring. Dolly Varden are probably also present occasionally. Salmon have not been documented thus far. The Valdez Glacier Stream is of little value to fish except possibly as a migratory corridor for fish en route to Upper Corbin and Slater Creeks.

Robe River Drainage

1. Lower Corbin Creek (Corbin Creek/Robe) - Subsequent to the diversion of Corbin Creek into Valdez Glacier Stream, the original stream channel between the dike and Robe Lake continued to carry water throughout most of its length because of groundwater seepage. The aerial survey in March disclosed scattered sections of open water and hydrological studies indicated that flow was present throughout the year. Discharge near the stream midpoint was about 0.07 cu. m/sec. (0.5 cfs) in the winter and about 0.2 cu. m/sec. (7 cfs) in the summer (DOWL Engineers). The stream originates at groundwater upwelling areas near the southern boundary of the refinery site. Several small tributaries coalesce to form the main stream (Figure 1).

   According to Williams (1978), Lower Corbin Creek has consistently been the major silver salmon (Oncorhynchus kisutch) spawning stream in the Valdez area. Numbers of silver salmon spawners have ranged from 780 to 4839 in recent years (Table 1). These numbers generally account for about half of the total spawners in the Port Valdez drainage and more than 80 percent of the spawners in the Robe River system. An aerial survey done in 1971 resulted in a count of 9690 silver salmon and an estimated escapement of 10,500 fish in the total Robe River drainage (Mattson 1971). These data were not broken down according to

TABLE 1

ADULT SALMON COUNTS WITHIN THE ROBE LAKE DRAINAGE SYSTEM

	Corbin Creek (Robe)	Brownie Creek	Robe Lake	Robe River
Silver Salmon				
1972	1706[2]			875[2]
1973	1400[3]			
1975	1232[1]			301[1]
1976	708[1]			341[1]
1977	1270[1]	3[1]		252[1]
1978	4839[1]	31[1]		221[1]
Red Salmon				
1972				
1973	9[3]	1300[3]*		
1975				10[1]
1976				
1977	5[1]	9188[1]		
1978		2[1]		
1979		2155[1]	6[1]	24[1]
Pink Salmon				
1972				
1973				15000[3]
1975				2461[1]
1976				
1977				330[1]
1978				1[1]
1979				1546[1]
Chum Salmon				
1972				40[2]
1973				125[3]
1975				1[1]
1976				
1977				
1978				1[1]
1979				11[1]

[1] ADF&G, unpublished data
[2] Williams 1973
[3] Williams and Morgan 1974

* Incomplete Count

individual spawning streams. Silver salmon spawing in Lower Corbin Creek occurs from the mouth up to a point about 800 m south of the headwaters. Typically 90 to 95 percent of the silver salmon spawn in the lower two-thirds of the stream -- south of the hog-back ridge (ADF&G, unpublished data). The spawning area is roughly coincident with that portion of the stream which has winter flow.

Small numbers of spawning red salmon have been observed at the lower end of the stream (Williams and Morgan 1974). Dolly Varden have been observed throughout and probably spawn in the stream. Moderate numbers of juvenile silver salmon have been observed in the lower two-thirds of Lower Corbin Creek (ADF&G, unpublished data).

Surveys of the upper mile of Lower Corbin Creek were conducted in late winter and summer. The water was clear during both surveys. Stream width varied from 3 to 8 m and depth from 10 to 50 cm during the summer. Substrate varied from sand to cobbles with some areas of organic debris. Banks were vegetated with overhanging shrubs. The quality of fish-rearing habitat was rated as only fair due to the lack of deep pools. Spawning habitat was rated as good. During the winter survey, about 10 fish ranging in size from 2 to 8 cm were observed but not captured and positive identification was not possible. The results of the summer shocker survey are presented in Table 2. The only fish captured were juvenile Dolly Varden, probably representing two year classes. Experience with the shocker indicated that the actual number of fish in the stream was at least 3 times the number captured. On this basis about 52 fish resided in the stream section that was shocked or about one fish for every 27 m of stream. The fish density was, therefore, quite low. In view of the extensive silver salmon spawning, the lack of juvenile silver salmon in the stream was surprising. The upper portion of Lower Corbin Creek was not being used as a rearing area by young salmon at the time of sampling.

TABLE 2

FISH CAPTURED OR OBSERVED DURING THE FIELD INVESTIGATIONS

Stream	Date	Method	Species	No.	Length (mm)
Slater Creek	06/21/79	Observed while shocking	Dolly Varden ?	1	~ 150
Lower Corbin Creek	04/10/79	Visual observation	Unknown	9 4	@ ~ 63 @ ~ 25
	06/20/79	Shocker	Dolly Varden	14	55, 61, 62, 62, 65, 66, 67, 68, 77, 88, 90, 102, 118
Lower Corbin Creek (Upper tributary)	06/20/77	Shocker	Dolly Varden	1	95
Brownie Creek	04/10/79	Seine	Red Salmon	14	28, 28, 28, 28, 29, 29, 29, 29, 30, 30, 30, 30, 30, 31
	06/21/79	Shocker	Dolly Varden	14	32, 34, 35, 60, 63, 65, 65, 67, 67, 77, 87, 110, 175, 219
		Visual observation Shocker	Dolly Varden Red Salmon Silver Salmon	12 9 1	@ 150-260 34, 36, 37, 39, 40, 41, 41, 44, 47 60

Schools of the young salmon containing several hundred fish each were distributed throughout the ice free portion of the stream except at the extreme upper end. Presence of these fish in the stream was first noticed during hydrological studies in the last week of March (DOWL Engineers). Therefore, emergence was quite early, presumably due to the unusually warm water. No other fish were observed during the April survey.

The results of the summer fish survey are presented in Table 2. Electroshocking of the stream was extremely difficult due to the thick overhanging brush; therefore, sampling was limited to a stream segment of about 200 m (Figure 1). The number of fish captured or observed in the segment was quite large including 24 Dolly Varden, 9 young-of-the-year red salmon and 1 silver salmon juvenile. The actual number of young red salmon present was much higher than the number captured, perhaps by a factor of 10. A conservative estimate of the density of fish present in this portion of Brownie Creek is 1 per meter of stream.

The Dolly Varden population present in Brownie Creek was composed of a variety of year classes from young-of-the-year to adult. It seems likely that the larger Dolly Varden were feeding on the small red salmon but this was not confirmed. Apparently, a substantial proportion of the young-of-the-year red salmon that hatched in Brownie Creek remained in the creek for at least several months rather than moving immediately into Robe Lake.

Brownie Creek is a productive stream and includes valuable red salmon spawning and rearing habitat. The unusually warm water temperature during the winter may enhance the value of Brownie Creek since egg development would require less time. At least some silver salmon also rear in the creek. The existence of a large Dolly Varden population probably depends to a considerable extent on the presence of the young red salmon.

3. Robe Lake - Robe Lake is located about 1 mile south of the proposed refinery site. Field investigations were not conducted on the lake during this study. The Robe Lake system has undergone a series of relatively recent physical changes that have affected its fish resources. These changes are summarized in the following exerpt (ADF&G 1979):

> "Robe Lake has a surface area in excess of 600 acres and a maximum depth of 15 feet. The average depth of the lake is 8 feet and the surface area is rapidly being reduced by peripheral weed growth.
>
> "Historically Robe Lake was a major red salmon producer. The Emil Packing Co. recorded case salmon packs up to 67,000 but provided no breakdown as to species. North Pacific Seafoods had their largest recorded red salmon case pack in 1938; 3,026 cases or approximately 42,000 red salmon. Subsequently, salmon production decreased until commercial fishing was closed in the mid-fifties.
>
> "The Robe Lake watershed has endured several physical changes since 1900 which have greatly reduced the volume of water through the system. Originally the lake received the entire flow of Corbin Creek..... Apparently about 1936 or 1938, a braided channel from the rapidly retreating Valdez Glacier broke into Corbin Creek and rapidly increased deposition of glacial sediments in the lake system.
>
> "The continuing flow of heavily silted water into Robe Lake precipitated sand and silt over the lake bottom, changed the lake's aquatic food organisms due to increased turbidity, and generally had a detrimental effect on salmon production.
>
> "The filling-in of the lake was stopped in 1956 or 1958 when concerned citizens with heavy equipment built a dike that diverted Corbin Creek into a braided channel of the Valdez Glacier stream. The dike was repaired once in the early sixties and is still effective.....
>
> "Dike construction on Corbin Creek eliminated one problem and created others. When the heavily silted water ceased going into the lake, lake

> turbidity cleared, water temperatures increased, and the aquatic weeds appeared. In fact conditions were so ideal that in ten years the aquatics have nearly overrun the lake. A dense growth of Potomogeton forms in late summer and hinders use of outboard motors on the lake. The outlet and inlet streams are barely discernable due to vegetative growth.....
>
> "A third loss of water flow into Robe Lake may have occurred during the late twenties. One story is that a mining operation diverted the outlet from Crater Lake for water needed in their mining operation. This story has not been documented, however, Crater Lake could easily have flowed into Robe Lake in the past."

Limnological characteristics and fish utilization of Robe Lake have been under investigation by the Alaska Department of Fish and Game intermittantly since 1973. Dissolved oxygen levels during February of 1973 were as low as 1 ppm in the southwest portion of the lake (Williams and Morgan 1974). The northern and eastern portions of the lake maintained satisfactory dissolved oxygen levels presumably due to the flow of water between the inlet streams and the outlet stream (Robe River). Dissolved oxygen levels in the summer are adequate for fish.

Although Robe Lake would appear to be satisfactory rearing habitat for young red and silver salmon, few juvenile salmon have been observed in recent years. A few silver salmon smolts were caught during test netting in 1973 (Williams and Morgan 1973). Attempts to capture juvenile salmon since 1975 have been unsuccessful (ADF&G, unpublished data). The location of rearing areas for red and silver salmon within the Robe Lake system remains somewhat of a mystery. The only place where older red salmon smolts have been observed is in the Robe River (ADF&G, unpublished data).

Small numbers of adult red salmon have been observed spawning within Robe Lake at the outlets of Brownie, Lower Corbin, and Deep Creeks, and possibly at other locations (Williams 1973).

In 1979, six red salmon were observed spawning along the shoreline on the south side of the lake (ADF&G, unpublished data). Both red and silver salmon adults can be expected to spend some time in the lake prior to entering spawning streams. In 1972, red salmon were entering the lake on June 5, before the ice was completely gone. Large schools of red salmon were present in the lake in mid-July (Williams 1973).

Other fish species present in the lake include both resident and anadromous populations of Dolly Varden and three-spine stickleback (Gasterosteus aculeatus). The life history of anadromous Dolly Varden is not well known. Adults apparently enter the Robe Lake system in both spring and fall (Williams, personal communication). Spawning areas are unknown. Three-spine stickleback adults enter the lake in May to spawn and then apparently die (Williams and Morgan 1974). Young sticklebacks probably leave the Robe Lake system in late summer. Predation and/or competition with Dolly Varden and stickleback is probably a factor influencing the carrying capacity of the Robe Lake system for salmon.

In summary, the productivity of Robe Lake in relation to fish resources has apparently been reduced over the past 50 years due to the combined effects of reduced lake area, reduced depth, increased aquatic plant growth, and reduced levels of dissolved oxygen in the winter. The current value of the lake to the substantial salmon resources in the Robe Lake drainage is questionable without further investigation. Some value as rearing habitat for red and silver salmon should probably be assumed.

4. Robe River - The Robe River flows out of Robe Lake and into Port Valdez via the Lowe River Delta. The Robe River serves as a migratory corridor for red and silver salmon that spawn in the Robe Lake system and, in addition, supplies spawning area for substantial numbers of pink and silver salmon and

small numbers of chum salmon (Oncorhynchus keta) (Table 1). Mattson (1973) estimated that 40 percent of the stream was suitable as salmon spawning area and concluded that the Robe River was under-utilized by chum salmon and over-utilized by pink salmon in peak years.

Moderate numbers of juvenile silver and red salmon have been found in the Robe River (ADF&G, unpublished data). The Robe River may be important as rearing habitat for these species, especially in view of the apparently limited rearing capacity of Robe Lake. Stickleback and Dolly Varden are also present in the river.

Streams of Eastern Port Valdez

In addition to the drainage systems discussed above in relation to the proposed refinery site, numerous other streams empty into eastern Port Valdez. These streams are discussed below because of proximity to the proposed effluent diffuser in the Old Valdez area, proximity to the proposed refinery dock on the south shore (Figure 1), or proximity to proposed pipeline/transportation corridors. A summary of the salmon escapement data for eastern Port Valdez tributaries is presented in Table 3. Systematic data for some of the streams, particularly on the south shore, are scanty.

1. City Limits Creek (Crooked Creek) - This short stream flows off the steep mountainside and onto the intertidal flat. The upper portion of the stream within the intertidal zone is heavily used by pink and chum salmon for spawning. The stream is the most important producer for chum salmon in the study area with the possible exception of the Lowe River system. Other fish observed in the stream during salmon fry studies included three-spine stickleback and one juvenile silver salmon. Chum salmon fry spend several weeks in the upper intertidal portion of the stream following emergence in the spring.

TABLE 3

SALMON ESCAPEMENT FOR SELECTED EASTERN PORT VALDEZ STREAMS, 1971-1978

Year	City Limits Creek	City Limits Slough	Ess Creek	Siwash Creek	Loop Rd. No. 2 Creek	Loop Rd. No. 1 Creek	Sewage Lagoon Creek	Robe Lake System	Lowe River System	Dayville Flats Creek	Solomon Gulch Creek	Allison Creek	Abercrombie Gulch Creek
Pink Salmon													
1971	940[3]			13,070[3]	100[3]	1,080[3]		4,500[1]	35,310[3]	1,300[6]		300[7]	250[6]
1972	30[3]			220[3]		475[1]		0[1]	0[1]				
1973	1,700[1]			34,080[3]	330[3]	7,000[1]		15,000[1]	8,000[3]			25[7]	250[7]
1974	860[3]			70[3]		262[1]			670[3]				
1975	1,520[3]			79,180[3]	3,790[3]	6,420[3]		2,461[1]	41,430[3]	1,300[4]	1,500[4]	500[4]	
1976	5[1]		65[4]	5[1]		18[1]		0[1]	1[1]				
1977	3,620[2]	333[4]		46,550[2]	4,101[1]	18,718[1]	1,418[1]	330[1]	1,441[1]				2,337[4]
1978	10[5]			0[5]	0[5]	66[5]	0[5]	2[5]	0[5]				
Chum Salmon													
1971	2,660[1]		32[4]	120[3]					411[1]				50[6]
1972	1,200[1]			220[3]		45[1]		40[1]	2,007[1]				
1973	1,930[3]			232[1]				125[1]	1,063[1]		10[3]		800[7]
1974	1,000[3]			16[1]		0[1]							
1975				100[3]								700[4]	
1976	1,080[1]			2[1]		6[1]		0[1]	270[1]				
1977	0[1]			0[1]		0[1]	0[1]	0[1]	0[1]				
1978	111[5]							1[5]					
Silver Salmon													
1971				57[1]				9690[1]	193[1]				50[6]
1972				41[1]				875[1]	711[1]				
1973				6[1]				4,000[1]	67[1]				
1974				0[1]				1,662[1]	78[1]				
1975				0[1]				1,553[1]	1,506[1]				
1976	2[1]			0[1]		0[1]		1,049[1]	1,310[1]				
1977					0[1]		0[1]	1,552[1]	1,363[1]				
1978								5,091[5]	1,643[5]				
Red Salmon													
1971						0[1]		6,000[4]					
1972						0[1]		5,000[1]	27[1]				
1973						0[1]		1,300[1]	0[1]				
1974						0[1]		3,000[1]	0[1]				
1975													
1976	1[1]			0[1]		0[1]			1[1]				
1977													
1978													

From:

[1] Williams, 1978 (one-time ground counts).
[2] McCurdy & Pirtle, 1978 (calculated total seasonal escapement based on aerial and ground counts).
[3] Pirtle, 1977 (calculated total seasonal escapement based on aerial and ground counts).
[4] Johnson & Rockwell, 1978 (various methods).
[5] Williams, personal communication (one-time ground counts).
[6] Hattson, 1971 (estimated escapement based on aerial or ground counts).
[7] Hattson, 1973 (estimated escapement based on aerial or ground counts).

2. City Limits Slough - This stream flows down a steep mountainside and onto the intertidal flat. A few pink salmon spawn within brackish ponds north of the Richardson Highway during peak years.

3. Ess Creek - Ess Creek flows along the base of the mountainside and onto the intertidal flat. Small numbers of pink and chum salmon spawn in the intertidal and above-tide zones in intermittant years.

4. Siwash Creek - This creek originates along the base of the mountainside near the airport and splits into two forks before crossing the intertidal flat. It is the most important pink salmon producer in Port Valdez. The pink salmon spawn both intertidally and throughout most of the stream length above tide level. Smaller numbers of chum and silver salmon also spawn in Siwash Creek in some years. Other fish observed in the creek during salmon fry studies included abundant Dolly Varden and a few juvenile silver salmon.

5. Loop Road No. 2 Creek (Pipe Creek) - This stream originates near the airport and flows parrallel to Siwash Creek. Moderate numbers of pink salmon spawn in the creek in odd years.

6. Loop Road No. 1 Creek (Airport Creek) - This short stream originates near the southern end of the airport and flows southwest into Port Valdez. It supports a substantial run of pink salmon along with a few chum salmon in intermittent years. Spawning occurs both intertidally and above tide level. Other fish observed during salmon fry studies included abundant Dolly Varden.

7. Sewage Lagoon Creek - This stream originates within perimeter ditches surrounding the City of Valdez sewage treatment ponds. Moderate numbers of pink salmon spawned in the creek in 1977 both within the intertidal zone and above tide level.

8. Lowe River System - This is a major river system that supplies the greatest freshwater input to Port Valdez. Substantial numbers of pink, chum, and silver salmon spawn within tributaries of the Lowe River. Other fish present include Dolly Varden.

9. Abercrombie Gulch Creek - This creek drains a mountainside gulley and flows into the Lowe River very near its mouth. The lower portion of Abercrombie Gulch Creek, below the abrupt mountainside, is utilized by moderate numbers of spawning pink and chum salmon and by small numbers of silver salmon. Most spawning is probably downstream from the Dayville Road bridge (Johnson and Rockwell 1978). The large flooded area upstream from the bridge and traversed by the TAPS pipeline, is reported to serve as a rearing area for juvenile salmon (Johnson and Rockwell 1978). Drainage into the flooded area is complex with several small mountainside creeks adding their flow to that of Abercrombie Gulch Creek. Dolly Varden have also been observed in the stream.

10. Dayville Flats Creek - This very short stream drops off the mountainside onto the intertidal area. The potential intertidal spawning area is limited but heavily used by pink salmon during peak years. Juvenile silver salmon in substantial numbers have also been observed in the creek (Roberson, personal communication).

11. Solomon Gulch Creek - This stream originates at Solomon Lake, flows down the steep mountainside and drops onto the intertidal area. Salmon use is poorly documented but substantial intertidal spawning by pink salmon is known to occur in peak years. Chum salmon spawners have also been observed in at least one year (Table 3). Spawning occurs primarily within the gravel fan downstream from the Dayville Road bridge.

PAGE NOT

AVAILABLE

DIGITALLY

12. Allison Creek - Allison Creek originates at Allison Lake and flows through relatively steep terrain into Port Valdez. Salmon use is poorly documented but moderate spawning by pink salmon occurs during peak years and chum salmon have been observed in one year (Table 3). Spawning occurs primarily within the intertidal zone on the gravel outwash fan but some spawning probably also occurs above tide level.

CRITICAL HABITATS

Figure 2 illustrates critical freshwater fish habitats within the study area. All of these habitats are used by salmon for spawning or rearing. As can be seen from the figure, salmon habitat is extensive. Studies by Mattson (1973) indicated that many of the streams are under-utilized by salmon; therefore, the potential probably exists for much higher salmon productivity in the area than now exists.

TIMING OF FISH UTILIZATION AND SENSITIVE TIME PERIODS

Most of the habitat areas shown in Figure 2 are used only seasonally because of the migratory habits of the salmon. Environmental sensitivity of a particular area may depend on time of year and may vary depending on which life history stage of the fish, if any, is present at the time of disturbance. Table 4 summarizes the life history chronology of the anadromous fish of Valdez. Table 5 summarizes sensitive time periods for streams within the study area.

Another aspect of salmon biology that may affect environmental sensitivity in any one year involves yearly variations in the number of salmon spawners. It is evident from Table 3 that pink salmon have been abundant only in odd years since 1971. This kind of cycle is not unusual for pink salmon since their invariable 2-year life cycle causes even- and odd-year stocks to be genetically isolated. Williams (1973) suggested that the harsh winter of 1970-71 may have nearly eliminated the even-year run thus creating the odd-year abundance cycle that now exists.

TABLE 4

TIMING OF MAJOR LIFE HISTORY EVENTS FOR ANADROMOUS FISH SPECIES IN THE VALDEZ AREA

Species	Adults Enter Port Valdez	Adults Begin Entering Spawning Streams	Spawning Peak	End of Spawning	Fry Emerge from the Gravel	Duration of Freshwater Residence	Outmigration of Young into Saltwater	Duration of Saltwater Residence
Pink Salmon	Early June	Late June	Late July	Late August	Early to Mid May	Less than 10 days	Early to Mid May	14 months
Chum Salmon	Mid June	Late July	Early September	Late October	Mid April to Early May	1-30 days	Mid April to Late May	2-4 years
Silver Salmon	Mid July	Mid August	Late September	Early November	April to May	1-2 years	May	1-3 years
Red Salmon		Early June	Mid July	Late September	Mid March	1-3 years	June & July	1-4 years
Dolly Varden (Anadromous)	Probably do not leave Port Valdez	Variable	October & November	December	April to May	3-4 years	May & June	Usually make annual migrations into freshwater in the summer

Sources: Williams 1973
ADF&G 1975 & 1979
Alyeska Pipeline 1977
Mattson 1971 & 1973

TABLE 5. FISH STREAM SUMMARY WITH SENSITIVE TIME PERIODS

Drainage System	Stream Name	Fish Species Present	Sensitivity: Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Comments
Valdez Glacier Stream	Slater Creek	DV?													Minimal fish resources
Valdez Glacier Stream	Upper Corbin Creek	DV?													Minimal fish resources
Valdez Glacier Stream	Valdez Glacier Stream	DV, EU													Minimal fish resources
Robe River	Lower Corbin Creek	DV, SS, PS, RS	■	■	■	■	■	▒	▒	▒	■	■	■	■	Most sensitive during silver salmon spawning and egg incubation
Robe River	Brownie Creek	DV, RS, SS	■	■	■	■	■	■	■	■	■	■	■	■	Sensitivity due to red salmon spawning and red and silver salmon rearing
Robe River	Robe Lake	DV, RS, SS, PS, SB	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	Red and silver salmon rearing potential -- data is scanty
Robe River	Robe River	DV, RS, SS, PS, CS, SB	■		▒	▒	▒	■	■	■	■	■	■	■	Sensitivity due to migratory and/or spawning salmon in summer and egg incubation in fall and winter
Port Valdez	City Limits Creek	CS, PS, SB, SS	■	■	■	■	■		■	■	■	■	■	■	Sensitivity due to pink and chum salmon spawning and chum salmon rearing
Port Valdez	City Limits Slough	PS	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Ess Creek	PS, CS	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Siwash Creek	PS, CS, SS, DV	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Loop Rd. No. 2 Stream	PS	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Loop Rd. No. 1 Stream	PS, CS, DV	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Sewage Lagoon Creek	PS	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Lowe River	PS, CS, SS, DV, RS				▒	▒		■	■	■	■	■	■	Sensitivity due to salmon migration times
Port Valdez	Dayville Flats Creek	PS, SS, DV, SC	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Solomon Gulch Creek	PS, CS	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Port Valdez	Allison Creek	PS, CS, DV, SC	■	■	▒	▒	▒		■	■	■	■	■	■	Sensitivity due to pink salmon spawning and egg incubation
Lowe River	Abercrombie Gulch Creek	PS, CS, DV, SS	■	■	▒	▒	▒	▒	▒	■	■	■	■	■	Sensitivity due to pink and chum salmon spawning and egg incubation and silver salmon rearing.

Species Key: DV Dolly Varden, SS Silver Salmon, CS Chum Salmon, RS Red Salmon, PS Pink Salmon, SC Sculpin, SB Stickleback, EU Eulachon

Sensitivity Key: High Sensitivity ■, Moderate Sensitivity ▒

Chum salmon abundance also has varied widely, although a marked cycle is not apparent from the limited data. Silver salmon abundance within the Robe Lake system has been relatively consistent in recent years.

2. Brownie Creek - The Brownie Creek drainage, although close to the Lower Corbin Creek drainage, is a completely separate system. Brownie Creek is outside of the refinery site but close to the southern boundary. The stream originates primarily within marsh terrain as indicated on Figure 1 and flows all year with discharge characteristics similar to Lower Corbin Creek. The aerial survey in March indicated that nearly the entire stream length was ice free. Water temperatures measured in late March and early April ranged from 3.9° to 5.6°C (39° to 42°F) (DOWL Engineers), whereas temperatures on Upper and Lower Corbin Creeks during the same period ranged from 0° to 1.7°C (32° to 35°F). Stream width ranged from 3 to 7 m and depth ranged from 10 to 80 cm. Substrate consisted of sand to fine gravel with substantial areas of organic debris. A reddish stain coated the bottom but the water was clear. The stream was rated as good to excellent habitat for rearing fish because of frequent pools and extensive brushy cover areas. Spawning habitat within the upper portion of the stream was rated as fair due to the lack of coarser gravels.

Brownie Creek is the most important red salmon spawning area in the Robe Lake system. Up to 9188 spawners have been observed in the creek (Table 1). Juvenile silver salmon have also been observed in the stream and small numbers of adult silver salmon were observed in 1977 and 1978 (ADF&G, unpublished data). Mattson (1973) surveyed Brownie Creek and estimated that 46 percent of the lower portion of the stream contained gravel suitable for spawning. Most of the red salmon spawning is in the lower two-thirds of the stream, downstream from the area surveyed in this study.

During the April 10 survey of the upper portion of Brownie Creek, large numbers of young-of-the-year red salmon were observed in the stream. A sample was captured by seine, identity was confirmed, and the fish were measured (Table 2).

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INTERTIDAL AND SHALLOW SUBTIDAL HABITATS OF PORT VALDEZ

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INTRODUCTION

Little research has been conducted in the intertidal and shallow subtidal habitats of Port Valdez. One of the first studies was a reconnaissance of intertidal habitats, mainly rock, by McRoy and Stoker (1969), in which they briefly described species composition and zonation. Subsequently, National Marine Fisheries Service (NMFS) initiated studies on the mud substrate at Dayville Flats. Initially, the study focused on the density and distribution of the small pink clam Macoma balthica, which was considered an indicator of oil contamination (Myren and Pella 1977). Subsequently, analysis has been expanded to permit consideration of distribution patterns for polychaetes.

Feder et al (1976) reported on the meiofauna (animals between 0.2 and 1.0 mm in length) of Island Flats, based on an intensive study near mean lower low water (MLLW) just south of Ammunition Island. This component of the fauna, with about 25 species identified, was dominated by nematode worms and benthic harpacticoid copepods. Of the several mudflats they studied, this area supported the greatest densities of harpacticoids, which are known to be important food items for pink and chum salmon fry (Sibert et al. 1977; Kaczynski et al. 1973).

Subtidal studies have been restricted to a small project assessing mainly the biota of shallow rocky habitats near the Alyeska terminal site and associated control sites in Galena and Jack Bay (NFMS 1975; Dames & Moore 1977) and an assessment of the soft bottom benthos living on the floor of Port Valdez and Valdez Arm (Feder and Matheke 1979). These subtidal studies generally are not applicable to the present effort because of substrate or depth.

The objectives of the study discussed herein were:

1) To characterize the biota of the mudflats, low intertidal shelf, and subtidal habitats to a depth of 16 meter (m) below MLLW.

2) To describe energy pathways in these assemblages, i.e., where does energy come from, what organisms are using it, and where does it go.

3) To estimate levels of productivity.

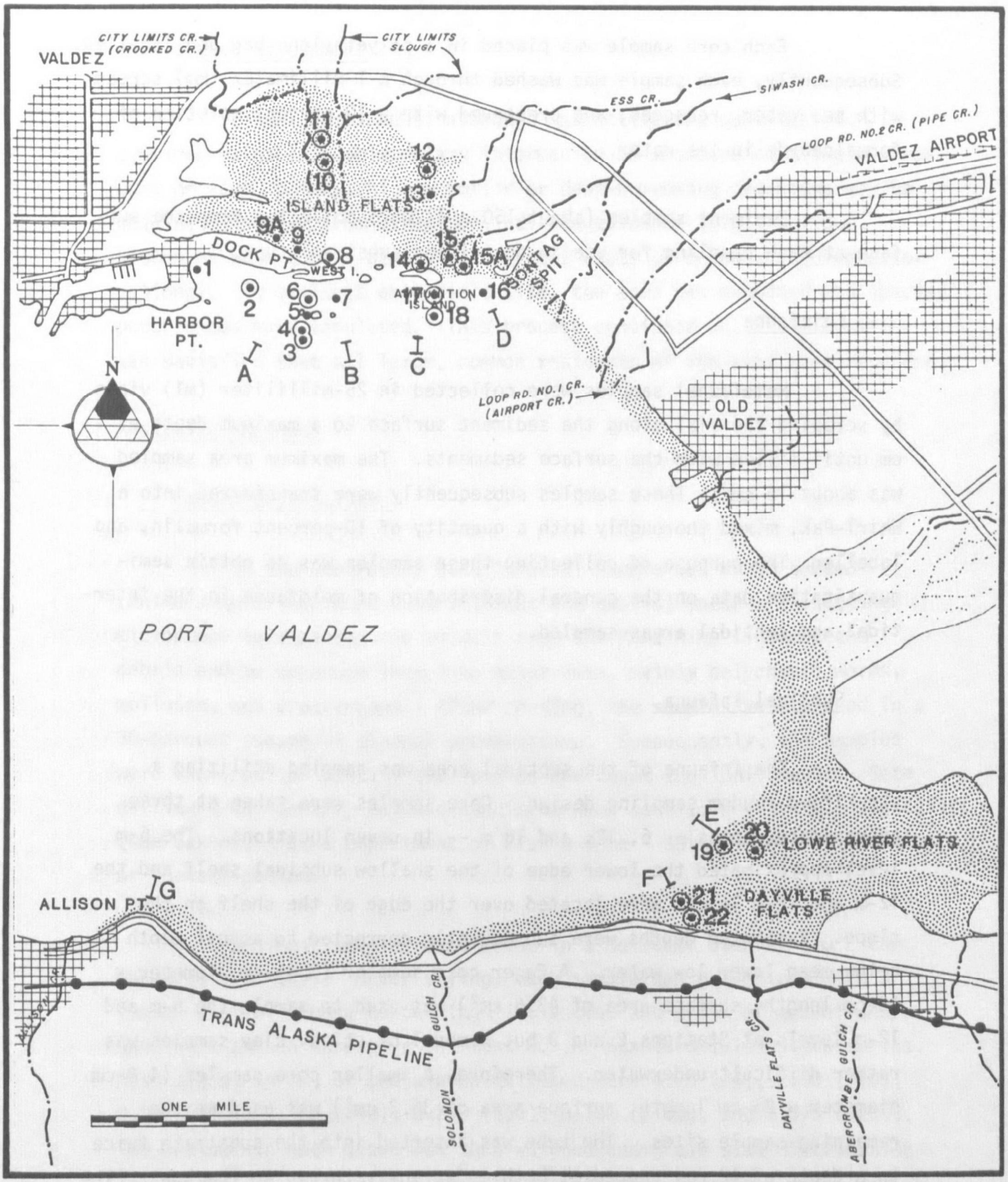
The habitats targeted above were studied at Island Flats, Lowe River Flats, Dayville Flats, and Allison Point (see Figure 1). Field work was conducted from 24 through 29 April 1979. Data from Dayville Flats would pertain directly to the Solomon Gulch area. Detailed investigations in the vicinity of Old Valdez were not conducted due to the unstable bottom conditions and early stages of facility siting.

METHODS

Field Procedures

Intertidal Infauna

A rough stratified random sampling design was employed to examine the infauna (animals living within the sediments) of the intertidal zones at Island Flats, Dayville Flats, and Lowe River Flats along the eastern shore of Port Valdez. At each station, vertical core samples were taken utilizing a 10-centimeter (cm) diameter sampler (surface area of 78.6 cm^2). The core sample collected was 30 cm in length except at Stations 10, 12, and 13 where cores were only 15 cm long due to either a dense mat of vegetation or densely compacted clay beneath the surface sediment. Infaunal organisms appeared restricted to the upper sediment layer. Numerical calculations were based on the surface area sampled. Replication varied depending on substrate of the station and suspected paucity of the area. Ten replicate core samples were taken at Stations 3, 4, and 6; five replicates were taken at Stations 2, 8, 11, 14, and 17 through 22. In apparently impoverished areas, two or four cores were collected as a single sample to reduce the statistical variability between samples and improve the estimate of density. Five replicates of two short cores per sample were taken at Stations 10, 12, and 13. At Siwash Creek sites, five replicates of double cores were collected on the east side and five replicates of quadruple cores on the west side of the channel.



INFAUNAL SAMPLING SITES

QUALITATIVE VISUAL ASSESSMENT SITES

TRANSECT

FIGURE 1

LOCATION MAP

DAMES & MOORE

Each core sample was placed in a polyethylene bag and labelled. Subsequently, each sample was washed through a 1-millimeter (mm) screen with sea water, rebagged, and preserved with a 10 percent solution of formaldehyde in sea water.

Sediment samples (about 150 cm^3) were collected from the surface at each sampling for use in describing substrate type.

Meiofauna

Meiofaunal samples were collected in 25-milliliter (ml) vials by scraping the vial along the sediment surface to a maximum depth of 1 cm until filled with the surface sediments. The maximum area sampled was about 16 cm^2. These samples subsequently were transferred into a Whirl-Pak, mixed thoroughly with a quantity of 10-percent formalin, and labelled. The purpose of collecting these samples was to obtain semi-quantitative data on the general distribution of meiofauna in the intertidal and subtidal areas sampled.

Subtidal Infauna

The infauna of the subtidal area was sampled utilizing a stratified random sampling design. Core samples were taken at three approximate depths -- 6, 12, and 18 m -- in seven locations. The 6-m level approximated the lower edge of the shallow subtidal shelf and the 12-m and 18-m levels were located over the edge of the shelf on the slope. Estimated depths were subsequently corrected to actual depth below mean lower low water. A Fager core sampler (7.45-cm diameter x 10-cm length; surface area of 43.6 cm^2) was used to sample the 6-m and 12-m levels at Stations C and D but removal of sticky clay samples was rather difficult underwater. Therefore, a smaller core sampler (4.8-cm diameter x 25-cm length; surface area of 36.2 cm^2) was used at the remaining sample sites. The tube was inserted into the substrate twice to a depth of 12 cm, capped at both ends, and returned to the boat. The availability of a generous supply of these core tubes facilitated sampling as it eliminated the need for underwater sample removal. The core samples were placed in polyethylene bags and labelled.

Visual Assessment

Visual assessment, although subjective and qualitative, provides valuable supplementary information to the core sampling program. Data on rare, patchy, highly motile or deep-burrowing organisms may be obtained visually from direct or indirect evidence (e.g., burrows, siphon or worm tubes, dead shells, fecal casts or mounds, feeding observations). To evaluate each field site, the area was examined and species occurrences were tabulated. This process continued until the examiner was satisfied that all large, common residents of the area were recorded.

Analytical Methods

Laboratory Analysis

In the laboratory each infaunal sample was rough sorted (animals were separated from sediment and debris) under a dissecting microscope to separate the animals from the remaining sediment and debris and to separate them into major taxa, mainly polychaete worms, molluscs, and crustaceans. After sorting, the samples were placed in a 30-percent isopropyl alcohol preservative. Subsequently, the samples were examined to identify the species and count the individuals. Some difficult to identify mollusc specimens were sent to a taxonomic specialist (Rae Baxter, Alaska Department of Fish & Game - Bethel) for verification or identification.

Sediment samples were dried in a Soiltest oven at 110°F for three to five days. After drying, each sample was pulverized with a rubber pestle. Those containing little clay and a lot of gravel and/or sand were shaken through a Soiltest U.S.A. Standard Tyler sieve series. Mesh sizes, in mm, of the sieves utilized were 4.75 (#4), 2.00 (#10), 0.841 (#20), 0.425 (#40), 0.250 (#60), 0.150 (#100), and 0.075 (#200). The residue in each sieve was then weighed and grain size distribution calculated. Samples with high clay content were sent to Alaska Testlab in Anchorage for hydrometer analyses.

Meiofaunal samples were sieved on a 0.075-mm sieve, placed in a volumetric flask, and sufficient water added to bring the volume up to 100 ml. Using a pipette, the sample solution was mixed and an aliquot withdrawn into the pipette. Immediately, four drops were pooled on the bottom of a petri dish and the remaining sample returned to the flask. Fifteen such replicates were obtained and the animals therein enumerated by major taxon (harpacticoid copepod, nematode, ostracod, etc.). Drop size was approximately 0.05 ml; replicates contained 0.2 ml.

Statistical Techniques

Analysis of species abundance/distribution data utilized ecological indices of diversity and association. Species diversity was calculated for the pooled data from each station using the Shannon-Wiener diversity index (H'), defined by the equation:

$$H' = -\sum_j \frac{n_j}{N} \ln \frac{n_j}{N}$$

where

N = total number of individuals.

n_j = number of individuals of the jth species.

Evenness was estimated by using the equation:

$$E = \frac{2^{H'}}{S}$$

where S = total number of species

Associations between stations and species were examined through multivariate classification techniques (Southwood, 1966). Similarity of distribution in species (among stations) or stations (among species) was determined with the Czekanowski similarity index (QS), defined as:

$$QS = \frac{2C}{A+B}$$

where

A = the number of species at station A.
B = the number of species at station B.
C = the number of species common at both stations.

Groups of similar species or stations were defined by comparing the similarity indices with a group averaging technique, in which the indices for various station or species combinations are averaged. These relationships are visually depicted in a dendrogram. Matrices which summarize species occurrences at sampling stations were the data base for this analysis.

RESULTS

Infaunal Assemblages

Numerical Parameters for Intertidal Zone

Core samples were taken from 17 locations within the intertidal zone at Island Flats, Lowe River Flats and Dayville Flats to assess species composition and faunal density. Ninety-four samples were obtained from various tidal elevations ranging from 2.7 m (Station 11) above MLLW to the lowest level at 1.0 m below MLLW (Station 3) (Figure 1). The substrate at these locations varied considerably from unconsolidated, sticky clay at the uppermost level (Station 11) to consolidated, gravelly sand with some clay in the mid-tidal zone east of Siwash Creek (Station 15) (Table 1). Six stations were located south of the Mineral Creek Islands complex along the low intertidal shelf area, seven stations inside Island Flats, two stations at the mouth of Lowe River (19 and 20), and two stations at the lower levels of Dayville Flats (21 and 22).

The number of species per station within the intertidal zone ranged from a low of six in the upper intertidal (Station 12) to a high of 29 species at the lowest station (Station 3) (Table 2). The pattern

TABLE 1

SUMMARY OF SEDIMENT CHARACTERISTICS AT THE INTERTIDAL SITES EXAMINED IN PORT VALDEZ IN APRIL 1979

Level	Consolidated	Unconsolidated	Gravel	Sand	Silt	Clay	Surface Water	Dry
High Tide	71%	29%		14%	15%	71%		100%
Mid Tide	75%	25%	13%	37%	38%	12%	25%	75%
Low Tide	67%	33%		67%		33%	80%	20%

TABLE 2

SUMMARY OF NUMERICAL PARAMETERS FOR ANIMALS FROM THE SOFT SUBSTRATE INTERTIDAL AREAS IN THE VICINITY OF VALDEZ, APRIL 1979

Location	Station Number	No. of Species (S)	Total Density (no./m^2)	Species Diversity (H)	Evenness (N/S)
		Macoma-Fabricia Assemblage			
W. side Upper	11	7	1153.8	1.217	164.8
W. side mid	10	8	3758.1	0.805	469.8
E. side upper	12	6	3073.1	0.651	512.2
E. side lower mid	14	12	13,743.4	1.148	1145.3
E. side lower mid	15	12	1324.8	1.430	110.4
E. side lower mid	15a	14	1662.4	0.996	118.7
		Polydora-Macoma-Haploscoloplos Assemblage			
Central lower mid	8	16	5589.6	1.597	349.4
W. side lower mid	6	23	9615.2	1.754	418.1
W. side low	2	24	11,692.2	2.385	487.2
W. side low	4	25	4666.5	2.437	186.7
W. side lower low	3	29	6102.4	2.321	210.4
E. side low	17	19	3589.0	1.963	188.9
E. side lower low	18	20	6127.8	2.14	306.4
Lowe River upper	20	8	2794.8	0.897	349.4
Lowe River lower	19	14	2358.7	1.932	168.5
Dayville upper	22	24	9409.6	2.206	392.1
Dayville lower	21	28	13,358.2	1.518	477.1

for species diversity (H') followed that of species richness; i.e., it increased from higher to lower elevations except at Dayville Flats. The area of the lowest diversity (H' = 0.651) was Station 12, located on the east side of Island Flats, whereas highest diversity (H' = 2.437) was found south of the Mineral Creek Islands at Station 4. Average densities (no./m^2) varied considerably from a low of 1,153.8 at the uppermost level (station 11) to a high of 13,743.4 just north of Ammunition Island (Station 14).

Based on patterns in species richness, species diversity, and density, the stations could be divided into two significantly different groups which were geographically distinct. These areas were the upper to middle intertidal zone and the lower intertidal zone. A statistical comparison of these two areas (Kruskal-Wallis nonparametric analysis of variance) showed the differences were significant for species richness and diversity ($P < 0.05$). However the differences in density were not highly significant ($P > 0.1$). In all cases the lower regions were richer than the upper regions.

Numerical Parameters for Subtidal Zone

The infauna of the shallow subtidal region off Island Flats, Lowe River flats, Dayville Flats and Allison Point was sampled during the same period by diving. Sixty-three core samples were taken from seven locations (Transects A through G, Figure 1). On each transect, samples were taken at depths of 0.3 - 3.7 m (the outer edge of the shallow subtidal shelf), 8.8 to 10.7 m and 14.9 to 15.9 m (on the subtidal slope). Differences in sediment between the shelf areas and the slope areas were considerable and generally reflected differences in current regime and slope. The sediments on the shelf were usually coarser, more consolidated and stable than those on the slope. Sand predominated at more than half of the shelf sites examined (Table 3). In contrast, clay predominated at all slope sites examined except off the Lowe River where the sediment was a fine sand. On the shelf, sediments at more than half of the sites were consolidated, whereas sediments at more than 90 percent of the slope sites were unconsolidated. Evidence

TABLE 3

SUMMARY OF SEDIMENT CHARACTERISTICS AT SUBTIDAL SITES EXAMINED IN PORT VALDEZ IN APRIL 1979

Average Depth (m)	Sediment Stability		Primary Sediment		
	Consolidated	Unconsolidated	Sand	Silt	Clay
2.3 (shelf)	57%	43%	57%	None	43%
9.6 (slope)	14%	86%	14%	14%	71%
15.8 (slope)	None	100%	14%	14%	71%

of slumping was noted at several sites on Transects B and D off Ammunition Island and the Mineral Creek Islands (D), and off Lowe River (E) (Appendix 7).

Species richness in the shallow subtidal samples ranged from a low of four species at the 2.7-m level at Dayville to 20 species at the 10.7-m level at Transect C (Table 4). Species richness and depth were clearly not correlated. Differences in species richness between individual transects were highly significant ($P < 0.01$, Kruskal-Wallis nonparametric analysis of variance). However, differences between the stations off the Mineral Creek Islands complex and the Lowe River, Dayville and Allison Point stations were not distinguishable from random ($P > 0.5$).

Species diversity (H') ranged from a low of 0.950 at the 8.8-m level at Lowe River to a high of 2.668 at the 10.7-m level at Transect C (Table 4). Species diversity varied significantly between areas ($P < 0.05$), but no difference between depth levels ($P > 0.95$) was observed. Densities (no./m^2) were highest at the upper levels and decreased with depth in all cases.

Transect C had the highest values for species richness, total density, and species diversity. However, only species richness and species diversity values were found to be significantly higher than at the other subtidal locations ($P < 0.05$).

Faunal Composition

Species lists by station for the common intertidal and subtidal species (Tables 5a, 5b, and 6) were subjected to a similarity analysis to elucidate station grouping and species groupings. The results of these analyses, depicted in Figures 2 and 3, generally reinforced a subjective interpretation of the raw numerical data. Stations separated into four major zonal groupings, namely: (a) upper and middle intertidal, (b) lower intertidal, (c) subtidal shelf and shallow slope, and (d) an impoverished low intertidal-shallow subtidal

TABLE 4

SUMMARY OF NUMERICAL PARAMETERS FOR ANIMALS FROM THE SUBTIDAL SOFT SUBSTRATE PORTIONS OF THE BORDER OF PORT VALDEZ; APRIL 1979

Area, Depth*		No. of Species (S)	Total Density (No./m^2)	Species Diversity (H)	Evenness (N/S)
Transect A	3.7m	6	2222.6	1.436	370.4
	9.8m	5	1111.1	1.099	222.2
	15.9m	6	1574.2	1.395	262.4
Transect B	2.4m	10	3240.9	1.911	324.1
	9.8m	7	2407.6	1.053	343.9
	15.9m	7	2685.3	1.514	383.6
Transect C	3.0m	13	5227.6	1.809	402.1
	10.7m	20	4697.3	2.668	234.9
	16.8m	14	2407.6	2.449	172.0
Transect D	2.1-3.7m	12	4205.8	1.585	383.3
	9.8m	11	2500.0	2.167	227.3
	15.8m	13	3488.7	1.867	268.4
Lowe River					
	0.3m	10	3940.1	1.706	394.0
	8.8m	9	2904.4	2.117	322.7
	14.9m	10	1389.0	2.079	138.9
Dayville Flats					
	0.9m	9	2576.2	1.728	286.2
	9.1m	4	1894.2	0.950	473.6
	15.2m	10	2273.2	1.848	227.3
Allison Point					
	3.0m	11	2955.1	1.864	268.6
	9.1m	15	2652.0	2.021	176.8
	15.2m	9	1515.4	2.013	168.4

* Depth below Mean lower low water (MLLW)

TABLE 5a

ABUNDANCE (NO./M^2) OF MAJOR ANIMALS FROM INTERTIDAL FIELD STUDIES IN APRIL 1979 ON THE SOFT SUBSTRATE PORTIONS OF ISLAND FLATS AND AROUND THE ASSOCIATED ISLETS

	Location (Code)												
	Macoma-Fabricia assemblage						Polydora-Macoma-Haploscoloplos assemblage						
Taxon	W. side upper (11)	W. side mid (10)	E. side upper (12)	E. side lower mid (14)	E. side lower mid (15)	E. side lower mid (15a)	Central lower mid (8)	W. side lower mid (6)	W. side low (2)	W. side low (4)	W. side lower low (3)	E. side low (17)	E. side lower low (18)
ANNELIDA - Polychaeta													
Barantolla americana				1641.0	38.2	38.2	716.9	230.8	897.4	602.6	987.2		1102.6
Eteone longa	25.6	140.1		153.8	25.5	31.8	76.9	115.4	51.3		25.6		25.6
Euchone analis							25.6	12.8	1000.0	282.1	564.1	487.2	1410.3
Fabricia sabella		280.3	31.8	3410.3	216.6	19.1						25.6	
Glycinde picta							102.6	166.7	333.0	140.0	128.2	153.8	307.7
Haploscoloplos panamensis						12.7	179.5	205.1	461.5	152.8	371.8	51.3	25.6
Laonome kroyeri				25.6	25.5	6.4	230.8	384.6	564.1			1359.0	769.2
Lumbrineris luti								12.8		64.1	128.2		
Owenia fusiformis									25.6	128.2	89.7	76.9	153.8
Pholoe minuta									205.1	165.5	230.8		
Polydora quadrilobata							794.9	4320.5	3410.3	1400.3	2243.6	153.8	1307.2
Prionospio steenstrupi							25.6			12.8	217.9		
Pygospio elegans	128.2	216.6	79.6										
Syllis sp									51.3	38.5	102.6		
Tharyx multifilis									435.9	102.6	38.5	25.6	359.0
MOLLUSCA - Gastropoda													
Aglaja diomedea						12.7	102.6	38.5	203.7	25.6		25.6	25.6
Cingula katherinae					25.5		51.3	243.6	865.6	115.4	115.4	25.6	51.3
Littorina sitkana				51.3									
MOLLUSCA - Pelecypoda													
Axinopsida sericata										25.6	141.0		
Macoma balthica	743.6	3006.4	2579.6	8025.6	802.5	1305.7	3051.3	2346.2	1935.0	576.5	230.8	794.9	256.4
Mytilus edulis	51.3		159.2	256.4	51.0	25.5	128.2	1046.9	538.5	397.4	115.4	205.1	153.8
Orobitella rugifera										141.0	51.3		
ARTHROPODA - Insecta													
Diptera larva a	51.3	12.7		51.3		63.7		76.9					
Diptera larva b	128.2	25.5	207.0		12.7	38.2							
ARTHROPODA - Crustacea													
Eudorella sp					12.7	6.4		89.7					
Gnorimosphaeroma oregonensis				51.3		89.2		89.7	51.3		25.6	51.3	25.6
Leptocuma sp		51.0		25.6	76.4	6.4						25.6	

TABLE 5b

ABUNDANCE (NO./M^2) OF MAJOR ANIMALS FROM INTERTIDAL FIELD STUDIES IN APRIL 1979 ON THE SOFT SUBSTRATE PORTIONS OF LOWE RIVER AND DAYVILLE FLATS

	Polydora-Macoma-Haploscoloplos assemblage			
	Lowe River		Dayville Flats	
Taxon	Upper (20)	Lower (19)	Upper (22)	Lower (21)
ANNELIDA - Polychaeta				
Eteone ?longa			153.8	102.6
Euchone analis				25.6
Exogone ?gemmifera			25.6	820.5
Glycinde picta			512.8	820.5
Haploscoloplos panamensis	102.6	153.8	743.6	461.5
Heteromastus sp				76.9
Laonome kroyeri			205.1	
Lumbrineris luti				51.3
Owenia fusiformis			102.6	
Pholoe minuta			179.5	230.8
Polydora quadrilobata	128.2	717.9	3615.2	8717.6
Prionospio steenstrupi			25.6	
Pygospio elegans				153.8
Tharyx ?multifilis			1025.6	25.6
MOLLUSCA - Gastropoda				
Aglaja diomedea				25.6
Cingula katherinae		25.6	25.6	25.6
Littorina sitkana			666.6	
MOLLUSCA - Pelecypoda				
Axinopsida sericata		51.3	51.3	51.3
Macoma balthica	2153.8	743.6	871.8	846.1
Mytilus edulis			564.1	102.6
ARTHROPODA - Insecta				
Diptera larva a	25.6		256.4	51.3

TABLE 6

ABUNDANCE (NO./M^2) OF MAJOR ANIMALS FROM SUBTIDAL FIELD STUDIES IN APRIL 1979
ON THE SOFT SUBSTRATE PORTIONS OF THE BORDER OF PORT VALDEZ

	West Island						Ammunition Island					
	West			East			West			East		
Taxon	6m*	12m	18m	6m	12m	18m	6m	12m	18m	6m	12m	18m
ANNELIDA - Polychaeta												
Ampharete finmarchia	277.8	92.6	185.2	277.8	92.6				92.6	227.3	77.8	
Barantolla americana							75.8			75.8		277.8
Haploscoloplos panamensis		92.6	92.6	92.6	92.6	185.2	75.8	378.8		454.6		92.6
Lumbrineris luti	1018.6	740.7	833.4	1111.2	1759.4	1111.2	2045.5	530.3	370.4	2348.6	681.8	1666.7
Nephtys sp								75.8	92.6		151.5	
Pholoe minuta							227.3		92.6			
Pista cristata				92.6	92.6		530.3	151.5		151.5		
Polydora quadrilobata				648.1			1363.6	378.8	185.2			
Prionospio steenstrupi	185.2							227.3		75.8		
Syllis sp							75.8	909.1				
Terebellides ?stroemi									92.6	75.8	303.0	92.6
MOLLUSCA - Pelecypoda												
Axinopsida serricata	555.6	92.6	277.8	463.8	185.2	833.3	378.8	454.5	463.0	378.8	303.0	92.6
Macoma obliqua	92.6			92.6		185.2	75.8	227.3	92.6	75.8		277.8
Mya arenaria										75.8	151.5	
Mytilus edulis								378.8			227.3	
ARTHROPODA - Crustacea												
Eudorella sp				185.2		185.2		78.8	185.2		227.3	46.3

* Depth below MLLW

TABLE 6 (Continued)

ABUNDANCE (NO./M^2) OF MAJOR ANIMALS FROM SUBTIDAL FIELD STUDIES IN APRIL 1979
ON THE SOFT SUBSTRATE PORTIONS OF THE BORDER OF PORT VALDEZ

Taxon	Lowe River			Dayville Flats			Allison Point		
	0.3m*	8.8m	14.9m	0.9m	9.1m	15.2m	3.0m	9.1m	15.2m
ANNELIDA - Polychaeta									
Ampharete finmarchia	227.3		92.6						
Haploscoloplos panamensis	1439.6	227.3	92.6	75.8			303.1	151.5	151.5
Heteromastus sp						75.8		75.8	
Lumbrineris luti				757.7	681.9	833.4	1060.7	1288.0	378.8
Nephtys sp				151.5					
Pholoe minuta							75.8		
Pista cristata	227.3	151.5		303.1	1060.7	227.3			
Polydora quadrilobata	1136.5	530.4	92.6	151.5			757.7	151.5	
Prionospio steenstrupi		404.1	92.6				75.8		
Terebellides ?stroemi							75.8		
MOLLUSCA - Pelecypoda									
Axinopsida sericata	530.4	454.6	463.0	909.2		530.4	227.3	75.8	303.1
Macoma obliqua		227.3	92.6			75.8			
Mya arenaria								75.8	
ARTHROPODA - Crustacea									
Oedicerotidae, unid.		454.6	92.6			75.8			

* Depth below MLLW

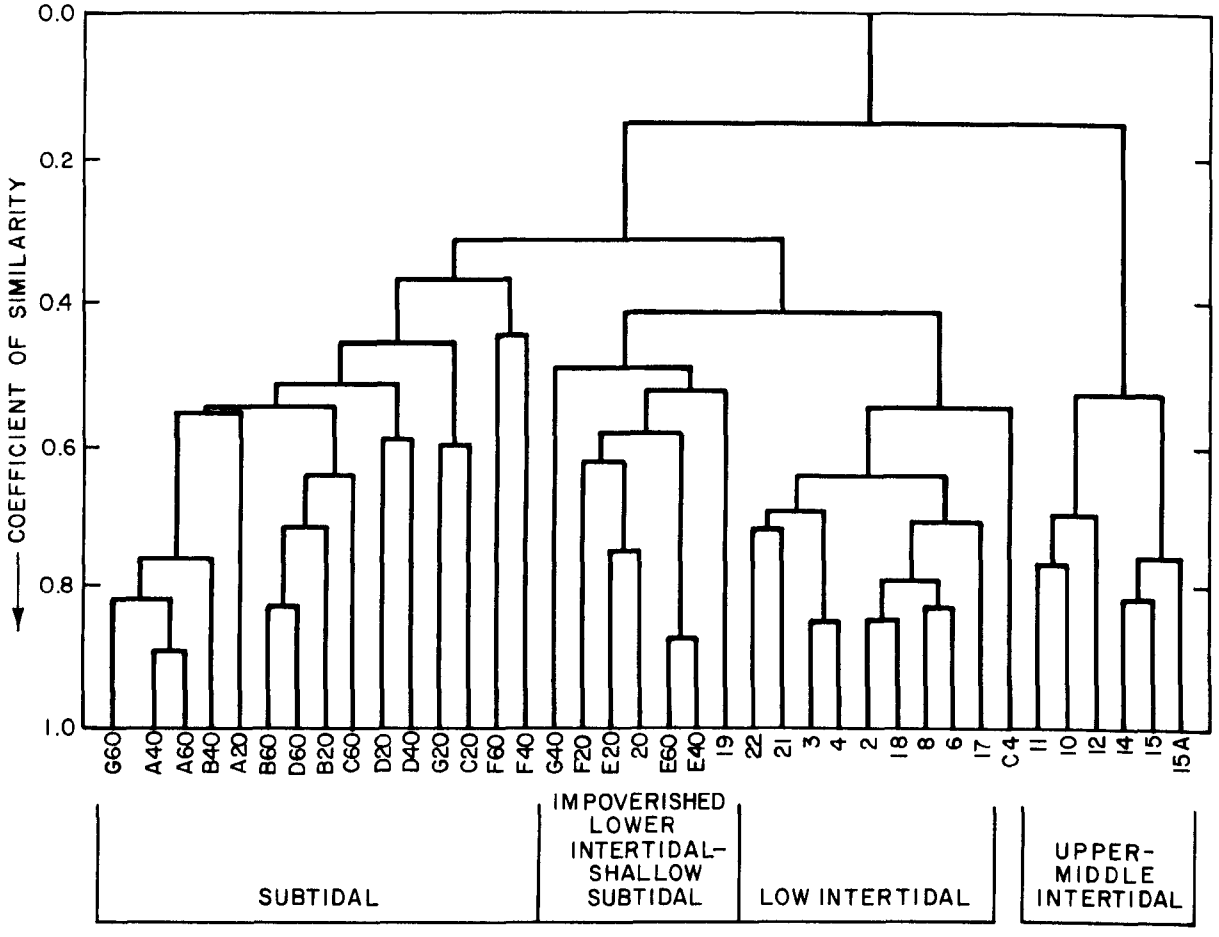


FIGURE 2

DENDROGRAM SHOWING THE RELATIONSHIP AMONG INFAUNAL STATIONS IN THE VICINITY OF PORT VALDEZ IN APRIL 1979

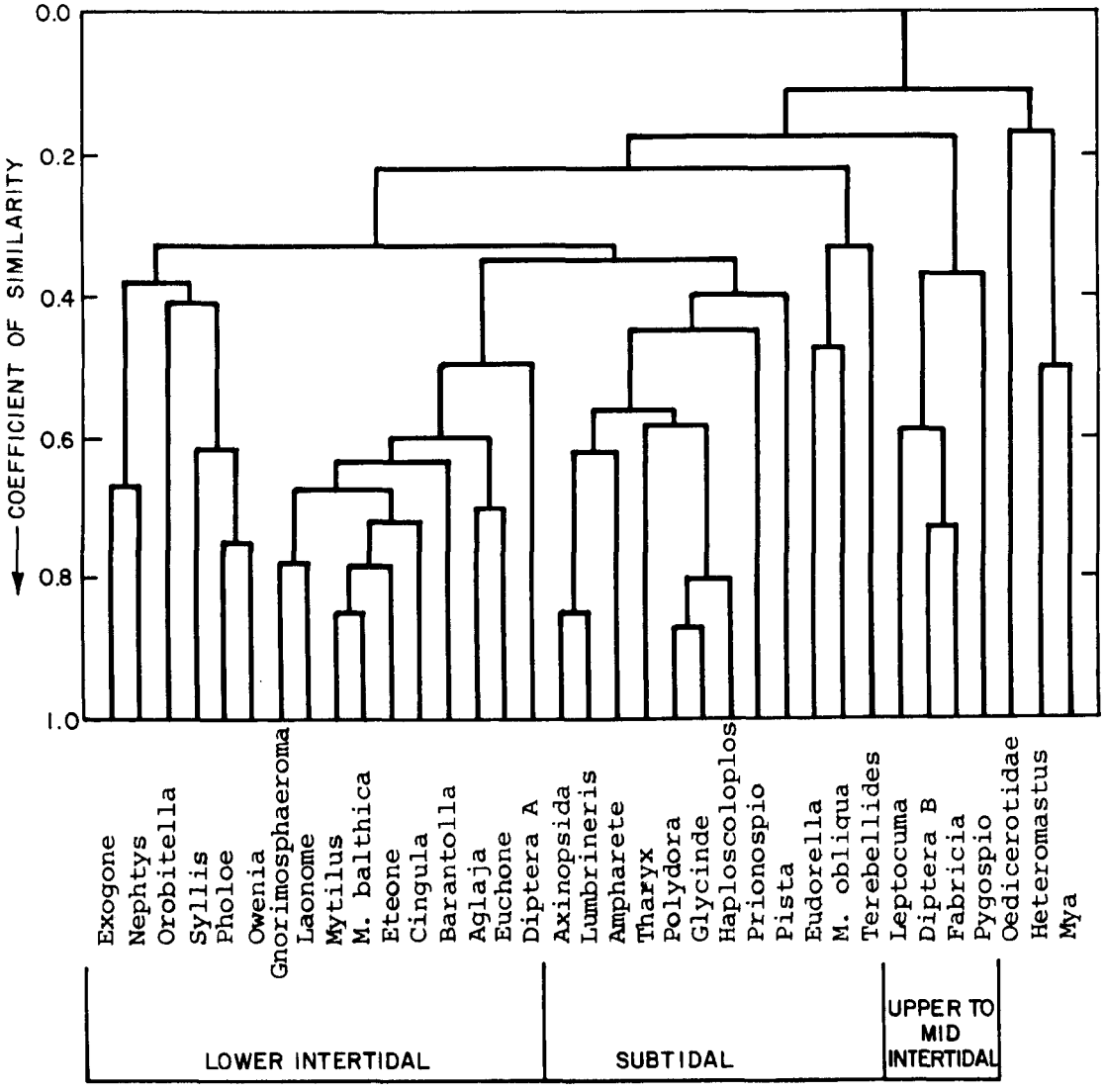


FIGURE 3

DENDROGRAM SHOWING THE RELATIONSHIP AMONG INFAUNAL SPECIES IN THE VICINITY OF PORT VALDEZ IN APRIL 1979

grouping. In contrast, analysis by species produced six main faunal groupings, one upper to mid-intertidal, two lower intertidal, one main subtidal, and two lesser subtidal groupings. Definition of these combinations suffered from a limitation of the technique in that the algorithm is constrained to include a major species (e.g., Macoma balthica) in only one grouping. As a consequence, this analysis was somewhat unsatisfactory as few of the species were strictly associated with either a single tidal zone or a specific location.

Intertidal Assemblages

The assemblage occupying the upper and middle intertidal zone was strongly dominated by the small deposit feeding clam, Macoma balthica, which contributed 60 to 84 percent of the individuals present at each location. Also abundant were the polychaete worms Fabricia sabella (a suspension feeder) and Eteone ?longa (a predator); both were present at five of the six stations. Highest densities for M. balthica and F. sabella were found north of Ammunition Island (Station 12). Pygospio elegans (deposit feeding polychaete) also appeared important at this level. Mytilus edulis (mostly spat) and an unidentified dipteran larva (Diptera larva b) were abundant, but they were not reliably associated with the group. This assemblage, designated the Macoma-Fabricia complex, was found only inside Island Flats (Figure 4).

The infaunal assemblage in the lower intertidal region was strongly dominated by polychaetes. Four polychaete species were found in at least eight of the 11 stations and had densities exceeding $100/m^2$ (Table 5). Three additional species were present in samples from a majority of the stations. Of these seven species, Polydora quadrilobata (probably a deposit feeder) was numerically dominant with Haploscoloplos panamensis (a deposit feeder) second in rank. Other dominant polychaete worms, in order of importance, were the predatory Glycinde picta and Euchone analis, a suspension feeder. Macoma balthica was again the dominant mollusc. The small gastropod, Cingula katherinae was found at all but one station, but overall density was rather low. A small predatory opisthobranch, Aglaja diomedea, was found in seven of the stations but

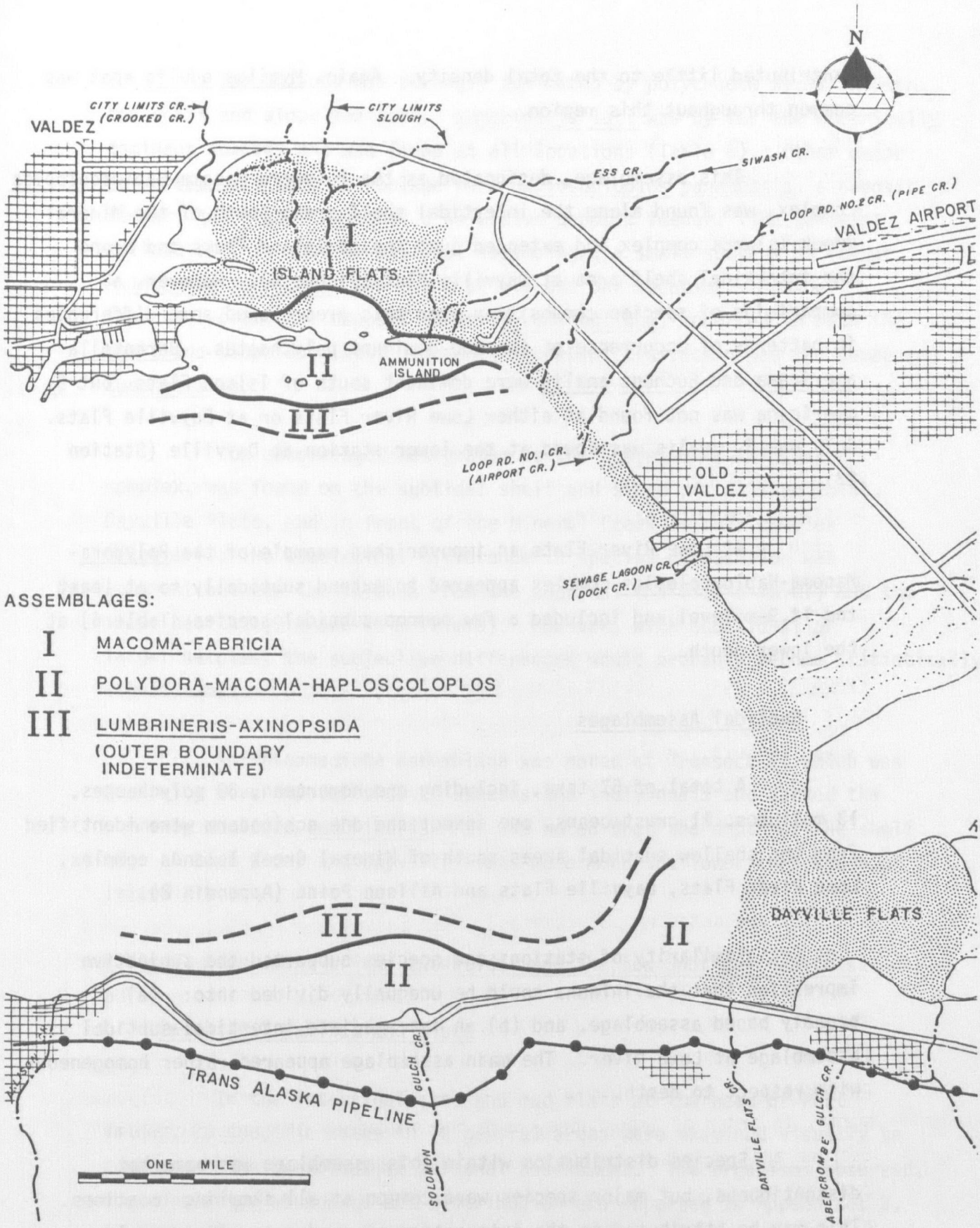


FIGURE 4

DISTRIBUTION OF INFAUNAL ASSEMBLAGES
PORT VALDEZ

DAMES & MOORE

contributed little to the total density. Again, Mytilus edulis spat was common throughout this region.

This assemblage, designated as the Polydora-Macoma-Haploscoloplos complex, was found along the intertidal shelf areas south of the Mineral Creek Islands complex and extended just inside Island Flats and along the intertidal shelf area at Dayville Flat (Figure 4). However, a comparision of species composition over this area showed some differences in patterns of occurrence of the sub-dominant polychaetes. Barantolla americana and Euchone analis were dominant south of Island Flats, but B. americana was not found at either Lowe River Flats or at Dayville Flats. Only one E. analis was found at the lower station at Dayville (Station 22).

At Lowe River Flats an impoverished example of the Polydora-Macoma-Haploscoloplos complex appeared to extend subtidally to at least the 14.9-m level and included a few common subtidal species (Table 6) at the lower depth.

Subtidal Assemblages

A total of 57 taxa, including one nemertean, 30 polychaetes, 13 molluscs, 11 crustaceans, one insect and one echinoderm were identified from the shallow subtidal areas south of Mineral Creek Islands complex, Lowe River Flats, Dayville Flats and Allison Point (Appendix 2).

Similarity of stations and species supported the subjective impression that the infauna could be unequally divided into: (a) a broadly based assemblage, and (b) an intermediate intertidal-subtidal assemblage at Lowe River. The main assemblage appeared rather homogeneous with respect to depth.

Species distribution within this assemblage was somewhat discontinuous, but major species were common at all sampling locations. This may be attributed to the interaction of random sampling and low density of various species.

The infauna was strongly dominated by polychaete worms in both the shelf and slope habitats. Lumbrineris luti was by far the numerically dominant species and was found at all locations (Table 6). Other major polychaetes of this assemblage were Haploscoloplos panamensis, a deposit feeder, and Pista cristata, a selective deposit feeder. The dominant mollusc of this shallow subtidal assemblage, a small suspension feeder Axinopsida serricata, was found at all but one location. Another important clam, the deposit feeder Macoma obliqua, occurred in both the shelf and slope habitats. The only important crustacean was the cumacean Eudorella sp.

The assemblage, designated as the Lumbrineris-Axinopsida complex, was found on the subtidal shelf and slope off Allison Point, Dayville Flats, and in front of the Mineral Creek Islands complex (Figure 4). No statistical difference in species composition was apparent between the infauna from the subtidal shelf (3-m level) and the slope habitat (9-m and 15-m levels). However, with additional or larger samples, the subjective differences would probably become statistically significant.

An intermediate assemblage was noted at Transect E, which was generally more impoverished in species and individuals and lacked the commonly dominant Lumbrineris. It was noted that the depth of the shelf edge at Lowe River and Dayville Flats were much shallower than south of Island Flats.

A Visual Assessment of the Intertidal and Shallow Subtidal Habitats

Intertidal Habitat and Biota

In the intertidal sand and mud flats at the head of Port Valdez, 23 specific sites in 12 general areas were examined visually to complement the quantitative infaunal assessment. The organisms observed, their relative abundance and distribution are reported in Appendices 3, 4 and 5. Abundance estimates of several of the infaunal species such as Macoma balthica or Echiurus were based on visual signs of their presence

at the surface of the sediment (Figures 5 and 6). The major species assemblages in these areas, based on visual assessments, appear to be typified by:

- Macoma balthica (pink clams).
- Macoma and Mya arenaria (soft shell clams).
- Mytilus edulis and Fucus distichus (blue mussels and rockweed).
- Echiurus echiurus, Laminaria saccarina, and Polydora quadrilobata (spoonworm, ribbon kelp, and tube worm).
- Polydora quadrilobata and Macoma balthica.

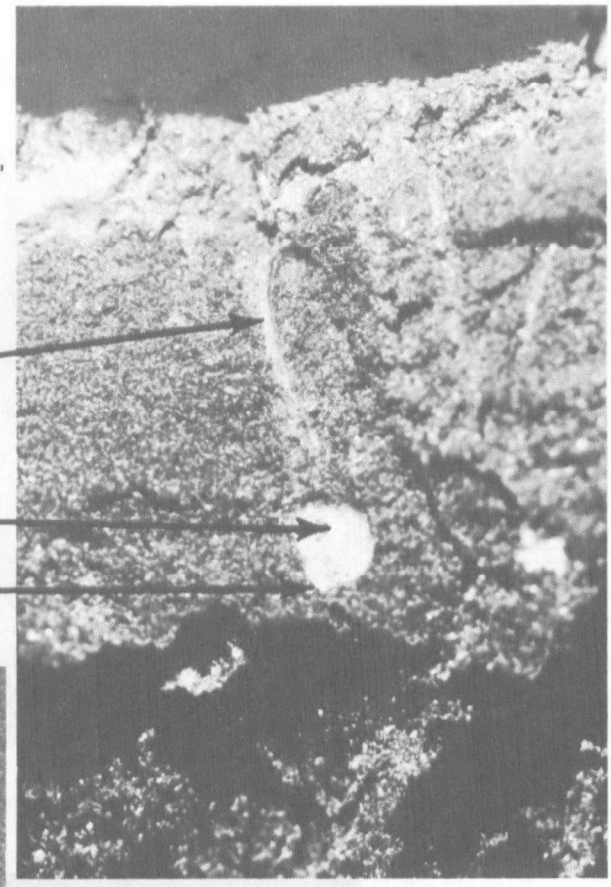
Approximate distribution of these assemblages is depicted in Figure 7. Their boundaries are based mainly on a qualitative visual assessment of dominance and, since variability is fairly high, the designated boundaries are not exact. The boundaries between these assemblages are rather ill-defined because both Macoma and Mytilus are abundant and very widely distributed throughout the area.

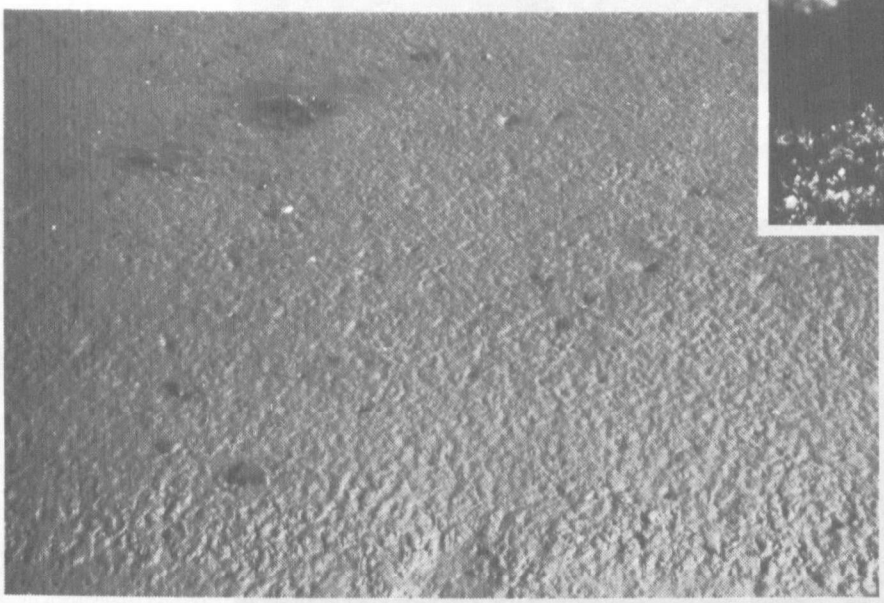
Generally, Macoma balthica (Figure 5) appeared to dominate most of Island Flats (Figure 7). Densities of adult clams were moderately high. The capitellid polychaete Barantolla was also common or abundant over much of that area. Generally, both Macoma and capitellids are considered deposit feeders. The former feeds at the sediment surface but it may also feed on suspended materials in the water column. Capitellids burrow through the sediments to ingest particles of sediment and organic debris. Dominant seaweeds (Pylaiella and Ulvales) cover about 10 percent of the substrate. Twelve invertebrate and eight algal species were noted.

The Macoma-Mya assemblage appeared restricted to the sandy mid-tidal level between the barrier rock outcrops of the outer island group, Dock Point, West Island, and Lowe River Flats. Densities of both

A

CROSS-SECTION OF SEDIMENT, SHOWING CLAM, FOOT, SIPHON HOLE





B

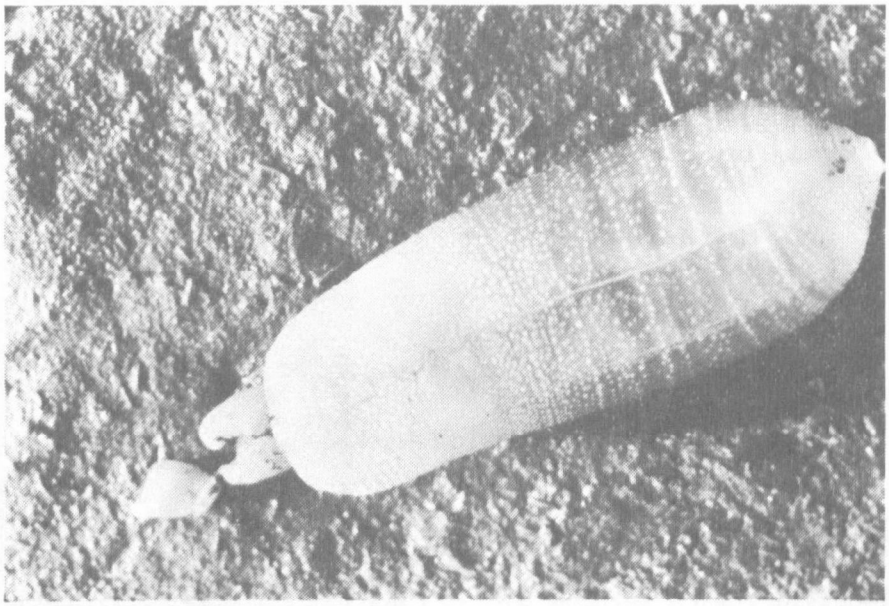
SURFACE OF MUDFLAT, SHOWING NUMEROUS INDIVIDUAL "DIMPLES" OF MACOMA

C

TRACK LEFT BY MOVEMENT OF MACOMA

FIGURE 5

MACOMA BALTHICA



A

ECHIURUS ECHIURUS ALASKANUS

B

ITS BURROW AND FECAL PELLETS

FIGURE 6

ECHIURUS ECHIURUS ALASKANUS

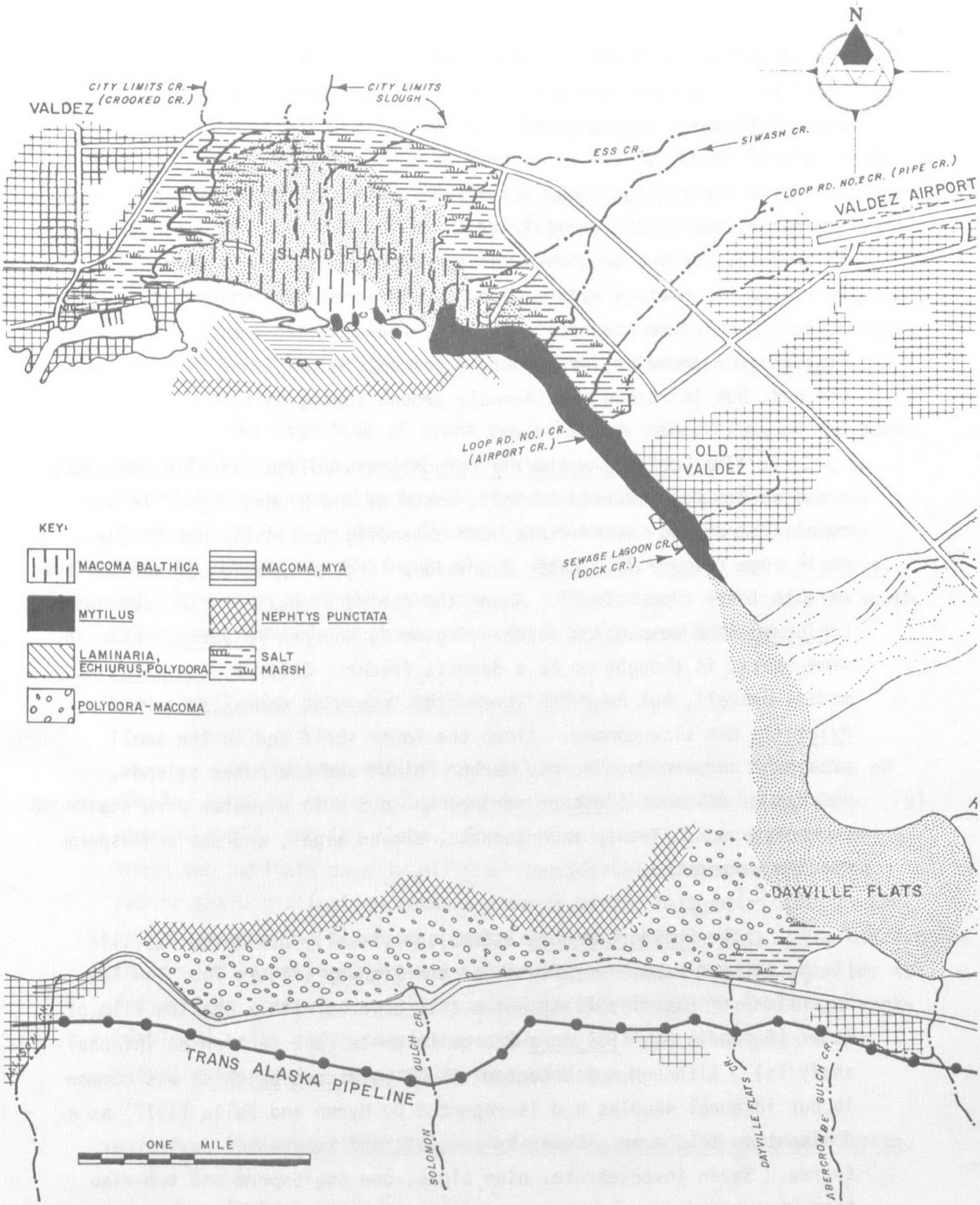


FIGURE 7

DISTRIBUTION
OF VISUALLY DETERMINED
ASSEMBLAGES

Macoma and Mya arenaria, a suspension feeder, were fairly low. Cover by the dominant seaweed (Pylaiella) was sparse. Eleven invertebrate and five algal species were noted.

The Mytilus-Fucus assemblage, easily assessed by visual methods, was restricted to the gravelly areas in the passages into Island Flats (Figure 7). In the southeast passage between Ammunition Island and Sontag Spit, coverage by a mature population of suspension feeding mussels was low to moderate. Cover by the dominant seaweed (Fucus distichus or rockweed) was about 10 percent in the lower portions of the bed, but increased considerably around Sontag Spit.

The Echiurus-Laminaria-Polydora assemblage visually dominated areas on the low intertidal shelf, south of the Mineral Creek Island complex bordering Island Flats, and extending subtidally out to the shelf edge (Figure 7). Water overlaid a large proportion of the surface at this level (Appendix 6). Among the dominant residents the spoonworm, Echiurus, is a suspension feeder (Figure 6) whereas Polydora, dense in some spots, is thought to be a deposit feeder. Cover by Laminaria was modest overall, but near the lower tide levels it increased markedly. Pylaiella was also common. Along the lower shelf and in the small embayment between Dock Point, Harbor Point, and the outer islands, patches of eelgrass (Zostera marina) up to 3 m in diameter were scattered commonly about. Twenty invertebrate, eleven algal, and one angiosperm species were noted.

The Polydora-Macoma assemblage visually dominated Dayville Flats, between Lowe River Flats and the highway (Figure 7). The low intertidal of Dayville Flats was mostly covered with a shallow film of water (Appendix 6). Polydora was quite dense (see section on infaunal analysis). Although not detected visually, Macoma balthica was common in our infaunal samples and is reported by Myren and Pella (1977) as a dominant in this area. Cover by seaweeds and seagrasses was rather sparse. Seven invertebrate, nine algae, one angiosperm and two fish taxa were noted.

Several differences existed between the assemblages observed at the Island Flats complex and those at Lowe River and Dayville Flats. Ribbon kelp (Laminaria saccharina) was absent at the latter sites. Sediments at the mouth of Lowe River were fairly unconsolidated sands and animal densities appeared fairly low. Echiurus was absent and Mya only occurred in scattered clay patches. At Dayville Flats, tubicolous worms, mainly Polydora and sabellids, were very abundant, forming a close cropped turf of worm tubes. Macoma was abundant, but both Mya and Echiurus appeared virtually absent. Since sediments at Dayville Flats appeared suitable for Mya and Echiurus, their absence was curious.

The magnitude of plant production by macrophytes on the sand and mud flats at the head of Port Valdez was not quantified, but appeared low compared with probable phytoplankton production over the flats and in Port Valdez. The most productive species are probably benthic diatoms and the brown algae, Pylaiella, Fucus, and Laminaria. Red algae were generally very sparse. Algal debris and scraps of marsh grass were commonly observed throughout the intertidal zone.

The Shallow Subtidal Habitat and Biota

At the east end of Port Valdez, the two major categories of shallow subtidal habitat observed during field investigations were: (a) shallow shelf, and (b) slope. The sediments and biotas characterizing these two habitats usually differed considerably (Appendix 7). The rather sharp distinction between them is marked bathymetrically by an abrupt increase in slope at a depth of 3 to 4 m below MLLW. The differences in species assemblages probably represent responses by the organisms to differences in current activity and type and stability of the sediments (Table 3). The major species assemblages in these areas, based on visual assessments, appeared to be typified by:

- Echiurus echiurus-Laminaria saccharina-Polydora quadrilobata.
- Nephtys punctata (a burrowing worm).

Species composition and appearance of the shelf community showed a moderate resemblance to that of the lower intertidal zone, as described above. Ribbon kelp (L. saccharina) was the dominant macrophyte, but although common, its standing crop was low (Appendix 8). Less important algae included hair kelp (Desmarestia spp.) and a small filamentous brown species (Pylaiella littoralis). Benthic diatoms were observed and probably contributed a considerable proportion to overall plant production, though it would appear that annual production is not high. Seven taxa of algae were noted on the shelf.

Faunal dominants in the intertidal zone that also were important on the subtidal shelf included the spoonworm Echiurus, and the small tubicolous worm Polydora. Other commonly observed, typically subtidal species in the shelf community included a large burrowing polychaete Nephtys punctata, the small snails Mitrella gausapata and Nassarius mendicus, tiny, very young tanner crabs (Chionoecetes bairdi), small cumaceans and gammarid amphipods. Echiurus and Polydora were generally found in consolidated sediments whereas N. punctata occurred in unconsolidated sediments (Appendix 8). Twenty-eight species of invertebrates were noted on the shelf.

In terms of biomass, Echiurus and N. punctata appeared to be dominant infaunal forms on the subtidal shelf in most areas. At Allison Point, the clams Mya truncata and Zirphaea pilsbryi were common at the edge of the shelf. However, data to estimate secondary production or standing crop are lacking for all locations.

The shelf community, a detritus-based system, appeared to support strong populations of long-lived suspension and deposit feeders. Its ability to support the former is largely due to relative sediment stability and water movement from tidal currents and wave action. The primary suspension feeder was Echiurus. The main deposit feeders included N. punctata and Polydora. Several predator/scavenger species were observed, including snails, crabs, and the starry flounder, Platichthys stellatus (Appendix 8).

Faunal variability in the subtidal areas was related to the differences observed in physical attributes of the habitats. At the Lowe River and Dayville Flats sites, the edge of the shelf is actually in the low intertidal zone. Sediments on the shelf and on the slope at Lowe River were clean fine sand, whereas at Dayville Flats, both shelf and slope were clay and at Allison Point, the shelf was silty sand and the slope was clay. These sites provided additional insight into the influences of current activity, sediment type and stability and other physical parameters, but also presented some puzzles. Ribbon kelp was absent at the shelf sites only off Lowe River and Dayville Flats. Whether a consequence of salinity, turbidity, strong offshore winds or ice rafting is not known, but it sets these sites apart. Furthermore, suspension feeders were absent at the shelf site at Transect B, suggesting that this area is exposed to very little current activity. The Lowe River site was rather impoverished; few polychaetes and no snails were observed. In contrast, Allison Point was the most diverse; a number of species, especially suspension feeding clams, were observed only at this site.

Our observations suggest that several types of predators concentrate their feeding efforts in the shelf habitat. As tide permits, a fairly dense starry flounder population moves back and forth between the flats, the shelf and the slope to feed. Based on stomach samples from fish collected during the ebbing tide, the clam *M. balthica* is one of their major food items on Island Flats. Harbor seals appear to congregate along the edge of the shelf, presumably to feed on starry flounder, the only fish that we commonly observed or captured in the area. Several species of sea ducks, mainly Barrow's goldeneye and scoters, were common in the vicinity of the shelf habitat at Island Flats and around the old wharf near Allison Point, but they seemed to concentrate their feeding efforts in the submerged intertidal areas. *Macoma balthica* and mussels appeared to be major food items for the sea ducks. Finally, sea otters were observed feeding along the edge of the shelf off Island Flats and at Allison Point, and on into the submerged intertidal area outside Island Flats. Based on shell fragments it appeared they were feeding mainly on mussels, *Mya arenaria*, and *Zirphaea pilsbryi*.

Twelve species of invertebrates were noted on the slope during visual assessment (Appendix 8), and several additional species were collected with an air lift sampler while attempting to collect animals creating mud cones and excavations. The polychaete N. punctata, indicated by fecal cones and feeding excavations, was observed at all slope sites examined. Population biomass appeared to be high and this species is probably an important consumer. Also, its constructions may modify the slope habitat in ways important to other species. The large sea anemone Metridium was commonly observed but at much lower densities and was therefore of lower rank than Nephtys. Several other species may serve important functions, but were less conspicuous because of size or behavior (refer to infauna assessment section). These include various clams, polychaete worms, recently settled young tanner crab, and the snail Mitrella gausapata. The abundance of recently settled tanner crabs suggested that the slope may be an important nursery area for them.

Six species of algae were noted on the slope, but most were drift material. Ribbon kelp plants were commonly observed on the slope above the 16-m level, but because they were always attached to small stones, we suspect they had drifted off the shelf as a consequence of tidal currents or wave action. Additionally, plant debris (Fucus, other seaweeds and marsh grass) were commonly observed on the slope. Most of the sites supported a moderate to heavy diatom film that probably contributed significantly to plant production. However, despite the diatoms and Laminaria, total plant production in the slope habitat is probably quite low because of limitations in light and suitable substrate.

The trophic structure of the slope assemblage appeared rather simple. Plant production is probably limited and most of the organic material utilized as food is imported from either the nearby marsh, mud flats, or from phytoplankton populations. The slope appeared to support mainly deposit feeders such as N. punctata and Macoma obliqua which probably constituted the bulk of the biomass. The large sea anemone Metridium senile was the only suspension feeder of consequence observed

on the slope off Island Flats. As reported in the infaunal section, the suspension feeding clam Axinopsida was also common. The number and abundance of predator/scavenger species observed was small and evidence of predation (excavations, shell middens, fecal pellets, etc.) was scanty. The most important predatory species appeared to be adult tanner crabs. Both juveniles and breeding adults were observed frequently.

In terms of trophic structure, the shelf and slope communities differed substantially as described above. In the shelf assemblage, both suspension and deposit feeding invertebrates were important in terms of biomass, abundance, and function; whereas deposit feeders strongly dominated the fauna in the slope assemblage. Species richness, abundance, and activity of predators seemed higher on the shelf than on the slope.

The Meiofaunal Assemblage

Because of the importance of meiofauna in the transfer of energy from plants to large animals, distribution patterns and relative abundance of the major meiofaunal taxa were examined. The intent was to make rough comparisons of abundance among the major taxa at a number of stations at several elevations in the study area and to attempt to discover distribution patterns across the elevation gradient. The techniques were crude (see METHODS) and because of the dilutions necessary to obtain workable samples, errors are potentially large (e.g., the multiplier to extrapolate the sample means to a number of organisms per square m was 312,500). However, the densities generally are of the same order of magnitude found by Feder et al. (1976) in samples from MLLW south of Ammunition Island. In any event, the errors should be fairly consistent throughout this analysis and so, with two important exceptions, patterns in distribution and relative abundance should be somewhat realistic. In the case of ostracods and foraminiferans, however, densities are probably substantially elevated because these animals will settle to the bottom of a pipette faster than the other organisms and thus are over-represented in our sample.

The data suggest several patterns (Table 7). First, it appears that overall meiofaunal density was higher in the low intertidal than at either higher or lower elevations. Also, subtidal densities were higher than the mid or upper intertidal levels. Harpacticoid copepods and nematodes were probably the most common meiofaunal organisms. They were most abundant at low intertidal and upper subtidal levels (1 m to 6 m below MLLW) and their numbers, down to the 12-m level, exceeded those at higher intertidal levels. Foraminiferans were considerably more abundant at low intertidal and subtidal levels than elsewhere. Ostracods were most abundant intertidally and became relatively scarse subtidally. Cumaceans and mites were probably the least abundant of the meiofaunal organisms counted. Cumaceans were absent in samples from the upper intertidal levels and the lower subtidal levels, while mites (Halacaridea) were absent subtidally.

The Rocky Intertidal Assemblage

The rocky intertidal areas, all at the mid to high tide level, were surprisingly impoverished. *Fucus* was the dominant alga and *Monostroma* was the only other plant observed commonly. *Fucus* grew densely in a rather narrow band. Important invertebrates included *Mytilus edulis*, dense but also in a narrow band; the grazers *Littorina sitkana* and *Acmaea ?persona* at moderate densities; and the barnacles *Balanus balanoides* and *B. glandula*, with moderate cover. Other typical forms such as *Nucella*, *Pentidotea*, chitons, and *Siphonaria* were not encountered, despite a specific search for them.

DISCUSSION

Basically five infaunal assemblages were identified through visual assessments or infaunal sampling in the sand and mud flats around the head of Port Valdez (Table 8). The species selected as characteristic on the basis of infaunal sampling were small, numerically dominant species, whereas those from visual assessment were large, conspicuous, or common organisms (such as the kelp *Laminaria*, *Macoma*,

TABLE 7

DISTRIBUTION AND DENSITY ESTIMATES FOR MAJOR MEIOFAUNAL TAXA ON ISLAND FLATS AND THE ASSOCIATED INTERTIDAL AND SUBTIDAL SHELF AND SLOPE HABITAT

Major Taxa	Density (10^{-3} x No./sq. m)						
					Subtidal Transect B		
	Upper Level West Island Flats	Mid Level East Island Flats	North of Ammunition Island	Lower Level South of Ammunition Island	6 m Level	12 m Level	18 m Level
Nematods	906.3	593.8	343.8	1,500.0	1,593.8	1,218.8	781.3
Harpacticoid copepods	531.3	500.0	656.3	2,812.5	1,281.3	1,281.3	406.3
Cumacens	--	--	62.5	40.6	21.9	--	--
Ostracods[1]	593.8	250.0	531.3	531.3	21.9	62.5	--
Foraminifera[1]	343.8	187.5	31.3	4,093.8	1,000.0	2,968.8	2,156.3
Mites	40.6	--	31.3	187.5	--	--	--
TOTAL MEIOFAUNAL DENSITY	2,415.8	1,531.3	1,656.5	10,697.0	3,918.9	5,532.5	3,343.9

[1]Density estimates probably somewhat elevated relative to other taxa because settling rates are possibly higher than for other meiofaunal forms.

TABLE 8

COMPARISON CHARACTERIZING SPECIES FOR MAJOR BIOLOGICAL ASSEMBLAGES IN AND AROUND THE PORT VALDEZ STUDY AREA

Area	Infaunal Analysis	Visable Components of the Assemblage
Island Flats (mid - upper intertidal)	Macoma-Fabricia	Macoma
Between Barrier Rock Outcrop and Dock Point (mid - intertidal)	Macoma-Fabricia	Macoma-Mya
Dayville Flats and Lowe River	Polydora-Macoma-Haploscoloplos	Polydora-Macoma
Shelf South of Mineral Creek Island Complex (low intertidal - shallow subtidal)	Polydora-Macoma-Haploscoloplos	Echiurus-Laminaria-Polydora
SE Corner of Island Flats (mid - intertidal)	Polydora-Macoma-Haploscoloplos	Mytilus-Fucus
Slope Below Shelf (shallow subtidal)	Lumbrineris-Axinopsida	Nephtys punctata

Polydora, or Nephtys). Although the species designated as characteristic of a specific assemblage are often different depending on the scale of examination (eye vs. microscope), the general results of the two techniques are quite similar (compare Figures 4 and 7).

Description of Biological Assemblages

The Macoma-Fabricia assemblage is located north of the Mineral Creek Islands complex, at the mid to upper intertidal levels. Sediments are diverse, including consolidated and unconsolidated clays, sandy silt, sandy gravel, and gravelly sand. The surface of the sediment is generally flat and often supports standing water. Several seaweeds (Ulvales, Fucus, and Pylaiella) provide sparse plant cover. The major animals include the clam Macoma and the worms Fabricia, Eteone, Barantolla, and Pygospio. Species richness and density are low in the upper level and moderate in the middle level. Densities of meiofaunal organisms are moderate. The meiofauna is dominated by nematodes and harpacticoid copepods. Apparent productivity and evidence of utilization by predators (sea ducks and fish) ranges from low in the upper level to moderate in the middle level.

The Mytilus-Fucus assemblage is located near MLLW in the southeast corner of Island Flats and the other passages into Island Flats. Sediments in the southeast corner of Island Flats are coarse sand with gravel and unconsolidated pockets of soft clay. The visually dominant organisms are the blue mussel (Mytilus) and rockweed (Fucus). Productivity appears to be moderate to high. Although direct evidence of utilization was not recorded, numerous records of drift Fucus and fecal shell middens dominated by Mytilus shells attest to the productivity of the area.

The Polydora-Macoma-Haploscoloplos assemblage is mainly located south of the Mineral Creek Islands complex at or below MLLW out to a depth of nearly 6 m. This assemblage also extends into Island Flats near the western tidal channels. Sediments are mainly silty sand or sandy clay, but sticky plastic clay occurs just south of Ammunition

Island. Algae or seagrass cover ranges from very light near MLLW to moderate near the edge of the shelf. The principal species are the algae Pylaiella and Laminaria, and in patches, eelgrass. Important animals include the worms Echiurus, Polydora, Barantolla, and Haploscoloplos, and the clams Macoma and Mya. Species richness and densities are relatively high in this assemblage. Meiofaunal density may be quite high especially below MLLW. Harpacticoids and nematodes were the dominant forms in the meiofauna, and foraminiferans appeared important. Productivity appears moderate. Utilization is relatively intense based on visual indications of predation and observations of predators (seaducks, fish, seals, and otters).

The Polydora-Macoma assemblage at Dayville Flats is quite similar to the assemblage described above with the following exceptions. The kelp Laminaria and the worm Echiurus were nearly absent at Dayville Flats and the capitellid polychaete Barantolla is replaced by Capitella capitata. The Polydora population is much denser and more extensive at Dayville Flats, where Mya is quite uncommon.

The Lumbrineris-Axinopsida assemblage is located on the upper portion of the slope defining the edge of the bay. Sediments are generally soft, unconsolidated clay and fine silt. The slope is fairly steep and evidence of instability is common. The flora is mainly drift plants which occur on the slope. The major animals of this assemblage include the polychaetes Lumbrineris, Ampharete, Nephtys, and Haploscoloplos, the clams Axinopsida and Macoma obliqua, and tiny, just settled tanner crabs. Species richness and densities are relatively low in this assemblage. Meiofaunal densities appear moderate and again harpacticoids and nematodes dominate. Foraminiferans may be abundant. Productivity and utilization appear fairly low. However, juvenile and adult tanner crabs were observed commonly in some locations and possibly forage on the moderate quantities of worms and clams available.

General Remarks

Several general patterns of distribution in the intertidal zone were observed. Species richness and the complexity of community structure generally increased along two gradients: from upper to lower intertidal and from the head of the bay toward the small boat harbor and terminal facility. Explanations for these patterns include: (a) the reduction in stress at lower tidal levels and away from the head of the port permits success of increased numbers and types of species (e.g., predators), and (b) increased current activity allows development of suspension feeding assemblages.

The mud flat and subtidal areas support faunal assemblages that convert plant material into animal tissue. These assemblages consist mainly of consumer systems, basically depending on phytoplankton from the bay or plant material imported from the marsh. The mud flat assemblages appear to be more productive than the adjacent subtidal assemblages and they assume special importance because numerous predator species from other systems, in some cases far removed, move onto the mud flats periodically to take advantage of the rich supply of animal tissue. In all seasons, resident sea ducks and starry flounder move over the flats during high tide to feed on clams and mussels. Visual evidence of these activities is commonly observed in mid and low intertidal areas and on the shallow subtidal shelf (Figures 8 and 9). In spring and fall, migrating birds rest on the flats and marsh and feed on worms, clams, and small meiofaunal organisms. In spring, outmigrating salmon fry forage in the flats for insect larvae and meiofaunal crustaceans. Harbor seals move in over the shelf and mud flats to feed on starry flounder and spawning salmon from spring through fall.

A comparison of the salient attributes among the areas examined suggests that the Island Flats area is the most productive. The largest areas of marsh vegetation and rockweed are located on the eastern side of the flats, along with a sizable mussel bed in the southeastern corner. High densities of *Macoma balthica* occur in the central portion of the flats (Table 5a). The clams and probably mussels sustain considerable predation from duck and fish populations, and constitute a significant

A

FEEDING EXCAVATIONS BY SEA DUCKS AND STARRY FLOUNDERS

B

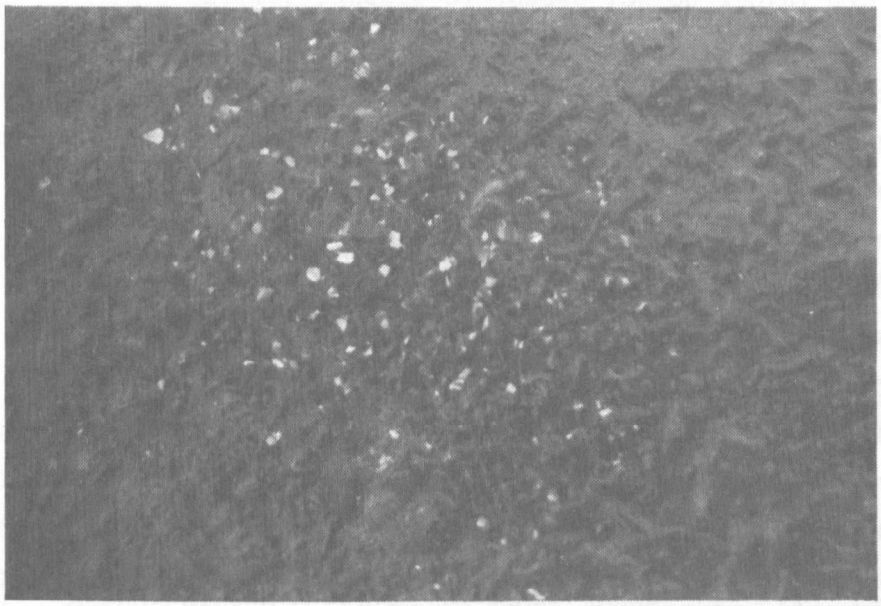
TEMPORARY "NEST" FOR STARRY FLOUNDER

C

FEEDING EXCAVATION, PROBABLY BY A SEA DUCK

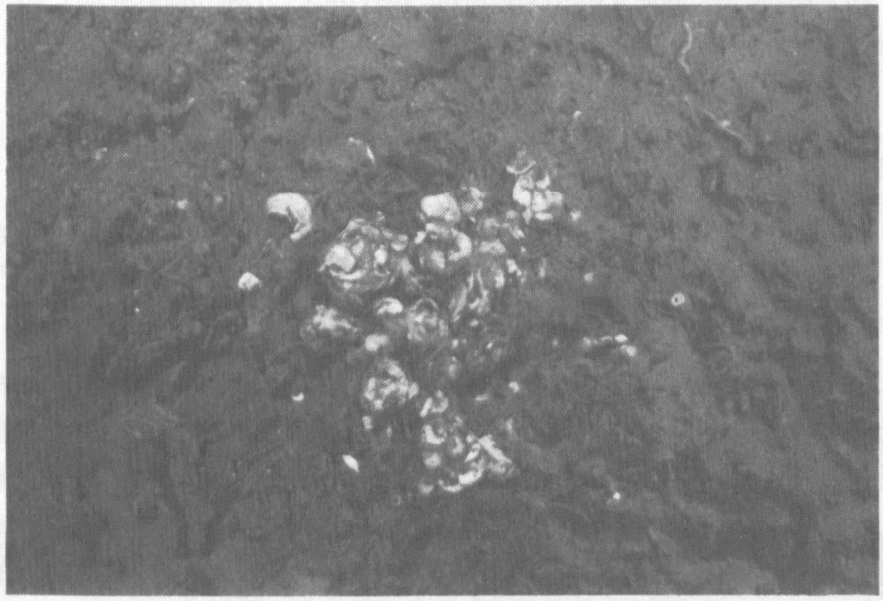
FIGURE 8

TYPES OF EXCAVATIONS OF SEDIMENT SURFACE



A

SEA DUCK FEEDING ON BLUE MUSSELS



B

STARRY FLOUNDER FEEDING ON MACOMA

FIGURE 9

TYPES OF FECAL SHELL MIDDENS

portion of the diet of several other species. The other sand or mud flats in Port Valdez do not appear to support similar predator populations. Little information is available for the intertidal assemblages at Mineral Creek Flats or at Shoup Bay. However, Island Flats seems to be the most productive or highly utilized mud flat in Port Valdez based on patterns of bird and salmon occurrences (Dames & Moore, 1979a and 1979b).

The subtidal assemblages, especially on the slope, are somewhat less robust than the mud flat assemblages, even though both have a similar structure. Although the subtidal assemblage is probably fairly widespread, it appears to be of relatively minor ecological significance, except for the possible importance as a nursery area for juvenile tanner crabs. Based on the appearance of the slope sediments, and patterns reported by Feder and Matheke (1979), the slope assemblage is probably well adapted to high levels of suspended silt and rates of deposition.

In terms of the construction project, the important environmental parameters affecting these soft bottom communities are:

- The depositional nature of the sediments, and
- The natural level of suspended solids (turbidity) of the water.

Because the animals forming these biological assemblages are adapted to live in mud flats, and on unstable slopes, they are highly tolerant of temporary increases in deposition rates and high turbidity. Generally, turbidity increases tremendously in summer, at the time of peak glacial melt, but the time of year is probably unimportant to the infaunal assemblages. For example, despite temporally opposite turbidity patterns in lower Cook Inlet, the mud flat assemblages are rather similar. It therefore seems rather unlikely that dredging activities, even including marine disposal over the edge of the slope, would create appreciable long-term reduction in the quality of the affected biological assemblages.

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APPENDIX

APPENDIX 1a

ABUNDANCE DATA FOR STATION 2;
27 APRIL 1979. .0078 M^2 CORE FROM -0.3 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
PRIAPULIDA								
Priapulus caudata	1	0	1	1	0	.6	.5	76.9
ANNELIDA - Polychaeta								
Barantolla americana	6	13	2	7	6	7.0	4.4	897.4
Eteone longa	0	1	0	1	0	.4	.5	51.3
Euchone analis	3	20	5	2	9	7.8	7.3	1000.0
Glycinde picta	1	2	5	1	4	2.6	1.8	333.3
Haploscoloplos panamensis	6	3	2	5	2	3.6	1.8	461.5
Laonome kroyeri	3	3	3	4	9	4.4	2.6	564.1
Nereis ?procera	1	1	0	0	0	.4	.5	51.3
Ophelia limacina	0	0	0	1	0	.2	.4	25.6
Owenia fusiformis	1	0	0	0	0	.2	.4	25.6
Pectinaria granulata	0	0	0	0	2	.4	.9	51.3
Pholoe minuta	1	3	2	1	1	1.6	.9	205.1
Polydora quadrilobata	12	41	24	21	34	26.6	11.0	3410.3
Syllis sp.	0	0	2	0	0	.4	.9	51.3
Tharyx multifilis	3	9	0	5	0	3.4	3.8	435.9
MOLLUSCA - Gastropoda								
Aglaja diomedea	1	1	4	2	0	1.6	1.5	205.1
Cingula katherinae	2	2	7	10	12	6.8	4.9	871.8
MOLLUSCA - Pelecypoda								
Hiatella arctica	2	1	0	0	1	.8	.8	102.6
Macoma balthica	12	9	16	20	19	15.2	4.7	1948.7
Mytilus edulis	4	4	1	5	7	4.2	2.2	538.5
ARTHROPODA - Insecta								
Diptera larvae a	2	0	0	1	0	.6	.9	76.9
ARTHROPODA - Crustacea								
Gnorimosphaeroma oregonensis	0	0	2	0	0	.4	.9	51.3
Monoculodes sp.	0	0	1	0	0	.2	.4	25.6
Photis sp.	0	2	2	1	4	1.8	1.5	230.8

NO. OF INDIVIDUALS/SQ M = 11692.2
NO. OF SPECIES = 24

APPENDIX 1b

ABUNDANCE DATA FOR STATION 3;

27 APRIL 1979. .0078 M^2 CORE FROM -1.0 M ELEVATION

TAXA	1	2	3	4	5	6	7	8	9	10	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta													
Ampharete ?finmarchia	0	0	1	0	0	0	0	0	0	0	.1	.3	12.8
Barantolla americana	33	3	17	3	9	1	1	4	5	1	7.7	10.2	987.2
Eteone longa	0	0	0	0	0	1	0	0	0	1	.2	.4	25.6
Euchone analis	6	9	2	0	1	3	7	2	2	12	4.4	3.9	564.1
Exogone ?gemmifera	0	0	0	0	0	0	0	1	0	0	.1	.3	12.8
Glycinde picta	1	1	0	1	0	1	3	1	1	1	1.0	.8	128.2
Haploscoloplos panamensis	5	3	7	1	1	1	1	7	1	2	2.9	2.5	371.8
Lumbrineris luti	1	0	2	0	1	0	3	1	2	0	1.0	1.1	128.2
Nepthys sp.	1	1	0	0	0	0	0	0	0	0	.2	.4	25.6
Nereis ?procera	0	0	0	0	0	1	0	0	0	1	.2	.4	25.6
Owenia fusiformis	1	0	3	1	0	0	0	2	0	0	.7	1.1	89.7
Pectinaria granulata	0	1	0	0	0	0	0	0	0	0	.1	.3	12.8
Pholoe minuta	3	1	3	1	0	2	1	2	1	4	1.8	1.2	230.8
Phyllodoce groenlandica	1	1	0	0	0	0	0	0	0	1	.3	.5	38.5
Polydora quadrilobata	32	63	8	2	2	8	12	20	1	26	17.5	19.2	2243.6
Prionospio steenstrupi	3	2	5	0	0	1	2	2	1	1	1.7	1.5	217.9
Syllis sp.	0	0	0	0	1	0	0	4	3	0	.8	1.5	102.6
Tharyx multifilis	0	1	1	0	0	0	1	0	0	0	.3	.5	38.5
MOLLUSCA - Gastropoda													
Cingula katherinae	1	0	0	0	0	2	0	2	2	2	.9	1.0	115.4
MOLLUSCA - Pelecypoda													
Axinopsida serricata	1	0	2	2	1	1	1	0	2	1	1.1	.7	141.0
Hiatella arctica	0	0	0	0	1	0	0	0	1	0	.2	.4	25.6
Macoma balthica	4	2	2	1	2	1	2	2	1	1	1.8	.9	230.8
Macoma obliqua	0	0	1	0	0	0	1	0	0	1	.3	.5	38.5
Mytilus edulis	0	1	0	0	1	0	0	0	1	6	.9	1.9	115.4
Urobitella rugifera	0	0	1	0	2	0	0	1	0	0	.4	.7	51.3
Protothaca staminea	0	0	0	0	0	0	1	0	0	0	.1	.3	12.8
ARTHROPODA - Crustacea													
Anisogammarus sp.	0	0	0	0	0	0	0	0	1	0	.1	.3	12.8
Gnorimosphaeroma oregonensis	0	0	0	1	0	0	0	1	0	0	.2	.4	25.6
Pentidotea wosnesenskii	0	1	0	1	0	0	0	1	1	2	.6	.7	76.9

NO. OF INDIVIDUALS/SQ M = 6102.4
NO. OF SPECIES = 29

APPENDIX 1c

ABUNDANCE DATA FOR STATION 4;

27 APRIL 1979. .0078 M^2 CORE FROM -0.6 M ELEVATION

TAXA	1	2	3	4	5	6	7	8	9	10	MEAN	ST.DEV	DENSITY
PRIAPULIDA													
Priapulus caudata	1	1	0	2	0	0	0	1	0	0	.5	.7	64.1
ANNELIDA - Polychaeta													
Ampharete ?finmarchia	1	0	1	0	0	0	0	0	0	0	.2	.4	25.6
Barantolla americana	2	0	34	0	5	0	0	2	2	2	4.7	10.4	602.6
Euchone analis	1	0	7	3	1	3	1	4	2	0	2.2	2.1	282.1
Glycinde picta	1	1	3	2	1	0	0	1	1	1	1.1	.9	141.0
Haploscoloplos panamensis	1	2	2	1	1	1	2	0	0	2	1.2	.8	153.8
Lumbrineris luti	0	0	0	1	2	1	0	0	0	1	.5	.7	64.1
Magelona pitelkai	0	0	0	0	0	0	1	0	0	0	.1	.3	12.8
Nereis ?procera	0	1	0	0	0	2	0	0	0	0	.3	.7	38.5
Owenia fusiformis	0	0	1	1	1	2	3	2	0	0	1.0	1.1	128.2
Pholoe minuta	1	0	0	2	2	1	4	2	0	1	1.3	1.3	166.7
Polydora quadrilobata	7	2	28	9	18	3	9	11	1	22	11.0	9.0	1410.3
Prionospio steenstrupi	0	0	0	0	0	0	0	1	0	0	.1	.3	12.8
Syllis sp.	1	0	0	0	0	0	0	0	0	2	.3	.7	38.5
Tharyx multifilis	0	0	8	0	0	0	0	0	0	0	.8	2.5	102.6
MOLLUSCA - Gastropoda													
Hiatella arctica	0	0	1	0	1	0	0	0	0	0	.2	.4	25.6
Cingula katherinae	0	1	2	1	1	2	0	2	0	0	.9	.9	115.4
MOLLUSCA - Pelecypoda													
Axinopsida serricata	0	0	0	1	0	0	1	0	0	0	.2	.4	25.6
Macoma balthica	2	3	3	2	7	5	2	9	5	7	4.5	2.5	576.9
Mytilus edulis	1	4	4	2	3	1	2	8	1	5	3.1	2.2	397.4
Orobitella rugifera	0	0	0	0	0	1	3	2	0	5	1.1	1.7	141.0
ARTHROPODA - Crustacea													
Eusiridae, unid.	0	1	0	0	0	0	0	0	0	0	.1	.3	12.8
Harpacticoida, unid.	0	2	0	0	0	0	0	0	0	0	.2	.6	25.6
Hippomedon sp.	0	0	0	6	0	0	0	0	0	0	.6	1.9	76.9
Photis sp.	0	0	0	0	1	1	0	0	0	0	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 4666.5
NO. OF SPECIES = 25

APPENDIX 1d

ABUNDANCE DATA FOR STATION 6;

27 APRIL 1979. .0078 M^2 CORE FROM +1.2 M ELEVATION

TAXA	1	2	3	4	5	6	7	8	9	10	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta													
Barantolla americana	2	0	3	0	3	1	1	3	3	2	1.8	1.2	230.8
Eteone longa	0	0	0	1	1	1	0	2	1	3	.9	1.0	115.4
Euchone analis	0	0	0	0	1	0	0	0	0	0	.1	.3	12.8
Glycinde picta	0	0	7	2	2	1	0	0	0	1	1.3	2.2	166.7
Haploscoloplos panamensis	1	0	2	3	3	0	1	0	3	3	1.6	1.3	205.1
Laonome kroyeri	1	1	4	9	1	4	3	1	3	3	3.0	2.4	384.6
Lumbrineris luti	0	0	1	0	0	0	0	0	0	0	.1	.3	12.8
Mediomastus sp.	0	2	0	0	0	0	0	0	0	0	.2	.6	25.6
Nepthys caeca	1	0	1	1	0	0	0	0	2	0	.5	.7	64.1
Polydora quadrilobata	24	24	67	48	23	20	26	45	43	17	33.7	16.2	4320.5
MOLLUSCA - Gastropoda													
Aglaja diomedea	0	0	2	0	0	0	0	0	0	1	.3	.7	38.5
Cingula katherinae	0	2	0	4	2	0	1	2	6	2	1.9	1.9	243.6
MOLLUSCA - Pelecypoda													
Macoma balthica	14	7	14	14	23	12	23	24	12	36	18.3	8.3	2346.2
Mytilus edulis	1	2	7	12	1	8	9	24	12	6	8.4	7.0	1076.9
ARTHROPODA - Arachnida													
Archaearanea	0	0	0	0	0	0	1	0	0	0	.1	.3	12.8
Halacaridae	0	0	0	0	0	0	0	1	0	0	.1	.3	12.8
ARTHROPODA - Insecta													
Diptera larvae a	0	0	0	0	0	0	0	6	0	0	.6	1.9	76.9
ARTHROPODA - Crustacea													
Anisogammarus sp.	0	0	1	1	0	1	0	0	0	0	.3	.5	38.5
Calanoida, unid.	0	0	0	0	0	0	0	0	1	0	.1	.3	12.8
Eudorella sp.	0	0	0	2	0	0	0	0	5	0	.7	1.6	89.7
Gnorimosphaeroma oregonensis	0	1	0	1	1	2	2	0	0	0	.7	.8	89.7
Harpacticoida, unid.	0	0	0	0	0	0	0	0	2	0	.2	.6	25.6
Pentidotea wosnesenskii	0	0	1	0	0	0	0	0	0	0	.1	.3	12.8

NO. OF INDIVIDUALS/SQ M = 9615.2
NO. OF SPECIES = 23

APPENDIX 1e

ABUNDANCE DATA FOR STATION 8;

27 APRIL 1979. .0078 M^2 CORE FROM +2.1 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Barantolla americana	10	8	3	2	5	5.6	3.4	717.9
Eteone longa	0	3	0	0	0	.6	1.3	76.9
Euchone analis	0	0	0	0	1	.2	.4	25.6
Glycinde picta	0	2	1	0	1	.8	.8	102.6
Haploscoloplos panamensis	0	1	3	2	1	1.4	1.1	179.5
Laonome kroyeri	1	0	4	0	4	1.8	2.0	230.8
Polydora quadrilobata	0	0	22	0	9	6.2	9.7	794.9
Prionospio steenstrupi	0	0	1	0	0	.2	.4	25.6
MOLLUSCA - Gastropoda								
Aglaja diomedea	1	0	3	0	0	.8	1.3	102.6
Cingula katherinae	1	1	0	0	0	.4	.5	51.3
MOLLUSCA - Pelecypoda								
Macoma balthica	26	33	18	19	23	23.8	6.1	3051.3
Mytilus edulis	0	0	3	0	2	1.0	1.4	128.2
ARTHROPODA - Crustacea								
Diastylis sp.	0	0	0	0	1	.2	.4	25.6
Eusiridae, unid.	0	0	0	0	1	.2	.4	25.6
Gnorimosphaeroma oregonensis	1	0	0	0	0	.2	.4	25.6
Leptocuma sp.	0	0	0	0	1	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 5589.6
NO. OF SPECIES = 16

APPENDIX 1f

ABUNDANCE DATA FOR STATION 10;

29 APRIL 1979. .0157 M^2 CORE FROM +2.1 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Eteone longa	3	4	1	0	3	2.2	1.6	140.1
Fabricia sabella	0	4	7	11	0	4.4	4.7	280.3
Pygospio elegans	0	7	0	10	0	3.4	4.8	216.6
MOLLUSCA - Pelecypoda								
Macoma balthica	42	47	49	49	49	47.2	3.0	3006.4
ARTHROPODA - Insecta								
Diptera larvae a	0	0	0	1	0	.2	.4	12.7
Diptera larvae b	0	0	1	1	0	.4	.5	25.5
ARTHROPODA - Crustacea								
Anisogammarus sp.	2	0	0	0	0	.4	.9	25.5
Leptocuma sp.	0	0	0	2	2	.8	1.1	51.0

NO. OF INDIVIDUALS/SQ M = 3758.1
NO. OF SPECIES = 8

APPENDIX 1g

ABUNDANCE DATA FOR STATION 11;
29 APRIL 1979. .0078 M^2 CORE FROM +2.7 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Eteone longa	0	0	0	0	1	.2	.4	25.6
Pygospio elegans	0	0	0	0	5	1.0	2.2	128.2
MOLLUSCA - Pelecypoda								
Macoma balthica	7	1	6	6	9	5.8	2.9	743.6
Mytilus edulis	0	0	2	0	0	.4	.9	51.3
ARTHROPODA - Insecta								
Diptera larvae a	1	1	0	0	0	.4	.5	51.3
Diptera larvae b	0	0	0	1	4	1.0	1.7	128.2
ARTHROPODA - Crustacea								
Harpacticoida, unid.	1	0	0	0	0	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 1153.8
NO. OF SPECIES = 7

APPENDIX 1h

ABUNDANCE DATA FOR STATION 12;

29 APRIL 1979. .0157 M^2 CORE FROM +2.1 M ELEVATION

TAXA	1	2	3	4	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta							
Fabricia sabella	0	1	0	1	.5	.6	31.8
Pygospio elegans	1	1	1	2	1.2	.5	79.6
MOLLUSCA - Pelecypoda							
Macoma balthica	40	46	44	32	40.5	6.2	2579.6
Mytilus edulis	10	0	0	0	2.5	5.0	159.2
ARTHROPODA - Insecta							
Diptera larvae b	4	1	6	2	3.2	2.2	207.0
ARTHROPODA - Crustacea							
Calanoida, unid.	1	0	0	0	.2	.5	15.9

NO. OF INDIVIDUALS/SQ M = 3073.1
NO. OF SPECIES = 6

APPENDIX 1i

ABUNDANCE DATA FOR STATION 14;

26 APRIL 1979. .0078 M^2 CORE FROM +2.1 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Barantolla americana	19	7	17	13	7	12.8	5.6	1641.0
Eteone longa	0	2	1	3	0	1.2	1.3	153.8
Fabricia sabella	19	0	53	51	10	26.6	24.2	3410.3
Laonome kroyeri	0	0	0	1	0	.2	.4	25.6
MOLLUSCA - Gastropoda								
Littorina sitkana	0	0	0	2	0	.4	.9	51.3
MOLLUSCA - Pelecypoda								
Macoma balthica	53	69	58	72	61	62.6	7.8	8025.6
Mytilus edulis	3	2	4	1	0	2.0	1.6	256.4
ARTHROPODA - Insecta								
Collembola sp.	1	0	0	0	0	.2	.4	25.6
Diptera larvae a	0	0	0	2	0	.4	.9	51.3
ARTHROPODA - Crustacea								
Gnorimosphaeroma oregonensis	0	0	2	0	0	.4	.9	51.3
Leptocuma sp.	0	0	0	1	0	.2	.4	25.6
Talitrus sp.	1	0	0	0	0	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 13743.4
NO. OF SPECIES = 12

APPENDIX 1j

ABUNDANCE DATA FOR STATION 15;

26 APRIL 1979. .0157 M^2 CORE FROM +1.2 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Barantolla americana	0	0	0	2	1	.6	.9	38.2
Eteone longa	0	0	1	0	1	.4	.5	25.5
Fabricia sabella	1	7	4	1	4	3.4	2.5	216.6
Laonome kroyeri	0	2	0	0	0	.4	.9	25.5
MOLLUSCA - Gastropoda								
Cingula katherinae	2	0	0	0	0	.4	.9	25.5
MOLLUSCA - Pelecypoda								
Macoma balthica	14	19	11	8	10	12.6	4.4	802.5
Mytilus edulis	1	3	0	0	0	.8	1.3	51.0
ARTHROPODA - Insecta								
Diptera larvae b	0	0	1	0	0	.2	.4	12.7
ARTHROPODA - Crustacea								
Calanoida, unid.	0	0	2	0	0	.4	.9	25.5
Eudorella sp.	0	0	1	0	0	.2	.4	12.7
Leptocuma sp.	0	0	6	0	0	1.2	2.7	76.4
Talitrus sp.	0	1	0	0	0	.2	.4	12.7

NO. OF INDIVIDUALS/SQ M = 1324.8
NO. OF SPECIES = 12

APPENDIX 1k

ABUNDANCE DATA FOR STATION 15a;

26 APRIL 1979. .0314 M^2 CORE FROM +1.2 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Barantolla americana	4	0	0	0	2	1.2	1.8	38.2
Eteone longa	5	0	0	0	0	1.0	2.2	31.8
Fabricia sabella	1	1	0	0	1	.6	.5	19.1
Haploscoloplos panamensis	2	0	0	0	0	.4	.9	12.7
Laonome kroyeri	0	0	1	0	0	.2	.4	6.4
MOLLUSCA - Gastropoda								
Aglaja diomedea	1	0	0	1	0	.4	.5	12.7
MOLLUSCA - Pelecypoda								
Macoma balthica	27	51	47	37	43	40.9	9.4	1305.7
Mytilus edulis	2	0	1	1	0	.8	.8	25.5
ARTHROPODA - Insecta								
Collembola sp.	0	0	0	0	1	.2	.4	6.4
Diptera larvae a	10	0	0	0	0	2.0	4.5	63.7
Diptera larvae b	0	1	2	1	2	1.2	.8	38.2
ARTHROPODA - Crustacea								
Eudorella sp.	1	0	0	0	0	.2	.4	6.4
Gnorimosphaeroma oregonensis	11	0	2	1	0	2.8	4.7	89.2
Leptocuma sp.	1	0	0	0	0	.2	.4	6.4

NO. OF INDIVIDUALS/SQ M = 1662.4
NO. OF SPECIES = 14

APPENDIX 11

ABUNDANCE DATA FOR STATION 17;

26 APRIL 1979. .0078 M^2 CORE FROM MLLW ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Ampharete ?finmarchia	1	0	0	0	0	.2	.4	25.6
Euchone analis	3	3	6	2	5	3.8	1.6	487.2
Exogone ?gemmifera	0	0	0	0	1	.2	.4	25.6
Fabricia sabella	0	0	0	0	1	.2	.4	25.6
Glycinde picta	2	0	1	1	2	1.2	83.7	153.8
Haploscoloplos panamensis	1	1	0	0	0	.4	.5	51.3
Laonome kroyeri	16	0	20	9	8	10.6	7.7	1359.0
Nephtys sp.	0	0	1	0	0	.2	.4	25.6
Owenia fusiformis	0	1	0	2	0	.6	.9	76.9
Polydora quadrilobata	1	0	5	0	0	1.2	2.2	153.8
Tharyx multifilis	0	1	0	0	0	.2	.4	25.6
MOLLUSCA - Gastropoda								
Aglaja diomedea	1	0	0	0	0	.2	.4	25.6
Cingula katherinae	0	0	0	0	1	.2	.4	25.6
MOLLUSCA - Pelecypoda								
Macoma balthica	9	9	5	4	1	5.6	3.4	717.9
Mytilus edulis	0	0	1	1	6	1.6	2.5	205.1
ARTHROPODA - Crustacea								
Anisogammarus sp.	1	0	0	0	0	.2	.4	25.6
Diastylis sp.	0	0	0	1	0	.2	.4	25.6
Gnorimosphaeroma oregonensis	1	0	0	1	0	.4	.5	51.3
Leptocuma sp.	0	0	0	1	0	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 3512.3
NO.OF SPECIES = 19

APPENDIX 1m

ABUNDANCE DATA FOR STATION 18;

26 APRIL 1979. .0078 M^2 CORE FROM -0.9 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
PRIAPULIDA								
Priapulus caudata	0	0	0	1	0	.2	.4	25.6
ECHIUROIDEA								
Echiurus echiurus	0	0	0	0	1	.2	.4	25.6
ANNELIDA - Polychaeta								
Ampharete ?finmarchia	0	0	0	0	1	.2	.4	25.6
Barantolla americana	1	1	3	1	37	8.6	15.9	1102.6
Eteone longa	0	0	0	1	0	.2	.4	25.6
Euchone analis	6	1	12	12	22	11.0	8.0	1410.3
Glycinde picta	3	2	3	1	3	2.4	.9	307.7
Haploscoloplos panamensis	1	0	0	0	0	.2	.4	25.6
Laonome kroyeri	5	5	10	6	4	6.0	2.3	769.2
Owenia fusiformis	0	2	0	3	1	1.2	1.3	153.8
Polydora pygidialis	0	0	0	0	1	.2	.4	25.6
Polydora quadrilobata	28	7	5	3	8	10.2	10.1	1307.7
Tharyx multifilis	3	1	3	0	7	2.8	2.7	359.0
MOLLUSCA - Gastropoda								
Aglaja diomedea	0	0	0	1	0	.2	.4	25.6
Cingula katherinae	0	0	0	1	1	.4	.5	51.3
MOLLUSCA - Pelecypoda								
Macoma balthica	2	3	1	1	3	2.0	1.0	256.4
Macoma obliqua	0	0	0	0	1	.2	.4	25.6
Mytilus edulis	1	1	1	2	1	1.2	.4	153.8
ARTHROPODA - Crustacea								
Diastylis sp.	0	1	0	0	0	.2	.4	25.6
Gnorimosphaeroma oregonensis	1	0	0	0	0	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 6127.8
NO. OF SPECIES = 20

APPENDIX 1n

ABUNDANCE DATA FOR LOWE RIVER UPPER INTERTIDAL AREA (STATION 20);
28 APRIL 1979. .0078 M^2 CORE FROM +0.3 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Aricidea neosuecica	0	1	0	0	0	.2	.4	25.6
Glycinde picta	0	1	0	0	0	.2	.4	25.6
Haploscoloplos panamensis	0	1	1	1	1	.8	.4	102.6
Polydora quadrilobata	0	5	0	0	0	1.0	2.2	128.2
MOLLUSCA - Pelecypoda								
Hiatella arctica	2	0	0	0	0	.4	.9	51.3
Macoma balthica	10	24	17	12	21	16.8	5.9	2153.8
ARTHROPODA - Insecta								
Diptera larvae a	0	0	0	1	0	.2	.4	25.6
ARTHROPODA - Crustacea								
Harpacticoida, unid.	0	0	4	0	7	2.2	3.2	282.1

NO. OF INDIVIDUALS/SQ M = 2794.8
NO. OF SPECIES = 8

APPENDIX 1o

ABUNDANCE DATA FOR LOWE RIVER LOWER INTERTIDAL AREA (STATION 19);
28 APRIL 1979. .0078 M^2 CORE FROM -0.6 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Capitella capitata	1	0	0	0	1	.4	.5	51.3
Glycinde picta	1	1	0	0	0	.4	.5	51.3
Haploscoloplos panamensis	1	3	0	0	2	1.2	1.3	153.8
Pista cristata	3	3	0	0	0	1.2	1.6	153.8
Polydora quadrilobata	20	4	2	0	2	5.6	8.2	717.9
MOLLUSCA - Gastropoda								
Cingula katherinae	0	0	0	0	1	.2	.4	25.6
MOLLUSCA - Pelecypoda								
Axinopsida serricata	0	0	0	0	2	.4	.9	51.3
Macoma balthica	6	10	6	2	5	5.8	2.9	743.6
Mya arenaria	0	0	0	0	1	.2	.4	25.6
ARTHROPODA - Insecta								
Collembola, unid.	0	0	0	0	1	.2	.4	25.6
ARTHROPODA - Crustacea								
Anisogammarus pugettensis	1	0	0	0	0	.2	.4	25.6
Calanoida, unid.	3	1	0	1	0	1.0	1.2	128.2
Diastylus sp.	0	0	1	0	0	.2	.4	25.6
Harpacticoida, unid.	1	6	0	0	0	1.4	2.6	179.5

NO. OF INDIVIDUALS/SQ M = 2358.7
NO. OF SPECIES = 14

APPENDIX 1p

ABUNDANCE DATA FOR DAYVILLE FLATS UPPER INTERTIDAL AREA (STATION 22); 28 APRIL 1979. .0078 M^2 CORE FROM +1.2 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Aricidea neosuecica	0	1	2	0	0	.6	.9	76.9
Capitella capitata	0	0	2	0	1	.6	.9	76.9
Eteone ?longa	1	2	2	1	0	1.2	.8	153.8
Exogone ?gemmifera	1	0	0	0	0	.2	.4	25.6
Glycinde picta	3	4	2	4	7	4.0	1.9	512.8
Haploscoloplos panamensis	10	5	9	3	2	5.8	3.6	743.6
Laonome kroyeri	2	1	3	0	2	1.6	1.1	205.1
Nepthys sp.	1	0	0	0	0	.2	.4	25.6
Nereis ?procera	0	0	0	0	2	.4	.9	51.3
Owenia fusiformis	1	1	2	0	0	.8	.8	102.6
Pholoe minuta	2	1	1	2	1	1.4	.5	179.5
Polydora quadrilobata	52	4	41	32	12	28.2	20.0	3615.4
Prionospio steenstrupi	0	0	1	0	0	.2	.4	25.6
Tharyx ?multifilis	6	11	20	3	0	8.0	7.8	1025.6
MOLLUSCA - Gastropoda								
Cingula katherinae	0	0	1	0	0	.2	.4	25.6
ARTHROPODA - Insecta								
Diptera larvae a	5	0	0	3	2	2.0	2.1	256.4
ARTHROPODA - Crustacea								
Gammaridea, unid.	0	0	0	1	0	.2	.4	25.6
Harpacticoida, unid.	1	0	0	0	0	.2	.4	25.6
Pontogeneia sp.	0	0	0	1	0	.2	.4	25.6

NO. OF INDIVIDUALS/SQ M = 7179.1
NO. OF SPECIES = 26

APPENDIX 1q

ABUNDANCE DATA FOR DAYVILLE FLATS LOWER INTERTIDAL AREA (STATION 21); 28 APRIL 1979. .0078 M^2 CORE FROM -0.6 M ELEVATION

TAXA	1	2	3	4	5	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta								
Ampharete ?finmarchia	1	1	0	1	1	.8	.4	102.6
Aricidea neosuecica	2	2	0	6	1	2.2	2.3	282.1
Eteone ?longa	0	1	0	3	0	.8	1.3	102.6
Euchone analis	1	0	0	0	0	.2	.4	25.6
Exogone ?gemmifera	0	27	0	2	3	6.4	11.6	820.5
Glycinde picta	11	7	7	4	3	6.4	3.1	820.5
Haploscoloplos panamensis	4	6	5	2	1	3.6	2.1	461.5
Heteromastus sp.	0	1	1	1	0	.6	.5	76.9
Lumbrineris luti	1	0	0	1	0	.4	.5	51.3
Malacoceros sp.	0	0	0	0	1	.2	.4	25.6
Nepthys sp.	2	0	2	0	0	.8	1.1	102.6
Pholoe minuta	0	1	1	2	5	1.8	1.9	230.8
Phyllodoce groenlandica	0	0	0	0	1	.2	.4	25.6
Polydora ?pygidialis	1	0	0	0	0	.2	.4	25.6
Polydora quadrilobata	78	90	57	52	63	68.0	15.7	8717.9
Pygospio elegans	0	0	0	0	6	1.2	2.7	153.8
Syllidae, unid.	0	1	0	0	0	.2	.4	25.6
Tharyx ?multifilis	0	0	1	0	0	.2	.4	25.6
ARTHROPODA - Insecta								
Coleoptera, unid.	1	0	0	0	0	.2	.4	25.6
Diptera larvae a	0	0	0	2	0	.4	.9	51.3
ARTHROPODA - Crustacea								
Anisogammarus sp.	0	1	0	0	0	.2	.4	25.6
Harpacticoida, unid.	1	12	0	0	1	2.8	5.2	359.0

NO. OF INDIVIDUALS/SQ M = 12538.2
NO. OF SPECIES = 22

APPENDIX 2a

ABUNDANCE DATA FOR STATION A;

30 APRIL 1979. .0036 M^2 CORE FROM -2.3 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?*finmarchia*	2	1	0	1.0	1.0	277.8
Lumbrineris luti	4	4	3	3.7	0.6	1018.6
Prionospio streenstrupi	1	1	0	.7	.6	185.2
MOLLUSCA - Pelecypoda						
Axinopsida serricata	1	5	0	2.0	2.6	555.6
Macoma obliqua	0	1	0	.3	.6	92.6
ARTHROPODA - Crustacea						
Talitrus sp.	0	1	0	.3	.6	92.6

NO. OF INDIVIDUALS/SQ M = 2222.4
NO. OF SPECIES = 6

APPENDIX 2b

ABUNDANCE DATA FOR STATION A;
30 APRIL 1979. .0036 M^2 CORE FROM -9.6 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?*finmarchia*	0	0	1	.3	.6	92.6
Haploscoloplos panamensis	1	0	0	.3	.6	92.6
Lumbrineris luti	4	4	0	2.7	2.3	740.7
Spio cirrifera	0	1	0	.3	.6	92.6
MOLLUSCA - Pelecypoda						
Axinopsida serricata	1	0	0	.3	.6	92.6

NO. OF INDIVIDUALS/SQ M = 1111.1
NO. OF SPECIES = 5

APPENDIX 2c

ABUNDANCE DATA FOR STATION A;
30 APRIL 1979. .0044 M^2 CORE FROM -15.8 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	0	0	2	.7	1.2	185.2
Haploscolplos panamensis	0	0	1	.3	.6	92.6
Lumbrineris luti	2	3	4	3.0	1.0	833.4
Tharyx multifilis	1	0	0	.3	.6	92.6
MOLLUSCA - Pelecypoda						
Axinopsida serricata	2	1	0	1.0	1.0	277.8
ARTHROPODA - Crustacea						
Lysianassidae, unid.	0	1	0	.3	.6	92.6

NO. OF INDIVIDUALS/SQ M = 1574.2
NO. OF SPECIES = 5

APPENDIX 2d

ABUNDANCE DATA FOR STATION B;

30 APRIL 1979. .0036 M^2 CORE FROM -2.3 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	1	2	0	1.0	1.0	277.8
Haploscoloplos panamensis	0	0	1	.3	.6	92.6
Lumbrineris luti	5	3	4	4.0	1.0	1111.2
Pista brevibranchiata	1	0	0	.3	.6	92.6
Polydora quadrilobata	0	2	5	2.3	2.5	648.1
Spio cirrifera	0	0	2	.7	1.2	185.2
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	4	1	1.7	2.1	463.0
Macoma obliqua	0	0	1	.3	.6	92.6
ARTHROPODA - Crustacea						
Diastylis sp.	0	1	0	.3	.6	92.6
Eudorella sp.	0	2	0	.7	1.2	185.2

NO. OF INDIVIDUALS/SQ M = 3240.9
NO. OF SPECIES = 10

APPENDIX 2e

ABUNDANCE DATA FOR STATION B;

30 APRIL 1979. .0036 M^2 CORE FROM -9.6 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	0	1	0	.3	.6	92.6
Glycinde picta	0	0	1	.3	.6	92.6
Haploscoloplos panamensis	0	1	0	.3	.6	92.6
Lumbrineris luti	3	6	10	6.3	3.5	1759.4
Pista brevibranchiata	0	0	1	.3	.6	92.6
Tharyx multifilis	0	0	1	.3	.6	92.6
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	2	0	.7	1.2	185.2

NO. OF INDIVIDUALS/SQ M = 2507.6
NO. OF SPECIES = 7

APPENDIX 2f

ABUNDANCE DATA FOR STATION B;

30 APRIL 1979. .0036 M^2 CORE FROM -15.8 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Aricidea neosuecia	0	0	1	.3	.6	92.6
Haploscoloplos panamensis	0	1	1	.7	.6	185.2
Lumbrineris luti	3	3	6	4.0	1.7	1111.2
MOLLUSCA - Pelecypoda						
Axinopsida serricata	6	2	1	3.0	2.6	833.3
Macoma obliqua	1	1	0	.7	.6	185.2
Yoldia montereyensis	1	0	0	.3	.6	92.6
ARTHROPODA - Crustacea						
Eudorella sp.	0	1	1	.7	.6	185.2

NO. OF INDIVIDUALS/SQ M = 2685.3
NO. OF SPECIES = 7

APPENDIX 2g

ABUNDANCE DATA FOR STATION C;
24 APRIL 1979. .0044 M^2 CORE FROM -2.3 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Barantolla americana	0	1	0	.3	.6	75.8
Haploscoloplos panamensis	0	0	1	.3	.6	75.8
Lumbrineris luti	10	10	7	9.0	1.7	2045.7
Owenia fusiformis	0	0	1	.3	.6	75.8
Pholoe minuta	1	1	1	1.0	.0	227.3
Pista brevibranchiata	0	3	4	2.3	2.1	530.3
Polydora pygidialis	0	0	2	.7	1.2	151.5
Polydora quadrilobata	3	1	13	6.0	7.0	1363.6
Syllis sp.	1	0	0	.3	.6	75.8
MOLLUSCA - Pelecypoda						
Axinopsida serricata	1	1	3	1.7	1.2	378.8
Macoma obliqua	0	0	1	.3	.6	75.8
Pandora filosa	1	0	0	.3	.6	75.8
ARTHROPODA - Crustacea						
Diastylis sp.	0	0	1	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 5227.8
NO. OF SPECIES = 12

APPENDIX 2h

ABUNDANCE DATA FOR STATION C;

24 APRIL 1979. .0044 M^2 CORE FROM -9.6 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Chaetozone setosa	1	1	0	.7	.6	151.5
Glycinde picta	1	0	1	.7	.6	151.5
Haploscoloplos panamensis	2	1	2	1.7	.6	378.8
Laonome kroyeri	0	0	1	.3	.6	75.8
Lumbrineris luti	0	4	3	2.3	2.1	530.3
Nepthys sp.	0	0	1	.3	.6	75.8
Pista brevibranchiata	2	0	0	.7	1.2	151.5
Polydora quadrilobata	2	1	2	1.7	.6	378.8
Prionospio streenstrupi	0	0	3	1.0	1.7	227.3
Syllis sp.	4	0	8	4.0	4.0	909.1
Tharyx multifilis	1	0	0	.3	.6	75.8
MOLLUSCA - Gastropoda						
?*Acteocina* sp.	1	1	0	.7	.6	151.5
Cingula katherinae	0	1	0	.3	.6	75.8
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	0	6	2.0	3.5	454.5
Macoma obliqua	0	1	2	1.0	1.0	227.3
Mytilus edulis	0	5	0	1.7	2.9	378.8
Nuculana fossa	1	0	0	.3	.6	75.8
ARTHROPODA - Crustacea						
Eudorella sp.	1	0	0	.3	.6	75.8
Hyperiidae, unid.	0	0	1	.3	.6	75.8
Leptocuma sp.	0	1	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 4697.3
NO. OF SPECIES = 20

APPENDIX 2i

ABUNDANCE DATA FOR STATION C;

30 APRIL 1979. .0036 M^2 CORE FROM -15.8 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	1	0	0	.3	.6	92.6
Euchone analis	0	0	1	.3	.6	92.6
Haploscolopos panamensis	2	1	0	1.0	1.0	277.8
Lumbrineris luti	1	1	2	1.3	.6	370.4
Nepthys sp.	0	0	1	.3	.6	92.6
Pholoe minuta	0	1	0	.3	.6	92.6
Polydora quadrilobata	0	2	0	.7	1.2	185.2
Spio cirrifera	0	1	0	.3	.6	92.6
Terebellides ?stroemii	0	1	0	.3	.6	92.6
MOLLUSCA - Pelecypoda						
Axinopsida serricata	2	2	1	1.7	.6	463.0
Macoma obliqua	0	1	0	.3	.6	92.6
Pandora filosa	1	0	1	.7	.6	185.2
ARTHROPODA - Crustacea						
Eudorella sp.	1	1	0	.7	.6	185.2
Leptocuma sp.	1	0	0	.3	.6	92.6

NO. OF INDIVIDUALS/SQ M = 2407.6
NO. OF SPECIES = 14

APPENDIX 2j

ABUNDANCE DATA FOR STATION D;

24 APRIL 1979. .0044 M^2 CORE FROM -2.3 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	1	2	0	1.0	1.0	227.3
Barantolla americana	0	0	1	.3	.6	75.8
Haploscoloplos panamensis	3	2	1	2.0	1.0	454.6
Lumbrineris luti	5	11	14	10.3	5.0	2348.5
Phyllodoce groenlandica	1	0	0	.3	.6	75.8
Pista brevibranchiata	2	0	0	.7	1.2	151.5
Prionospio steenstrupi	1	0	0	.3	.6	75.8
Terebellides ?stroemii	0	0	1	.3	.6	75.8
MOLLUSCA - Pelecypoda						
Axinopsida serricata	1	4	0	1.7	2.1	378.8
Mya arenaria	0	1	0	.3	.6	75.8
Pandora filosa	3	0	0	1.0	1.7	227.3
ARTHROPODA - Crustacea						
Diastylis sp.	0	1	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 4243.1
NO. OF SPECIES = 12

APPENDIX 2k

ABUNDANCE DATA FOR STATION D;

24 APRIL 1979. .0044 M^2 CORE FROM -9.6 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	0	0	1	.3	.6	75.8
Lumbrineris luti	0	3	6	3.0	3.0	681.9
Nepthys sp.	1	1	0	.7	.6	151.5
Terebellides ?stroemii	0	1	3	1.3	1.5	303.0
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	1	3	1.3	1.5	303.0
Mya arenaria	0	1	1	.7	.6	151.5
Nuculana fossa	0	1	1	.7	.7	151.5
Oenopota excurvata	0	1	1	.7	.6	151.5
Oenopota sp.	0	1	0	.3	.6	75.8
Orobitella rugifera	0	1	0	.3	.6	92.6
Pandora filosa	0	1	3	1.3	1.5	303.0
ARTHROPODA - Insecta						
Diptera larvae a	0	0	1	.3	.6	75.8
ARTHROPODA - Crustacea						
Eudorella sp.	0	2	1	1.0	1.0	227.3

NO. OF INDIVIDUALS/SQ M = 2651.6
NO. OF SPECIES = 11

APPENDIX 21

ABUNDANCE DATA FOR STATION D;

30 APRIL 1979. .0036 M^2 CORE FROM -15.8 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Barantolla americana	3	0	0	1.0	1.7	277.8
Haploscoloplos panamensis	1	0	0	.3	.6	92.6
Lumbrineris luti	4	5	9	6.0	2.6	1666.7
Terebellides ?stroemii	0	0	1	.3	.6	92.6
MOLLUSCA - Gastropoda						
Mitrella gausapata	0	0	1	.3	.6	92.6
Oenopota excurvata	1	0	0	.3	.6	92.6
Oenopota sp.	0	1	0	.3	.6	92.6
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	0	1	.3	.6	92.6
Macoma obliqua	2	0	1	1.0	1.0	277.8
Nuculana fossa	0	1	0	.3	.6	92.6
Pandora filosa	0	1	0	.3	.6	92.6
ARTHROPODA - Crustacea						
Eudorella sp.	2	2	1	1.7	.6	463.0
Photis sp.	0	1	0	.3	.6	92.6

NO. OF INDIVIDUALS/SQ M = 3518.7
NO. OF SPECIES = 13

APPENDIX 2m

ABUNDANCE DATA FOR LOWE RIVER SUBTIDAL AREA (STATION E);
25 APRIL 1979. .0044 M^2 CORE FROM -0.3 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	1	1	1	1.0	.0	227.3
Eteone ?longa	0	0	1	.3	.6	75.8
Glycinde picta	1	0	0	.3	.6	75.8
Haploscoloplos panamensis	12	6	1	6.3	5.5	1439.4
Lumbrineris luti	3	2	0	1.7	1.5	378.8
Nereis ?procera	0	1	0	.3	.6	75.8
Pista cristata	1	0	2	1.0	1.0	227.3
Polydora quadrilobata	5	5	5	5.0	.0	1136.4
MOLLUSCA - Pelecypoda						
Axinopsida serricata	2	3	2	2.3	.6	530.3
Macoma balthica	1	0	0	.3	.6	75.8
Pandora filosa	1	0	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 4318.5
NO. OF SPECIES = 11

APPENDIX 2n

ABUNDANCE DATA FOR LOWE RIVER SUBTIDAL AREA (STATION E);
25 APRIL 1979. .0044 M^2 CORE FROM -8.8 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Chaetozone setosa	1	2	0	1.0	1.0	227.3
Glycinde picta	1	1	1	1.0	.0	227.3
Haploscoloplos panamensis	0	0	3	1.0	1.7	227.3
Pista cristata	0	1	1	.7	.6	151.5
Polydora quadrilobata	0	4	3	2.3	2.1	530.3
Prionospio steenstrupi	0	0	4	1.3	2.3	303.0
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	0	6	2.0	3.5	454.5
Macoma obliqua	1	2	0	1.0	1.0	227.3
ARTHROPODA - Crustacea						
Oedicerotidae, unid.	4	0	2	2.0	2.0	454.5

NO. OF INDIVIDUALS/SQ M = 2803.0
NO. OF SPECIES = 9

APPENDIX 2o

ABUNDANCE DATA FOR LOWE RIVER SUBTIDAL AREA (STATION E);
30 APRIL 1979. .0036 M^2 CORE FROM -14.9 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	0	1	0	.3	.6	92.6
Glycinde picta	0	1	0	.3	.6	92.6
Haploscoloplos panamensis	0	1	0	.3	.6	92.6
Polydora quadrilobata	0	0	1	.3	.6	92.6
Prionospio steenstrupi	0	0	1	.3	.6	92.6
MOLLUSCA - Gastropoda						
Oenopota sp.	0	1	1	.7	.6	185.2
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	0	5	1.7	2.9	463.0
Macoma obliqua	0	1	0	.3	.6	92.6
ARTHROPODA - Crustacea						
Anisogammarus sp.	0	0	1	.3	.6	92.6
Oedicerotidae, unid.	0	0	1	.3	.6	92.6

NO. OF INDIVIDUALS/SQ M = 1389.0
NO. OF SPECIES = 10

APPENDIX 2p

ABUNDANCE DATA FOR DAYVILLE FLATS SUBTIDAL AREA (STATION F);
25 APRIL 1979. .0044 M^2 CORE FROM -0.9 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Ampharete ?finmarchia	0	0	1	.3	.6	75.8
Glycinde picta	0	0	1	.3	.6	75.8
Haploscoloplos panamensis	0	0	1	.3	.6	75.8
Lumbrineris luti	3	3	4	3.3	.6	757.6
Nepthys sp.	0	2	0	.7	1.2	151.5
Pista cristata	0	2	2	1.3	1.2	303.0
Polydora quadrilobata	2	0	0	.7	1.2	151.5
MOLLUSCA - Gastropoda						
Aglaja diomedea	1	0	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 1666.8
NO. OF SPECIES = 8

APPENDIX 2q

ABUNDANCE DATA FOR DAYVILLE FLATS SUBTIDAL AREA (STATION F);
25 APRIL 1979. .0044 M^2 CORE FROM -1.9 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Lumbrineris luti	7	2	0	3.0	3.6	681.8
Pista cristata	10	2	2	4.7	4.6	1060.6
Tharyx ?multifilis	0	1	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 1818.2
NO. OF SPECIES = 3

APPENDIX 2r

ABUNDANCE DATA FOR DAYVILLE FLATS SUBTIDAL AREA (STATION F);
25 APRIL 1979. .0044 M^2 CORE FROM -15.2 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Artacama conferi	0	1	0	.3	.6	75.8
Heteromastus sp.	1	0	0	.3	.6	75.8
Lumbrineris luti	4	4	3	3.7	.6	833.3
Pista cristata	1	2	0	1.0	1.0	227.3
ARTHROPODA - Crustacea						
Gammaridea, unid.	0	1	0	.3	.6	75.8
Oedicerotidae, unid.	0	1	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 1363.8
NO. OF SPECIES = 6

APPENDIX 2s

ABUNDANCE DATA FOR ALLISON POINT SUBTIDAL AREA (STATION G);
29 APRIL 1979. .0044 M^2 CORE FROM -3.0 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Euchone analis	0	0	1	.3	.6	75.8
Haploscoloplos panamensis	2	0	2	1.3	1.2	303.0
Lumbrineris luti	6	5	3	4.7	1.5	1060.6
Owenia fusiformis	0	0	2	.7	1.2	151.5
Pholoe minuta	1	0	0	.3	.6	75.8
Polydora quadrilobata	0	0	10	3.3	5.8	757.6
Prionospio steenstrupi	0	1	0	.3	.6	75.8
Pygospio elegans	0	0	1	.3	.6	75.8
Terebellides ?stroemi	0	1	0	.3	.6	75.8
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	3	0	1.0	1.7	227.3
Pandora filosa	0	1	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 2954.8
NO. OF SPECIES = 11

APPENDIX 2t

ABUNDANCE DATA FOR ALLISON POINT SUBTIDAL AREA (STATION G);
29 APRIL 1979. .0044 M^2 CORE FROM -9.1 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Eteone ?longa	1	0	0	.3	.6	75.8
Glycinde picta	1	1	0	.7	.6	151.5
Haploscoloplos panamensis	2	0	0	.7	1.2	151.5
Heteromastus sp.	0	0	1	.3	.6	75.8
Lumbrineris luti	7	6	4	5.7	1.5	1287.9
Nepthys punctata	0	0	1	.3	.6	75.8
Polydora quadrilobata	2	0	0	.7	1.2	151.5
Sternaspis scutata	0	0	1	.3	.6	75.8
Tharyx ?multifilis	0	2	0	.7	1.2	151.5
MOLLUSCA - Gastropoda						
Acteocina sp.	1	0	0	.3	.6	75.8
Oenopota sp.	1	0	0	.3	.6	75.8
MOLLUSCA - Pelecypoda						
Axinopsida serricata	0	0	1	.3	.6	75.8
Mya arenaria	0	0	1	.3	.6	75.8
ECHINODERMATA - Ophiuroidea						
Ophiuroidea, unid.	0	0	1	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 2576.1
NO. OF SPECIES = 14

APPENDIX 2u

ABUNDANCE DATA FOR ALLISON POINT SUBTIDAL AREA (STATION G);
29 APRIL 1979. .0044 M^2 CORE FROM -15.2 M DEPTH

TAXA	1	2	3	MEAN	ST.DEV	DENSITY
ANNELIDA - Polychaeta						
Amphisamytha sp.	1	0	0	.3	.6	75.8
Haploscoloplos panamensis	1	1	0	.7	.6	151.5
Lumbrineris luti	2	1	2	1.7	.6	378.8
Malacoceros sp.	0	0	1	.3	.6	75.8
Polydora quadrilobata	1	4	0	1.7	2.1	378.8
Sternaspis scutata	0	2	1	1.0	1.0	227.3
Tharyx ?multifilis	0	1	0	.3	.6	75.8
MOLLUSCA - Pelecypoda						
Axinopsida serricata	2	0	2	1.3	1.2	303.0
Nuculana fossa	2	0	0	.7	1.2	151.5
ARTHROPODA - Crustacea						
Calanoida, unid.	0	1	0	.3	.6	75.8

NO. OF INDIVIDUALS/SQ M = 1894.1
NO. OF SPECIES = 10

APPENDIX 3

DISTRIBUTION AND ABUNDANCE ESTIMATES FOR PLANTS OBSERVED DURING INTERTIDAL FIELD STUDIES IN APRIL 1979 ON THE SOFT SUBSTRATE PORTIONS OF ISLAND FLATS AND AROUND THE ASSOCIATED ISLETS AND WHALEBACKS

		Location (Code)													
		North of Ammunition Island complex					Adjacent to or South of Ammunition Island complex								
Taxon		W. side - upper (11)	E. side - upper (12)	W. side - mid (10)	E. side - lower mid (15)	Central - lower mid (8)	E. of Ammo Is. low (16)	Outer Cove mid (1)	W. side - lower mid (6)	W. side - lower mid (7)	E. side - low (17)	W. side - low (4)	W. side - low (2)	W. side - lower low (3)	E. side - lower low (18)
ALGAE - Bacillariophyta															
Diatom film	(%)	15													
ALGAE - Chlorophyta - green seaweeds															
Enteromorpha sp	(%)		S*											S	
Spongomorpha sp	(%)				T										
Ulvales, unid. spp.	(%)	5	S	10	T	5	1		S	S		T	S	0.6	4.7
ALGAE - Rhodophyta - red seaweeds															
Halosaccion ?ramentaceum	(%)					S									S
Rhodophyta, unid. (filamentous)	(%)											S	S	S	T
Rhodophyta, unid. (broad fronds)	(%)													S	
ALGAE - Phaeophyta - brown seaweeds															
Desmarestia spp.**														S	T
Fucus distichus	(%)	D	P	2	12		5	C				D	D	D	P
Laminaria saccharina	(%)											T	5	3.3	6.8
L. saccharina	(no./m^2)											-	-	2	12.4
Melanosiphon intestinalis	(%)		S	S	T	S			S	S		C			
Pylaiella ?littoralis	(%)	15	S	10	3	10			Dom		S	T	10	1.2	0.9
Scytosiphon lomentaria	(%)				S	S			S			S	S	0.3	T
ANGIOSPERMAE															
Zostera marina												S	S	S	

* S = sparse or uncommon, T = Trace, D = drift, P = present, C = common, Dom = dominant

** Includes D. aculeata and E. viridis

APPENDIX 4

DISTRIBUTION AND ABUNDANCE ESTIMATES FOR ANIMALS OBSERVED DURING INTERTIDAL FIELD STUDIES IN APRIL 1979 ON THE SOFT SUBSTRATE PORTIONS OF ISLAND FLATS AND AROUND ASSOCIATED ISLETS AND WHALEBACKS

		Location (Code)																	
		North of Ammunition Island complex									Adjacent to or South of Ammunition Island complex								
Taxon		W. side - upper (11)	E. side - upper (12)	W. side - mid (10)	E. side - mid (13)	W. side - lower mid (9a)	W. side - lower mid (9)	E. side - lower mid (14)	E. side - lower mid (15)	Central - lower mid (8)	E. of Ammo Is. low (16)	Outer Cove - mid (1)	W. side - lower mid (6)	W. side - lower mid (7)	E. side - low (17)	W. side low (4)	W. side - low (2)	W. side - lower low (3)	E. side - lower low (18)
CNIDARIA - sea anemones and hydroids																			
Anthopleura artemisia																S			S
NEMERTINA - worm																			
Paranemertes peregrina								S*							3.5	0.4		0.8	1.2
ECHIURIDA - worm																			
Echiurus echiurus alaskanus													S			4.4	S	6.4	2.8
PRIAPULA - worm																			
Priapulus caudatus																P			
ANNELIDA - Polychaeta - worm																			
Abarenicola pacifica												C							
Aphroditoidea, unid. sp.																			P
Capitellidae, unid. spp								A		Dom									
Nephtys caeca																P			P
Nereidae, unid. sp												D							
Polydora quadrilobata													S			S	A	C	
Polychaeta, unid. tubicolous sp		S																	
MOLLUSCA - Pelecypoda - clams																			
Clinocardium nuttallii																P	S		
Macoma balthica	(no./m²)	800	Dom	2000	A	A	A	A		Dom			P	C	P	P	P	P	
Mya arenaria	(no./m²)							S		S			S	C		S		S	1.2
Mytilus edulis	(%)	S	S	S					9	S	36		S		S	S			T
M. edulis	(no./m²)										1923						1		
Protothaca staminea																		S	
MOLLUSCA - Gastropoda - snails																			
Acmaea ?persona									S										
Aglaja ocelligera																		S	
Littorina sitkana			P						S						S				
ARTHROPODA - Crustacea - Crabs, barnacles, beach hoppers																			
Anisogammarus pugettensis		P	P																
Balanus cariosus & B. crenatus	(%)		S							S	P				S	S	S		
Eudorella sp										A			A						
Gnorimosphaeroma oregonensis									P						P				

APPENDIX 4 (Cont.)

Taxon	Location (Code) North of Ammunition Island complex									Adjacent to or South of Ammunition Island complex								
	W. side - upper (11)	E. side - upper (12)	W. side - mid (10)	E. side - mid (13)	W. side - lower mid (9a)	W. side lower mid (9)	E. side - lower mid (14)	E. side - lower mid (15)	Central - lower mid (8)	E. of Ammo Is. low (16)	Outer Cove - mid (1)	W. side - lower mid (6)	W. side - lower mid (7)	E. side - low (17)	W. side - low (4)	W. side - low (2)	W. side - lower low (3)	E. side - lower low (18)
ARTHROPODA cont.																		
Leptocuma sp									A			A						
Pagurus ochotensis																		P
Telmessus cheiragonus																		P
ARTHROPODA - Insecta																		
Chironomidae, unid.												P						
CHORDATA - Pisces - fish																		
Leptocottus armatus										P								
Microgadus proximus																		P
Pholis laeta																		P
Platichthys stellatus										P		P						

* P = present, T = trace, D = drift, S = sparse, scattered or uncommon, C = common, A = abundant, Dom = dominant

APPENDIX 5

DISTRIBUTION AND ABUNDANCE ESTIMATES FOR PLANTS AND ANIMALS OBSERVED DURING INTERTIDAL FIELD STUDIES IN APRIL 1979 ON THE SOFT SUBSTRATE PORTIONS OF LOWE RIVER AND DAYVILLE FLATS

		Location (Code)				
		Lowe River		Dayville Flats		
Taxon		Mid level (20)	Lower level (19)	Upper level (23)	Mid level (22)	Lower level (21)
PLANTS						
ALGAE - Bacillariophyta						
Diatom film					P	P
ALGAE - Chlorophyta - Green seaweeds						
Enteromorpha sp	(%)	S		S	P	1
Ulvales, unid. spp.	(%)	S		S	3	1
ALGAE - Rhodophyta - Red seaweeds						
?Pterosiphonia bipinnata					P	S
ALGAE - Phaeophyta - Brown seaweeds						
Fucus distichus	(%)				D	
Laminaria saccharina, juveniles					S	S
Melanosiphon intestinalis				S	P	S
Pylaiella littoralis		1	S	S	2	1
ANGIOSPERMAE						
Zostera marina					S	
INVERTEBRATES						
CNIDARIA - Hydroida						
Syncoryne mirabilis	(%)				C	2
NEMERTINA - Worm						
Paranemertes peregrina			S		P	
ANNELIDA - Polychaeta - worm						
?Capitellidae, unid.		S	S			
Polydora quadrilobata			S-A	S	Dom,A	Dom,A
MOLLUSCA - Pelecypoda - Clams						
Macoma balthica		Dom,C	U	P		
Mya arenaria	(No./m^2)	5-7	S	1		
Mytilus edulis				S	S	S
MOLLUSCA - Gastropoda - Sea slug						
Aglaja diomedea			S-C			
ARTHROPODA - Crustacea						
Cumacea, unid. spp.		C	C		A	
Gammaridea, unid. spp.		S				
CHORDATA - Pisces - Fishes						
Leptocottus armatus						P
Platichthys stellatus		C	S-C			S-C

APPENDIX 6

DESCRIPTION OF PHYSICAL CHARACTERISTICS OF INTERTIDAL LOCATIONS SURVEYED IN APRIL 1979 IN THE VICINITY OF ISLAND FLATS

Location	Map Designation	Approximate Elevation (m)	General Appearance	Nature of Sediment and Debris	Type and Amount of Biogenic Activity
W. side of flats, 200 m S. of Richardson Hwy., approximately 500 m E. of City Limits Creek	11	+2.7 High Tide	Flat with scattered shallow puddles	Unconsolidated layer of sticky viscous clay over a root mat; drift Fucus	Macoma tracks and dimples common
W. side of flats, 700 m S. of Hwy.	10	+2.1 High Tide	As above	Consolidated clay with some shell debris; very compact below 6 cm	As above, plus some shell middens
E. side of flats, 500 m S. of Hwy., 400 m W. of Loop Road turn off	12	+2.1 High Tide	Flat with scattered large gravel, with little surface water	Consolidated clay with some gravel and shell debris	As above
E. side of flats, 400 m N. of Ammunition Island	13	+1.2 Mid Tide	As above	Consolidated sandy silt with some large gravel and shell debris	As above
E. side of flats, 50 m N. of Ammunition Island	14	+2.1 High Tide	Flat, clean surface, without surface waters	Consolidated sticky stiff clay	As above, plus some feeding excavations
W. side of flats, 25-50 m N. of middle whaleback	9+9a	+2.1 High Tide	Uneven, slightly sloping surface, with considerable surface water	Soft unconsolidated silt	Macoma tracks common
Center of flats, 50 m W. of western channel into flats, N. of middle whaleback	8	+2.1 High Tide	Smooth, slightly sloping surface, swept clean by tidal currents, without surface water	Consolidated clayey sand to sticky clay with gravel	Macoma tracks
E. side of flats, 200 m NE of Ammunition Island, E. of Siwash Creek channel	15	+1.2 Mid Tide	Undulating surface with small hummocks of mussels and Fucus; without surface water	Unconsolidated gravelly sand some clay	--
E. side of flats, 50-100 m E. of Ammunition Island	16	+0.3 Mid Tide	Undulating surface with large hummocks of mussels and silty gravel pockets	Sandy gravel with pockets of unconsolidated, soft clay	Macoma tracks
W. side of flats, S. of base of middle whaleback	1	+1.2 Mid Tide	Soft mud flat at base of sloping gravel beach, with considerable surface water	Soft unconsolidated layer of silt	Macoma tracks, and fecal costs
Center of flats, in channel between middle whaleback	6&7	+1.2 Mid Tide	Very flat, without surface water	Consolidated silty sand with scattered cobbles and boulders, and some shell debris	Macoma tracks, feeding excavations of fish, birds, and sea otters, and shell middens; flounder prints
W. side of flat, in cove S. of middle whaleback	2	-0.3 Low Tide	Flat mudflat with considerable surface water	Soft silty sand, some algal debris	Abundant Polydora worm tubes and shell middens
Center of flat, 35 m S. of barrier rock outcrops (Z)	4	-0.6 Low Tide	Flat with moderate surface water	Consolidated silty sand with some algal debris	Some shell middens, bird and fish feeding excavations, Echiurus fecal pellets and burrows

APPENDIX 6 (Cont.)

DESCRIPTION OF PHYSICAL CHARACTERISTICS OF INTERTIDAL LOCATIONS SURVEYED IN APRIL 1979 IN THE VICINITY OF ISLAND FLATS

Location	Map Designation	Approximate Elevation (m)	General Appearance	Nature of Sediment and Debris	Type and Amount of Biogenic Activity
E. side of flat, 40 m S. of Ammunition Island	17	MLLW Low Tide	Flat with scattered cobbles and little surface water	Stiff, sticky plastic clay with scattered cobbles	*Macoma* tracks
E. side of flat, 100 m S. of Ammunition Island	18	-0.9 Lower Tide	Flat with shallow puddles and considerable surface water; near lower edge of tidal shelf	Consolidated silty sand with scattered patches of gravel; algal and marsh grass debris	*Macoma* tracks, *Echiurus* burrows and fecal pellets, feeding excavation from ducks and fish; shell middens
Center of flat, 75 m S. of barrier rock outcrops	3	-1.0 Lower Tide	As above	Sticky consolidated sandy clay	As above
Lowe River Flats, 400 m S. of river mouth, 200 m E. of shelf edge	20	+0.3 Mid Tide	Sand flat with scattered puddles and numerous feeding excavations; several small drainage channels; patches of consolidated clay common; little surface water outside puddles	Layer of soft fine silty sand 3 cm thick over coarse sand; some shell debris	*Macoma* tracks, bird and fish feeding excavations, flounder prints, few shell middens; *Macoma* dimples on clay; some *Mya* burrows
As above, except at shelf edge	19	-0.6 Low Tide	Sand flat with small shallow drainage channels, some small scattered puddles, otherwise little surface water	Sand with silty pockets; the latter get soupy in spots	Some *Macoma* tracks, sparse feeding excavations, common flounder prints
Dayville Flats, about 750 m from road, at shelf edge	21	-0.6 Mid Tide	Uneven surface with numerous small puddles and much standing water, and a turf of dense worm tubes about 1 cm high	Consolidated sandy silt	Flounder prints common in spots, some shell middens; *Polydora* worm tubes very abundant
Dayville Flats, about 200 m from road, about 100 m from shelf edge	22	+1.2 Mid Level	As above	Sticky sandy clay with some shell and algal debris	Sparse shell middens, very abundant *Polydora* worm tubes
Dayville Flats, about 40 m off road	23	+2.4 High Level	Slightly sloping surface with much surface water	Stiff clay, rather clean with some shell	Sparse *Macoma* tracks and *Mya* burrows

APPENDIX 7

DESCRIPTION OF PHYSICAL CHARACTERISTICS OF SUBTIDAL LOCATIONS SURVEYED IN APRIL 1979 AT THE HEAD OF PORT VALDEZ

Location	Map Designation	Depth[1] (m)	General Appearance	Nature of Sediment and Debris	Type and Amount of Biogenic Activity
Off gap between outer whaleback and barrier outcrops	A	3.7	Mudflat with very uneven surface, pockmarks and mud cones common; light diatom film	Sticky soft clay	Fecal mounds and excavations of *Nephtys punctata* common, some smooth-walled burrows and worm tubes
		9.8	Steep slope of mud, pockmarks, and mud cones common. Heavy diatom film	Soft sticky clay with some plant debris (*Fucus* and marsh grass); some small cobbles	Fecal mounds and excavations of *N. puncata* common, some shell middens and worm tubes
		15.9	As above	As above	Fecal mounds and excavations of *N. punctata* common
Off channel E. of barrier outcrops	B	2.4	Sandy flat at edge of slope	Fine silty sand with some shell and plant (*Fucus*) debris	Shell middens, crab tracks common; *Echiurus* burrows and fecal pellets common
		9.8	Steep slope with heavy diatom film, evidence of slumping, with uncommon pockmarks and mud cones	Soft silty clay with marsh grass debris	Fecal mounds and excavations of *N. punctata* sparse; some smooth walled burrows
		15.9	As above, with considerable evidence of a channel and slumping	As above	As above
Off E. end of Ammunition Island	C	3.0	Gently sloping flat at edge of shelf, numerous small and large mud cones and pockmarks, with diatom film	Fine soft silty sand with plant debris (*Fucus* and marsh grass) common	Numerous fecal mounds and excavations of *N. punctata*, burrows and fecal pellets of *Echiurus*, some shell middens
		10.7	Steep slope with numerous large mud cones and pockmarks, heavy diatom film	Fine silt	Numerous fecal mounds and excavations of *N. punctata*
		16.8	As above	Fine silt	As above
Off gravel spit at E. end off Island Flats	D	2.1-3.7	Gently sloping flat at edge of shelf, with heavy diatom film and dense turf of worm tubes; numerous large mud cones and pockmarks	Fine soft gray sticky clay with plant debris (algae and marsh grass) common	Numerous fecal mounds and excavations of *N. punctata*, fecal pellets and burrows of *Echiurus*; dense patches of *Polydora* worm tubes, some small middens
		9.8	Steep slope with considerable evidence of slumping, heavy diatom film, numerous mud cones and pockmarks	As above	Numerous fecal mounds and excavations of *N. punctata*
		15.8	As above	As above	As Above

[1] Approximate depth, corrected for tidal variation.

APPENDIX 7 (Cont.)

DESCRIPTION OF PHYSICAL CHARACTERISTICS OF SUBTIDAL LOCATIONS SURVEYED IN APRIL 1979 AT THE HEAD OF PORT VALDEZ

Location	Map Designation	Depth* (m)	General Appearance	Nature of Sediment and Debris	Type and Amount of Biogenic Activity
Off Lowe River Flats, near main channel	E	0.3	Clean sand flat with small ripplemarks, rather fresh looking to edge of shelf	Fine silty sand, some areas without silt, some gravel and cobble	Some bird and fish feeding excavations and shell middens, and flounder prints
		2.7	Moderate slope	As above, plus plant debris of and marsh grass	-
		8.8	Moderate to steep slope with evidence of slumping, apparent channels from turbity currents; moderate diatom film in spots. Some mud cones and pockmarks	Loose sand, plant debris moderate (algae, marsh grass and tree branches), some shell debris	Some fecal mounds and excavations of N. punctata
		14.9	As above	As above	As above
Off Dayville Flats, toward S. side of Port Valdez	F	0.9	Flat with a turf of worm tubes and small mud cones; edge of slope indistinct	Sticky well-consolidated clay with plant debris (Fucus and marsh grass)	Abundant small fecal mounds; Polydora worm tubes very abundant; shell middens and flounder prints common
		9.1	Gentle slope with abundant mud cones	As above	Fecal mounds and excavations abundant, shell middens common
		15.2	Steep slope with heavy diatom cover and some mud cones	Unconsolidated slippery clay with marsh grass debris	Some shell middens and fecal mounds and excavations of N. punctata
First point E. of Allison Creek and Alyeska terminal	G	3.0	Gently sloping flat at edge of slope with light diatom film and excavations 0.3 to 0.6 mm diameter along edge of slope	Fine silty sand with some shell	Excavations by feeding sea otters common along edge of slope, some clam siphon holes
		9.1	Moderate slope with light diatom film and mud cones common	Soft sticky clay with scattered cobbles	Fecal mounds and excavations of N. punctata
		15.2	As above, except heavy diatom film	As above	As above

* Approximate depth, corrected for tidal variations

APPENDIX 8

DISTRIBUTION AND ABUNDANCE ESTIMATES FOR PLANTS AND ANIMALS OBSERVED DURING SUBTIDAL FIELD STUDIES IN APRIL 1979 ON SOFT SUBSTRATE PORTIONS OF THE BORDER OF PORT VALDEZ

Taxon	Edge of flats ∿2.3m							Slope ∿9.6m							Slope ∿15.8m						
	Transect D	Transect C	Transect E	Transect F	Transect B	Transect A	Transect G	Transect D	Transect C	Transect E	Transect F	Transect B	Transect A	Transect G	Transect D	Transect C	Transect E	Transect F	Transect B	Transect A	Transect G
PLANTS																					
ALGAE - Bacillariophyta																					
Diatom film	M[a]	H				L	L	H	H	M		H	H	M	H	L	M	H	H	H	H
ALGAE - Chlorophyta - green seaweeds																					
Ulvales, unid. spp.	S					S	S		C	D		D			D	D	D				
ALGAE - Phaeophyta - brown seaweeds																					
Desmarestia spp.[b]		S				S	S		S				S								
Fucus distichus	D	D	C	D	D			D		D			D		D		D			D	
Laminaria saccharina	S	C			C	S	C		C			C	C	C	D					C	
Pylaiella ?littoralis		S	C	S	S					S			S								
Scytosiphon lomentaria			S																		
INVERTEBRATES																					
PORIFERA - Sponges																					
Yellow sponge, unid.														S							
CNIDARIA - Sea anemones and hydroids																					
Metridium senile		S			S	C	C		S			S		C		S				S	C
Ptilosarcus gurneyi																					S
Stomphia ?didemon												S		C							C
Syncoryne mirabilis				C																	
ECHIURIDA - worm																					
Echiurus echiurus alaskanus	A	C			C		C														
ANNELIDA - Polychaeta - worm																					
Nephtys punctata	A	S		A		C		C	C	S	A	S	C	C	C	C	S	S	S	C	C
Phyllodoce ?madeirensis			S							S											
Polydora quadrilobata	A			A	S	S				C			S								
Sabellidae, unid.																					S
MOLLUSCA - Pelecypoda - clams																					
Clinocardium nuttallii							P														
Macoma calcarea	P																				
Mya truncata							C														
Mytilus edulis							S														
Saxidomus giganteus							P														

Taxon	Edge of flats ~2.3m							Locations Slope ~9.6m							Slope ~15.8						
	Transect D	Transect C	Transect E	Transect F	Transect B	Transect A	Transect G	Transect D	Transect C	Transect E	Transect F	Transect B	Transect A	Transect G	Transect D	Transect C	Transect E	Transect F	Transect B	Transect A	Transect G
MOLLUSCA - Pelecypoda cont.																					
Serripes laperousii		P					P														
Zirphaea pilsbryi							C														
Clam, unid. siphon	P																				
MOLLUSCA - Gastropoda - snails																					
Aglaja ocelligera		S									S										
Coryphella sp		S			S	S					S			S			S		S		
Cylichna sp	S																				
Mitrella gausapati	C	A			C	C	C			C				P							
Nassarius mendicus	C	C			S		S			C	S		S	C							
Natica clausa	S	S		C			C							S				S			
Odostomia sp					C		C														
ARTHROPODA - Crustacea - crab, shrimp, etc.																					
Chionoecetes bairdii					C		S		S	S			C	S	S					C	S
?Diastylis sp	C	C		S	S																
Gammaridea, unid. spp[c]	C	C	C	C	C							S							S	C	
Mysidacea, unid.														S							
Pagurus ?capillatus																				S	
P. ochotensis	S	S					S						S								
Pandalidae, unid. shrimp									S											S	
Chionoeceles (juveniles)	C	A	A	A	C	C	S			A	S	S					S	C			
?Upogebia pugettensis						S															
ECTOPROCTA - moss animals																					
Microporina borealis														S							
ECHINODERMATA - Asterozoa - starfish																					
Evasterias troschelii						S															S
CHORDATA - Pisces - fish																					
Ammodytes hexapterus							P														
?Hemilepidotus sp														S							
Platichthys stellatus	S		C	C					S												
Pleuronectidae, unid.													S	S							
Cottidae, unid.									S												
CHORDATA - Pinnipedia - seals and sea lions																					
Phoca vitulina - Harbor seal	C	P	C	U	P	P															
Eumetopias jubatus - Steller sea lion			U																		

[a] M = moderate; H = heavy; L = light; P = present, D = drift, T = trace, S = sparse or uncommon, C = common, Dom = dominant

[b] Includes D. aculeata and D. viridis

[c] Includes Anisogammarus pugettensis and Monoculodes sp

THE MAMMALS OF PORT VALDEZ

Prepared for

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INTRODUCTION

This study is part of a general program designed to acquire baseline biological data for a proposed refinery to be built by Alaska Petrochemical Company (Aleptco). The site is located approximately 13 kilometers (km) east of Valdez. This report details the results of an investigation of the mammal fauna of the proposed site. Mammals also were investigated within the Valdez area and in the marine environment near the proposed dock facility. Data were acquired through literature review, interviews with local residents, visual field surveys on the refinery site in late winter (April) and summer (June), and observations of the Port Valdez marine environment in April and May. In addition, a small mammal trapping survey was conducted on the refinery site in June to fill a specific data gap identified during preliminary investigation.

This report is divided into three sections. The first section presents the results of the small mammal study. The second section consists of an annotated list of mammals combining information from all sources. The third section is a summary discussion of habitat utilization by mammals in the area and a designation of any important or critical habitats.

SMALL MAMMAL STUDY

Methods

A qualitative trapping survey within the proposed Alpetco refinery site boundaries was conducted on June 19 through June 22, 1979. Six 100-meter (m) transects were established. Each transect was located within a representative habitat type. The six transects are shown on Figure 1 and the habitats crossed by each are described below.

1. Riparian woodland -- A shrub habitat within the Valdez Glacier Stream floodplain characterized by very shallow

soils, in some places bare alluvium. Dense bands of alder are interspersed with open areas containing scattered cottonwood seedlings.

2. Deciduous forest -- A forest habitat characterized by a mixed-age stand of cottonwood with a dense understory of young cottonwood, alder, and ferns and a well-developed soil/litter layer.

3. Alder shrub -- A mountainside shrub habitat characterized by clumps of alder interspersed with a dense cover of ferns, false hellebore, and grasses. Soil is deep and moist. The transect included the ecotone between the cottonwood forest and the mountainside habitats.

4. Deciduous forest -- This transect covered an atypical variation of the deciduous forest habitat adjacent to Upper Corbin Creek (Corbin Creek/Glacier). It is characterized by widely spaced cottonwoods and shallow dry soil. The understory consists of willow and alder.

5. Riparian woodland -- A variation of the riparian woodland habitat consisting of a tall shrub/forest adjacent to Lower Corbin Creek (Corbin Creek/Robe). It is characterized by dense alder and willow with a few older cottonwoods. Soils are generally deep and moist.

6. Spruce forest -- A closed canopy forest habitat dominated by Sitka spruce with a few old cottonwoods. The sparce understory consists of ferns and devil's club. Soils are deep and relatively dry.

Trap stations were spaced at 10-m intervals along each transect and two museum special snap traps, baited with peanut butter and oatmeal, were set at each station. In addition, two pitfall traps made from 2-

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liter juice cans were imbedded flush with the soil surface and set along each transect. Traps were checked once each day for three days.

Results

The results of the trapping study are shown in Table 1. The species captured during this study were generally those that would be expected to occur in this area based on existing information (e.g. Rausch 1963; Manville and Young 1965). Three species of small mammals were captured for a total of 69 individuals.

The red-backed vole (*Clethrionomys rutilus*) was the most widespread and abundant member of the small mammal community. Red-backed voles were found in all habitats examined but were most common in the deciduous forest habitat. The density of red-backed voles was very high in the area sampled by Transect 2. Table 2 provides some information on the population structure and suggests that breeding pairs were spaced at intervals of 10 to 20 m. If it is assumed that all animals within an area 120 m X 20 m were captured by traps at Transect 2, then the density of red-backed voles is approximately 70 per hectare. Because the greatest proportion of habitat within the proposed refinery site is the deciduous forest type, high densities of red-backed vole can be expected throughout the development area.

Tundra voles (*Microtus oeconomus*) were found in only one habitat type, the moist ecotone between the alder shrub community and the deciduous forest covered by Transect 3. An additional tundra vole specimen was captured incidental to the bird studies on the south shore of Robe Lake at the ecotone between spruce forest and riparian woodland.

Shrews (*Sorex cinereus*) were most common in the area sampled by Transect 3. Like the tundra vole, shrews were most common in the ecotone between the alder shrub community and the deciduous forest in moist habitats.

TABLE 1

TOTAL ANIMALS CAPTURED ON EACH TRANSECT

Transect No.	*Clethrionomys rutilus*	*Microtus oeconomus*	*Sorex cinereus*	Total Animals
1	3			3
2	17			17
3	9	4	17	30
4	4			4
5	7		3	10
6	4		1	5
Total	44	4	21	69

TABLE 2

TRAP HISTORY BY TRANSECT AND STATION NUMBER
FOR RED-BACKED VOLES

Transect 1				Transect 2				Transect 3			
Station	Day 1	Day 2	Day 3	Station	Day 1	Day 2	Day 3	Station	Day 1	Day 2	Day 3
1				1				1	AF		
2				2				2			
3				3	AF		AM	3	AM		
4				4	AM	AF,JM	JF,JF	4	AM		
5	AM	AM,AF		5	AF			5			
6				6	AM		AM	6			AF
7				7	AM	JF	JF,AF	7		AM	
8				8	AM			8	AF		
9				9	AF			9	AM,JF		
10				10	AF			10		JF	

Transect 4				Transect 5				Transect 6			
Station	Day 1	Day 2	Day 3	Station	Day 1	Day 2	Day 3	Station	Day 1	Day 2	Day 3
1				1				1			
2				2				2	JM		
3	AM,AF			3				3			AF
4				4		AM		4			
5				5	JF			5			
6				6				6			
7	AM,JM			7				7			
8				8			JF	8	JF		
9				9			AM	9			
10				10	AM,AF		AF	10		AF	

AM = Adult male
AF = Adult female
JM = Juvenile male
JF = Juvenile female

The areas covered by Transects 1 and 4 yielded very few animals in the traps, probably because the habitats along these transects are characterized by shallow soils with very small amounts of litter.

ANNOTATED LIST OF MAMMALS PRESENT OR LIKELY TO BE PRESENT ON OR NEAR THE PROPOSED DEVELOPMENT SITES

Masked Shrew (*Sorex cinereus*) -- The presence of this shrew was confirmed on the proposed refinery site during the trapping study. It is abundant in moist habitat areas. Its presence in the Valdez area also has been noted by Manville and Young (1965).

Little brown bat (*Myotis lucifugus*) -- Manville and Young (1965) reported that the range of this species includes all of Prince William Sound. Perkins (personal communication 1979) reported a bat of unknown species in the Valdez area.

Snowshoe hare (*Lepus americanus*) -- The snowshore hare is present in the Valdez area but numbers were very low at the time of this study (Perkins, personal communication 1979). No evidence of hares was found on the proposed refinery site during this field investigation.

Pika (*Ochotona collaris*) -- The pika is present in rocky habitats at higher elevations in the Valdez area (Perkins, personal communication 1979). It may be present in the mountains near the proposed refinery site.

Hoary marmot (*Marmota caligata*) -- The marmot is present in rocky habitats in the Valdez area (Perkins, personal communication 1979). It may be present on the mountain slopes adjacent to the proposed refinery site.

Arctic ground squirrel (*Citellus undulatus*) -- This species is

present in alpine terrain at higher elevations in the Valdez area. It is probably present in suitable habitat within the mountains adjacent to the proposed refinery site.

Red squirrel (*Tamiasciurus hudsonicus*) -- This species was confirmed on the proposed refinery site during several field studies. It is a common resident of the spruce forests within the study area.

Red-backed vole (*Clethrionomys rutilus*) -- The presence of this species was confirmed on the proposed refinery site during the trapping study. It is undoubtedly the most abundant mammal within the development area. It is found in various habitats but is most abundant in deciduous forest areas with relatively deep soil.

Tundra vole (*Microtus oeconomus*) -- The presence of this species was confirmed on the proposed refinery site during the trapping study. It is probably limited to relatively moist habitat areas. Although present, this species was not abundant within the development area.

Porcupine (*Erethizon dorsatum*) -- The presence of this species was confirmed on the proposed refinery site during the field study. It is probably not abundant on the site.

Wolf (*Canis lupus*) -- Occasional reports of this species have been recorded in the Valdez area (Perkins, personal communication 1979). The wolf is probably rare in the area if it occurs at all.

Coyote (*Canis latrans*) -- This species is present in the Valdez area (Perkins, personal communication 1979). It may be an occasional visitor to the development area.

Red fox (Vulpes fulva) -- This species is present in the Valdez area. Fox tracks were observed on the proposed refinery site during this study.

Black bear (Ursus americanus) -- The presence of this species was confirmed on the proposed refinery site during field surveys. It is a common resident utilizing a variety of habitat types depending on seasonal food availability (McIlroy 1970). Black bears are generally abundant in the Valdez area (Reynolds 1976a).

Brown/Grizzly bear (Ursus arctos) -- This species is present in the Valdez area (Reynolds 1976b). It is a common summer resident of the proposed refinery site, particularly when salmon are spawning in Brownie Creek and Lower Corbin Creek (Corbin Creek/Robe) (Williams, personal communication 1979).

Alaska marten (Martes americana) -- This species is found in the spruce forests of the Valdez area (Perkins, personal communication 1979). It may be an occasional visitor to the refinery site area.

Ermine (Mustela erminea) -- Ermine are present in the Valdez area (Perkins, personal communication 1979). It is a probable inhabitant of the refinery site area although its presence was not confirmed.

Mink (Mustela vison) -- This species is present in the Valdez area (Perkins, personal communication 1979). It is a probable inhabitant along streams on the proposed refinery site, although its presence was not confirmed.

River otter (Lutra canadensis) -- The presence of this species was confirmed on the proposed refinery site near Lower Corbin Creek during field investigations. It is probably a permanent

resident of the Lower Corbin (Corbin Creek/Robe)/Brownie Creek area at the southern end of the site. Its presence also was confirmed in the Port Valdez marine environment near the Mineral Creek Islands.

Wolverine (*Gulo gulo*) -- This species is present in the Valdez area (Perkins, personal communication 1979). It may rarely visit the refinery site area.

Lynx (*Lynx canadensis*) -- Lynx are present in the Valdez area (Perkins, personal communication 1979). It is a probable visitor to the refinery site area, although its presence was not confirmed.

Sea otter (*Enhydra lutris*) -- The presence of this species within the Port Valdez marine environment was confirmed during this study. Twenty-nine sea otters were observed at the eastern end of Port Valdez in April 1979. Otters were observed feeding on the north side of the bay near the Mineral Creek Islands and regular feeding activity was noted in the Solomon-Allison Creek area throughout the study period.

Harbor seal (*Phoca vitulina*) -- This species is common in Port Valdez at all times of the year (Sangster, unpublished data). Its presence was confirmed during this study with concentrations noted in the Mineral Creek Islands area (27 seals seen in May 1979) and in the Dayville Flats area. Small numbers of seals were regularly observed in the Solomon-Allison Creek area.

Steller sea lion (*Eumetopias jubata*) -- This species is observed occasionally in Port Valdez (Pitcher 1975; Dames & Moore 1977).

Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) -- This species is present in the Valdez area (Perkins, personal

communication 1979). Tracks were observed on the refinery site in April 1979 during this study. The presence of deer in the Valdez area apparently represents a recent range extension. Use of the refinery site area by deer is probably only occasional.

Moose (*Alces alces*) -- This species is present in the Lowe River Valley east of Keystone Canyon but rare in the Valdez area. Marginal habitat, deep snow, and geographic barriers apparently prevent extensive use of this area by moose. No evidence of moose was noted during this study.

Mountain goat (*Oreamnos americanus*) -- This species is present at high altitudes within the mountains adjacent to Port Valdez (Manville and Young 1965). Utilization of the refinery site area is unlikely.

Harbor porpoise (*Phocoena phocoena*) -- This species is present occasionally in Port Valdez (Perkins, personal communication 1979).

Dall porpoise (*Phocoena dalli*) -- This species is present occasionally in Port Valdez (Perkins, personal communication 1979).

Killer whale (*Orcinus orca*) -- This whale is present occasionally in Port Valdez (Perkins, personal communication 1979).

Humpback whale (*Megaptera novaeangliae*) -- This species of whale is probably rare in Port Valdez. Perkins (personal communication 1979) reported one unconfirmed sighting.

Minke whale (*Balaenoptera acutorostrata*) -- This species is common in Prince William Sound in the summer (Pitcher 1975). It may rarely enter Port Valdez.

HABITAT CONSIDERATIONS

Refinery Site and Pipeline Corridor

Mammal use of the proposed refinery site and adjoining area is light. Most of the species mentioned in the previous section would be expected to be present only occasionally or in small numbers. Red-backed voles are an exception to the above and probably play a significant role in the community metabolism of the deciduous forest habitat. The only large mammal that is common on the site is the black bear. Black bears can be expected to utilize a variety of habitat types in response to the seasonal availability of preferred food items. Food habitat data obtained by McIlroy (1970) suggests that the habitats most used by black bears include marsh areas, mountainside shrub areas, and areas adjacent to streams. Brown bears are present on the proposed refinery site primarily during late summer and fall in response to salmon.

The proposed refinery site does not occupy any habitat that would be considered unique or critical to local mammal populations with the exception of the salmon spawning areas on Lower Corbin Creek (Corbin Creek/Robe) and Brownie Creek, which are heavily utilized by black and brown bears (Figure 1). The general area adjoining the above creeks and bordering the southern margin of the site (also crossed by the proposed pipeline/roadway) is important for a variety of species because of its ecological diversity (Figure 1). Salmon and other fish within the streams are an important food source not only for bears, but also for river otter and mink. The mixed habitat types would be expected to enhance the area's value to large mammals and furbearers.

Most of the remainder of the site is covered by either a relatively uniform deciduous forest dominated by cottonwood or a flood-plain shrub community. Neither of these habitat types is unique to the area or of exceptional value to mammal populations. Small mammal populations are very high in the deciduous forest but disturbance to this habitat type is likely to have only local effects.

Port Valdez Marine Environment

The refinery dock facility proposed for the southern shore of eastern Port Valdez would occupy some potential habitat for marine mammals. These habitats are currently used as feeding areas by sea otters and harbor seals (Figure 1). It is unlikely that any portion of the south shore area is critical to these animals because of their mobility and the general availability of similar habitat throughout the area.

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PLANT COMMUNITIES OF EASTERN PORT VALDEZ, ALASKA

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INTRODUCTION

A general reconnaissance survey of the major plant communities occuring in the area from Valdez, Alaska eastward to Valdez Glacier, south to Robe Lake, and west to Allison Creek was conducted from March to August 1979. Special emphasis was given to the area east of Valdez Glacier Stream which is proposed for use as a petrochemical refinery. The study focused on the dominant plant species of these communities. The species listed do not represent total species present in the study area.

METHODS

Published literature on the vegetation of Port Valdez is sparse and limited to coastal wetlands (Crow 1977 and Batten et al. 1977). All data on terrestrial and aquatic plants presented in this report was collected during the course of this study.

Initially, the major vegetation patterns were delineated from 1978 black and white aerial photographs at a scale of 1:24,000 using standard remote sensing techniques. Vegetation maps were constructed after all the vegetation types were field-checked for accuracy (Figure 1).

Representative sites within the vegetation types and successional stages were selected and systematically sampled. Sampling involved the use of 1/4 m^2 quadrats spaced every 5 meters (m) along a 50-m transect with the exception of Transect 1 where a 100-m transect was sampled. Total cover contributed by each species was estimated within each quadrat. Occurrence and percent cover were used to determine major species. Station data are listed in Appendix I. Only qualitative random sampling was used in the freshwater marsh vegetation type. Additional taxa located during other field operations were added to the species list.

Plant specimens collected were prepared by standard botanical techniques. Scientific names are according to Hulten (1968) and common names are according to Welsh (1974).

RESULTS

An attempt was made to characterize the plant communities that were meaningful for analysis of bird and mammal distribution within the study area. This approach was first applied in Alaska by Dice (1920).

The basic ecological formations identified during this study are:

Streamside alluvium	Deciduous-Spruce forest
Riparian woodland	Spruce forest
Freshwater marsh	Alder shrub
Deciduous forest	

Dominant species occuring in each formation sampled are listed in Table 1.

Streamside alluvium

Included here are the well drained gravel deposits, often dominated by sedge (*Carex lyngbyaei*) but usually unvegetated. This formation was not systematically sampled during this study.

Riparian woodland

The largest expanse of riparian woodland occurs along Valdez Glacier Stream on newly exposed floodplains and is characterized by small clumps of young black cottonwood (*Populus balsamifera*), Sitka alder (*Alnus crispa sinuata*) and willow (*Salix alaskensis* and *Salix chamissonis*) interspersed with large open areas largely covered by folious lichens (*Stereocaulon* sp and unidentified species) and two moss species (*Stelaginella sibirica* and *Lycopodium selago*). Species diversity is very low in this area with only a few hardy species such as sweet-scented bedstraw (*Galium triflorum*) and horsetails (*Equisetum arvense* and *Equisetum variegatum*) occuring under the shrubs.

This vegetation type represents the pioneer successional stage of the adjacent deciduous cottonwood forest. Other riparian woodlands

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TABLE 1
COMMON PLANT SPECIES FOUND IN MAJOR PLANT COMMUNITIES
JULY AND AUGUST, 1979

Scientific Name	Common Name	AREA OF OCCURRENCES				
		Riparian Woodland	Freshwater Marsh	Spruce Forest	Deciduous Forest	Alder Shrub
LICHENS:						
Streocaulon sp		X			X	
Folious lichens, unid.		X		X	X	
MOSSES:						
Bryophytes, unidentified	mosses	X		X	X	
Sphagnum sp			X			
Lycopodium selago	fir clubmoss	X				
Selaginella sibirica	northern selaginella	X			X	
HORSETAIL:						
Equisetum arvense	meadow horsetail	X		X	X	
E. fluviatile	swamp horsetail		X			
E. variegatum	variegated scouring-rush	X				
FERNS:						
Thelypteris phegopteris	northern beech-fern					X
Athyrium filix-femina	lady fern			X	X	X
Dryopteris dilatata	spinulose shield-fern			X	X	X
Gymnocarpium dryopteris	oak-fern			X	X	X
FLOWERING PLANTS:						
Picea sitchensis	Sitka spruce	X		X	X	
Calamagrostis canadensis	bluejoint			X	X	X
Poa glauca	glaucous bluegrass				X	
Carex aquatilis	water sedge		X			
Carex sp	sedge		X			
Veratrum viride	false hellebore					X
Streptopus amplexifolius	clasping twist-stalk			X	X	
Populus balsamifera	black cottonwood	X			X	
Salix alexensis	Alaska willow	X				
Salix Chamissonis	Chamisso willow	X				
Salix spp	willow	X	X	X	X	X
Alnus crispa sinuata	Sitka alder	X		X	X	X
Betula glandulosa	dwarf birch		X			
Aconitum delphinifolium	monkshood				X	

TABLE 1 (Continued)
COMMON PLANT SPECIES FOUND IN MAJOR PLANT COMMUNITIES
JULY AND AUGUST, 1979

Scientific Name	Common Name	AREA OF OCCURRENCES				
		Riparian Woodland	Freshwater Marsh	Spruce Forest	Deciduous Forest	Alder Shrub
FLOWERING PLANTS (Continued):						
Actaea rubra arguta	baneberry			X	X	
Thalictrum sparsiflorum	few-flower meadowrue				X	
Heuchera glabra	alpine heucheria				X	
Ribes bracteosum	stink current			X		
Aruncus sylvester	goatsbeard			X	X	X
Geum macrophyllum	large-leafed avens				X	
Rubus spectabilis	salmonberry			X	X	X
Sorbus scopulina	western mountain ash				X	X
Astragulus alpinus	alpine milk-vetch	X			X	
Lupinus nootkatensis	lupine				X	
Circaea alpina	enchanter's nightshade			X	X	
Epilobium angustifolium	fireweed			X	X	
E. lalifolium	river beauty	X			X	
Hippuris vulgaris	common marestail		X			
Echinopanax horridum	devil's club			X	X	X
Heracleum lanatum	cow parsnip				X	
Osmorhiza depauperata	sweet cicely	X		X	X	
Pyrola asarifolia	olive-leafed wintergreen			X	X	
Pyrola secunda	one-sided wintergreen	X		X	X	
Menyanthes trifoliata	buckbear		X			
Boschniakia rossica	ground cone	X			X	X
Utricularia intermedea	flat-leafed blatterwort		X			
Galium triflorum	sweet-scented bedstraw	X		X	X	X
Sambucus racemosa	red-berried elder			X	X	X
Viburnum edule	highbush cranberry			X	X	
Achillea borealis	yarrow			X	X	
Arnica ?latifolia				X	X	
Artemisia arctica					X	
Solidago multiradiata	northern goldenrod				X	

occur along Corbin and Brownie Creeks but have floral compositions very similar to the deciduous forest. However, they are dominated by willow and alder.

Freshwater marsh

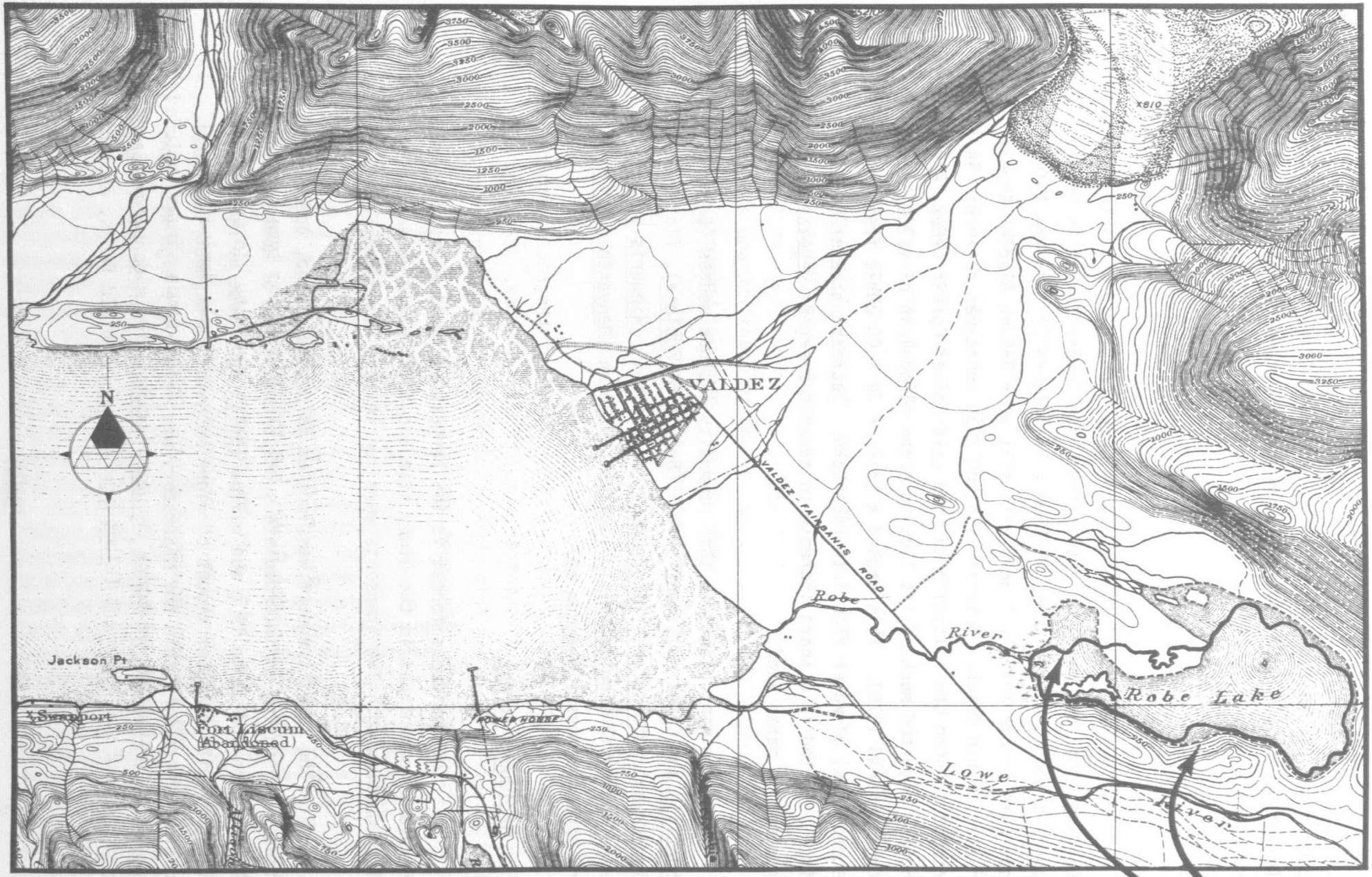
The marshes of the Valdez area are generally characterized by standing water and emergent vegetation. The largest marsh in this region occurs in the old bed of Robe Lake (Figure 2). In the 1930's Robe Lake became heavily loaded with silt when Valdez Glacier Stream invaded Corbin Creek. Between 1956 and 1958 concerned citizens, in an attempt to stop the siltation of Robe Lake, diked Corbin Creek, and thereby diverted much of its flow into the floodplain of Valdez Glacier Stream (ADF&G 1979). This caused a loss of 30 - 40 cubic feet per second (cfs) of water flow into Robe Lake. Decreasing water levels have since resulted in a sharp increase in aquatic emergent vegetation and an increase in marsh land.

Dominant plants in this community include sedges (Carex aquatilis and Carex sp), dwarf birch (Betula glandulosa), flat-leafed bladderwort (Utricularia intermedia), mare's tail (Hippuris vulgaris), swamp horsetail (Equisetum fluviatile), buckbean (Menyanthes trifoliata), and sphagnum moss (Sphagnum sp).

Deciduous forest

The deciduous forest is the largest and most widespread of all the plant communities in the study site and is strongly dominated by black cottonwood. Two transects were run in this deciduous forest type.

The first transect was located in a middle-aged, open-canopy stand representing an intermediate successional stage of development. Black cottonwood up to 19 m and willow (Salix spp) made up most of the overstory with a lesser amount of alder occuring throughout the stand. Species diversity within the understory was relatively high with the ground cover composed of mosses, lichens, one-sided wintergreen (Pyrola



1916 U.S.G.S. Topographic Map of Valdez & Vicinity

One Mile

FIGURE 2

ROBE LAKE SHORELINE

1916 & 1979

DAMES & MOORE

secunda), liver-leafed wintergreen (P. asarifolia) and bedstraw. Other major species occuring throughout the community were bluejoint grass (Caliamagrostis canadensis), lady fern (Athyrium filix-femina), river beauty (Epilobium latifolium), yarrow (Achillea borealis) and monkshood (Aconitum delphinifolium delphinifolium). Additional species are listed in Table 1.

The second transect was located in a mature, closed-canopy cottonwood forest representing the highest level of development for this sub-climax community. The overstory was all black cottonwood 20 - 25 m tall. Dense alder and mountain ash (Sorbus scopulina) up to 5 m tall and devil's club (Echinopanax horridum), along with lady fern, spinulose shield-fern (Dryopteris dilata americana), and oak fern (Gynmocarpium dryopteris) make up most of the understory. Other common species included salmonberry (Rubus spectabilis), goatsbeard (Aruncus sylvester), clasping twisted-stalk (Streptopus amplexifolius), cow parsnip (Heracleum lanatum), and sweet cicely (Osmorphiza despauperata). Ground cover was mainly liver-leafed wintergreen with lesser amounts of bedstraw and enchanter's nightshade (Circaea alpina). Many of these species, however, occur to some degree throughout the seral stages of the forest.

Deciduous-Spruce forest

The deciduous, black cottonwood forest intergrades with the spruce forest in much of the area south of Corbin Creek. Although no sampling was done within this type, it appeared to have a mixture of species common to both plant communities.

Spruce forest

Pure stands of Sitka spruce (Picea sitchensis) are found along the access corridor near Robe River, but this vegetation type is the least abundant in the vicinity of the proposed project. In the spruce forest the understory is a low shrub complex, strongly dominated by devil's club and smaller amounts of alder. Other common shrubs included salmonberry, highbush cranberry (Viburnum edule), red elderberry (Sambucus racemosa) and stink current (Ribes bracteosum). Shield ferns, enchanter's

nightshade, liver-shaped wintergreen and moss dominated the ground cover portion of the understory.

This formation is believed to be the climax vegetation of the lowland areas of eastern Port Valdez.

Alder shrub

This community occurs on essentially all the lower mountain slopes surrounding the study area and is strongly dominated by the Sitka alder. Mountain ash and red elderberry are commonly mixed in with the alder. The understory is heavily dominated by devil's club, salmonberry, shield ferns, lady fern and one species of marsh fern (*Thelypteris phegopteris*) -- only found in this habitat. Open areas along the slope are heavily vegetated by tall bluejoint grass and false hellebore (*Veratrum viride*).

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APPENDIX Ia

SPECIES COMPOSITION AND PERCENT COVER IN RIPARIAN WOODLAND, ALPETCO SITE

1/4 M SQUARE QUADRATS

TAXA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Stereocaulon	50	50	30	50	40	40		40	80	T			95		40	50	40	85		
Folious Lichen, unid.	10	T	T	T	T	2			T						T					
Lycopodium selago	T	15	5	10	10	25		15	5	1			T		5	20	10			
Selaginella sibirica	T	T	1	10	2	1		T		T					5	10	45	15		
Populus balsimifera									25				5		25	5				
Salix spp			5			20			10	50								5	15	
Alnus crispa	10		25				100	1	1	50	100	100		100					80	95
Galium triflorium							T												5	5
Pyrola secunda										1										
Osmorhiza depauperata												5								
Equisetum variegatum												5								
E. arvense												T								

T = trace

APPENDIX Ib

SPECIES COMPOSITION AND PERCENT COVER IN OPEN CANOPY DECIDUOUS FOREST, ALPETCO SITE

1/4 M SQUARE QUADRATS

TAXA	1	2	3	4	5	6	7	8	9	10
Stereocaulon sp					T	30	50			
Folious lichen, unid.		1			10	20	1		1	
Lycopodium spp		50	60	80	5		5			
Sphagnum sp					20			30	80	5
Athyrium filix-femina				25						
Calamagrostis canadensis				5		3		25		
Poa glauca		T	30	40	T					
Populus balsamifera	80			60	100	10	10	15		100
Salix sp		5	100				80		50	
Alnus crispa sinuata	2				20	1		5		
Epilobium angustifolium	2		1	4	3			10	15	
Pyrola secunda							15	2	20	30
Galium triflorum	T	T		1	1			T	20	10
Achillea borealis	20	50								

T = trace

APPENDIX Ic

SPECIES COMPOSITION AND PERCENT COVER IN CLOSED CANOPY DECIDUOUS FOREST, ALPETCO SITE

1/4 M SQUARE QUADRATS

TAXA	1	2	3	4	5	6	7	8	9	10
Athyrium filix-femina	10						10			
Gymnocarpium dryopteris			5							
Populus balsamifera	100	100	100	100	100	100	100	100	100	100
Salix sp								T		
Alnus crispa sinuata	75	60			100		100	80	100	100
Actaea rubra arguta				10			50			
Streptopus amplexifolius		15				15	10			
Aruncus sylvester							5			
Sorbus scopulina			25						10	
Circaea alpina								10		
Echinopanax horridum	50	25	90	90	85	100		20	75	80
Heracleum lanatum							20			25
Osmorhiza depauperata				2						
Pyrola asarifolia	25	20	5	15	10	30	20	50	10	15
Galium triflorum		20		T		25			10	1
Viburnum edule									20	

T = trace

APPENDIX Id

SPECIES COMPOSITION AND PERCENT COVER IN CLOSED CANOPY SPRUCE FOREST, ALPETCO SITE

1/4 M SQUARE QUADRATS

TAXA	1	2	3	4	5	6	7	8	9	10
Lycopodium spp	10	T	25	30	T	75	10	5	30	T
Athyrium filix-femina			30					25		
Dryopteris dilatata	25	10		10		20	60		20	10
Gymnocarpium dryopteris	5				1			1		
Picea sitchensis	100	100	100	100	100	80	100	50	100	100
Alnus crispa sinuata	30	10	10	80	90			50	30	100
Geum macrophyllum				5						
Aruncus sylvester	T								10	
Circaea alpina	5	10	10	5	1	25	10	5	5	30
Echinopanax horridum	100	80	100	70	100	100	100	30	50	50

T = trace

APPENDIX Ie

SPECIES COMPOSITION AND PERCENT COVER IN ALDER SHRUB COMMUNITY, ALPETCO SITE

1/4 M SQUARE QUADRATS

TAXA	1	2	3	4	5	6	7	8	9	10
Thelypteris phegopteris	5		15	10						
Athyrium filix-femina						25		30	20	10
Dryopteris dilatata	20	40	100		100		100			
Gymnocarpium dryopteris		30	10	15	25	50	10	T	5	5
Calamagrostis canadensis				30		5				
Veratrum viride								40		
Alnus crispa sinuata		100	100	10	80	90	30		100	100
Rubus spectabilis	80	20		15					75	100
Sorbus scopulina	50									
Echinopanax horridum	10			80		100	50		10	
Sambucus racemosa			20					5		

T = trace

BIOLOGICAL STUDIES REPORT
SALMON FRY DISPERSION IN EASTERN PORT VALDEZ

THE ALASKA PETROCHEMICAL COMPANY

Prepared by

DAMES & MOORE
Anchorage, Alaska

September 1979

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INTRODUCTION

As part of a general program to acquire baseline biological data for a proposed refinery and dock to be built by Alaska Petrochemical Company (Alpetco), various field studies were initiated to address areas of specific concern. Preliminary investigations and discussions with regulatory agency personnel revealed apprehension about the potential for impact on juvenile pink and chum salmon in Port Valdez. Pink and chum salmon, in contrast to the other salmon species, spend little time in fresh water. Rather, the young fish (fry) migrate downstream into salt water soon after emergence from the spawning gravels in the spring. During this time very large numbers of fry become concentrated in estuarine inshore areas and, thus, become particularly vulnerable to impact from shoreline disturbances. This report presents the results of a brief field study conducted to gain information specific to this early stage in the life history of pink and chum salmon. The following topics were considered during the study:

1. Timing and duration of use of eastern Port Valdez by pink and chum salmon.

2. Areas of fry concentration.

3. Ecological value of the area to the fry.

At least 12 stream systems within eastern Port Valdez are known to support pink and chum salmon spawning activity (Figure 1). Escapement estimates for these streams are presented in Table 1. Pink salmon spawners have been abundant only during odd years, whereas chum salmon numbers have fluctuated irregularly from year to year. Some of the salmon utilizing eastern Port Valdez streams spawn within the intertidal zone; therefore, the fry are partly under the influence of salt water from the time of hatching. Studies by various investigators (Noerenberg et al. 1964; Kirkwood 1963) have indicated that once the young salmon reach the estuarine environment they form schools and

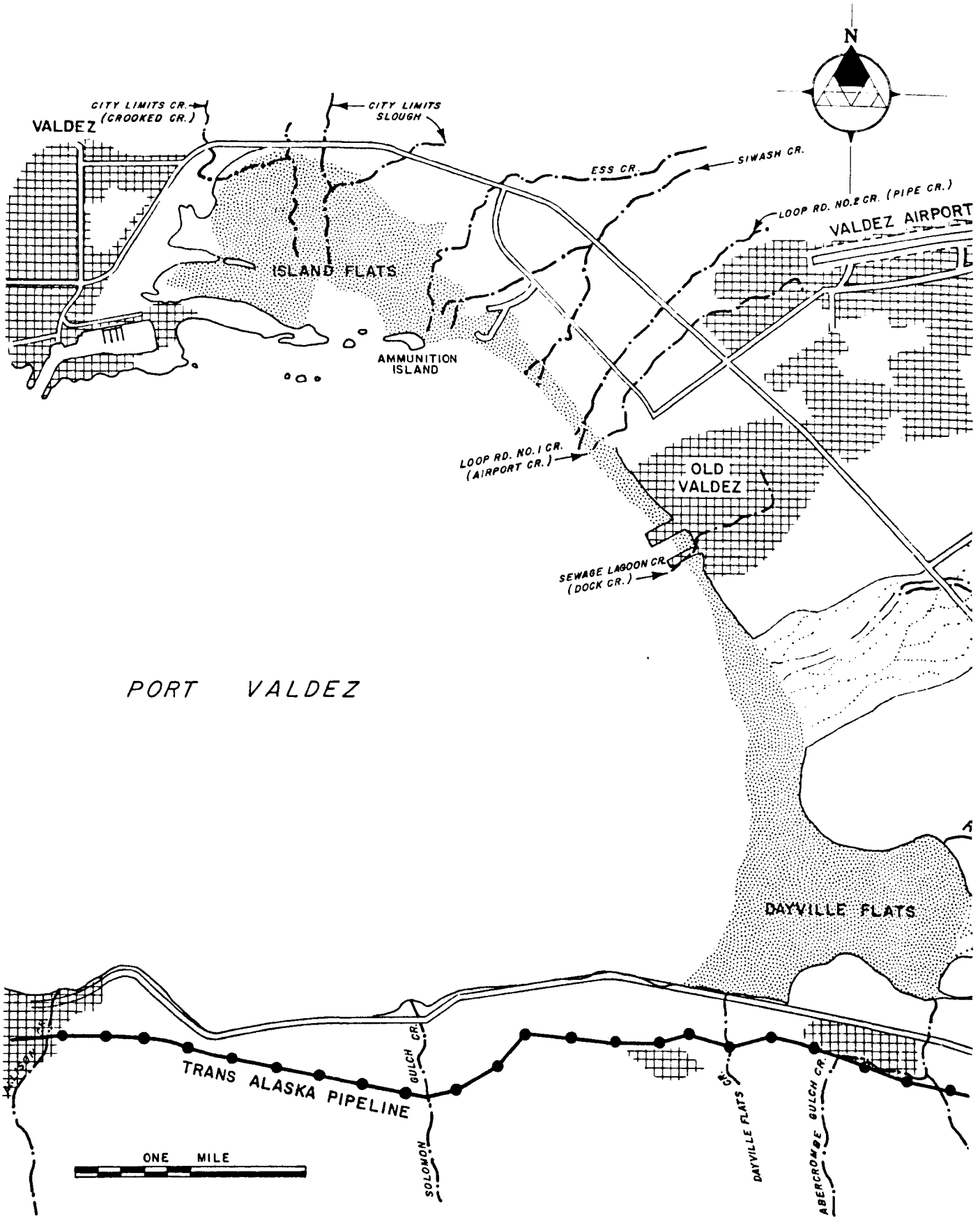

FIGURE 1

STUDY AREA LOCATION MAP

TABLE 1

SALMON ESCAPEMENT FOR SELECTED EASTERN PORT VALDEZ STREAMS, 1971-1978

Year	City Limits Creek	City Limits Slough	Ess Creek	Siwash Creek	Loop Rd. No. 2 Stream	Loop Rd. No. 1 Stream	Sewage Lagoon Creek	Robe Lake System	Lowe River System	Dayville Flats Creek	Solomon Gulch Creek	Allison Creek
Pink Salmon												
1971	940[3]			13,070[3]	100[3]	1,080[3]		4,500[1]	35,310[3]	1,300[6]		300[7]
1972	30[3]			220[3]		475[1]		0[1]	0[1]			
1973	1,700[1]			34,080[3]	330[3]	7,000[1]		15,000[1]	8,000[3]			25[7]
1974	860[3]			70[3]		262[1]			670[3]			
1975	1,520[3]			79,180[3]	3,790[3]	6,420[3]		2,461[1]	41,430[3]	1,300[4]	1,500[4]	500[4]
1976	5[1]		65[4]	5[1]		18[1]		0[1]	1[1]			
1977	3,620[2]	333[4]		46,550[2]	4,101[1]	18,718[1]	1,418[1]	330[1]	1,441[1]			
1978	10[5]			0[5]	0[5]	66[5]	0[5]	2[5]	0[5]			
Chum Salmon												
1971	2,660[1]		32[4]	120[3]					411[1]			
1972	1,200[1]			220[3]		45[1]		40[1]	2,007[1]			
1973	1,930[3]			232[1]				125[1]	1,063[1]		10[3]	
1974	1,000[3]			16[1]		0[1]						
1975				100[3]								700[4]
1976	1,080[1]			2[1]		6[1]		0[1]	270[1]			
1977	0[1]			0[1]		0[1]	0[1]	0[1]	0[1]			
1978	111[5]							1[5]				

From:

[1] Williams, 1978 (one-time ground counts).
[2] McCurdy & Pirtle, 1978 (calculated total seasonal escapement based on aerial and ground counts).
[3] Pirtle, 1977 (calculated total seasonal escapement based on aerial and ground counts).
[4] Johnson & Rockwell, 1978 (various methods).
[5] Williams, personal communication (one-time ground counts).
[6] Mattson, 1971 (estimated escapement based on aerial or ground counts).
[7] Mattson, 1973 (estimated escapement based on aerial or ground counts).

concentrate along shoreline areas. The schools of fry then move gradually seaward with varying times of residence in estuarine "nursery" areas. Mattson (1971; 1974; 1977) studied the behavior of salmon fry in Port Valdez, particularly in relation to impacts from the Alyeska Pipeline Service Company tanker terminal. He visually observed salmon fry (he was not able to distinguish between pink and chum salmon) along various sections of the shoreline. He concluded that the fry moved out of Port Valdez relatively quickly, usually over a period of about three weeks and that the greatest concentrations of fry were found in the west end of Port Valdez.

METHODS

Study Constraints

It was apparent from the early stages of the field work that the study was subject to a number of constraints. The following factors served to dictate the course of the investigation:

1. Pink salmon fry were not abundant in the study area. Therefore, study effort concentrated on chum salmon.

2. The primary chum salmon streams are located in the northeast portion of Port Valdez. Greatest concentrations of fry were found in this area and greatest study effort was expended in this area.

3. Characteristics of the Lowe River and its delta precluded stream sampling and shoreline observations in the Lowe River vicinity.

Fry Outmigration Monitoring

Preliminary visual observations to detect fry emergence from

stream gravels were initiated on April 2 and continued at irregular intervals until April 24. City Limits Creek, Siwash Creek, Loop Road No. 1 Stream, and Robe River were observed.

On April 24, trapping was initiated on the above streams to estimate the number of fry moving past a point near the mouths of the streams. A 32-millimeter (1/8-inch) mesh seine was stretched across the streams and anchored at each end. The streams were completely blocked, except Robe River where about 25 percent of the stream width was blocked. The seine was left in place for a suitable interval depending on fry abundance. It was found that an interval of 15 to 20 minutes avoided catching too many fry but usually yielded a reasonable sample. At the end of the sampling interval, one end of the seine was brought across the stream to retain those fish caught in the net. The fish were counted, identified, and released. Representative samples of up to 40 fish were retained and preserved for length measurements and stomach content analysis. The trap locations on Siwash Creek and Loop Road No. 1 Creek were immediately downstream from the Mineral Creek Loop Road culverts. The trap location on City Limits Creek was about 100 meters (m) downstream from the Richardson Highway crossing, near the edge of the mud flat. The "mouths" of these streams were difficult to define because of the extensive intertidal flat. Sample locations were selected at the upper intertidal zone (about +3 m MLLW) to minimize tidal interference with the sampling.

Trapping was conducted on City Limits Creek at 2 to 8-day intervals between April 24 and May 28 with a total of seven successful samples. Four successful trap samples were collected at approximately 10-day intervals on Siwash Creek. Samples were taken on five days at 4 to 10-day intervals on Loop Road No. 2 Creek. Only one successful sample was collected on the Robe River because of the inaccessibility of the stream mouth. Kirkwood (1963) found that the peak outmigration occurred during the early night hours. Therefore, trapping was conducted in dark or near-dark conditions usually between 2100 hours and 2300

hours. On May 19 and 20, sampling of City Limits Creek was conducted at intervals of 2 to 4 hours over a 24-hour period to determine daily variation in fry outmigration.

Estuarine Shoreline Observations

Visual observations of shoreline areas were made between April 24 and May 23. The technique involved driving a skiff along the shoreline while an observer tallied the number of fry seen. Numbers of fry in any one school were subjectively estimated. This technique has been used by Mattson (1971) and by the Alaska Department of Fish and Game in some areas of Alaska to obtain an index on which to base salmon abundance forecasts. Because of the shallow water in most of the study area, these observations could be made only during higher tide stages.

Visual observations were conducted in the Island Flats/Mineral Creek Islands area at intervals of 3 to 4 days during the study period. Observations on the south shore between Solomon Gulch and Allison Creek were conducted on May 6. Similar observations were conducted by walking along the shoreline between Dayville Flats and Solomon Creek on May 18.

Samples of fry were collected by seine during several of the shoreline surveys to verify species identification and obtain information on growth.

Food Habits

Stomach contents were qualitatively analyzed from small numbers of salmon fry caught within the stream and estuarine environments. Feeding behavior was visually observed also.

RESULTS

Fry Outmigration Monitoring

A summary of the trapping results is presented in Table 2. It

TABLE 2

SUMMARY OF FRY OUTMIGRATION TRAPPING RESULTS

Stream Name	Date (1979)	Time	Duration of Trapping Period (min.)	Chum Salmon Fry				Pink Salmon Fry				Other Fish Captured Total Length in Parentheses
				Total Catch	Catch Rate (No./Hr.)	Mean Total Length (mm)	Length Range (mm)	Total Catch	Catch Rate (No./Hr.)	Mean Total Length (mm)	Length Range (mm)	
City Limits Creek	04/24	2040	20	315	945	--	--	0	--	--	--	1 silver salmon (109 mm)
	04/26	2100	15	155	620	36.5	33-41	0	--	--	--	0
	05/02	2125	15	91	364	--	--	0	--	--	--	0
	05/12	2255	15	54	216	--	--	20	80	--	--	5 three-spine stickleback
	05/20	2125	15	43	172	--	--	1	4	--	--	0
	05/24	2140	10	5	30	38.8	38-40	0	--	--	--	0
	05/28	2235	15	4	16	40	37-45	0	--	--	--	0
Loop Road Creek No. 2	04/26	2205	20	26	78	36	35-38	6	18	32	31-33	3 Dolly Varden (107, 56, 58 mm)
	05/10	2135	20	0	--	--	--	25	75	--	--	1 Dolly Varden (~150 mm)
	05/20	0025	15	77	308	--	--	87	348	--	--	4 Dolly Varden (all ~60 mm)
	05/24	2055	15	4	16	36	35-38	3	12	32	32	1 Dolly Varden (29 mm)
	05/28	2150	15	8	32	35.6	35-36	3	12	31.3	31-32	0
Siwash Creek (North Fork)	04/25	2240	20	2	6	37	37	0	--	--	--	2 Silver Salmon (82, 87 mm); 2 Dolly Varden (73-74 mm)
	05/02	2225	15	3	12	--	--	2	8	--	--	14 Dolly Varden (all ~60 mm)
	05/10	2225	15	0	--	--	--	0	--	--	--	0
	05/20	0405	15	1	4	--	--	0	--	--	--	10 Dolly Varden (9 @ ~60 mm; 1 @ ~150 mm)
Robe River	05/05	2225	15	1	16	--	--	1	16	--	--	1 Dolly Varden (60 mm)

was felt that the nets trapped essentially all of the fry that passed the sample point. Current velocities at the stream sample sites were sufficient to prevent fry from swimming out of the net.

Chum salmon fry were first observed in City Limits Creek on April 13 and outmigrants were abundant when trap sampling commenced on April 24. Trapping results suggest that outmigration was greatest in late April and gradually tapered off over a period of five or six weeks (Figure 2). The larger size of the late May outmigrants suggests that some of these fry had remained in the stream for a period of time prior to moving out. A portion of the chum salmon fry apparently move into the estuary soon after emergence, whereas others spend up to several weeks in the creek. On May 11, about 15,000 fry were observed within the upper part of the stream system. These fry were schooled and feeding in the eddys, pools, and slough areas. Pink salmon fry were never abundant in City Limits Creek; however, a few were observed in trap samples in mid-May.

The results of the 24-hour sampling on May 19-20 are presented in Figure 3. An abrupt peak in chum salmon fry outmigration rate occurred at 1300 hours. This was somewhat surprising since it had been assumed that peak migration was at night. An estimated 9200 fry per day passed the sample location, based on the mean hourly catch rate for the eight samples.

The results of the sampling in Loop Road No. 2 Creek are presented in Table 2 and Figure 4. The somewhat limited data suggest that the peak of chum salmon outmigration was about four weeks later than in City Limits Creek. Substantial numbers of pink salmon fry were also captured in mid-May. The number of fry caught in Siwash Creek and the Robe River were very low.

Estuarine Shoreline Observations

The results of the shoreline observations are summarized in Table 3. Figure 5 shows the shoreline segment designation used during

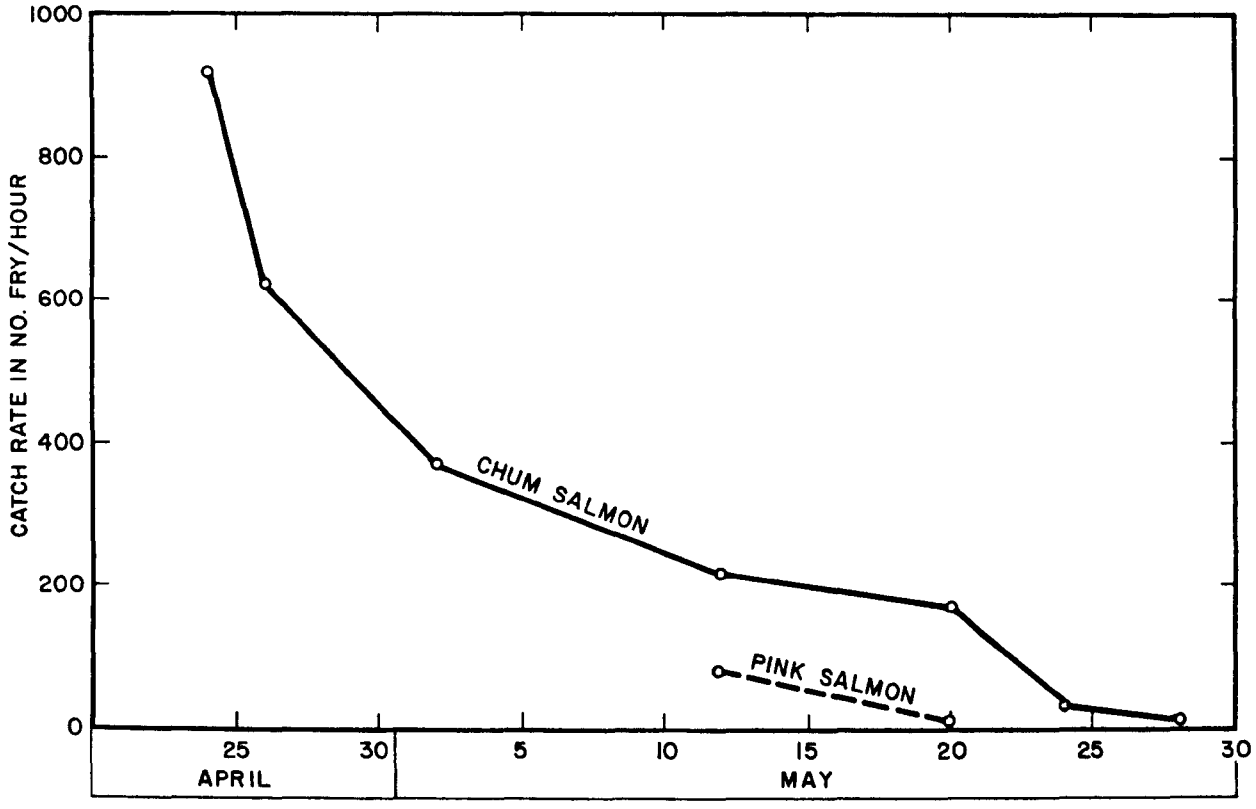

FIGURE 2

DOWNSTREAM MIGRATING PINK AND CHUM SALMON FRY
IN CITY LIMITS CREEK
AS REFLECTED IN NIGHT TRAP CATCHES

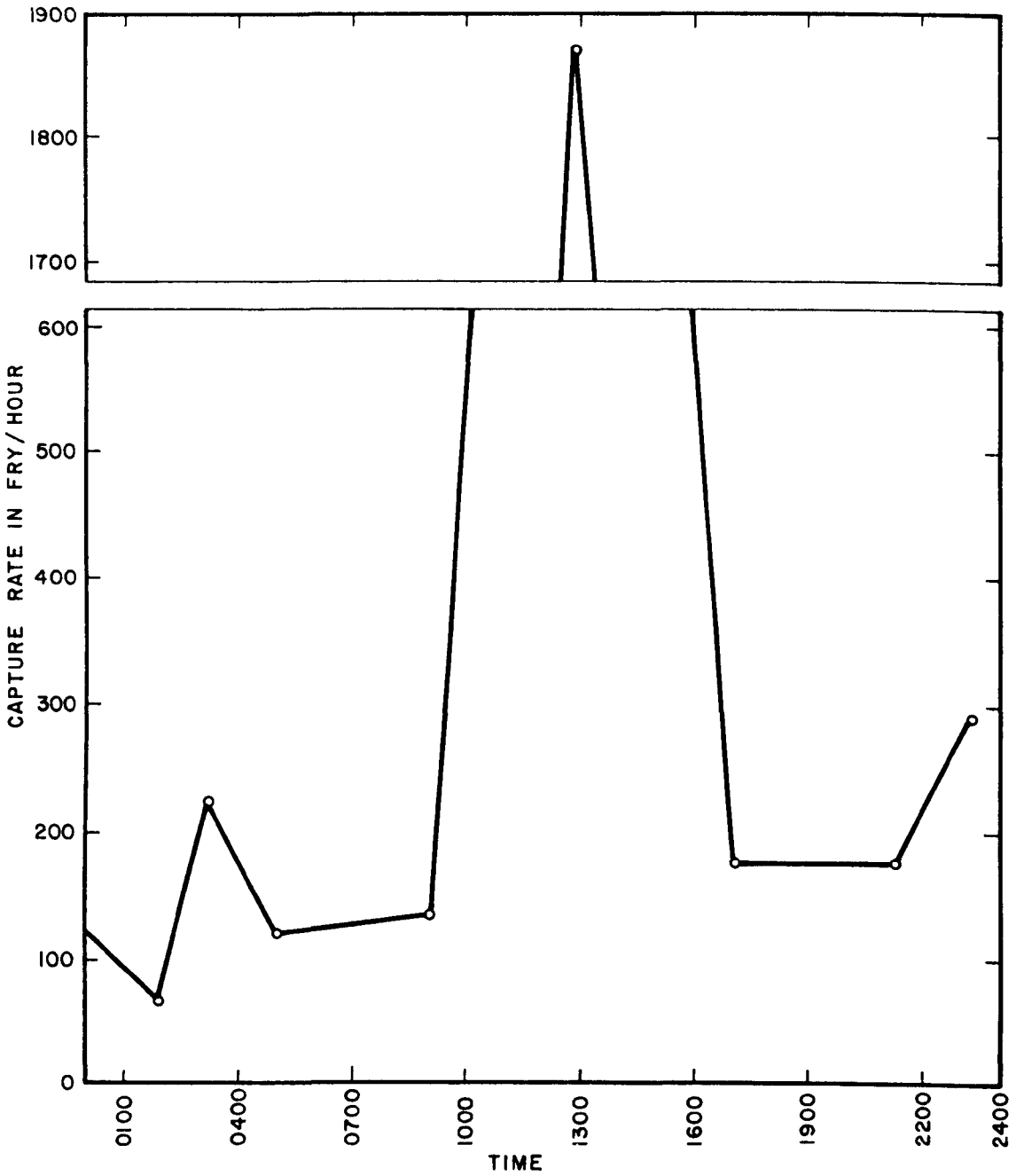

FIGURE 3

FRY CAPTURE RATES OVER A 24-HOUR PERIOD
BASED ON INTERMITTENT 15-MINUTE CAPTURE PERIODS

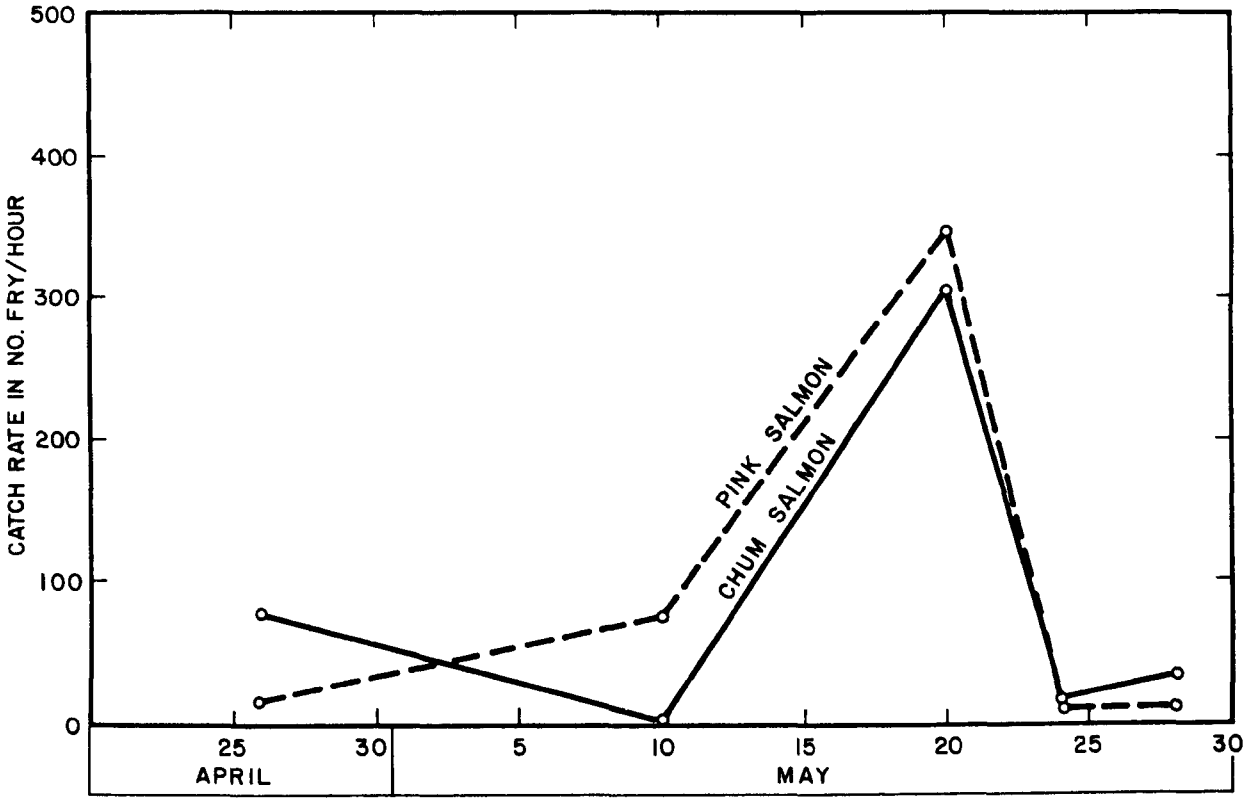

FIGURE 4

DOWNSTREAM MIGRATING PINK AND CHUM SALMON FRY
IN LOOP ROAD CREEK NO. 2
AS REFLECTED IN NIGHT TRAP CATCHES

TABLE 3

SUMMARY OF ISLAND FLATS SALMON FRY SHORELINE OBSERVATIONS

NUMBER OF FRY OBSERVED WITHIN DESIGNATED SHORELINE SEGMENTS

Shoreline Segment*	4/24	4/26	4/29	5/3	5/6	5/10	5/13	5/16	5/20	5/23	Mean No. Fry Per 100 Ft. of Shoreline
1	0	0	0	2100	1050		675	0	40	30	30.3
2		780	1500	70	0	0	170	0	23	0	30.4
3	500	20	3100	7615	5080		700	0	115	50	74.3
4		0	400	90	100	400	0	0	20	0	8.7
5		0	0	380	100		0		3	350	13.8
6	100	40	0	0	0		0		0	120	1.6
7		120	0	50	60		0			0	4.1
8	0	60	0	1130	50		0	30	0	0	16.4
9	0	110	100	175	750	200	0		0	0	10.9
10		935	100	275	0	0	10	80	210	25	6.4
11		0	0	20	0		0		0	0	0.1
12		70	0	20	0		5			0	1.1
13		0	120	250	0		0		0	0	3.7
14	550	25	0	0	0		0		0	0	5.0
Totals	1150	2160	5320	12175	7190	600	1560	110	411	575	

*see Figure 5

the study in the Mineral Creek Islands area. Visibility varied, depending on wind, sun, and turbidity. Therefore, some of the observations are incomplete. Turbidity generally increased toward the end of the study period. Fry were observed in schools ranging from 10 to about 500 fish. They were usually seen within three feet of shore and appeared to prefer abrupt shoreline habitats where currents were minimal. This behavior conforms with that observed by other investigators (Mattson 1971; Cooney et al. 1978).

No fry were observed on the south shore of Port Valdez. Preliminary observations, as well as indications of very poor 1978 pink salmon escapements, suggested that intense investigation of the south shore area would not be fruitful. The greatest effort was expended within the area where salmon fry were known to be entering the estuary. Salmon fry were seen along nearly all the abrupt shoreline habitats within the Island Flats/Mineral Creek Islands area. The greatest number of fry was consistently observed along the south shore of Dock Point (Figure 5, Shoreline Segment 3). Discrimination between chum and pink salmon was not posssible during these observations. However, seine samples contained only chum salmon and it is likely that most of the fish observed were chum.

The number of fry observed over the study period suggests that fry utilized the Island Flats/Mineral Creek Islands habitat for a period of at least a month with peak use occurring in early May (Figure 6). Decreased visibility during the last half of May because of increased glacial silt from the Lowe River and the Valdez Glacier Stream may have partly accounted for the decrease in numbers of fry observed in that time period.

The length distribution of fry caught within the estuary suggests that schools consisted of fry of mixed ages (Figure 7). For example, fry caught on May 10 ranged in size from 34 to 45 millimeters (mm). The age of these fish probably ranged from a few days post-

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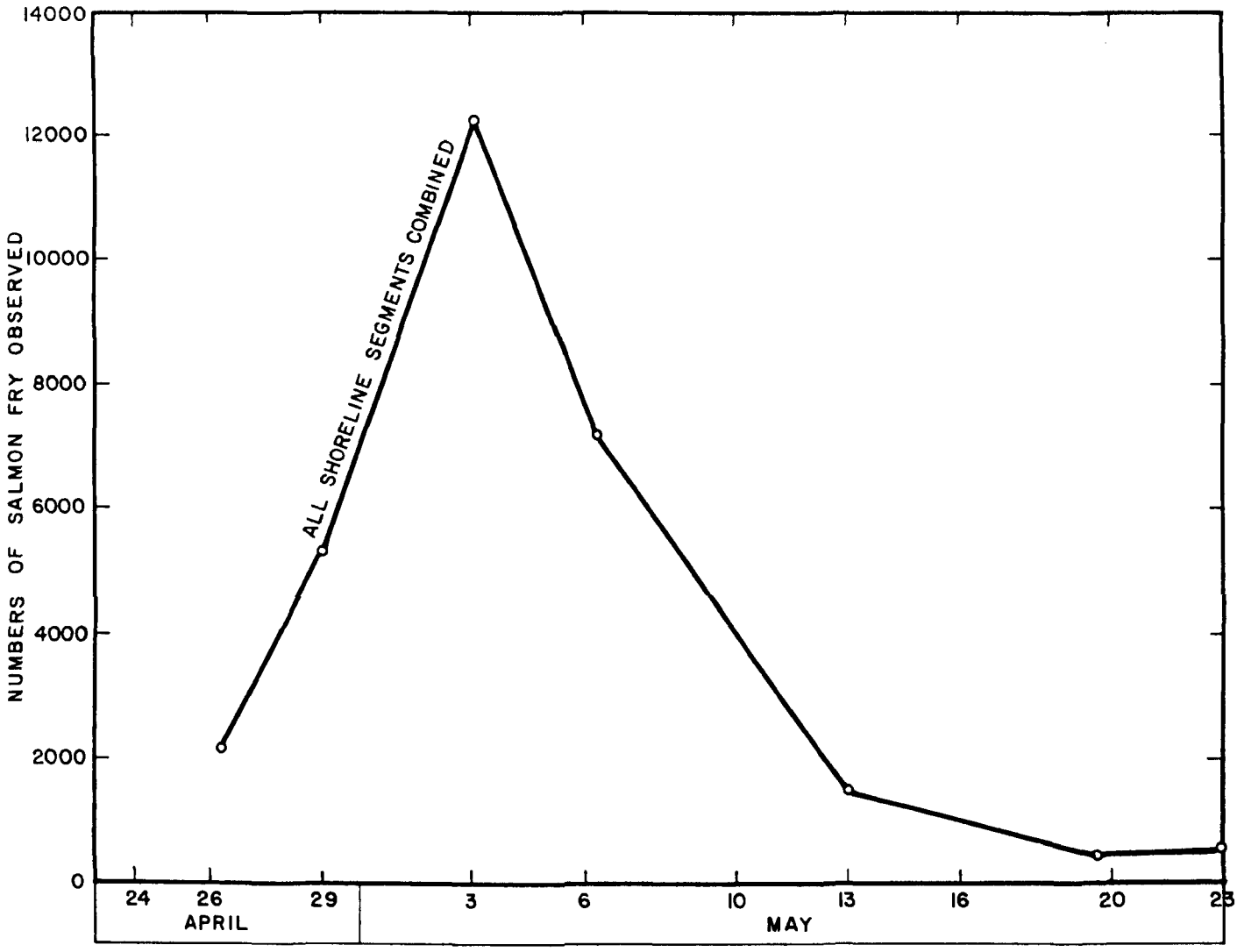

FIGURE 6

NUMBERS OF SALMON FRY OBSERVED
IN THE ISLAND FLATS / MINERAL CREEK AREA
VS. OBSERVATION DATE

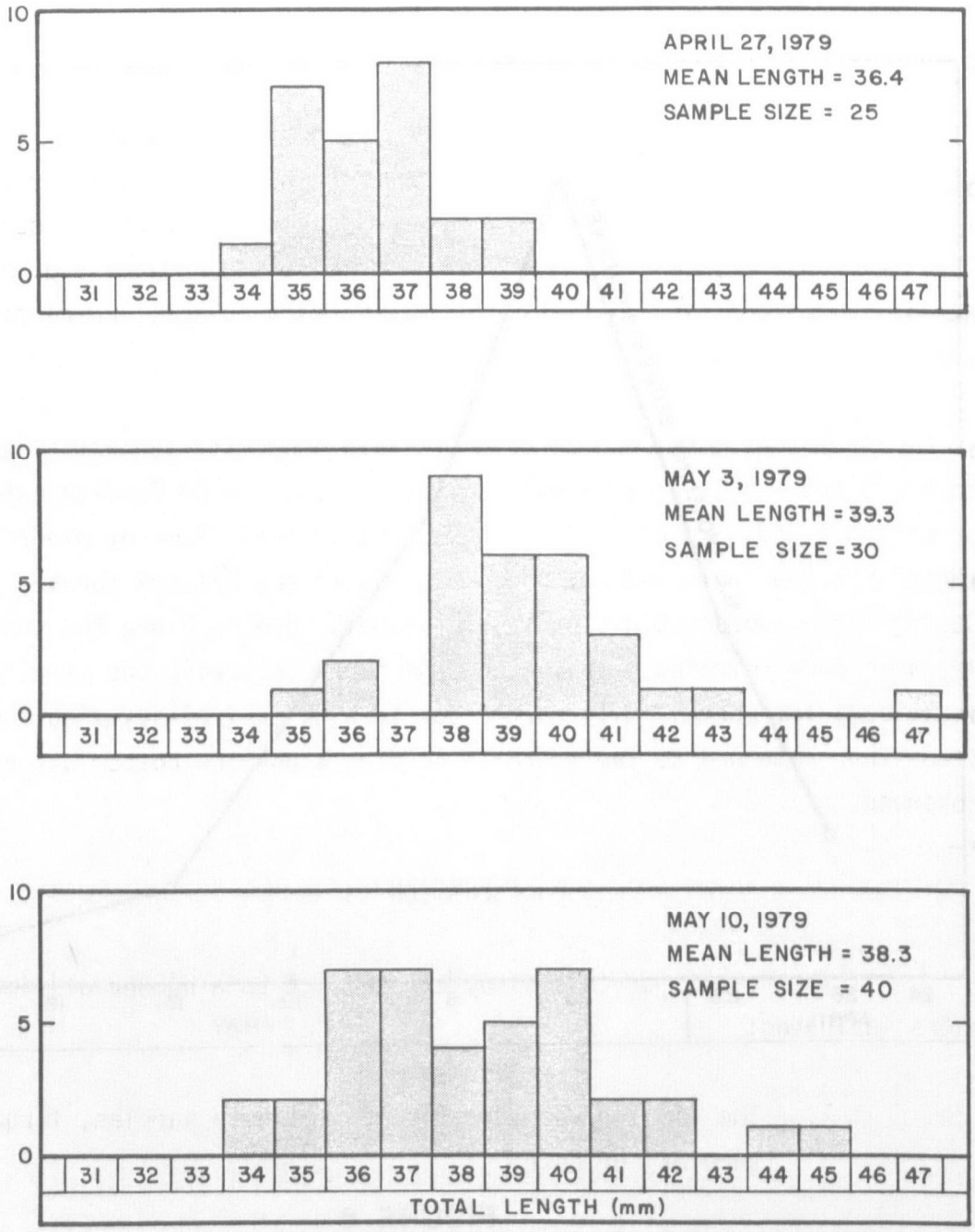

FIGURE 7

LENGTH DISTRIBUTIONS OF CHUM SALMON FRY FROM ISLAND FLATS

emergence to about four weeks post-emergence, based on a growth rate of 2 to 3 mm per week (Cooney et al. 1978) and an average size at emergence of 33 mm.

Food Habits

The examination of five chum salmon fry from City Limits Creek and three from Loop Road No. 2 Creek, sampled on April 26, indicated that the fry began feeding as soon as the yolk was completely absorbed. Three of the eight fry contained yolk fragments and had empty digestive tracts. The remaining five fry had been feeding on small unidentified copepods and chironomid larvae.

Six chum salmon fry caught within shoreline segments 9 and 10 on May 3 and May 10 were examined. These fry had been feeding extensively on calanoid and harpacticoid copepods. Other food items of minor importance included cyclopoid copepods, Hyperiidae and Diptera larvae. During visual observations of salmon schools feeding along the shoreline, fry were seen swimming slowly along the shore following the tidal edge. Individual fry occasionally darted out to pick up free-swimming food items then returned to the school. Feeding along the bottom was not observed.

DISCUSSION

The results of this study are subject to a number of limitations including:

1. The limited scope precluded replicate samples, large samples, or both.

2. Environmental variation -- particularly in regard to tides, water clarity, and weather -- often interfered with sampling or observations.

The data should be interpreted in light of these limitations. Nevertheless, it is felt that a fairly complete picture of early chum salmon life history can be derived from the data.

Emergence of chum salmon in City Limits Creek occurred over a period of about five weeks beginning in mid-April and continuing until late May. Emergence in the other streams appeared to lag 2 to 3 weeks behind. Substantial numbers of fry remained and fed in the upper intertidal portions of City Limits Creek for several weeks, whereas others outmigrated to the estuary soon after emergence. During high tides the fry moved in schools and fed along abrupt rocky shorelines and within flooded marsh areas. The fry fed primarily on free-swimming and epibenthic copepods and thus entered into the food web of the Island Flats ecosystem. Since the swimming ability of these small fish is limited, their movements must depend to a considerable extent on tidal currents. No data were collected regarding their behavior during low tide, but it seems likely that some may have concentrated in the creek channels within Island Flats and others may have retreated with the tidewater beyond the Mineral Creek Islands. Chum salmon fry utilized the study area at least during the late April to late May period and some individual fry probably spent three to four weeks in the area. The last successful shoreline survey was on May 23 and by June 1 the water of eastern Port Valdez was too turbid because of the influx of glacial meltwater to continue observations. It is likely that the fry abandon the Mineral Creek Islands when the water becomes too silty and head seaward, but this has not been confirmed.

The above scenario is similar to that reported for chum salmon by investigators in other areas (Healey 1979). The data contradict to some extent the conclusions of Mattson (1977) who indicated that fry move rapidly out of eastern Port Valdez, generally entering Valdez Arm in less than three weeks. It is likely, however, that much of Mattson's data were based on pink salmon rather than chum. The literature suggests that pink salmon fry have less tendency to remain in proximity to their home streams than do chum salmon and tend to favor different kinds of shallow water environments (Cooney et al. 1978).

The fate of salmon fry outmigrating from the Lowe and Robe River systems is not known. However, it seems possible that some of these fry would be moved into the Mineral Creek Islands area by the weak counterclockwise currents in eastern Port Valdez (Sharma and Burbank 1973). Some of the fry observed during shoreline surveys in the Mineral Creek Islands might have originated from the Lowe and Robe Rivers rather than Island Flats streams. Fry originating from Dayville Flats, Solomon and Allison Creeks also might end up on the north shore but this seems less likely. Mattson (1971; 1974; 1977) observed small numbers of fry around Jackson Point and at points on the south shore at the west end of Port Valdez. The fry from the south shore streams (primarily pink salmon) might swim actively seaward against the weak prevailing currents.

This study demonstrates that at least some of the chum salmon fry originating in eastern Port Valdez streams ecologically depend on the Island Flats/Mineral Creek Island area for varying periods of time. Selective feeding by chum salmon fry on harpacticoid copepods has been documented in several divergent areas (Healey 1979; Simenstad 1976) and suggests a dependency on certain kinds of shallow water habitats. A series of recent studies in Nanaimo Estuary in British Columbia (Healey 1979; Sibert 1979; Naiman and Sibert 1979) have established direct links between the production of chum salmon and the detritus-based estuarine ecosystem. It is likely that this interdependence also exists within the similar Island Flats ecosystem.

The chum salmon fry would be expected to be vulnerable to disturbance during the period of time spent in the Island Flats/Mineral Creek Islands area because of the large numbers of fry present in a reasonably small area and because of the probable benefit that the fry derive from the area. Artificially increased turbidity could interfere with feeding, and fry schools could be mechanically disrupted if activities were to occur in this area during the April 15 to May 31 period. It appears from the very limited data that the south shore of eastern Port Valdez is not particularly sensitive in regard to pink and chum salmon. Locally produced pink salmon fry probably pass through the Solomon/Allison

Creek shoreline zone but large concentrations or prolonged residence is unlikely.

It is strongly recommended that a follow-up study be conducted in an even year (1980) when pink salmon fry would be expected to be abundant. The early life history of pink salmon appears to be slightly different from that of chum salmon and the numbers of pink salmon fry in an even year would be expected to be much greater than the number of chum salmon fry. In addition, the salmon streams on the south shore of Valdez are used almost exclusively by pink salmon. An even year study would allow a more complete evaluation of the sensitivity of the south shore area.

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Oceanography

OCEANOGRAPHY

REPORT TO
CCC/HOK-DOWL
ON
OCEANOGRAPHIC STUDIES
OF ALPETCO DISCHARGE
IN PORT VALDEZ, ALASKA

October, 1979

VOLUME I - REPORT

METCALF & EDDY, INC. / ENGINEERS
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Metcalf & Eddy, Inc.
Engineers & Planners

October 18, 1979

J-6341

Mr. John E. Paulson
Project Manager
CCC/HOK-DOWL
4040 B Street
Anchorage, Alaska 99503

Dear Mr. Paulson:

In accordance with our agreement dated July 12, 1979, we are pleased to submit our report on Oceanographic Studies relative to the environmental impact on Port Valdez from the construction and operation of the proposed Alaska Petrochemical Company's facilities in Valdez.

Although this report was prepared by Metcalf & Eddy, it also reflects materials and findings of other agencies, firms, and individuals. Their participation and contributions are acknowledged in the report.

The study was conducted by Dr. Abu M.Z. Alam, Mr. David R. Bingham, and other members of our staff under the direction of Jekabs P. Vittands.

We also wish to acknowledge the cooperation and assistance given by your staff, the various other members of the project team, and the involved public agencies.

Very truly yours,

Jekabs P. Vittands
Vice President

JPV:alh

NEW YORK PALO ALTO CHICAGO

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CHAPTER 1

INTRODUCTION

General

This report describes the oceanographic investigations made in Port Valdez, Alaska, as part of the preparation of an environmental impact statement (EIS) required by the U.S. Environmental Protection Agency (EPA) for a project planned by the Alaska Petrochemical Company (ALPETCO).

Port Valdez

Port Valdez is the northeastern extension of Prince William Sound in south-central Alaska. As shown in Figure 1-1, the fjord of Port Valdez extends about 23 km (kilometers) eastward from Valdez Narrows, its narrow silled entrance. The City of Valdez is at the northeast corner of the Port while the Alyeska Marine Terminal, the southern end of the Alaska Pipeline, is on the south shore at Jackson Point.

Port Valdez is about 5 km wide and 18 km long with steep sides on the north and south. It has a nearly horizontal bottom at a depth of about 240 m (meters) over three-quarters of its length. In its easternmost quarter, the bottom rises rather uniformly to the eastern shore at the former townsite of Valdez. The maximum depth of Port Valdez is 247 m (in the southwestern corner) while the overall mean depth of the fjord is about 180 m. At Valdez Narrows, there is a sill with maximum depth of

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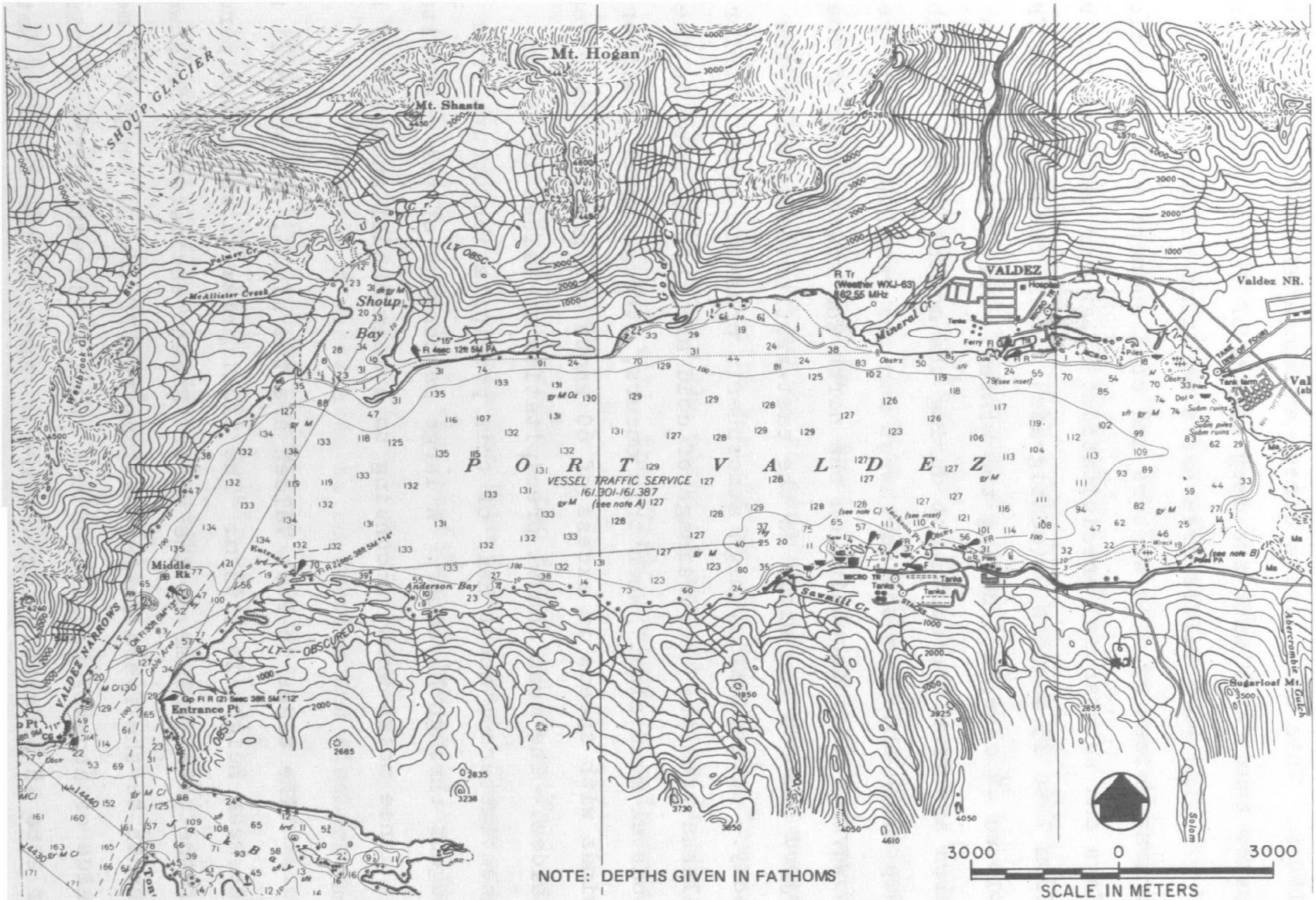

FIG. 1-1 PORT VALDEZ

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160 m. This sill limits direct exchange of Port Valdez water below that depth with the deep waters of Prince William Sound.

The Port Valdez area has a maritime climate that is characterized by mild winters and cool summers with many cloudy days and substantial precipitation. Mean air temperatures range from 7 to 13 degrees C (centigrade) during the summer and from -10 to -4 degrees C during the winter. Prevailing winds in the area are from the southwest during the months of May through September and from the northwest for the remainder of the year. However, steep mountains on the north and south sides of the fjord channel the winds to the east-west orientation of the water body. Occasionally, high atmospheric pressure over interior Alaska promotes the drainage of cold air through gaps in the coastal mountains. When this occurs, strong easterly winter winds with speeds in excess of 60 knots are produced over Port Valdez. The mean annual precipitation at Valdez is 158 cm (centimeters); about half of this precipitation occurs from August through November. A large percentage of the precipitation is dense moist snow, amounting to a mean annual snowfall of 620 cm.

The tides in Port Valdez are the mixed, semi-diurnal type; the mean height is 3.05 m. The tidal prism is about 1.6 percent of the total volume of the Port. Recent estimates of freshwater inputs to the fjord during maximum runoff (July) suggest a mean value of about 7 percent of the tidal prism with extreme values of 2 to 15 percent. The seaward movement of the brackish water generally occurs in the upper 15 m of the water column.(1)

Description of the Project

The proposed project entails the construction and operation of ALPETCO's refinery and petrochemical facility at the eastern end of Port Valdez. The facility is expected to start up in 1982 and be fully operational in 1984.

The project includes a 150,000 barrels per day refinery using latest proven technology to process crude oil and produce unleaded gasoline, jet fuel, No. 4 fuel oil, benzene, toluene, xylene, clarified oil, naphtha, and sulfur for sale or use as petrochemical feedstocks. Sufficient by-product fuel will be produced during processing to generate all necessary steam and electrical power, and to satisfy process energy requirements. All fuel burned within the plant is expected to be in the form of desulfurized gas and will, therefore, present no extraordinary environmental problems.

As part of the project, two docks and an outfall pipeline and diffuser will be extended into Port Valdez. These are shown in Figure 1-2 along with the locations of the existing City of Valdez and Alyeska treated wastewater discharges.

Sources of wastewater to be treated and discharged into Port Valdez are process operations, process area stormwater runoff, and ballast water. Since air cooling will be used, no cooling water discharges are expected. Also sanitary wastes are expected to be discharged to the City of Valdez water pollution control facilities for treatment and discharge. The expected average wastewater flow to be treated is about 0.31 cms (cubic

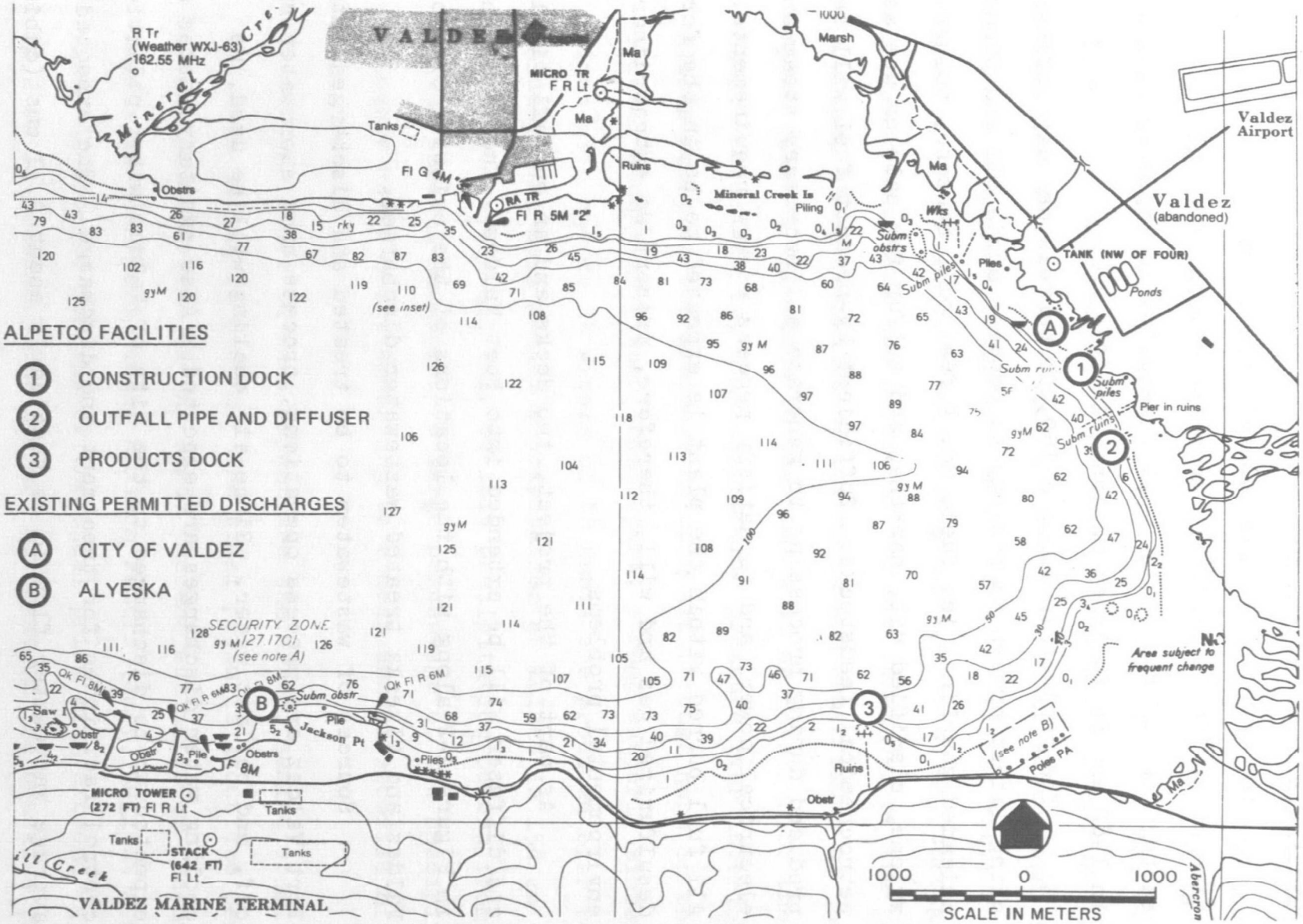


FIG. 1-2 LOCATION OF PROPOSED ALPETCO FACILITIES WITHIN PORT VALDEZ

meters per second). The expected sanitary flow is about 0.001 cms.

Wastewater treatment will include primary separation of materials less dense than water, equalization to ensure uniformity of wastewater to be treated, dissolved air flotation for further oil and suspended solids removal, biological treatment for the removal of organic materials, and filtration for further suspended solids removal. The draft application for a National Pollutant Discharge Elimination System (NPDES) Permit for ALPETCO is presented in Appendix A.

Scope of Study

Available literature was reviewed to determine oceanographic and water quality conditions in Port Valdez, as they relate to the proposed project. A limited field measurement program was carried out to provide additional oceanographic data.

Studies of the proposed discharge's initial dilution in the near field, its circulation and dispersion in the intermediate field, and its overall flushing from Port Valdez were conducted. Also, estimates were made of annual sediment loads entering Port Valdez, as a basis for predicting relative sediment impacts from the proposed project.

Impacts expected on Port Valdez water quality from the proposed discharge and from activities during construction were studied and commented on.

Study Participants

Metcalf & Eddy was assisted in preparing the study by the following individuals and organizations.

Consultant Board. The following Consultant Board advised on the approaches taken, on the review of results and on the formulation of findings:

Dr. E. Eric Adams, Research Associate
Ralph M. Parsons Laboratory for Water Resources
and Hydrodynamics
Massachusetts Institute of Technology

Dr. Joseph M. Colonell, Professor
Institute of Marine Science
University of Alaska

Dr. Donald R.F. Harleman, Professor and Director
Ralph M. Parsons Laboratory for Water Resources
and Hydrodynamics
Massachusetts Institute of Technology

Field Oceanographic Studies Under the direction of Dr. Joseph M. Colonell, the Institute of Marine Science at the University of Alaska conducted the oceanographic measurements for Metcalf & Eddy.

Sedimentology. On the basis of existing available data, estimates of the sediment load entering Port Valdez were made by Research Planning Institute, Inc., under the direction of Dr. Miles O. Hayes.

Field Program

On behalf of Metcalf & Eddy, a field program was undertaken by the Institute of Marine Science, University of Alaska, to collect essential physical oceanographic data in parts of Port Valdez. This program was limited to providing measurements

essential in determining the initial dilution and possible circulation at the proposed ALPETCO discharge. These measurements also were necessary in observing the exchange of water between Port Valdez and Prince William Sound. Measurements consisted of currents, salinity, temperature, and density of eastern waters of Port Valdez near the proposed ALPETCO discharge, and currents at Valdez Narrows.

On May 12, 1979, continuous recording current meters were deployed at three stations shown in Figure 1-3. Each eastern Port station consisted of three meters, while the station at Valdez Narrows had four meters. At the same time, salinity, temperature, and density (STD) profiles were obtained at locations shown in Figure 1-4.

A subsequent field effort on July 28-30, 1979 provided for the recovery of the current meters and an additional set of STD profiles at both low and high tide. A detailed report of the field results is included in Appendix B.

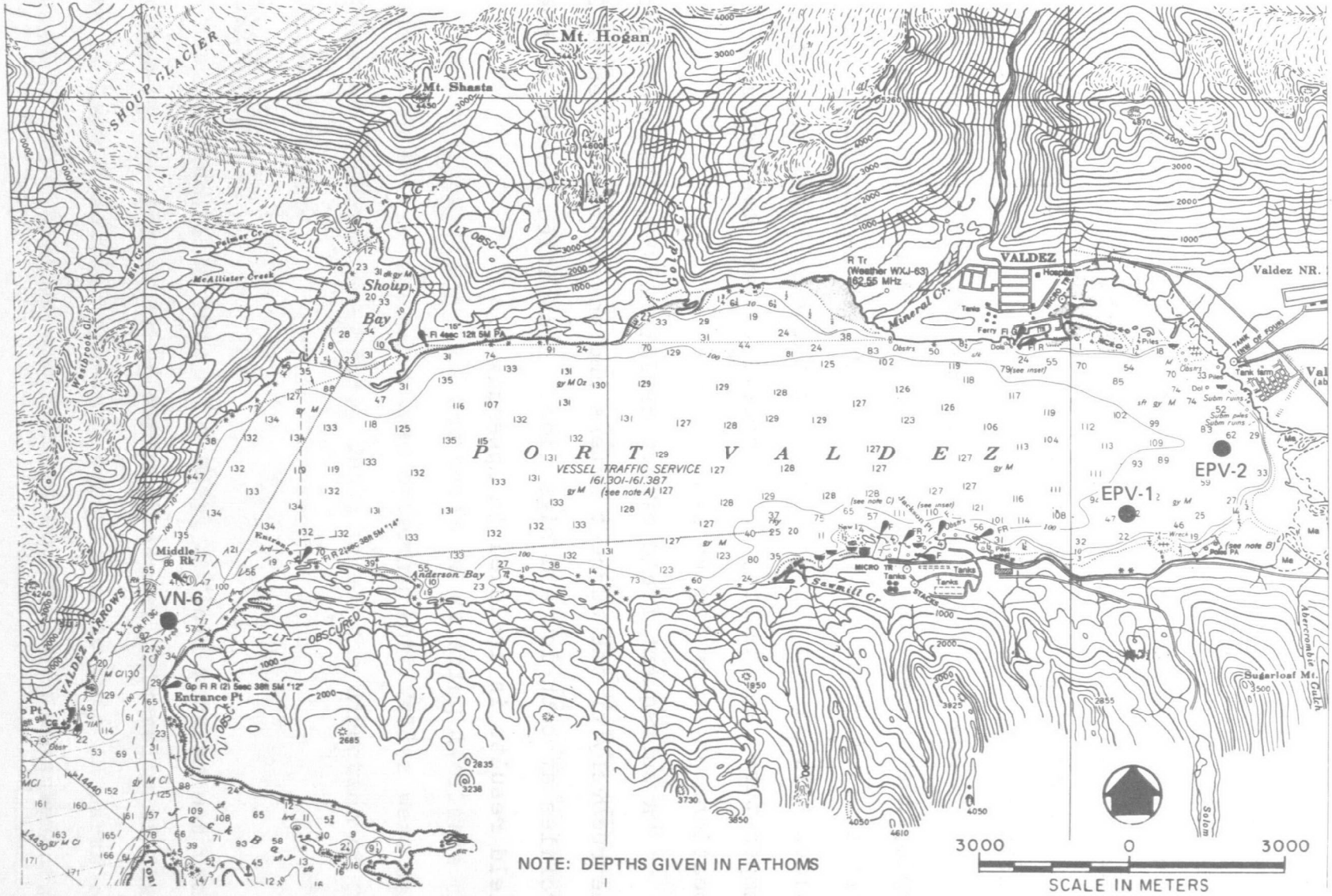


FIG. 1-3 LOCATION OF CONTINUOUS RECORDING CURRENT METER STATIONS

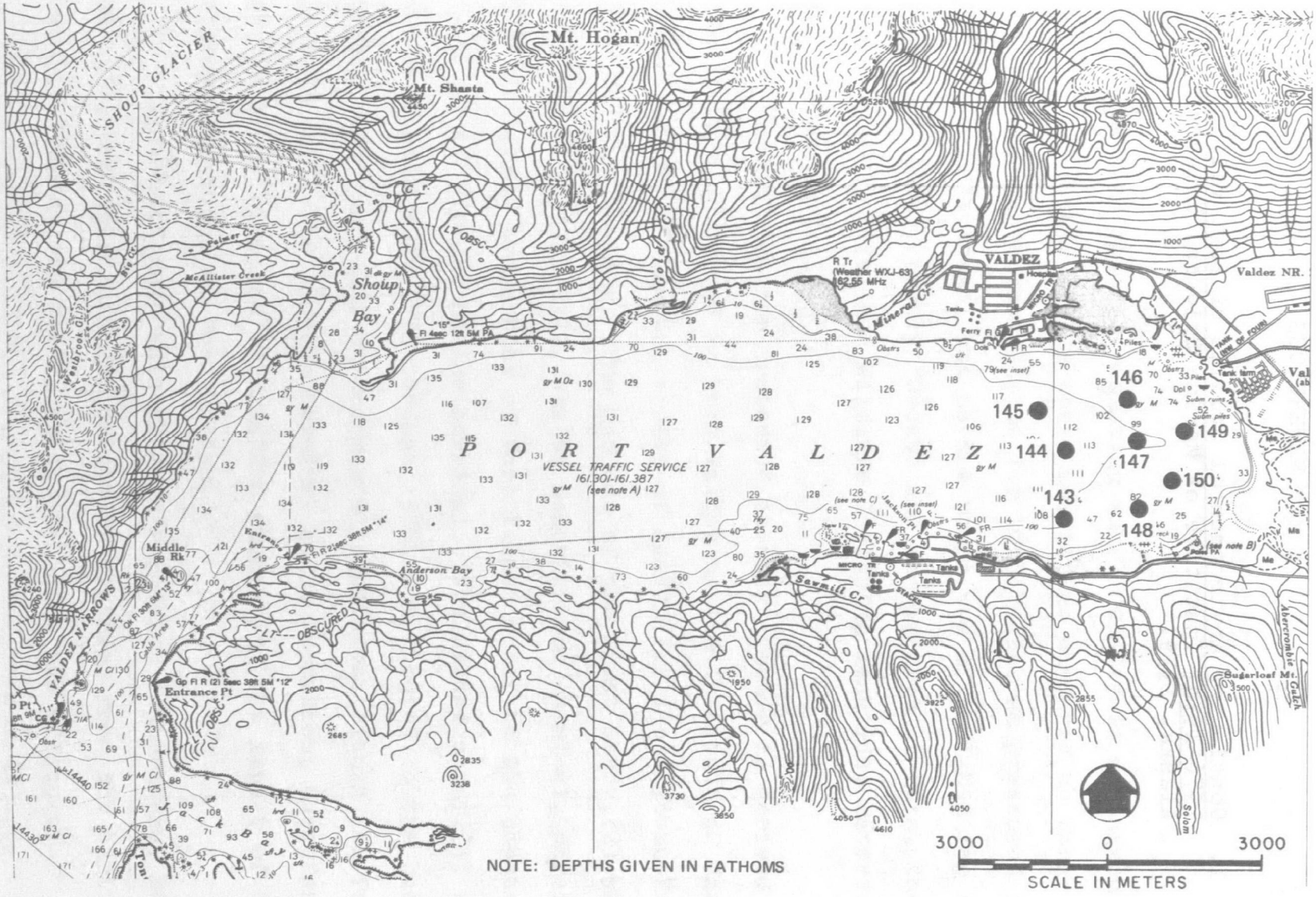


FIG. 1-4 LOCATION OF SALINITY-TEMPERATURE-DENSITY (STD) PROFILE STATIONS

REFERENCES

1. Continuing Environmental Studies of Port Valdez, Alaska, 1976-1978, Institute of Marine Science, University of Alaska, 1979.

CHAPTER 2

EXISTING WATER QUALITY

General

In this chapter, existing water quality is discussed based on available data. This water quality is compared to water quality standards established for Port Valdez as presented in Table 2-1. As shown, the marine water use established for Port Valdez is II(c), namely "Growth and Propagation of Fish, Shellfish, Aquatic Life, and Wildlife Including Seabirds, Waterfowl and Furbearers".(1)

The information presented in this chapter is derived from two studies conducted in Port Valdez by the Institute of Marine Science (IMS) of the University of Alaska for the Alyeska Pipeline Service Company. The purpose of the first study,(2) which took place in 1971-1972, was to describe the chemical, physical and biological properties of Port Valdez prior to the construction of the Alyeska marine terminal. The second study,(3) which was conducted from 1976 through 1978, contributed to the background data regarding environmental conditions within the Port. In July 1977, the Alyeska terminal began operation; therefore the second study obtained information describing the impact of the Alyeska discharge on Port Valdez.

Information in this chapter regarding temperature, DO, pH, salinity and nutrients was primarily gathered from the earlier report. The second study, which discussed the effect of

TABLE 2-1. COMPARISON OF WAT
WITH EXISTING WATER QUALI'

Parameter	Water quality standard outside of ZID Category II(C)	Background levels(1),(2)
Dissolved oxygen	a. Surface water (to 1 meter depth) must be greater than 6 mg/l DO. b. Below surface, DO must be greater than 4 mg/l. c. DO may never exceed 17 mg/l. d. In estuaries and tidal tributaries, DO shall not be less than 5 mg/l unless natural conditions cause this value to be depressed.	1. Near proposed site, lowest measured DO at 1 meter above bottom was 7.6 mg/l. 2. Lowest observed DO was 6.7 mg/l.
pH	a. Lowest pH allowed - 6.5. b. Highest pH allowed - 8.5. c. Variation of pH for waters naturally outside specified range shall be towards the range. d. No variation of more than 0.1 pH unit from natural condition.	1. Lowest surface water observed in winter, pH = 8.1 2. Highest surface water observed in summer, pH = 8.86. 3. Lowest observed in bottom waters in winter, pH = 7.96.
Turbidity	a. Shall not exceed 25 NTU. b. Shall not reduce depth of compensation point by more than 10 percent. c. Shall not reduce maximum Secchi disk depth by more than 10 percent.	No NTU turbidity data is available.
Temperature	a. Weekly average temperature will not increase by more than 1 degree C. b. Normal daily cycles shall not be changed in amplitude or frequency. c. Maximum rate of change must be less than 0.5 degrees C per hour.	No weekly average temperature data is available.
Dissolved inorganic substances (salinity)	a. Isohaline patterns may not change by more than 10 percent. b. Maximum allowable change: 1 o/oo if naturally 0-35 o/oo; 2 o/oo if naturally 13.5-35 o/oo.	1. Least saline at eastern end of Port Valdez. 2. In August, surface water 1 o/oo. 3. Typical salinity measurements between 25 o/oo and 33 o/oo.

TABLE 2-1 (Contin WITH EXIST

WATER QUALITY STANDARDS PORT VALDEZ

Parameter	Water outside of ZID Category II(C)	Background levels(1),(2)
Sediment	a. No measurable increase in concentrations above natural conditions	No data available
Toxic and other deleterious organic and inorganic substances	a. See EPA Quality Criteria for Water and Alaska Drinking Water Standards b. OR 0.01 times the lowest measured 96-hr LC_{50} for most biologically sensitive species (whichever value is less)	As, Cr, Cu, Hg, Ni and Se are all within "generally established range". Two values of Al found above range and one value of Cd found above range.
Color	a. Shall not exceed 60 color units. b. Shall not reduce depth of compensation point by more than 10 percent from seasonal norm.	No data available.
Petroleum hydrocarbons, oil and grease	a. Total HC in water column shall not exceed 15 ppb or 0.01 times the 96-hr LC50 for most biologically important species (whichever is less). b. Aromatic HC shall not exceed 10 ppb. c. No concentration allowed that causes deleterious effects on aquatic life. d. No floating oil, film, sheen or discoloration on surface waters or adjoining shoreline.	Most samples analyzed contained less than 1.0 ppb saturated and unsaturated hydrocarbons. Never found greater than 10 ppb.
Total chlorine residual	a. Concentrations shall not exceed 2.0 µg/l for salmonoid fish or 10.0 µg/l for other organisms.	No data available.
Residues, floating solids, debris, sludge deposits, foam scum	a. Shall not make water unfit or unsafe for use, cause a sludge or solid to be deposited, cause a sheen or discoloration on surface or shoreline, nor cause a sludge, solid or emulsion to deposit beneath or in water.	No data available.

1. All background levels derived from Environmental Studies of Port Valdez, Alaska, Institute of Marine Science, 1973, with the exception of the background levels for petroleum hydrocarbons, oil and grease, which are derived from Continuing Environmental Studies of Port Valdez, Alaska, 1976-1978, Institute of Marine Science, 1979.
2. No violations of Category II(C) Water Quality STandards were observed.

hydrocarbons on the biota of the Port and presented existing concentrations of metals, is the source of the information in this chapter on hydrocarbons and other pollutants.

Background Conditions

Dissolved Oxygen. As mentioned, the first IMS study reported the dissolved oxygen concentrations in Port Valdez. During the winter, DO concentrations of 7.6 mg/l (milligrams per liter) were measured at 1 meter from the bottom. Measurements taken in March at one meter from the bottom indicated DO concentrations of 8.8 mg/l. It is apparent from these measurements that oxygen replenishment occurs in Port Valdez between December and March. This replenishment appears to result from an annual overturn during which surface and bottom waters are mixed.

Dissolved oxygen concentrations in the surface waters of Port Valdez were found to be fairly high throughout the year. Values of 10.6 mg/l have been recorded during the summer months when there are periods of high plant productivity. Minimum dissolved oxygen concentrations were found in the bottom waters during winter; however, concentrations less than 6.7 mg/l have not been recorded in either Port Valdez or Valdez Narrows. In summary, DO concentrations in Port Valdez are very high and will not violate the water quality standards.

pH. Variations in the pH of the surface waters of Port Valdez correspond to periods of minimum and maximum biological productivity. These occur in December and July, respectively. This is common in marine waters and typically results from the production of carbon dioxide during biological decomposition.

A surface water pH of 8.1 was measured in December. In the bottom waters during the winter, the lowest recorded pH value was 7.96. It was found that during December the pH decreased linearly with depth. In July, a surface water pH of 8.86 was recorded during the first IMS study. As shown in Table 2-1, this value exceeds the maximum pH permitted by the water quality standards. It does not constitute a water quality violation, however, because the cause is of natural origin.

Temperature. A maximum surface water temperature of 15 degrees C (centigrade) has been observed in the summer in Port Valdez. In the winter, a surface water temperature of 2.44 degrees C has been recorded. At depths greater than 75 meters, the temperature typically ranges between 3 and 6 degrees C. Maximum stratification occurs in late July or early August. This results from the increase in the surface water temperature due to solar warming and the decrease in surface water salinity due to the addition of freshwater from precipitation and melting snow and glaciers. During the summer, surface waters at the western end of Port Valdez are warmer than those at the eastern end. The maximum temperature difference is about 6 degrees C.

Dissolved Inorganic Substances. The seasonal variation in salinity in the upper 20 meters of Port Valdez is substantial. Large volumes of glacial runoff contribute to the low salinity values (less than 1.0 o/oo (parts per thousand)) observed during the summer. A maximum salinity of 32.38 was observed during March 1972.

Below the upper 20 meters of the water column, the salinity generally varies between 28 o/oo and 32.5 o/oo. In the summer, the eastern end of Port Valdez has been observed to have a salinity approximately 10 o/oo less than that of the western end.

Nutrients. Seasonal cycles of nitrogen, phosphate and silicon were observed during the first IMS study.(3) Because nitrogen is considered the limiting nutrient in marine waters, this discussion presents the seasonal variations in nitrogen found during the study.

The concentration of ammonia within the sunlight-influenced euphotic zone reached its annual maximum of about 35 mg/l (micrograms per liter) during the late spring. Concentrations of nitrate (NO_3-N) in the euphotic zone were greatest during the periods of deep vertical mixing in the winter. The maximum concentration measured was 280 µg/l NO_3-N. An abrupt decrease in the concentrations of these nutrients occurred in the spring. Reported measurements were 2.8 µg/l NO_3-N. Below the euphotic zone, nitrate concentrations were found to increase with depth. The NO_3-N concentration measured at the bottom was 322 µg/l. These values represent normal conditions found in marine waters.(4)

Toxic and Other Deleterious Organic and Inorganic Substances. Table 2-2 summarizes the measured concentrations of heavy metals in Port Valdez and their relationship to generally established concentration ranges. As shown in Tables 2-1 and

TABLE 2-2. CONCENTRATIONS OF METALS IN PORT VALDEZ

Element	Generally established concentration range in marine systems water, ppb	Measured concentration in Port Valdez, ppb	
		Average	Maximum
Aluminum	1-10	<5	20
Arsenic	15-37	<5	30
Cadmium	≈0.1	≈0.03	≈0.30
Chromium	4-100	≈0.4	≈4.0
Copper	0.6-30	<0.5	25
Lead	≈2	No data available	
Manganese	3-20	No data available	
Mercury	8-36	≈0.01	0.20
Molybdenum	6-16	No data available	
Nickel	0.43-43	<0.3	3.5
Selenium	0.01-0.5	<0.1	-
Silver	1-30	No data available	
Vanadium	1-4	No data available	
Zinc	≈10	No data available	

Information from Continuing Environmental Studies of Port Valdez, Alaska, 1976-1978, Institute of Marine Science, University of Alaska, 1979.

2-2, maximum values of aluminum (Al) and cadmium (Cd) exceeded the generally established range in marine systems. In the case of Al, this represents only one value which is not directly over the Alyeska diffuser and is attributable to a chemical addition in the treatment of ballast water prior to discharge. This chemical addition is reportedly no longer practiced by Alyeska, however.

In the case of Cd, almost all measurements fall at the low detectable limit range of 0.01 ppb (parts per billion). The one value at 0.30 ppb does not represent general conditions found in Port Valdez waters.

According to the IMS's Continuing Environmental Studies of Port Valdez, "Port Valdez was and is a clean to very clean environment in all aspects with respect its trace element content."(3)

Petroleum Hydrocarbons, Oil and Grease. Water column monitoring was conducted by the Institute of Marine Science by analyzing unfiltered samples.(3) Concentrations of saturated and unsaturated hydrocarbons were generally found to be less than 1.0 ppb. A few water samples were found to contain higher amounts of hydrocarbons, but concentrations in excess of 10 ppb were never observed, except near the Alyeska diffuser. Water samples collected directly above the Alyeska diffuser have been found to contain between 44 and 104 ppb total hydrocarbons. Water samples collected at points approximately 1.0 km from the diffuser were found to contain no hydrocarbons of ballast water origin.

Existing Discharges

Currently, Port Valdez receives treated wastewater from two permitted sources, the City of Valdez wastewater treatment plant and the Alyeska Pipeline Service Company ballast water treatment plant. Figure 2-1 shows the location of these two discharges. Effluent from the ballast water treatment plant is discharged into Port Valdez at depths ranging from 65 meters to 75 meters through a 61 meter long diffuser. The City of Valdez discharges treated wastewater into a stream which flows into Port Valdez.

City of Valdez Discharge. The effluent limitations portion of the NPDES permit for the City of Valdez, presented in Table 2-3, summarizes the permissible discharges from the treatment lagoon. Recent treatment plant reports(5) indicate that the maximum flow through the plant occurs in late spring. The maximum effluent flow rate measured in May of 1979 was 0.042 m^3/sec (cubic meters per second) or 0.961 mgd (million gallons per day). Reports also indicate that the plant is achieving effluent BOD and SS concentrations below the maximum allowable effluent concentrations. During a four-month period in 1979, the maximum suspended solids concentration observed in the effluent was 41.0 mg/l while the maximum monthly average concentration was measured to be 28.0 mg/l. During the same four-month period, the maximum effluent BOD_5 concentration was found to be 13.6 mg/l, while the largest monthly average concentration observed was 11.5 mg/l.

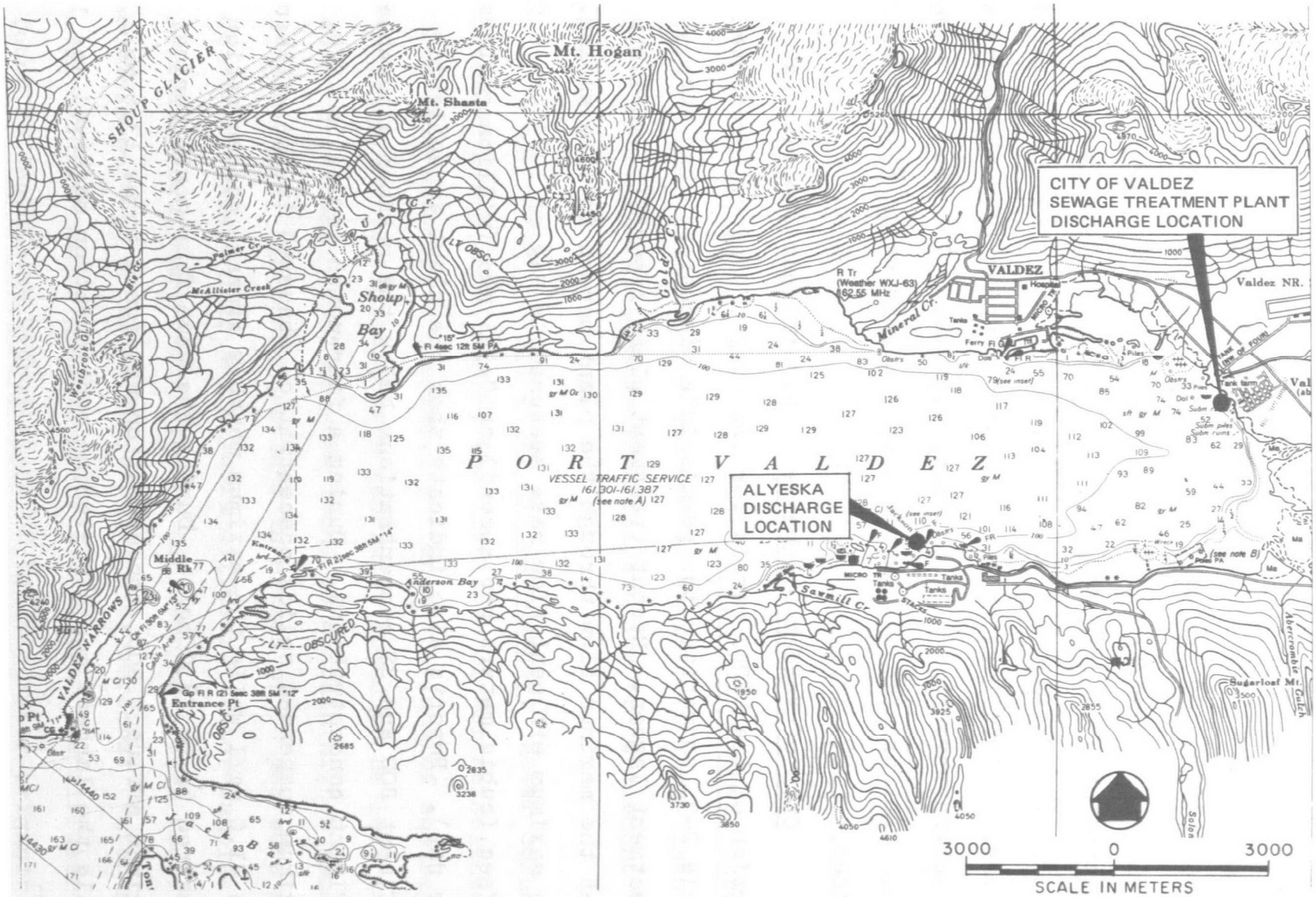


FIG. 2-1 LOCATION OF EXISTING DISCHARGES IN PORT VALDEZ

TABLE 2-3. EFFLUENT LIMITATIONS FOR THE CITY OF VALDEZ

During the period beginning on the effective date of this permit and lasting until the expiration date, discharges from outfalls shall be limited and monitored by the permittee as specified below:

a. The monthly average quantity of effluent discharged from the wastewater treatment facility shall not exceed 4,731 m^3/d[1] (1.25 mgd).

b. The pH shall not be less than 6.0 nor greater than 9.0.

c. There shall be no discharge of floating solids, visible foam in other than trace amounts or oily wastes which produce a sheen on the surface of the receiving water.

d. The effluent dissolved oxygen content shall not be less than 7.0 mg/l.

e. The following limitations and monitoring requirements shall apply:

Effluent characteristic	Unit of measurement	Monthly average	Weekly average	Daily maximum
Effluent Concentrations				
Biochemical oxygen demand (5-day)	mg/l	30	45	60
Suspended solids	mg/l	70	-	-
Fecal coliform bacteria	#/100 ml	200	400	800
Total chlorine residual (maximum)	mg/l	-	-	0.01
Effluent Loadings				
Biochemical oxygen demand (5-day)	kg/day[2]	115	172	230
	(lbs/day)[3]	(252)	(379)	(504)
Suspended solids	kg/day	332	-	-
	(lbs/day)	(730)		

1. Cubic meters per day.
2. Kilograms per day.
3. Pounds per day.

Alyeska Terminal Discharge The effluent limitations and monitoring requirements section of the operating permit for the Alyeska terminal is presented in Table 2-4. The permit specifies that the effluent be diluted within a mixing zone which is defined in plan as the area extending 150 meters from the ends and sides of the diffuser pipe. The top of the mixing zone is defined to be 5 meters below the surface, while the bottom of the mixing zone is 0.5 meters from the bottom of Port Valdez. The allowable oil and grease concentration at the horizontal limits of the mixing zone boundaries is 0.05 mg/l. The allowable concentration is 0.10 mg/l at the vertical limits of the mixing zone.

Two dye dispersion studies were performed to determine the diffuser's capacity to achieve the necessary dilutions when the effluent contains the maximum allowable daily average concentration (8 mg/l). The findings of these studies are summarized in Chapter 3, Initial Dilution.

TABLE 2-4. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS FOR ALYESKA

During the period beginning on the effective date and lasting through the expiration date, the permittee is authorized to discharge treated ballast and storm waters and other wastewaters from outfall.

a. Such discharges shall be limited and monitored by the permitee as specified below:

Effluent characteristic	Discharge limitations		Monitoring requirements	
	Daily avg.	Daily max.	Measurement frequency	Sample type
Flow	157,000 m^3/day (41.4 mgd)	212,000 m^3/day (56.0 mgd)	Continuous	Recording
Oil and grease	8 mg/l	10 mg/l	Daily	24-hour composite

b. The discharge shall also be monitored by the permittee as specified below:

Effluent characteristic	Monitoring requirements	
	Measurement frequency	Sample type
Total suspended solids	Weekly	24-hour composite
BOD_5	Weekly	24-hour composite
Phenols	Weekly	24-hour composite
Temperature	Daily	Not applicable

c. The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be recorded and monitored continuously.

METCALF & EDDY

REFERENCES

1. Water Quality Standards, Alaska Department of Environmental Conservation, February 1979.

2. Environmental Studies of Port Valdez, Alaska, Institute of Marine Science, University of Alaska, 1973.

3. Continuing Environmental Studies of Port Valdez, Alaska, 1976-1978, Institute of Marine Science, University of Alaska, 1979.

4. Sverdrup, H.U., Martin W. Johnson, and Richard H. Fleming, The Oceans Their Physics, Chemistry, and General Biology, Prentice Hall, Inc., New York, N.Y., 1942.

5. National Pollutant Discharge Elimination System Discharge Monitoring Reports, City of Valdez Sewage Treatment Plant, 1/1979-7/1979.

CHAPTER 3

INITIAL DILUTION

General

Current practice for disposal of treated wastewater effluent into the ocean uses diffuser manifolds for efficient mixing and dilution of the discharge with the ambient water. These diffusers usually consist of round pipes with circular ports placed alternately on both sides of the pipe. Treated effluent is discharged through these ports as round turbulent jets, either horizontally or at an angle from the horizontal. Because the effluent density is smaller than the ambient density, these jets rise toward the surface forming a buoyant plume. During the buoyant rise, these plumes entrain ambient water due to self-induced turbulence; grow appreciably in size; and thereby dilute the effluent. If the ambient density is uniform, these buoyant plumes rise to the surface, spread horizontally and create a surface field of effluent mixed with sea water. In the case of stratified ambient density, the plume, due to entrainment of heavier ambient water, might reach neutral buoyancy at some level below the surface. At this neutral buoyancy level, known as the trap level, the plume spreads horizontally creating a submerged field of diluted effluent.

Many factors affect the initial dilution of a buoyant jet during its convective rise to the surface. Important among these are characteristics of the effluent; design of the diffuser

relative to impacts such as merging of jets; depth of ambient water; ambient density stratification; and the magnitude of ambient current.

Ambient current plays a very significant role in determining initial dilutions and in establishing the location and magnitude of the zone of initial dilution (ZID). This is because currents cause an increase in the trajectory of the plume, as well as increased entrainment of ambient water. Depending on the magnitude of the ambient current, the location of the plume can be away from the diffuser and the increase in dilution can be several times the value under stagnant conditions.

A number of mathematical models have been developed to aid in the calculation of initial dilution, plume formation and dispersal. A model's ability to represent the expected conditions is an important factor in selecting a particular model.

This chapter reviews the performance of the Alyeska diffuser on the basis of two studies conducted by IMS for that purpose(1,2). Further, this chapter establishes the procedures used for diffuser design, and presents the proposed design for the ALPETCO diffuser and its recommended ZID.

The location of the diffuser and its depth were taken as given and were supplied by DOWL Engineers as "Discharging into 30 fathoms of water on a line about 130 meters south of the existing pier (in ruins) and parallel to it."

Alyeska Diffuser Performance

The major existing discharge into Port Valdez is Alyeska Pipe Line Company ballast water tr-

dye studies have been conducted by the IMS to determine the dilution and dispersion of the Alyeska discharge.

The procedure and findings of these studies by IMS, as they relate to the design of the ALPETCO diffuser, are briefly summarized here. In each of these studies, a 20 percent aqueous solution of Rhodamine WT dye was introduced into the outfall pipe to trace the effluent and its concentrations in the ambient water following initial dilution. The average wastewater discharge rate during the first field test program, conducted during the period from October 31 to November 2, 1977, was 1.057 m^3/sec (cubic meters per second). The dye concentration in the effluent ranged from about 68 ppb (parts per billion) to 82 ppb. During the second field test program, conducted between April 17 and April 21, 1978, the average discharge rate was 1.091 m^3/sec and the average dye concentration was about 74 ppb.

A grid, centered on the diffuser, was established to measure concentrations of dye in the ambient water following initial dilution. The approximate location of this grid is shown in Figure 3-1. Dye concentrations as well as salinity and temperature were measured in the water column at each of the grid stations during these two test programs.

Density variations with depth were calculated and profiles were plotted using the measured salinity, temperature and depth data. Figure 3-2 illustrates two sets of vertical profiles of dye concentration, temperature and sigma-T (density in grams/cubic centimeter is obtained by dividing sigma-T by 1000 and adding the result to 1) values taken over the Alyeska diffuser during these

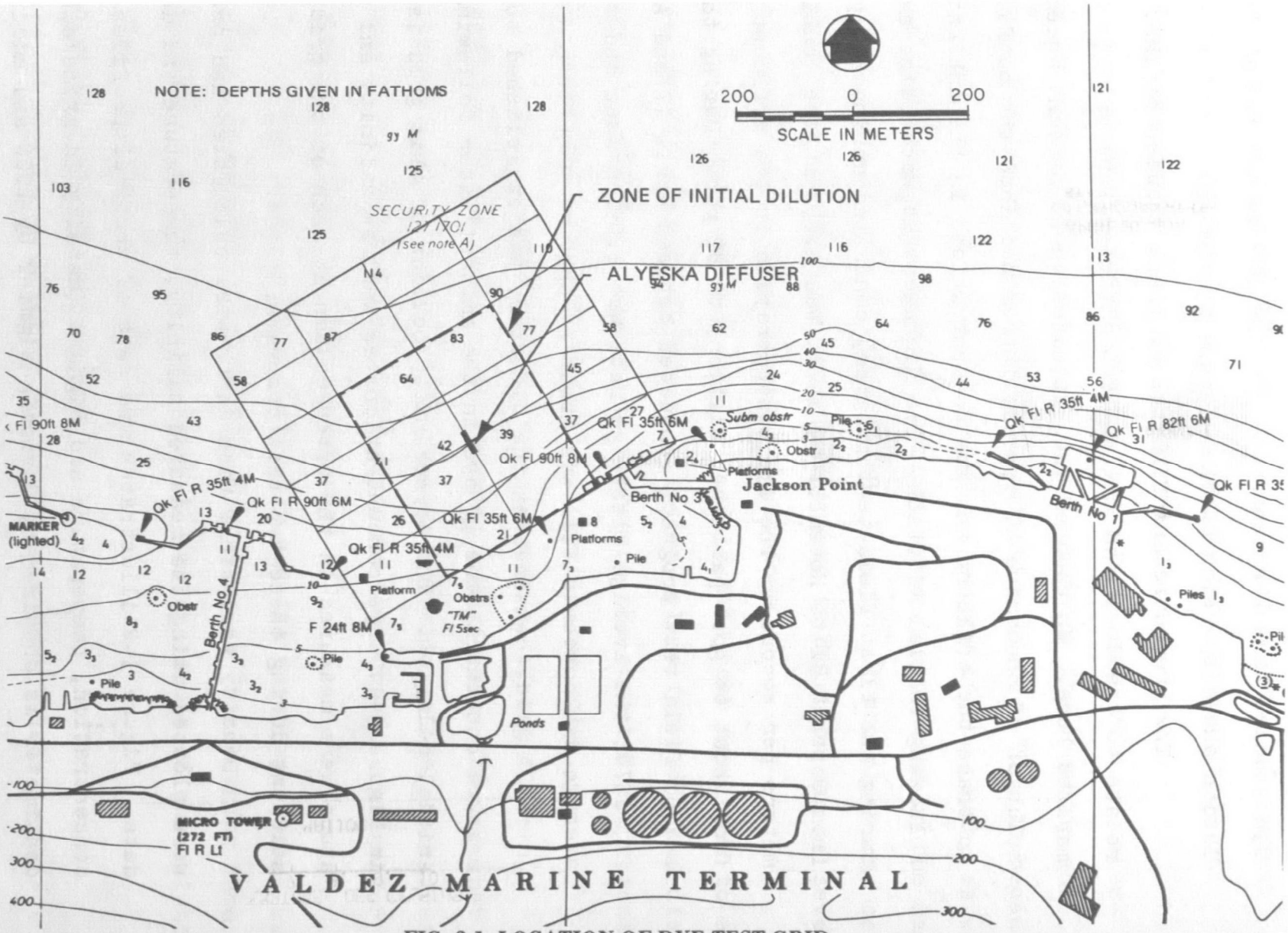


FIG. 3-1 LOCATION OF DYE TEST GRID

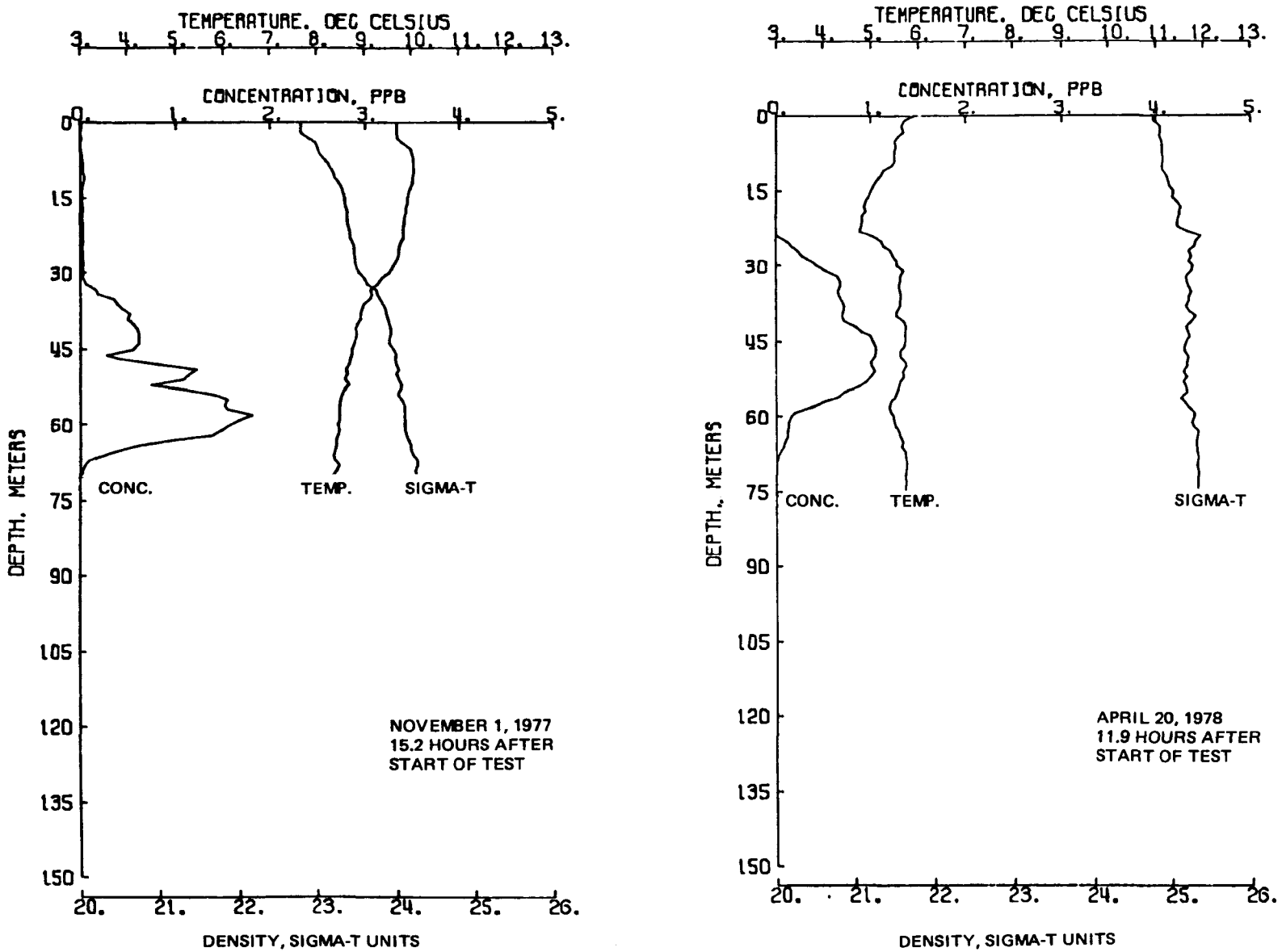
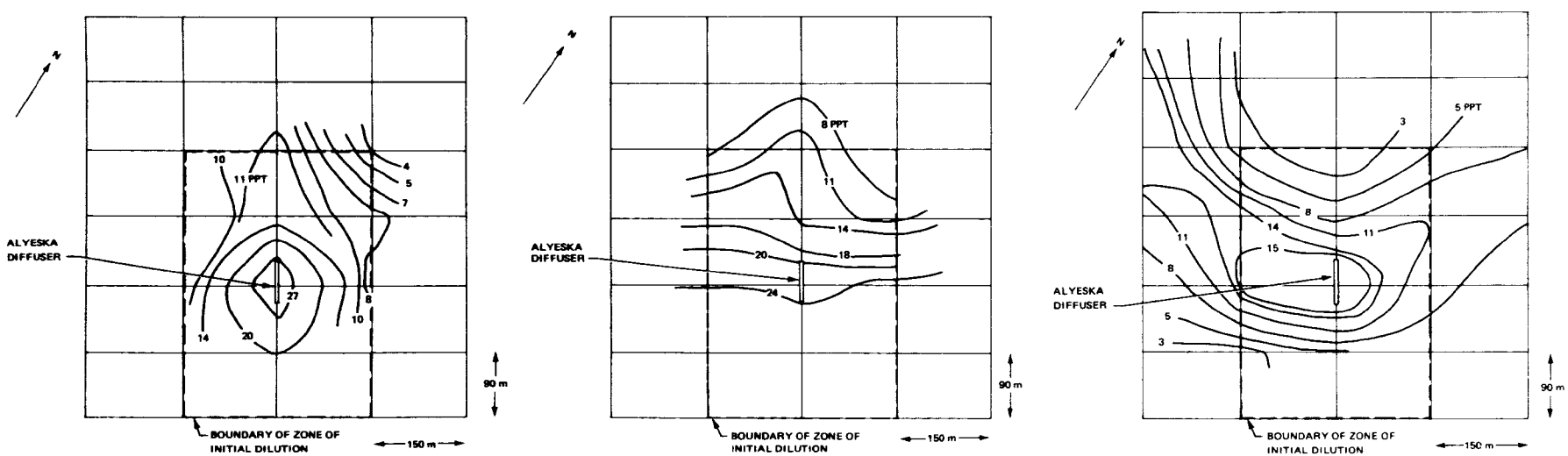


FIG 3-2 VERTICAL PROFILES OF DYE CONCENTRATION, TEMPERATURE AND DENSITY VALUES AT GRID STATION 33 OVER THE ALYESKA DIFFUSER

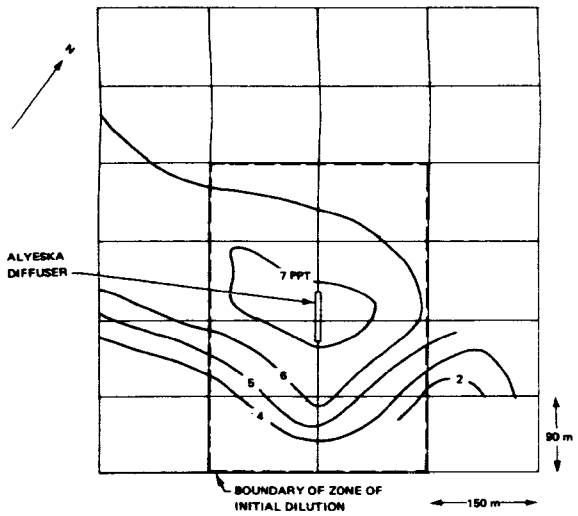
two tests. These are reproduced from the IMS reports. The density profiles indicate that during the first test program there was a strong vertical density gradient while a weak density gradient existed during the second program. In both tests the dye plume was found to be trapped below the surface because of this density stratification. Composite plots of maximum effluent concentration contours irrespective of depth were prepared from the results of these dye tests to determine the approximate shape and extent of the plumes at different times after start of the tests. Figure 3-3 presents the contours for the test conducted during October and November of 1977. The results of the second test, conducted during April, 1978, are presented in Figure 3-4. It should be noted that these composite plots are approximate representations of the constantly varying conditions that result from the action of ocean tides and currents.

During the first test, the highest concentration in the near field plume resulted in a dilution of about 30 while the highest concentration during the second test indicated a minimum dilution of 77. Both of these measurements were taken exactly above the diffuser manifold and not at the ZID boundary. The NPDES Permit for Alyeska requires that initial dilutions at the vertical ZID boundaries (150 meters on each side and from each end of the diffuser) be at least 80 with values of at least 160 at 5 meters beneath the surface and 0.50 meters above the bottom. These values correspond to effluent concentrations of about 13 ppt and 6 ppt, respectively, shown in Figures 3-3 and 3-4.

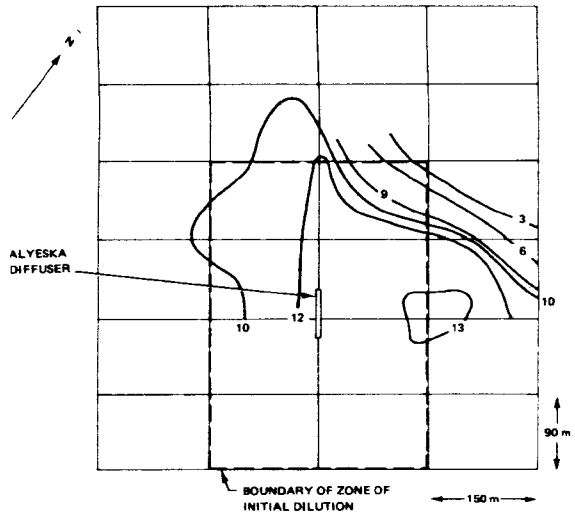


NOTE: NUMBERS SHOWN REPRESENT THE CONCENTRATION OF EFFLUENT WATER (NOT DYE). TO CONVERT TO DILUTIONS, DIVIDE 1,000 BY THE CONCENTRATION SHOWN.

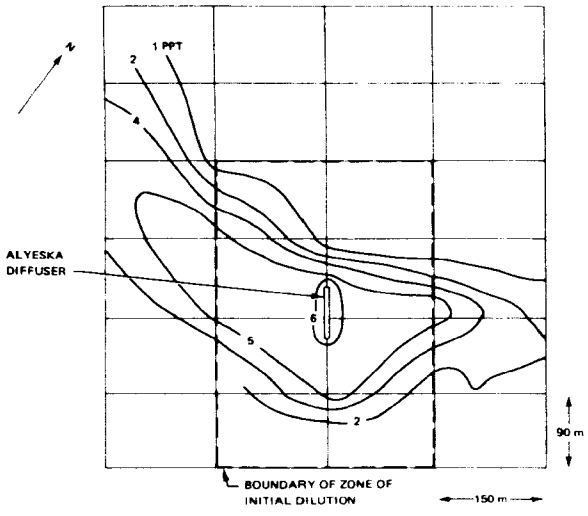
FIG. 3-3 COMPOSITE PEAK CONCENTRATION CONTOURS OF DISCHARGE WATER FOR TEST CONDUCTED IN OCTOBER AND NOVEMBER, 1977



DEPTH RANGE: 24 TO 50 METERS FROM SURFACE
TIME: 21.5 TO 24 HOURS AFTER START OF DYE TEST
CONCENTRATION: PARTS PER THOUSAND (PPT)



DEPTH RANGE: 29 TO 50 METERS FROM SURFACE
TIME: 30.5 TO 34.0 HOURS AFTER START OF DYE TEST
CONCENTRATION: PARTS PER THOUSAND (PPT)



DEPTH RANGE: 23 TO 42 METERS FROM SURFACE
TIME: 11.5 TO 15.5 HOURS AFTER START OF DYE TEST
CONCENTRATION PARTS PER THOUSAND (PPT)

NOTE: NUMBERS SHOWN REPRESENT THE CONCENTRATION OF EFFLUENT WATER (NOT DYE).
TO CONVERT TO DILUTIONS, DIVIDE 1,000 BY THE CONCENTRATION SHOWN.

FIG 3-4 COMPOSITE PEAK CONCENTRATION CONTOURS OF DISCHARGE WATER FOR TEST CONDUCTED IN APRIL, 1978

In general, the two IMS studies indicated that the necessary dilutions are being achieved by the Alyeska diffuser. Since both studies occurred during stratified conditions, no data were available to compare calculated dilutions with measured dilutions under uniform density conditions. During these studies, it was also observed that the dye tended to move along shore in easterly and westerly directions rather than offshore and that under certain conditions the dilution requirements were not achieved at those boundaries.

Initial dilutions and trap level heights for the Alyeska diffuser were calculated by IMS using the EPA PLUME model(3) for the discharge conditions that existed during the second field dye test program. These results were compared with results of field measurements. The calculated dilutions agreed reasonably well with the measured dilutions. However, in most cases, the measured trap levels were 15 to 20 meters above the calculated values.

Diffuser Design

In order to obtain optimal initial dilution of the treated effluent, it is essential to have efficient hydraulic design of the outfall pipe and the diffuser based on a manifold analysis. Properly designed multiple-port diffusers greatly increase initial dilution over a single port outfall and require consideration of the following important factors:

1. variation of water depth over the length of the diffuser;
2. variation of discharge coefficient of the ports on the manifold;

3. changes in pressure head due to friction losses and velocity changes; and
4. difference in density between the ambient water and effluent.

These factors were considered in the design of the diffuser for the discharge of ALPETCO oil refinery and ballast water treatment plant effluent. A procedure developed by Brooks(4), which included consideration of the previously mentioned factors, was used to design the diffuser manifold.

Uniform Flow Distribution. In designing multiple-port diffusers, it is desirable to achieve a near-uniform flow distribution between the ports for the range of expected flow conditions. The diffuser was designed on the basis of an average flow of 0.310 m^3/sec (cubic meters per second), or 7.08 mgd (million gallons per day). It was then analyzed for flow distribution at the minimum flow of 0.179 m^3/sec (4.08 mgd) and the maximum flow of 0.418 m^3/sec (9.53 mgd). Table 3-1 summarizes the flow distribution between ports for the minimum, average and maximum estimated flows from the selected diffuser during maximum stratification. Some minor variations from these flow distributions occur during uniform density, the largest of which is about 4.4 percent at the minimum flow. As can be seen from this table, the ratio of minimum to maximum port flows is 0.93 for the average flow and 0.96 for the peak flow. Therefore, the port discharges are nearly uniform for average and peak flows. At the minimum flow, this ratio drops to 0.52 and the flow distribution is somewhat non-uniform. However, at

TABLE 3-1. FLOW DISTRIBUTION BETWEEN DIFFUSER PORTS AT VARIOUS FLOW RATES DURING JULY STRATIFICATION

Port No.(1)	Port discharges at minimum flow (m^3/sec)	Port discharges at average flow (m^3/sec)	Port discharges at maximum flow (m^3/sec)
1	0.0074	0.019	0.025
2	0.0079	0.019	0.026
3	0.0085	0.019	0.026
4	0.0091	0.019	0.026
5	0.0096	0.019	0.026
6	0.010	0.019	0.026
7	0.011	0.019	0.026
8	0.011	0.019	0.026
9	0.012	0.020	0.026
10	0.012	0.020	0.026
11	0.012	0.020	0.026
12	0.013	0.020	0.026
13	0.013	0.020	0.026
14	0.014	0.020	0.026
15	0.014	0.020	0.026
16	0.014	0.020	0.026
Total	0.18	0.31	0.42

1. Ports are numbered from the downstream end of the diffuser manifold.

minimum flow, the individual port flows are small and this non-uniformity is not a significant factor. Differences in pressure head along the diffuser due to increasing water depth make the achievement of near-uniform flow distribution at all flow rates somewhat difficult, but the selected design would give near-uniform flow distribution most of the time.

Prevention of Sea Water Intrusion. In order to prevent the intrusion of sea water into the diffuser manifold through the ports, the number and size of ports were chosen such that all the port densimetric Froude numbers were much greater than the critical value of 1 at all flow conditions and the sum of the area of all the ports was about 60 percent of the pipe area. For the selected design, the smallest densimetric Froude number for the minimum flow was 5.48 and the total area of all the ports was about 58 percent of the area of the manifold. Since both of the above mentioned criteria were met, the proposed diffuser should discharge without intrusion of sea water at all flow conditions.

Sizes of Manifold and Ports. A diffuser manifold diameter of 0.53 meters (21 inches) was selected to maintain a reasonable velocity in the pipe at the minimum flow. This is to minimize deposition at low flows near the downstream end of the manifold where velocities are small. However, higher velocities at average and peak flows would scour and remove any deposition that may have occurred at low flows and would prevent accumulation of solids in the diffuser manifold. Figure 3-5 illustrates the selected diffuser manifold for the ALPETCO outfall together with arrangements of ports.

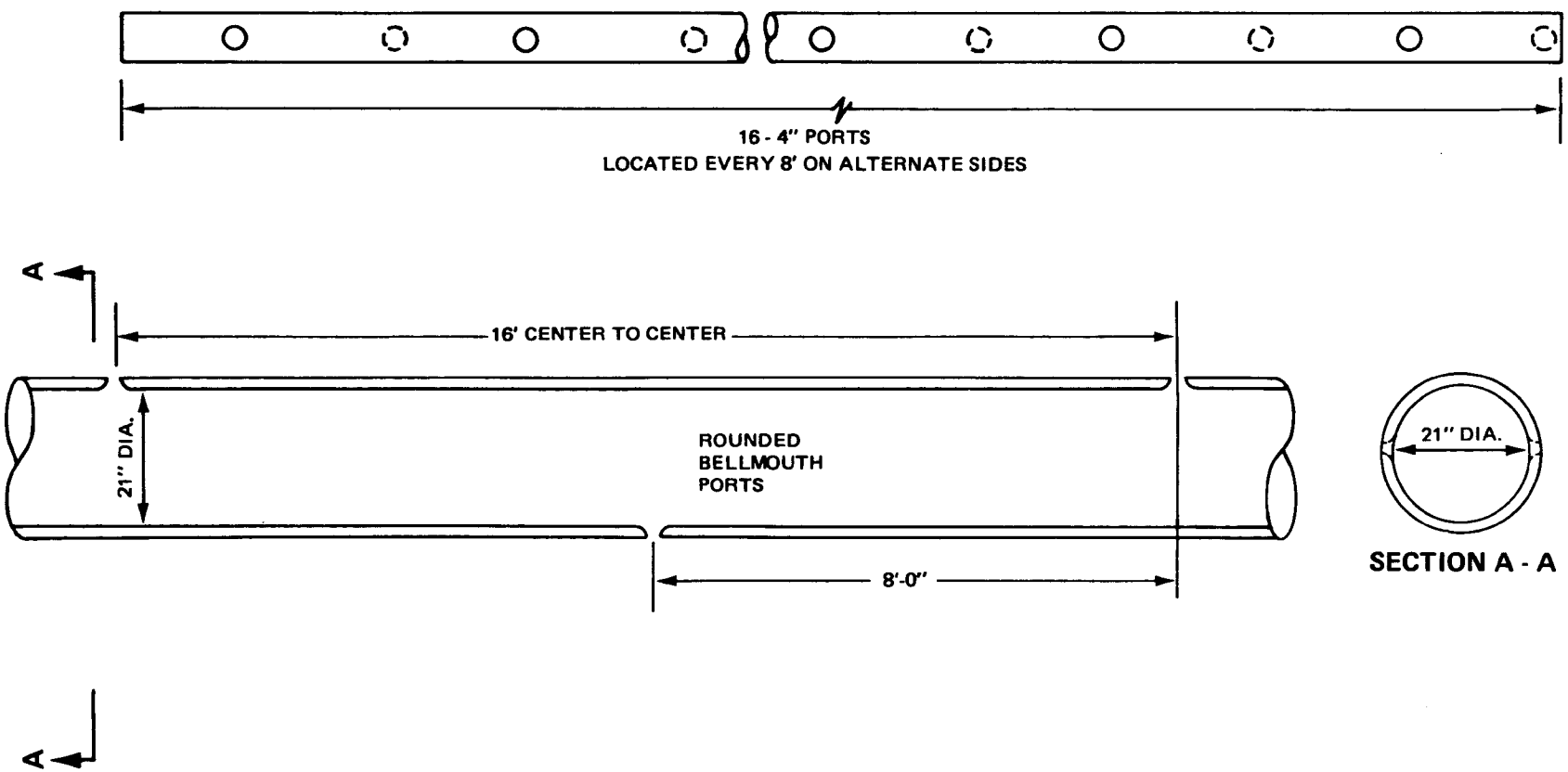


FIG 3-5 SCHEMATIC OF ALPETCO DIFFUSER MANIFOLD WITH ARRANGEMENTS OF PORTS

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Rounded, bell-mouth ports were selected to minimize head loss and to reduce the diffuser head requirements. A minimum port diameter of 0.102 meters (4 inches) was selected because port diameters smaller than 4 inches may get clogged easily. Port diameters larger than 4 inches reduced port velocities and their densimetric Froude numbers and were not as effective. Sixteen ports, each 4 inches in diameter, were used in the selected design.

Port Spacing and Orientation. Maximum initial dilution for a buoyant jet discharging into stagnant ambient water of uniform density occurs with the longest jet trajectory to the surface without interference from adjacent jets. This is usually attained by making the jets discharge horizontally through properly sized diffuser ports. To avoid interference between adjacent jets, the spacing of the ports is usually made equal to the plume width (diameter) at the surface. Analysis of the buoyant jets discharging into Port Valdez showed that the plumes would get trapped below the surface during the biologically active parts of the year when the receiving water body is stratified. In order to achieve maximum initial dilution and yet minimize the length of the diffuser manifold, a center to center port spacing of 2.44 meters (8 feet) was chosen. The ports were placed alternately on both sides of the diffuser so that the spacing between adjacent ports on the same side was 4.88 meters (16 feet) or equal to the smallest plume width at the maximum height of rise during maximum stratification.

Proposed Diffuser. The proposed diffuser shown in Figure 3-5, consists of a single 36.6 meter (120 feet) long manifold placed at the end of the outfall pipe. It has the same alignment as the outfall. The manifold is placed at an average depth of about 52.5 meters (172 feet) below mean sea level. Because of the steep slope of the ocean floor, the depth of water varies from 50 meters (164 feet) at the near shore end to 55 meters (180 feet) at the off shore end.

Initial Dilution

Dilution Models. The validity of the mathematical basis of some models developed to calculate the initial dilution of buoyant plumes has been established from results of laboratory experiments. One of these models is based on the analysis by Fan and Brooks(5) for discharge into stagnant, stratified or uniform density ambient water. This model produces dependable results when applied to the conditions for which it was developed.

EPA, in its Final Rules and Regulations for Modification of Secondary Treatment Requirements for Discharge into Marine Waters (published in the Federal Register on Friday, June 15, 1979) recommended the use of certain models for calculating initial dilution. Two of these models, PLUME(3) and DKHPLM(6), as well as the Fan and Brooks' model were considered in order to analyze the diffuser discharges performed under various expected conditions.

The Fan and Brooks' Model was developed by Ditmars(7) based on the analysis of Fan and Brooks. It was intended for calculating initial dilution from individual round jets into stagnant and either constant density or stratified density ambient water.

This model conserves mass, horizontal momentum, vertical momentum and density deficiency flux. Profiles of velocity, density deficiency and effluent concentration distributions are assumed to be Gaussian and similar in shape in this model. It does not take into account jet interference nor the effect of current on dilution.

The EPA PLUME Model was developed by Baumgartner et al (1971) and has the same basic features as the Fan & Brooks' Model described above. Like Fan and Brooks, it does not include jet interference or the effect of ambient current on dilution. Gaussian profiles are also used in this model and dilutions are calculated only up to the trap level. Dilutions calculated by this model are comparable to the Fan and Brooks' Model results.

The EPA DKHPLM Model is based on the work of Kannberg and Davis(1976). In addition to calculating conditions similar to the above models, it can analyze the discharge of a series of round buoyant jets into a stratified, flowing ambient environment. This model carries the plume analysis into three zones: the zone of flow establishment; the zone of established flow, and the zone of merging flow. In the zone of merging flow, the model superimposes adjacent plumes to determine actual plume concentrations and dilutions. As opposed to the other models, this model uses a 3/2 power approximation of the Gaussian profile for velocity and pollutant concentration distribution. The definition of the plume width is therefore different from that used in the other two models, making it difficult to compare the results of DKHPLM with other models' results. Also, only limited

verification of the model is available at this time. In spite of this, this model does have the advantage of taking into account the effects of merging plumes and ambient current on dilution.

Model Analysis. Recognizing the importance of merging plumes and ambient currents on the determination of the ZID and the initial dilutions achieved, it was decided that both the Fan and Brooks' Model and the DKHPLM Model should be used in the establishment of the ZID. The former model would provide reliable and previously verified results for certain limited conditions of the diffuser performances; further it would provide a check on the latter model for those conditions. The latter model, on the other hand, would provide results for all expected conditions, including ambient currents which can position the plume outside the ZID if currents are not considered in establishment of the ZID.

Initial dilutions were calculated using these two models for discharge into constant density (March) or stratified density (July) ambient waters. Ambient density profiles used in these calculations are presented in Figure 3-6. The corresponding data is presented in Table 3-2. Both Fan and Brooks' and DKHPLM models were used for zero current (stagnant water) while only the DKHPLM model was used for discharge into ambient current. Due to the current meter threshold limit, the lowest recorded current magnitude was 0.015 m/sec (meters per second). The recorded near peak velocity at the level of the diffuser was about 0.06 m/sec. These two current values were used in DKHPLM to determine initial dilutions and plume trajectory. Results of the initial dilutions are summarized in Tables 3-3 and 3-4 for discharge into stratified

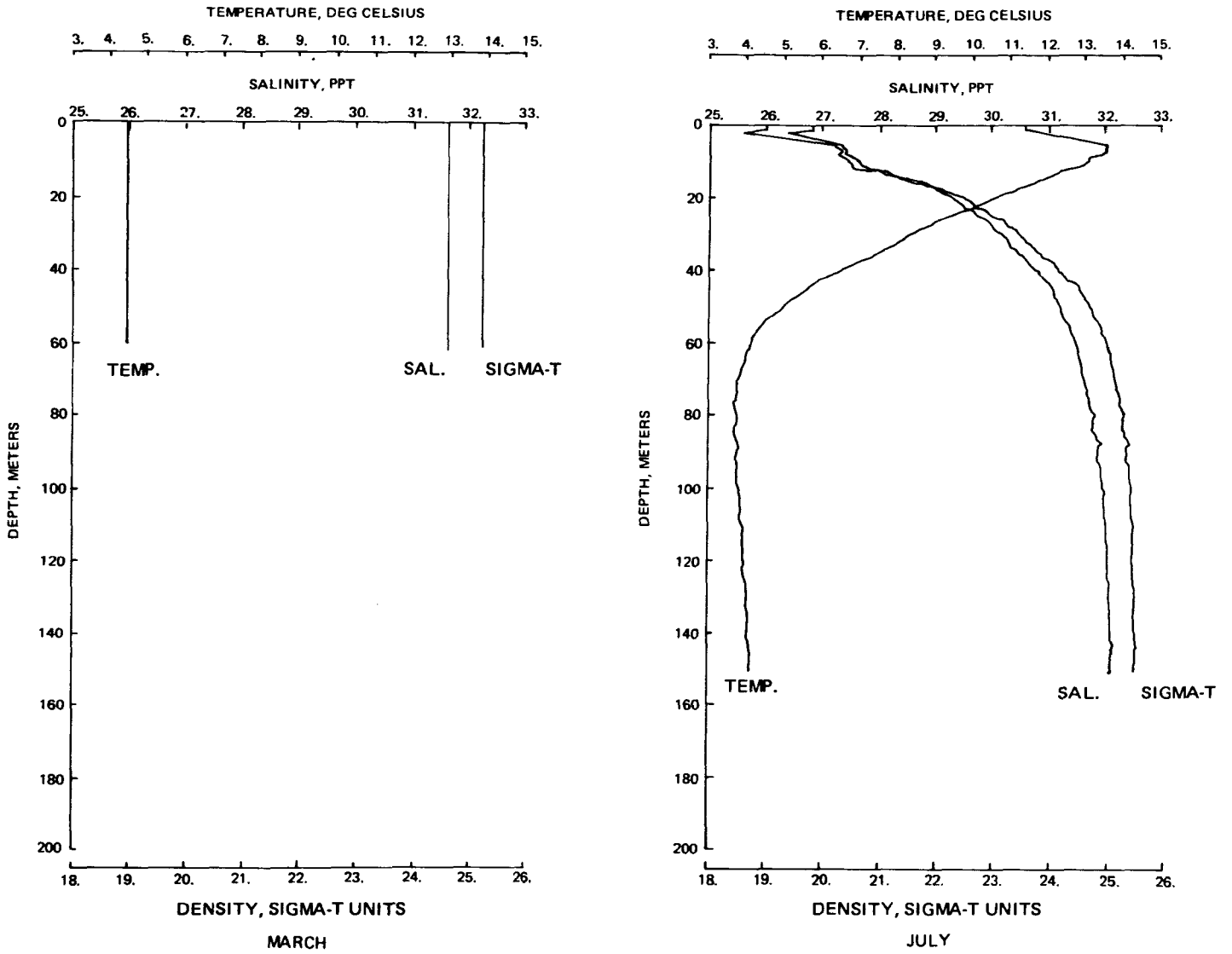

FIG 3-6 TEMPERATURE, SALINITY AND DENSITY PROFILES USED FOR INITIAL DILUTION ANALYSIS

TABLE 3-2. TEMPERATURE, SALINITY, AND DENSITY (SIGMA-T) DATA USED IN INITIAL DILUTION ANALYSIS

March 27, 1976 data				July 29, 1979 data			
Depth, meters	Temperature, deg C	Salinity, ppt	Density (Sigma-T units)	Depth, meters	Temperature, deg C	Salinity, ppt	Density (Sigma-T units)
0.0	4.31	31.687	25.16	0.0	11.39	26.077	19.83
10.0	4.31	31.687	25.16	1.0	11.39	26.077	19.83
20.0	4.31	31.687	25.16	5.0	13.52	27.199	20.31
30.0	4.31	31.687	25.16	10.0	13.03	27.533	20.66
40.0	4.31	31.687	25.16	15.0	11.74	28.501	21.64
50.0	4.31	31.687	25.16	20.0	10.51	29.365	22.52
60.0	4.31	31.687	25.16	25.0	9.26	29.842	23.09
				30.0	8.29	30.185	23.50
				35.0	7.41	30.466	23.84
				40.0	6.43	30.801	24.23
				45.0	5.56	31.048	24.53
				50.0	4.95	31.192	24.71
				60.0	4.12	31.462	25.00
				70.0	3.82	31.594	25.14
				75.0	3.73	31.669	25.20
				80.0	3.78	31.760	25.27
				90.0	3.79	31.819	25.32
				100.0	3.80	31.920	25.40
				125.0	3.97	32.016	25.46
				150.0	4.12	32.050	25.47

TABLE 3-3. AVERAGE INITIAL DILUTION DURING MAXIMUM STRATIFICATION IN JULY

Flow condition and flow, m^3/sec	Port number(1)	Effluent density (g/cm^3)	Port velocity, m/sec	Average dilutions without ambient current		Average dilutions with ambient current	
				Fan & Brooks	EPA DKHPLM	EPA DKHPLM Ua = 0.015 m/sec	EPA DKHPLM Ua = 0.060 m/sec
Minimum flow without ballast water 0.1790	1	0.9982	0.90	163	137	201	314
	16	0.9982	1.76	136	111	153	234
Average flow including ballast water 0.3100	1	1.0094	2.29	97	75	103	159
	16	1.0094	2.48	96	74	100	155
Maximum flow including surface runoff and ballast water 0.4180	1	1.0064	3.16	102	77	102	155
	16	1.0064	3.27	101	77	101	153

1. Ports are numbered from the downstream end of the diffuser manifold and all ports are 0.1016 m (4 inches) in diameter.

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TABLE 3-4. AVERAGE INITIAL DILUTION DURING NO STRATIFICATION IN MARCH

Flow condition and flow, m^3/sec	Port number(1)	Effluent density (g/cm^3)	Port velocity, m/sec	Average dilutions without ambient current		Average dilutions with ambient current	
				Fan & Brooks	EPA DKHPLM	EPA DKHPLM Ua = 0.015 m/sec	EPA EKHPLM Ua = 0.060 m/sec
Minimum flow without ballast water 0.1790	1	1.0003	0.94	1,255	742	1,436	4,268
	16	1.0003	1.74	868	520	864	2,317
Average flow including ballast water 0.3100	1	1.0115	2.31	630	352	639	1,761
	16	1.0115	2.46	611	337	606	1,682
Maximum flow including surface runoff and ballast water 0.4180	1	1.0089	3.17	565	317	509	1,303
	16	1.0089	3.26	558	312	498	1,279

1. Ports are numbered from the downstream end of the diffuser manifold and all ports are 0.1016 m (4 inches) in diameter.

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and unstratified water, respectively. As can be seen from these tables, the lowest average initial dilution occurred during the July stratification. Fan and Brooks' model calculated lowest average initial dilution to be 96 while the corresponding value from DKHPLM was 74. During uniform or near-uniform density in March, the plumes reach the surface; as a result, they have much larger trajectories resulting in higher dilutions. Initial dilutions are also much larger with ambient current and increase with the current speed. Table 3-5 summarizes the trap levels and maximum heights of rise for the plumes during the period of maximum stratification in July.

Proposed Zone of Initial Dilution. The ZID is a three-dimensional space. In stagnant ambient water of constant density, discharge from a diffuser would rise to the surface and form a three-dimensional space with a parabolic cross section in the vertical plane and a rectangle in the horizontal plane.

For a diffuser's discharge into an ambient current, the ZID would increase and elongate prior to reaching the surface. On the surface, the plume would expand in the direction of the current and would move from one side of the diffuser to the other with reversing current due to ebb and flood tides. When jet buoyancy and momentum-induced fluctuations of velocity and concentrations cease, initial dilution is considered complete (EPA, 1973)(8). The distance from the diffuser where this occurs at the surface under the strongest currents, the weakest density gradients, and the smallest discharge from the diffuser is considered the boundary of the ZID.

TABLE 3-5. TRAP LEVELS AND MAXIMUM HEIGHT OF RISE IN STAGNANT WATER DURING MAXIMUM STRATIFICATION IN JULY

Flow condition and flow, m^3/sec	Port Number(1)	Effluent density (g/cm3)	Port velocity, m/sec	Height of trap level above discharge level, meters		Height of maximum level above discharge level, meters	
				Fan & Brooks	EPA DKHPLM	Fan & Brooks	EPA DKHPLM
Minimum flow without ballast water 0.1790	1	0.9982	0.90	12.1	7.6	16.2	10.9
	16	0.9982	1.76	13.1	8.2	17.6	12.1
Average flow including ballast water 0.3100	1	1.0094	2.29	10.9	5.9	16.7	9.1
	16	1.0094	2.48	10.9	5.7	16.5	9.0
Maximum flow including surface runoff and ballast water 0.4180	1	1.0064	3.16	11.7	6.7	17.5	10.1
	16	1.0064	3.27	11.5	6.6	17.5	10.1

1. Ports are numbered from downstream end of the diffuser manifold and all ports are 0.1016 m (4 inches) in diameter.

Size and dimensions of the ZID were calculated using results from the DKHPLM Model. In addition to calculating initial dilutions, this model calculates the centerline trajectory of the buoyant plume. The ZID size varies with the magnitude of the ambient current. Therefore, to contain the initial dilution process within the ZID at all times, its size was determined using maximum recorded current at the proposed ALPETCO diffuser site. To obtain the ZID width, the plume width (W) at the surface was added to twice the maximum horizontal distance from the diffuser (2Xmax) where the plume reaches the surface to obtain the ZID width. The length of the ZID was obtained by adding this dimension (W + 2Xmax) to the length of the diffuser. Table 3-6 presents the ZID dimensions and Figure 3-7 shows the extent and general location of the ZID in Port Valdez.

TABLE 3-6. ZID DIMENSIONS

Length, meters	Width, meters	Depth, meters
316	280	55

During March, discharge from the proposed ALPETCO diffuser in Port Valdez would reach the surface because the receiving ambient water would be unstratified at that time. Average dilutions at the surface during March would range from about 310 at peak discharge to about 630 at the minimum discharge. At 5 meters below the surface, the corresponding dilutions would be 260 and 560, respectively.

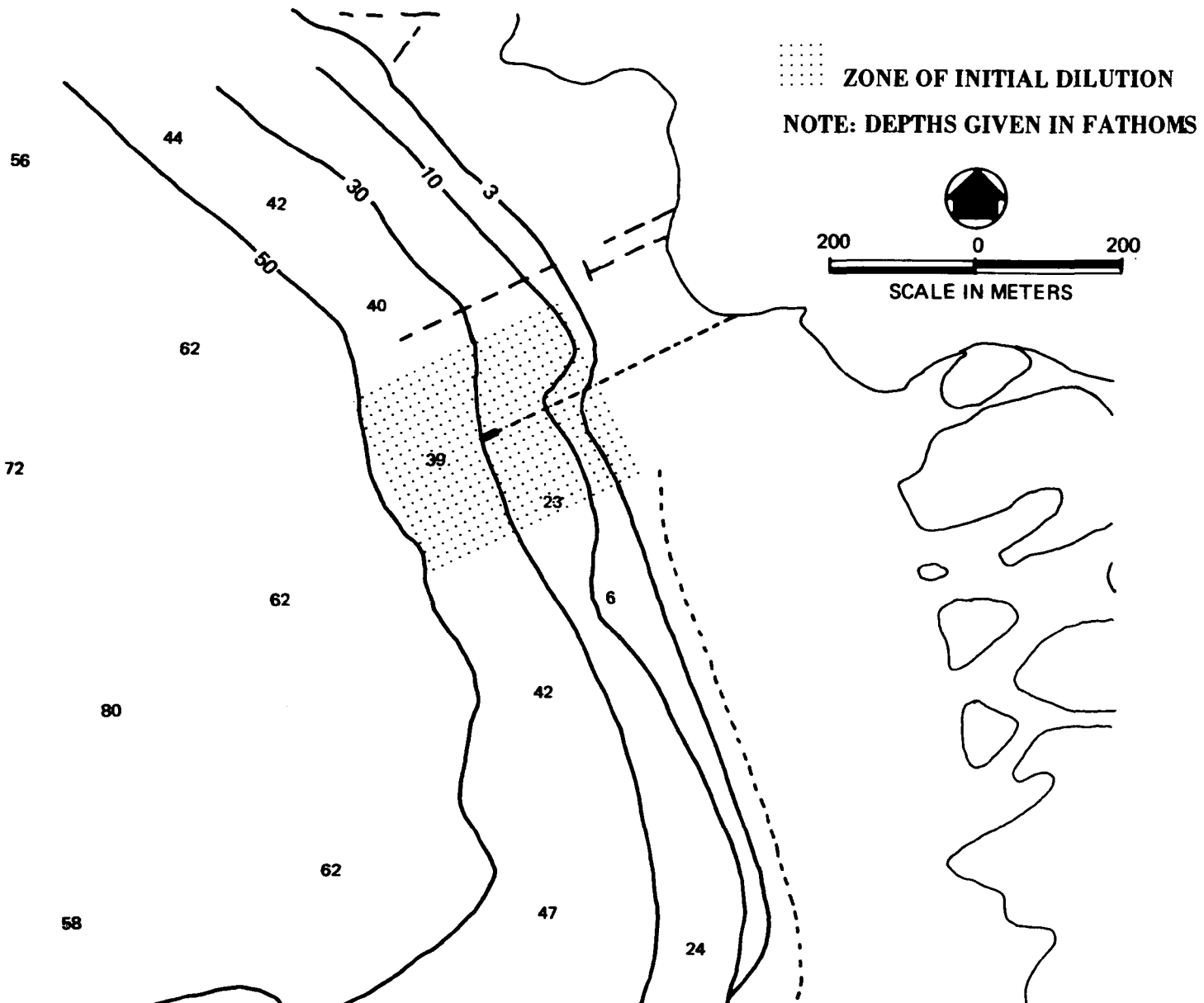

FIG. 3-7 ZONE OF INITITAL DILUTION FOR ALPETCO DISCHARGE

Table 3-7 presents the lowest calculated average dilutions achieved at different levels together with recommended values which should be incorporated in the ALPETCO NPDES Permit. The recommended average dilutions were obtained from the calculated values by using a safety factor of 2 to account for the variation found within the plume for the horizontal boundaries at the surface and 5 meters below the surface. As the plume spreads to the vertical boundary, the plume concentration will be uniform and the calculated value would be representative of dilution found at all areas of the boundary.

TABLE 3-7. INITIAL DILUTIONS AT ZID BOUNDARY

Location	Average dilutions	
	Calculated	Recommended for permit
Surface	310	155
5 meters below surface	260	130
At vertical boundary (sides) 40 meters below surface (trap level)	75	75

A criteria for the bottom is not recommended because the immediate area of the diffuser will receive discharge which has not had the opportunity to mix with the ambient water. This, of course, changes quickly as the distance from the diffuser increases.

REFERENCES

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CHAPTER 4

FLUSHING

General

The long-term flushing or exchange of water in Port Valdez is discussed in this section. This aspect of Port Valdez oceanography is of particular importance in estimating pollutant residence times. To this end, physical oceanographic processes such as stratification, advective flows, currents, winds, and their interrelationships and effects on flushing were evaluated.

A detailed analysis of continuous recording current meter measurements in Valdez Narrows was performed. Analysis of these currents indicated that the flow in and out of Port Valdez generally behaves as a two-layered system. This led to development of a two-layer flushing model to calculate inflow, outflow, mass exchange, and average pollutant concentrations in Port Valdez over long time periods (greater than a year). Results from this model were used to pinpoint critical time periods during the year for pollutant discharges into the Port.

The flushing model describes the long-term fate of pollutants in Port Valdez, assuming that the pollutant is completely mixed within each of the two layers. The assumption of complete mixing in each layer throughout the Port limits the model to its intended use of providing an average overall long-term pollutant concentration picture. As discussed later in this chapter, there are significant impacts which cause a high degree of mixing and facilitate flushing in Port Valdez.

In the subsequent chapter on circulation, a model which describes pollutant concentration distributions in the eastern end of Port Valdez is presented.

Annual Salinity, Temperature and Density Cycles

Annual variations of salinity and temperature in Port Valdez have been observed in data taken by the University of Alaska for Alyeska(1) as well as in data measured during this study. Complete listings of these data are included in Appendixes B and C.

On the basis of data measured in 1978, Figure 4-1 shows typical annual cycles of salinity, temperature and density (sigma-T). The cycles are similar throughout Port Valdez, based on transects run by IMS.(1) In March, densities (calculated from salinity and temperature) are nearly uniform, with little stratification evident. In April, solar warming raises the temperature of the upper waters, which are simultaneously freshened by snowmelt runoff. The freshwater flows continue to increase and reach their peak in July or August, resulting in density stratification of the upper 20 to 30 meters of the water column. This upper layer tends to flow outward due to the driving force of the advective freshwater inflow. As temperatures drop in October and November, the stratification becomes weaker, and virtually disappears by December.

Data in the two IMS studies done for Alyeska indicate an intrusion of dense water into Port Valdez beginning in mid to late summer(1,2). This occurrence has also been observed in

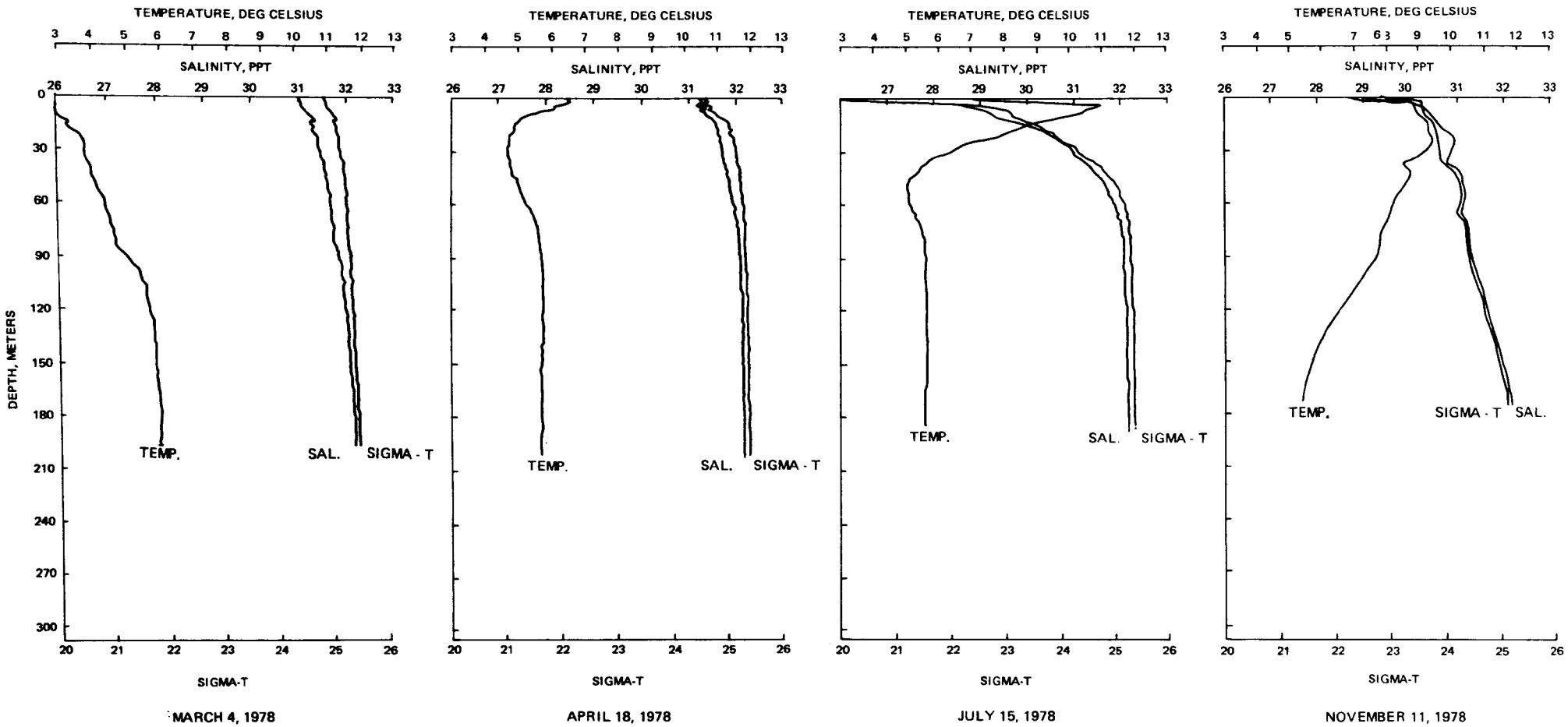

FIG. 4-1 SEASONAL SALINITY TEMPERATURE - DENSITY PROFILES IN PORT VALDEZ

other southern Alaska fjords. It is theorized that the intrusions are a combined effect of the large volume of freshwater runoff and the prevailing atmospheric conditions. During the winter, the prevailing winds over the Gulf of Alaska produce downwelling conditions along the south-central Alaskan coast. Subsidence of these winds during the summer months is believed to result in the relaxation of the downwelling tendency to the extent that dense bottom water from the Gulf is transported onto the continental shelf and then into the deeper fjords and inlets of south-central Alaska. These observed intrusions of denser water, in addition to the annual turnover of the water column, replenish the bottom waters of Port Valdez.

Analysis of Valdez Narrows Transport

Continuous recording current meters were placed in Valdez Narrows during this study, and during an earlier study for Alyeska by the Institute of Marine Science, University of Alaska (1). The meter installations analyzed in this chapter are summarized in Table 4-1. Meter locations are shown in Figure 4-2.

Figure 4-3 is an example of measured current speed and direction plotted with time. Only the upper current meter of station VN-6 is shown. Complete plots of data from Station VN-6 are included in Appendix B. Plots of data from Stations VN-5 and VN-2 are in Appendix C. Average current is approximately 0.10 to 0.15 meters per second with reversing direction due to tidal fluctuations; 180 degrees represents a southerly flow.

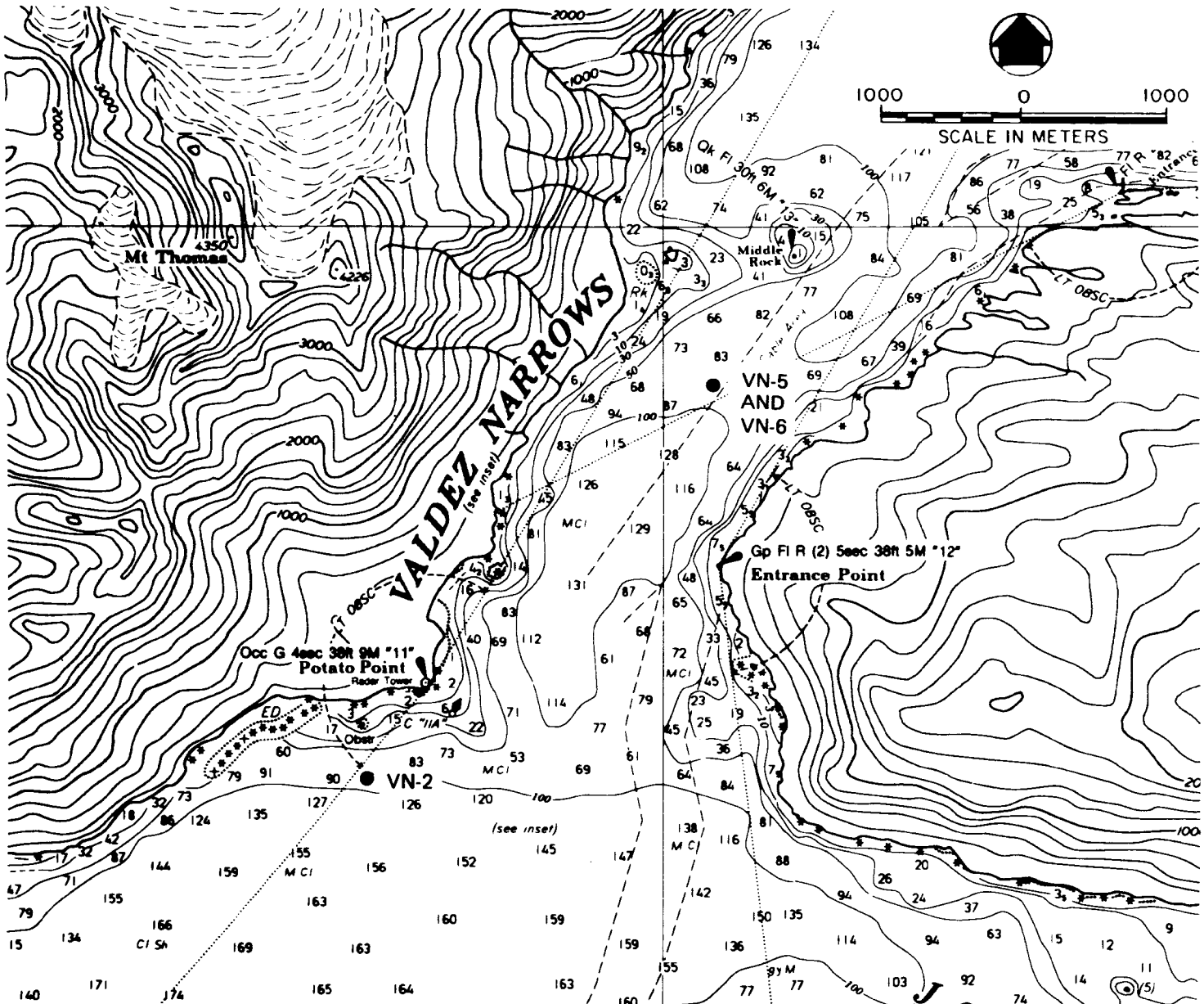

FIG. 4-2 LOCATION OF CONTINUOUS RECORDING CURRENT METER STATIONS

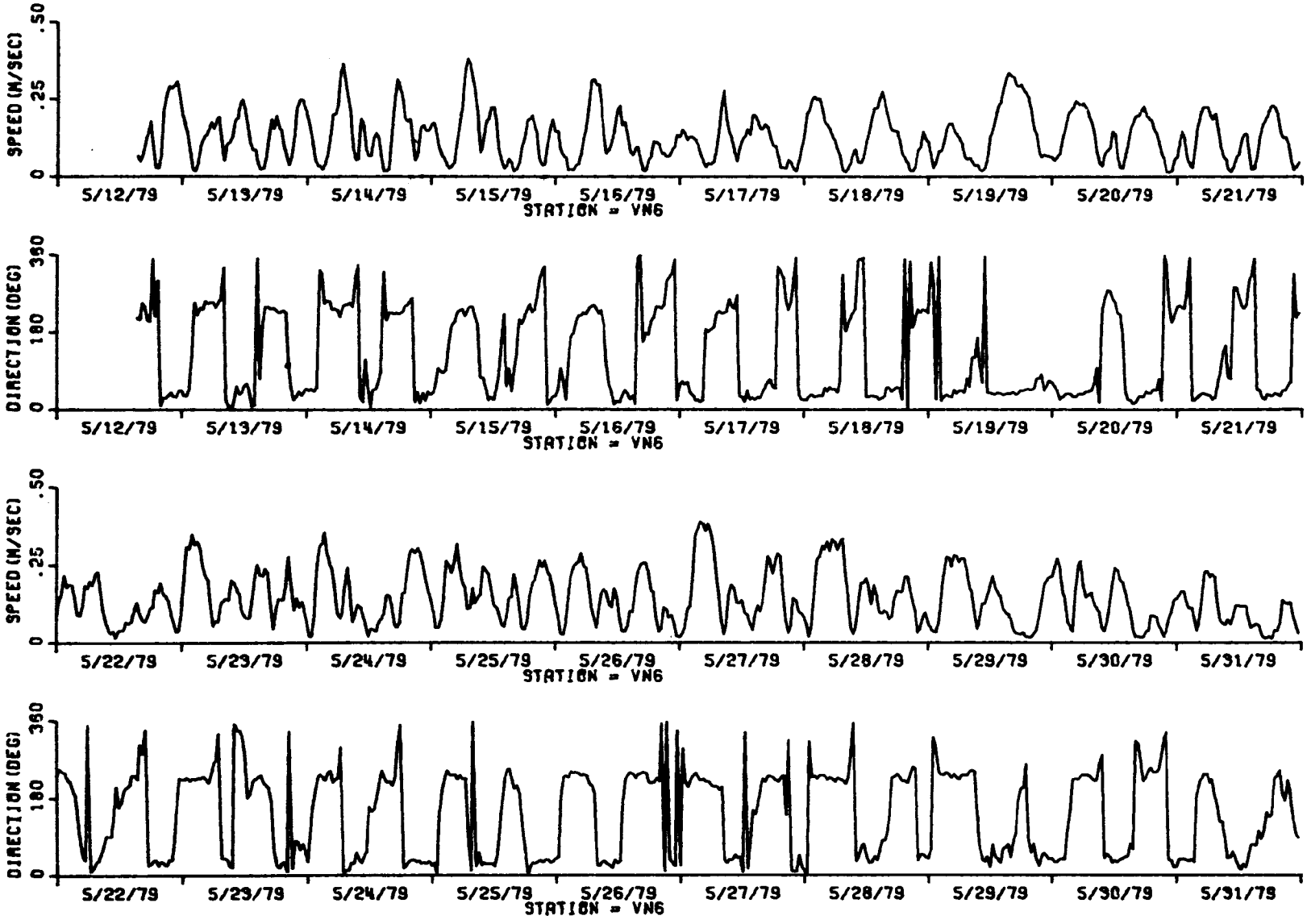

FIG. 4-3 CURRENT SPEED AND DIRECTION AT STATION VN-6 - METER DEPTH = 23M

TABLE 4-1. CONTINUOUS RECORDING CURRENT METER STATIONS AT VALDEZ NARROWS

Station	Dates of deployment	Meter depths (meters)	Useful record length (days)
VN-6	5/12/79-7/29/79	23	78
		59	78
		114	78
		147	33
VN-5	7/16/78-11/11/78	28	108
		66	88
		110	108
		152	108
VN-2	10/23-76-4/25/77	52	184
		75	184
		94	184
		116	158
		146	184

A progressive vector plot of data from the shallowest meter at Station VN-6 is shown in Figure 4-4. During most of the May through July period, the net movement at the level of this meter (23 m depth) is southwest or out of Port Valdez. This is largely due to the driving force of the freshwater advective flow during this summer period which moves the top layer out of the Port. A rapid outward motion occurs from June 8 to June 14. There are periods, however, when the top layer moves inward. Most notable is the period from May 18 to May 21, during which rapid inflow can be observed.

A method of observing the net inflow and outflow of all layers is presented in Figures 4-5 and 4-6, using data from Station VN-6. The flows are computed by assigning a cross-sectional area to each current meter. The generally outward flow

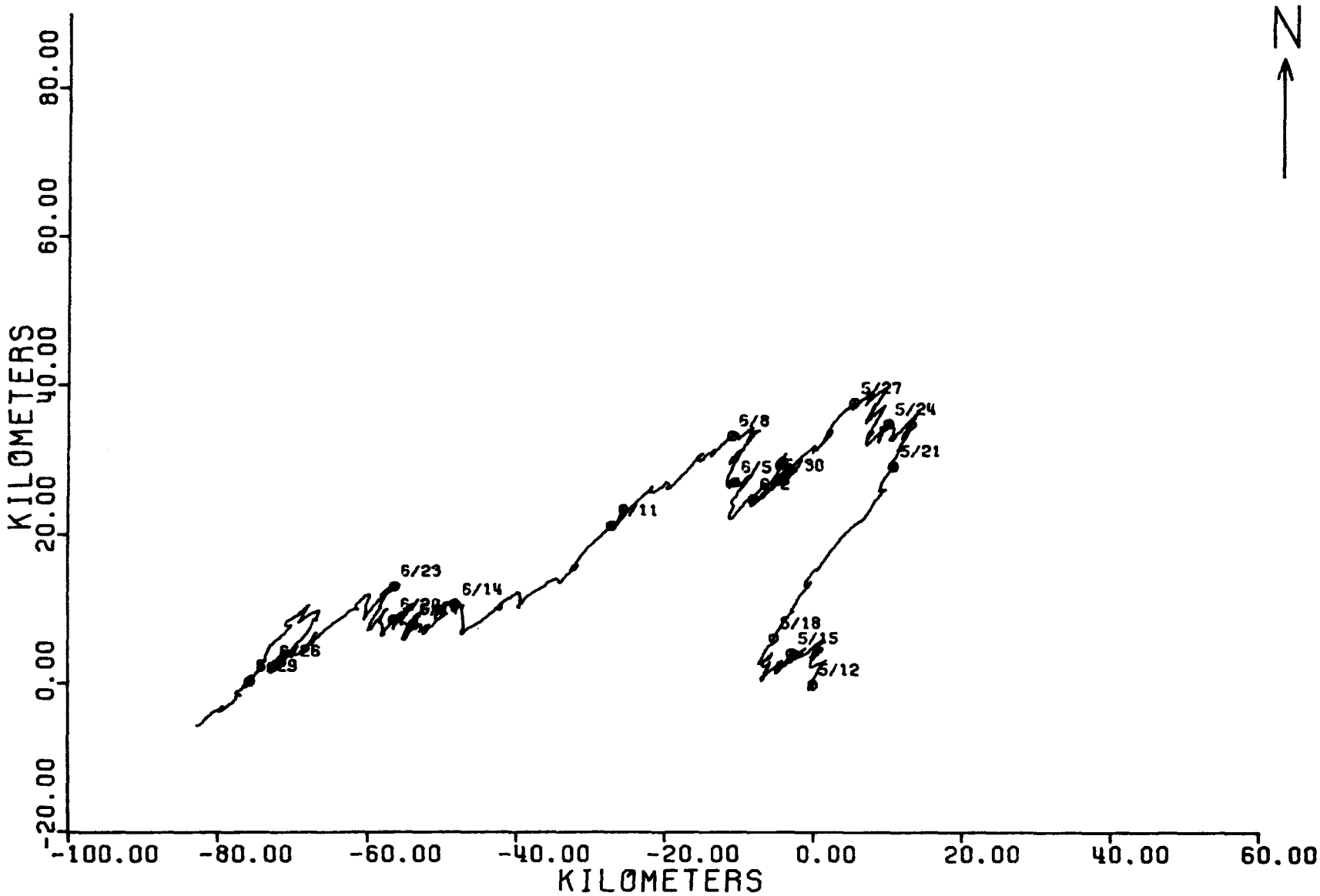

FIG. 4-4 PROGRESSIVE VECTOR PLOT AT STATION VN6 - METER DEPTH = 23M - 5/12/79 TO 7/1/79

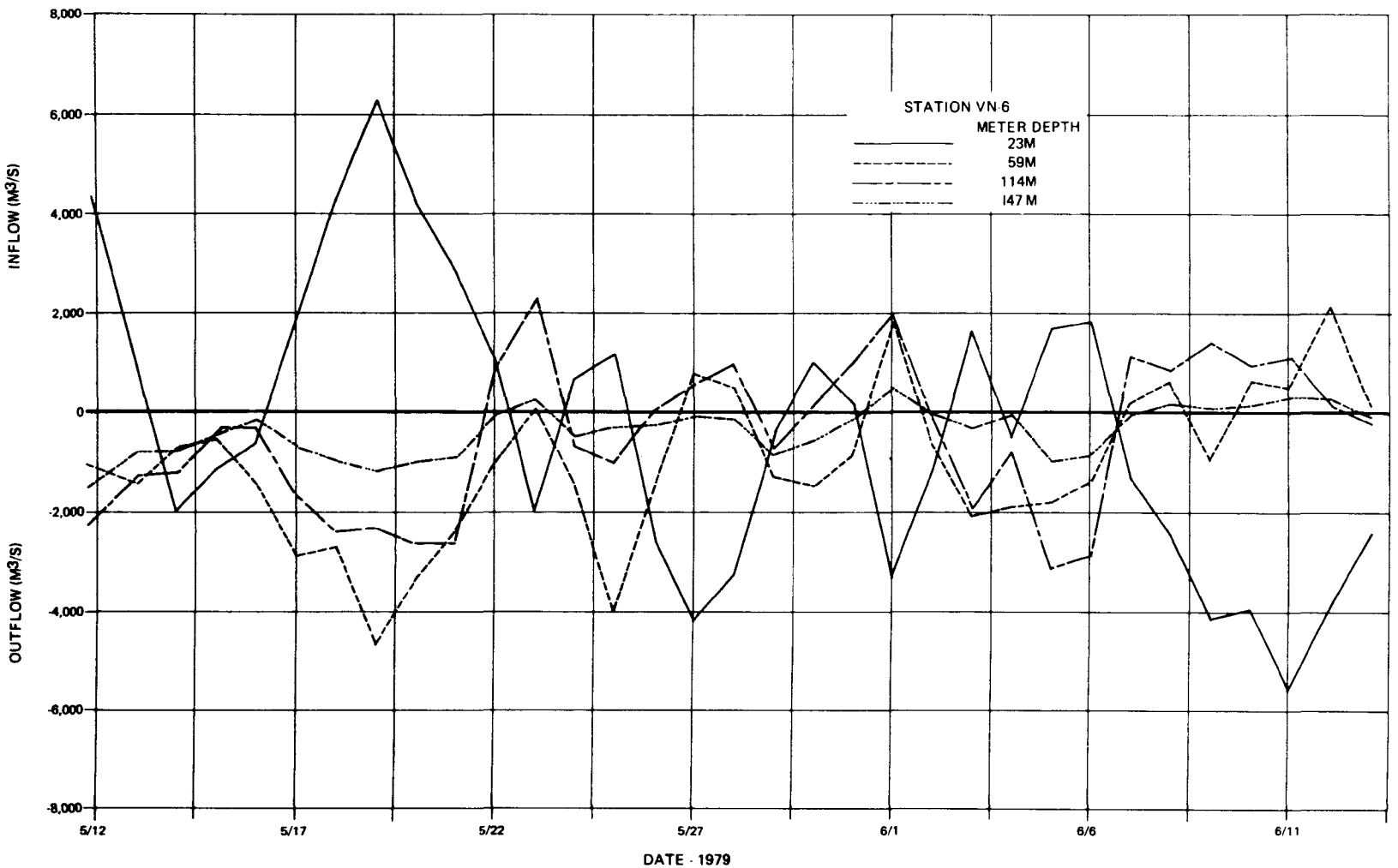

FIG. 4-5 FLOW AT VALDEZ NARROWS - STATION VN-6

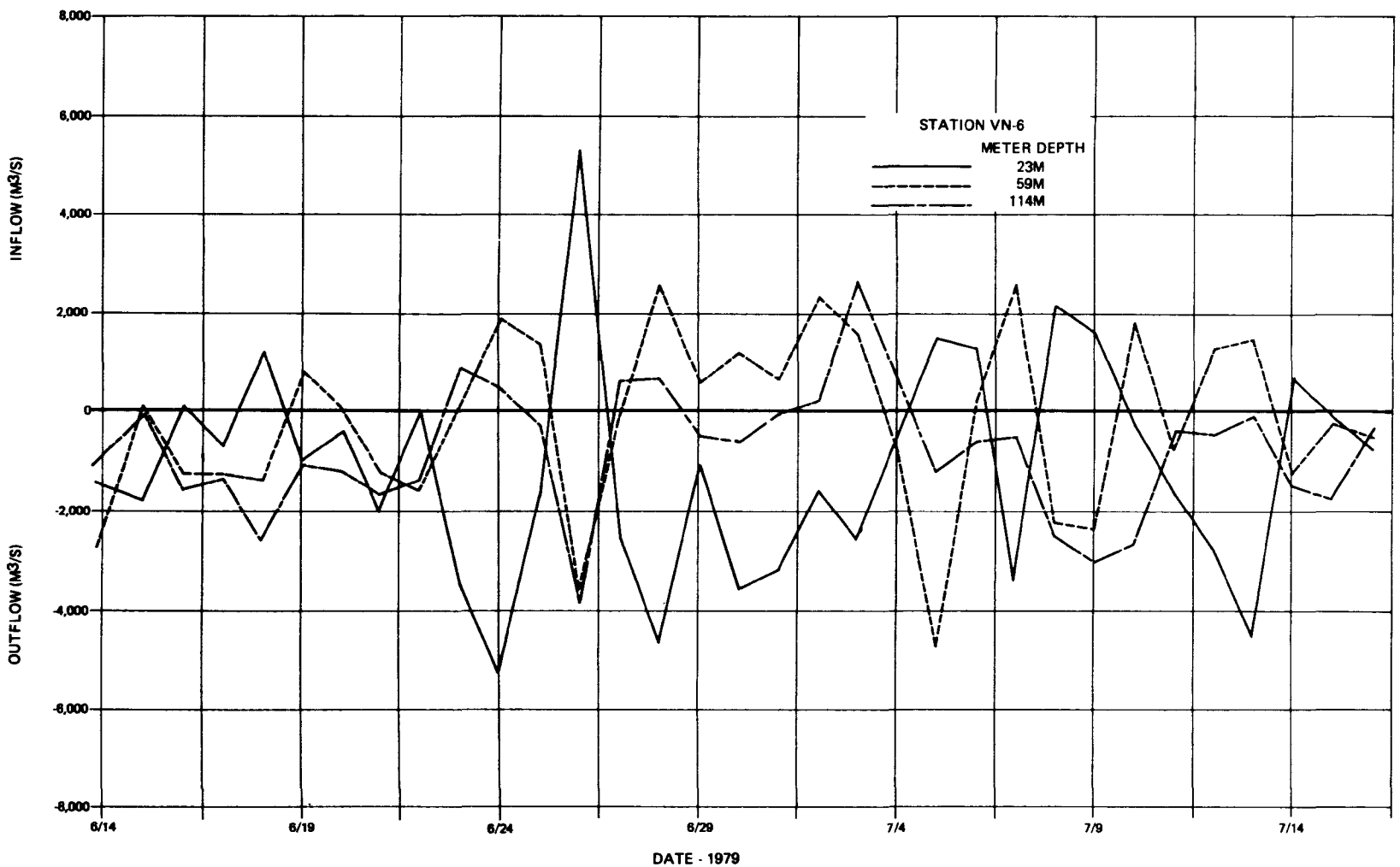

FIG. 4-6 FLOW AT VALDEZ NARROWS - STATION VN-6

in the upper layer is particularly strong from June 8 to June 14, as mentioned earlier. However, a strong inward flow in the upper layer is also evident from May 18 to May 21. In general, the flow of the lower layer, as represented by the other three current meters, opposes the upper layer flow. The layer flow directions reverse several times during the May through July period of record.

On certain days, the sum of the flows through Valdez Narrows does not balance. This is caused by two factors. Firstly, freshwater advective flow in the upper layer, particularly in mid-summer, results in net outflows. Secondly, the methodology of assigning a constant cross-sectional area to each current meter is only an approximation. Due to the limitation of having only four current meters, the actual smooth velocity profile is approximated by four points. The flows tend to balance over periods of several days, however, if the advective flow is subtracted from the total.

To estimate the effect of the flow-reversing events on Port Valdez flushing, the approximate hydraulic residence times of the upper and lower layers were calculated using May 19, 1979 velocity data. This was done by dividing the layer volume by the net inflow or outflow over the sill at Valdez Narrows. Results are presented in Table 4-2. It is apparent that for events such as that which occurred on May 19, the flow reversals help to flush a significant amount of water in Port Valdez.

TABLE 4-2. HYDRAULIC RESIDENCE TIMES ON MAY 19, 1979

	Net inflow or outflow, cms	Layer volume, m^3	Hydraulic residence time, days
Upper layer	8,000	3×10^9	4
Lower layer	6,500	14×10^9	25

For purposes of comparison, a hydraulic residence time may be estimated for the upper layer based on summer freshwater advective flows. Minimum, mean, and maximum July freshwater flows for the Port Valdez watershed have been estimated by the University of Alaska by extrapolation of U.S. Geological Survey Lowe River gaging data.(1) These flows and their corresponding residence times are presented in Table 4-3. July flows are the largest, thus giving the smallest or most conservative residence times. By comparing data from Tables 4-2 and 4-3, it is evident that more flushing occurred at Valdez Narrows on May 19 than during maximum estimated July freshwater flows.

TABLE 4-3. HYDRAULIC RESIDENCE TIMES BASED ON ESTIMATED JULY FRESHWATER INPUT

	Freshwater flow, cms	Upper layer volume, m^3	Hydraulic residence time, days
Minimum	197	3×10^9	176
Average	445	3×10^9	78
Maximum	1,017	3×10^9	34

Flow data for Station VN-5, from July to November 1978, are presented in Figures 4-7 through 4-9. Many direction reversals of the upper and lower layer occur; the frequency of these increases toward the latter part of the data set. This appears to be related to the fact that weather conditions become more variable during late summer and early autumn. As analyses of weather data taken from the NOAA Station at Valdez Airport during the May to July 1979 period indicate, pressure decreases are the probable cause of the flow reversals. Figure 4-10 is a plot of barometric pressure and upper layer flow from August 17 to September 16, 1978. The upper layer flow reverses and enters the Port with nearly every significant pressure decrease.

Storm systems moving over the Gulf of Alaska are responsible for these pressure changes. As they pass through, the storms apparently cause large surface flows into Prince William Sound and Port Valdez which in turn result in the exchange of a significant volume of water. This possibility was first suggested by Professor Joseph M. Colonell of the Institute of Marine Science.(1) The magnitude of inflow appears to depend on the rate of change of pressure drop. That is, the larger the rate of change of pressure, the larger the inflow into the Port.

Flushing Model

Model Formulations. To observe the effect of a waste discharge into Port Valdez, a two-layer, completely mixed flushing model was developed. This model accounts for pollutant flow and concentration; freshwater advective flows; an upper and

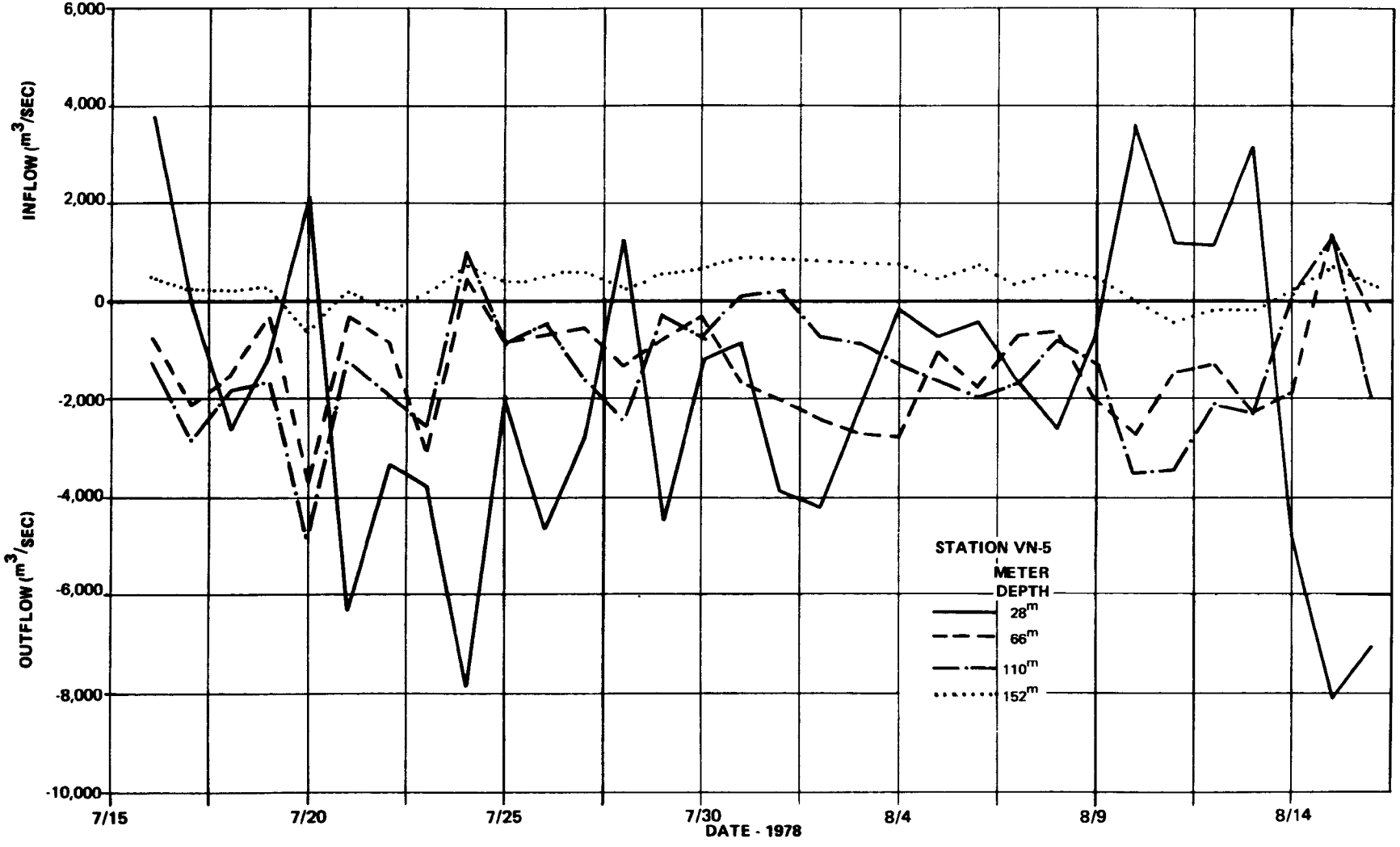

FIG. 4-7 FLOW AT VALDEZ NARROWS - STATION VN-5

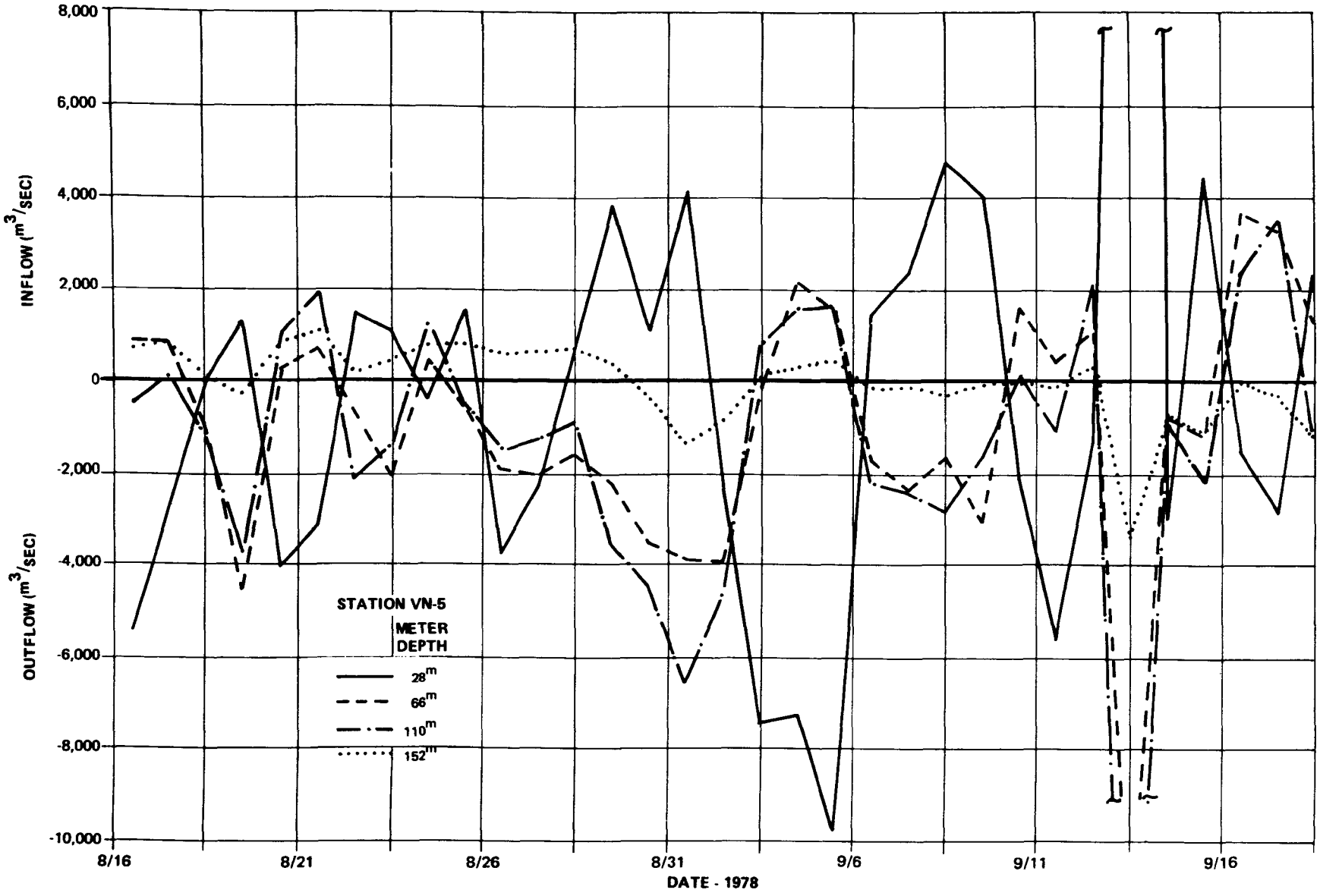

FIG. 4-8 FLOW AT VALDEZ NARROWS - STATION VN-5

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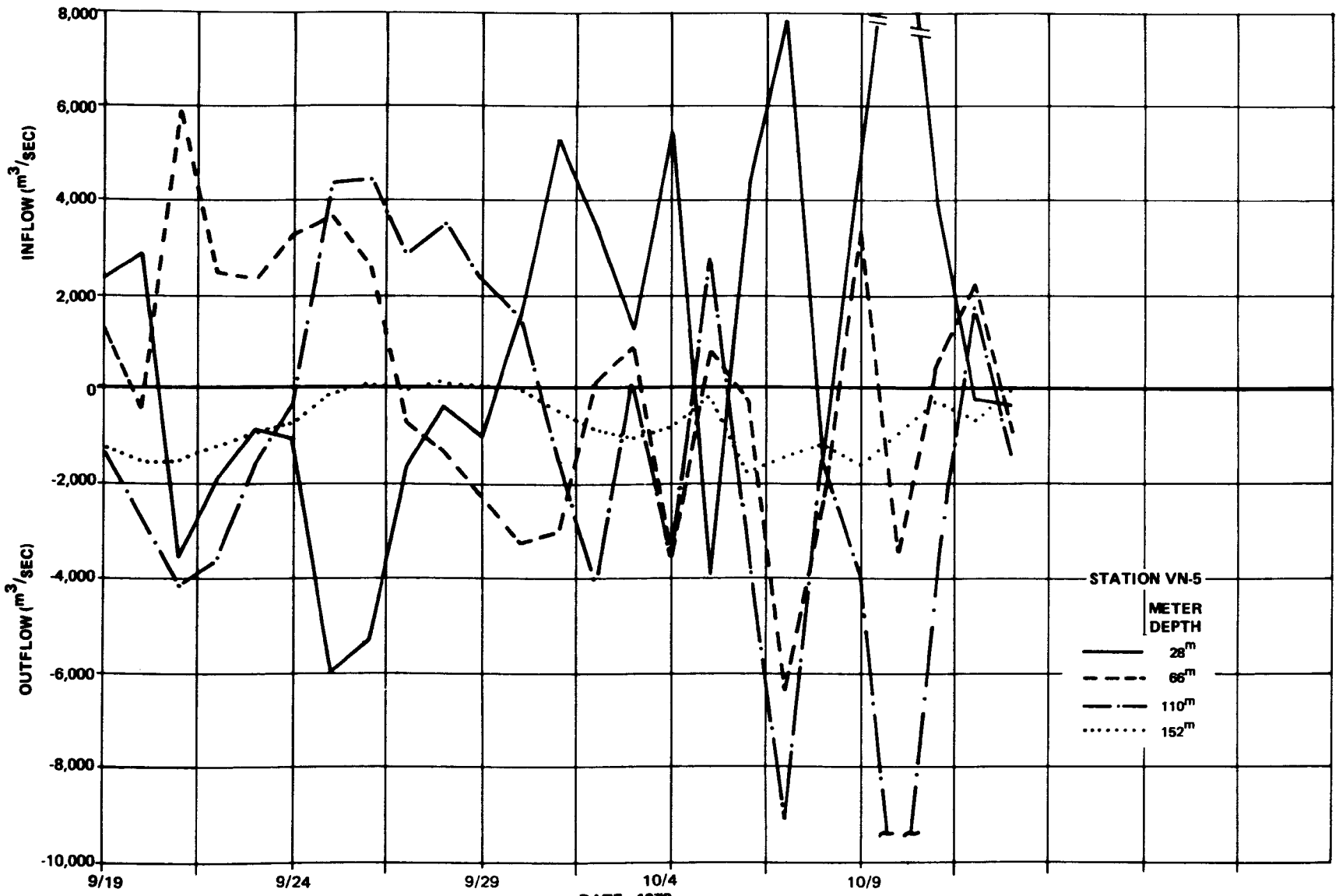


FIG. 4-9 FLOW AT VALDEZ NARROWS - STATION VN-5

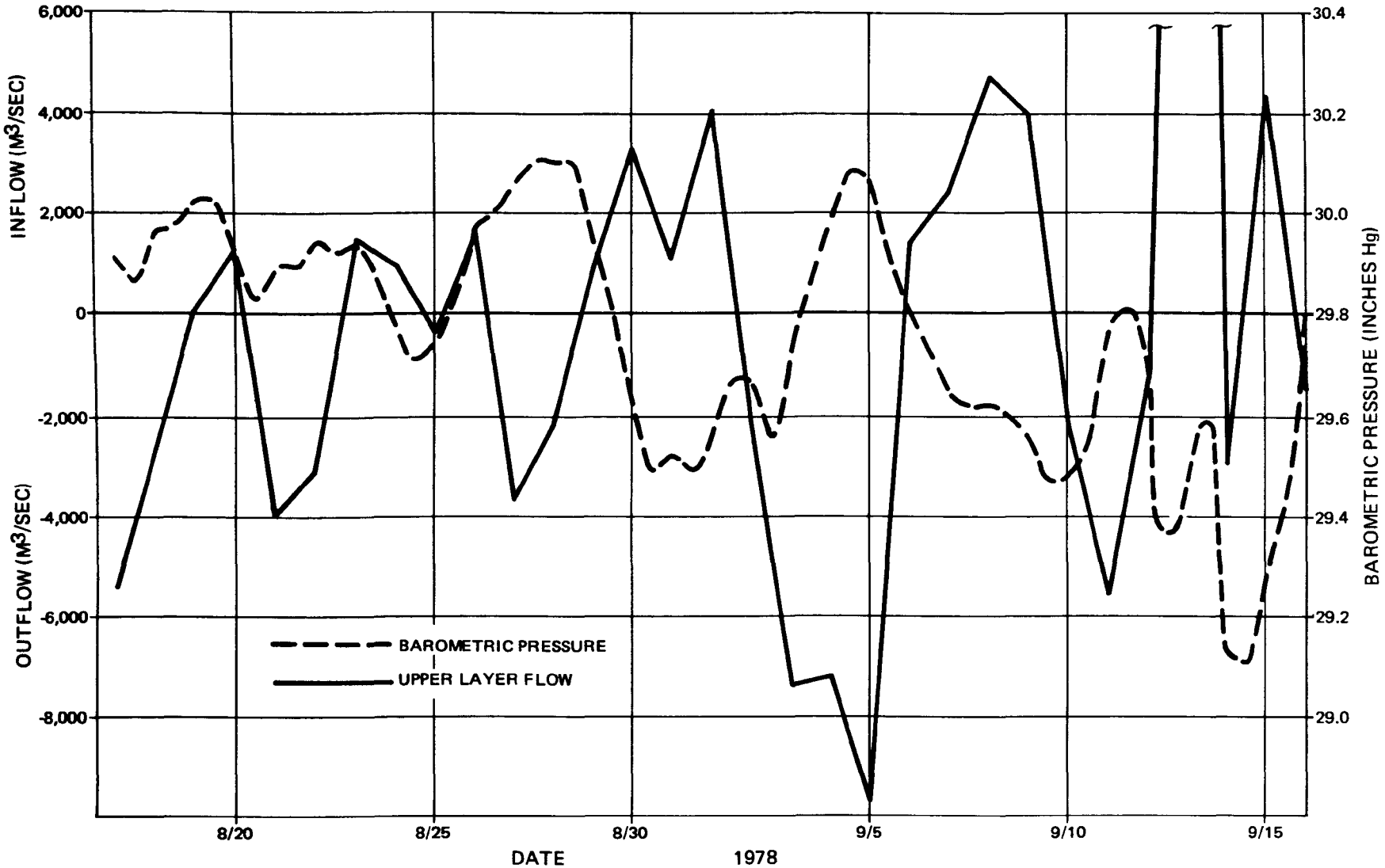


FIG. 4-10 UPPER LAYER FLOW AT STATION VN-5 VS. BAROMETRIC PRESSURE

a lower layer divided by a prescribed interface (represented by the measured depth of maximum stratification over time); and the measured currents at Valdez Narrows at four depths. The purpose of the flushing model is to observe time-varying pollutant concentrations in the upper and lower layers. This information indicates the average long-term concentrations and critical time periods of pollutant build-up in either layer for which more detailed and localized investigations must be made. The model also allows calculation of pollutant residence times. The model formulations are presented in detail in Figure 4-11. A complete program listing is furnished in Appendix E.

The method of calculations of the flushing model is as follows. Measured currents at Valdez Narrows are averaged for one day at each of the four depths. These daily average currents are then converted into daily average flows by assigning a constant cross-sectional area to each current meter. The daily average flows for the upper layer (Q_1) and lower layer (Q_2) are then computed based on the specified vertical location of the layer interface for that day. When the interface falls within the area of influence of a certain current meter, a linear interpolation is used to divide the flows between the two layers.

This layer interface is based on date measured by IMS;(1) at least a slight density stratification is assumed to exist throughout the year. This is a conservative assumption since the wastewater discharge is confined to the lower layer; velocities are lower here and therefore, the flushing is not as effective.

```
C*****************************************************************
C**                                                             **
C**                                                             **
C**     VALDEZ HARBOR TWO LAYER MODEL FORMULATION               **
C**                                                             **
C**                                                             **
C*****************************************************************
C
C
C |                                                             |
C +-------------^-----------------------^----------------------+
C +---> QA      |                       |       Upper          |
C |               |        Cu             | Hu    Layer        <--+-- Q1
C |   ^           |                       |                      |
C +---+---------+---------------^-------------------------------+     CO
C |   | QT      |               |                              |
C |   |         |               |                              <--+-- Q2
C |             |               |                              |
C |             |               |                              /
C |             |               |                             /
C |             | H     C1      | H1            Lower        /
C |             |               |               Layer       /
C |             |               |                          /
C +--->         |               |                         /
C |   Q         |               |                        /
C |   C         |               |                       /
C |             |               |                      /
C |             |               |                     /
C |_____________+_______________+____________________/
C
C
C
C=================================================================
C
C       DEFINITION OF TERMS
C
C       Q1      UPPER LAYER INFLOW OR OUTFLOW AT VALDEZ NARROWS
C       Q2      LOWER LAYER INFLOW OR OUTFLOW AT VALDEZ NARROWS
C       QA      FRESH-WATER ADVECTIVE FLOW INTO HARBOR
C       Q       WASTE FLOW
C       QT      TRANSFER FLOW BETWEEN LAYERS
C       H       TOTAL DEPTH OF PORT VALDEZ
C       dH      CHANGE IN TOTAL DEPTH OF PORT VALDEZ
C       dHi     CHANGE IN DEPTH DUE TO INTERFACE MOVEMENT
C       Hu      UPPER LAYER DEPTH
C       H1      LOWER LAYER DEPTH
C       C       WASTE CONCENTRATION
C       Cu      UPPER LAYER CONCENTRATION
C       C1      LOWER LAYER CONCENTRAION
C       CO      OCEAN CONCENTRATION
C       C1B     UPPER LAYER OCEAN TRANSFER LOADING
C       C2B     LOWER LAYER OCEAN TRANSFER LOADING
C       As      SURFACE AREA OF PORT VALDEZ
C       dT      TIME STEP
C
C=================================================================
```

FIG. 4-11 FLUSHING MODEL FORMULATIONS

```
C=================================================================
C
C---- COMPUTE Q1 & Q2 FROM MEASURED CURRENTS
C       (POSITIVE FLOWS ARE INTO HARBOR)
C
C----   COMPUTE NEW CONCENTRATIONS RESULTING FROM INTERFACE MOVEMENT
C
C--     CASE 1 LAYER INTERFACE MOVES DOWN (dHi IS POSITIVE)
C
C            Cu(Hu)+Cl(dHi)
C       Cu = --------------
C                Hu+dHi
C
C--     CASE 2 LAYER INTERFACE MOVES UP (dHi IS NEGATIVE)
C
C            Cl(Hl)-Cu(dHi)
C       Cl = --------------
C                Hl-dHi
C
C----   COMPUTE NEW LAYER DEPTHS CAUSED BY INTERFACE MOVEMENT
C
C       Hu = Hu+dHi
C
C       Hl = Hl-dHi
C
C---- COMPUTE CHANGE IN DEPTH
C
C            (Q1+Q2+Q+QA)dT
C       dH = --------------
C                  As
C
C---- COMPUTE TRANSFER FLOW (POSITIVE IS FROM LOWER TO UPPER)
C
C       QT = Q2 + Q
C
C---- COMPUTE OCEAN TRANSFER LOADS AT VALDEZ NARROWS
C
C--     Q1 POSITIVE
C
C       C1B = Q1(dT)CO
C
C--     Q1 NEGATIVE
C
C       C1B = Q1(dT)Cu
C
C--     Q2 POSITIVE
C
C       C2B = Q2(dT)CO
C
C--     Q2 NEGATIVE
C
C       C2B = Q2(dT)Cl
C
C=================================================================
```

FIG. 4-11 FLUSHING MODEL FORMULATIONS (Cont.)

```
C=================================================================
C
C---- COMPUTE NEW LAYER CONCENTRATIONS
C
C----    CASE 1 TRANSFER FROM LOWER TO UPPER (QT POSITIVE)
C
C--
C       LOWER LAYER CONCENTRATION
C
C             C1(H1)As+C2B+Q(dT)C
C       C1 = ---------------------
C             H1(As)+Q2(dT)+Q(dT)
C--
C       UPPER LAYER CONCENTRATION
C
C            Cu(Hu)As+C1B+QT(dT)C1
C       Cu = ---------------------
C                 (Hu+dH)As
C--
C
C----    CASE 2 TRANSFER FROM UPPER TO LOWER (QT NEGATIVE)
C
C--
C       UPPER LAYER CONCENTRATION
C
C            Cu(Hu)As+C1B+QT(dT)Cu
C       Cu = ---------------------
C                 (Hu+dH)As
C--
C       LOWER LAYER CONCENTRATION
C
C            C1(H1)As+Q(dT)C-QT(dT)Cu+C2B
C       C1 = ----------------------------
C                    H1(As)
C--
C
C----
C
C--
C       COMPUTE NEW UPPER LAYER DEPTH
C
C       Hu = Hu+dH
C
C=================================================================
```

FIG. 4-11 FLUSHING MODEL FORMULATIONS (Cont.)

A mass balance for flow is written for the lower layer which includes flow at Valdez Narrows and the waste discharge flow (Q). The sum of these flows is equivalent to a transfer flow (Q_T) which is assumed to move to the upper layer for the case of net lower layer inflow, or is taken from the upper layer for the case of net lower layer outflow. A flow balance in the upper layer includes advective flow, which is significant during summer months, and the upper layer flow at Valdez Narrows (Q_1). A mass balance of all flows entering or leaving the Port Valdez system is performed to calculate any depth change in the Port.

Pollutant mass balances are written separately for each layer for each daily time step. The concentration of waste (C) in the discharge is assumed to enter and mix with the lower layer; it may be transferred to the upper layer or out of Port Valdez, depending on the existing hydraulic conditions. The waste concentration in the water body outside Port Valdez, as well as in the freshwater advective flow, is assumed to be zero.

The flushing model was run using the average expected daily flow from the ALPETCO diffuser of 0.31 m^3/sec (cubic meters per second). This represents the total mass of the discharge flow. The model was run for 1-1/2 years by piecing together the current data at Valdez Narrows from Stations VN-2, VN-5 and VN-6 (see Table 4-1). These data span nearly an entire year, and although the measurements were taken in different years, they were assumed to be indicative of flows which occur during that time period of the year. The 16-day gap in data from April 26 to

May 11 was filled by repeating the previous 16 days of flow measurements. Also, the second half year was taken as a repeat of the previous year. The results of this simulation are presented in Figure 4-12.

Model Results. The model was run under the condition that ALPETCO's discharge is initiated on January 1. As shown in Figure 4-12, concentrations in both layers, which begin at zero, gradually increase to a peak value in the upper layer in about two months and in the lower layer in about four months. These same peak value points were reached when the simulation was continued into the second year, showing attainment of an annual steady-state.

Lower layer concentrations remain relatively constant throughout the year at about 65 ppm (parts effluent per million parts Port Valdez water). This reflects the fact that the lower layer volume is very large; once steady-state conditions have been attained, only extremely large flow events can change the concentrations. Upper layer concentrations fluctuate between 5 and 90 ppm, with an average of about 45 ppm. The upper layer concentration fluctuations are due to the effect of large flow events on the smaller volume. Concentrations of less than 100 ppm indicate a dilution factor of over 10,000.

The most critical time period for buildup of pollutants in both layers is late June and early July, despite the fact that freshwater advective flow is near its annual peak. This is because flow conditions at Valdez Narrows are quite "tame" during

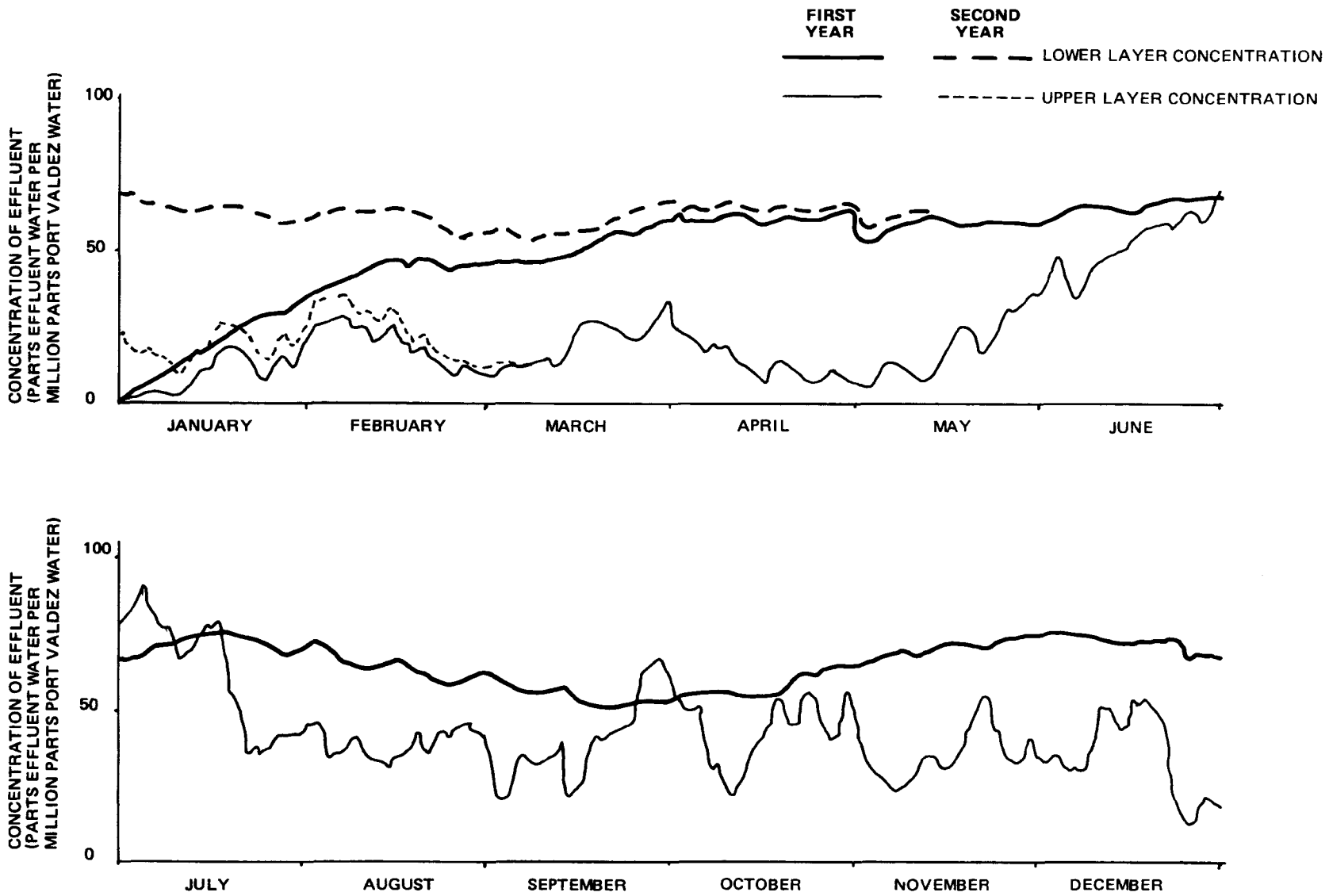


FIG. 4-12 MODELED AVERAGE CONCENTRATION OF EFFLUENT IN PORT VALDEZ DURING A SELECTED 1-1/2 YEAR PERIOD

this period. At Valdez Narrows, the upper layer flow is predominantly outward and the lower layer flow is inward. The upper layer is replenished with lower layer water. Since the wastewater is discharged into the lower layer, the upper layer concentration increases.

An approximate overall pollutant residence time can be calculated by dividing the mass of pollutant in Port Valdez by the mass flow rate of pollutant load. Using the July concentration of 75 ppm in each layer, this calculation results in a residence time of 48 days. This value represents the critical time period for pollutant buildup during early July. The residence time is subject to variation depending on flow conditions at the Narrows, but is indicative of the flushing capacity of Port Valdez during the worst period.

In summary, Port Valdez has excellent flushing capacity, considering its size. This is due to freshwater advective flows in summer, and large exchanges of water during the remainder of the year. Significant flow events at Valdez Narrows, which may be caused by storm-induced barometric pressure variations, are instrumental in the good flushing characteristics of the Port. Flushing model results indicate pollutant concentrations in the far field are diluted by a factor of 10,000 or more.

REFERENCES

1. Continuing Environmental Studies of Port Valdez, Alaska, 1976-1978, Institute of Marine Science, University of Alaska, 1979.

2. Environmental Studies of Port Valdez, Alaska, Institute of Marine Science, University of Alaska, 1973.

CHAPTER 5
CIRCULATION AND DISPERSION

General

Circulation patterns in eastern Port Valdez, particularly near the proposed ALPETCO diffuser site, are summarized in this section. A detailed analysis of currents measured in the eastern end of the Port was performed. The relationship of these measurements to current measurements at Valdez Narrows is discussed. The effects of stratification, advective flows, and weather on net motions are also discussed. This is followed by an analysis of pollutant concentration distributions under various conditions using the Transient Plume Model,(1) developed at the Massachusetts Institute of Technology. Pollutant concentrations in the eastern end of Port Valdez, but outside the zone of initial dilution, are predicted. Since complete mixing of pollutants in Port Valdez is assumed in the flushing model, the Transient Plume Model provides a more realistic picture of concentrations in the area of the proposed discharge.

Analysis of Eastern Port Valdez Currents

As part of the oceanographic field program conducted this year, continuous recording current meters were positioned in the eastern end of Port Valdez at two locations. Meter locations are indicated in Figure 5-1 and the related data are summarized in Table 5-1. An explanation of the field measurement program has been presented in Chapter 1. Computer plots of the current speed

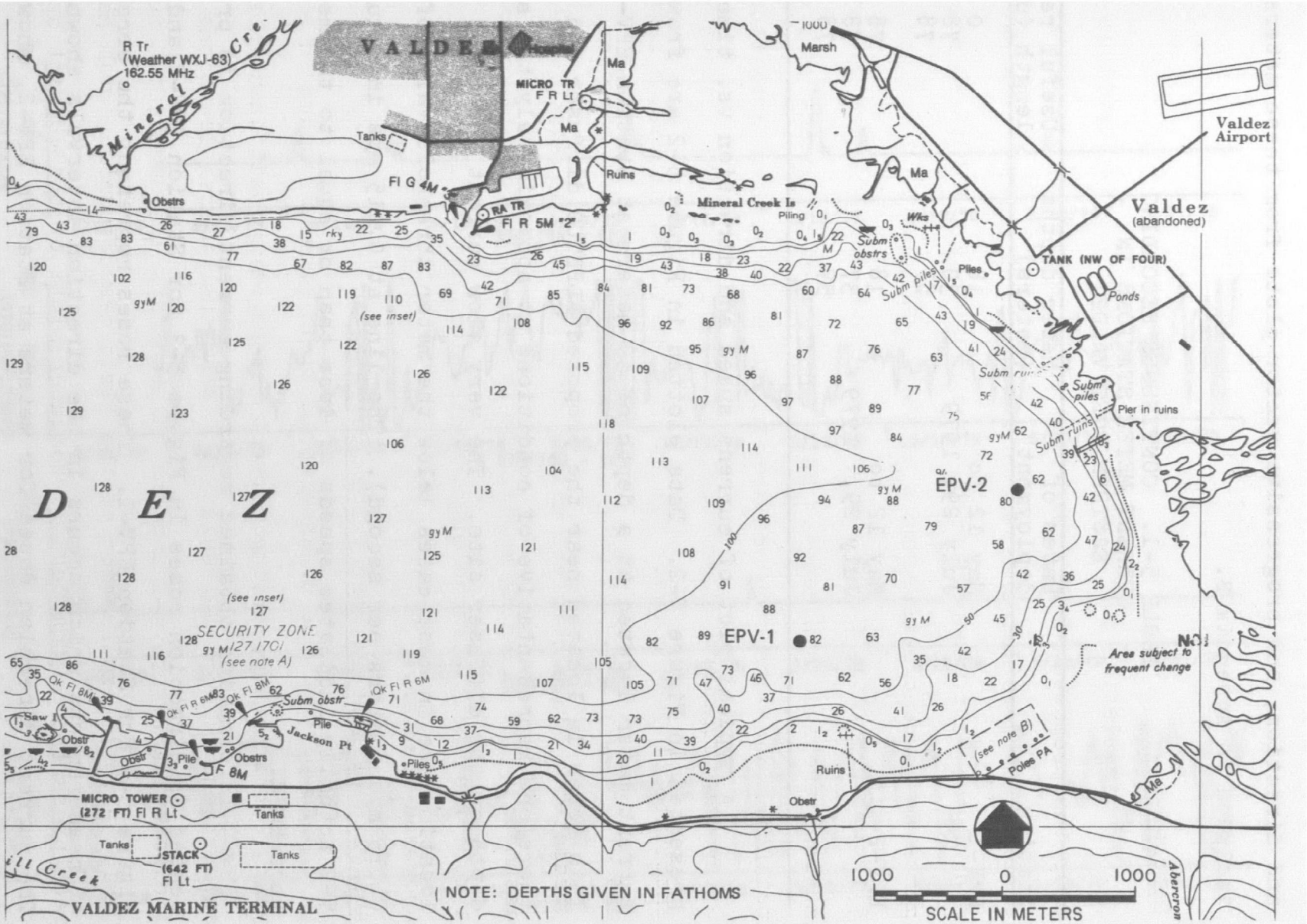


FIG. 5-1 LOCATION OF CONTINUOUS RECORDING CURRENT METER STATIONS

and direction, and progressive vector plots from these meters are included in Appendix B.

TABLE 5-1. CONTINUOUS RECORDING CURRENT METER STATIONS IN EASTERN PORT VALDEZ

Station	Dates of deployment	Meter depths (meters)	Useful record length (days)
EPV-1	May 12 to July 29, 1979	18	0
		30	78
		57	78
EPV-2	May 12 to July 29, 1979	18	78
		37	78
		59	78

A typical plot of current speed and direction vs. time is presented in Figure 5-2. Data plotted in Figure 5-2 are from the current meter located at a depth of 59 meters at Station EPV-2. This meter is located near the proposed ALPETCO diffuser and is therefore representative of conditions at approximately the same depth at the diffuser site. The very slow current speeds at this location are in most cases below the meter threshold value of 0.015 mps (meters per second). The line at 0.015 mps in Figure 5-2 actually indicates speeds of less than or equal to the meter threshold.

Information obtained regarding current direction is presented as direction roses in Figure 5-3 for Station EPV-2 and in Figure 5-4 for Station EPV-1. These roses represent the percent of measurements which occurs in the direction intervals shown. The current direction roses for meters at Station EPV-2, shown in

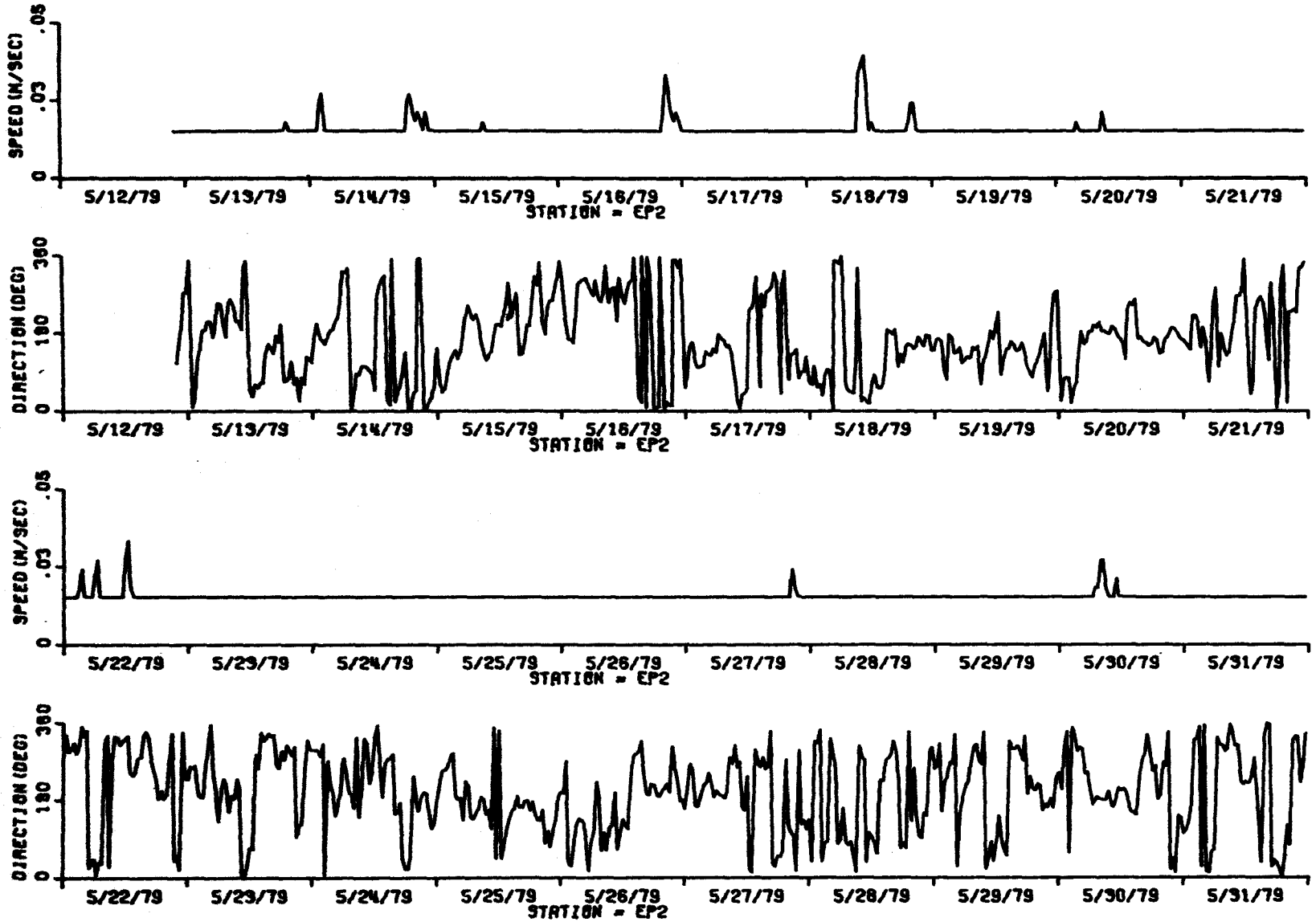


FIG. 5-2 CURRENT SPEED AND DIRECTION AT STATION EPV-2 – METER DEPTH = 59M

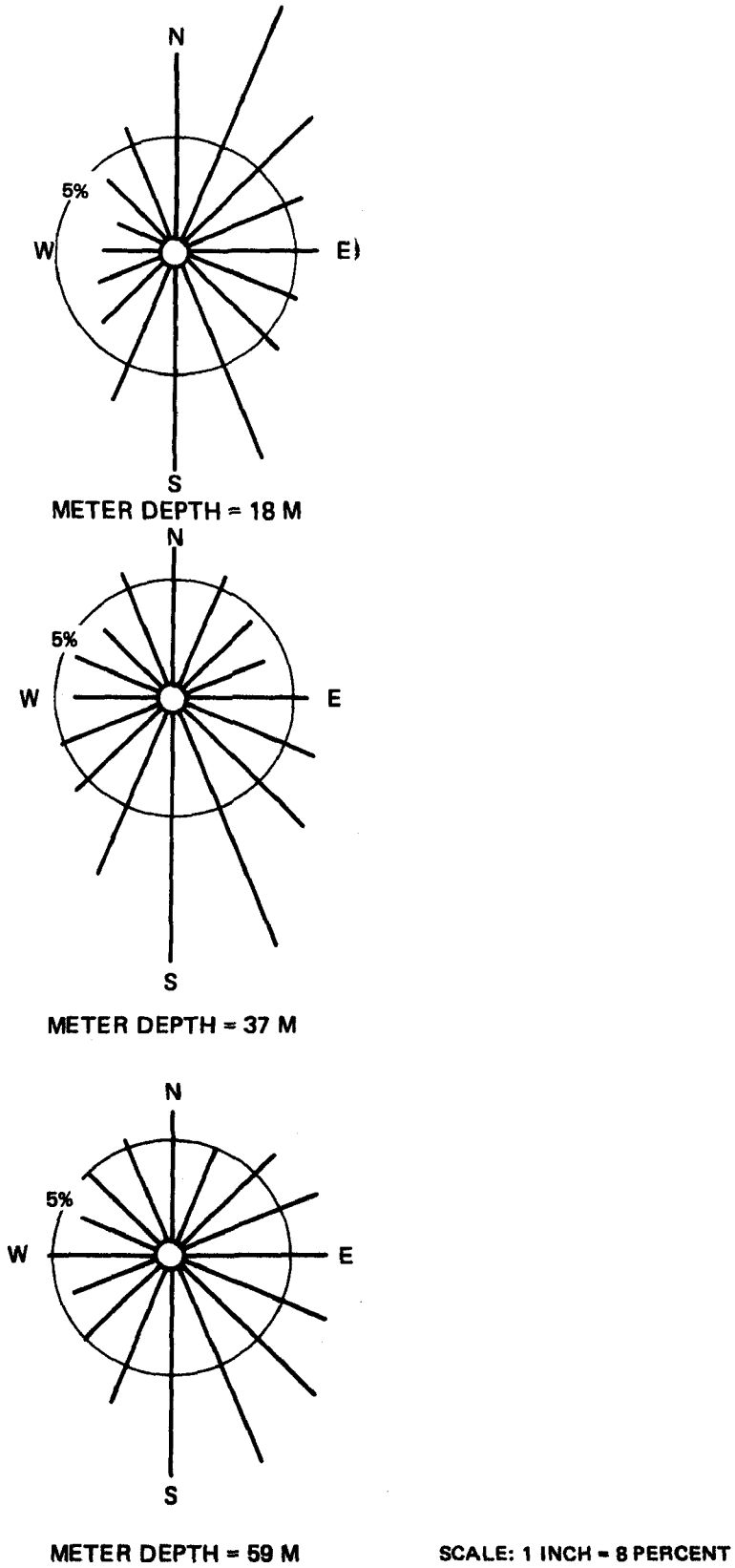
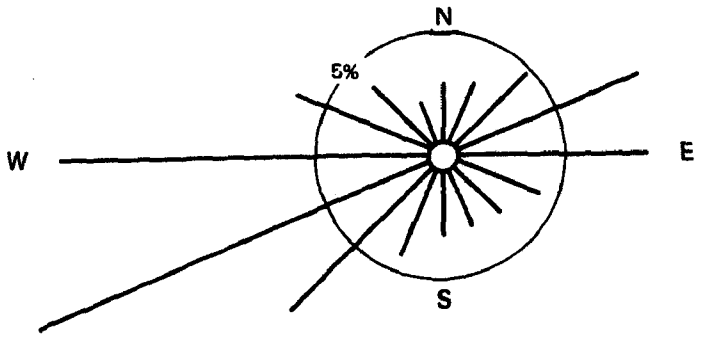
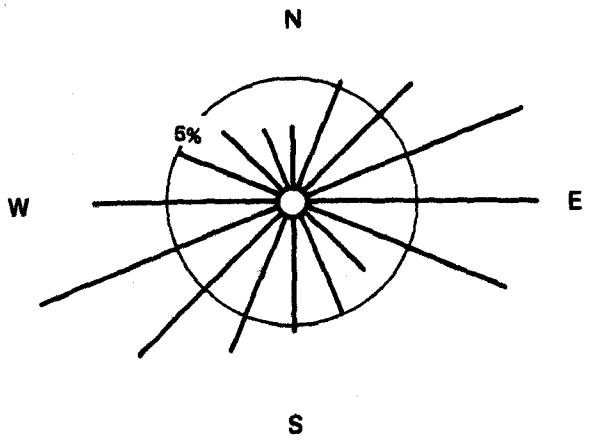


FIG. 5-3 FREQUENCY DISTRIBUTION OF CURRENT DIRECTION, STATION EPV2



METER DEPTH = 30 M



METER DEPTH = 57 M

SCALE: 1 INCH = 8 PERCENT

FIG. 5-4 FREQUENCY DISTRIBUTION OF CURRENT DIRECTION, STATION EPV1

Figure 5-3, indicate a preferred south to southeast direction for all meters. At the upper meter, there is also a stronger preference for northeasterly motion.

Figure 5-5 is a progressive vector plot of the upper meter at Station EPV-2. A rapid northeast motion (almost 2 kilometers per day) occurs during the period from May 18 to May 21. This period had a strong upper layer inflow at Valdez Narrows, which is accompanied by a resulting net motion of the upper layer in the eastern end of the Port. Before this period, weather observations at Valdez indicated a drop in pressure from 30.15 inches Hg on May 14 to 29.56 inches Hg on May 16. The upper layer inflow conditions seem to be correlated with such pressure drops as mentioned in Chapter 4. A comparison of Figure 5-5 and the corresponding flows at Valdez Narrows shown in Figure 5-6, indicates that northeast motion at the upper meter of Station EPV-2 is associated with upper layer inflows at Valdez Narrows, and southeast or clockwise motion is associated with upper layer outflows.

The current direction roses for meters at Station EPV-1, shown in Figure 5-4, demonstrate a predominantly east-west flow. The upper meter malfunctioned and no useful results were obtained. The middle meter had a stronger westerly direction preference, which was judged as resulting from the driving force of summer freshwater advective flow in the upper layer. This station showed more tidal influence and somewhat stronger currents than Station EPV-2. A comparison of the progressive vector plot for the middle

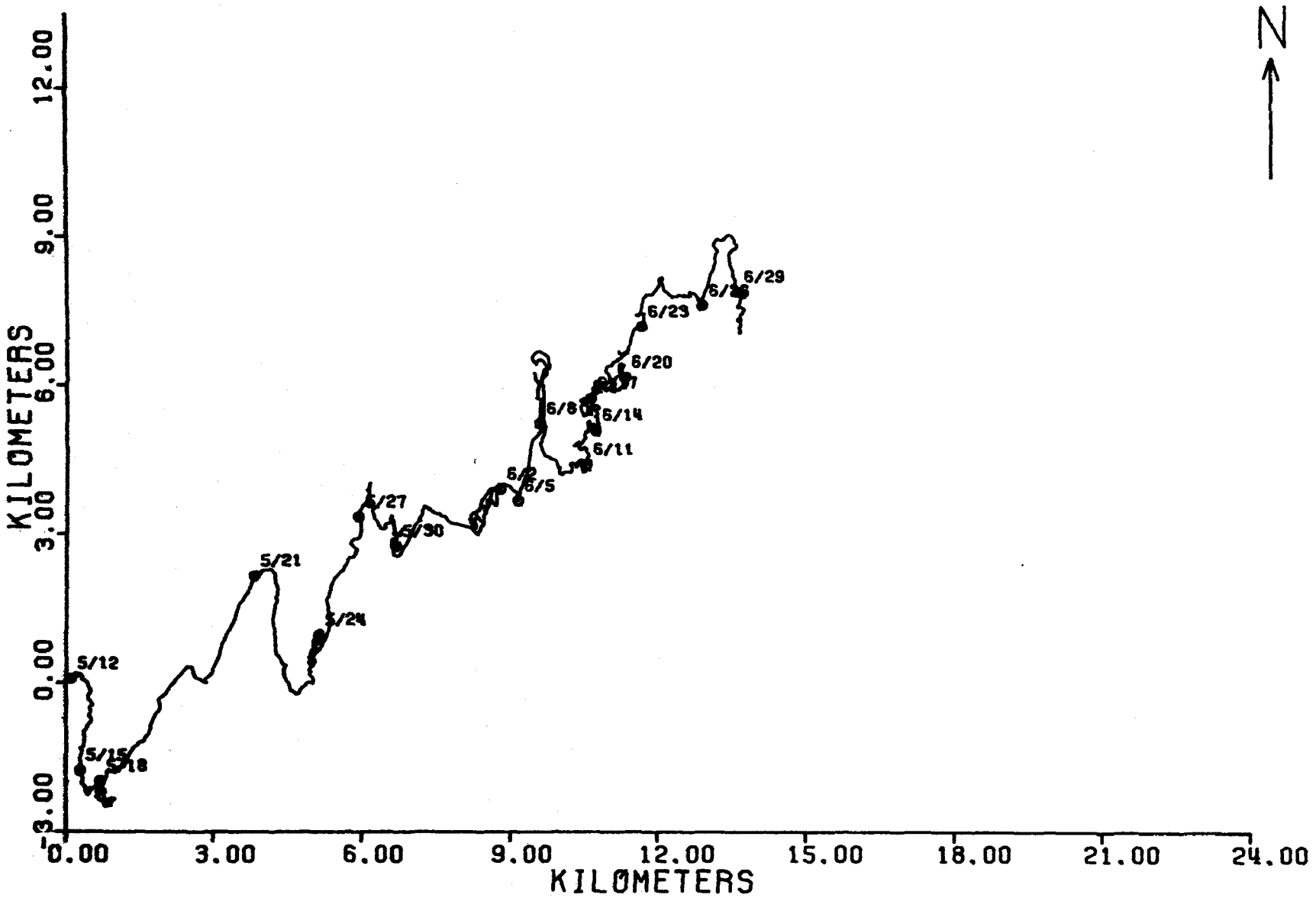


FIG. 5-5 PROGRESSIVE VECTOR PLOT AT STATION EPV-2 - METER DEPTH = 18M - 5/12/79 TO 7/1/79

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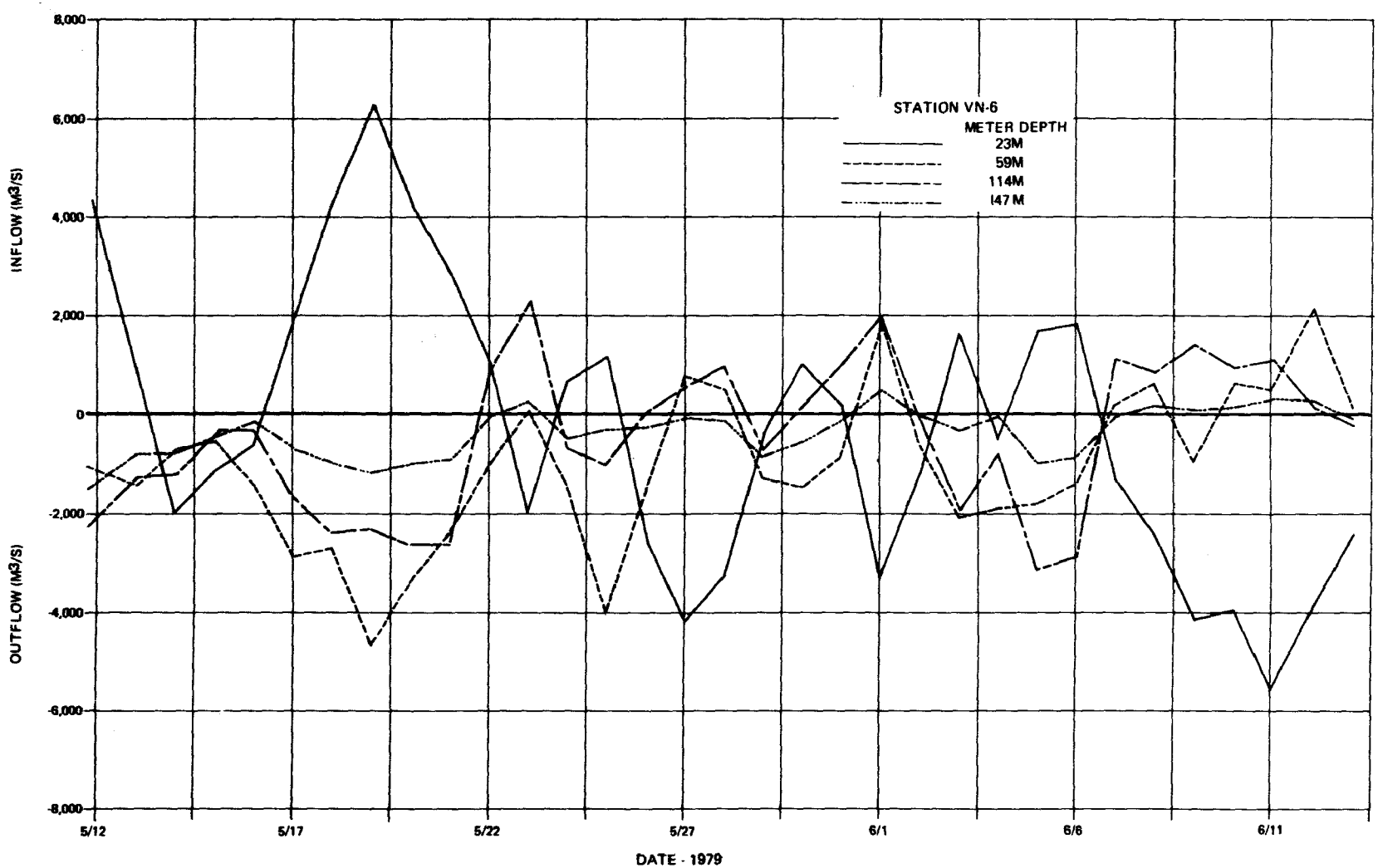

FIG. 5-6 FLOW AT VALDEZ NARROWS - STATION VN-6

METCALF & EDDY

meter at Station EPV-1, shown in Figure 5-7, and the flow at Valdez Narrows (see Figure 5-6), shows that upper layer inflows at Valdez Narrows appear to cause the current at EPV-1 to change direction and head eastward. This is similar to current behavior at Station EPV-2, and indicates that events at Valdez Narrows are closely related to events in the eastern end of the Port.

Large flow events, such as that on May 18, have a definite effect on currents in the eastern end of the Port. From this it follows that quiet periods at Valdez Narrows are also quiet periods in eastern Port Valdez. A review of all the available velocity data at Valdez Narrows indicates that summer periods generally have low velocities while winter periods have high velocities, probably caused by intense storm activity. A long "quiet" period with low velocities occurred during the 1979 field study, from about June 27 to July 10. This is the period which has high pollutant buildup in the flushing model simulation presented in Chapter 4. The low flows result in lack of exchange, which causes pollutant concentrations to increase. This period is therefore the most critical in terms of pollutant buildup.

Motion at Stations EPV-2 and EPV-1 may be seen more clearly by observing progressive vector plots of the upper and lower meters for specific time periods. Two time periods are presented: May 18 to 20, shown in Figure 5-8, which corresponds with a rapid upper layer inflow at Valdez Narrows, and June 10 to 12, shown in Figure 5-9, which corresponds with an upper layer outflow.

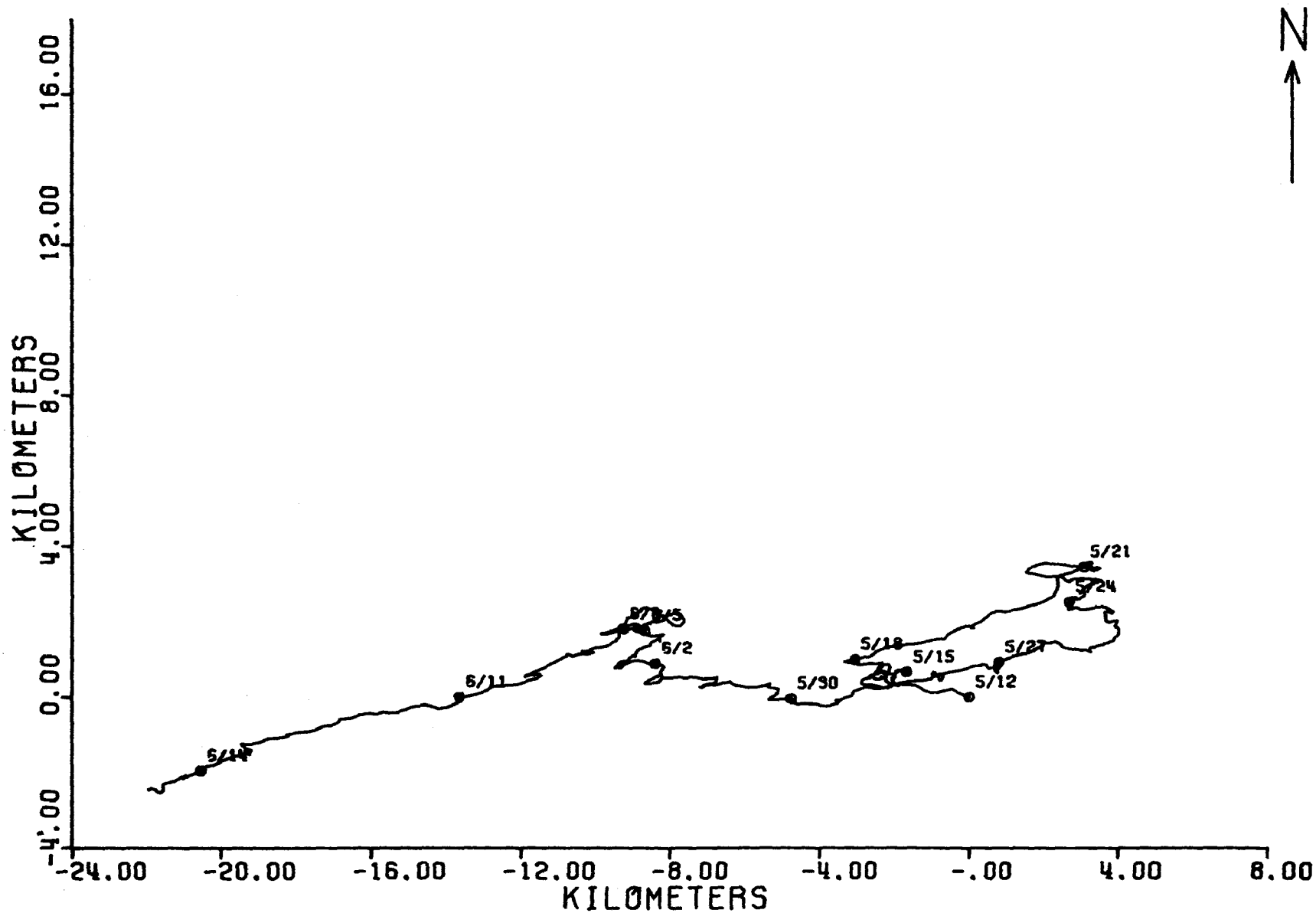

FIG. 5-7 PROGRESSIVE VECTOR PLOT AT STATION EPV-1 - METER DEPTH = 30M - 5/12/79 TO 6/15/79

METCALF & EDDY

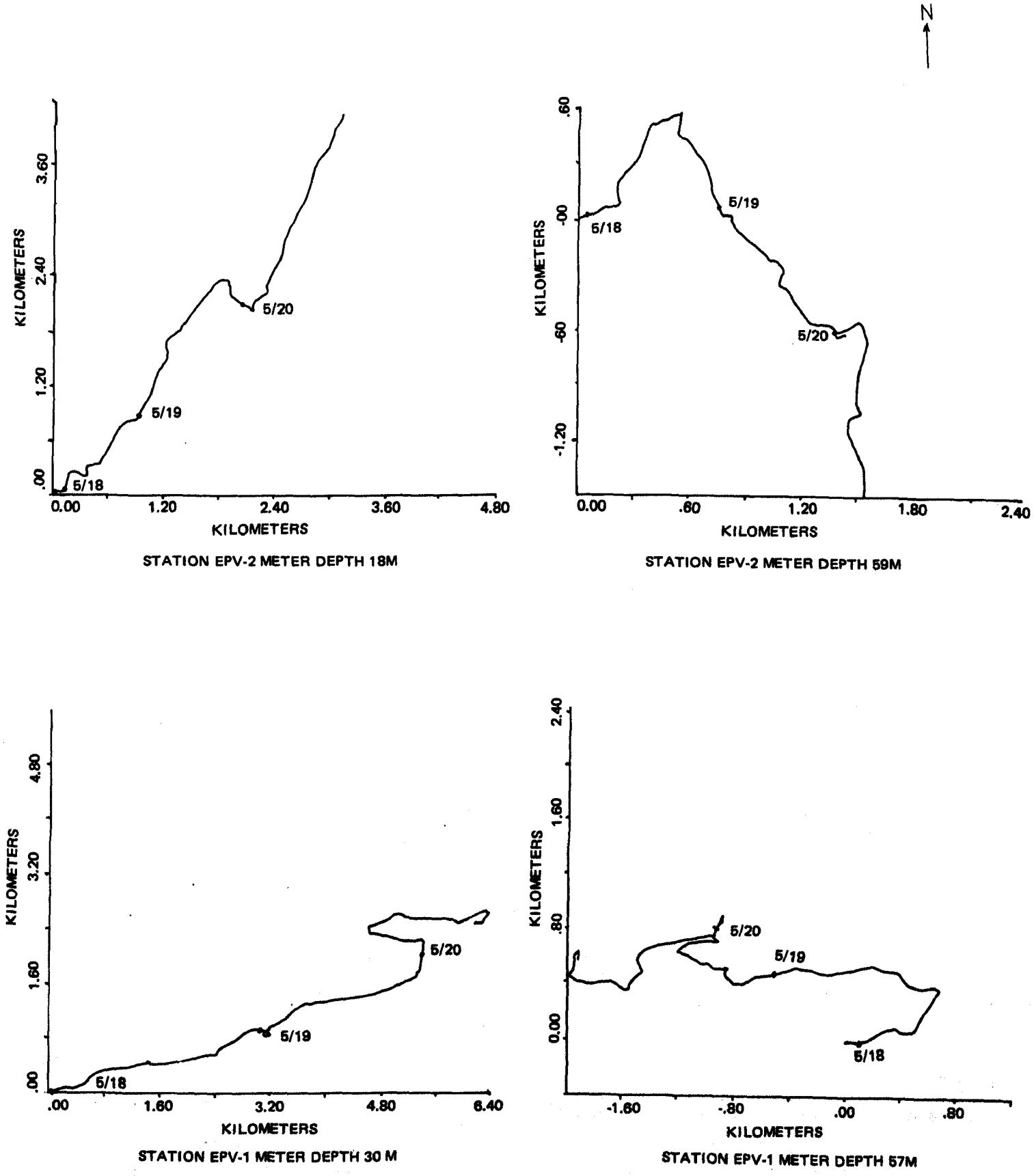

FIG. 5-8 PROGRESSIVE VECTOR PLOTS FOR MAY 18-20, 1979

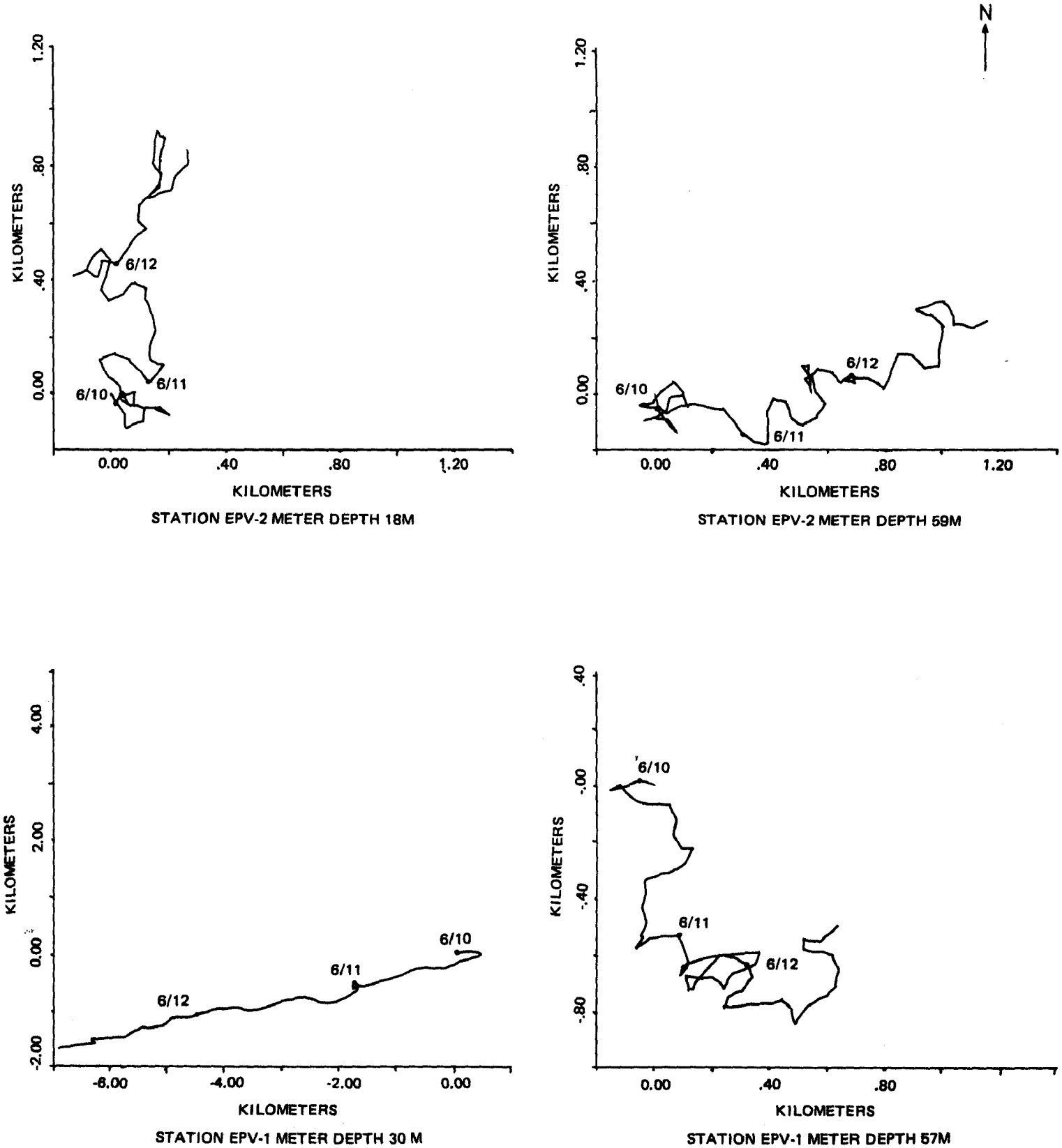

FIG. 5-9 PROGRESSIVE VECTOR PLOTS FOR JUNE 10-12, 1979

Firstly, in studying the progressive vector plots for the period May 18 to 20 at Station EPV-2 near the proposed ALPETCO diffuser site (shown in Figure 5-8), the upper meter shows northeasterly motion while the lower meter shows southeasterly motion. At Station EPV-1, the upper meter velocity is east-northeasterly, and the lower meter velocity is westerly. The circulation pattern which is evident here is that of inflow of an upper layer heading east at Station EPV-1 and then turning north at the easterly end of the port at Station EPV-2, parallel to the eastern shoreline. The current measurements at lower depth indicate a bottom layer heading west at Station EPV-1 and southeast at Station EPV-2, parallel to the shoreline. Therefore, the layer flows are opposing, with counter-clockwise flow in the upper layer, clockwise flow in the lower layer, and both flows generally parallel to the shoreline.

The condition during the upper layer outflow period, shown in Figure 5-9 for June 10 to 12, is nearly the opposite. The lower layer velocities are inward (east or southeast) at both stations, while the upper layer velocities are outward (west or southwest) at Station EPV-1. The upper meter at Station EPV-2 is the exception to the pattern with northerly currents. Large freshwater advective flows from the Lowe River and the Valdez Glacier Stream probably could affect the upper layer current measurements. Stream flow measurements of Valdez Glacier Stream taken by CCC/Hok-Dowl during this study indicate a significant flow increase from about 23 to about 57 cms (cubic meters per

second) from May 29 to June 6, 1979. This precedes, by a few days, the period covered by the progressive vector plots.

To help clarify the situation, the progressive vector plots shown in Figures 5-8 and 5-9 are depicted in a different manner in Figures 5-10 and 5-11. Figure 5-10 shows the progressive vector plots at Stations EPV-1 and EPV-2 as straight lines or "head to toe" vectors from the beginning to end of the the May 18 to May 20 time period. Figure 5-11 is a similar drawing from the June 10 to 12 period. Also included is the middle meter (37 meters depth) at Station EPV-2, which was not shown in Figures 5-8 and 5-9. The opposing layer motions are again apparent in Figures 5-10 and 5-11.

In summary, the currents in eastern Port Valdez appear to be closely related to those at Valdez Narrows. A large inflow or outflow at Valdez Narrows apparently affects the currents in the eastern end of the Port. Opposing layer flows occurred in the eastern Port area during May to July 1979, the period of observation for this study. There was a preference during the measurement period for the upper layer to move north and the lower layer to move south at Station EPV-2. Near the proposed ALPETCO diffuser site, the flow tends to turn parallel to follow the boundary of the eastern shore. The wastewater plume is therefore expected to turn south or north following this motion parallel to the eastern boundary. These observations suggest that there is a fairly equal chance of the plume heading north or south. As mentioned in Chapter 3, for stratified conditions, the

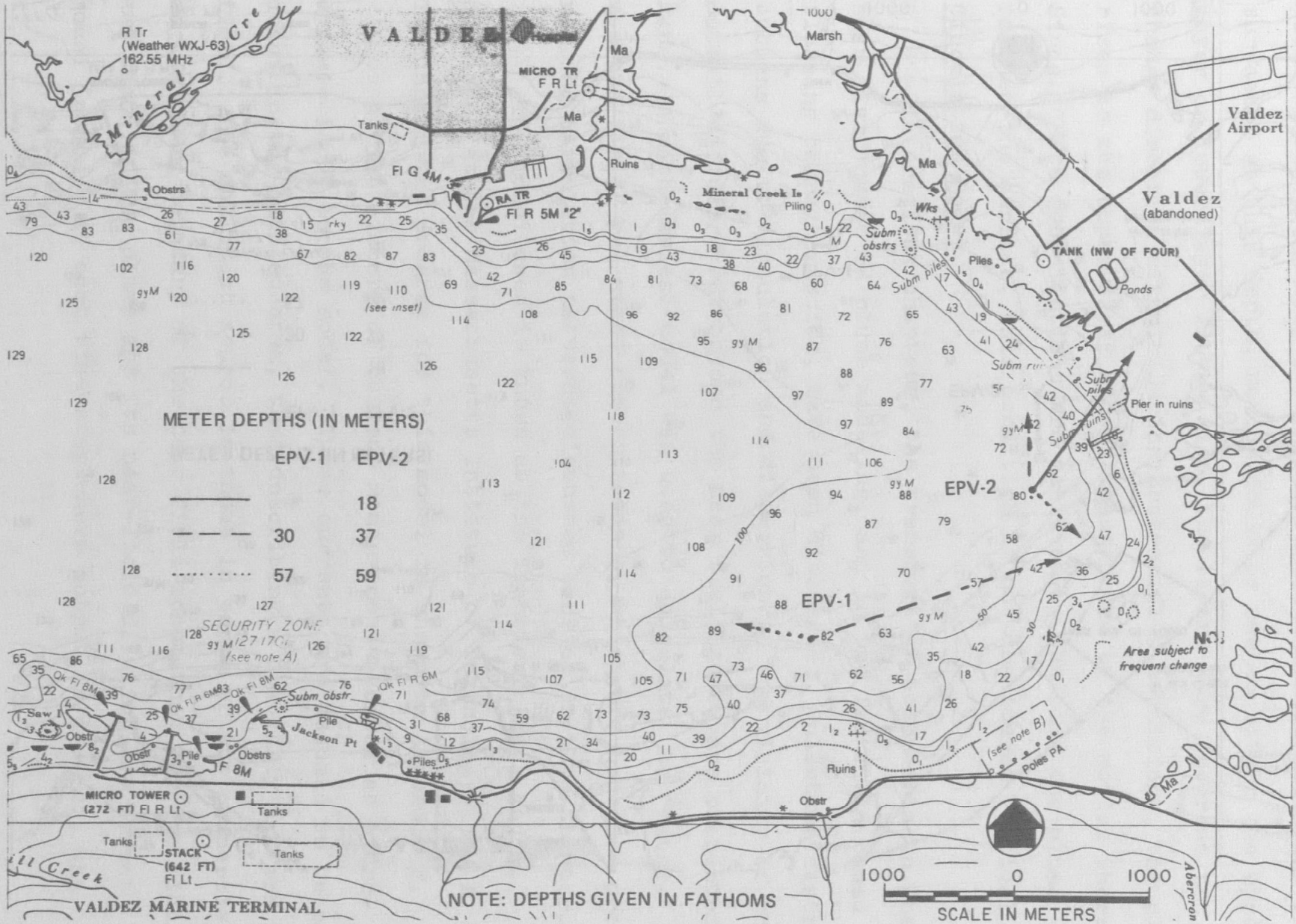

FIG. 5-10 CURRENT VECTORS FOR MAY 18-20, 1979

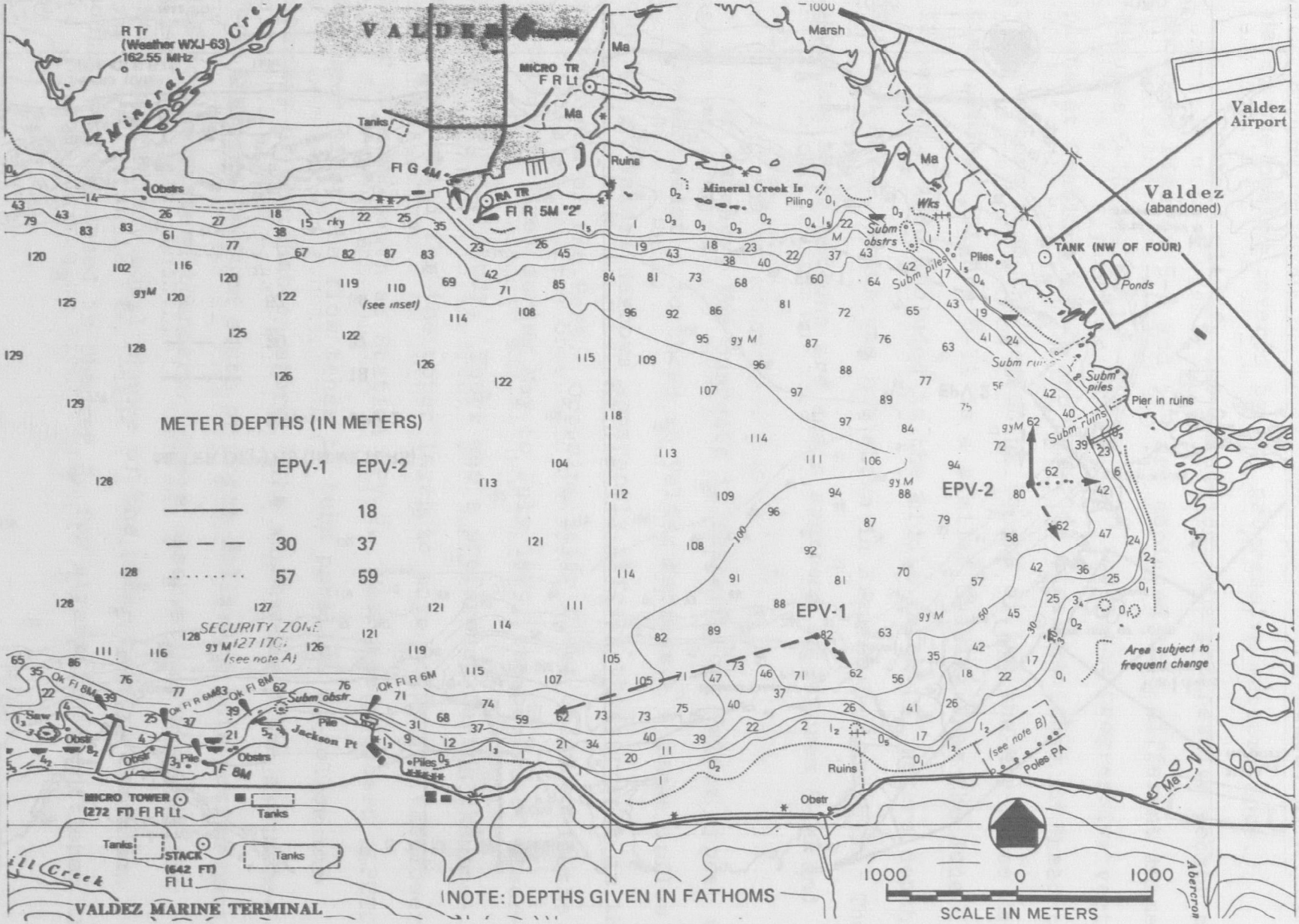

FIG. 5-11 CURRENT VECTORS FOR JUNE 10-12, 1979

plume rises to the trap level which is about 40 meters below the surface. At this depth, motion could be due to either the upper layer or lower layer flow. Also, the layers were observed to change direction often. During unstratified conditions, the plume rises to the upper layer and is transported by the motion there. Since 300 to 600 dilutions are achieved by the time the plume reaches the surface, this condition is not considered critical.

Circulation Model

In previous chapters, the transport of pollutants in the near field based on plume modeling, and in the far field based on flushing characteristics, have been discussed. Pollutant distributions due to circulation and dispersion in the vicinity of the outfall diffuser, but beyond the near field zone, are presented here. A mathematical model was used to calculate the "intermediate field" pollutant concentrations, which are based on prevailing circulation patterns discussed earlier in this Chapter.

The model used is known as the Transient Plume Model, developed at the Massachusetts Institute of Technology(1). A listing of the program for this model is shown in Appendix F.

A time history of current measurements serves as hydrodynamic input to the model. These currents are assumed to be constant in the modeled area, thus describing a spatially uniform flow field. The pollutant source is input in terms of its properties at the outer boundary of the near field zone; that is, the width and depth of the plume and its near-field dilution are direct model inputs. At each time-step where output is desired, the

pollutant is approximated by the superposition of a series of plume patches, each of which has undergone dispersion, and advection due to the recent current time-history. A concentration profile is then produced. Thus, the wastewater plume changes characteristics over time depending upon the current which is input.

A grid system was designed to model the proposed ALPETCO diffuser. This is shown in Figure 5-12. The currents measured at Station EPV-2 are used as model input because of this station's proximity to the proposed discharge. The model was run for stratified conditions using the current meter at 37 meters depth, since the plume becomes trapped at about that level. Unstratified conditions were not run since over 300 dilutions are achieved in the near field. The material was assumed to be completely mixed within a vertical layer of 15 meters. This depth is based on dye studies done for Alyeska. As a conservative assumption, vertical diffusion and pollutant decay were set to zero, thus confining the material to the layer. A range of horizontal dispersion coefficients from 1 m^2/sec (square meter per second) to 10 m^2/sec was estimated from a dye study performed by the Institute of Marine Science for Alyeska.(2) Currents at the Alyeska site are of the same order of magnitude as those at the ALPETCO site. A conservative value of 1 m^2/sec was selected for use in the model. This gives the smallest amount of spreading, and therefore, results in the highest pollutant concentrations.

The first two time periods simulated with the circulation model were May 19 and June 10. These correspond to the two

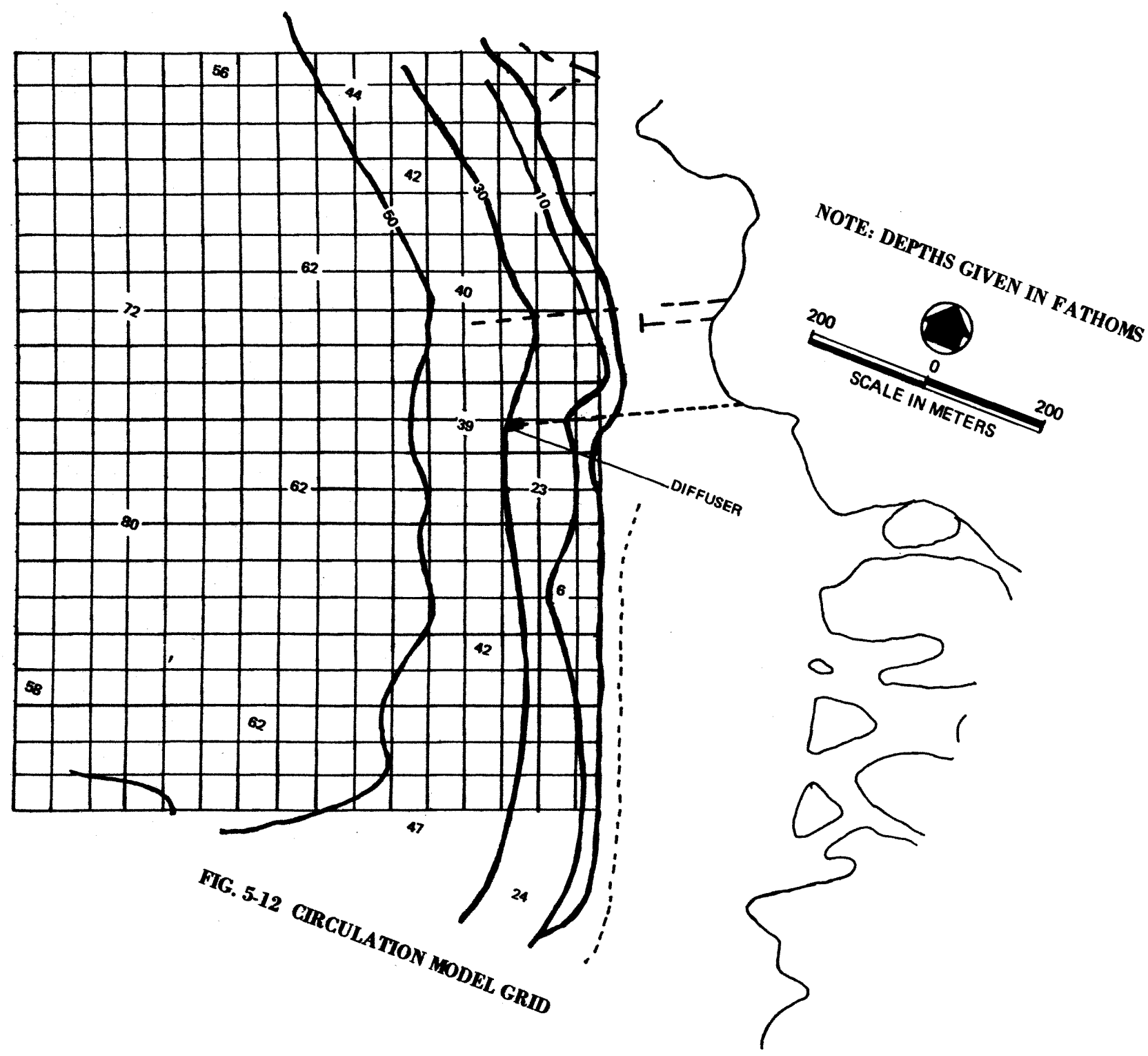

FIG. 5-12 CIRCULATION MODEL GRID

circulation patterns discussed earlier in the chapter. The daily average wastewater flow of ALPETCO was input with a concentration equivalent to the total mass of water. This was also done in the flushing model. Contours of constant dilution are plotted in Figures 5-13 and 5-14 for May 19 and June 10, respectively. Dilutions ranging from 300 to 1,000 are achieved on the May date with the plume oriented northeasterly. The velocities are comparatively rapid during this period and therefore result in high values of dilution. The June plot is indicative of the upper layer outflow condition, with the plume oriented toward the south.

In Chapter 4, the critical time period for pollutant build-up in Port Valdez was shown to be late June and early July. The circulation model was run using data from this period. Contours of constant dilution are plotted in Figures 5-15 and 5-16 for two typical days, June 29 and July 5, 1979. In both cases the plumes are oriented toward the south.

Figures 5-13 through 5-16 show that various circulation patterns result in different concentration profiles. Any of these profiles could occur at different times, and no particular situation is expected to predominate. In general, good additional dilution occurs beyond the near field zone. The worst case in terms of high pollutant concentrations would result from a current heading directly onshore. This is not a likely occurrence since the water tends to flow parallel to the shoreline; it could happen, however, during a large storm. Even during this condition, the discharge would be diluted by a factor of about 100

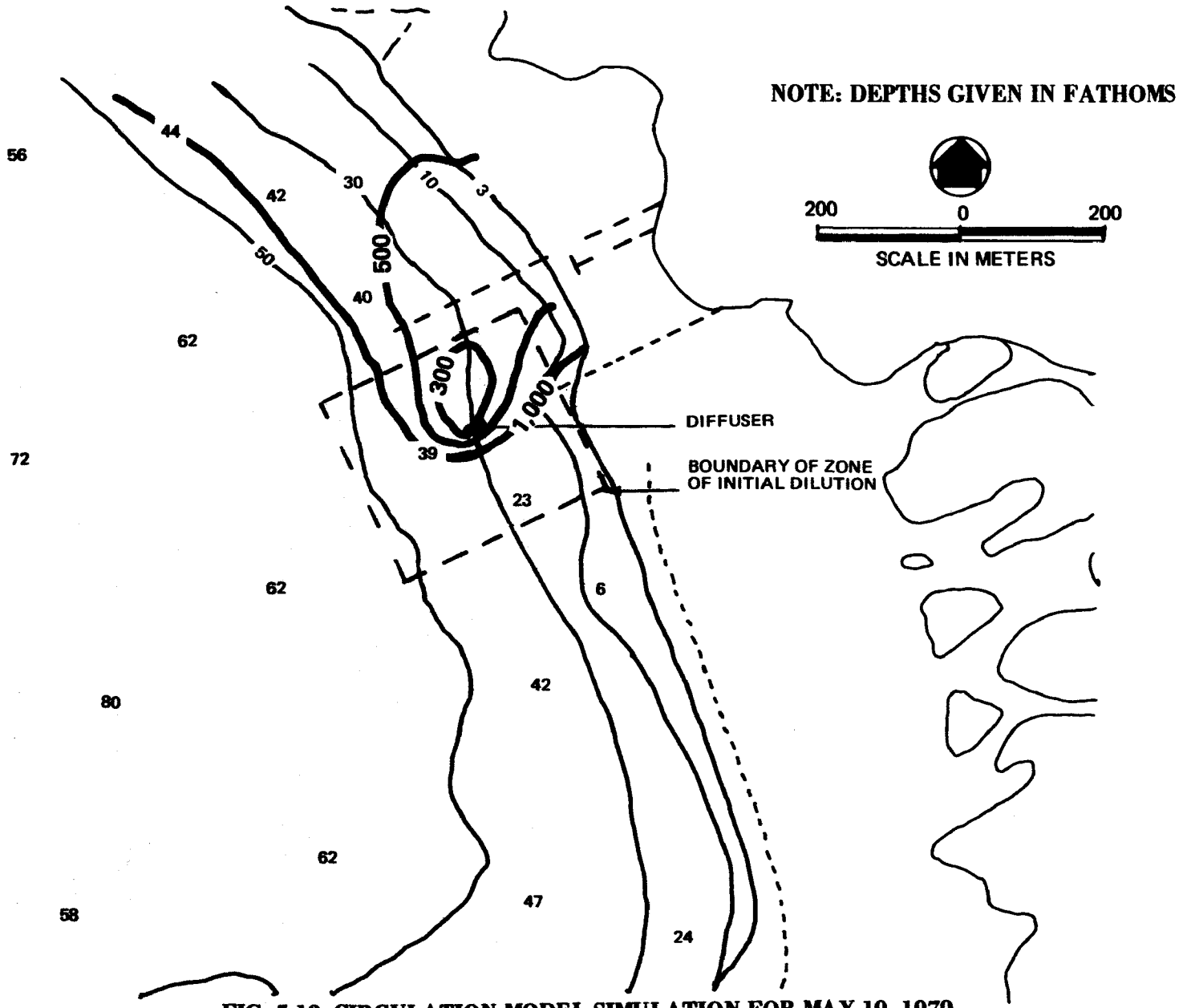

FIG. 5-13 CIRCULATION MODEL SIMULATION FOR MAY 19, 1979

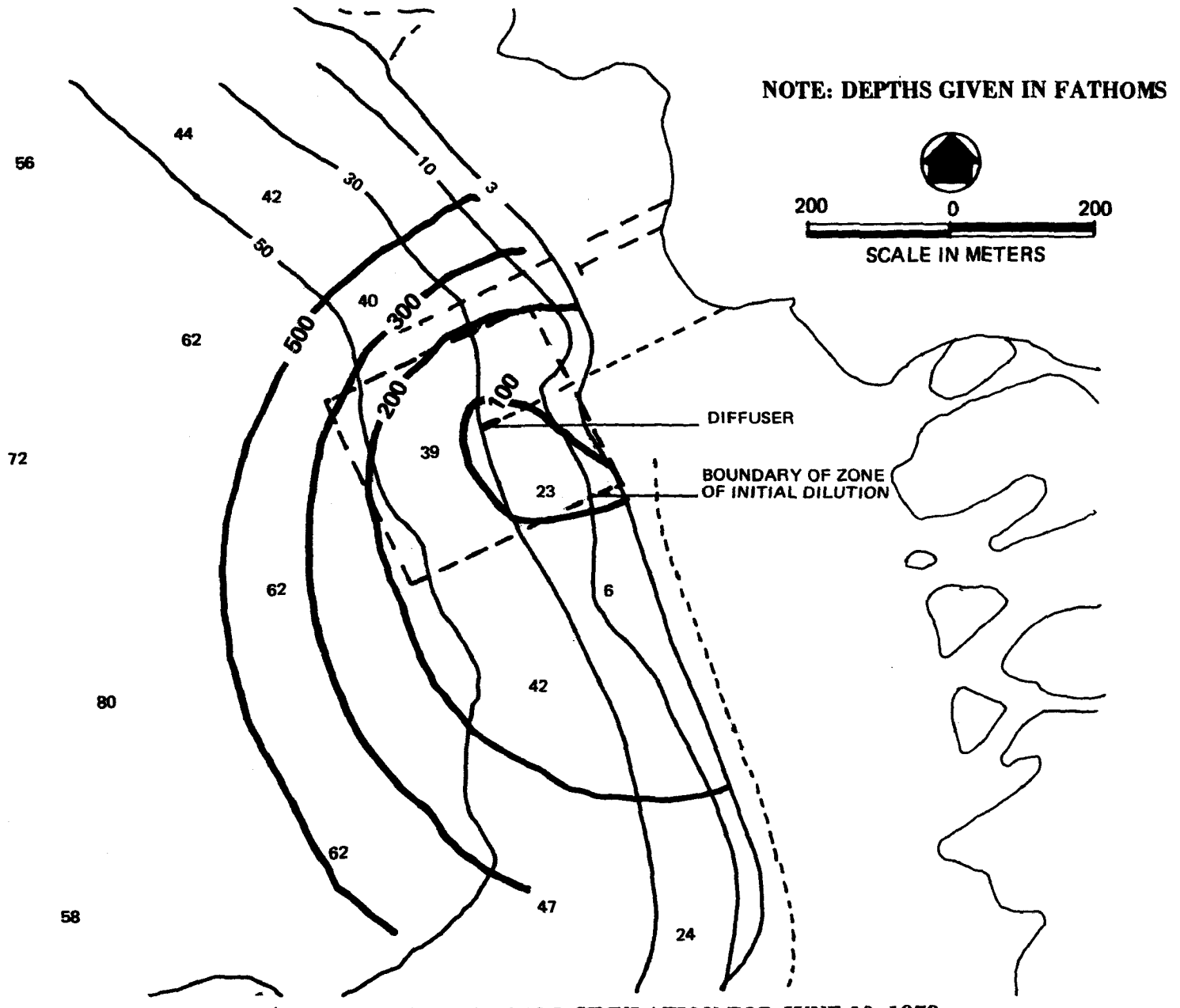

FIG. 5-14 CIRCULATION MODEL SIMULATION FOR JUNE 10, 1979

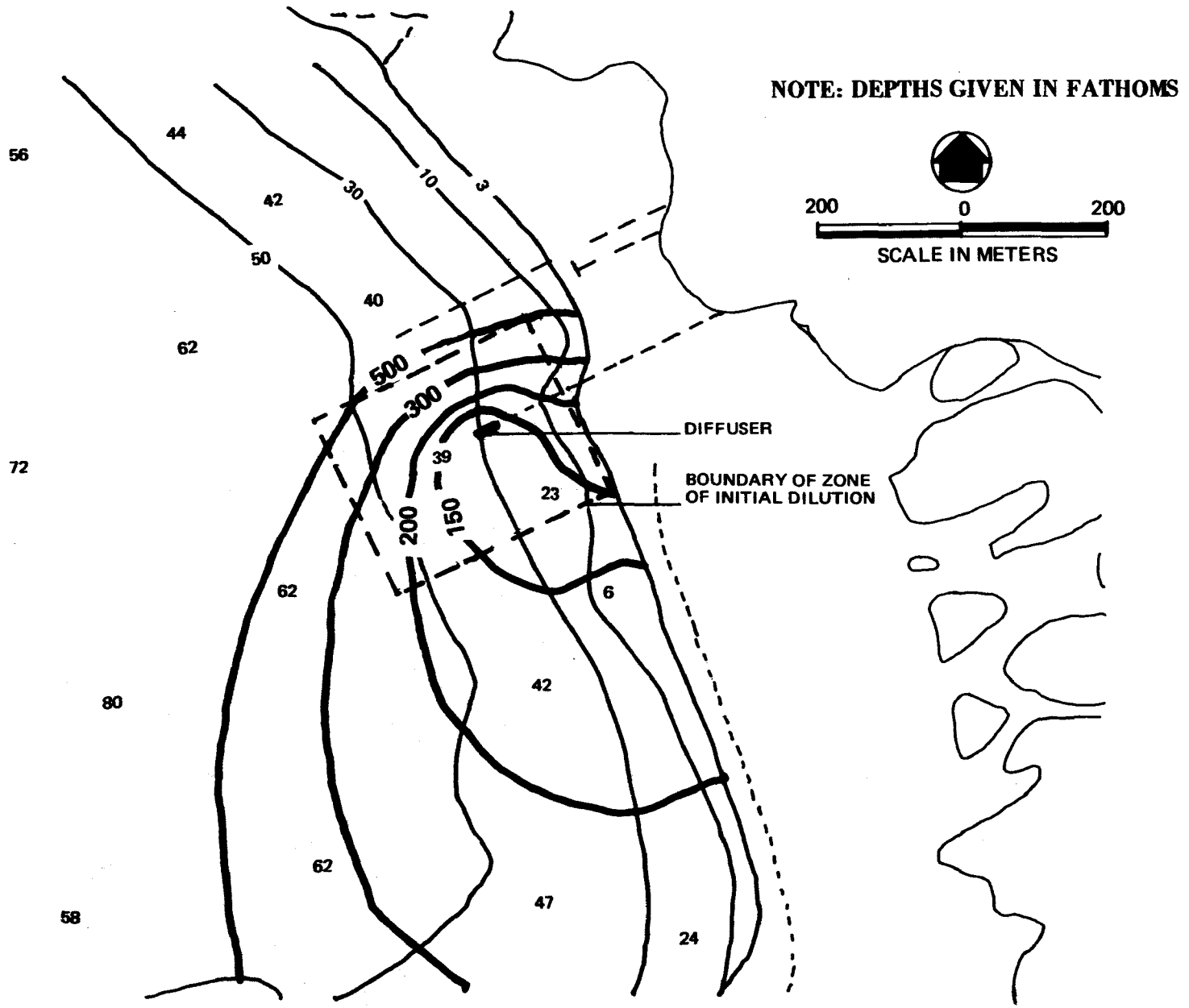

FIG. 5-15 CIRCULATION MODEL SIMULATION FOR JUNE 29, 1979

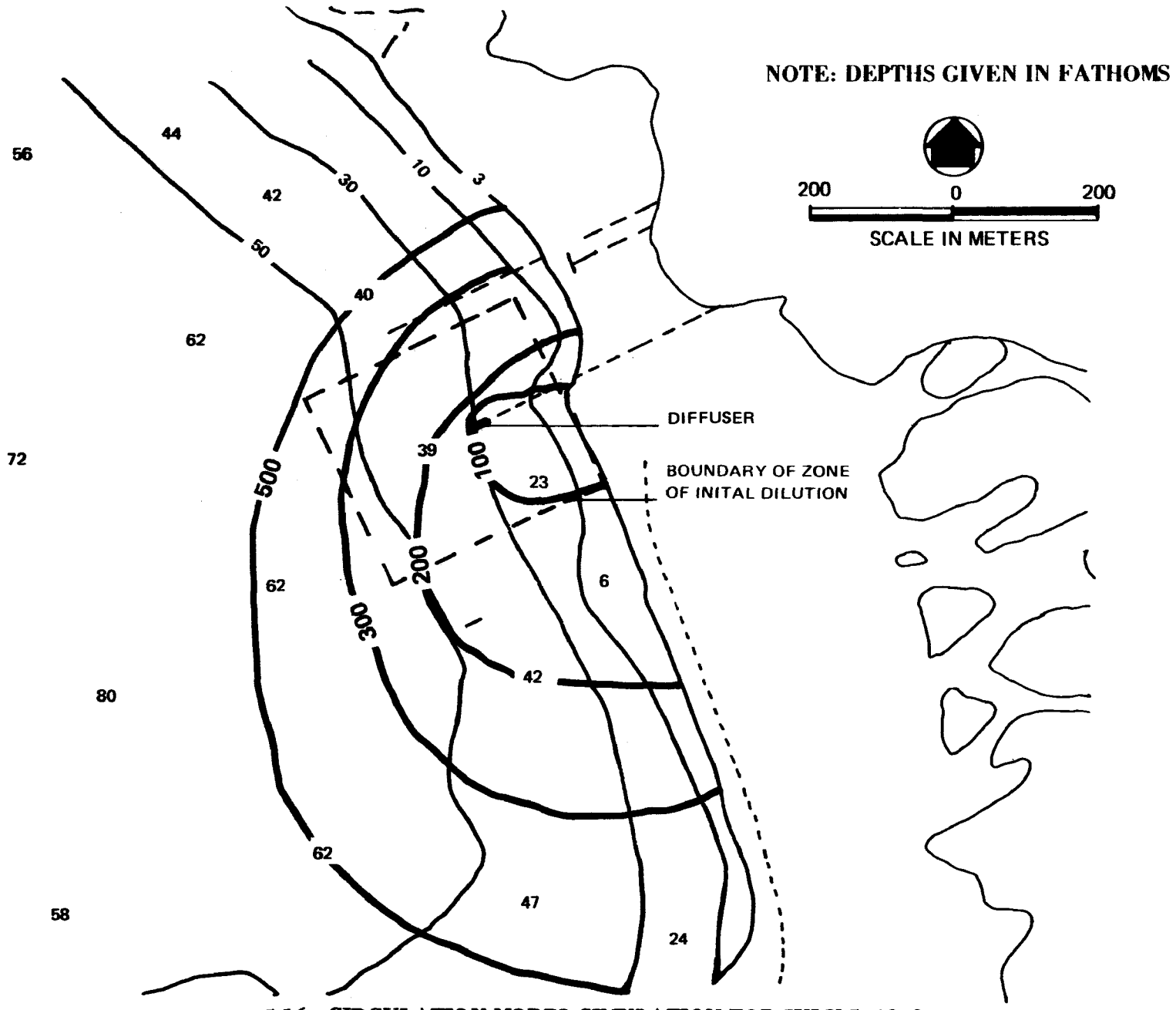

FIG. 5-16 CIRCULATION MODEL SIMULATION FOR JULY 5, 1979

based on near-field model results, and assuming no further dilutions occur. The plume would be trapped at a depth of approximately 40 to 45 meters, thus hitting the shoreline at that depth. The biologically active shallow shoreline area would therefore not be affected.

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2. Outfall Diffuser Study, Special Report No. 2 to Alyeska Pipeline Service Company, Institute of Marine Science, University of Alaska, June 15, 1978.

CHAPTER 6

SEDIMENTOLOGY

General

In this chapter, the expected average annual sediment load entering Port Valdez is estimated and the nature and composition of near shore bottom sediment deposits are discussed on the basis of available data.

Sediment Loads

The principal sediment load into Port Valdez originates as glacial outwash, mainly from the Lowe River and Valdez Glacier Stream at the head of the fjord, and Mineral Creek and Shoup Glacier Stream to the north, as depicted in Figure 6-1. A minor undetermined amount of sediment entering the Port is derived from bank erosion under normal wave activity or ship wakes. Studies completed to date, including the detailed Environmental Studies of Port Valdez by Hood, et al.,(1) have not determined the extent of marine suspended sediments transport into the Port from Prince William Sound. However, based on the reported low sedimentation rates at the mouth of the Port, it is likely that this component is very small. The majority of sediments reaching the fjord by way of glacial meltwater runoff are deposited within the easternmost third of the Port.

During earthquakes, exceedingly significant volumes of sediment may enter Port Valdez as massive landslides and submarine slides are triggered. For example, according to Coulter

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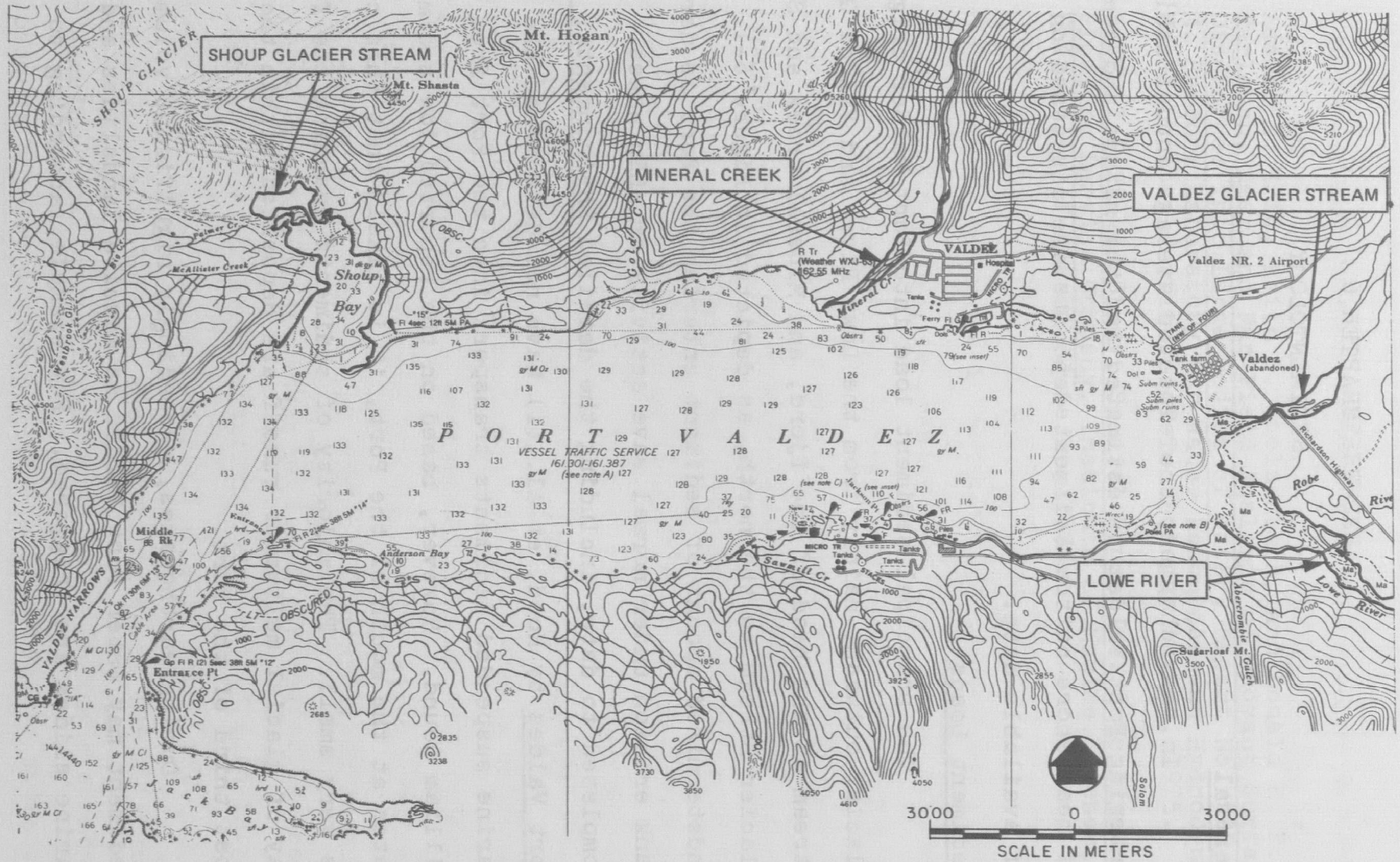

FIG. 6-1 MAJOR STREAMS INFLUENT TO PORT VALDEZ

and Migliaccio, during the Great Alaskan Earthquake of March 27, 1964, approximately 75 x 10^6 m^3 of sediment, including gravel, broke away from the head of the Port and were deposited in the basin.(2) This volume is as much as 30 times higher than the typical yearly influx of sediment from normal sources. Since there is no way of predicting the magnitude and frequency of earthquakes, the relative importance of this component is difficult to assess. Evidence of submarine slides can be seen in sediment cores from Port Valdez, with significant events indicated by a layer of generally coarser than normal sediments interbedded between cyclic sedimentation layers (varves). Data available for the preparation of this report did not include information on the relative importance of earthquake-generated slides on the sedimentation in Port Valdez; therefore, no further generalization will be made.

The sediment input into Port Valdez occurs primarily during summer as glacial meltwater increases the discharge of outwash streams by as much as two orders of magnitude over the winter discharge rates. Mean monthly combined discharge rates for all streams discharging into Port Valdez are given in Table 6-1. These estimates are based on extrapolation of Lowe River flow gaging data to the other drainage basins in Port Valdez.

The rapid rise in discharge rates outlined in Table 6-1 occurs as the heavy accumulations of snow melt and as ice dams begin to break up in late spring, freeing large volumes of glacial meltwater trapped behind them. Sudden bursts of trapped

meltwater (referred to as glacier bursts) increase the capacity of glacial streams to move coarse sediment, including boulders and coarse gravel. Thus, there is a general coarsening of mean grain sizes transported during peak runoff each summer. In terms of this effect on sediment discharge into Port Valdez, the seasonal discharge characteristics tend to cause cyclic sedimentation in the Port. For instance, during low flow in winter, mean grain size is smaller, and the dominant sediments discharged into the Port are fine clays. In summer, mean grain size is large, and the sediments discharged include coarse clay and silt. Although larger class sizes also enter the Port during peak flows, they are generally deposited proximal to the outwash fan of their origin.

TABLE 6-1. MEAN COMBINED DISCHARGE FOR STREAMS ENTERING PORT VALDEZ(1)

Month	Discharge, cfs	Discharge, m3/sec
November-April	<100	<4
May	1,600	45
June	7,000	198
July	15,700	445
August	12,000	340
September	7,000	198
October	1,400	40

1. Data provided by the University of Alaska.

The effect of this alternating fine and coarse sediment influx is to produce a graded bed of sediments each year, referred to as varves or cyclic sedimentation. The thickness of the deposit depends primarily on distance from the source with the eastern portion of Port Valdez having the highest sedimentation rates.

Sharma and Burbank(3) estimated that 2.26×10^6 metric tons were discharged into Port Valdez in 1972 for an average sedimentation rate of 1.67 cm/year, if distributed uniformly throughout the basin. Their gravity cores, however, indicated considerable variability, with up to 13.5 cm/year occurring 3 km from the mouth of the Lowe River; 4.3 cm/year in sediments 3.5 km from the mouth of the Lowe; and 1.9 cm/year from Valdez Glacier Fan. In the western portion of the Port, sedimentation rates were generally less than 1 cm/year, based on the analysis of the cores.

During the same study, it was estimated that the majority of sediments entering Port Valdez originate in the Lowe River, Mineral River and Valdez Glacier Stream, with the bulk of Shoup Glacier Stream sediments being deposited in Shoup Bay. The 1972 estimated total sediment load for each river is given in Table 6-2. Note that the Lowe River accounted for over one-third of all sediment entering the Port that year.

TABLE 6-2. TOTAL SUSPENDED SEDIMENT DISCHARGE FROM THE MAJOR RIVERS AND STREAMS INTO PORT VALDEZ DURING 1972(1)

Lowe River	9.66×10^5 metric tons
Mineral Creek	6.48×10^5 metric tons
Shoup Glacier Stream	3.69×10^5 metric tons
Valdez Glacier Stream	6.4×10^5 metric tons

1. Data provided by Sharma and Burbank.

The estimated sediment load is based on an average suspended sediment concentration of approximately 0.7 g/l (grams per liter) at the point of discharge to the Port. Using the data in Table 6-1 and an estimated mean concentration of 1.0 g/l, which appears more realistic based on recent measurements by the University of Alaska,(4) the estimated flux of sediment into Port Valdez is 3.3×10^6 metric tons annually (Table 6-3).

TABLE 6-3. ESTIMATED SUSPENDED SEDIMENT DISCHARGE INTO PORT VALDEZ FOR A MEAN CONCENTRATION OF 1.0 g/l

Month	Discharge, m3/sec	Concentration, g/l	Metric tons/ month
November-April	4	1.0	$.10 \times 10^5$
May	45	1.0	1.17×10^5
June	198	1.0	5.13×10^5
July	445	1.0	11.53×10^5
August	340	1.0	8.8×10^5
September	198	1.0	5.13×10^5
October	40	1.0	1.03×10^5
Estimated yearly total (in metric tons)			3.29×10^6

Although sediments transported by glacial streams are highly variable in size, the dominant components entering Port Valdez are clay-sized and silt-sized. Coarse sediments such as gravel are generally deposited along the middle and distal portions of outwash fans due to the decrease in slope downstream and consequent decrease in the flow's carrying capacity. As fine-grained clays enter the Port, they are transported by the surface water circulation, which appears to be counter-clockwise around the Port, based on satellite photographs taken in summer months. This effect would produce higher concentrations of suspended sediment in a surface water layer 2 to 10 m thick along the north side of Port Valdez. Since the Port is a tidal estuary, there are natural zonations of salinity both laterally and vertically, with fresher water on the north side and at the head of the fjord near the major outwashes. It is thought that flocculation of clays as freshwater meets incoming seawater is an important process causing rapid sedimentation in estuaries. The relative importance of this phenomenon in Port Valdez is not known.

In summary, the mean annual sediment load into Port Valdez is on the order of 2.3 to 3.1 x 10^6 metric tons with as much as one-third of the input derived from the Lowe River. Over 95 percent of the influx of sediments occurs during the meltwater season from May to October, with about 60 percent occurring in July and August alone. The seasonality of sedimentation causes variations in grain size of the discharged sediments which produce

graded cyclic sedimentation, or annual varves, in Port Valdez bottom sediments.

Bottom Deposits

Between 1971 and 1972, the University of Alaska obtained numerous grab samples of bottom sediments in Port Valdez for analysis of sediment texture and composition.(1) Thirty-one samples were taken from the eastern portion of the Port near the ALPETCO project site. The results of these samples, which are pertinent to the present report, are plotted in Figure 6-2 and listed in Table 6-4.

In general, sediments in the eastern portion of Port Valdez are poorly sorted clays and silts with local accumulations of sand- and granule-sized sediment at the distal portions of the glacial outwash fans. Figure 6-3 shows the approximate distribution of surficial bottom deposits with coarse clay forming the dominant grain size. Mean grain size increases toward the mouths of the Valdez Glacier Stream and the Lowe River. The nearshore and intertidal zones around the Port consist mainly of sand and mud, forming extensive tidal flats east of Valdez due to the tidal range (3.0 m). Beaches, located principally near the high water level, consist of coarse granule to gravel-sized sediments.

Sorting and skewness maps are shown in Figures 6-4 and 6-5. Due to the seasonal change in grain size and variety of sediment types and sizes available in Port Valdez, bottom sediments are poorly to very poorly sorted. Calculated values of standard deviation are given in Table 6-4. As shown in Figure 6-5, the majority of bottom sediments are fine to strongly fine

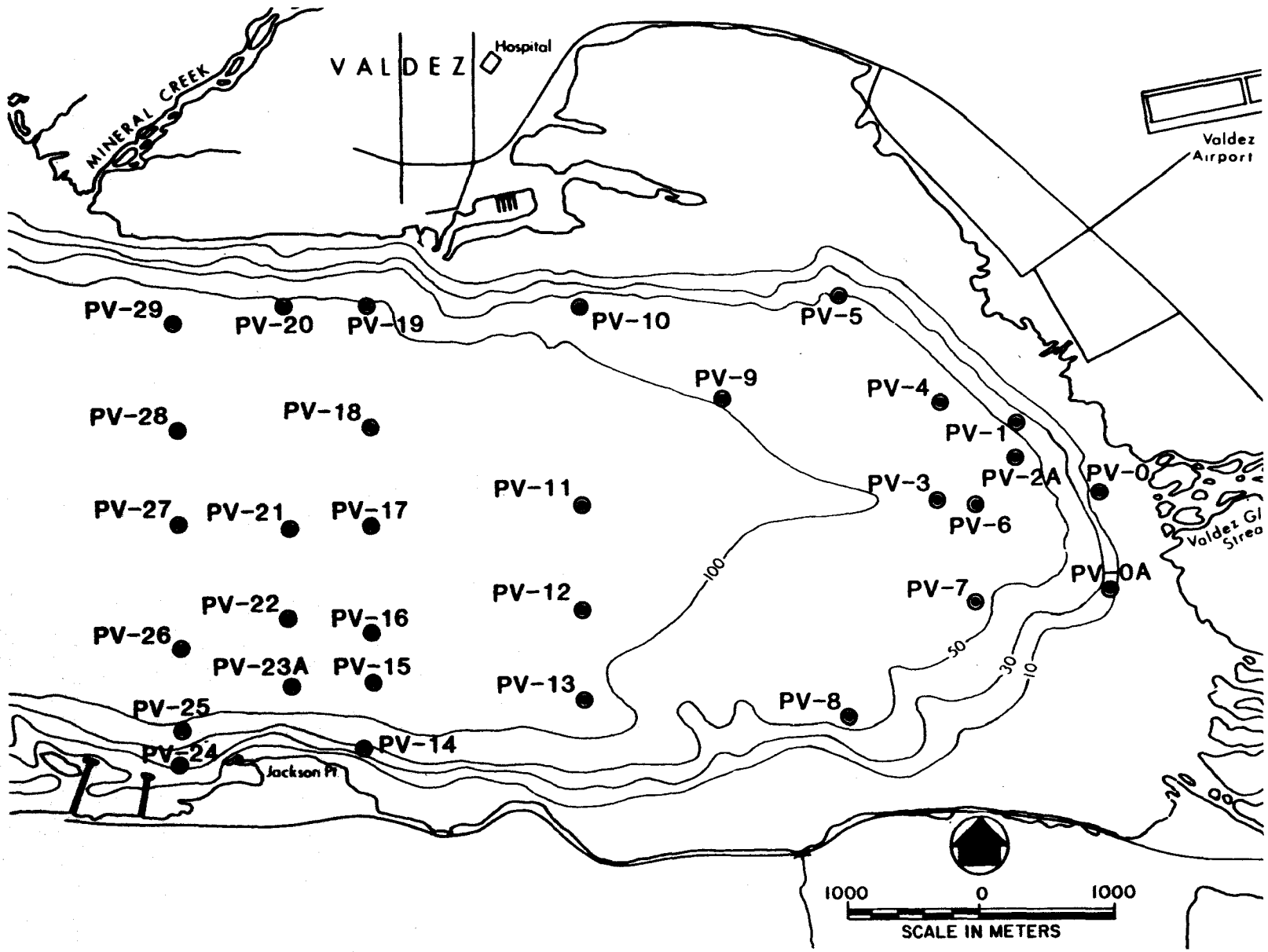

FIG. 6-2 LOCATION OF SURFICIAL BOTTOM SEDIMENT SAMPLES FOR THE EASTERN PORTION OF PORT VALDEZ

TABLE 6-4.
SUBSURFACE SEDIMENT STATISTICS (PORT VALDEZ)

Station	ϕ Mean Size (m_z)	Size Class[1]	ϕ Standard Deviation (σI)	Sorting[2]	Skewness (SK_I)[3]
PV-0	-1.33	G	1.61	PS	0.00 NS
PV-0A	5.97	MS	2.60	VPS	0.04 NS
PV-1	6.04	FSL	4.41	EPS	-0.37 SCS
PV-2A	6.50	FS	2.14	VPS	0.29 FS
PV-3	2.53	FSL	0.91	MS	0.08 NS
PV-4	8.01	CC	2.08	VPS	0.18 FS
PV-5	8.41	CC	2.20	VPS	0.27 FS
PV-6	6.50	FSL	2.79	VPS	0.16 FS
PV-7	8.39	CC	2.21	VPS	0.34 SFS
PV-8	8.01	CC	2.13	VPS	0.26 FS
PV-9	8.65	CC	1.99	PS	0.33 SFS
PV-10	8.59	CC	1.99	PS	0.23 FS
PV-11	7.47	VFS	2.32	VPS	0.05 NS
PV-12	8.42	CC	2.09	VPS	0.29 FS
PV-13	8.32	CC	1.92	PS	0.24 FS
PV-14	5.81	MS	2.32	VPS	0.57 SFS
PV-15	8.45	CC	2.00	PS	0.22 FS
PV-16	8.40	CC	2.13	VPS	0.17 FS
PV-17	8.50	CC	2.08	VPS	0.26 FS
PV-18	6.15	FSL	2.45	VPS	0.34 SFS
PV-19	8.28	CC	2.25	VPS	0.23 FS
PV-20	8.25	CC	2.25	VPS	0.26 FS
PV-21	7.96	VFS	2.25	VPS	0.20 FS
PV-22	8.87	CC	2.19	VPS	0.37 SFS
PV-23A	8.73	CC	2.20	VPS	0.32 SFS
PV-24	6.88	FSL	2.74	VPS	0.16 FS
PV-25	7.95	VFS	2.57	VPS	0.02 NS
PV-26	8.58	CC	2.16	VPS	0.24 FS
PV-27	7.55	VFS	2.22	VPS	0.14 FS
PV-28	6.84	FSL	2.29	VPS	0.25 FS
PV-29	8.14	CC	2.19	VPS	0.24 FS

[1]Size Class	mm Size
G = Granule	4-2
FS = Fine Sand	0.25-0.125
CS = Coarse Silt	0.0625-0.031
MS = Medium Silt	0.031-0.0156
FSL = Fine Silt	0.0156-0.0078
VFS = Very Fine Silt	0.0078-0.0039
CC = Coarse Clay	< 0.0039

[2]Sorting

MS = Moderately Sorted
PS = Poorly Sorted
VPS = Very Poorly Sorted
EPS = Extremely Poorly Sorted

[3]Skewness

SFS = Strongly Fine Skewed
FS = Fine Skewed
NS = Near Symmetrical
SCS = Strongly Coarse Skewed

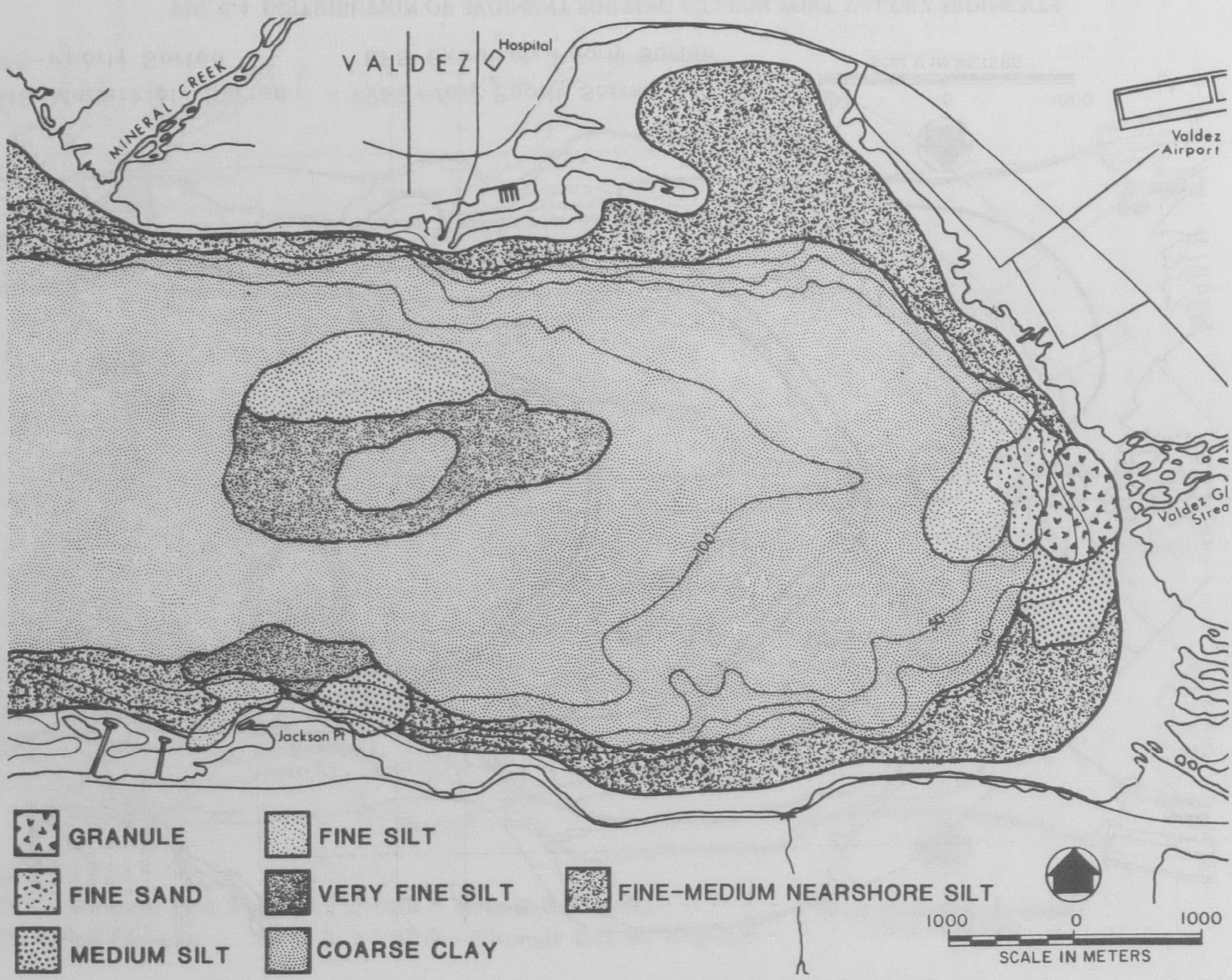

FIG. 6-3 INFERRED SEDIMENT DISTRIBUTION FOR EASTERN PORT VALDEZ

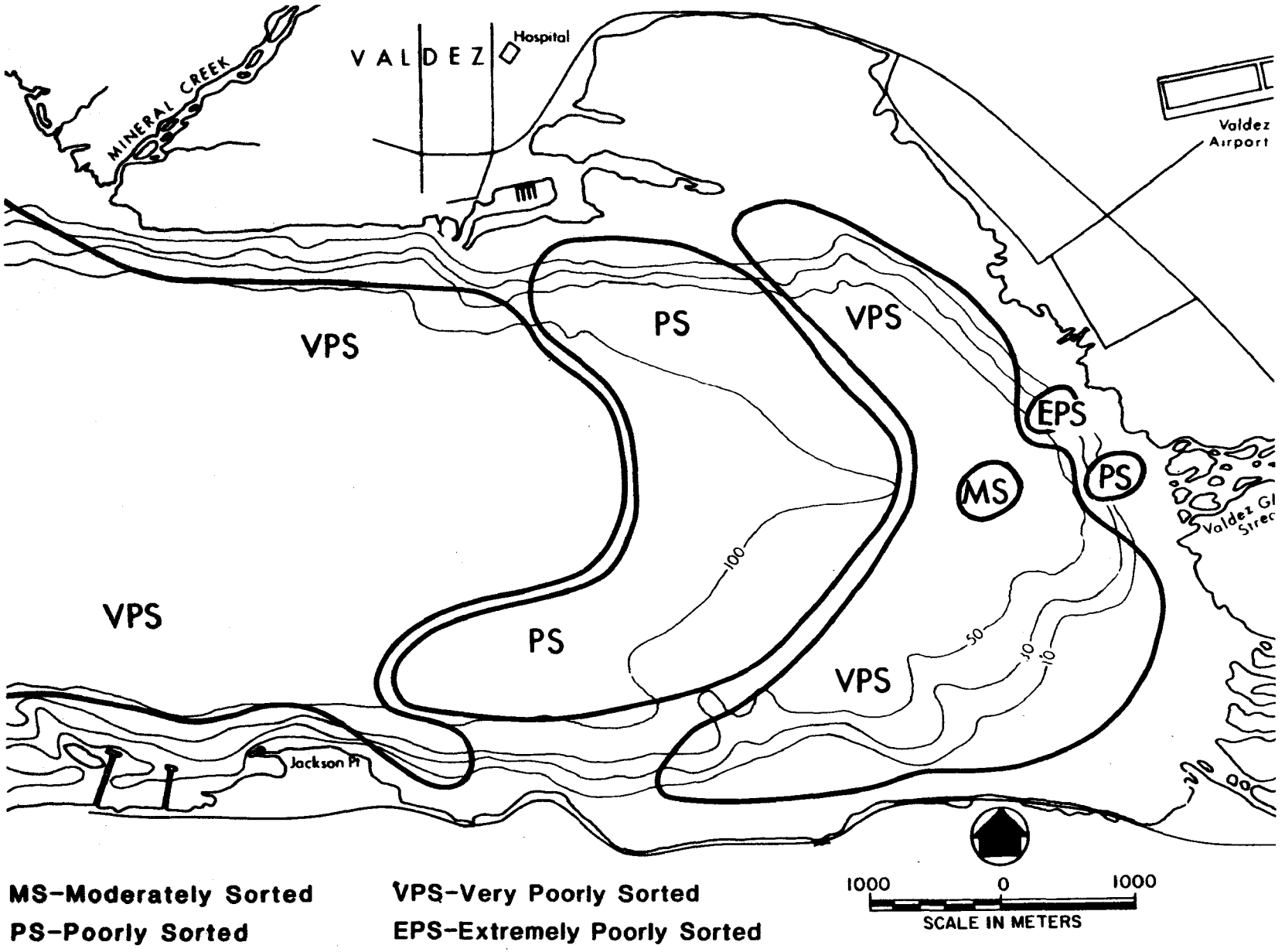

FIG. 6-4 DISTRIBUTION OF SEDIMENT SORTING (σ) FOR PORT VALDEZ SEDIMENTS

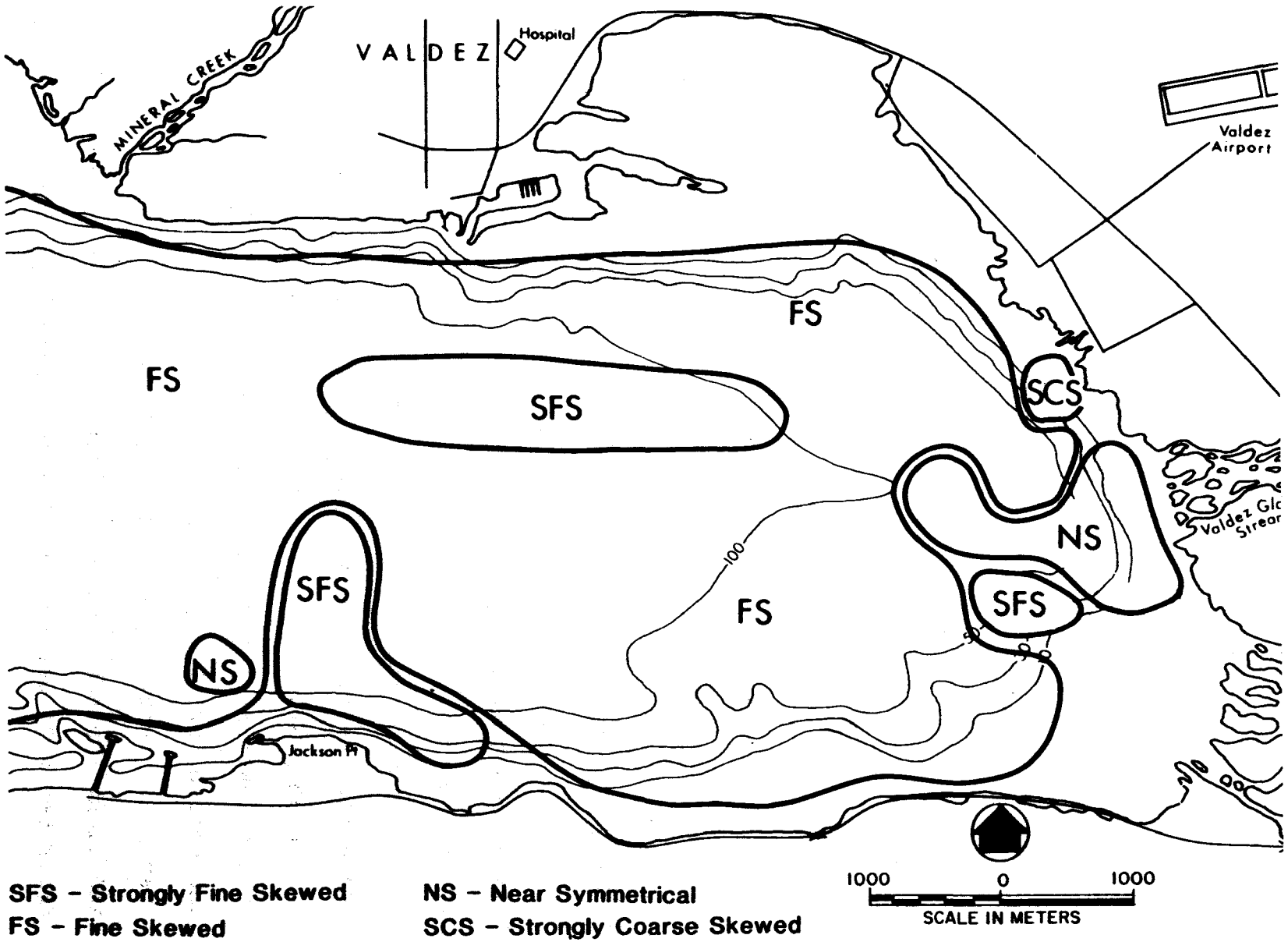

FIG. 6-5 SEDIMENT SKEWNESS FOR PORT VALDEZ SEDIMENTS

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skewed due to the mixture of clay-sized sediment in most samples. Clay is present in sediments throughout the Port and along the near-shore zone. Fine-grained sediments are generally absent from beaches fringing Port Valdez near the high water level. Five of the 31 samples included in this report were poorly sorted and the rest were very poorly sorted ($\sigma > 2.00$).

Sediments along the shoreline of Port Valdez are of fairly uniform composition, reflecting the dominant source rocks including gray or bluish-gray graywacke, argillite, and bluish-gray or black slate. Gravel clasts of gray to black slaty shales and dark gray shaly siltstones with quartz veins are dominant.(3) The predominant clay minerals of Port Valdez bottom sediments are chlorite and illite. Sharma and Burbank reported an increase in chlorite-quartz and illite-quartz ratios away from river mouths, indicating that heavier quartz particles settle faster and remain near the outwash fans of their origin.(3) The relatively slow-settling illite and chlorite minerals form the major component of the obscured sediment plumes in Port Valdez.

Landsat imagery for various months from 1972 to 1978 indicates the Port is relatively clear of suspended sediment until June each year. Plumes of sediment are most dense near the mouths of the Lowe River and Valdez Glacier Stream. By July, virtually the entire Port has significant quantities of clay sediments in suspension, with highest concentrations near the head of the Port and along the north side. Suspended sediment decreases rapidly by September with portions of the Port along the south side remaining

clear. By October, there is little sediment in suspension. Thus, during high runoff periods in the summer, there are continual additions to the bottom sediments. The extent of bottom sediments' resuspension is not known, but it is probable, given the deep bathymetry of the Port, that turbidity flows are the predominant mechanism. Wave and current action in the 200-m plus depths are relatively minimal.

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CHAPTER 7

ENVIRONMENTAL CONSEQUENCES OF PROPOSED ACTION

General

Environmental consequences of the proposed ALPETCO refinery on Port Valdez, which are expected to be predominantly from sediment contributions during construction and treated effluent discharges during operation, are discussed in this chapter. Consideration is given to the transport of accidental oil spills. The necessary mitigating measures for reducing the impact of these consequences are also outlined in this chapter.

Construction Effects

It is anticipated that oceanographic conditions within Port Valdez will be only slightly and temporarily affected by the construction of the proposed project. The primary impact will be a relatively small increase in the amount of sediment deposited in Port Valdez.

Excavation of the site and construction of the retaining dike will increase sediment runoff into the Valdez Glacier Stream. Once completed, the dike is expected to prevent erosion and runoff during the remainder of the construction process. The ocean floor will be disturbed temporarily by the driving of steel and concrete piles for both the products dock and the construction dock. Dock fill material will be selected to minimize the impact on the water quality should dredging be required at the construction dock site.

Installation of the outfall system will require a certain amount of trenching across the intertidal area and will disturb and suspend bottom sediments. During construction of the refinery itself, it is expected that the barge traffic will also stir up sediment and cause a small amount of shoreline erosion at the construction dock site.

The estimated suspended sediment created by all the construction activites is very small relative to the normal amount of sediment which is deposited annually by influent rivers and streams (see Chapter 6). However, the amount of suspended sediment resulting from the construction will be minimized if construction occurs during periods of low meltwater runoff and low sedimentation, such as, prior to June or after September.

Operation Effects

Environmental effects of operating the proposed ALPETCO refinery will result mainly from the discharge of treated effluent into Port Valdez. The operational impacts of mixing and dilution of this discharge, and its pollutants, metals and toxics, together with the transport and dispersion of accidental spills, are discussed separately.

Effects of Discharge. The effects of the discharge in the near field zone, in the far field zone, and in the circulation zone within the eastern end of the Port, have been presented and discussed in Chapters 3, 4, and 5, respectively. Impacts of the worst case concentrations or dilutions in these three zones are discussed here. Worst case implies maximum stratification of

the receiving waters of Port Valdez and lack of flow exchange at Valdez Narrows. Similar conditions were measured in late June and early July of 1979. Maximum stratification results in the lowest near field dilutions, and lack of exchange allows for build-up of pollutants in Port Valdez. Dilutions under these conditions are 75 to 100 in the near field, 100 to 500 in the circulation zone, and 13,000 or greater in the far field.

Thus, even during the worst condition, the discharge water would be effectively mixed and diluted with the ambient water and only very small traces of the discharge water would be present. Therefore, the impact of the discharge water on Port Valdez would be insignificant.

Effects of Pollutants, Metals and Toxics in Discharge Water. Table 7-1 summarizes conservatively estimated concentrations of pollutants, metals and toxics that are expected to be in the ALPETCO treated water discharge based on the proposed NPDES Permit. Concentrations of these substances in the receiving water following initial dulution using the smallest dilution factor of 75 are presented. The concentrations normally found in sea water are given as well. As can be seen from this table there are very few noticeable increases in concentrations of these substances above those normally found in sea water. These negligible increases in concentrations would be further reduced in the circulation zone and in the far field zone due to further mixing and dilution. Thus, there would be no noticeable impact of the concentrations of these pollutants, metals and toxics on the receiving waters of Port Valdez.

TABLE 7-1. CONCENTRATIONS OF POLLUTANTS, METALS AND TOXICS BEFORE AND AFTER INITIAL DILUTION

Parameter	Concentrations		
	Assumed in discharge mg/l	Normally found in sea water mg/l	Following initial dilution(1) mg/l
Aluminum	Trace	0.01	0.01
Ammonia	7	0.04	0.13
BOD	10	1	1.120
Chloride	8,000	19,000	19,106
Chlorine	<0.01	0	<0.0001
Cyanide	<1.0	0	<0.0135
Phenols	<0.02	0.0	<0.00027
Nickel	0.5	0.0001	0.0068
Total Suspended Solids	5.0	5.0	5.0

1. Using the smallest dilution factor of 75.

Effects of Accidental Spills. The movement of an accidental spill due to human error is considered here. Two areas in Port Valdez are the most likely spill locations. The first is the loading dock at the southeast corner of the eastern end of Port Valdez. This spill could be due to a loading accident. The second location is at Valdez Narrows. A spill here might be caused by a ship colliding with another ship, or Middle Rock, due to bad weather or oceanographic conditions at the Narrows.

The two main causes which effect transport of the spill are currents and wind. Several mathematical models have been developed to account for oil slick movement under the influence of current and wind. An excellent summary of these models has been prepared by Stolzenbach et al, (1977)(1). An often used "rule of thumb", which relates oil slick transport due to current and wind, is known as the "3 percent rule". This rule, incorporated into many oil slick models, states that the speed of the oil slick is 3 percent of the wind speed plus the current speed. The "3 percent rule" is used here to obtain an approximate estimate of the movement of probable accidental spills in eastern Port Valdez and at Valdez Narrows.

An accidental spill at the proposed loading dock is considered first. The currents in this area of the Port, as discussed in detail in Chapter 5, are small (0 to 10 centimeters per second (cms)) and tend to move alongshore parallel to the land boundary. The upper layer of the water body moves both

clockwise and counter-clockwise. During the May to July, 1979 measurement period, a predominance toward counter-clockwise motion was observed. A counter-clockwise motion has also been observed in the landsat photographs of eastern Port Valdez taken during the summer months to study the motion of suspended sediments. Information on this motion is not available for non-summer months.

Available wind data (Dames & Moore, 1979)(2) indicate that the east-west orientation of the Valdez Basin helps funnel winds in those directions. There is a predominance of easterly winds (toward the ocean) over westerly winds. This is caused by the flow of air from the high pressure zones in the interior of the state toward the low pressure zones in the Gulf of Alaska. Records at Valdez weather service office (WSO) indicate wind magnitudes of 6 knots or less about 76 percent of the time.

Applying the 3 percent rule to eastern Port Valdez, oil movement due to wind would be from 0 to about 9 cms. This is about the same order of magnitude as movement due to currents. Thus, slick movement would be due to both current and wind and would respond to specific weather and current patterns occurring on the day of the spill. Movement of the oil spill would be on the order of 1 to 16 kilometers/day (km/day) and would more likely go toward Valdez Narrows than onshore, based on wind direction preference.

A spill at Valdez Narrows would move much faster due to higher winds and faster currents. Measured upper layer currents

at this location are on the order of 10 to 50 cms and change direction due to the tide. The funneling effect of the Narrows geography causes northeast or southwest current motion. The winds are also funneled through the Narrows in the same directions due to the mountains on either side, and tend to be faster than those at Valdez WSO.

It has been shown in Chapter 4 that the tidally averaged upper layer motions at Valdez Narrows are inward or outward with direction changes every few days. Outward motion predominates during the summer due to large freshwater flow and calm weather. Thus, a spill at Valdez Narrows would be equally likely to move into or out of the Port, except during summer, when it would most likely move out. Since tidal currents are fast, the time at which a spill occurs becomes an important factor. A spill during an incoming tide would rapidly move out of the Narrows. Based on tidal current alone, the spill would move out of the Narrows in several hours. It must be remembered that once the spill moved into or out of the Port, it would be affected by different current and wind regimes.

Mitigating Measures

During construction, the predominant impact is expected to be from sedimentation effects. Mitigating measures will include sedimentation control practices. The most significant of these will be implementation of sedimentation control at the project site prior to facility construction.

A second significant measure will be to consider the timing of excavations in the scheduling of projects. Excavation will be maximized during times of the year when sedimentation impacts are least important.

During operation, the most significant impact is expected from effluent discharge and from runoff, as well as from accidental spills. Spill control measures will be in force at all times when tankers are within the Port. Similarly, tanker traffic through Valdez Narrows will be limited to times when weather conditions are acceptable.

All discharges from the site, including runoff, will be treated to the level equivalent to advanced wastewater treatment, including effluent filtration. The discharge into the Port will be through properly designed diffusers which will ensure adequate mixing of the effluent. The natural circulation and flowing capabilities of the Port are expected to provide efficient dispersion and movement of the discharge from Port Valdez.

Unavoidable Adverse Environmental Impacts

Excluding unavoidable accidents that might occur in spite of the safety and control measures which would be taken, the most important unavoidable impact on Port Valdez would result from the effluent discharge.

The discharge will constitute a new source of wastewater in Port Valdez. Due to climate, soils and groundwater conditions, elimination of the discharge via land application is not an environmentally feasible alternative.

During part of the year (e.g., July) when significant quantities of fine clay sediments are carried into the Port in the vicinity of the discharge, entrapment and settling of these wastes to the bottom is expected to occur. However, since this will occur during times of stratification, settling is not expected to be in shallow areas (less than 40 m deep) along the shoreline. The extent of bottom sediments resuspension is not known. It is probable, however, given the relatively deep channel of the Port, that such impacts are small. Wave and current action in the 200-m plus depths is relatively small.

REFERENCES

1. Stolzenbach, Keith D., Ole S. Madsen, E. Eric Adams, Andrew M. Pollack, and Cortis K. Cooper, A Review and Evaluation of Basic Techniques for Predicting the Behavior of Surface Oil Slicks, Report No. 222, Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, MIT, February, 1977.

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