DRAFT ENVIRONMENTAL IMPACT STATEMENT
Prudhoe Bay Oil Field
Waterflood Project

Prudhoe Bay, North Slope Borough
Alaska

June 1980

Prepared by: U.S. Army Corps of Engineers, Alaska District
P. O. Box 7002, Anchorage, AK 99510.
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Cooperating Agencies: National Marine Fisheries Service
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service

Technical Assistance Provided by: Dames & Moore, Anchorage

Volume 2

APPENDICES

Last Date to Accept Comments: 21 July 1980

LIST OF APPENDICES

APPENDIX A

RESULTS OF SCOPING

DEPARTMENT OF THE ARMY
ALASKA DISTRICT, CORPS OF ENGINEERS
P.O. BOX 7002
ANCHORAGE, ALASKA 99510

REPLY TO
ATTENTION OF:

13 FEB 1980

NPAEN-PL-EN

Dear Participant:

The Alaska District, Corps of Engineers has completed the scoping process for our environmental impact statement now in preparation for the proposed Prudhoe Bay Unit Waterflood Project. This process consisted of various meetings involving the public, other agencies and the oil industry.

Through an analysis made of comments and concerns exchanged at these meetings and through our study of the proposed project, the attached list of issues has evolved. It is premature, at this time, to provide a detailed ranking of concern for each issue. However, effects of the proposed action relative to the causeway extension into the Beaufort Sea, social and economic conditions, and cumulative changes in the area clearly rank high in our consideration.

As you review the list please feel free to contact us by writing or by calling Mr. Ben Kutscheid at (907) 752-2572 to suggest any changes.

Sincerely,

LEE R. NUNN
Colonel, Corps of Engineers
District Engineer

1 Incl
As stated

PBU Waterflood Environmental Analysis
List of Issues

GRAVEL SOURCES AND USE

Subissues:

a. Quantity needed and cumulative impacts

Waterflood
Gas Conditioning Plant
Gas Pipeline
Beaufort Sea Development
Miscellaneous (mining, recreation)
Prudhoe Bay expansion, Kuparuk field, Colville, etc.

b. Source location(s)

Putuligayuk oxbows most probable

c. Methods and effects of removal; stockpiling requirements

Direct habitat loss
Effects on wetlands and surface water

d. Rehabilitation, potential use as fish or bird habitat, reservoirs, etc.

e. Detailed gravel placement plan

SOCIAL, CULTURAL, AND ECONOMIC

Subissues:

Impacts of Construction and Operation:

1. Local

   a. Can existing camp facilities handle extra personnel? What if gas conditioning plant construction is coincident?

   b. Any additional service company facilities required? New shops, etc.?

   c. How many extra trips up Haul Road?

   d. Program for Native/local hire?

   e. Any impact on barge traffic to DH-3?

   f. Land ownership

   g. Effects on cultural resources, i.e. archaeological, historical, religious

   h. Effect on the sense of "home" felt by the Eskimo

   i. Effect on subsistence hunting and fishing and related traditions, Eskimo diet, and traditional transportation routes.

   j. Effects on lifestyle, rate of cultural change.

   k. Long-term effects of project abandonment.

   l. Effects on tax base.

   m. Effects on fuel availability and cost.

   n. Any plans for multiple use of causeway?

   o. Compatibility with NSB interim ordinance.

   p. Incremental recovery cost of production.

   q. Land ownership status -- all State-owned, oil company leased but some Native selection.

2. State

   a. Employment

   b. Tax base (royalties)

   c. Consistency with CZMP, gaining of other permits.

   d. Energy costs and availability

   e. Effect on conservation of energy reserves.

3. National

   a. Need for project.

   b. Effect on conservation of energy reserves.

   c. Effect on national need for energy.

   d. Effect on U.S. dependence on foreign oil and gas including national security implications.

   e. Effect on cultural diversity.

ICE PROBLEMS

Subissues:

a. Design constraints imposed by ice

Intake: physical damage from keeling, bottom scoring, effects of frazzle and slush ice

Discharge: effects on buried pipeline, discharge effects on ice thickness

Causeway and treatment plant: ice forces used in design

b. Effects of ice override

c. Effects on ice movement

d. Probability, magnitude and severity of ice override

RESERVOIR CONSIDERATIONS

Subissues:

a. Effectiveness of waterflooding

b. Alternative recovery methods, field management. Will waterflooding preclude recovery (later) by other methods?

c. Effects of delay of waterflooding (e.g., one year, five years, 10 years)

d. Effects of interruption of waterflooding (e.g., one day, one month, six months). (Important in considering alternative intake locations, reliability requirements, etc.)

e. Effects of alternative configurations of onshore facilities

f. Seismic implications

g. Effects on production rates, life of field, cost/bbl

h. Land subsidence potential (would accelerate coastal erosion?)

i. Plan for produced water (increased volume due to waterflood).

j. Thermal effects of injecting cold water into warm formation -- any effects on permafrost thickness?

TREATMENT PROCESS AND DISCHARGE

Subissues:

a. Nature and use of chemical additives

   biocides
   anti-foaming agents
   coagulants
   corrosion inhibitors

b. Nature of normal discharge (include annual cycle)

   Backwash procedures (frequency, water source)
   Temperature
   TSS
   BOD
   Chemicals (specific constituents and concentrations)
   Potential for freezing of discharge line

c. Physical behavior of discharge

   Dilution, diffusion (four seasons)
   Build-up of solids, BOD (under ice)
   Effects on ice formation
   Effects of local currents, scouring, etc.?

d. Biological effects of discharge

   Acute toxicity
   Long-term effects
   Behavioral effects (attraction to discharge)

e. Compliance with WQ criteria; mixing zone size.

f. Low pressure line evacuation

   Conditions requiring discharge; probability of occurrence
   Location of discharge
   Volume and nature of discharge; resultant impacts

g. Effects of fouling in discharge line

h. Alternative locations; back-up contingencies if discharge damaged.

i. Evaluation of effluent treatment alternatives, i.e., achievable reductions in effluent volume (esp. solids) and toxicity (e.g., biocides), and associated costs, energy requirements, and displaced impacts (e.g. of land disposal).

INTAKE CONSIDERATIONS (EXCLUSIVE OF CAUSEWAY EXTENSION)

Subissue:

a. Alternative intake locations and designs; rationale for selecting preferred alternative

b. Detailed intake design

c. Magnitude of impingement and entrainment problem

d. Backup measures if intake inoperative.

e. Clean Water Act Section 316B requirements?

CAUSEWAY EXTENSION

Subissues:

a. Feasibility of alternatives that would obviate the extension.

b. Physical effects on circulation, WQ, flushing of Simpson Lagoon, nutrient and sediment transport.

c. Effects on wave regime impacting Stump Island.

d. Biological effects of "b" and "c".

e. Barrier effects to movement of fish, birds (include above ground power lines), marine mammals, recolonization by invertebrates.

f. Feasibility and effects of breaching, both shoreward and seaward of DH-3.

g. Legal status of existing and extended causeway; compliance with ACMP.

h. Effects of erosion and ice action.

i. Effects of extension on future cargo handling needs or other uses.

j. Probability, magnitude, and severity of wave events that could affect causeway stability.

k. Any other plans for causeway extension?

WETLANDS AND TERRESTRIAL ECOLOGY

Subissues:

a. Direct destruction of habitat; cumulative losses to entire North Slope.

b. Alternative routing, especially between Pad E and Term Well A. Include discussion of plans to integrate this road into future development plans for the field.

c. Alternative construction methods -- use of insulating layer

d. Effects of dust, increased traffic, road maintenance.

e. Effects on caribou migration; include irreversible and irretrievable loss of habitat, mitigative measures, etc.

f. Effects on drainage patterns

g. Effects of saltwater spill

h. Effects on rare and endangered species (e.g., peregrine falcon)

i. Cumulative impacts on bird and mammal distributions (e.g., Kaktovik Village contention that duck and fish harvests have declined in recent years)

j. Effects on barrier islands

k. Effects on terrestrial productivity, use by water oriented birds, grazers, energy contributions to fresh water ecosystems

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MISCELLANEOUS ENGINEERING, CONSTRUCTION AND PROJECT DESCRIPTION ISSUES

Subissues:

a. Schedule

What is impact of delay in project implementation?
How will construction sequence with barge traffic?
Priority based on economic significance of delays in beginning construction and/or operation of project.

b. Solid waste disposal

Priority based on availability of landfill areas.

c. Energy cost to produce versus quantity of energy produced.

Priority based on importance of produced energy.

d. List pressure vessels

Priority based on low likelihood of failure.

e. Effects of produced water injection system (potential need for expansion due to recycling of waterflood water?)

Priority based on relative size of facilities and expected adequate definition of same.

AIR QUALITY

Subissues:

a. Nature and volume of construction and operational emissions

b. Cumulative impacts

c. Adequacy of PSD application

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CUMULATIVE EFFECTS

Effect Sources:

a. Existing development

b. Waterflood

c. Gas conditioning plant

d. Gas pipeline

e. Kuparuk field

f. On-land development from Canning to Colville

g. Local population growth and economic development

h. Beaufort Sea development

Subissues:

a. Effects of gravel extraction

b. Effects on wilderness value

c. Effects on traditional Native values including subsistence needs.

d. Effects on aquatic resources (especially fish, birds, and mammals)

e. Effects on wetlands (especially large mammals and birds)

f. Effect on economy and foreign energy dependence

g. Air quality

EFFECTS OF DREDGING AND DREDGED MATERIAL DISPOSAL

Subissues:

a. Alternative dredging and disposal methods of construction and maintenance.

b. Physical effects including changes in substrate, bathymetry, shore processes, circulation patterns.

c. Water column effects including the following: turbidity, nutrient concentrations, toxic materials, dissolved oxygen, mixing zone and the dilution and dispersion zone (Fed. Reg. Vol. 44, No. 182, pg. 54-227).

d. Effects on benthic communities including: smothering, substrate changes including grain size distribution and chemical changes, diversity, density, and productivity changes, ecological effects related to food web, recolonization patterns and rates.

e. Chemical-biological interactions relating to release or availability of chemical constituents as they might influence biota.

f. Cost and reliability.

g. Effects on the movement of fauna.

h. Timing of activities.

i. Effects on aesthetics, recreation, or economic values.

j. Effects on fish spawning or nursery areas.

k. Effects on water supply.

l. Effects on wildlife including marine mammals, birds, and threatened species.

m. Effects on wetlands or submerged vegetation.

n. Must specify disposal site based on following a least detrimental approach considering the above factors.

MONITORING AND MITIGATION

Subissues:

a. Monitoring: Monitoring of project performance and environmental alterations caused by it is necessary to allow a judicious application of mitigative measures. The following aspects of the project will require monitoring:

Waterflood effect on formation performance and pressure.

Effects of project structures and activities on wetlands fauna, vegetation, and hydrology.

Effects of causeway extension on circulation patterns and water quality.

Effects of causeway on migrations of biota and on the ecology of Simpson Lagoon.

Severity of impingement and entrainment losses of biota.

Nature and quantity of chemicals and solids in the discharge; degree of dilution and dispersion achieved; accumulation of solids burying under ice conditions.

Biological effects of discharge.

Air quality monitoring.

What party will be responsible for monitoring?

b. Mitigation

What measures are incorporated into the proposed project?

What additional measures are recommended based on current knowledge?

What measures can be instituted later if monitoring programs indicate a need?

APPENDIX B

APPLICANT'S PROPOSED PROJECT

DETAILED DESCRIPTION

1.0 INTRODUCTION

The Prudhoe Bay Unit (PBU) Waterflood Project has been developed through the conceptual design stage by the applicant. The precise economic viability of the project and optimum rate of water injection will be determined during preliminary and detail design. The planned facilities are subject to changes during detailed design to allow for economic and technical optimization and to allow for possible incorporation of other Prudhoe Bay facilities.

Planned facilities have been described by the applicant in the December 1979 Update of the Prudhoe Bay Unit Waterflood Project Overview, Volume 1, Engineering. This appendix supplements and provides more detail on the description of the proposed action provided in Section 2.4 of the EIS. The material presented herein is essentially an edited version of the applicant's description of individual facilities in Section 4 through 11 of the Overview document with the addition of more recent design parameters.

2.0 SEAWATER TREATING PLANT

FUNCTIONAL DESCRIPTION

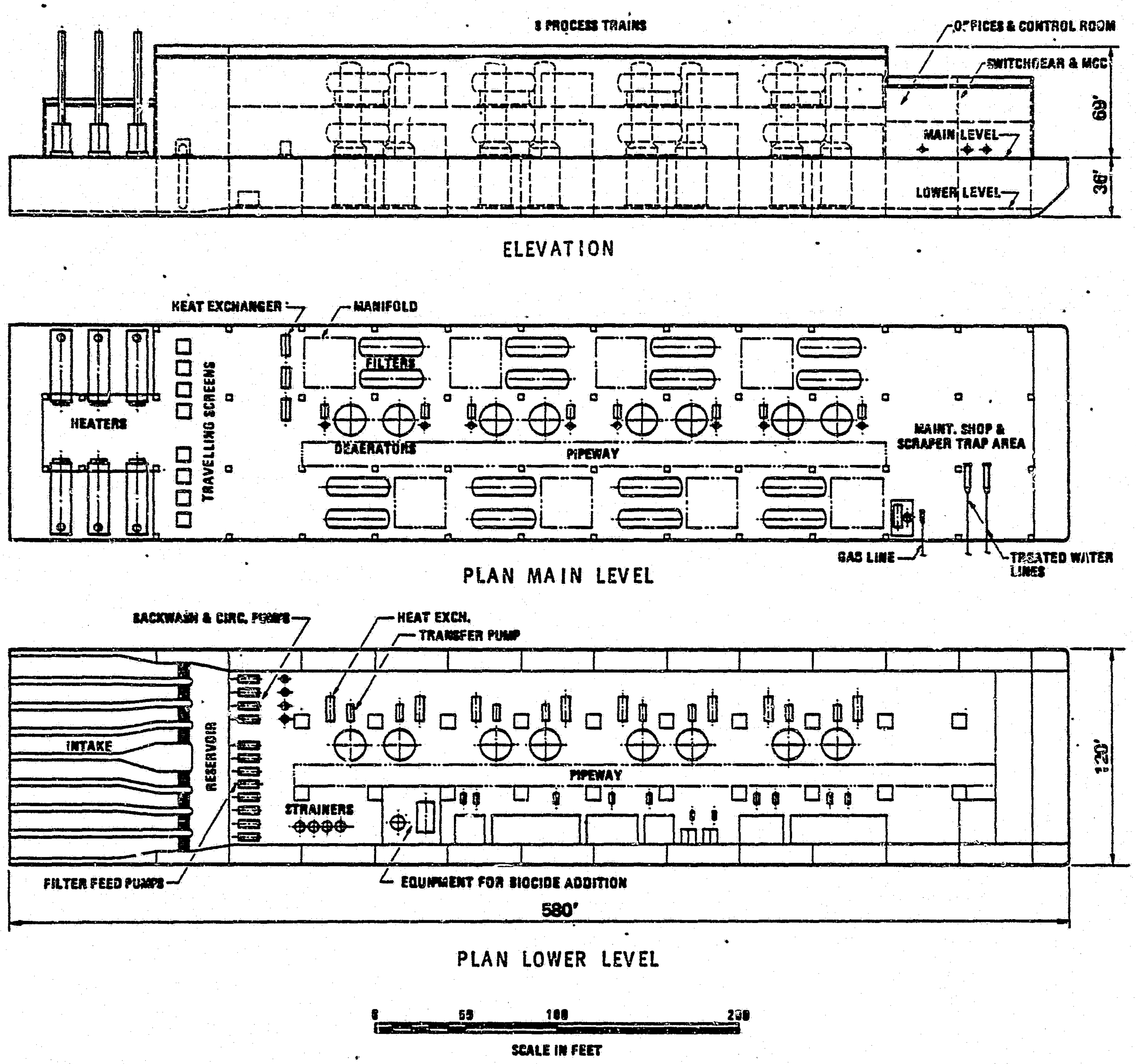
The seawater treating plant with integral water intake would be located at the end of a 1125-m (3700-ft) causeway extending northward from DH 3 to a water depth of about 3.7 m (12 ft). At this depth, intake openings can be located below winter ice and above the seabed to assure a reliable water source of good quality with minimum intake of marine organisms. The plant would condition the raw seawater to make it suitable for waterflood injection. The necessary equipment to achieve this required quality would be installed on a barge as shown in Figure B-1.

Processing would remove suspended solids and dissolved oxygen and provide heat for freeze protection in the low-pressure pipeline system.

FACILITY DESCRIPTION

Seawater would flow directly into the seawater treating plant inlet reservoir through openings in the shoreward end of the platform. The bottom of the openings would be approximately 0.3 m (1 ft) above the seabed and about 0.3 m below maximum sea ice thickness allowing an opening 1.5 m (5 ft) in height. The area of opening created would provide a water intake velocity of less than 15 cm/s (0.5 ft/s) and the upper and lower sills would minimize entrainment of organic and inorganic solids and slush ice. Flow would then be directed through traveling screens fitted with fish recovery buckets (Appendix H). Fish would be sluiced off the screens and returned to the sea. An untreated seawater spray would then remove any other debris from the screens. This debris would be collected and returned to the Beaufort Sea through the main outfall line. The seawater would then be pumped through in-line strainers to remove fibrous tundra particles that would be detrimental to the media filter performance. The accumulation of particles on the in-line strainers would be backwashed and pumped back to the sea through the main outfall pipeline.

After straining, the seawater would be heated to approximately 4.4°C (40°F) to prevent freezing. A small volume of heated water (21°C, 70°F) would be returned to the intake reservoir to mitigate frazil and slush ice problems. The amount of heat added is anticipated to have little measurable effect on the intake reservoir water temperature. The main process flow of seawater would next enter



PROPOSED SEAWATER TREATING PLANT
PLANS & ELEVATION

PBU Waterflood Environmental Impact Statement	Figure B-1

filters containing media such as gravel and sand for the removal of very fine particles. As needed, a coagulant (probably a polyamine) and a biocide (probably chlorine) will be added to improve filter performance. Periodically, each of the filters would be backwashed with strained unheated and untreated seawater to remove the accumulation of solid particles and coagulant within the media. The backwash effluent would be returned to the sea through the outfall line.

The filtered seawater would flow through deaerators for dissolved oxygen removal to prevent piping system corrosion. The deaerators would consist of columns containing packing material and would operate at less than atmospheric pressure. The seawater would flow down over the inert packing material, while a small volume of natural gas would flow up. Vacuum pumps would reduce the internal operating pressure of the column. The reduced pressure, combined with the stripping action of the natural gas, would liberate oxygen and mix it with the gas. The gas from the deaerators would be burned in heaters.

Probable water treating chemicals that would be added at three locations in the treating plant process flow, estimated concentration in the system, and frequency of application are provided in Table B-1.

Only chemicals added upstream of the filters (coagulant and biocide) would be discharged in the outfall line through backwash operations. The chemicals added upstream and downstream of the deaerators would not be discharged into the sea during normal operations. The filter aid chemical would be nontoxic and biodegradable. Various types of biocidal treatment are still under consideration. These include chlorine (providing no free chlorine in the discharge) and hydrogen peroxide.

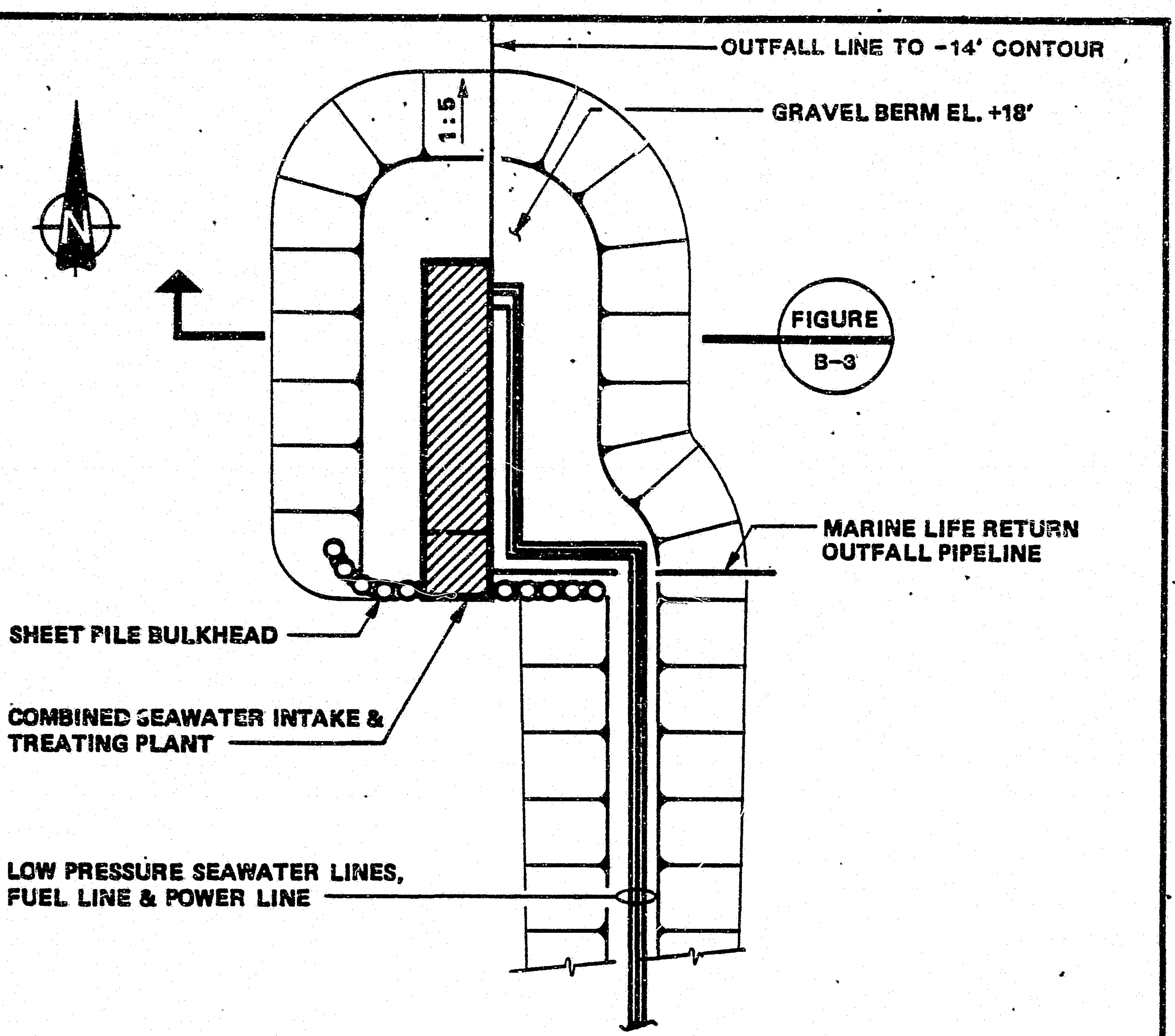
The seawater treating plant would be protected from ice forces and waves by a gravel berm as shown in Figures B-2 and B-3. Treated seawater would be pumped through low-pressure pipelines to the injection plants located on each side of the field. These pipelines

TABLE B-1

TYPICAL SYSTEM CHEMICAL USAGE (Estimated Average)

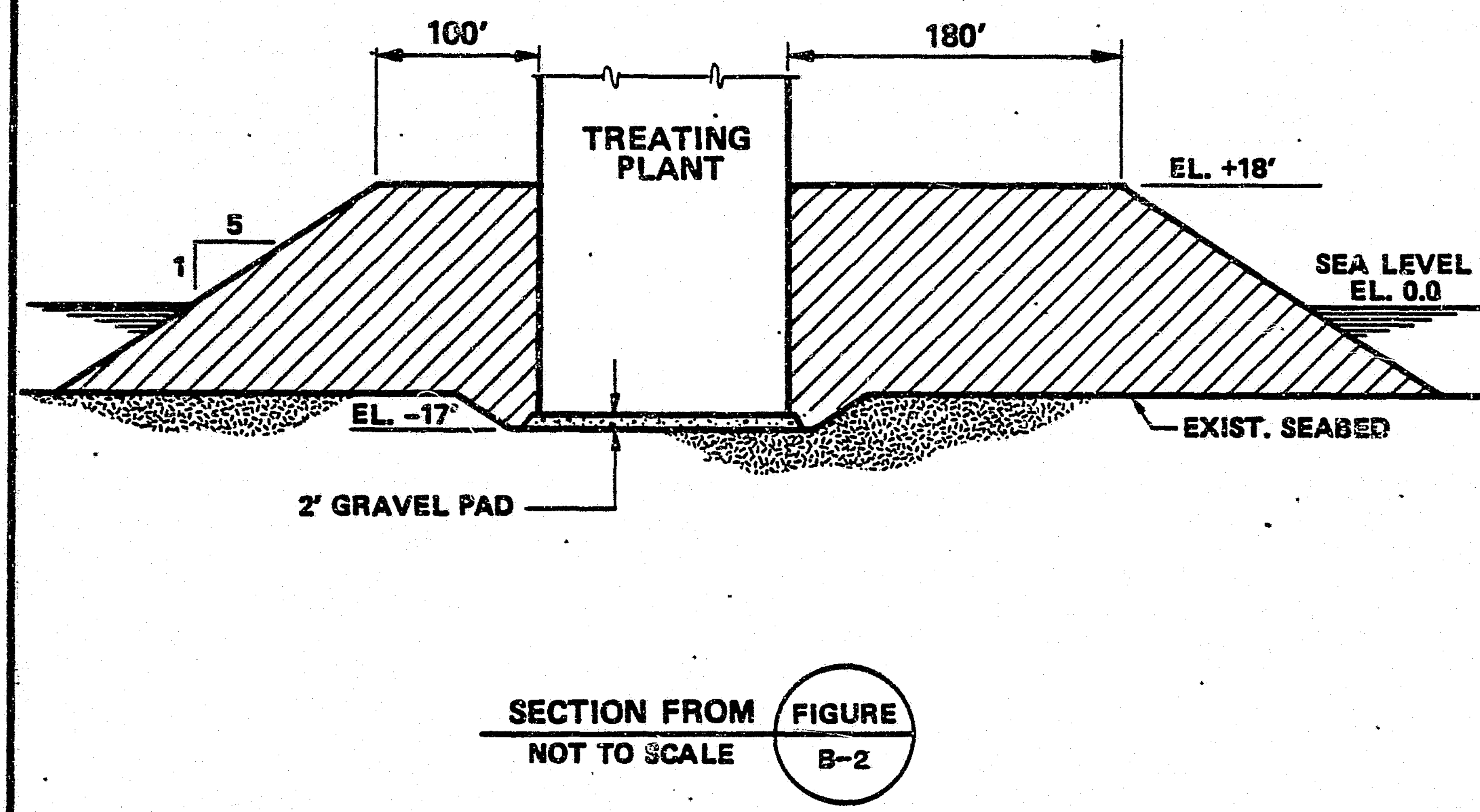
Where Added	Chemical Type	Effective Concentration	Use	Frequency
Upstream of Filters	Sodium Hypochlorite[a]	0.1 ppm	Biocide	Continuous
	Cationic Polyelectrolyte[b]	0.85 ppm	Coagulant	Continuous
Upstream of Deaerators	Fatty Acid and Polyglycol[c]	0.25 ppm	Anti-foam	Continuous
Downstream of Deaerators	Catalyzed Sodium Bisulfite[c]	0.9 ppm	O_2 Scavenger	During Deaerator Malfunction
	Filming Amine[c]	7.0 ppm	Corrosion Inhibitor	During Deaerator Malfunction
	Phosphate Ester[c]	7.0 ppm	Scale Inhibitor	During Deaerator Malfunction

(a) Added upstream of the filters to establish a 0.1 ppm residual concentration at the filter feed inlet.
(b) Typical brands are NALCO 3332; NALCO 3364; TFL 3910 (Tretolite).
(c) Added downstream of filters and thus will not be present in the outfall except during emergency displacement of both low-pressure supply lines.



PROPOSED SEAWATER TREATING PLANT
FACILITY LAYOUT

PBU Waterflood Environmental Impact Statement | Figure B-2



PROPOSED SEAWATER TREATING PLANT
GRAVEL BERM

PBU Waterflood Environmental Impact Statement	Figure B-3

would be incorporated in the causeway extension to DH 3 as discussed in Section B-3.

CONSTRUCTION

The installation plan for the seawater treating plant is shown in Figure B-4. Initial gravel placement and installation of a sheet pile bulkhead would be in summer 1981. Dredging (probably using a clam-shell dredge) of the slip for grounding the plant and placement of foundation gravel would be completed prior to arrival of the plant, which would be towed to the site in 1983. Upon arrival, the plant would be positioned in its slip and secured to the anchor piles. The ballast compartments would be filled with calcium chloride solution by controlled pumping to ground the plant on the gravel foundation. The calcium chloride would contain a corrosion inhibitor. Previously installed outfall lines, fuel gas lines, and treated seawater low-pressure supply lines would be connected and the remaining gravel placed around the plant. The design would allow reflotation and removal at the end of project life.

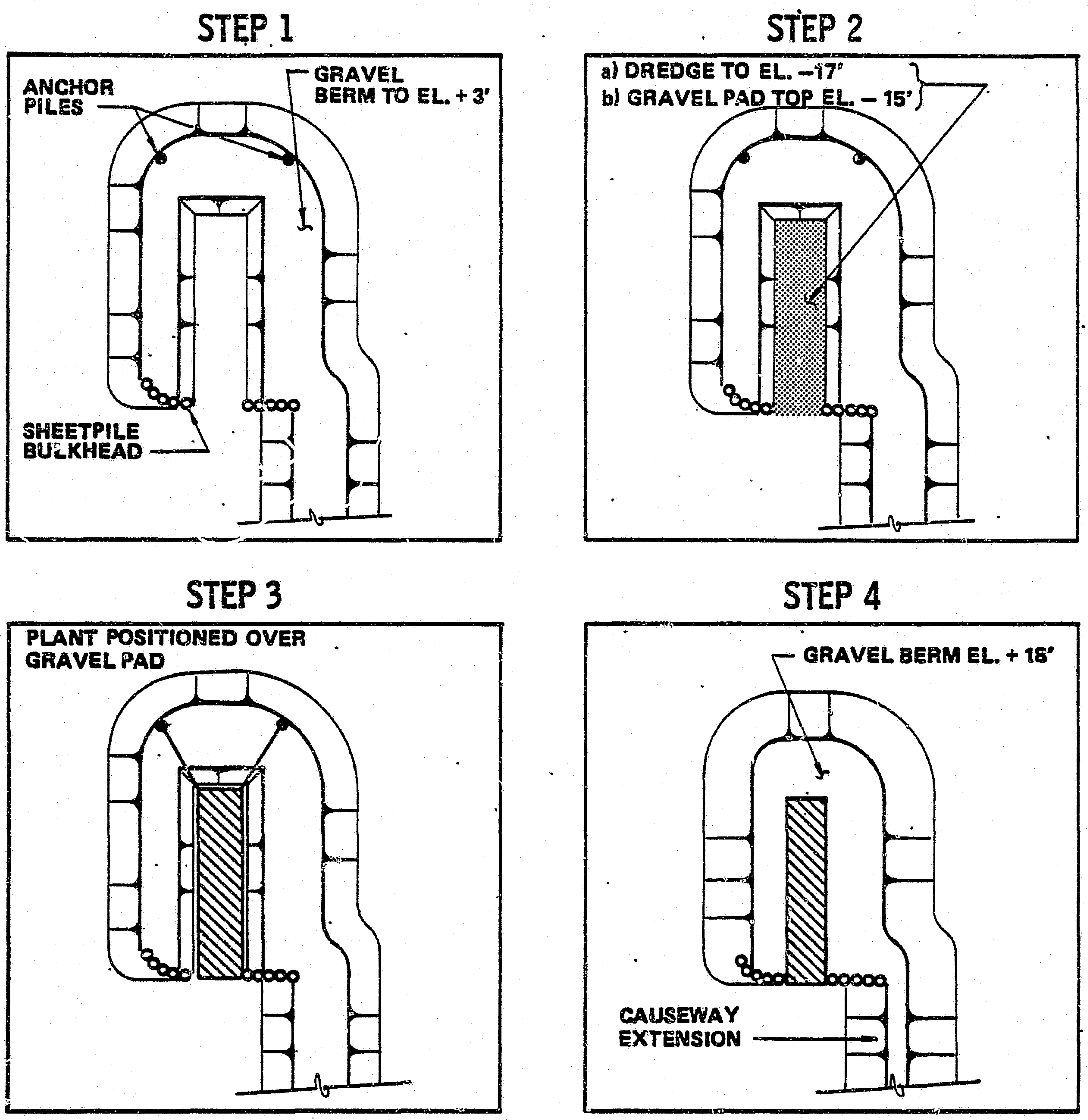
ICE FORCE DESIGN CRITERIA

The ice force criteria used in the design of the treating plant berms and hull are summarized in Table B-2.

3.0 PROPOSED CAUSEWAY EXTENSION AND MODIFICATIONS

FUNCTIONAL DESCRIPTION

The proposed causeway extension would provide access to the seawater treating plant located approximately 1125 m (3700 ft) north of DH 3 in about 3.7 m (12 ft) of water. This causeway would incorporate low-pressure seawater supply and fuel gas pipelines and power lines. Modification of the existing causeway to DH 3 would accommodate pipelines and power lines and provide additional logistics capability. DH 3 would be reoriented slightly to the northeast.



INSTALLATION PLAN
PROPOSED SEAWATER TREATING PLANT

PBU Waterflood Environmental Impact Statement | Figure B-4

TABLE B-2

ICE FORCE DESIGN CRITERIA FOR VARIOUS WATERFLOOD FACILITIES

Causeway Widening

Ice Force: 260 lb/in^2 x depth below MLLW x 110%

Maximum Ice Force: 270,000 lb/lin ft

Frost penetration assumed 6 m (20 ft) below seabed under existing causeway (based on coring and thermal analysis).

Frozen gravel shear strength for local shear: 4000 lb/ft^2

Local shear failure between ice and pipelines controls width.

Causeway Extension

Ice Force: 270,000 lb/lin ft

Frost penetration assumed to be 1.8 m (6 ft) below seabed.

Treating Plant Berms

Ice Force: northern and eastern exposure - 400,000 lb/lin ft

Ice Force: southern and western exposure - 270,000 lb/lin ft

No frost penetration assumed below seabed.

Treating Plant Hull

Indirect ice load: N, E, W - 35 lb/in^2 (150,000 lb/lin ft)

Direct ice load: South - 270,000 lb/lin ft

Gravel fill weight above MLLW - 115 lbs/ft^3

Gravel fill weight below MLLW - 065 lbs/ft^3

Sliding Friction Co-efficient, Gravel/Soil - 0.5

FACILITY DESCRIPTION

The gravel causeway extension from DH 3 to the seawater treating plant would incorporate the low-pressure seawater supply pipelines as well as the fuel gas pipeline and electric power lines. The causeway extension would be designed to withstand predicted ice forces. Cross-section dimensions, shown in Figure B-5a, reflect the associated gravel quantities, but dimensions may be altered during detailed design to reflect updated open-water surge and wave predictions. The causeway extension would provide only vehicle access to the seawater treating plant and would not constitute an extension of the existing dock offload facilities. The extended causeway would be breached with a 7.6-m (25-ft) diameter semi-elliptical structure to allow fish passage (Figure B-6). The existing causeway to DH 3 would be expanded as shown in Figure B-5b to provide protection for the low-pressure seawater supply and fuel gas pipelines and the electrical distribution system cables. In addition, this expansion would accommodate two-way crawler traffic. A 7.6-m (25-ft) semi-elliptical culvert breach in the extension outside DH 3 is proposed to aid fish passage.

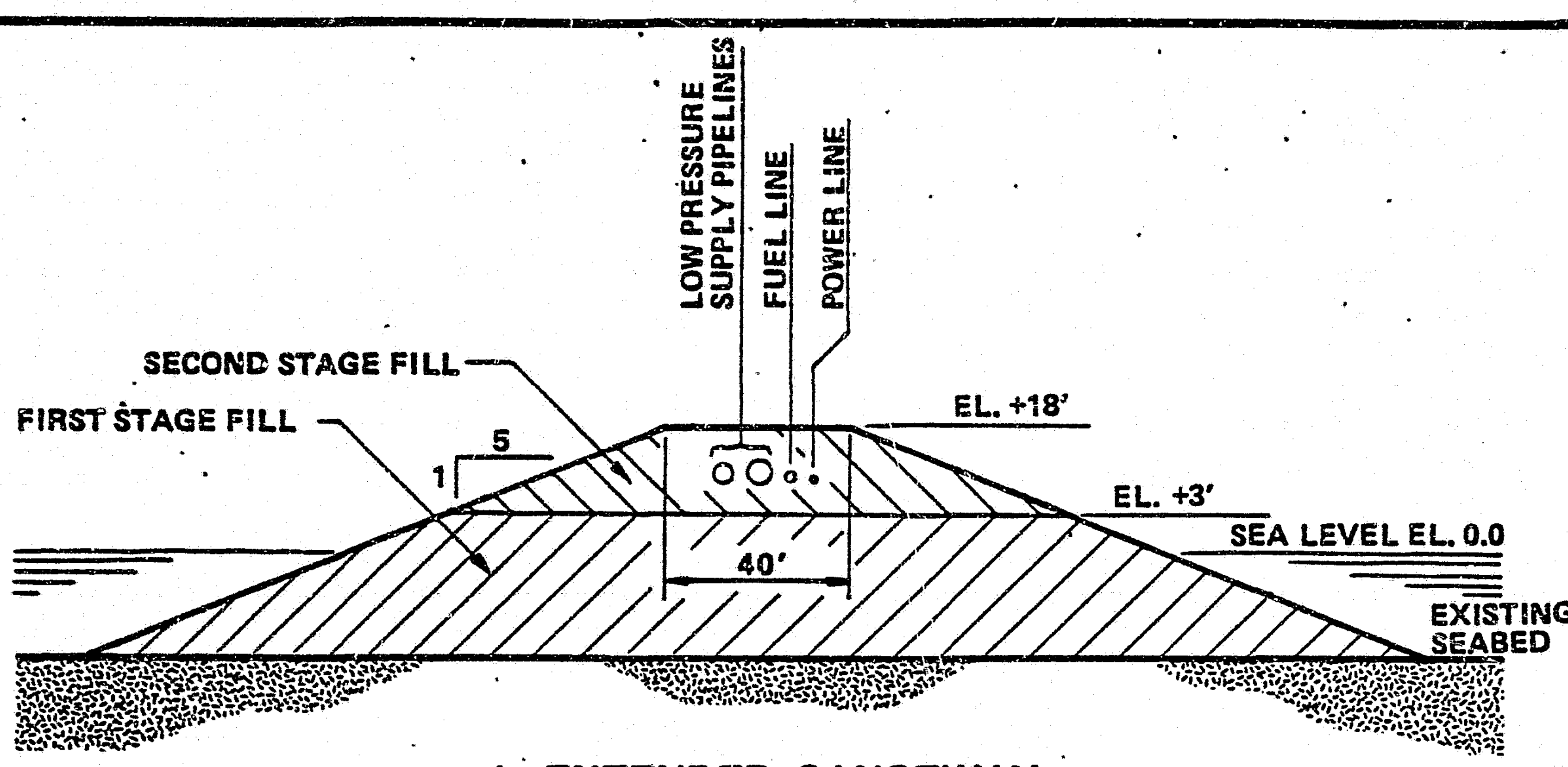
DH 3 would require a slight reorientation to the northeast to allow extension of the causeway to the seawater treating plant. This reorientation would utilize, for the most part, existing gravel at DH 3.

CONSTRUCTION

Gravel placement for the causeway extension and expansion would be accomplished in two increments. Initial placement for both would be in summer 1981. Pipeline construction and placement for the remaining gravel would be completed in 1982.

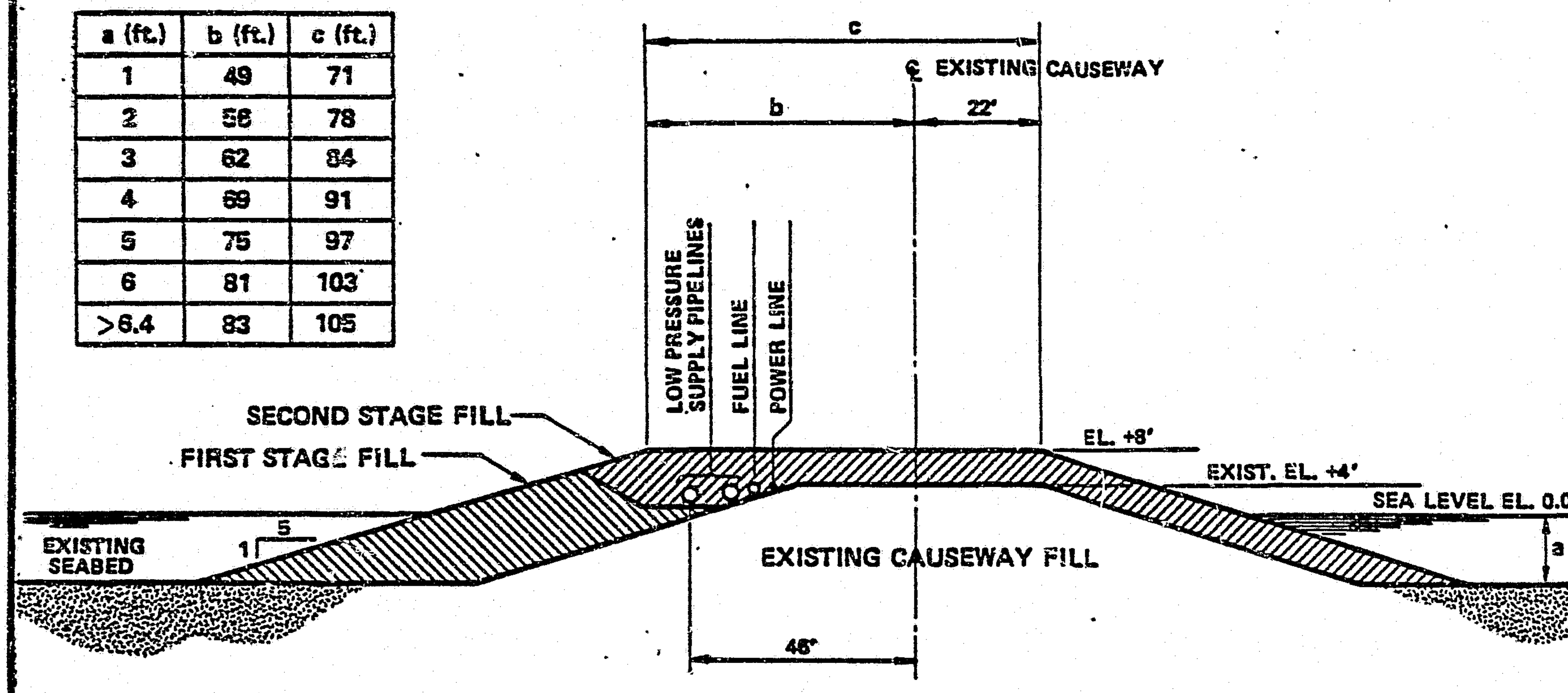
ICE FORCE DESIGN CRITERIA

The ice force criteria used in the design of the causeway extension and widening are summarized in Table B-2.



A. EXTENDED CAUSEWAY

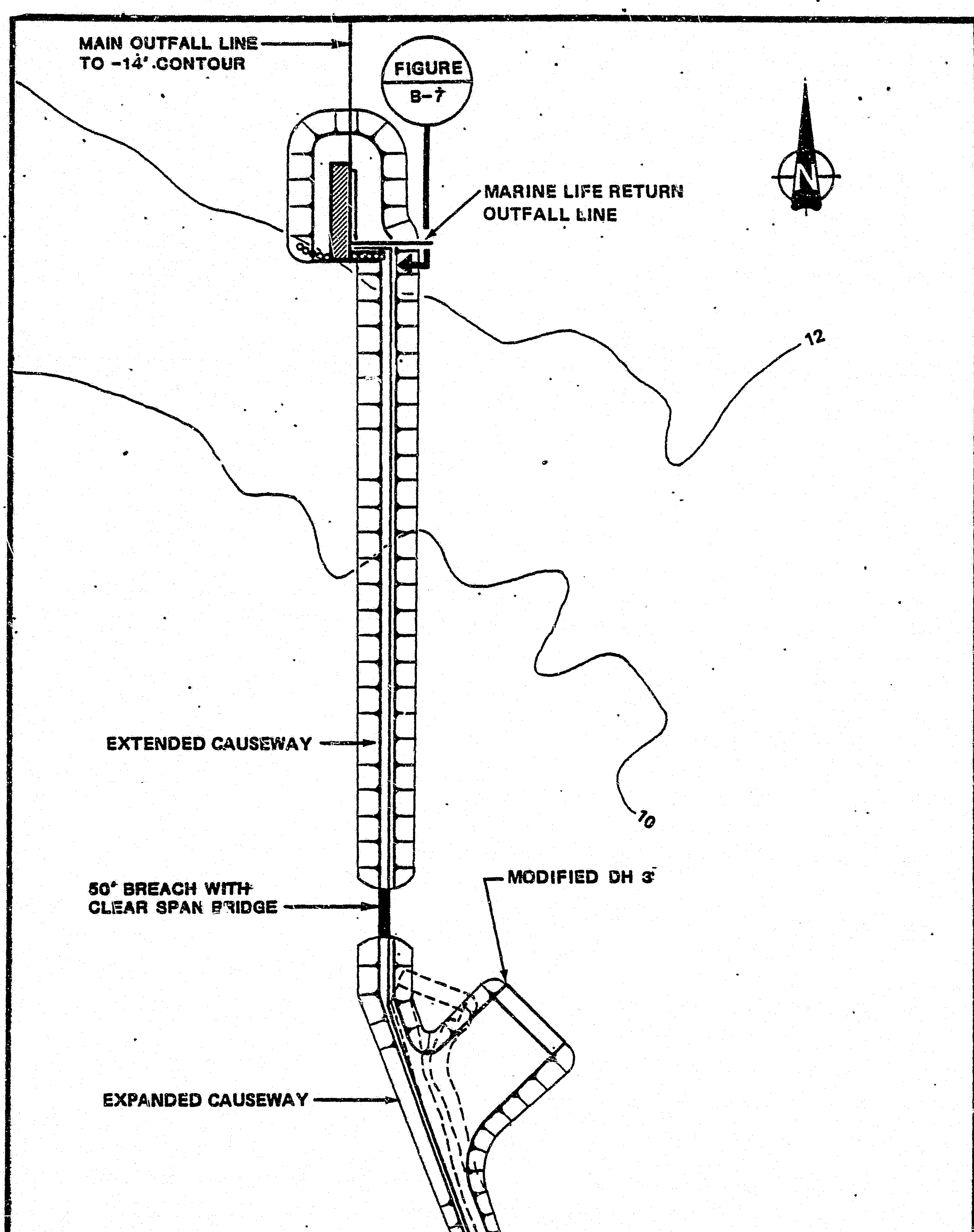
a (ft.)	b (ft.)	c (ft.)
1	49	71
2	56	78
3	62	84
4	69	91
5	75	97
6	81	103
>6.4	83	105



B. EXISTING CAUSEWAY

PROPOSED CAUSEWAY MODIFICATIONS

PBU Waterflood Environmental Impact Statement | Figure B-5



PROPOSED OUTFALL PIPELINES
LOCATION PLAN

PBU Waterflood Environmental Impact Statement | Figure B-6

4.0 OUTFALL PIPELINES

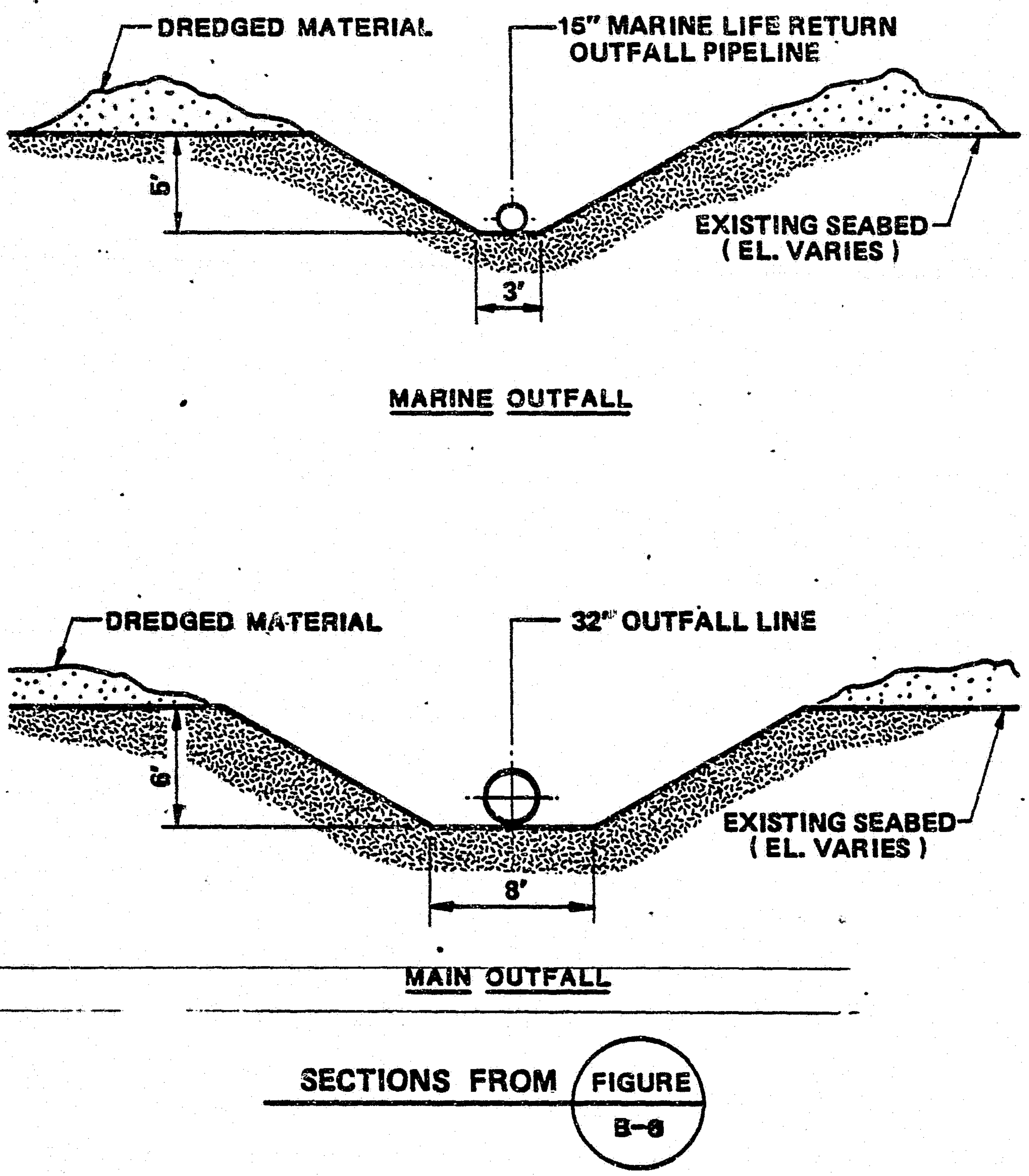
FUNCTIONAL DESCRIPTION

The main outfall pipeline would transport process effluents from the seawater treating plant to an outfall located approximately 760 m (2500 ft) north and 300 m (1000 ft) west of DH 3, in a water depth of about 3 m (10 ft). The marine life return outfall line would transport fish and other marine life removed from the traveling screens in the seawater treating plant inlet reservoir, to an outfall located approximately 150 m (500 ft) east of the seawater treating plant. Pipeline locations are shown on Figure B-6.

FACILITY DESCRIPTION

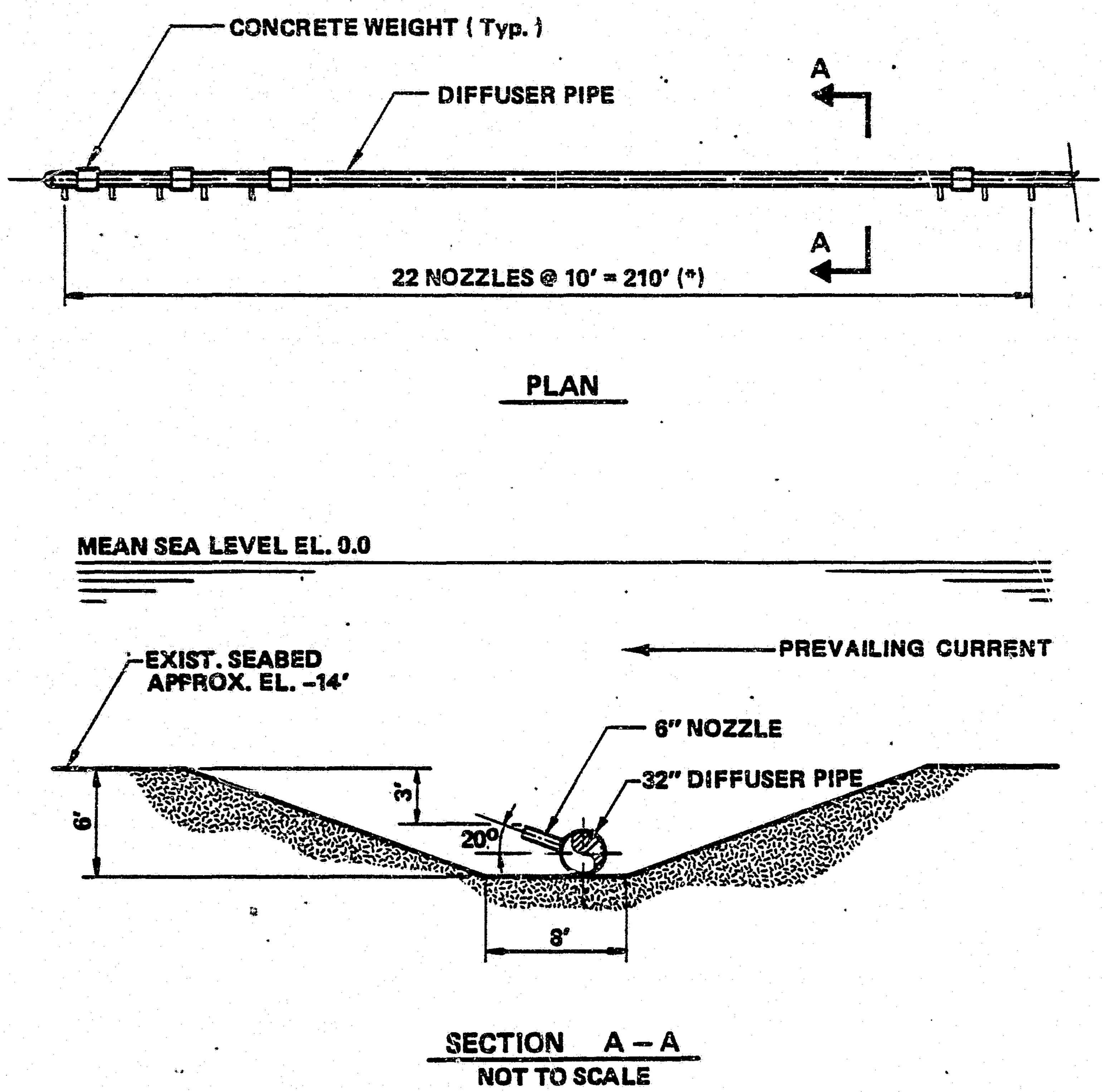
The main 81-cm (32-in, outside diameter) outfall pipeline would be routed from the seawater treating plant back along the causeway extension to a point about 760 m north of DH 3 (Figure B-6). It would then extend for about 300 m west terminating at the outfall location. Between the causeway and the outfall location it would be placed in a trench beneath the seabed at a depth lower than ice keels that have been known to penetrate the area (Figure B-7). The barrier islands and shallow water generally keep large masses of ice with keels from moving into the area. If the line did become damaged, however, it would be repaired as quickly as possible. Natural sediment deposition would be expected to backfill the trench within one or two open-water seasons.

The diffuser section would have 22, 15.2-cm (6-in) diameter nozzles, spaced 3 m (10 ft) apart. These diffuser nozzles would be located beneath the original seabed elevation, angled about 20° to the horizontal, and oriented parallel to the prevailing current (Figure B-8). This design would provide for dilution ranges of 10 - 15 within a radius of about 30 m (100 ft) of the point of discharge. This would result in a maximum mixing zone of less than 0.4 ha (1 acre) and, by definition, the discharge would meet State of Alaska water quality criteria outside this zone.



PROPOSED MARINE LIFE RETURN OUTFALL PIPELINE
&
PROPOSED MAIN OUTFALL PIPELINE

PBU Waterflood Environmental Impact Statement	Figure B-7



(*) These dimensions to be verified.

PROPOSED MAIN OUTFALL PIPELINE DIFFUSER
PLAN & SECTION

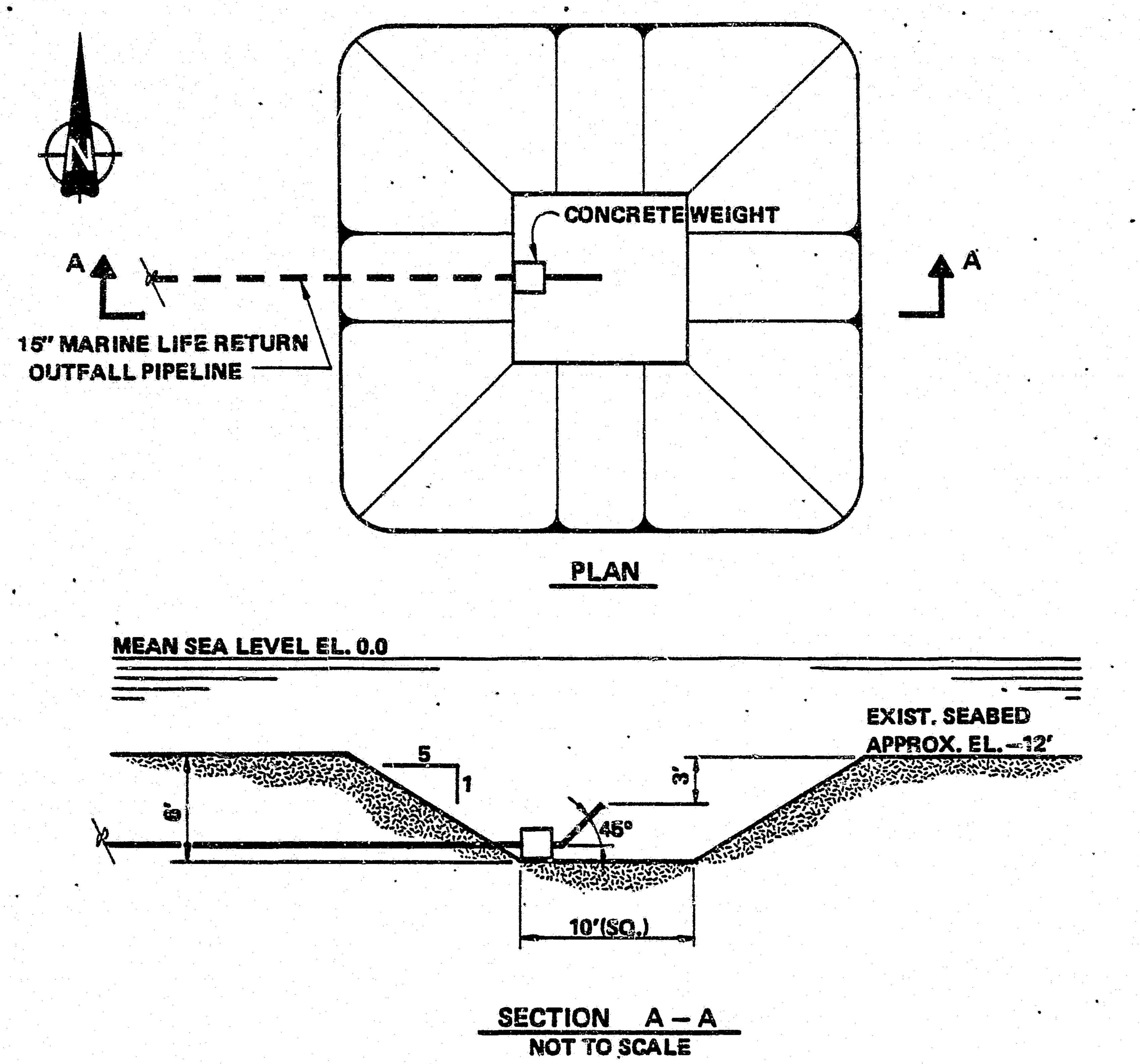
PBU Waterflood Environmental Impact Statement | Figure B-8

The coagulated particles within the effluent would be deposited over an area of 2.0 - 18.2 ha (5 - 45 acres) and would be further dispersed by summer wind and wave activity.

The maximum effluent flow rate in the main outfall line would be about 1.10 m^3/s (17,325 gal/min) and would be derived from three sources within the seawater treating plant. Most of the flow, 0.51 m^3/s (8080 gal/min), would result from filter backwashing operations. During maximum loading conditions when filters are not being backwashed, untreated seawater would be used to maintain the total flow rate at 1.16 m^3/s (18,360 gal/min). The strainer backwash contributes 0.44 m^3/s (7030 gal/min). Traveling screen spray water, which removes solid particles accumulated on screens, would contribute 0.14 m^3/s (2220 gal/min). The annual average effluent flow rate would be 0.19 m^3/s (2915 gal/min) since backwashing frequency would be considerably less than for the maximum condition and makeup water to maintain the flow rate would be used only during maximum loading conditions.

Effluent character would depend upon the seawater quality. During the open-water season, wave action greatly increases suspended solids concentrations in the seawater and consequently, would increase the total amount of effluent solids. The outfall design is based on this maximum case. Raw seawater conditions used in outfall effluent calculations are based on seawater sampling done during pilot filtration tests conducted during the summer of 1979, and on earlier periodic year-round sampling. Pilot tests were conducted at 2.4 m (8 ft), but samples were obtained at water depths from 2.4 - 6.7 m (8 - 22 ft). The data for the 2.4-m depth represent the most stringent load conditions and were used for design purposes.

The 20-cm (8-in) open-ended marine life return outfall line (Figure B-9) would be installed from the seawater treating plant to an outfall location approximately 150 m (500 ft) to the east as shown in Figure B-6. This line would transport fish and other marine life sluiced with



PROPOSED MARINE LIFE RETURN OUTFALL PIPELINE

PBU Waterflood Environmental Impact Statement	Figure B-9

untreated seawater from the traveling screens back to the sea. The anticipated velocity in this line would be about 30 cm/s (12 in/s) with a discharge rate of about 1920 m^3/d (506,000 gal/d).

CONSTRUCTION

Pipeline materials would be trucked to Prudhoe Bay in the first quarter of 1982. Pipeline portions buried in the causeway or berm and submarine portions would be installed in 1982. Submarine pipelines would be assembled on the causeway extension, floated into position, and placed into a dredged trench by controlled sinking. The diffuser unit for the main outfall line would be connected after line installation and secured in place with concrete weights.

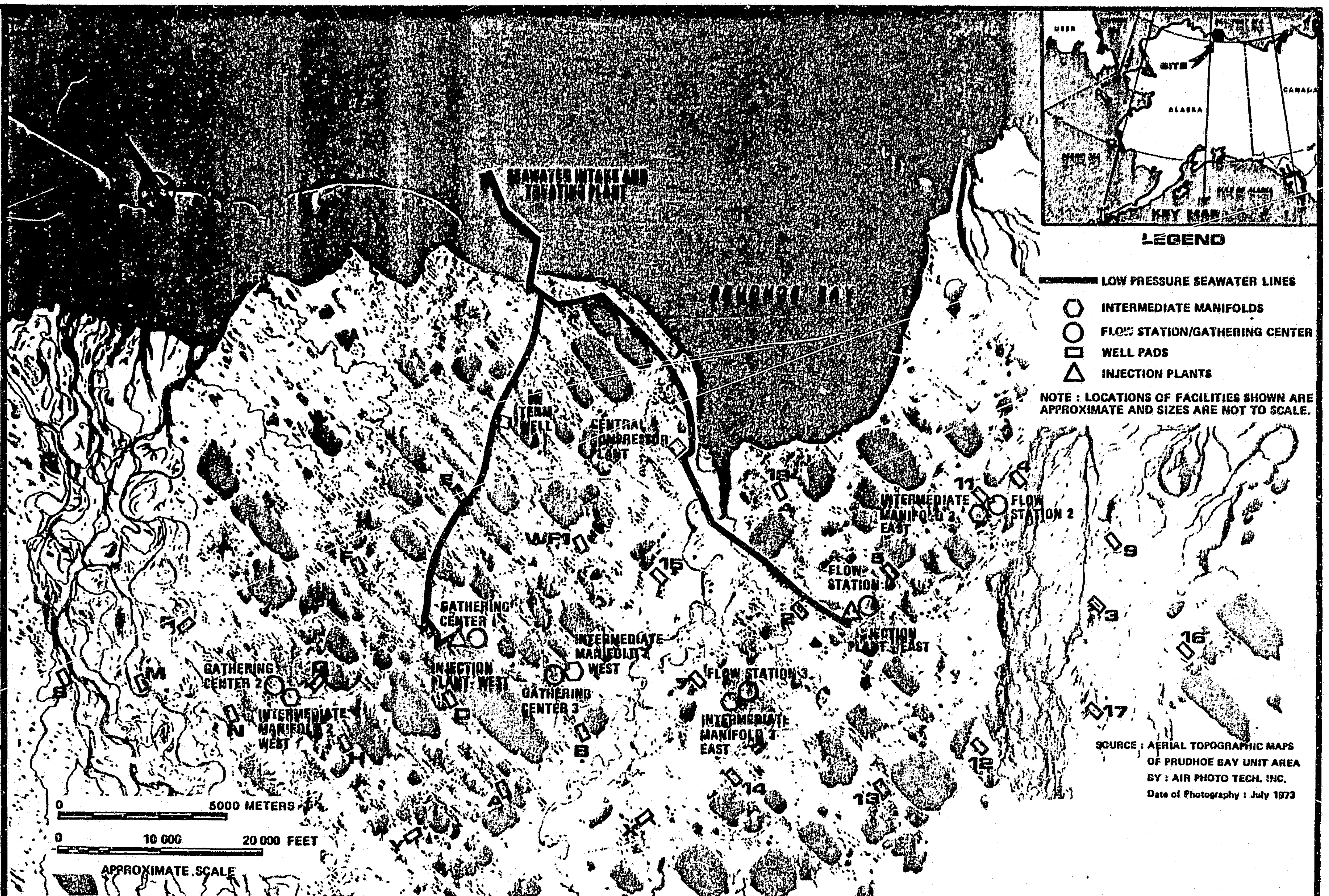
5.0 LOW-PRESSURE PIPELINES

FUNCTIONAL DESCRIPTION

The treated seawater low-pressure supply pipelines would have capacity to transmit the total flow rate of 4.07 m^3/s (64,506 gal/min) of seawater from the seawater treating plant to the injection plants. This total would be divided into 2.22 m^3/s (35,185 gal/min) to the east side of the field and 1.85 m^3/s (29,320 gal/min) to the west side.

FACILITY DESCRIPTION

One 102-cm (40-in) diameter insulated low-pressure seawater supply pipeline, about 20.8 km (13 mi) long, would be installed between the seawater treating plant and the east injection plant. Similarly one 96-cm (36-in) insulated line, about 16 km (10 mi) long, would be installed between the seawater treating plant and the west injection plant (Figure B-10). Both lines would start at the seawater treating plant and would be installed in the causeway extension and expansion as described in Section B-3. After reaching shore, the lines would be installed above ground, supported on pile bents. The clearance between



PROPOSED LOW-PRESSURE PIPELINE ROUTE MAP

Figure B-10

the tundra and the bottom of the pipelines would be sufficient to avoid thermal degradation of the permafrost. Caribou passage would be provided.

The east line would follow the existing roadway between the module staging area (at the shore end of the causeway) and the CCP. The line would then follow the existing pipelines between the CCP and Flow Station 1 to the proposed east injection plant location. The west line would follow the existing roadway between the module staging area and Term Well A and a planned road extension to Well Pad E, a total distance of approximately 8 km (5 mi). The line would then follow the existing road and flow lines between Well Pad E and Gathering Center 1 (an additional 4.4 km, 2.8 mi) to the west injection plant. Adequate precautions would be taken to minimize the effect on natural drainage in the area.

The lines would be insulated for freeze protection and would include anchors and expansion loops to accommodate thermal movements. The above-ground section would provide for passage of caribou.

CONSTRUCTION

The offshore portion of these pipelines would be trucked to Prudhoe Bay in the first quarter of 1982 and would be installed in 1982. The onshore pipeline material would be shipped in 1982 for construction commencing in the fall of that year. The pipelines would be constructed using gravel work pads in the summer and gravel and snow pads in the winter. Existing gravel roads would be utilized except for:

- A new extension road (approximately 2 km, 3 mi) from Term Well A to Well Pad E. The road would be 1.5 m (5 ft) thick, and have 3:1 side slopes.

- A gravel pad from the module staging area to the CCP parallel to an existing road.

6.0 INJECTION PLANTS

FUNCTIONAL DESCRIPTION

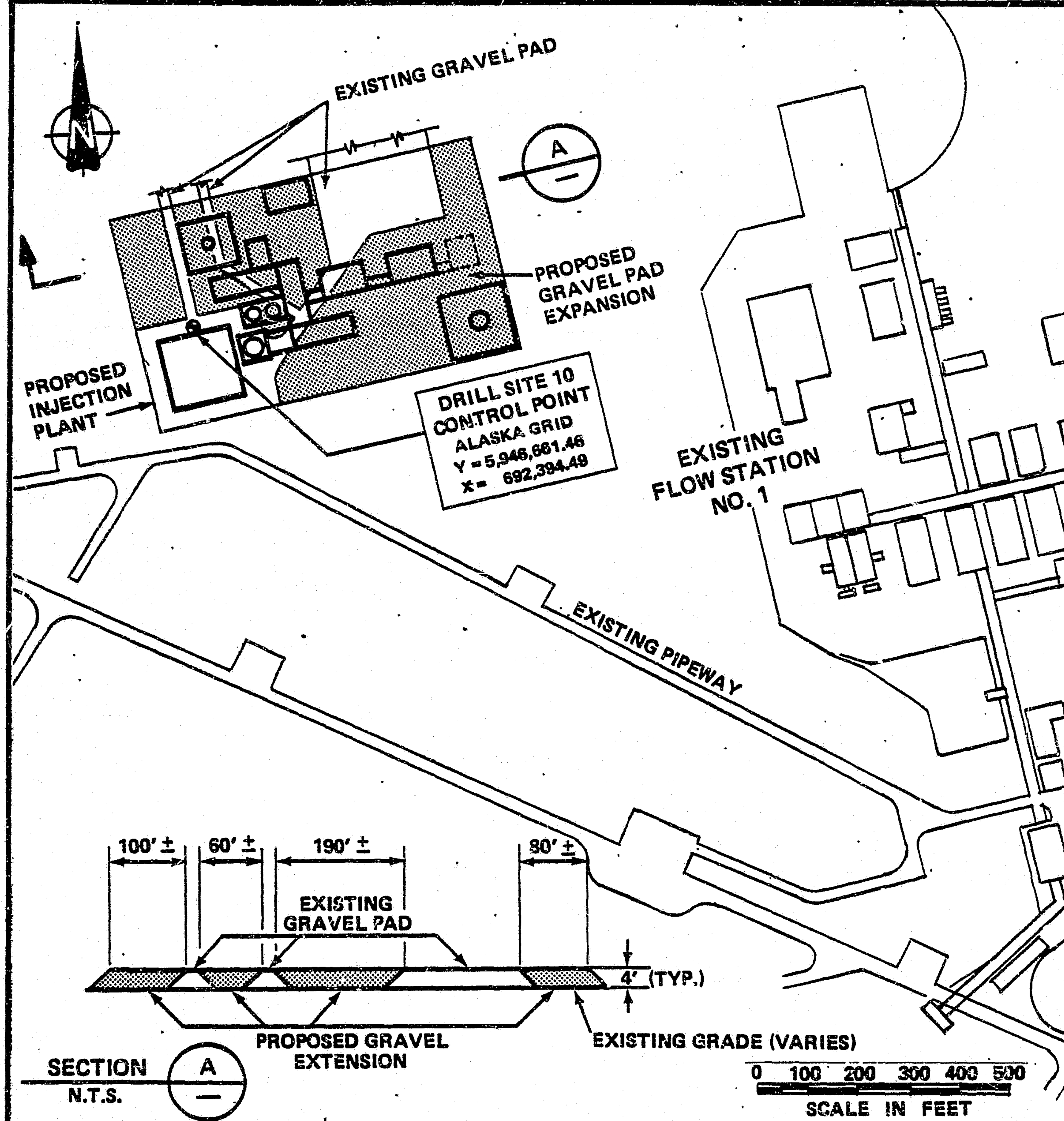
An injection plant would be provided on each side of the field, adjacent to Flow Station 1 on the east and Gathering Center 1 on the west. The treated seawater from the seawater treating plant would be received at each injection plant through a low-pressure manifold that would route the seawater to an inlet tank. Associated with this tank would be an emergency overflow pit. Water from the tank would pass through booster pumps that would provide sufficient suction pressure for the main gas turbine-driven injection pumps. The main pumps would increase seawater pressure up to 3200 lb/in^2 for delivery to the discharge manifold and subsequent distribution to the injection well sites. Between the booster pumps and main pumps, the seawater would be heated using waste heat recovered from the main pump turbine exhausts.

High-pressure produced water from the adjacent production center would be transferred to each injection plant high-pressure manifold. The produced water and seawater would not be mixed; however, it would be possible at the discharge manifold to permit the use of any high-pressure distribution pipeline for either produced or seawater.

FACILITY DESCRIPTION

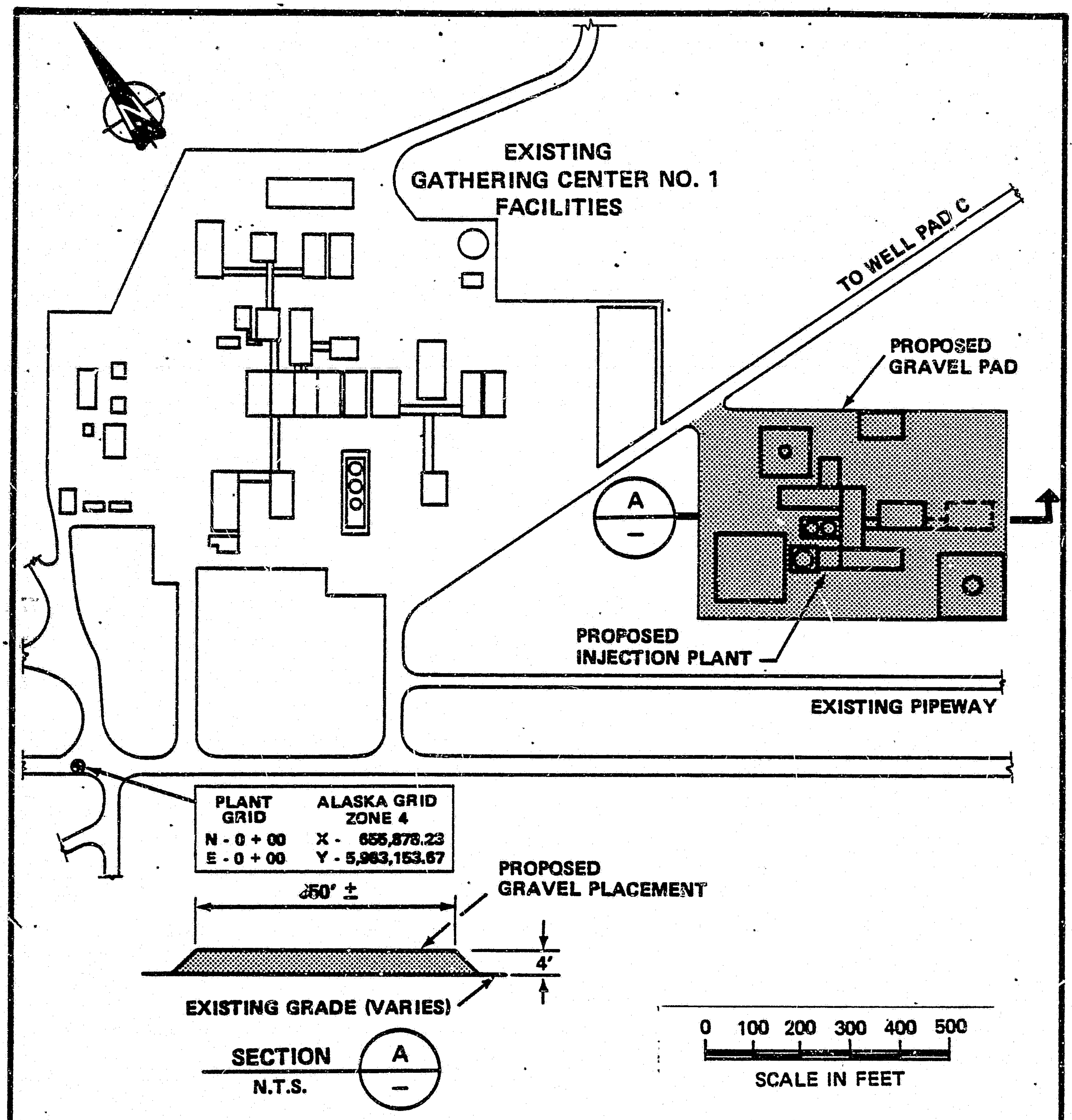
The east injection plant pad (Figure B-11) would utilize some gravel originally placed for Drill Site 10 (now used for storage purposes). This location is central to the east side, affords vehicle access, and is adjacent to the existing main pipe routes.

The west injection plant pad (Figure B-12) would be located between the existing road to Well Pad C and the existing pipeway between



PROPOSED INJECTION PLANT – EAST
LOCATION PLAN

PBU Waterflood Environmental Impact Statement	Figure B-11



PROPOSED INJECTION PLANT – WEST
LOCATION PLAN

PBU Waterflood Environmental Impact Statement	Figure B-12

Gathering Centers 1 and 3. This location is central to the west side, affords vehicle access, and is convenient to existing pipe routes.

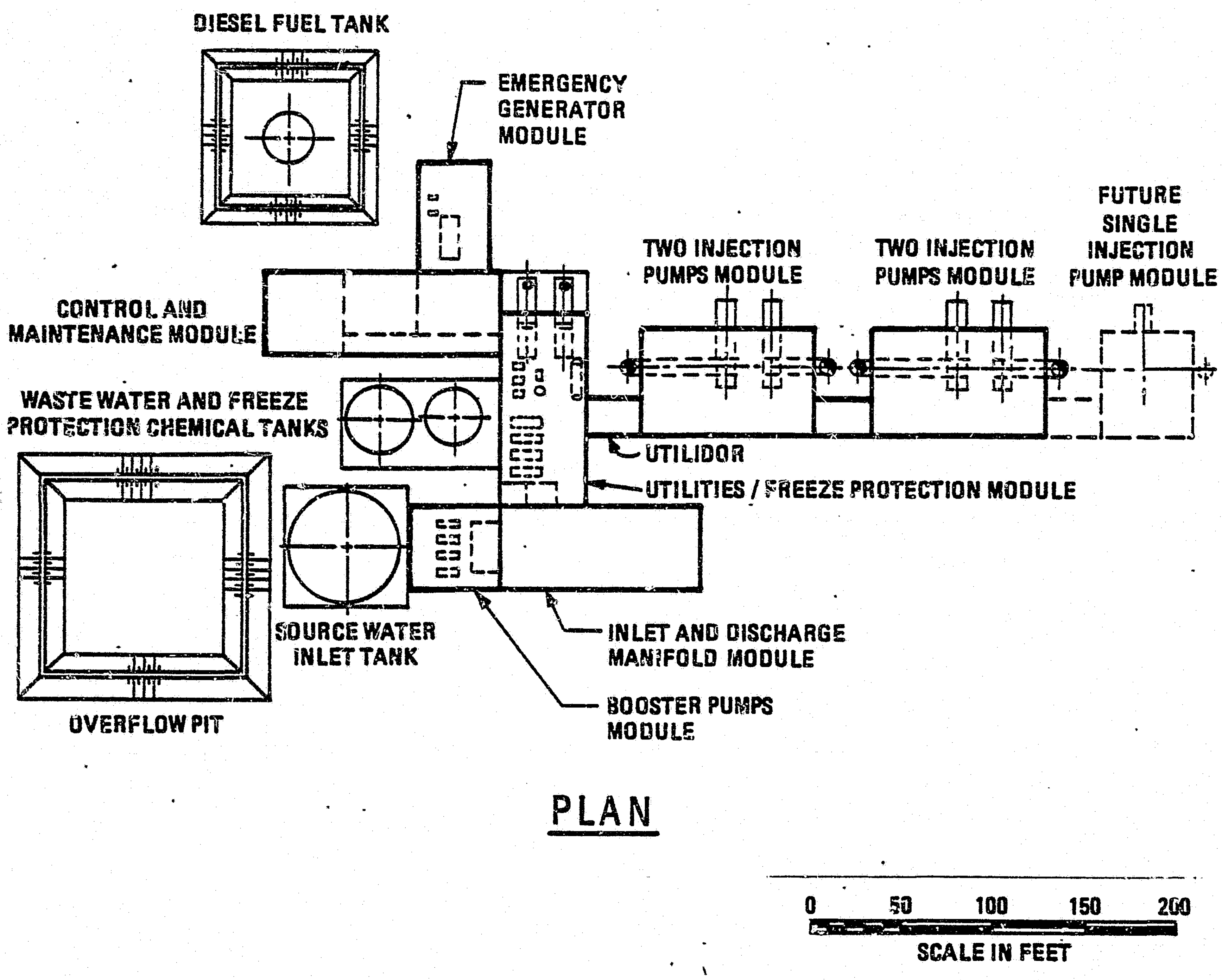
The east injection plant would be composed of eight major modules; the west injection plant, seven major modules. Each plant would also have module-connecting utilidors and outside tanks. The modules would house equipment required to boost water pressure and heat the seawater as well as equipment for control and auxiliary freeze protection. Modules and outside equipment at each plant would occupy an area of approximately 7400 m^2 (80,000 ft^2). The facilities would be arranged as shown in Figures B-13 and B-14 to provide flexibility. They would be installed in a single increment, except for the high-pressure pump modules.

Capacity for the east injection plant would be approximately 2.22 m^3/s (35,185 gal/min) of seawater; for the west injection plant, 1.85 m^3/s (29,320 gal/min). Initial high-pressure pump capacity for the east plant would be 1.85 m^3/s; and for the west plant, 0.93 m^3/s (14,740 gal/min). Initial installation would include four injection pumps in the east plant and two in the west plant. In the second construction increment, one pump would be added to the east plant and two to the west plant.

The main injection pumps would require approximately 16,000 hp each. They would be driven by gas turbines utilizing fuel gas from the flow stations and gathering centers. Heat recovery units installed in the gas turbine exhausts would provide approximately 50 million BTU/hr each for freeze protection. Gas-fired heaters would provide heating when heat recovery is not available.

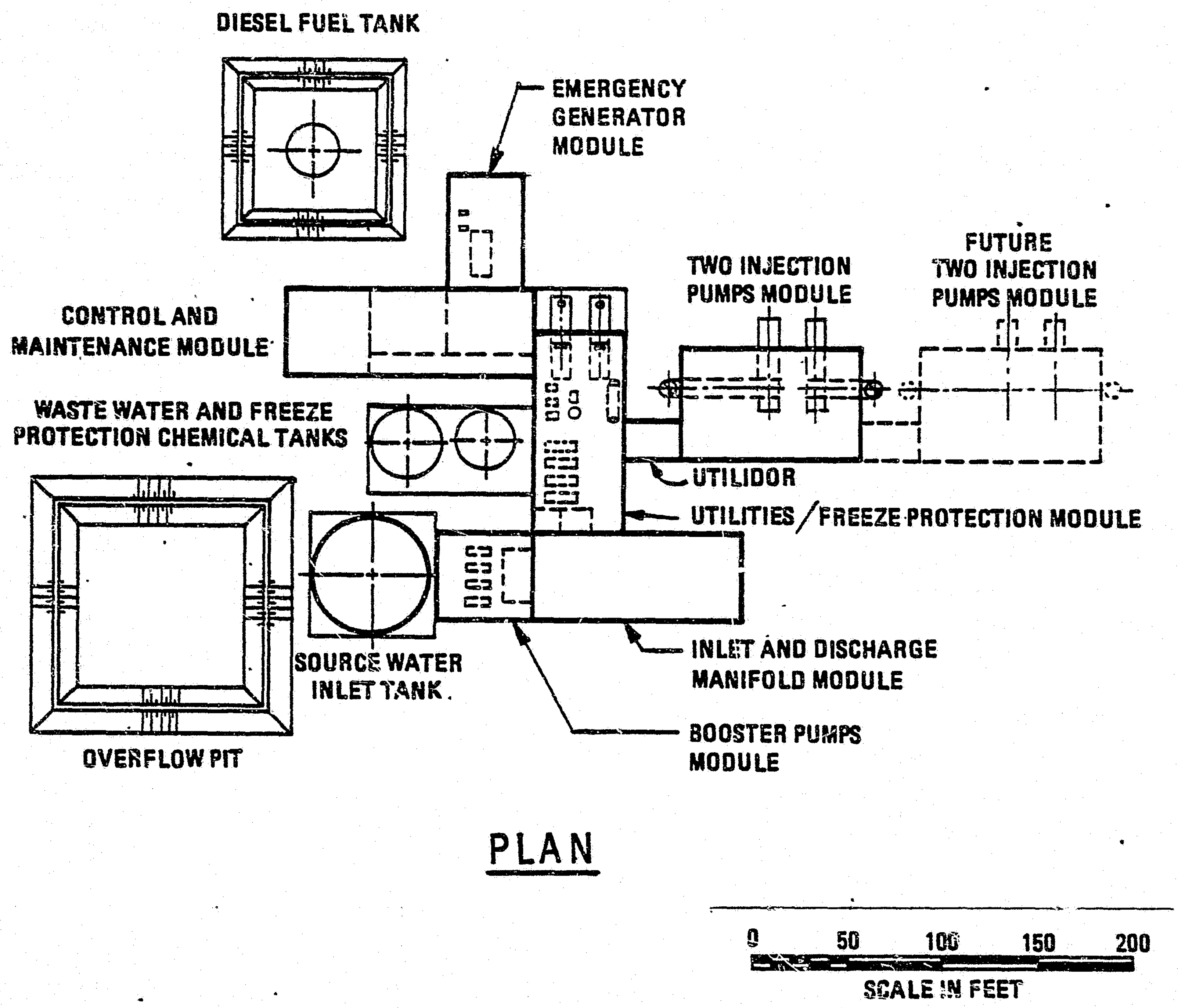
CONSTRUCTION

Injection plant construction would take place in two increments. Gravel placement is scheduled for summer 1982. This would be followed by piling installation in winter 1982-1983 and module placement in



PROPOSED INJECTION PLANT – EAST
FACILITY LAYOUT

PBU Waterflood Environmental Impact Statement | Figure B-13



PROPOSED INJECTION PLANT – WEST FACILITY LAYOUT

PBU Waterflood Environmental Impact Statement | Figure B-14

fall 1983 to meet a 1984 start-up of the first increment. The second increment pump modules (one module per plant) would lag the first by one year.

7.0 HIGH-PRESSURE PIPELINES

FUNCTIONAL DESCRIPTION

The high-pressure pipeline system would transfer seawater from the injection plants to the intermediate manifolds and would distribute produced and seawater from injection plants and intermediate manifolds to the well pads. The design flow rate for each line would be based on the total volume required for injection at each well pad. The system design operating pressure would be based on wellhead injection pressure of 2700 lb/in^2.

FACILITY DESCRIPTION

The high-pressure pipeline system would consist of:

- transfer lines from the injection plants to the intermediate manifolds.
- distribution lines from the intermediate manifolds to the well pads.
- well lines from the well pad manifolds to the individual wells.

The high-pressure pipeline routes would follow existing (by 1984) pipeline corridors as shown in Figure B-15. The total length of high-pressure pipelines would be approximately 160 km (99 mi), ranging in size from 15.2 - 61 cm (6 - 24 in) diameter. All lines would be insulated for freeze protection. The pipelines would include

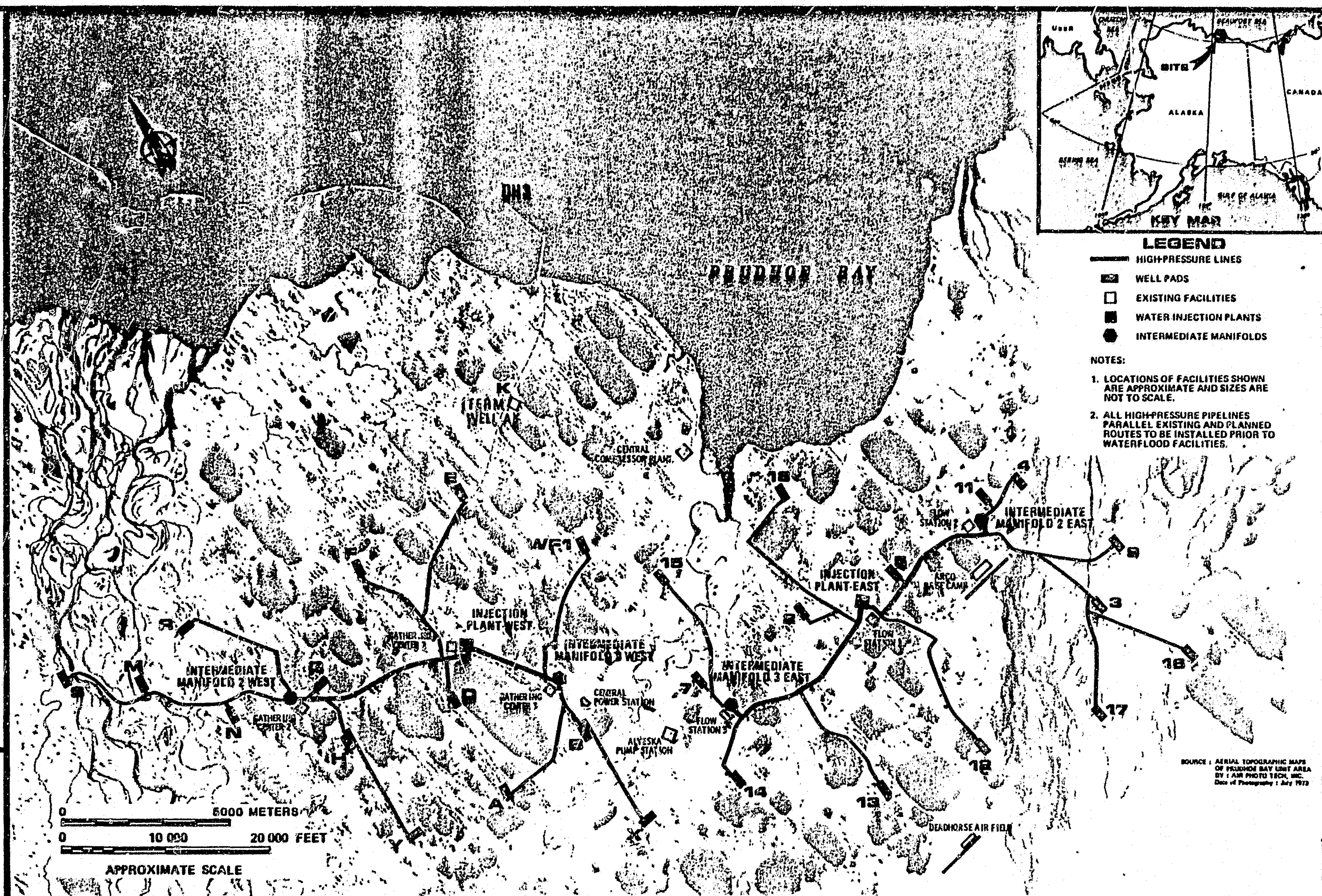


Figure B-15

PROPOSED HIGH-PRESSURE PIPELINE ROUTE MAP

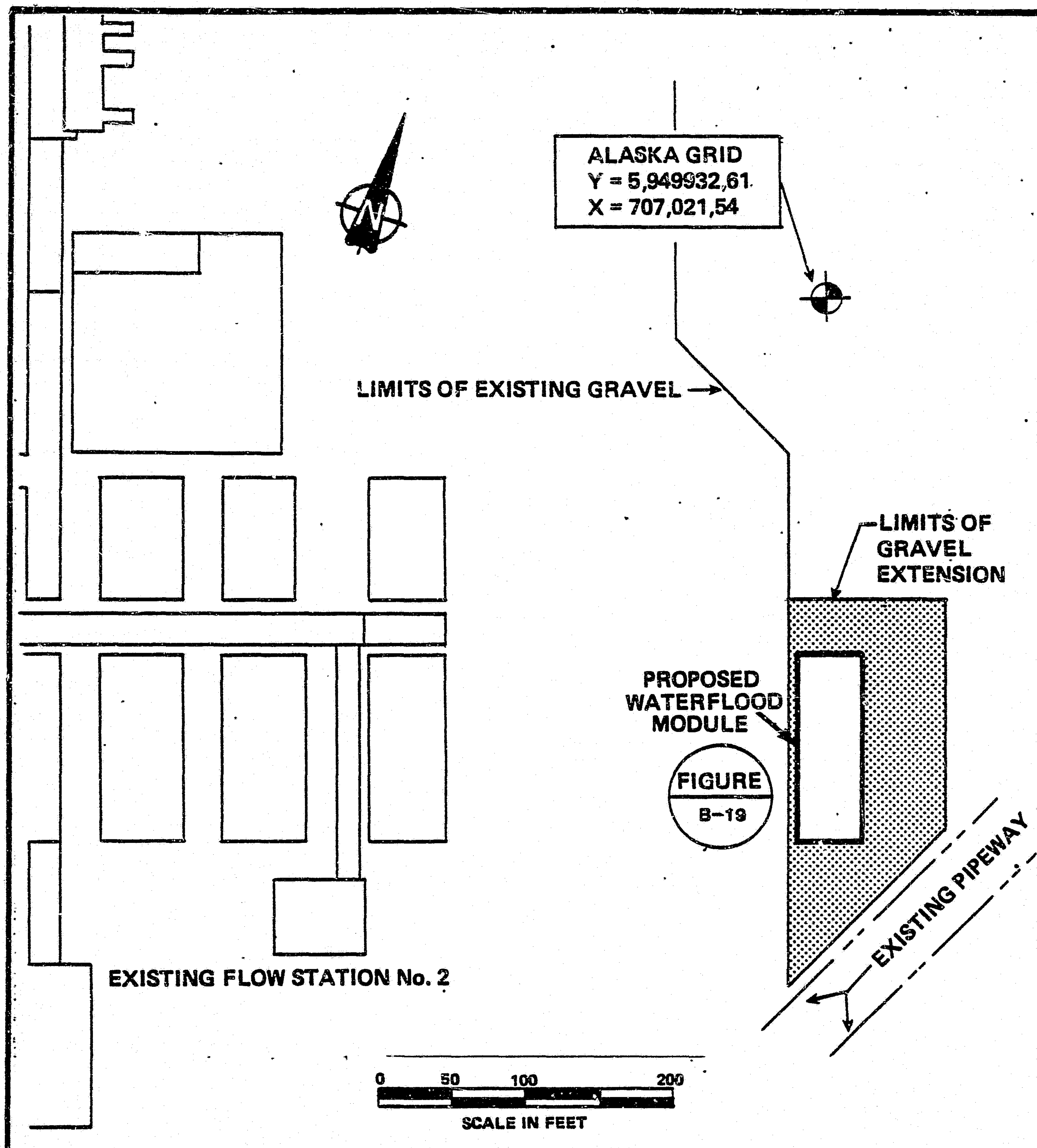
anchors and expansion loops to accommodate thermal movements. All pipelines would be installed above ground, supported on pile bents. The clearance between the tundra and the bottom of the pipelines would be sufficient to avoid thermal degradation of the permafrost. The new lines would be incorporated into existing crossings for caribou. Where lines are not already present, caribou passage would be accommodated.

The intermediate manifolds would be located at Gathering Centers 2 and 3 on the west side and Flow Stations 2 and 3 on the east side as shown in Figures B-16 through B-19. Each intermediate manifold would consist of a module housing manifold piping and pipeline freeze protection equipment as shown typically in Figure B-20. The manifold modules (about 14.3 x 39.6 m, 47 x 130 ft) would be elevated above ground and supported on piles. The clearance between the bottom of the modules and the top of the gravel pads would be sufficient to avoid snow pile-up and to allow for maintenance.

CONSTRUCTION

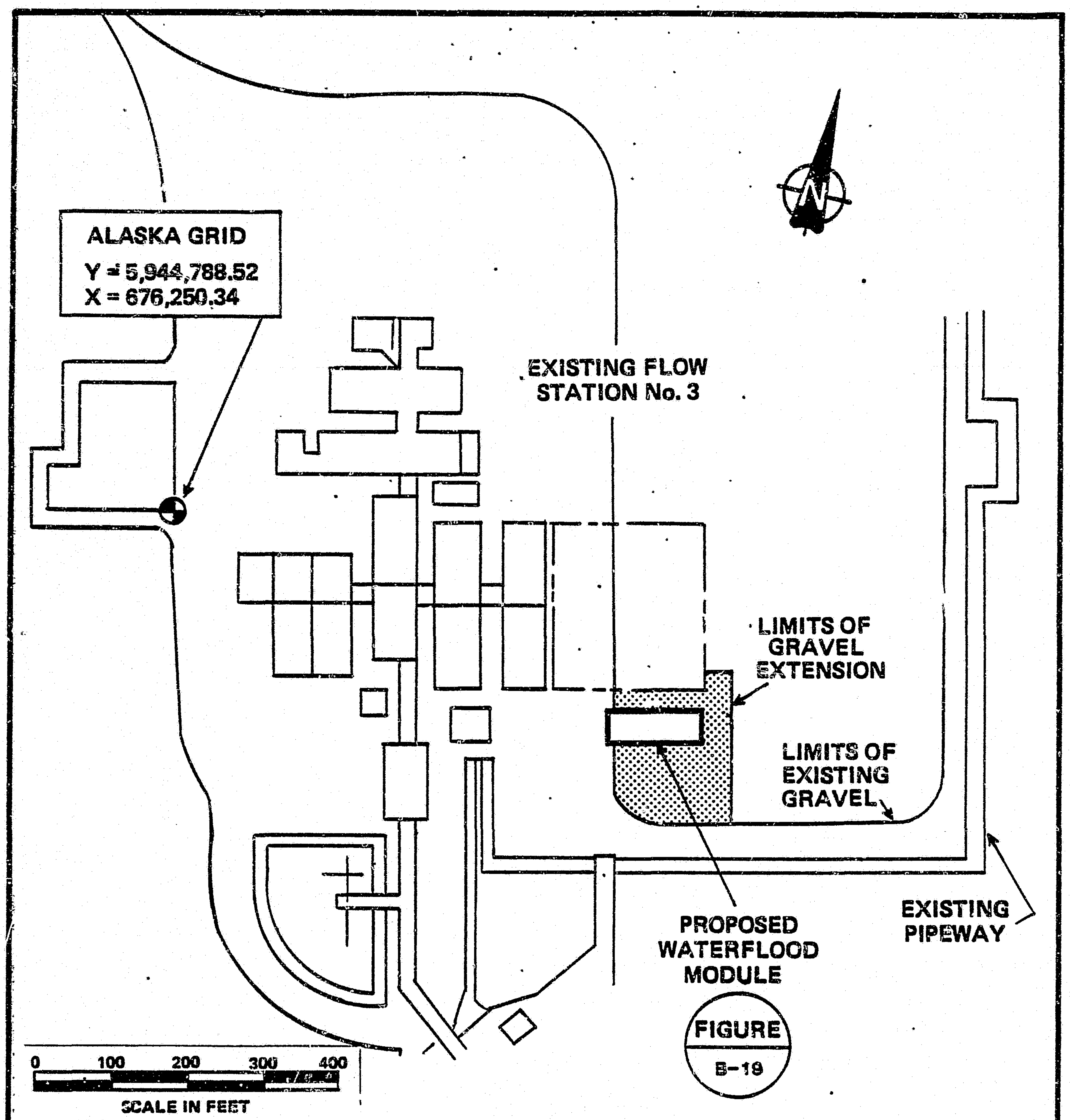
The lines would be installed in two construction increments. The majority of the pipeline materials would be sealifted or trucked to Prudhoe Bay during 1982 and 1983 for the first and second construction increments, respectively. The intermediate manifolds would be prefabricated in the Lower 48 and shipped to Prudhoe Bay on barges in 1983 and 1984. Installation of the first increment would commence in the fall of 1982 and the second would begin one year later. Increment I would be completed in 1984 and Increment II in 1985.

The pipelines would be constructed using snow or gravel pads in the winter and gravel pads in the summer. Existing gravel pads and roads would be utilized, except for the short extension to Well Pad WF-1 from the existing gravel pad parallel to the west side gas line to the CCP.



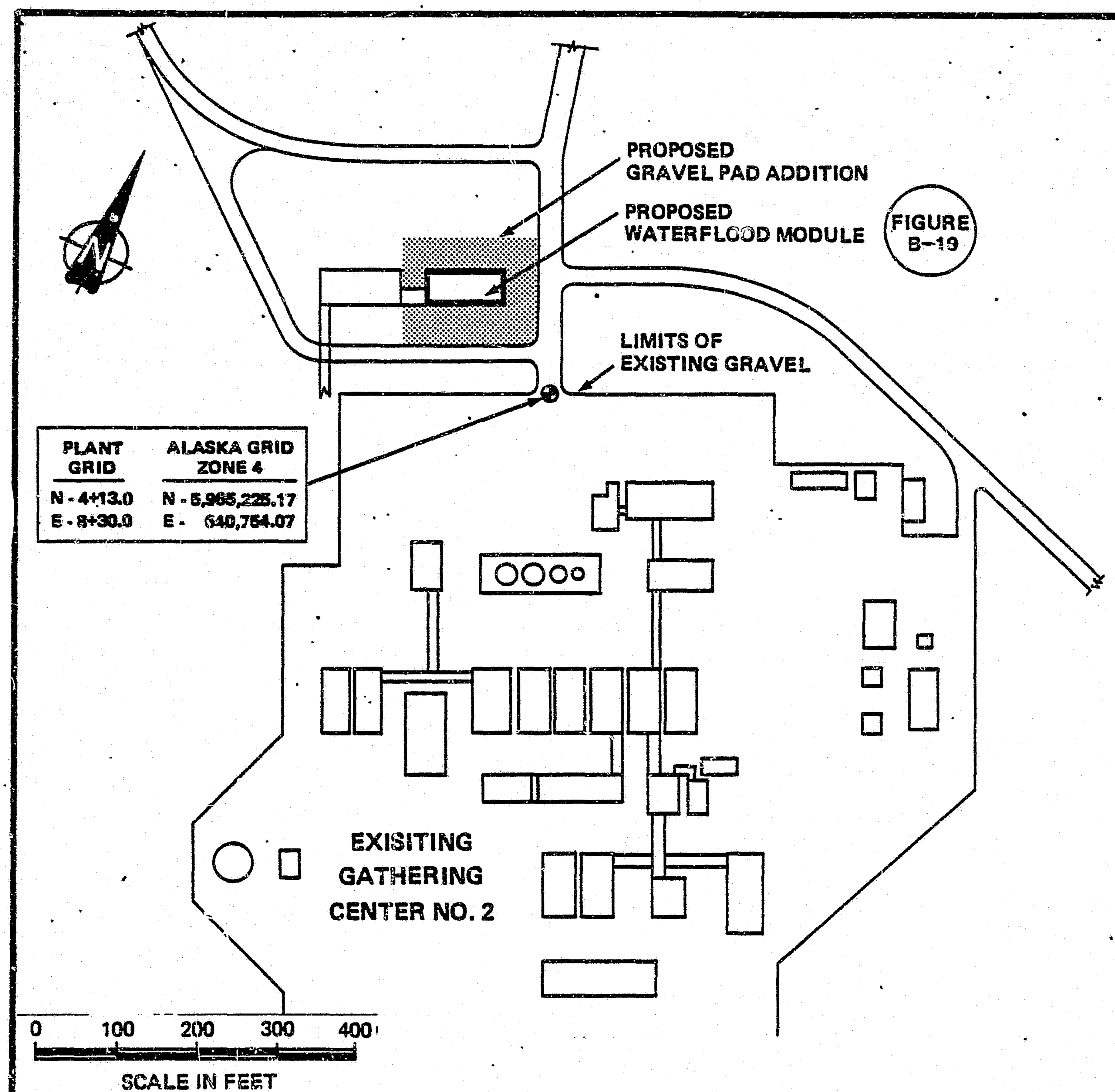
PROPOSED INTERMEDIATE MANIFOLD 2 - EAST
LOCATION PLAN

PBU Waterflood Environmental Impact Statement | Figure B-16

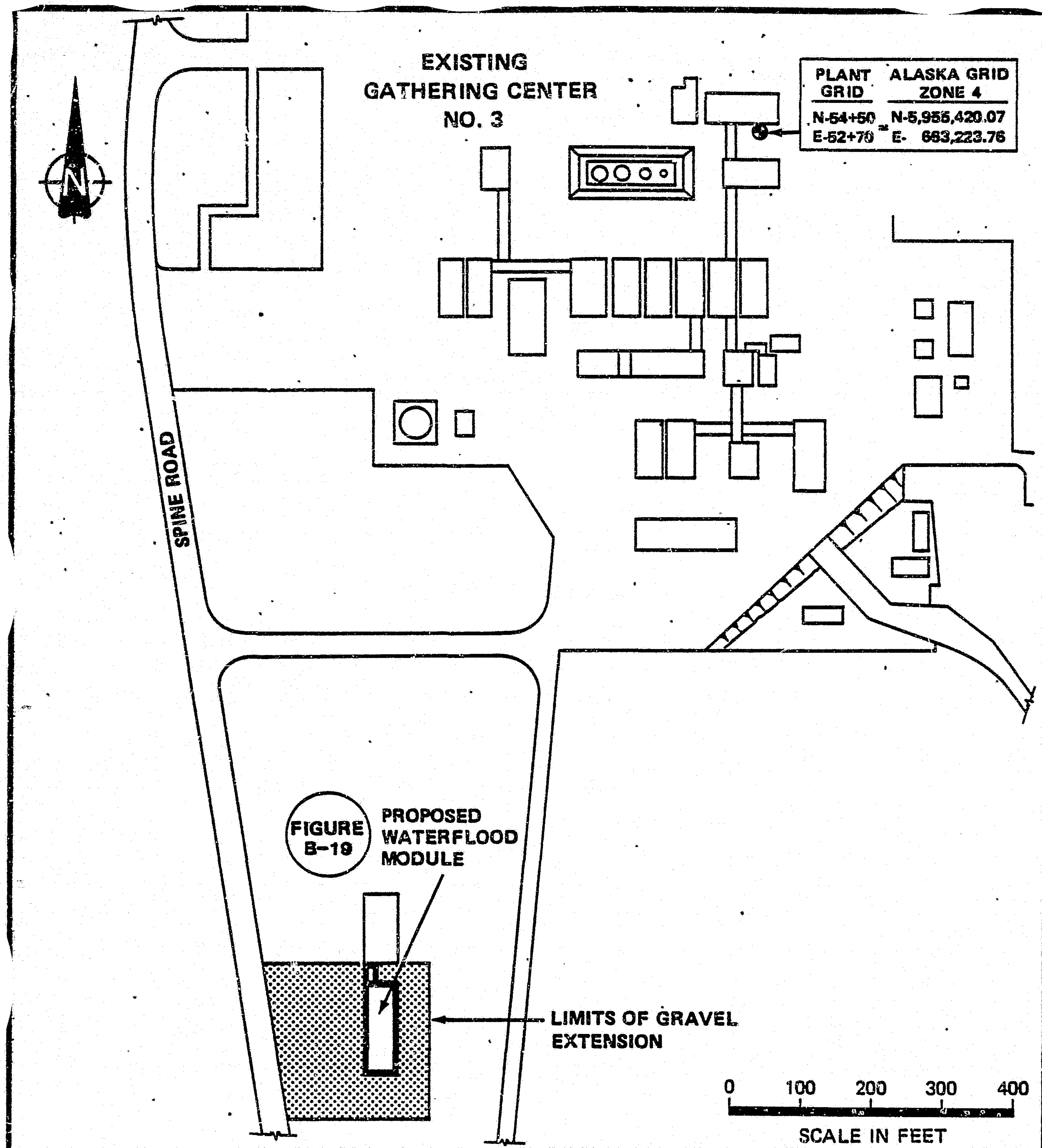


PROPOSED INTERMEDIATE MANIFOLD 3 – EAST
LOCATION PLAN

PBU Waterflood Environmental Impact Statement	Figure B-17

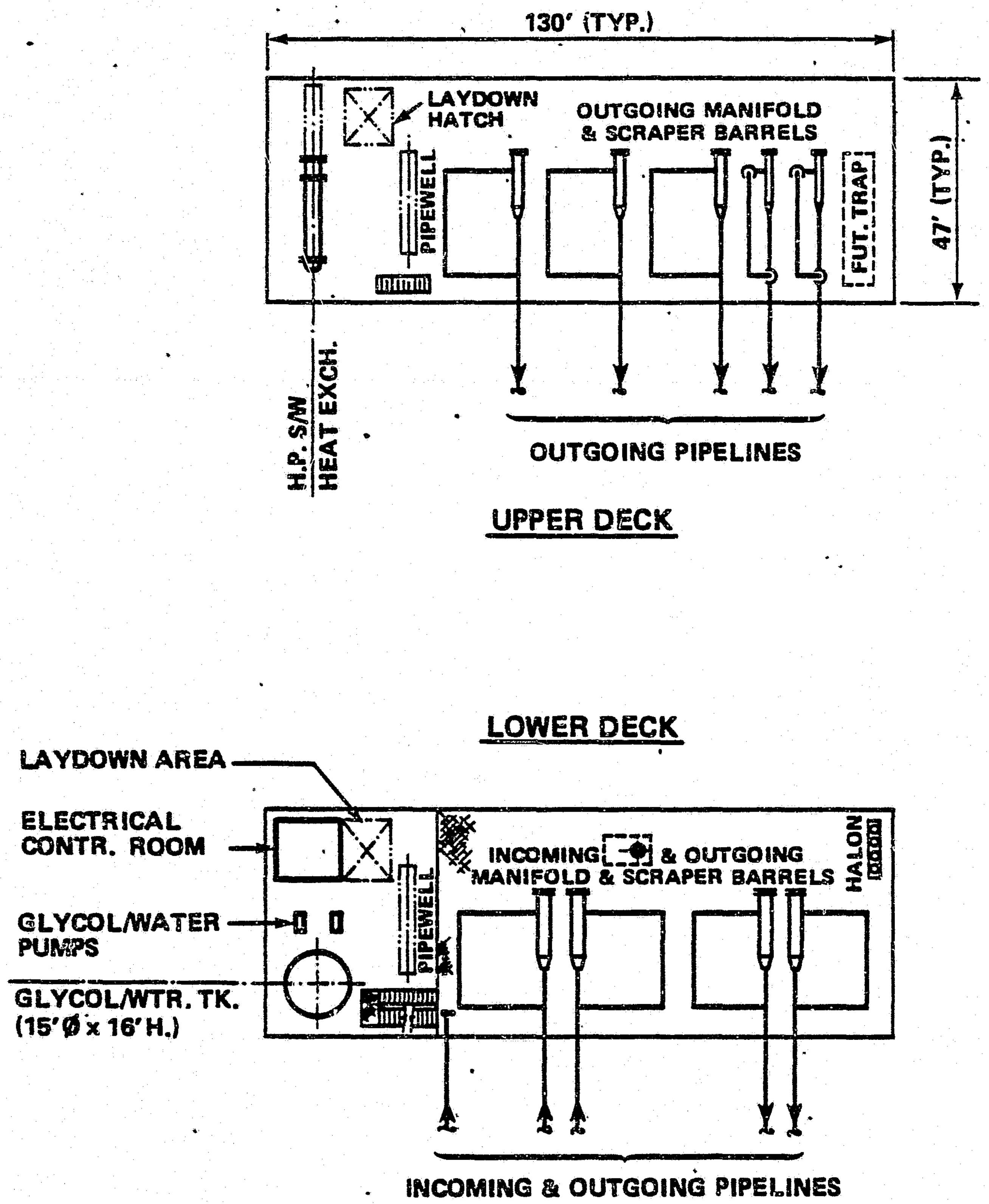


PROPOSED INTERMEDIATE MANIFOLD 2 - WEST
LOCATION PLAN



PROPOSED INTERMEDIATE MANIFOLD 3 - WEST
LOCATION PLAN

PBU Waterflood Environmental Impact Statement	Figure B-19



PROPOSED INTERMEDIATE MANIFOLD (TYP.) FACILITY LAYOUT

PBU Waterflood Environmental Impact Statement	Figure B-20

8.0 INJECTION SITE FACILITIES

FUNCTIONAL DESCRIPTION

The injection site facilities would receive high-pressure water from the incoming line(s) and distribute it to the injection wells. Monitoring and control facilities would be incorporated for flow and pressure to individual wells. Facilities would also be included to protect the well lines and wells from freezing in case of a shut-down. The design wellhead injection pressure would be 2700 lb/in^2. The injection facilities would be incorporated into the existing production site facilities wherever possible.

FACILITY DESCRIPTION

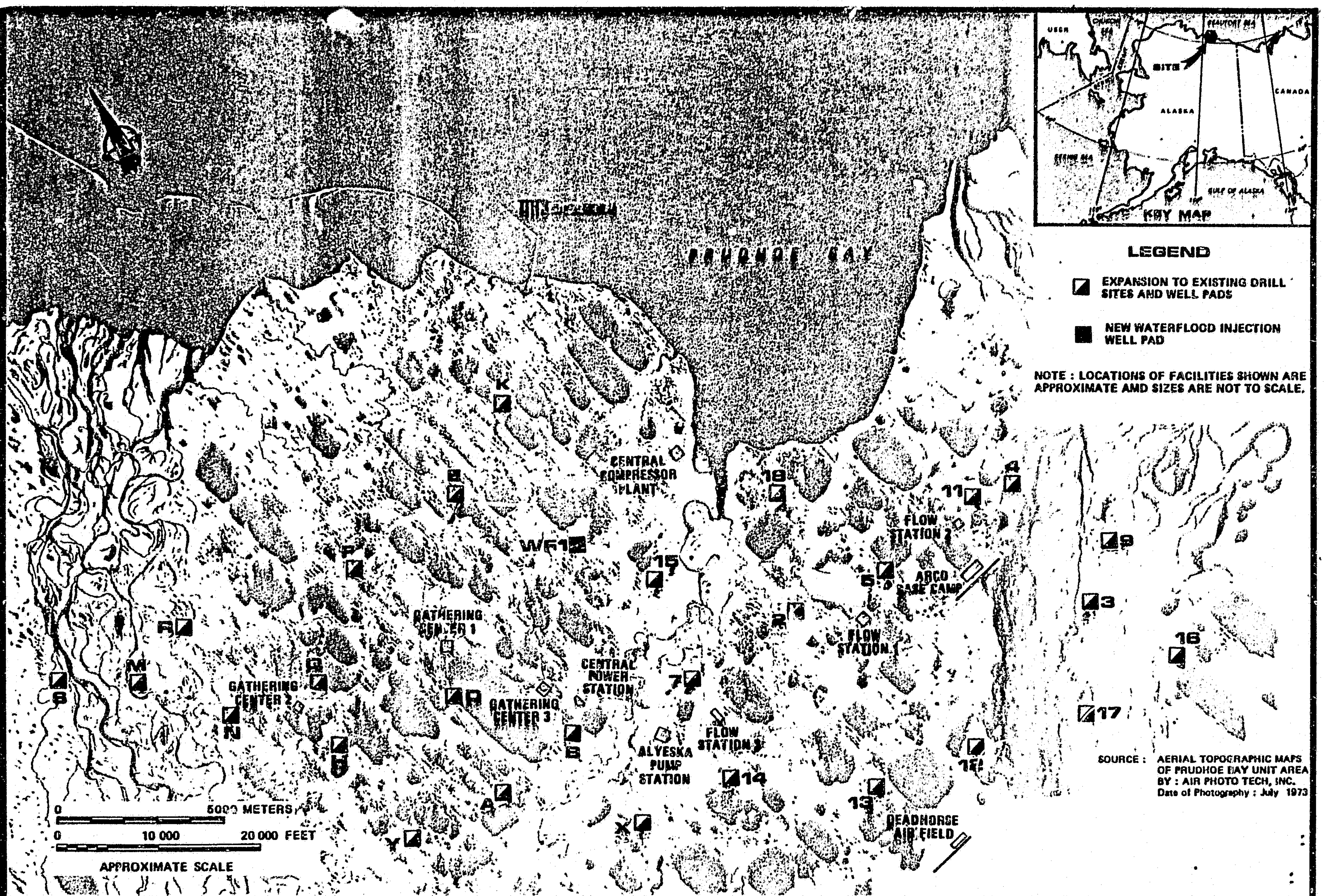
There would be approximately 28 injection sites, 14 on the east side and 14 on the west side of the field, as shown in Figure B-21. One new injection pad would be required, designated WF-1 on Figure B-21. The total number of injection wells would be approximately 154. The wells would either be converted producing wells or new injection wells.

Each injection site facility would consist of a well pad module containing piping and freeze protection equipment as shown typically in Figures B-22 and B-23. Water would be received at each injection site and distributed to the injection wells through 15.2-cm (6-in) or 20.3-cm (8-in) diameter lines. A choke on each injection well line would control injection rate and pressure. Flow to each well would be measured in addition to the total flow to that site.

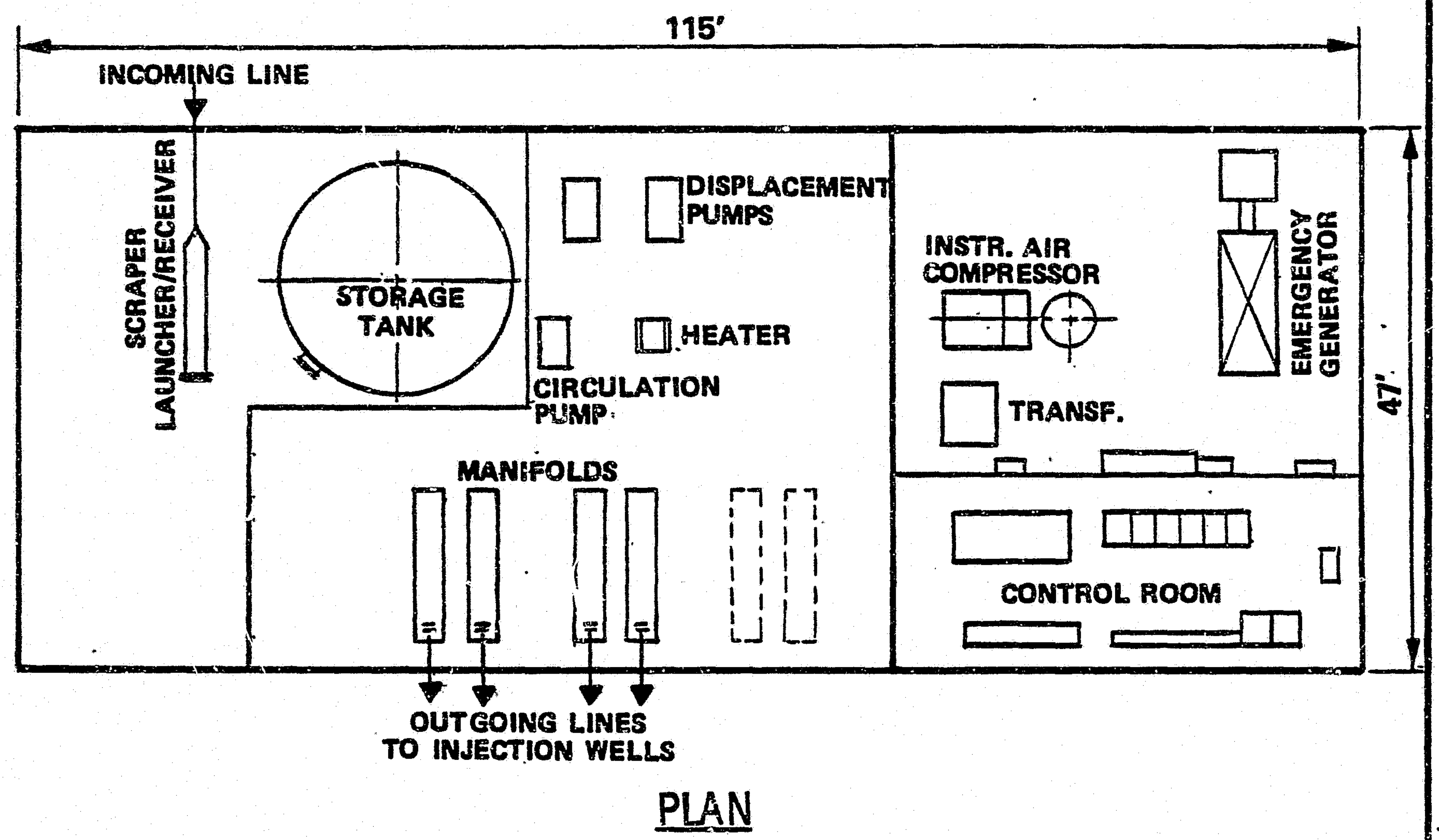
All well lines outside the modules would be insulated and installed above ground on pile bent supports. Individual wellheads would be enclosed inside separate heated wellhead houses. Each injection site facility would be provided with an emergency dump pit.

PBU Waterflood Environmental Impact Statement

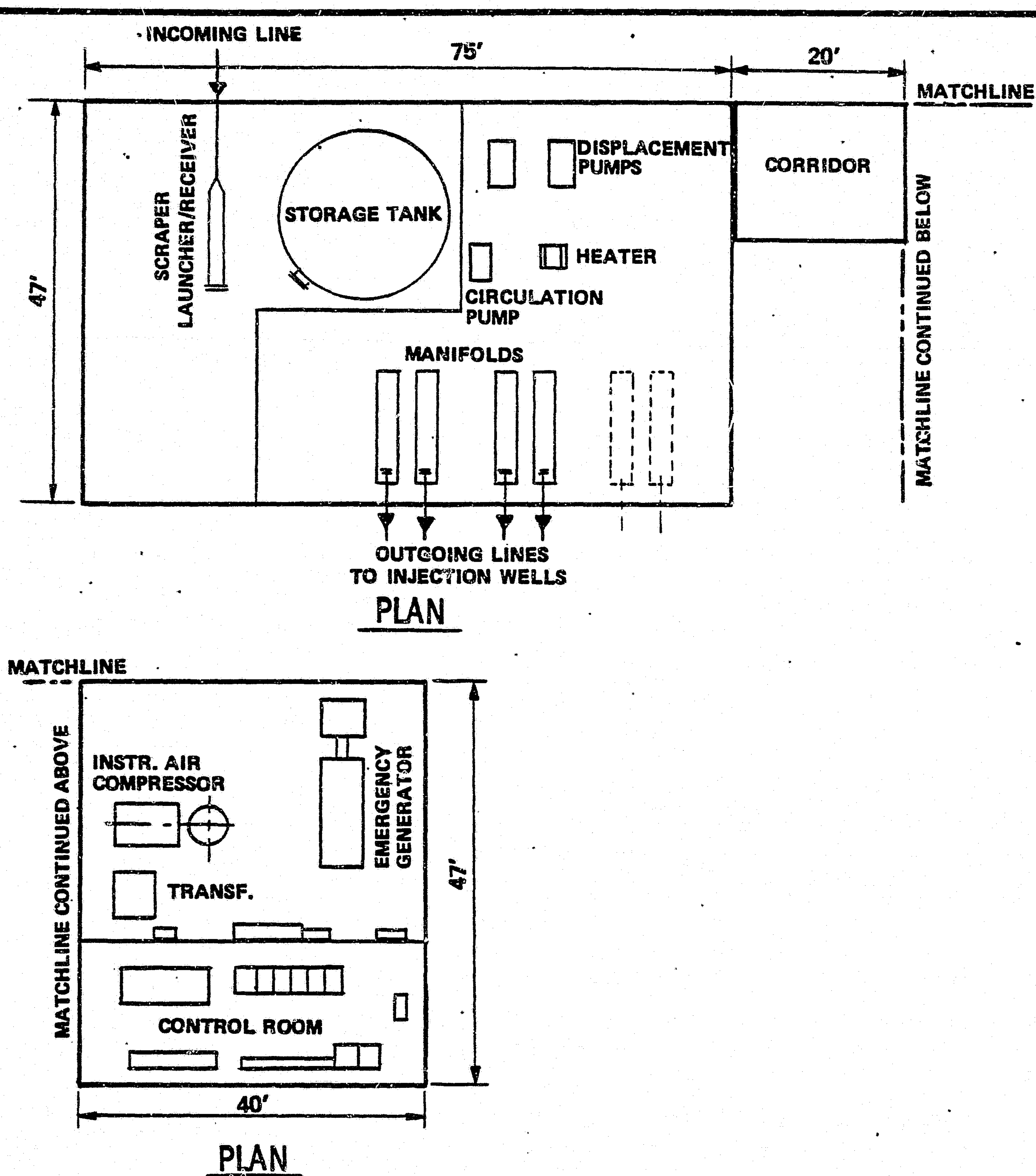
Figure B-21



OVERALL DRILL SITE BANDWELL PAD LOCATION MAP



PROPOSED INJECTION WELL PAD MODULE (TYP.) – EAST FACILITY LAYOUT



PROPOSED INJECTION WELL PAD MODULE (TYP.) – WEST FACILITY LAYOUT

PBU Waterflood Environmental Impact Statement | Figure B–23

CONSTRUCTION

The injection site facilities would be installed in two construction increments. The required well pad modules would be fabricated in the Lower 48 and shipped by barge to Prudhoe Bay. Increment I would be completed in 1984 and Increment II in 1985.

Increment I	Well Pads Numbers	3, 4, 5, 7, 9, 11, 13, 14, 15,17, A, B, D, F, H, M, N, Q, R, S, X
Increment II	Well Pads Numbers	2, 11*, 12, 13*, 14*, 15, 17*, 18, A*, E, H*, N*, X*, Y, WF-1

New construction will involve the work pad for the WF-1 injection site (approximately 305 m x 91 m, 1000 ft x 300 ft). The exact size cannot be determined until the total number of wells required is determined, based on some waterflood operating history.

No new road would be needed to the WF-1 injection site since it could be approached by the existing work pad for the gas line between the CCP and Gathering Center 3. A short entrance road would be required, but has not been designed in detail. Gravel quantity would be minimal.

No new pipeline pad would be required. The high-pressure lines to WF-1 would be constructed from the pad described above.

9.0 RELATED SYSTEMS

FREEZE PROTECTION

Seawater obtained from the Beaufort Sea, at about -1.7°C (29°F) in the winter and 1.1°C (34°F) in the summer, would require heating to allow field-wide distribution and well injection without freezing. Produced

* Note: Indicates expansion of Increment I

water would enter the waterflood system at elevated temperature and would not require additional heat during normal operations. The freeze protection system would thus be required to protect the water pipelines and injection wells from freezing during original start-up, normal and reduced flow operation, and shut-down/restart.

The primary freeze protection scheme would utilize inherent or added heat. Pipelines would be insulated to maintain the water temperature above freezing during transit and provide an acceptable time period between shut-down and freezing. Emergency power supplies and diesel fuel back-up for heaters and turbines would be provided to maintain a sufficient flow of heated water to prevent freezing during electrical or fuel gas failures.

Conversion of flow from produced water to seawater, or vice-versa, would be possible in transfer and distribution pipelines if the supply from one source were lost. In those portions of the waterflood system where parallel lines exist, it would be possible to circulate heated water when supply is lost.

In the unlikely event that all of the above methods should fail for an extended period, all or part of the waterflood pipeline system would require evacuation. The injection wells would be protected by displacement below permafrost level with a nonfreezing fluid.

During normal operation, heat would be added at the seawater treating plant and injection plants. During reduced flow conditions, the seawater would also be heated at the intermediate manifolds utilizing glycol/water heat medium from the existing production centers. Fired heaters utilizing deaerator waste gas would be the primary heat source at the seawater treating plant. Waste heat recovery from the injection pump turbine drivers would provide for primary heat source at the injection plants with fired heaters as a standby heat source. The added heat would compensate for water cooling during transit and would provide the following reaction times between shut-down and commencement of freezing during normal operations when ambient temperature is -48.3°C (-55°F).

	Discharge Temperature	Reaction Time
Seawater Treating Plant to Injection Plants	4.4°C (40°F)	66 hours
Injection Plants to Intermediate Manifolds	8.9°C (48°F)	24 hours
Intermediate Manifolds to Well Pads	8.9°C (48°F)	16-36 hours

Shut-downs exceeding these reaction times may be tolerated if a higher ambient temperature prevails. In the event these times are approached and the previously described systems fail, the pipelines would be displaced with gas.

A batch of nonfreezing fluid would be introduced at the gas/liquid interface to prevent ice formation of any water bypassing the displacement pig. Displacement of the system would be as follows:

- Between the injection plants and seawater treating plant, water would be displaced toward the treating plant. Displaced water would be redistributed in the event of a single line evacuation. If both lines are to be evacuated, displaced water would be directed to the outfall line and discharged to the Beaufort Sea.

- Between the injection plants and seawater treating plant, water would be displaced toward the treating plant. Displaced water would be redistributed in the event of a single line evacuation. If both lines are to be evacuated, displaced water would be directed to the outfall line and discharged to the Beaufort Sea.

- Between the intermediate manifolds and the injection plants, the water would be displaced toward the injection plants where it would be diverted to the low-pressure side of the plant for redistribution.

- Between the intermediate manifolds and the well pads, the water would be displaced into the injection wells. In addition, the water would be displaced into emergency dump pits at each well pad. The emergency dump pits would be utilized only when all other alternatives had been exhausted.

Contents of the low-pressure pipelines would be discharged from the system as liquid effluent via the main outfall line, in the unlikely event that evacuation of pipelines by displacement of water with a gas is required for freeze protection. Water evacuated from high-pressure pipelines between the injection plants and intermediate manifolds would be displaced toward the injection plants where it would be diverted to the low-pressure side of the plant for redistribution in other high-pressure pipelines. Water displaced from high-pressure pipelines between the intermediate manifold and the well pad would be displaced into emergency dump pits provided at each well pad when alternative displacement into injection wells has been exhausted. The pits would be pumped out during the summer thaw period and the effluent disposed of at existing liquid waste disposal facilities.

For start-up after displacement, the pipelines would be preheated with warmed gas before introducing injection water. A heated methanol/water start-up batch would be utilized to warm the well lines and wells. Any gas used for displacement or warm-up would be captured in the existing oil production systems.

One central methanol/water storage tank would be located near each injection plant to re-fill the individual small tanks at the well pads.

FUEL GAS

Fuel gas would be required for building and process heaters at the injection plants and at the seawater treating plant. Fuel gas would also be required for injection pump turbine drivers, for oxygen stripping in the seawater treating plant deaerators, and for line evacuation. The existing distribution system would service the injection plants, requiring only appropriate tie-ins at each facility. A new 30.5-cm (12-in) fuel gas supply line would be provided for the seawater treating plant. This pipeline would run from the CCP above ground on pile bents, parallel to the eastern low-pressure seawater supply pipeline, to the shore end of the causeway and would be installed concurrently with that line. The offshore portion would be buried in the causeway modification and extension and would be installed with the other buried pipelines.

POWER

Waterflood electric power of approximately 45 megawatts would be generated by the permitted capacity in the central power station. The waterflood facilities would operate at a medium-voltage level of 4160V and a low-voltage level of 480V. The existing electric distribution systems would serve the injection plants, intermediate manifold modules, well pad modules, and wellheads with the addition of substations and secondary line extensions. A new 69 kV distribution line would be required from the CCP to the seawater treating plant. In addition to this field-connected power source, the individual facilities would be provided with emergency backup generators as required for life support and freeze protection systems.

PRESSURE VESSELS

Specifications on the pressure vessels for various waterflood facilities are provided in Table B-3. These are subject to change with better definition in detail design.

TABLE B-3

TYPICAL PRUDHOE BAY UNIT WATERFLOOD PRESSURE VESSELS

SEAWATER TREATING PLANT

SERVICE	TYPE	SIZE	OPERATING PRESS. PSIA	MATERIAL	No. REQ'D
Deaerator	Vert.	16 ft Dia. x 68 ft	0.5 Norm. 20 max.	Coated Carbon Steel	8
Seal Liquid Separator	Vert.	2 ft Dia. x 10 ft	20	Fiberglass	8
Expansion Tank	Horiz.	10 ft Dia. x 30 ft	15	Coated Carbon Steel	1
Flash Tank	Vert.	7 ft Dia. x 20 ft	75	Coated Carbon Steel	1
Fuel Gas K.O. Drum	Vert.	5 ft Dia. x 8 ft	35	Coated Carbon Steel	1
Scour Air K.O. Drum	Vert.	3 ft Dia. x 9 ft	15	Coated Carbon Steel	1
Condensate Recovery	Horiz.	3 ft Dia. x 8 ft	20	Coated Carbon Steel	1
Air Receiver	Vert.	6 ft Dia. x 10 ft	140	Coated Carbon Steel	1
Filters	Horiz.	10 ft Dia. x 30 ft	140	Coated Carbon Steel	32

EAST MANIFOLD MODULE

SERVICE	TYPE	SIZE	OPERATING PRESS. PSIA	MATERIAL	No. REQ'D
Gas Boot	Vert.	8 ft Dia. x 24 ft	65	Coated Carbon Steel	1
H.P. Heat Exchanger	Horiz.	1 ft Dia. x 10 ft	3015	Coated Carbon Steel	1
Gas Heat Exchanger	Horiz.	4 ft Dia. x 25 ft	615	Coated Carbon Steel	1
Fuel Gas K.O. Drum	Vert.	4 ft Dia. x 7 ft	465	Coated Carbon Steel	1
Fuel Gas K.O. Drum	Vert.	2 ft Dia. x 7 ft	165	Coated Carbon Steel	1

EAST HEATER/UTILITY MODULE

SERVICE	TYPE	SIZE	OPERATING PRESS. PSIA	MATERIAL	No. REQ'D
Heat Exchanger	Horiz.	5 ft Dia. x 26 ft	215	Coated Carbon Steel	1
Air Receiver	Vert.	6 ft Dia. x 10 ft	140	Coated Carbon Steel	1

WEST MANIFOLD MODULE

SERVICE	TYPE	SIZE	OPERATING PRESS. PSIA	MATERIAL	No. REQ'D
Gas Boot	Vert.	8 ft Dia. x 24 ft	65	Coated Carbon Steel	1
H.P. Heat Exchanger	Horiz.	1 ft Dia. x 10 ft	3015	Coated Carbon Steel	1
Gas Heat Exchanger	Horiz.	4 ft Dia. x 25 ft	615	Coated Carbon Steel	1
Fuel Gas K.O. Drum	Vert.	4 ft Dia. x 7 ft	465	Coated Carbon Steel	1
Fuel Gas K.O. Drum	Vert.	2 ft Dia. x 7 ft	165	Coated Carbon Steel	1

WEST HEATER/UTILITY MODULE

SERVICE	TYPE	SIZE	OPERATING PRESS. PSIA	MATERIAL	No. REQ'D
Heat Exchanger	Horiz.	5 ft Dia. x 26 ft	215	Coated Carbon Steel	1
Air Receiver	Vert.	6 ft Dia. x 10 ft	140	Coated Carbon Steel	1

PROJECT ABANDONMENT

Site-specific abandonment plans are not available. Pursuant to lease stipulations and existing regulations, PBU surface facilities (including waterflood related facilities) would be left in an acceptable condition.

APPENDIX C

PHYSICAL AND CHEMICAL OCEANOGRAPHY

1.0 INTRODUCTION

The marine area that may be affected by the Waterflood Project extends from the Sagavanirktok River delta to a point just east of the Colville River delta (Figure C-1) and from the shores of the Alaska Coastal Plain to just seaward of the Jones and Return Island groups. The major geomorphic features within this region include Prudhoe Bay, Simpson Lagoon, Gwydyr Bay, the islands of the Jones and Return groups, and the deltas of the Sagavanirktok and Kuparuk Rivers.

The first of the following sections describes the general geomorphological features found in the area, traces documented changes that these features have undergone, and describes the processes most likely responsible for these modifications. The next section describes the currents in the area, emphasizing the fact that the major currents are wind-generated. The third and fourth sections describe the wave climate in the Prudhoe Bay area and the phenomenon of storm surge that is primarily responsible for major changes in sea level off the north coast of Alaska. The fifth section describes water quality characteristics, including temperature, salinity, nutrients and trace element concentrations. The final section discusses the characteristics of the marine sediments with emphasis on chemical concentrations.

2.0 BATHYMETRY AND GENERAL GEOMORPHOLOGY

The study area is part of the Beaufort Sea continental shelf and inside the 6-m (20-ft) contour. Bathymetric data show Prudhoe Bay to have a basin-like character with depths in excess of 2.4 m (8 ft) in its central region (Figure C-2). A set of shoals, to 1 m (3 ft) and including several small islets, almost encloses Prudhoe Bay. A channel occurs on the northwest side.

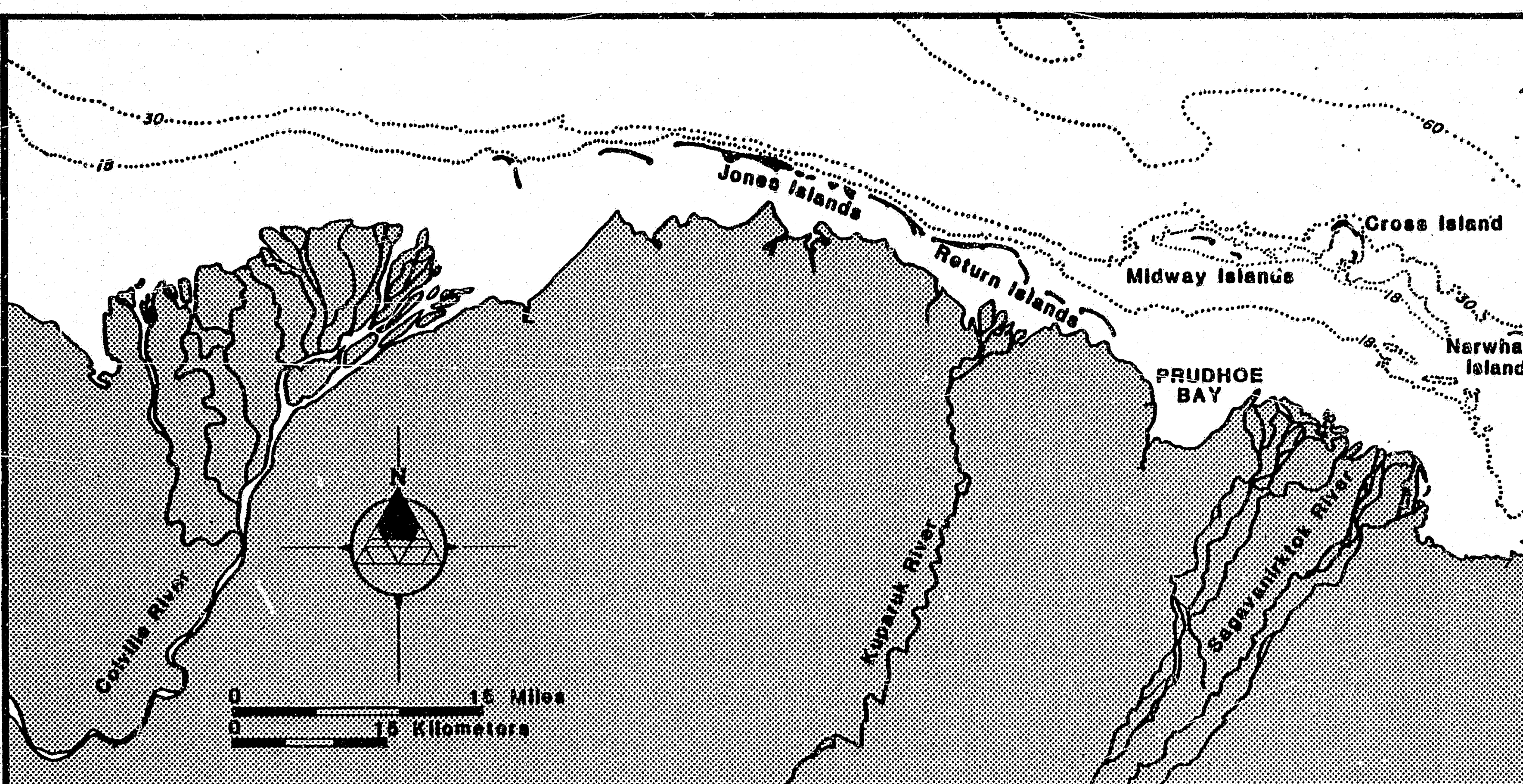


Figure C-1

REGIONAL BATHYMETRY (IN FEET) & LOCATION MAP

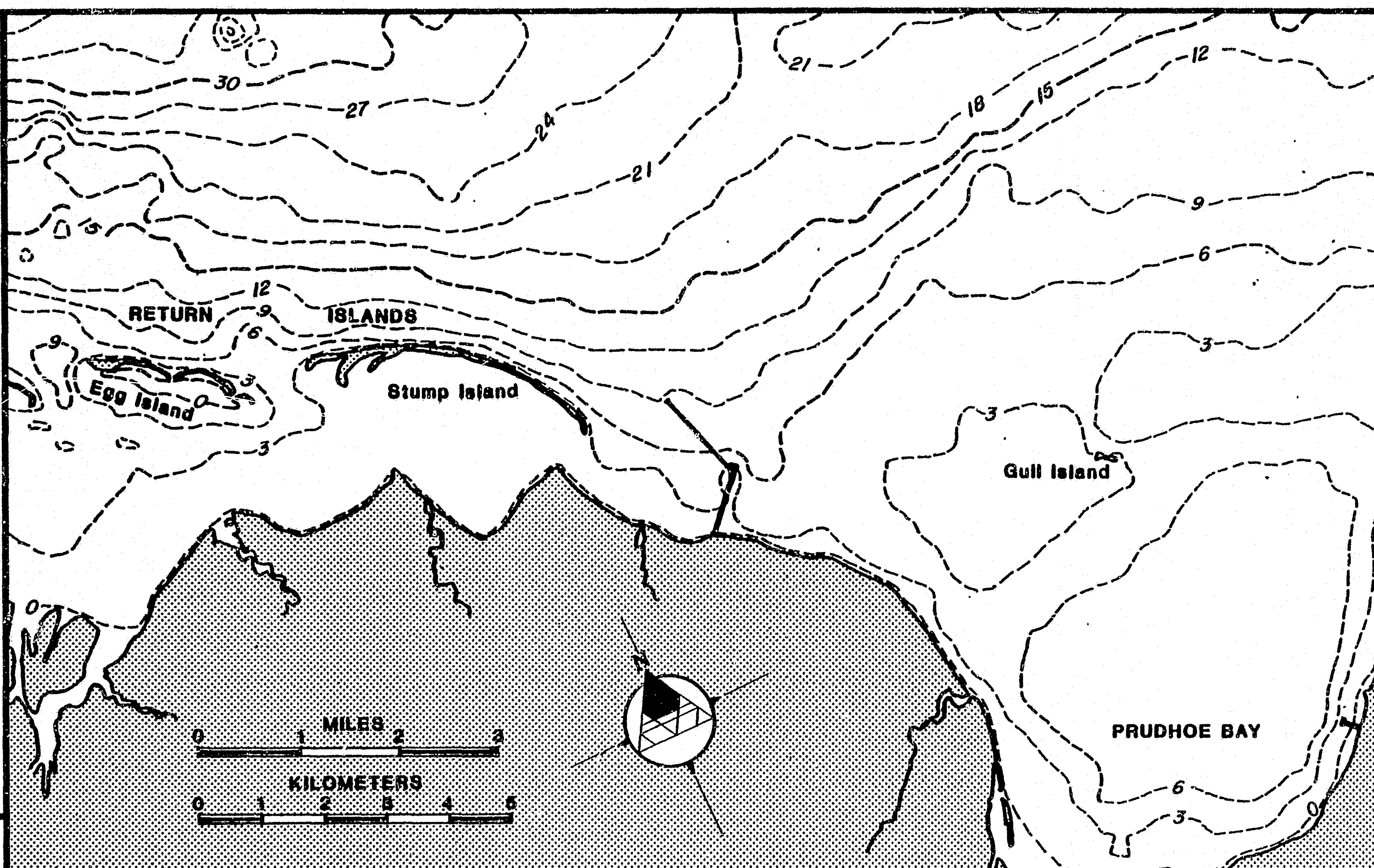


Figure C-2

PBU WATERFLOOD PROJECT STUDY AREA BATHYMETRY (IN FEET)

Simpson Lagoon and its eastern extension into Gwydyr Bay lies between the mainland coast and the barrier islands of the Jones and Return groups. The lagoon system is quite shallow, generally less than 2 m (6.5 ft) (Dygas 1975). Certain inlets entering Simpson Lagoon from the offshore region are considerably deeper; for example, Egg Island channel is over 5 m (16 ft) deep (Matthews 1979) and represents a major outlet for the Kuparuk River during the peak spring runoff. The deepest part of the lagoon generally coincides with its central axis, with shoaling toward both the mainland and barrier island coasts. Sediments in the central portion of the lagoon contain more than 50 percent mud, while closer to the shorelines, both north and south, sediments contain over 50 percent sand (Naidu 1978).

An important geomorphic feature is the chain of barrier islands extending from Harrison Bay east to Prudhoe Bay. In certain respects, these islands are quite different from barrier islands found in the Gulf of Mexico or on the southeast coast of the United States. Historically, barrier islands have been thought to be products of sediment transport from either offshore or longshore sediment sources. However, the origin of these arctic islands is uncertain since coarse clastic sediments of gravel size do not appear to be transported in the major river drainage systems (Cannon and Rawlinson 1978).

The western group of the arctic barrier islands is partially blanketed with tundra; sands and gravels make up the eastern islands. Boulders are present on the tundra-covered islands, but are noticeably absent from the sand and gravel islands (Naidu 1978). It is speculated that the tundra islands are relics of breached or drowned shorelines in which topographic lows behind the present islands became submerged leaving the islands as isolated features. The lack of tundra on the eastern islands may be indicative of a similar mode of formation with subsequent reworking by waves. Naidu (1978) suggests that ice processes may be responsible for obliterating boulders on the eastern islands. It may also be that these islands, during the course of wave alteration, have migrated (probably shoreward). This migration may not have been sufficiently intense to transport boulders. Isolated offshore boulder patches may be due to a similar process whereby the larger clasts are remnants of previous islands.

There is little doubt that the islands are elongating, predominantly through spit formation to the west. Estimates of rates of spit growth vary between 2 m/yr (6.5 ft/yr) (Naidu 1978) and 6 m/yr (19.5 ft/yr) (Wiseman et al. 1973). Their shoreline and nearshore features are continuously changing. The tundra-blanketed islands appear, at the present time, to be eroding from both the north and south sides (Cannon and Rawlinson 1978).

It is widely accepted that net littoral transport in this area is to the west. Several factors influence quantity, including the longshore flux of wave energy which may encompass many of the wave and beach parameters, and the quantity of material available for transport. Beach morphology is also crucial in directing energy flux, as observed by Dygas and Burrell (1975). They measured mean longshore currents of 7.5 cm/s (2.9 in/s) and 58 cm/s (1.9 ft/s) on the west and east sides of Oliktok Point, respectively. Both currents were directed toward the seaward extension of that headland.

Much of the sediment being transported as littoral drift is derived from the erosion of both mainland and barrier island coasts. Using aerial photographs, Burrell et al. (1975) assessed long-term changes from immediately west of Oliktok Point east to Beechey Point. Observed shoreline recession rates ranged between < 1.0 m/yr (3.2 ft/yr) and > 4.5 m/yr (14.7 ft/yr). Similarly, Cannon and Rawlinson (1978) found erosion rates from the barrier islands to vary 1.4 - 2.0 m/yr (4.5 - 6.5 ft/yr). They observed lower rates on higher topographic areas with the mainland sides of the barrier islands eroding more rapidly than seaward sides. They suspected that this was due to dune protection and reduced thermal erosion processes on the seaward coastline. It is also possible that the seaward side may go through cycles of erosion and accretion that reduce net erosional effects on the exposed side.

Several littoral drift estimates have been made at specific areas on the Beaufort coast (Hume and Schalk 1967, Kinney et al. 1972, Dygas and Burrell 1975). More recent estimates of drift rates have been made by Grider et al. (1978). Through volumetric estimates on the east side of the West Dock, they determined an annual accumulation of 1000 m^3/yr (1308 yd^3/yr). Possibly one-third of this material came directly from the degradation of the dock itself; therefore, the actual drift rate may be significantly lower than this accumulation rate.

Barnes et al. (1977) examined changes in morphology between 1950 - 1976 (Figure C-3) and found several noteworthy differences:

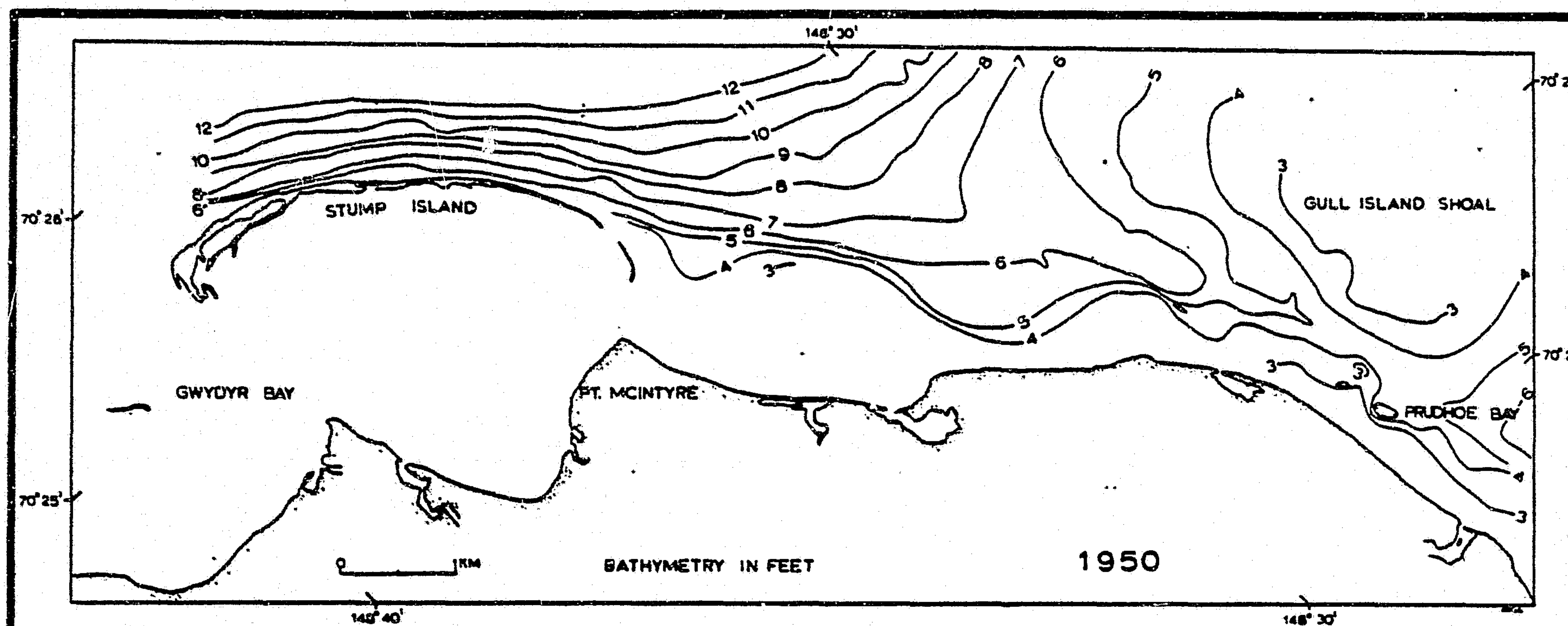
- The channel on the western side of Prudhoe Bay migrated shoreward from 50 - 176 m (164 - 577 ft).

- A shoal developed between the east end of Stump Island and the causeway.

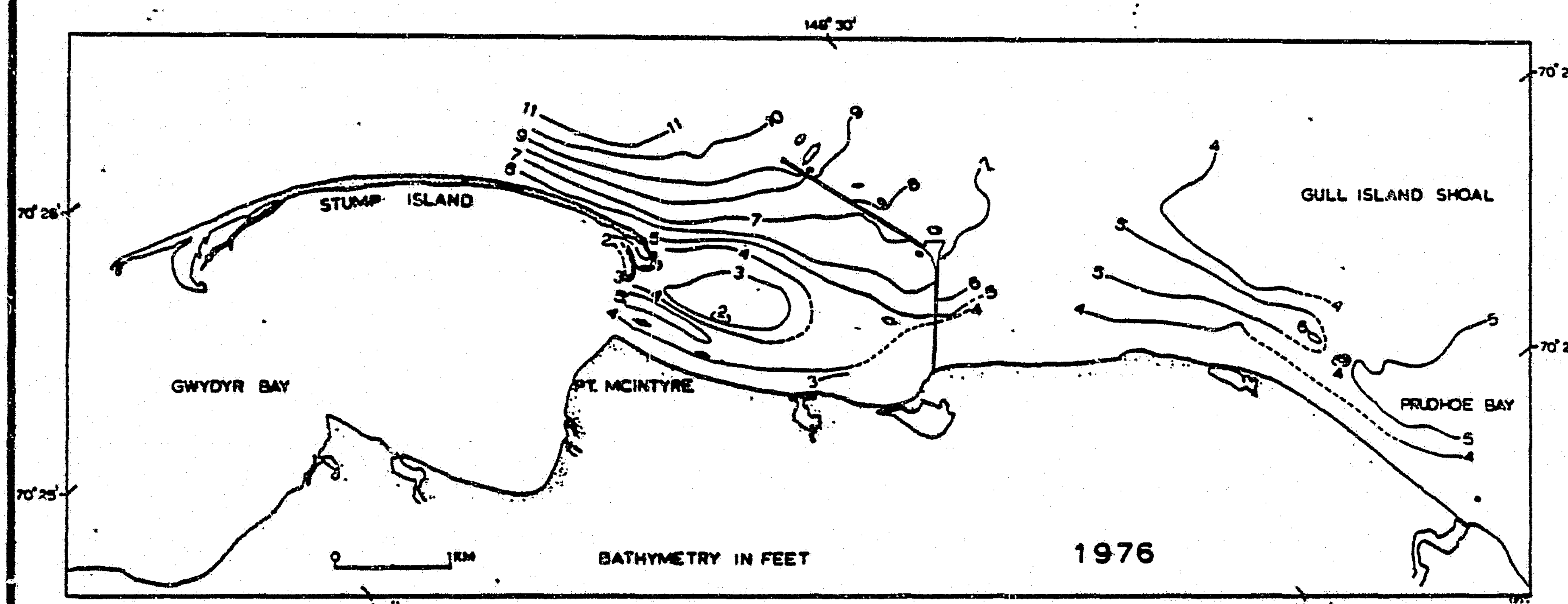
- Stump Island grew both to the east and to the west and increased in area as well.

- Between 1950 - 1970, Stump Island migrated 75 - 200 m (246 - 656 ft) shoreward.

It appears that coastal processes change the morphology of this portion of the arctic coast more slowly than other shorelines of the world with similarly low relief. However, rapid changes can and do occur. Barnes and Ross (1980) documented some major changes that occurred during a 9-day storm in September/October of 1979. The storm produced winds from the northeast and caused severe alterations to several of the barrier islands of the Midway group, a man-made island, and some changes to the present PBU causeway. Figure C-4 illustrates some of the changes that took place on the causeway and the artificial island of Niakuk III.



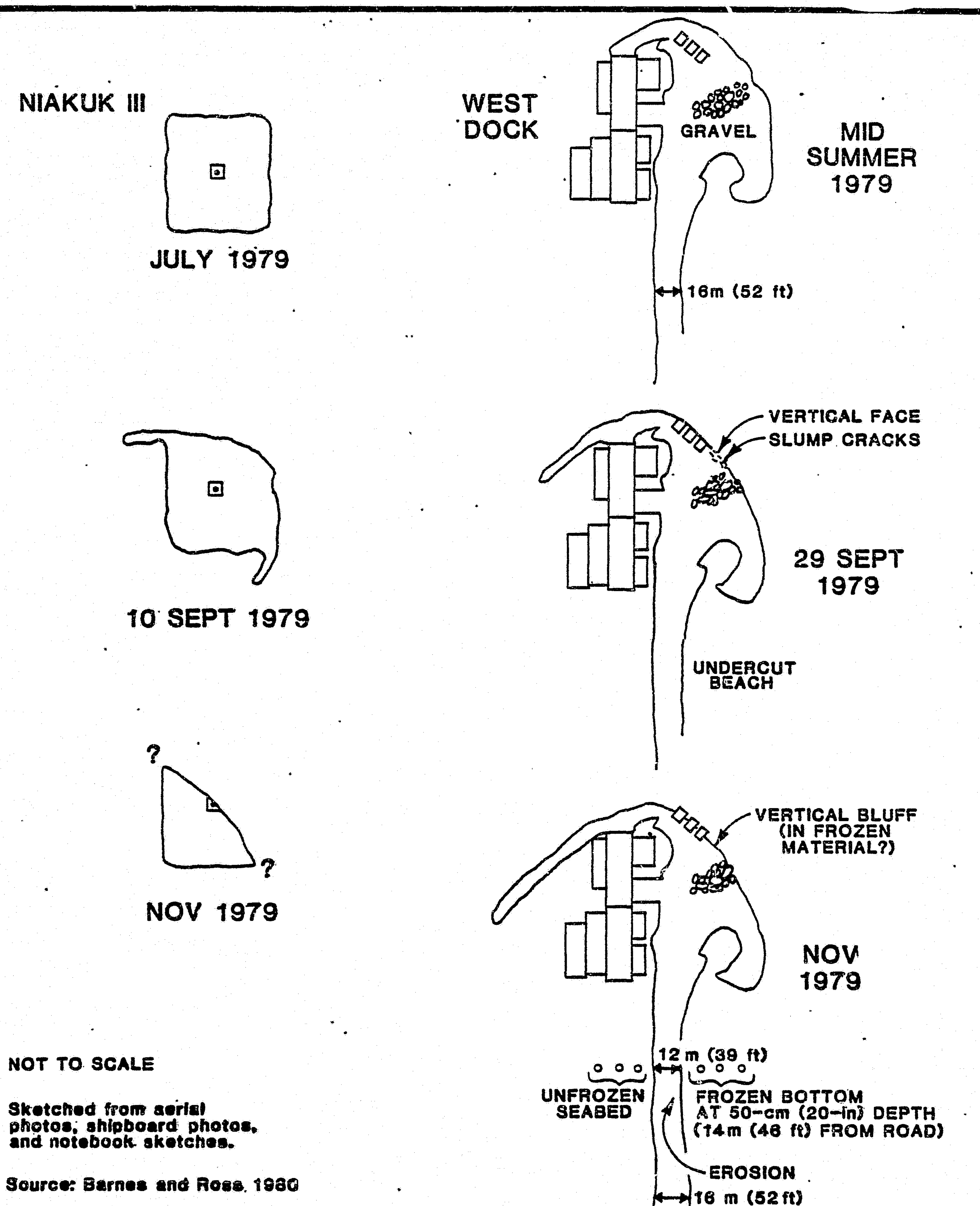
a. Bathymetric contours at 1-ft (0.5m) intervals and landforms from the 1950 survey, U.S. Coast and Geodetic Survey smooth sheet 7857.



b. Bathymetric contours at 1-ft (0.3m) intervals from the 1976 U.S. Geological Survey, KARLUK data. Landforms from June 26, 1970 aerial photography for U.S.G.S. orthophotomap of Beechey Point B-4 NW. The inner causeway segment was constructed in spring 1975 and the outer segment in the winter of 1975-76.

Source: Barnes et al. 1977

STUMP ISLAND MIGRATION



DIAGRAMATIC REPRESENTATION OF THE SEQUENTIAL EROSION OF THE HEAD OF WEST DOCK & THE ARTIFICIAL ISLAND NIAKUK 3

PBU Waterflood Environmental Impact Statement	Figure C-4

Several unanswered questions remain concerning morphology as well as beach and nearshore dynamics in the Prudhoe Bay area including: the present status of the barrier island groups; the present sources and pathways of littoral drift and its variability along the coast; the relative effects of easterly and westerly wind systems on sediment changes and nearshore dynamics during average and abnormal years; the roles of the Sagavanirktok and Kuparuk Rivers in influencing coastal processes; and the role of sea ice in beach and nearshore processes. These unresolved questions make it difficult to evaluate some potential impacts from the proposed alternatives.

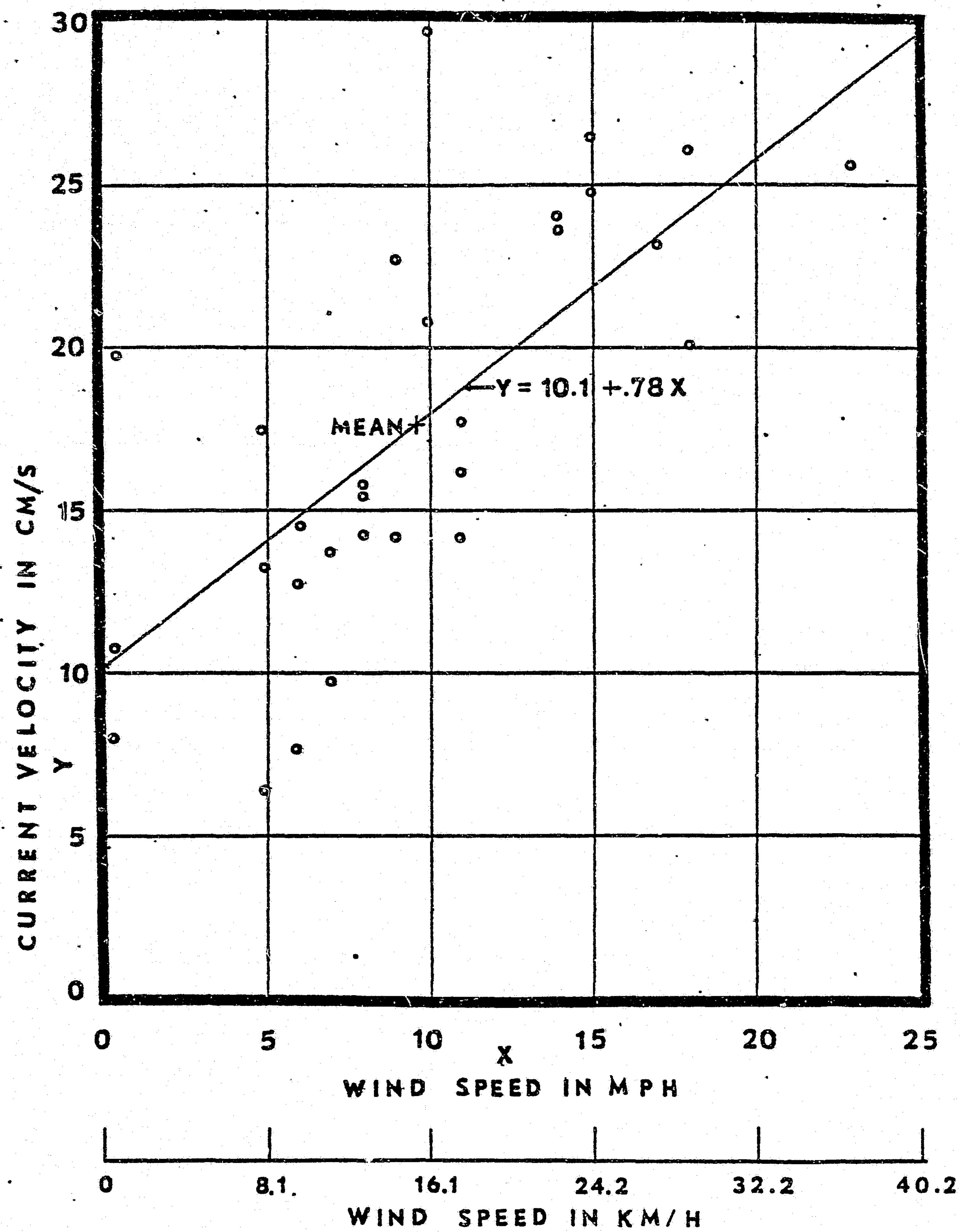
3.0 CURRENTS

Currents off the arctic coast of Alaska, well north of coastal influences, respond in a westward direction to the anticyclonic (clockwise) gyre of the Arctic Ocean. Currents on the intershelf, but seaward of the barrier islands, have been reported by Aagaard and Haugen (1977) as weak and variable; on the order of 5 cm/s (1.9 in/s) to the east.

Kinney et al. (1972) measured nearshore currents on the eastern side of the Colville River. Tethered drogues and current drifters indicated currents within Simpson Lagoon move either toward the east or west in response to northwest or northeast winds, respectively, with velocities reaching 37 cm/s (14.5 in/s). All currents tended to have longshore components and net transport appeared to be to the west, resulting from the predominance of northeast winds during the open-water season. A typical scatter diagram (Figure C-5) indicates that currents were approximately 3 percent of the wind speed.

Additional drogue studies, conducted just seaward of Pingok Island in 1972 (Wiseman et al. 1973), produced results similar to those found in the previous investigations.

These studies demonstrate that nearshore currents during open-water periods are controlled primarily by meteorological, rather than tidal



SIMPSON LAGOON

Source: Kinney et al. 1972

CORRELATION BETWEEN RECORDED CURRENT VELOCITIES AND WIND SPEED

PBU Waterflood Environmental Impact Statement | Figure C-5 forces. This fact has been further confirmed by spectrum analysis (Dygas 1975). During a 30-day recording period, 80 percent of the energy associated with surface currents in the west end of Simpson Lagoon possessed a periodicity of 4 days or longer. These currents were interpreted as wind-generated. A minor energy peak occurred at the diurnal frequency (approximately 0.4 cycles/hour), but no peaks were observed at the semidiurnal period (12.4 hours) and only about 5 percent of the energy occurred there. Currents moved at a speed equivalent to about 2.5 percent of the wind speed.

A current meter was deployed in the inlet between Stump Island and the PBU causeway during August 1977 (Matthews 1978). Flow through this inlet was mainly southward into the lagoon and was associated with easterly winds. Waters flowing toward Simpson Lagoon were more brackish (less saline) than the water on its eastern end. For short periods when water flowed north through the inlet, it possessed a higher salinity and lower temperature than water that had entered previously. The average current immediately east of Stump Island was approximately 6 cm/s (2.4 in/s) and reached a value of 18 cm/s (7 in/s) under the influence of strong ENE winds. If these current values persist across the entire inlet, the flushing rate from this inlet alone would be 225 days at 6 cm/s and 76 days at 18 cm/s (Matthews 1978). However, since this inlet is not the only nor the deepest inlet from the east to Simpson Lagoon, it is suspected that actual flushing times will be significantly less.

Also as part of the study, surface drifters were released near Oliktok Point prior to a storm possessing easterly winds. A drifter was picked up 5 days later 225 km (140 mi) from the release point, suggesting a mean surface current of about 57 cm/s (1.9 ft/s) over that period.

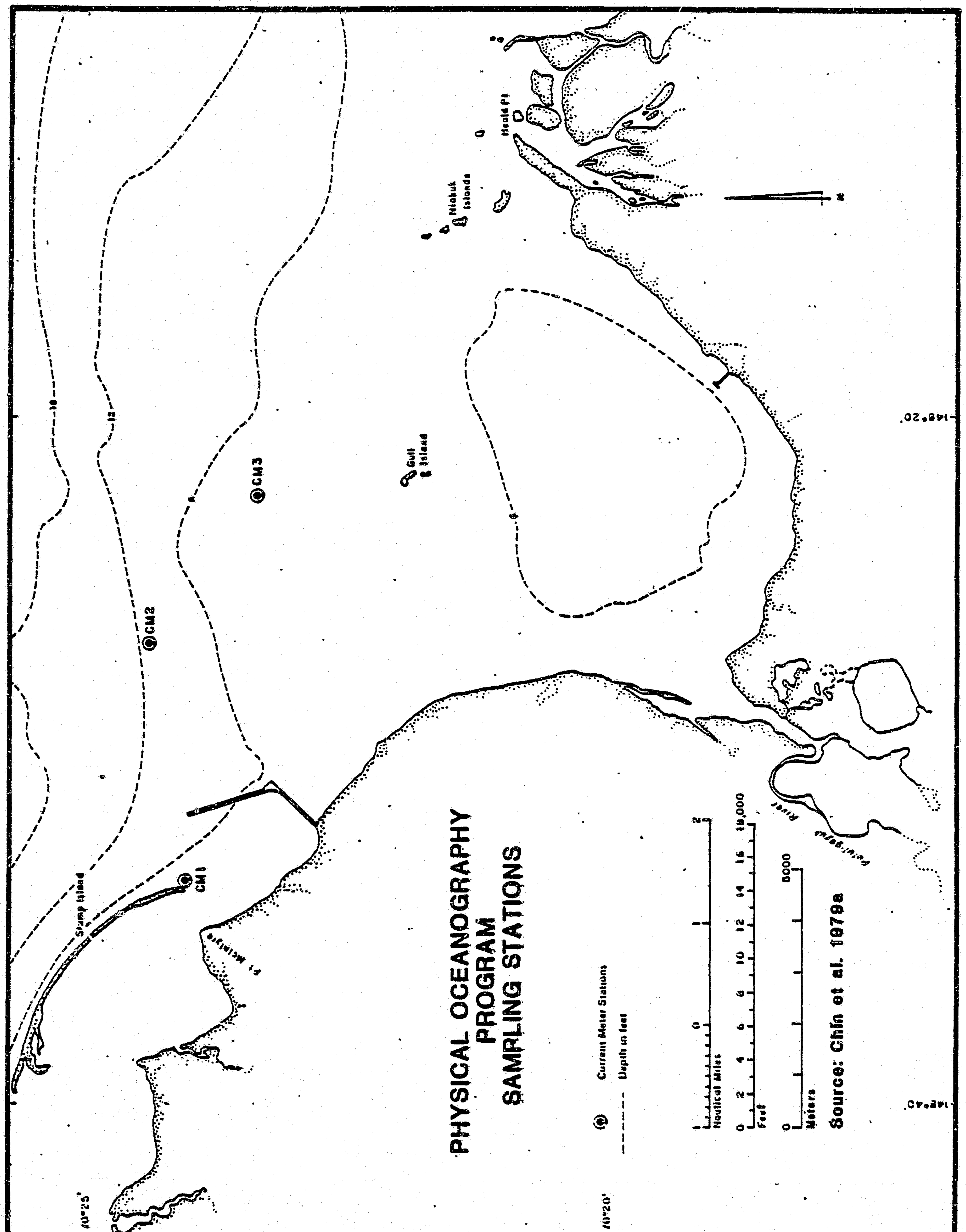
Currents within Simpson Lagoon were modeled numerically by Mungall et al. (1978) and again a ratio of about 3 percent was used between the current and wind speed. It was shown that complete flushing of the lagoon for 5 m/s (16 ft/s) ENE winds would occur in about 5 days (recall the 76 to 225 days based on a single inlet found by Matthews).

Additional modeling (Mungall et al. 1979) also demonstrated that there was approximately a 2-hour lag between wind changes and current response in the lagoon. This was further confirmed through a series of drogue studies. The surface drogues moved at a slightly higher ratio of the wind speed (approximately 0.045) than were observed in the model (0.03). Drogue speeds up to 60 cm/s (2 in/s) occurred in the lagoon in response to westerly winds.

During the 1978 field season, Matthews (1979) obtained additional data showing higher current values than were recorded by him the previous year. However, this is primarily indicative of increased wind speeds for the recording period during the latter year as the ratio of about 0.03 - 0.04 between the current and wind speed remained constant for both years.

Currents were measured by Chin et al. (1979a) during a field program conducted in 1978 for the PBU owners at three locations (Figure C-6). Winds during this recording period were predominately from the east and, as in the previous studies, appeared to drive the currents. Flow at the Stump Island station averaged 9.5 cm/s (4 in/s) into the lagoon. East winds produced average currents between 11 - 13 cm/s (4.3 - 5.1 in/s) at the other two locations.

During this study, drifters released north of the causeway were found on Stump Island, while releases in or near the inlet entered Simpson Lagoon. It was speculated that the flow immediately north of the causeway proceeds into the lagoon while water just seaward of this zone is carried westward along the seaward side of Stump Island. It was also postulated that a zone of upwelling occurs just inside the lagoon as a consequence of flow being diverted to either side of a submerged bar just inside the lagoon. More measurements are needed to investigate this in detail.



PBU Waterflood Environmental Impact Statement	Figure C-6

During the winter (1978 - 1979) following this field program, current measurements were also taken under the ice (Mangarella et al. 1979). As expected, currents were much reduced, averaging less than 5 cm/s (2 in/s). These currents were probably driven by tidal variations.

Results of hindcasting 15 storms known to have occurred in the area between 1962 - 1978 have been reported by Heideman (1979). Currents in excess of 80 cm/s (2.6 ft/s) have been hindcast north of the West Dock in 5.5 m (18 ft) of water. Actual measurements in this area are significantly less than these unverified hindcast values but extreme currents of this magnitude may be possible.

4.0 WAVE CLIMATE

Few measurements have been made of Beaufort Sea wave conditions. Visual observations suggest that 6-m (20-ft) waves have occurred off Point Barrow (Hume and Schalk 1967). The wave regime in the Beaufort Sea is heavily controlled by the location of the permanent ice pack. Since the fetch over which wind stress can effectively generate waves is the open (or semi-open) water between the front of the pack ice and the shoreline, the potential for wave growth varies widely from year to year.[1] According to Brower and Searby (1977), the maximum distance from the edge of pack ice to the coastline at Point Barrow was 390 km (242 mi) in 1954 and 1958; in 1970 and 1975 it was zero.

Wave measurements were made on the seaward side of Pingok Island in 1972 (Wiseman et al. 1973). Wave data were acquired with a resistance wave gauge mounted on a tripod at the 2-m (6.5-ft) depth. Two distinct sets of wave measurements were collected, each covering several recording intervals. One was heavily filtered, supplying information for waves with periods of 30 - 1000 s. Spectra of these waves showed a decrease in energy with wave period. It was speculated that the pack

[1]The amount of ice coverage that can seriously dampen wave growth is not well known.

ice may be responsible for producing such an energy distribution. Waves with periods of 0.5 - 30 s were also recorded. Within this range, waves appeared to have greatest energy concentrations in the 2 - 3 s range.

Waves were generally 10 - 30 cm (4 - 12 in) high. Analysis indicated that wave growth may have been limited by the distance to the pack ice. It was also suggested that longer period waves could be generated by winds blowing parallel to the opening between the pack ice and the shoreline where the fetch may, at times, be essentially unlimited. These longer period waves would, however, experience greater attenuation prior to reaching the coast.

Dygas (1975) measured waves at Oliktok Point, inside the barrier islands, on the west end of Simpson Lagoon. Results of the measurements during 1971 and 1972 indicated a mean breaker height of 17.7 cm (7 in) with a period of 2.2 s. The spectra of these records contained energy contributions in the 7.5 - 15.0 s range although these waves (within the lagoon) were not visually perceptible. However, Dygas reported swells on the seaward side of the islands as high as 1.5 - 2.0 m (5 - 6.5 ft).

Oceanographic studies were conducted for the PBU owners near the West Dock and in Prudhoe Bay during the 1976 - 1978 open-water periods (Grider et al. 1978, Chin et al. 1979a). In the course of two of these investigations, photographic techniques were used to obtain wave measurements. Photographs of the waves were taken as they passed a hand-held stadia rod. This method was limited to depths within "hip-boot" range and therefore could not measure heights of larger waves that broke before reaching this depth. The results of these measurements point out a generally benign wave climate.

Storm severity varies greatly; therefore, a long-term, systematic monitoring program may be necessary to provide a good understanding of the wave characteristics around Prudhoe Bay. During September of 1979, both McCollum (1979) and Barnes (1979) observed that waves during a storm were greater than 1 m (3 ft) at DH 3 and some appeared to have periods of 7 - 8 s.

Information can be obtained about extreme waves through hindcasting techniques. Heideman (1979) presented partial results of such a hindcast. It appears that the heights of larger waves are controlled by water depth. The standard breaking criterion suggests that shoaling waves increase in height until they break at a wave height equal to 0.78 times the water depth. This is probably the best estimate of the design wave that can be obtained at this time.

More data is needed on wave climate off the arctic coast and the role it plays in the life of the barrier islands and the shaping of the shoreline. Based on the dominate westward direction of littoral drift, most waves approach the shore from the east. The power associated with waves is dependent on the square of the wave height. This implies that rare storms from the west could produce effects equal to several weeks of relatively steady winds from the east. The permanence of the barrier islands over the last half century may reflect this situation.

5.0 STORM SURGES

Storm surges are extra-astronomical changes in sea level and serve as vehicles for transporting wave energy shoreward. On the arctic coast, storm surges are produced by the combined effects of wind stress and variations in atmospheric pressure. Surges on the Beaufort Sea coast are more important in changing sea level than are astronomical tides, which produce changes generally 20 cm (8 in) or less (Chin et al. 1979). Surges generally affect hundreds of kilometers of coastline simultaneously although the magnitude will vary somewhat from place to place depending on the three-dimensional geometry of the nearshore water body relative to the forces creating the surge.

A positive surge is created by westerly winds moving water toward the coast, a negative surge by easterlies moving water away from the coast. This results, in part, from the Coriolis acceleration that tends to divert moving objects to the right in the northern hemisphere. As the currents move in response to wind stress, they are transported toward or away from the shoreline. The degree to which a particular area is affected by storm surge is inversely proportional to the water depth.

As a result of the sparse population on the margins of the Beaufort Sea, the history of storm surges there is incomplete and lacking in detail. However, the few area residents recognize the changes in sea level associated with east and west winds as a commonly occurring phenomenon. A particularly noteworthy surge occurred in the fall of 1970 that was documented by Reimnitz and Maurer (1978). Gale force westerly winds created a sea level elevation in excess of 1 m (3 ft) almost everywhere along the northern coast. In Prudhoe Bay, it appears to have exceeded 3 m (10 ft). No direct measurements were made at the time of the storm, but the elevation of driftwood carried shoreward with the rising water appeared to give a fair representation of its extent. Barges were lifted out of the water and set on top of the East Dock causeway, requiring a sea level elevation of nearly 3 m (Reimnitz and Maurer 1978.)

Reimnitz and Maurer (1978) also described the effect of the storm in the Canadian Beaufort. Water began rising approximately 5 hours before the storm. The pack ice was more than 150 km (93 mi) from shore. When the storm began, the pack ice was transported almost to the coast, indicating that storm surges may be accompanied by processes that will cause them to subside. It is assumed that a significant open-water (or nearly so) fetch is required for surge formation, although surges have been observed at times of almost complete ice cover (Henry and Heaps 1976). The shoreward moving water moves the pack ice toward the shore, thereby reducing the fetch and inhibiting surge development.

Heideman (1979) compiled the results of a surge hindcast study (1978 - 1979) and found the 25-year extreme storm surge to be approximately 1.3 m (4 ft) in 5.5 m (18 ft) of water (just seaward of Stump Island). This was slightly less than that hindcast for a 1963 storm and approximately equal to that hindcast for the 1970 storm. In general, the results of the hindcast procedure for the 1970 storm were in reasonable agreement with the measurements of Reimnitz and Maurer (1978).

Negative surges can occur at all times of the year, but, based on observations in Mackenzie Bay by Henry (1975), are thought to be most common in December and January (Aagaard 1978). Unpublished data by Matthews show a peak negative surge of 60 cm (2 ft) for three winters record at Barrow and 89 cm (2.9 ft) for one winter record at Oliktok Point (Aagaard 1978). Henry's observations (1975) from Mackenzie Bay indicate negative surges are typically 1 m (3.3 ft) or less.

6.0 WATER QUALITY CHARACTERISTICS

Water quality characteristics depend on seasonal events such as ice cover, wind, and freshwater inflow. The nearshore waters are ice-free for 3 months each year. Freeze-up begins between mid-September and mid-October and ice attains its greatest depth, 2 - 2.6 m (6.5 - 8.5 ft), by March or April. Ice extends to the bottom from the shoreline out to a depth of 1 - 2 m (3 - 6.5 ft). Ice melt begins along the coast in early June; the nearshore waters are normally ice-free by late July.

Vertical mixing by wind-generated currents is usually strong enough to prevent stratification in shallow and, at times, in deep water. A distinct two-layer stratification has been observed in deep water with relatively fresh, warm water overlying cold, more saline water. Areal variations in temperature and salinity are often as much as 5°C and 10 parts per thousand (ppt) in Prudhoe Bay and from one side of the existing causeway to the other.

The area between the causeway and the Sagavanirktok River is a mixing zone for the clearer, usually colder, and more saline marine waters with the warmer, freshwater inflows from the rivers. Since nearshore currents are generally westerly during open water, the Sagavanirktok River discharge can influence water quality near the causeway. The Putuligayuk River, although closer, appears to affect this area to a lesser extent, because its discharge is much less.

The general trend during winter, under ice, is for the offshore waters to be less saline and slightly warmer than nearshore waters.

Review of the following discussion of water quality and sediment characteristics should be made with the dates of causeway construction in mind. The original causeway and DH 2, 1340 m (4396 ft) long, were completed in July 1975, and the extension with DH 3, an additional 1524 m (5000 ft), was completed in August 1976.

DISSOLVED OXYGEN

Dissolved oxygen (DO) concentrations in the nearshore zone are usually high (Hufford 1974, FERC 1979, Chin et al. 1979b). Alexander et al (1974) found mean DO concentrations of 7.73 mg/l in Simpson Lagoon during August 1970. Concentrations near, and in excess of, 15 mg/l were observed in all samples in proximity to the causeway as well as in deeper water in August and September 1976 (Grider et al. 1977). A survey conducted in July and August 1979, found most DO levels ranging between 9 - 11 mg/l (Chin et al. 1979a). It was noted that this range was similar to the previous summer and winter measurements near DH 3 and in deeper water. The near-bottom water generally had higher DO concentrations than the near-surface water and some values approached saturation (Chin 1980). During the 1979 survey, at stations north of DH 3 in waters about 3 - 6.6 m (9.8 - 21.6 ft) deep, the DO range was 8.2 - 14.0 mg/l at all stations and all depths (Metz 1979).

Although the winter ice cover eliminates atmospheric reaeration, DO levels usually remain high during winter. Significant decreases can occur, however, in pockets of water trapped under the winter fast ice (Chin et al. 1979b), and water may become anoxic (Schell 1974).

During February - April 1979, samples collected at stations in 2 - 5.8 m (6.5 - 19 ft) of water north of DH 3 had DO concentrations ranging from 11.2 - 12.4 mg/l, while in Prudhoe Bay in 1.8 - 2 m (5.9 - 6.5 ft) of water DO ranged from 7.5 - 11.5 mg/l (Woodward-Clyde 1979). Within the water column, values were generally uniform with depth (Mangarella et al. 1979). Although the measured values were relatively high, they were usually several mg/l below saturation values (Mangaella et al. 1979).

PH

Measurements of pH in the area are sparse. In August 1970, Alexander et al. (1974) measured pH in Simpson Lagoon and found the range to be 7.0 - 7.4, with a mean of 7.14. A survey of three stations north of DH 3 in 2.4, 4.2, and 6 m (9, 14 and 20 ft) of water and two stations in the main part of Prudhoe Bay was conducted under ice in March, June, and November 1976, and once in August (13th) during open water (Metz 1979). The pH ranges noted during these sample periods are presented below.

	North of DH 3	Prudhoe Bay
Under Ice	7.4 - 8.0	6.8 - 7.9
Open Water	7.6 - 8.0	7.8 - 8.2

TEMPERATURE

Moderate fluctuations in water temperature occur during the open-water period in the nearshore zone (Chin et al. 1979b). Generally, water temperatures decrease with increasing distance offshore (Chin et al. 1979a,b; Chin 1980), and may also vary with depth (Chin et al. 1979a).

Over the Beaufort Sea shelf, temperatures in the upper layers were generally near the freezing point during fall and winter and were within about 0.3°C of being isothermal (Aagaard 1976).

Temperatures during the open-water period tend to be highest along the mainland side of the lagoon, typically being about 7°C (45°F) (Mungall et al. 1978, Matthews 1979), versus 2° - 5°C (36° - 41°F) along the barrier islands (Mungall et al. 1978). In the river deltas and shallow marine environment, temperature may vary from near 0° - 12°C (32° - 54°F) as river runoff becomes warmer in the summer (Alexander et al. 1974). Matthews (1979) measured temperatures up to 12°C (54°F) off Beechey and Milne Points, and Schell (1974) noted -12°C (10°F) in high saline water trapped under ice. Peterson (1980) measured temperatures from -2.0° to -2.4°C (28° - 27°F) near DH 2 and DH 3 in February 1980.

At the eastern end of Simpson Lagoon and in Prudhoe Bay, summer water temperatures generally increased until early August, then dropped gradually as freeze-up approached (Doxey 1977). Water temperatures vary widely both in space and time during open water due to wind-driven currents and the influence of river runoff (Doxey 1977). Temperature changes, on the order of 6°C, can occur in a single day (Mungall et al. 1978). Temperature variations of almost 2°C have been noted between the eastern and western sides of Prudhoe Bay at the 1-m (3-ft) depth (Chin et al. 1979a,b). Horner (1972) found supercooled water (-4.2°C, 24°F) in the middle of the bay under ice. Such temperatures are probably common under the Prudhoe Bay ice as they were observed again in 1979 (Woodward-Clyde 1979).

Water temperatures near DH 3 during 1979 decreased from an average near -1.8°C (29°F) in February to about -2.4°C (28°F) in April (Mangarella et al. 1979, Woodward-Clyde 1979). Variations in temperature between stations did not exceed 0.6°C during the February to April sampling period, and temperatures were uniform with depth (Mangarella et al. 1979). During this same period at stations in 2 - 5.8 m (6.5 - 19 ft) of water north of DH 3, temperatures ranged from -3.4° to -1.5°C (26° - 29°F) (Woodward-Clyde 1979).

In water north of DH 3, vertical temperature gradients were observed during August and September of 1976 (Grider et al. 1977). At similar stations the following August, the water column was isothermal in shallow water (less than 1.8 m, 5.9 ft), but in deep water (greater than 1.8 m) the bottom to surface differential ranged from 3° - 8°C, being coldest at the bottom (Chin 1980). On August 6, 1979, a storm occurred that caused wind-induced mixing to penetrate to at least the 4.2-m (14-ft) depth, and the temperature between the surface and the 4.2-m (14-ft) depth only varied by 0.06°C (2.75° - 2.81°C, 36.9° - 37°F) (Chin 1980).

Water temperature often differs from one side of the causeway to the other, and this difference is most pronounced during storms (Doxey 1977). Temperature is consistently warmer east of the causeway than west (Mungall et al. 1978, Spight 1979). Between June 23 and September 22, 1976, the greatest difference between the two sides was 5.5°C. The greatest change in water temperature from one day to the next was 6°C (August 30-31) on the east side of the causeway. The average difference in temperature from one side to the other was 1.6°C (Doxey 1977).

SALINITY

During the summer, a widespread low salinity surface layer (26 - 29 ppt) developes north of the barrier islands over the middle and outer continental shelf, which is due apparently to freshwater river discharges along the entire North Slope coast (Niedoroda et al. 1979). During the fall, salinity of this upper layer was always less than 30 ppt, and on the inner shelf considerably less than 28 ppt (Aagaard 1976). During winter, salinity was above 31 ppt everywhere on the shelf (Aagaard 1976).

The shallow barrier lagoons and areas offshore large rivers may exhibit salinities near zero during spring breakup and large river discharge. Salinities may remain lower in the barrier island lagoons than in the open ocean during the summer and early fall, though salinity will often reach levels of 30 ppt (Alexander et al. 1974). In August 1970, the salinity of Simpson Lagoon ranged between 3.4 - 25.8 ppt, with a mean of 17.7 ppt (Alexander et al. 1974). Matthews (1979) measured salinities near 20 ppt off Beechey and Milne Points and noted that, as the freezing season approaches, the lagoon waters salinity rises to 30 - 32 ppt. Restriction of water movement in Simpson Lagoon as ice depths increased caused salinity values to vary widely with many values over 50 ppt and a maximum value of 65.9 ppt (Kinney et al. 1972). Pockets of seawater trapped beneath the ice in shallow water become more saline because saline brine drains from the forming ice. Schell (1974) measured salinity as high as 183 ppt in such pockets.

Large fluctuations in salinity may occur over a short period (Chin et al. 1979b). Salinity varies widely during summer due to wind currents and the influence of river runoff (Doxey 1977). The Sagavanirktok, Putuligayuk, and Kuparuk Rivers' discharge is responsible for keeping the salinity well into the estuarine range for much of the open-water season (Spight 1979). Runoff from the Sagavanirktok River extends to the 6-m (20-ft) isobath, and a major portion of this runoff normally moves in a westerly direction toward the causeway (Grider et al. 1977). Under less common westerly winds, the Kuparuk's discharge moves east into the causeway area. Salinity may vary with depth in deeper water (Chin et al. 1979a). Salinity tends to increase as the summer season progresses, probably due to reduced freshwater input (Doxey 1977).

The water in Prudhoe Bay and near the mouth of the Sagavanirktok River appears to be well mixed. In some shallow areas, the water masses are unstratified from the surface to the bottom (Nierdoroda et al. 1979). It has been speculated that a slow landward component of the bottom water brings saline water up to the pycnocline where it mixes with the freshwater discharges and the water masses of the shelf surface water (Nierdoroda et al. 1979). Within Prudhoe Bay, there is an area of marked vertical stratification, and within the 1.8-m (5.9-ft) isobath, there appears to be a pond of cool, high-salinity water lying beneath a warmer, fresher surface layer (Nierdoroda et al. 1979). Surface salinity on August 13, 1978, was about 15 ppt, and a marked salinity gradient was apparent across the shoal area lying at the mouth of Prudhoe Bay (Nierdoroda et al. 1979). The salinity on the eastern side of the bay was about 2 ppt lower than on the western side (Grider et al. 1977, Chin et al. 1979a). Salinity is higher than normal seawater (32 ppt) by late winter in Prudhoe Bay. From February to April 1979, salinity ranged from 32 - 56 ppt (Woodward-Clyde 1979). Horner (1972) measured a salinity of 72 ppt in the middle of the bay on May 10, 1971.

Measurements made in August and September 1976 (Grider et al. 1977) and August 1977 (Grider et al. 1978) indicated vertical salinity gradients in water north of DH 3. During the storm of August 1979, the normal stratification was eliminated for a short period (Chin 1980).

Large differences in salinity can occur across the causeway (18 ppt) with the less saline water tending to be found on the upwind side (Mungall et al. 1978). Doxey (1977) measured salinity from June 23 to August 8, 1976, and noted that the difference in salinity from one side of the causeway to the other was most pronounced during storms. Between July 31 and August 8, 1977, salinities were about 1.5 - 6.0 ppt higher on the west side (Grider et al. 1978).

Although rapid changes in salinity can occur at the causeway (e.g. 14.7 - 30.7 ppt) in one day, changes of a similar magnitude can occur at points less likely to be affected by the causeway (e.g. 13.4 - 27.4 ppt at the East Dock on the eastern side of Prudhoe Bay) (Mungall et al. 1978).

During winter, salinity is about the same on both sides of the causeway near DH 2 (31.5 - 33.7 ppt) but slightly lower north of DH 3 (29.8 - 30.9 ppt) (Peterson 1980).

SUSPENDED SEDIMENT

The water beyond the continental shelf is relatively free of suspended sediment; whereas, the shallow, nearshore waters are turbid during the summer. Freshwater inflow carrying sediment and wind-generated currents resuspending bottom sediment create this turbid condition.

During spring breakup, the rivers discharge their runoff and sediment load out over the shorefast ice. Sediment reaches the nearshore zone through holes in the ice and as the nearshore ice breaks up.

Samples collected in August 1979, near DH 3 in about 2.7 m (9 ft) of water had suspended solids concentrations that exceeded 50 mg/l in more than 12 percent of the samples (Chin 1980). Farther offshore (neglecting the data from the wind event described below), the mean suspended solids concentrations at 1.2 m (4 ft) below the surface at stations in 3 - 6.6 m (9 - 22 ft) of water was 4.8 mg/l; the mean for samples taken deeper in the water column at these stations was 3.6 mg/l (Chin 1980). The highest concentration of suspended solids at the deeper stations was 13.5 mg/l.

The August 6, 1979 storm mixed the water to at least the 4.2-m (14-ft) depth as evidenced by samples collected in deep water that displayed higher suspended solids concentrations near the bottom than near the surface (Chin 1980). Samples collected at the shallower stations (3 - 4.2 m, 9 - 14 ft) 1.2 m (4 ft) below the surface had suspended solids concentrations peak at about 90 mg/l (Chin 1980). The author concludes that storms with wind speeds of 20 knots or more, sustained for at least 24 hours, are able to mix the usually stratified water north of DH 3 and resuspend bottom sediments. He also notes that resuspended bottom sediments combine with Sagavanirktok River runoff to produce high suspended solids concentrations; however, river discharges appear to have a much lesser effect than sustained winds on suspended solids north of DH 3.

Suspended solids data are available at three stations north of DH 3 in 2.4, 4.2 and 6 m (9, 14 and 20 ft) of water and two stations in the main part of Prudhoe Bay that were sampled under ice in March, June, and November 1976, and once in August during open water (Metz 1979). The ranges of suspended solids concentrations for these stations are presented below:

	North of DH 3	Prudhoe Bay
Under Ice	1.0 - 6.0 mg/l	0.6 - 18.5 mg/l
Open Water	2.5 - 20.6 mg/l	60.0 - 168.0 mg/l

Peterson (1980) measured suspended solids concentrations ranging from less than 2 - 13 mg/l at stations near DH 2 and north of DH 3 in February 1980.

According to Barnes (1979), fall storms usually create high concentrations of silt-sized material that become incorporated in the forming slush ice. These concentrations are much higher than normally found in the water column, on the order of 1000 mg/l.

WATER CLARITY

Transmissivity and turbidity patterns correlate well with the pattern of suspended solids concentrations. That is, transmissivity is high and turbidity low in water beyond the continental shelf. In the nearshore zone during summer, transmissivity will be relatively low and turbidity high; during winter, turbidity will be low and transmissivity high.

Samples collected in July and August 1979, in 2.4 - 5.4-m (9 - 18 ft) depths, had higher bottom water transmissivities (22 - 36 percent) than the near-surface waters (0 - 18 percent) (Chin 1980).

Samples collected under ice during February through April 1979, within 4400 m (4812 yd) of the causeway showed that undisturbed waters beneath the ice were quite clear (Woodward-Clyde 1979). Values ranged from 60 - 82 percent referenced to a standard of 85 percent (Mangarella et al. 1979).

Turbidity measurements were made on water samples collected in the vicinity of the causeway during August and September 1976, with the following ranges in Formazin-Turbidity-Units (FTU) (Grider et al. 1977).

	August	September
Surface	1.0 - 16.0 FTU	1.5 - 14.0 FTU
Bottom	3.0 - 58.0 FTU	2.0 - 19.0 FTU

Windy days resulted in higher turbidity than calm days, and there was less mixing in the shallow water to the west (leeward) of the causeway (Grider et al. 1977).

NUTRIENTS

In a study along the north Alaska shelf in 1971 and 1972, nutrient concentrations in the surface waters were generally low and variable (Hufford 1974). Silicate concentrations were almost always greater than 2 microgram-atoms per liter (μg-at/l) in the surface layer. Phosphate and nitrate concentrations showed great regional variability in the surface layer (phosphates ranged between undetectable and 0.8 μg-at/l; nitrates changed from undetectable to 2.2 μg-at/l). The lowest phosphate levels occurred near melting ice and near shore, indicating that neither melting ice nor river runoff are sources of phosphate to the coastal waters (Hufford 1974). Mountain (1974) reported little offshore upwelling of nutrients.

Fresh water in the rivers and deltas is primarily phosphate limited, whereas the coastal marine waters are primarily nitrogen limited (Schell 1974). River runoff and coastal erosion constitute a source of nitrogen (Schell 1974). The river discharges during spring add much nitrogen. This nitrogen is primarily of tundra origin (Schell 1980a). During summer, phytoplankton use the available nutrients, removing nitrate, ammonia, and phosphate from the water column (Kinney et al. 1972). Schell (1974), analyzing data from Simpson and Elson Lagoons, reported that the inorganic nitrogen present at the start of summer is rapidly depleted through biological utilization. He indicated that nitrogenous nutrients limit phytoplankton productivity, and that phosphate appears to be well in excess of limiting concentrations throughout the year in the marine environment. The average phosphate concentrations in Simpson Lagoon and Harrison Bay were 0.6 - 1.2 μg-at/l when nitrate and nitrite were virtually undetectable and ammonia averaged 0.1 - 0.2 μg-at/l (Kinney et al. 1972). Hufford (1974) observed nitrate concentrations in excess of 1 μg-at/l in the surface layer near the Kuparuk and Sagavanirktok deltas.

Silicate concentrations are highly variable and reflect the mixing zones of fresh and marine waters, with higher values near shore and lower values offshore. Kinney et al. (1971) measured a range of 6.2 - 14.1 μg-at/l (mean of 10.4 μg-at/l) in Simpson Lagoon. Schell (1974) indicates that it is unlikely that silicate is a principal limiting nutrient to the diatom population in view of the severe nitrogen depletion in nearshore waters.

Schell (1974) measured nutrients in Simpson Lagoon, under ice, in May 1971. The ten stations between the mainland and Cottle Island on the east and Pingok Island on the west had the following ranges and means expressed in μg-at/l:

	Range	Mean
Nitrate	3.4 - 10.5	7.96
Phosphate	0.96 - 1.24	1.10
Silicate	27.0 - 53.5	43.2

Peterson (1980) measured nitrate and phosphate values at seven stations near DH 2 and DH 3 in February 1980. Nitrate at all stations was 0.2 mg/l, and total phosphate was 0.05 mg/l at all stations. Orthophosphate ranged between 0.03 and 0.05 mg/l, with a mean of 0.037 mg/l. Horner (1972) found under-ice levels of phosphate and nitrate to be lower near Reindeer Island than in Prudhoe Bay.

The concentrations of nutrients reach an annual peak in the spring. With an increase in the amount of light, nutrients are removed by the epontic ice algae that are beginning to grow on the bottom of the ice.

In the nearshore environment, the major portion of the fixed nitrogen and phophorus is present as dissolved organic nitrogen and phosphorus (Kinney et al. 1971). Dissolved organic nitrogen in Simpson Lagoon averaged 5.69 μg-at/l, while in the Beaufort Sea immediately seaward of the barrier islands it had a mean value of 4.86 μg-at/l (Kinney et al. 1972).

TRACE ELEMENTS

Sparse data exist for trace elements in the waters near the causeway. According to Burrell (1976), levels of chromium vary from undetectable to average values for open-ocean waters. He also indicates that the concentrations of lead are within normal ranges for seawater. Peterson (1980) reports arsenic, cadmium, chromium, copper, lead, and nickel as undetectable in a sample collected near the location of the proposed seawater treating plant. Mercury was 16 μg/l and zinc 17 μg/l in the sample collected in February 1980.

7.0 SEDIMENT CHARACTERISTICS

Sediment composition and changes result from river runoff, coastal erosion, waves, and ice scour. According to Feder et al. (1976a), the Sagavanirktok River is the predominant source of the fine-grained sediments at the causeway, in Prudhoe Bay, and in the shallow marine area south of Reindeer and Cross Islands. Sediments of the area around the causeway are composed of fine silt, silt, very fine sand, and fine sand. These categories make up over 85 percent of the sediment sampled (Chin et al. 1979b). Sediments within the 1.8-m (6-ft) contour are dominated by fine sand, whereas silts were found only in waters deeper than 1.8 m (Chin et al. 1979b). An overall pattern of increasing amounts of fine material with deeper water was apparent (Grider et al. 1977, Chin et al. 1979b).

CARBON CONTENT

There are two sources of carbon in sediments, organically bound carbon and carbonate carbon (Burrell et al. 1974). Prudhoe Bay sediments have a high carbonate content, which is typical of the North Slope (Spight 1979). This high carbonate content of sediments is terrestrial in origin, introduced by river runoff. Feder et al. (1976a) notes that the carbonate content increased seaward. They measured the concentration of carbonates in gravel-free sediments near the causeway during the summers of 1974 and 1975. The ranges and means for both years are:

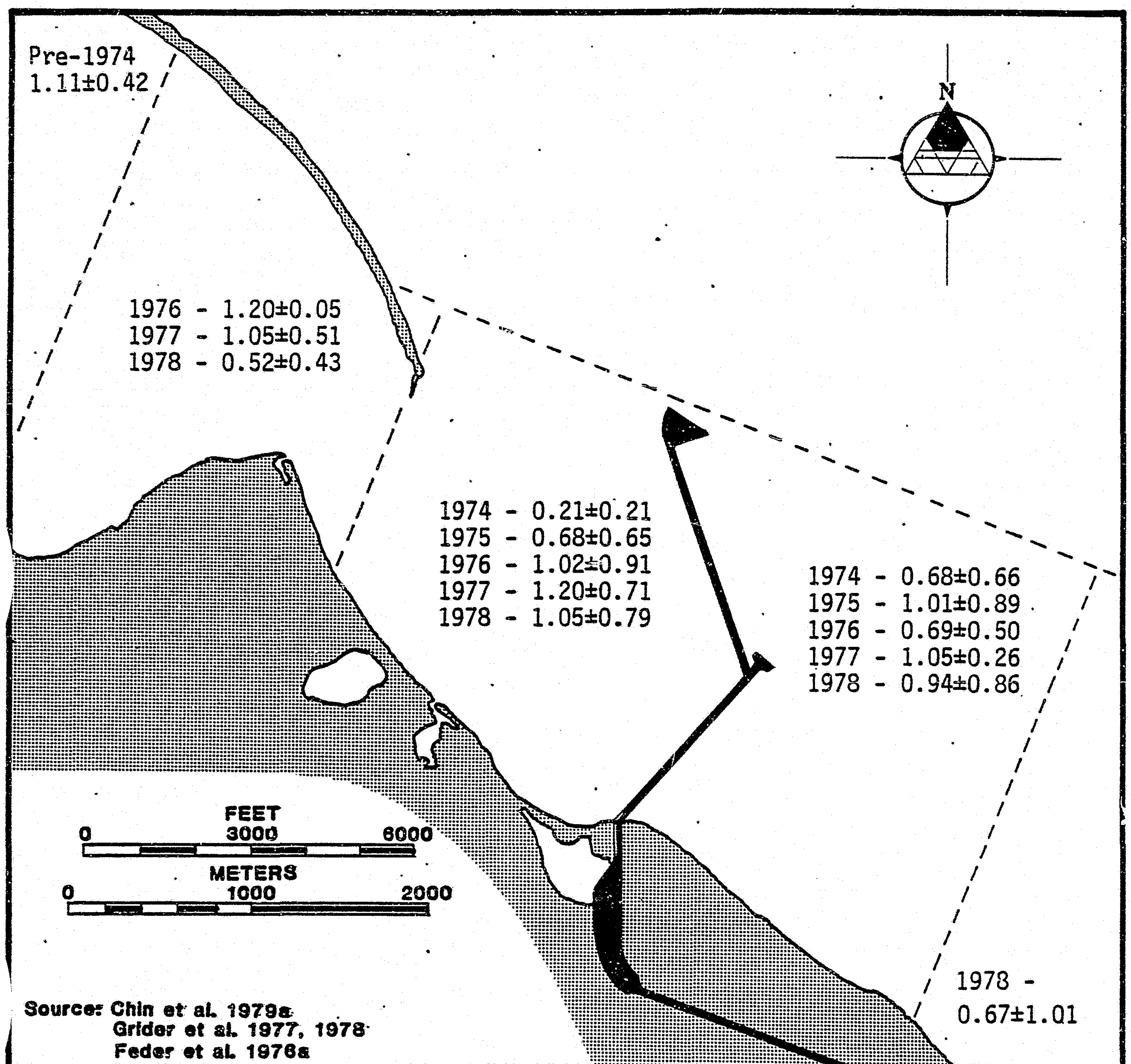
Year	Range	Mean
1974	2.44 - 32.42 percent	12.50 percent
1975	4.18 - 18.49 percent	13.42 percent

General spatial and temporal patterns for total organic carbon (TOC) concentrations are shown for the eastern end of Simpson Lagoon, the vicinity of the causeway, and the western side of Prudhoe Bay in Figure C-7. Although variability is high, TOC accounts for about 0.85 percent of the dry sediment by weight. Although this level has been cited as low (Grider et al. 1977, 1978; Chin et al. 1979a; Naidu 1978), it is similar to levels observed in temperate silty sand habitats on the continental shelf. Lees (1975) reported that average TOC concentrations on the Hueneme Shelf in southern California averaged about

0.35 percent. Data on the flux of organic carbon in these areas are lacking. Based on $^{12}C/^{13}C$ ratios, Schell (1978) found that over 75 percent of the organic carbon available to the nearshore faunal assemblages is of terrigenous origin, i.e. peat tundra vegetation, and only about 22 percent is of marine origin, i.e. phytoplankton, ice algae and benthic algae. Approximately one-half of the total carbon input is derived from coastal erosion.

Based on the apparent importance of terrigenous organic material, the prevailing westerly current flow, and the resultant reduction in the energy level of the water mass west of the causeway, one might expect to see increased deposition of both fine sediment and organic debris in the causeway's "shadow". Decreased deposition of those components should occur farther downstream because of depositional loss from the water near the causeway. Basically, a sediment trap would be created near the causeway and deposition rates could be reduced in Simpson Lagoon.

The high degree of sampling variability in TOC precludes detection of any differences between sites or sampling dates. Grider et al. (1977, 1978) and Chin et al. (1979a) repeatedly state that TOC concentrations and depth are positively correlated, but note that variability is high. Examination of mean annual TOC calculated for selected geographical areas suggests the occurrence of several trends (Figure C-7). Average TOC concentrations east of the existing causeway have varied widely between 0.68 - 1.05 percent since 1974, but no temporal patterns are apparent. West of the causeway (downstream), average TOC concentrations have increased evenly from 0.21 in 1974 to over 1.2 percent since 1977. In the eastern end of Simpson Lagoon, average TOC has decreased evenly from 1.2 percent in 1976 to 0.5 percent in 1978. Since 1976, the highest averages were observed in the area west of the causeway. These trends suggest that a shadow behind the existing causeway may have permitted an accumulation of TOC in this area.



DISTRIBUTION OF TOTAL ORGANIC CARBON (%)

PBU Waterflood Environmental Impact Statement | Figure C-7

Schell (1980b) suggested such a shadow effect could not be detected. He indicated three principal mechanisms operate in distributing organic debris: (1) storm surge from the northwest, (2) ice gouging, and (3) redistribution of sediments and debris frozen to the bottom of shorefast ice. He believes the role of currents in distribution of organic debris is small by comparison, and that the magnitude of effects from these influences would completely override any potential effects of the causeway on the distribution of organic debris.

Schell (1980b) suggests that concerns over changes in the distribution patterns of terrigenous organic debris are unimportant because he contends that material does not contribute significantly to the marine food webs. Despite the preponderance of terrigenous material in organic carbon reserves (about 78 percent) (Schell 1978), organic material of marine origin is apparently the most important source of carbon to the nearshore assemblages (Schell 1980b). However, future studies may prove that detritus of terrigenous origin is significant for its ultimate nutrient and energy contribution to nearshore marine systems in this area.

Both petroleum and biogenic hydrocarbons were found, and in about equal concentrations. However, the hydrocarbons were largely of tundra origin. No change in hydrocarbon levels between 1974 - 1975 was indicated (Feder et al. 1976b). In 1976, sediment samples from Prudhoe Bay were analyzed for high molecular weight hydrocarbons. It was concluded that they were characteristic of marine sediments from petroleum-free environments, and that marine organisms were probably the principal source of the hydrocarbons isolated from these sediments.

TRACE ELEMENTS

Information on trace elements in sediments is sparse for the nearshore marine environment. Weiss et al. (1974) reported the mercury content of sediments from the Sagavanirktok River was 111.5 ppb. In a 1974 study, Feder et al. (1976a) measured nickel, vanadium, and chromium concentrations in sediments. The vanadium content of Prudhoe Bay sediments was low, but the nickel content was relatively high, and increased seaward. In a 1975 sampling near the causeway, Feder et al. (1976b) obtained the following trace metal concentrations:

Trace Metal	Range(ppm)	Mean(ppm)
Copper	5 - 26	13
Chromium	21 - 87	52
Nickel	14 - 63	43
Vanadium	35 - 110	64

The following ranges were observed from sediment samples near the causeway in 1976 (Grider et al. 1977):

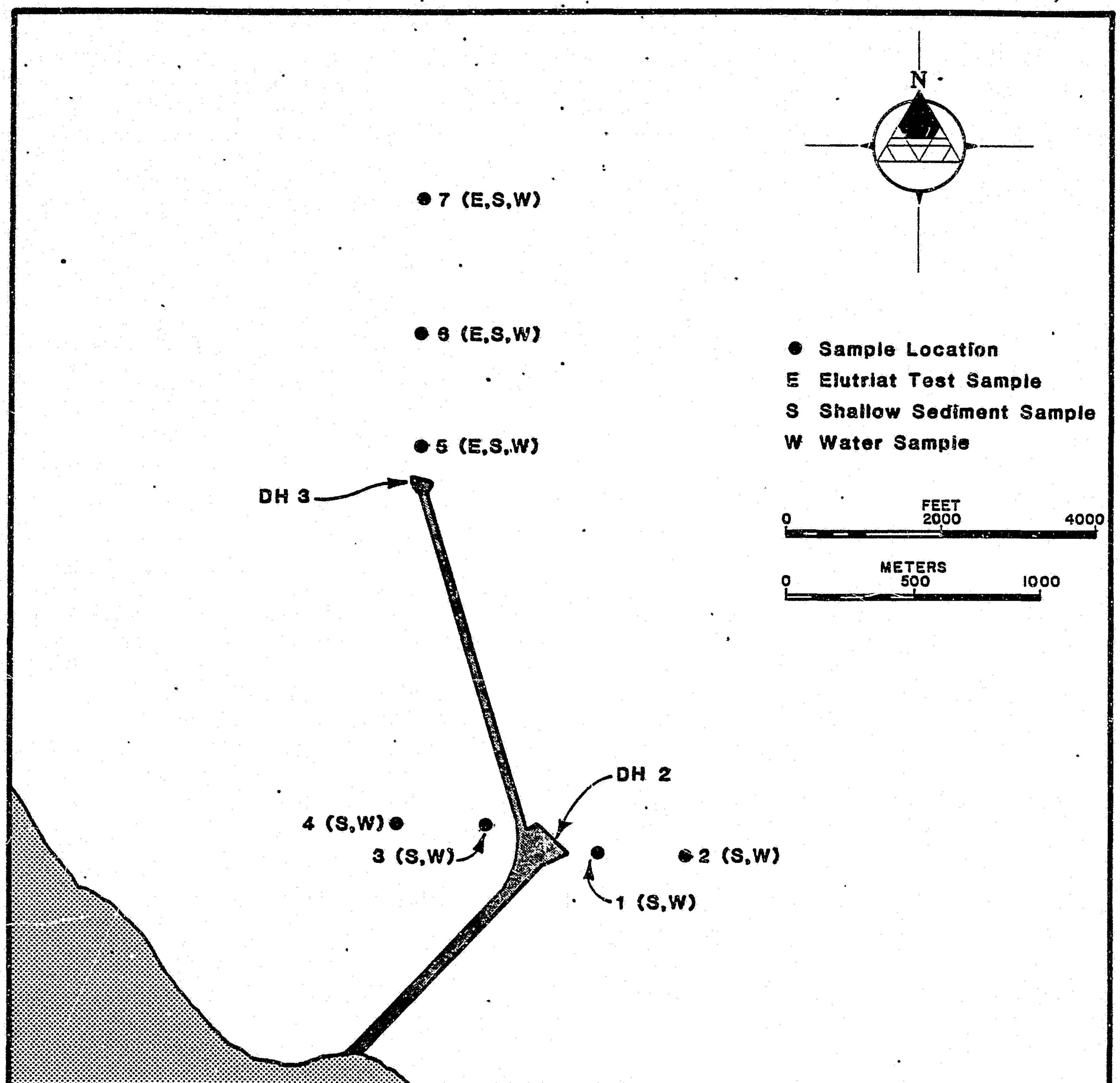
Metal	Range(ppm)	Metal	Range(ppm)
Nickel	21 - 47	Iron	11,800 - 15,400
Zinc	76 - 313	Copper	8 - 29
Lead	28 - 35	Barium	197 - 322
Cadmium	5 - 9	Vanadium	50 - 66
Chromium	17 - 50		

Feder et al. (1976b) reported concentrations of phosphorus measured in in gravel-free sediments near the causeway in 1974 and 1975 as follows:

Year	Range	Mean
1974	0.034 - 0.331 percent	0.101 percent
1975	0.044 - 0.097 percent	0.068 percent

The difference in concentrations between the years was insignificant according to Feder et al. (1976b). They also measured phosphorus in the adjacent shallow marine sediments in 1974. The mean for all 1974 samples was 0.09 percent.

Peterson (1980) collected sediment core samples 122, 579, and 1128 m (400, 1900, and 3700 ft) north of DH 3 in February 1980 (Figure C-8 and Tables C-1 and C-2). Concentrations of arsenic, chromium, and mercury were detected in the elutriat. Cadmium, copper, lead, nickel and zinc concentrations were low to normal. Total organic carbon and total organic nitrogen values were acceptable. There was no oil and grease sheen, and no PCB's were detected. Of the 11 chlorinated hydrocarbon pesticides determined, lindane exhibited a trace (less than 1 ug/l) at all three stations and DDT exhibited a trace at one station.



SEDIMENT & WATER SAMPLE LOCATIONS

PBU Waterflood Environmental Impact Statement	Figure C-8

TABLE C-1

ELUTRIATE TEST DATA

Parameter	Detection Limit	Background Water	Sample Location 5	Sample Location 6	Sample Location 7
Arsenic	1	ND	ND	ND	ND
Cadmium	0.5	ND	ND	3.9	ND
Chromium	5	ND	ND	ND	ND
Copper	2	ND	2	3	ND
Lead	5	ND	13	ND	ND
Mercury	2	16	ND	ND	ND
Nickel	2	ND	7	6	2
Zinc	1	17	32	84	16
Total Organic Carbon	1	1.6	2.7	5	3.1
Total Organic Nitrogen	0.3	ND	0.6	0.6	0.4
Chlorinated Hydrocarbons					
Endrin	1	ND	ND	ND	ND
Lindane	1	ND	T	T	T
Heptaclor	1	ND	ND	ND	ND
Heptaclor Epoxide	1	ND	ND	ND	ND
Aldrin	1	ND	ND	ND	ND
Dieldrin	1	ND	ND	ND	ND
DDT	1	ND	T	ND	ND
Thiodan	1	ND	ND	ND	ND
Methoxychlor	5	ND	ND	ND	ND
Chlordene	5	ND	ND	ND	ND
Toxaphene	5	ND	ND	ND	ND
Oil & Grease Sheen	-	-	None	None	None
PCB's	5	ND	ND	ND	ND

All concentrations in μ/gl except Oil & Grease Sheen (no units) and Total Organic Nitrogen (mg/l as N), and Total Organic Carbon (mg/l).

ND indicates value below detection limit
T indicates "trace" but less than detection limit

TABLE C-2

WATER AND SHALLOW SEDIMENT DATA

WATER DATA

Parameter	Detection Limit	Sample Location 1	2	3	4	5	6	7
Nitrate, as N, mg/l	0.05	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total Phosphate, as P, mg/l	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Orthophosphate, as P, mg/l	0.02	0.04	0.03	0.05	0.03	0.04	0.03	0.04
Salinity, ppt	0.01	31.46	33.05	33.72	32.27	30.87	30.42	29.85
Total Suspended Solids, mg/l	2	ND	2	13	4	ND	ND	2.5
Temperature, °C	0.1	-2.3	-2.1	-2.4	-2.3	-2.1	-2.0	-2.0
Water Depth, ft	0.1	1.9	1.7	1.0	0.4	2.6	5.4	8.1
Ice Thickness, ft	0.1	5.0	4.7	5.1	4.9	4.7	4.9	4.6

ND indicates value below detection limit--250 ml volume filtered for Locations 1 through 6, 1 liter filtered for Location 7

SHALLOW SEDIMENT DATA

Parameter	Detection Limit	Sample Location 1	2	3	4	5	6	7
Total Organic Carbon, %	0.1	4.2	2.9	4.4	4.6	3.8	4.5	3.8
Total Organic Nitrogen, %	0.05	0.10	0.07	0.11	0.11	0.07	0.12	0.09
Total Carbon, %	0.05	3.4	3.4	4.5	4.1	4.4	4.3	3.8
Total Solids, %	--	74.3	72.5	67.5	68.0	70.2	63.2	69.8

Percentage is on a dry weight basis
TOC and TC were determined by different methods--TOC is actually total oxidizable material

REFERENCES

Aagaard, Knut, 1976. STD mapping of the Beaufort Sea shelf. In: Environmental assessment of the Alaskan continental shelf, Vol. 11, physical oceanography and meterology. Principal Investigators' Reports for the Year Ending March 1976. NOAA/BLM, pp 249-266.

______, 1978. Physical oceanography and meteorology. In: Interim Synthesis Report: Beaufort/Chukchi, Outer Continental Shelf Environmental Assessment Program, NOAA, Boulder, Colorado.

______, D. Haugen, 1977. Current measurements in possible dispersal regions of the Beaufort Sea. Annual P.I. Reports, Environmental Assessment of the Alaskan Continental Shelf, Vol. XIV, Transport. NOAA/BLM.

Alexander, V., C. Coulon, and J. Chang, 1974. Studies of primary productivity and phytoplankton organisms in the Colville River system. In: Environmental studies of an arctic estuarine system--final report. Institute of Marine Science, Report R74-1, University of Alaska, Fairbanks, pp 283-410.

Barnes, P., (USGS) 1979. Personal communication (December 3) with D. Jones, Dames & Moore.

______, E. Reimnitz, G. Smith and D. McDowell, 1977. Bathymetric and shoreline changes in northwestern Prudhoe Bay, Alaska. Northern Engineer 9(2).

______, R. Ross, 1980. Fall storm, 1979 - a major modifying coastal event. In: P. Barnes and E. Reimnitz (Editors), Geologic processes and hazards of the Beaufort Sea shelf and coastal regions. Quarterly P.I. Reports, Environmental Assessment of the Alaskan Continental Shelf. NOAA/BLM.

Brower, A. and W. Searby, 1977. Climatic atlas of the outer continental shelf waters and coastal regions of Alaska. Vol. III - Chuckchi-Beaufort Sea. AEIDC, University of Alaska, Anchorage.

Burrell, D.C., 1976. Natural distribution of trace heavy metals and environmental background in three Alaskan shelf areas. NOAA/BLM/OCSEAP, Boulder, Colorado.

______, J.A. Dygas and R.W. Tucker, 1975. Beach morphology and sedimentology of Simpson Lagoon. In: Environmental studies of an arctic esturine system. Institute of Marine Science, R74-1, University of Alaska, Fairbanks.

Cannon, J.P. and S.E. Rawlinson, 1978. The environmental geology and geomorphology of the barrier island-lagoon system along the Beaufort Sea coastal plain from Prudhoe Bay to the Colville River. Annual P.I. Reports, Environmental Assessment of the Alaskan Continental Shelf, Vol. X, Transport. NOAA/BLM.

Chin, H., 1978. Physical/chemical measurements taken in the Beaufort Sea - July/August 1979. In: Environmental studies of the Beaufort Sea summer 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

_______, M. Busdosh, G.A. Robilliard and R.W. Firth Jr., 1979a. Environmental studies associated with the Prudhoe Bay Dock: physical oceanography and benthic ecology. Final report prepared for Atlantic Richfield Company by Woodward-Clyde Consultants, Anchorage, Alaska. 253 pp.

_______, A. Niedoroda, G. Robilliard, and M. Busdosh, 1979b. Related studies. In: Biological effects of impingement and entrainment from operation of the proposed intake. Draft report prepared for ARCO Oil and Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska. 136 pp.

Doxey, M.R., 1977. Fishery impact survey on the Atlantic Richfield Company causeway at Prudhoe Bay. Alaska Dept. of Fish & Game, Fairbanks, Alaska.

Dygas, J.A., 1975. A study of wind, waves and currenets in Simpson Lagoon. In: Environmental studies of an arctic esturine system. Institute of Marine Science, R74-1, University of Alaska, Fairbanks.

_______, D.C. Burrell, 1975. Dynamic sedimentalogical processes along the Beaufort Sea coast of Alaska. In: D.W. Hood, D.C. Burrell (Editors), Assessment of the arctic marine environment. Occasional Publications No. 4, Institute of Marine Science, University of Alaska, Fairbanks.

Feder, H.M., D.G. Shaw and A.S. Naidu, 1976a. The arctic coastal environment of Alaska: Vol. I, the nearshore marine environment in Prudhoe Bay, Alaska. Institute of Marine Science, R76-7, University of Alaska, Fairbanks.

_______, A.S. Naidu, D. Schamel, D.G. Shaw, and E.R. Smith, 1976b. The arctic coastal environment in Alaska: Vol. III, the nearshore marine environment in Prudhoe Bay, Alaska. Institute of Marine Science, R76-7, University of Alaska, Fairbanks.

FERC, 1979. Prudhoe Bay project environmental impact statement, construction and operation of a sales gas conditioning facility at Prudhoe Bay, Alaska. Federal Energy Regulatory Commission, Washington, D.C. 259 pp.

Grider, G.W., G.A. Robilliard, and R.W. Firth, 1977. Environmental studies associated with the Prudhoe Bay dock: coastal processes and marine benthos. Final report prepared for Atlantic Richfield Company by Woodward-Clyde Consultants, Anchorage, Alaska. 394 pp.

_______, G.A. Robilliard, and R.W. Firth, Jr., 1978. Environmental studies associated with the Prudhoe Bay dock: coastal processes and marine benthos. Final report prepared for Atlantic Richfield Company by Woodward-Clyde Consultants, Anchorage, Alaska. 145 pp.

Heideman, J., 1979. Oceanographic design criteria. In: Technical seminar on Alaska Beaufort Sea gravel island design. Exxon Production Research Co.

Henry, R.F., 1975. Storm surges: Beaufort Sea Technical Report No. 19, Department of the Environment, Victoria, B.C.

_______, and N.S. Heaps, 1976. Storm surges in the southern Beaufort Sea. Journal of the Fisheries Research Board of Canada 33(10).

Horner, R., 1972. Ecological studies on arctic sea ice organisms. Institute of Marine Science, R72-17, University of Alaska, Fairbanks.

Hufford, G.L., 1974. Dissolved oxygen and nutrient along the north Alaskan shelf. In: The coast and shelf of the Beaufort Sea. Arctic Institute of the North America, Arlington, Virginia, pp. 567-588.

Hume, J.D. and M. Schalk, 1967. Shoreline processes near Barrow, Alaska: a comparison of the normal and catastrophic. Arctic, 20(2): 86-103.

Kinney, P.J., D.M. Schell, V. Alexander, D.C. Burrell, R. Cooney and A.S. Naidu, 1972. Baseline data study of the Alaskan arctic aquatic environment. Institute of Marine Science, R72-3, University of Alaska, Fairbanks.

_______, D.M. Schell, V. Alexander, S. Naidu, C.P. McRoy, and D.C. Burrell, 1971. Baseline date study of the Alaskan arctic aquatic environments, eight month progress, 1970. Institute of Marine Science, R 71-4, University of Alaska, Fairbanks.

Lees, D.C., 1975. City of Oxnard predischarge receiving water monitoring study - results of biological studies. Final report. Prepared for City of Oxnard by Environmental Quality Analysts, Inc. and Marine Biological Consultants, Inc. pp 45-138.

McCollum, R. (NORTEC) 1979. Personal communication to D. Jones, Dames & Moore.

Mangarella, P., H. Chin, and A. Niedoroda, 1979. Under-ice conditions in the Beaufort Sea relative to the proposed waterflood discharge. In: Environomental studies of the Beaufort Sea - winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska. 251 pp.

Matthews, J.B., 1978. Characterization of the arctic barrier island-lagoon system. Annual P.I. Reports. Environmental Assessment of the Alaskan Continental Shelf, Vol. X Transport. NOAA/BLM.

_______, 1979. Characterization of the nearshore hydrodynamics of an arctic barrier island-lagoon system. Annual Report, 1 April - 31 March 79, R526-77. NOAA/BLM.

Metz, W.P. (ARCO Oil & Gas Company), 1979. Personal communication (December 25) with Laurence Peterson, L.A. Peterson & Assoc.

Mountain, D.G., 1974. Preliminary analysis of Beaufort Sea circulation in summer: the coast and shelf of the Beaufort Sea. Arctic Institute of North America, Arlington, Virginia, pp 27-42.

Mungall, J.C.H., R.W. Hann, D.J. Horne, R.E. Whitaker, and C.E. Able, 1978. Oceanographic processes in a Beaufort Sea barrier island-lagoon system: numerical modelling and current measurements. Annual Report, RU 531. NOAA/ BLM/OCSEAP.

_______, R.E. Whitaker, and S.D. Pace, 1979. Oceanographic processes in a Beaufort Sea barrier island-lagoon system: numerical modelling and current measurements. Annual P.I. Reports, Environmental Assessment of the Alaskan Continental Shelf. NOAA/BLM.

Naidu, A., 1978. Sediment characteristics, stability, and origin of the barrier islands-lagoon complex, North Arctic, Alaska. Annual P.I. Reports. Environmental Assessment of the Alaskan Continental Shelf, Vol. X, Transport. NOAA/BLM.

Niedoroda, A., H. Chin, and P. Mangarella, 1979. Addendum to 1978 summer environment studies associated with the Prudhoe Bay Dock: physical oceanoography and benthic ecology. Draft report to ARCO Oil & Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska. 23 pp.

Peterson, L.A., 1980. Prudhoe Bay waterflood project: elutriate, shallow sediment, and water quality data. Prepared for Dames & Moore.

Reimnitz, E. and D.K. Maurer, 1978. Storm surges in the Alaskan Beaufort Sea. Open-file 78-593. U.S. Geological Survey, Menlo Park, California. 26 pp.

Schell, D.M., 1974, Seasonal variation in the nutrient chemistry and conservative constituents in coastal Alaskan Beaufort sea waters. In: Environmental studies of an arctic estuarine system-final report. Institute of Marine Science, R74-1, University of Alaska, Fairbanks. pp 217-282.

_______, 1978. Nutrient dynamics in nearshore under-ice waters. Annual Report. NOAA/BLM/OCSEAP, Boulder, Colorado, 25 pp.

_______, 1980a. Personal communication to Laurence Peterson, L.A. Peterson and Associates.

_______, 1980b. Personal communication to D. Lees, Dames & Moore.

Spight, T., 1979. Prudhoe Bay west dock extension - synthesis of environmental studies 1974-1978. Draft report to ARCO Oil and Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska.

Weiss, H.V., K. Chew, M. Guttman, and A. Host, 1974. Mercury in the environs of the North Slope of Alaska. In: The coast and shelf of the Beaufort Sea. Arctic Institute of North America, pp. 737-746.

Wiseman, W.J., J.M. Coleman, A. Gregory, S.A. Hsu, A.D. Short, J.N. Suhoyda, C.D. Walters, Jr. and L.D. Wright, 1973. Alaskan arctic coastal processes and morphology. Coastal Studies Institute, Tech. Rep. No. 149, Louisiana State University, Baton Rouge.

Woodward-Clyde Consultants, 1979. Prudhoe Bay Waterflood Project, Volume II, Environmental, July 1979. Prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

APPENDIX D

HYDRODYNAMIC AND WATER QUALITY MODELING OF SIMPSON LAGOON AND PRUDHOE BAY

1.0 INTRODUCTION

PURPOSE OF THE STUDY

A number of options have been suggested to extend or modify the existing PBU causeway structure and facilities in the vicinity of Prudhoe Bay (see Figure D-1). The proposed options include a straightforward extension of the causeway structure to the 3.6 - 3.9-m (12 - 13-ft) water depth contour line, breaches in the causeway structure, and the construction of an offshore island.

The purpose of the present study is to estimate the impact of these various options on the circulation and water quality in the vicinity of the causeway. Because of the nature of the study, primarily evaluation of the various alternatives, it is the comparative, rather than the absolute, aspects of the impact of these alternatives that are of major concern for this study. The applicability and limitations of the model are discussed in detail in Section D-2.0.

THE SITE

Prudhoe Bay is located on the Beaufort Sea coast immediately west of and adjacent to the mouth of the Sagavanirktok River. Approximately 20 km (32 mi) offshore lie the Midway Islands, a widely spaced series of barrier islands (Reindeer Island, Argo Island, and Cross Island) connected by a shallow-water ridge. On the main shoreline at the western mouth of Prudhoe Bay is the PBU dock, which extends approximately 2288 m (7500 ft) offshore. Here, where water depths are approximately 3 m (10 ft), begins a 6-km (40-mi) chain of barrier islands located 0.8 - 9.7 km (0.5 - 6 mi) offshore, known as the Return Islands. The easternmost of these is Stump Island, whose southeast tip is 1.4 km (0.9 mi) west of the dockhead and 0.8 km (0.5 mi) from shore.

To the west of the dock is Simpson Lagoon. The lagoon is 48 km (30 mi) long, narrowing from 8.8 km (5.5 mi) in the west to 0.8 km (0.5 mi) in the east. Depths within the lagoon typically range between 0.9 and 2.1 m (3 and 7 ft), although entrance depths can reach 6.1 m (20 ft) or more. Depths are generally greatest on the western sides of entrances, and the existence of the entrances themselves can change with time.

Situated several hundred miles above the Arctic Circle, the Beaufort Sea coast exists in a climate of subfreezing temperatures which persist 7 months a year. Hence, from October through May, the coastal region is frozen from the shoreline out to a bottom depth of 0.4 - 2.1 m (3 - 7 ft). Offshore, from several to 97 km (60 mi) or more, the Arctic Ocean is covered year-round by the ice pack, a thick layer of permanent ice whose southern boundary moves on and off shore, constantly producing forces on the seasonal shorefast ice (Spight 1979).

As the sun begins to reverse its winter trend and the air temperatures rise above freezing, the rivers and land areas are the first to thaw. In the short time of 2 or 3 weeks in May, the rivers discharge their runoff out over the shorefast ice, which is beginning to break up. The peak discharge period for most rivers (e.g. the Putuligayuk) is short. The exceptions to this are the Kuparuk and the Sagavanirktok Rivers, which flow into Simpson Lagoon and Prudhoe Bay, respectively. Consequently, nearshore zone salinity increases gradually through the summer as river flow decreases (Spight 1979).

By mid-to-late July, the nearshore zone has become ice free. The ocean is open from the shore to the edge of the pack ice. The boundary between open water and the permanent pack ice is indistinct, made up of breaks in the ice and scattered ice floes. Around late September, the ice cover begins to reform.

Local winds are predominantly from the east-northeast (approximately 70 percent of the time). Severe storms occur every few summers, many of which blow out of the northwest. Waves are generally less than 0.3 m (1 ft) high with periods less than 1 s. Semidiurnal tide heights of less than 0.2 m (0.8 ft) occur, but are masked by wind-induced water level changes as great as 1.0 m (3.2 ft) (Spight 1979). Associated with the storms are possible sea level rises of 1.8 - 3.0 m (6 - 10 ft) (Mungall et al. 1978).

2.0 METHODOLOGY

INTRODUCTORY COMMENTS

A complement of mathematical models was selected for the purposes of the study outlined in the previous section. Specifically, these models included:

- A hydrodynamic model, TIDAL, to simulate the flow and circulation patterns in Prudhoe Bay and Simpson Lagoon as influenced by the wind and river input.

- A water quality model, WQUAL, to simulate the salinity concentrations in the study area under a range of flow conditions and causeway modifications.

The models TIDAL and WQUAL are proprietary computer software developed by Dames & Moore. These models are depth-averaged, two-dimensional numerical models and are suitable for examining the meso-scale impact of the existing and proposed physical conditions. Details of these models are discussed in published literature (Runchal 1978).

THE HYDRODYNAMIC MODEL, TIDAL

The local circulation patterns and the water heights in the vicinity of the causeway were estimated from the Dames & Moore hydrodynamic model TIDAL.

This model is based on the classical shallow water equations (Stoker 1957), which are solved by means of Integrated Finite-Differences (IFD). Among the advantages of the IFD methods are: the ease and economy of application, numerical stability, and conservation of such important physical quantities as the mass, momentum, and energy of the fluid elements.

The particular form of the equations used here is derived by integration of the three-dimensional, time-dependent set of hydrodynamic equations (e.g. Bird et al. 1960) over the vertical dimension. This results in a two-dimensional, time-dependent set of equations of mass and momentum balance, in which the horizontal components of velocity now represent "depth-averaged" values. The physical mechanisms that are accounted for in the equations governing momentum exchange are: local and convective accelerations, hydrostatic pressure variations in the water body, Coriolis force, bottom friction, surface wind drag, and atmospheric pressure variations. Other mechanisms, such as the intrafluid viscous forces, are likely to play only a minor role and are omitted; however, their inclusion is a mere matter of detail. The bottom friction and the surface wind drag are modeled by the empirical formulas well known in oceanographic practice (Dronkers 1964).

The governing equations, when solved with appropriate boundary and initial conditions, yield a complete time history of water movement. These equations form a set of coupled nonlinear hyperbolic equations for which no general solution can be obtained by known analytical means. At present, the best solution techniques seem to be of the numerical kind, and one such has been used in the present work.

THE WATER QUALITY MODEL, WQUAL

The water quality parameter of interest in this study was the salinity. The Dames & Moore water quality model, WQUAL, was employed to estimate the salinity distribution in the region of the causeway under specified flow conditions.

The model WQUAL is an IFD model similar in concept to the TIDAL model discussed earlier.

The governing equation, when solved with appropriate boundary and initial conditions, and using water velocities and heights produced by TIDAL, yields the time history of the local values of the water quality parameters.

APPLICABILITY AND LIMITATIONS OF THE MODELS

Both the TIDAL and WQUAL are depth-averaged models, and this represents their single most prominent theoretical limitation. In essence, the models therefore are most suitable for water bodies with near-uniform condition with depth at any location (for water bodies with little or no stratification). In the presence of stratification, the depth-averaged nature of the predictions needs to be accounted for in interpreting them.

From the evidence available (Chin et al. 1979), it is seen that the water body in the vicinity of Prudhoe Bay and Simpson Lagoon is a well mixed body of water and that it is rather shallow. It is possible that certain oceanographic and meteorological conditions may lead to weak stratification (Chin et al. 1979); however, any such stratification is likely to be of short duration especially in comparison with the transport and residence time scales for the bay.

For adequate resolution of the water body of interest, compatible with the constraints of computational costs, a discretization grid size of typically 305 m (1000 ft) was employed in the vicinity of the causeway and of 610 - 915 m (2000 - 3000 ft) in regions remote from the causeway. Because only one value of water column depth is specified per grid cell, the model simplifies the irregular bathymetry in terms of rectangular prisms. The simulated grid node values will thus be representative of a water column typically 305 by 305 m (1000 by 1000 ft) in horizontal extent and should not be interpreted as local point values.

There are also some practical considerations that, though not being limitations of the model, may yet limit the validity of the predictions. TIDAL and WQUAL are very general and comprehensive models. Ideally, they need very detailed and sophisticated level of input. This relates to the initial and boundary conditions, time histories of the flow rates and pollutant loads, the tidal and current history at open boundaries and surface winds, diffusivity, and bottom-friction coefficients throughout the field of computation. Almost always, for any practical application, these inputs to the required detail and reliability, are not available. Thus, simplifying assumptions need to be made and these, in turn, limit the quality of the model predictions. This fact is of considerable importance both in comparing the predictions with the field data and in relating the predictions to the likely behavior of the water body.

3.0 CALIBRATION AND VERIFICATION OF THE MATHEMATICAL MODEL

Within the resources available for this study, it was not possible to calibrate or verify the model with local data. The models TIDAL and WQUAL have been, of course, verified at other sites and these results are available in published literature (Runchal 1978, Dames & Moore 1977, Dames & Moore 1978).

An attempt was made to verify the TIDAL model with some available storm surge data (Intersea Research and Ott Water Engineering 1980); however, this attempt had to be abandoned because of lack of adequate time and boundary condition input.

The predicted comparisons between the so-called historic case (pre-causeway situation (see Section D-4.0 for description of cases) and the existing causeway agree in their qualitative and overall quantitative features with the available data (Spight 1979). Furthermore, the predicted currents, as a fraction of the prevailing wind speed, are in general agreement with the recorded observations (Woodward-Clyde 1979) and other numerical simulations (e.g. Callaway 1976).

It should be noted here that the primary objective of the present study was a comparative evaluation of alternative causeway options. Although the predicted results may not in themselves be verified, the predicted differences between the various options can still be relied upon with a certain measure of confidence for practical decision. This approach can be generally substantiated on theoretical ground. Furthermore, a fair amount of sensitivity studies were conducted to provide an additional measure of confidence in these predicted differences. Details of these studies are given later.

4.0 CASE STUDIES

SELECTION OF THE STUDY AREA

The two major freshwater sources for the region of concern are the Sagavanirktok and the Kuparuk Rivers. The offshore intrusion of the existing PBU causeway is on the order of 2288 m (7500 ft). The study area was selected primarily with the consideration of these features. The selected total study area is shown in Figure D-1. The extreme shoreward extent of the study area was placed approximately 3.2 km (2 mi) beyond the Sagavanirktok and Kuparuk Rivers. In the offshore direction, the study area boundary was selected to about 12.2 km (7.6 mi) from the shore, which corresponds to roughly 5.3 times the offshore extent of the existing causeway. It was felt that with this selection of the study area, the region of the immediate vicinity of the causeway will be largely unaffected by minor perturbations or uncertainties in the boundary values.

It was noted during the preliminary stages of the study that the impact of the causeway was limited largely to a region 3.2 - 8.0 km (2 - 5 mi) in the vicinity of the causeway. Thus, for ease of presentation of a result, a smaller zone of the total study area was selected for graphic and illustrative purposes. This is also shown in Figures D-1, D-3, and D-4. Note that all of the figures in Section D-6 show only this subsection of the total study.

SELECTION OF SCENARIOS

The modeled scenarios incorporated three varying parameters: (1) the wind condition (speed and direction); (2) amount of flow from rivers in the area; and (3) the physical set-up of the causeway. All other required parameters in this study were held constant (e.g. bottom friction, dispersion coefficient). The effects of a 6.1-m (20-ft) breach in the existing causeway were computed analytically and, hence, do not appear in this discussion.

Four wind conditions were taken into account. These conditions were felt to be typical of prevailing winds in the area. Two "calm wind" conditions and two storm conditions were modeled. River discharge input was taken at both a peak flow period (June), and also at a lower flow period (July-September). A detailed description of input for fresh water from river discharge and the various wind conditions is given in Section D-5.0.

The four physical set-ups which were investigated include: (1) historic case - no causeway; (2) existing causeway; (3) extended causeway (directly north to the 3.7-m (12-ft) water depth contour line); and (4) existing causeway with an island (at the 3.7-m water depth contour line). These options are shown in Figures D-2a through D-2d.

Table D-1 summarizes the cases modeled. Not all combinations of parameters were used. The cases selected, however, give a good indication of the impact of varying the individual parameters, and generalizations may be made from the results obtained.

5.0 INPUT FOR THE MATHEMATICAL MODELS

SPACIAL AND TEMPORAL SPACING

The finite-difference grid for TIDAL and WATER models, superimposed on the study area of the causeway is shown on Figure D-3. The grid size

TABLE D-1

MODELED CASES

Wind Condition / Physical Set-Up	High River Discharge: 10 Knots at 60°	High River Discharge: 10 Knots at 240°	High River Discharge: 25 Knots at 60°	High River Discharge: 25 Knots at 300°	Low River Discharge: 10 Knots at 60°	Low River Discharge: 10 Knots at 240°	Low River Discharge: 25 Knots at 60°	Low River Discharge: 25 Knots at 300°
Historic Case - No Causeway	x	x			x			
Existing Causeway	x	x	x	x	x	x		
Causeway with Extension	x	x	x	x	x	x		
Existing Causeway with Island	x	x						

is seen to vary from 305 - 1219 m (1000 - 4000 ft). The boundaries of the grid do not correspond exactly to the physical boundaries of the water body; this is a consequence of the cartesian grid employed in the models. Of necessity, this will cause minor distortions of the flow pattern in the vicinity of the boundary. However, the general pattern of the flow is not likely to be affected.

After experimentation with a range of values, time steps ranging from 180 - 300 s were employed for TIDAL simulations and from 5000 - 30,000 s for WQUAL simulations. These values were selected to satisfy the requirements of the computational stability, economy, and adequate resolution of the physical processes involved.

BATHYMETRIC INPUT

An important input required by the model is that of local depth of water based on a common datum. This input was obtained from NOAA maps (Numbers 16061 and 16062) over each of the grid cells of Figure D-3. Bathymetric input to the model was provided with respect to the mean lower low water (MLLW) datum. The resulting bathymetric contours are shown on Figure D-4.

BOUNDARY CONDITIONS

At the land boundaries of the model, the specification of the boundary conditions was that of zero normal velocity component and zero flux of the salinity (i.e., zero normal gradient of the salinity concentrations). These are the natural and widely employed boundary conditions.

At the open-sea boundary, the specification of the boundary condition was rather difficult especially in the absence of the lack of any field-specific data. A number of options were tried including:

- Flow through boundary with zero normal gradient of the mass flow rate.

- Fixed depth - with no change in the depth of water with time either uniform for all locations or varying from one location to another.

- A specified gradient of η - the departure from the mean depth according to the relation

  $$\eta_B = \eta_{B-1} + \eta_{B-2}$$

  where η_B, η_{B-1} and η_{B-2} are, respectively, the value of η at the boundary, at the nearest inside grid node and the next-nearest inside grid node.

- Specified velocity influx at the boundary.

Results of these are presented in later sections.

The ambient sea concentration of the salinity was taken to be 28 ppt (Chin 1979).

FRESHWATER INPUT

The salinity near the Prudhoe Bay dock is a function of the input of fresh water from the Putuligayuk River at the west and the Kuparuk and Sagavanirktok at the east.

The Putuligayuk and Kuparuk have daily records of discharge in the ocean (USGS). The flow rate at the gaging point of the Sagavanirktok (161 km, 100 mi, upstream from the mouth) is not representative of the discharge of the river in the ocean; therefore, an estimate of the total volume of fresh water based on the ratio of the drainage areas was needed. The flow rate of rivers in the northern part of Alaska is roughly proportional to the drainage area to the power of 0.8 (USGS, 1979). The flow rate of the Sagavanirktok River given in the USGS tables is associated with a drainage area of 5698 km^2 (2200 mi^2). The total drainage area of the Sagavanirktok is approximately 14,245 km^2 (5500 mi^2). This yields to a total freshwater discharge in the ocean of about two times the flow rate measured at the gauge.

The representative high flow rates used in the study are the average of the June flow rate for the years 1970 - 1977 (USGS records).

$Q = 304\ m^3/s\ (10{,}738\ ft^3/s)$ (Kuparuk)
$Q = 12.3\ m^3/s\ (435\ ft^3/s)$ (Putuligayuk)
$Q = 2 \times 206 = 412\ m^3/s\ (14{,}554\ ft^3/s)$ (Sagavanirktok)

The representative low flow rates used are the composite monthly averages for July, August, and September for the years 1970 - 1977 (USGS records).

$Q = 25.2\ m^3/s\ (900\ ft^3/s)$ (Kuparuk)
$Q = 0.4\ m^3/s\ (15\ ft^3/s)$ (Putuligayuk)
$Q = 2 \times 102.5 = 205\ m^3/s\ (7335\ ft^3/s)$ (Sagavanirktok)

A value of zero salinity was taken for the river discharge.

WIND CONDITIONS

Since the wind appears to be the main driving force in generating currents in Prudhoe Bay and Simpson Lagoon, four separate wind conditions were chosen for this modeling effort. Two "calm" condition winds were taken at 10 knots (5.15 m/s, 16.88 ft/s): one at 60° from true north (ENE) and the other at 240° (WSW). Available data (Ott Water Engineers 1980) indicates that wind speeds in a summer storm are around 25 knots (12.87 m/s, 42.19 ft/s). This speed was also taken in two directions: 60° from true north (ENE) and 300° (WNW).

WIND STRESS COEFFICIENT

The relationship governing wind stress T_o, is usually of the form:

$$T^o = \rho_a \; C_D \; U2 \frac{\vec{U}}{1U1}$$

where C_D= drag coefficient
ρ_a = density of air
U = wind velocity (at the 10 m, 33 ft, level)

Several studies (Wilson 1960, Keulegan 1951, Van Dorn 1953) indicate that the drag coefficient, C_D, has a velocity dependence of the form:

$$C_D = A + B\ (1-U_o/U)^2$$

where A and B are constants and U_o = critical wind velocity below which C_D = A.

The wind stress coefficient, k, however, involves a density ratio and has the form:

$$k = \rho_a/\rho_w\ [A+B(1-U_o/U)^2]$$

Wilson (1960) correlates the work of numerous investigators in an attempt to determine the value of the coefficients A and B. It appears, from the above investigation, that the following values for A and B are indicated:

$$A = 1.0 \text{ to } 1.1 \times 10^{-3}$$
$$B = 1.2 \text{ to } 1.8 \times 10^{-3}$$

In addition, the works of Keulegan (1951) and Van Dorn (1953) indicate that the critical wind velocity, U_o, is between 21 and 26 km/hr (13 and

16 mi/hr). The density ratio, ρ_a/ρ_w for standard condition (20°C and 760 mm Hg) and for seawater is taken to be:

$$(\rho_a/\rho_w)_{STP} = 1.17 \times 10^{-3}$$

The wind stress coefficient is obtained from the relationship:

$$k = [CSK1 + CSK2\ (1-U_o/\ U)]^2 \times 1.17$$

Values of CSK1 = 1.0×10^{-6} and CSK2 = 1.4×10^{-6} where determined by "best fit" of real hurricane data (FSAR 1973), and the critical velocity, U_o is taken as 15 mph.

BOTTOM FRICTION COEFFICIENT

A consideration of the bottom friction coefficient on the basis of Manning's work (1891) for open channel flow indicate that the bottom friction coefficient is inversely proportional to the one-third power of depth.

$$k = \frac{1}{\alpha^2} \cdot g\ n^2 \frac{1}{H^{1/3}}$$

k = bottom friction coefficient
n = Manning coefficient
= dimension constant (1 in the metric system, 1.489 in English system)
H = water depth

According to Chow (1953) the value of the Manning coefficient varies between 0.016 and 0.025. A value of n = 0.02 has been used in this study.

CORIOLIS FORCE

The Coriolis parameter depends only on the latitude of the point considered:

$$f = 2\ \Omega \sin \psi$$

where Ω is the angular speed of the earth and ψ the latitude.

In this modeling study the average latitude of the area of concern is approximately 70°. The corresponding Coriolis parameter becomes:

$$f = 1.37 \times 10^{-4} \text{ rads/s}$$

TIDAL INPUT

All the available evidence (e.g. Chin et al. 1979, Callaway 1976) indicates that the circulation patterns in the region of interest are dominated by the wind forces and that tide is of minor importance. Therefore, the tidal component was ignored for this study.

DISPERSION COEFFICIENT

Based upon the nature of the water body and the spatial and temporal scales, a value of 4.7 m^2/s (50 ft^2/s) was selected for the dispersion coefficient. Sensitivity studies were also conducted with 0.5 m^2/s (5 ft^2/s) to assess the importance of the effect of this parameter.

6.0 RESULTS AND DISCUSSIONS

10-KNOT, 60 DEGREE WIND (CALM) WITH HIGH FRESHWATER FLOW

The hydrodynamic circulation patterns and salinity contour for the four cases of interest (existing, historic, extended, and island) are given in Figures D-5 to D-15. It is seen from these that in general the salinity pattern in the vicinity of the causeway are dominated by the freshwater influx from the Sagavanirktok River. The general current direction is shore-paralleled, and the freshwater influx strongly influences the salinity level in the nearshore regions. The primary impact of the causeway structure is to deflect the saline water offshore with a later influx into the Simpson Lagoon on the downwind side of the causeway. These patterns are to be expected on theoretical as well as intuitive grounds.

It is also seen by comparison that the island option has a negligible additional impact as compared to that of the causeway.

10-KNOT, 240 DEGREE WIND (CALM) WITH HIGH FRESHWATER FLOW

The predicted results for this case are shown on Figures D-16 to D-26. The circulation patterns are now seen to be generally opposed to those with the west wind. The salinity in Simpson Lagoon is now seen to be dominated by the freshwater influx from Kuparuk with prevailing values lower than those for the west wind.

10-KNOT, 60 AND 240 DEGREE WINDS (CALM) WITH LOW FRESHWATER FLOW

The predicted patterns are shown on Figure D-27 to D-39. The general trends are the same as those for the high freshwater influx. Quantitively, the salinity levels are seen to be much higher now than before.

25-KNOT, 60 AND 300 DEGREE WINDS (STORM)
WITH HIGH AND LOW FRESHWATER FLOW

The predicted results are shown on Figure D-40 to D-49. The current speeds are, as expected, much higher. These result in narrower freshwater plumes and nearshore travel of fresh water as compared to the low wind case. Otherwise, the qualitative trends are identical to those corresponding to the low wind cases.

SENSITIVITY STUDIES

The results of the sensitivity studies are shown in Figure D-50 to D-63. It is seen from Figures D-52 to and D-56 that the boundary conditions at the three open boundaries of the study area have negligible impact outside the immediate vicinity of the boundaries. Thus, it can be concluded that the flow patterns in the vicinity of the causeway are primarily governed by the local oceanographic and wind effects. Thus, for the final simulations, the boundary condition of zero was selected as being the simplest adequate choice.

The effect of the Mannings friction factor on the currents and salinities is shown on Figures D-57 to D-60. It is seen that currents vary almost inversely, as expected, to the Mannings coefficient. A value of 0.020 was selected as being appropriate for the water body under consideration.

The effect of the change in the water depth (to simulate the wind set-up) is shown in Figures D-61 and D-62. It is seen that, as expected, no significant change in the current occurs, although the salinities, in general, increase because of the influx of a larger amount of saline water from the ambient.

Finally, the effect of the change in the dispersion coefficient is shown on Figure D-63. It is seen, by comparison with the base case, Figure D-51, that a smaller dispersion coefficient leads to a narrower freshwater plume. This is to be expected on theoretical grounds.

COMPARATIVE EVALUATION

A tabulated summary of the salinities in the vicinity of the PBU causeway at six locations (see Figure D-64) is given in Table D-2. The values marked with an asterisk were deduced from comparable simulations and not directly from the model. It is seen that, in general, the causeway, as compared to the historic case, leads to change on the

TABLE D-2 Effect of the Wind and Freshwater Conditions On Salinity in the Vicinity of the Causeway

(See Figure D-64 for Locations)

Location 1

Flow Condition	Wind Condition	Historic	Existing	Extended	Island
Max	10 E	4.8	7.8	11.2	7.8
Min	10 E	10.9	14.6	17.8	14.6*
Max	10 W	7.3	3.2	2.2	3.2
Min	10 W	23. *	21.3	20.8	21.3*
Max	25 E	11. *	16.3	20.2	16.3*
Min	25 E	25. *	26. *	27. *	26. *
Max	25 W	13. *	12.1	10.9	12.1*
Min	25 W	26. *	25. *	24. *	25. *

Location 2

Flow Condition	Wind Condition	Historic	Existing	Extended	Island
Max	10 E	5.9	7.9	11.2	7.9
Min	10 E	11.6	14.6	17.8	14.6*
Max	10 W	0.5	0.5	0.5	0.5
Min	10 W	20. *	19.5	19.4	19.5*
Max	25 E	12. *	16.4	20.2	16.4*
Min	25 E	25. *	26. *	27. *	26. *
Max	25 W	10. *	9.5	9.5	9.5*
Min	25 W	25. *	24. *	24. *	24. *

*These values are estimated from the computations performed for similar conditions.

TABLE D-2 Continued

Location 3

Flow Condition	Wind Condition	Historic	Existing	Extended	Island
Max	10 E	11.2	7.6	7.0	7.6
Min	10 E	18.3	14.3	13.6	14.3*
Max	10 W	15.6	11.4	13.7	11.3
Min	11 W	27. *	25.5	26.3	25.5*
Max	25 E	18. *	16.6	15.5	16.6*
Min	25 E	25. *	22. *	20. *	22. *
Max	25 W	25. *	20.2	22.6	20.2*
Min	25 W	28. *	25. *	28. *	25. *

Location 4

Flow Condition	Wind Condition	Historic	Existing	Extended	Island
Max	10 E	14.1	11.8	10.9	11.7
Min	10 E	21.2	19.1	18.3	19.1*
Max	10 W	16.9	14.7	15.5	14.6
Min	10 W	28. *	26.6	26.7	26.6*
Max	25 E	23. *	23.3	22.7	23.3*
Min	25 E	25. *	24. *	22. *	24. *
Max	25 W	25. *	22.9	23.5	22.9*
Min	25 W	28. *	25. *	28. *	25. *

*These values are estimated from the computations performed for similar conditions.

TABLE D-2 Continued

Location 5

Flow Condition	Wind Condition	Historic	Existing	Extended	Island
Max	10 E	8.4	9.9	12.1	9.8
Min	10 E	15.5	16.8	18.8	16.8*
Max	10 W	0.8	0.8	0.8	0.8
Min	10 W	22. *	21.6	21.6	21.6*
Max	25 E	18. *	18.8	20.7	18.8*
Min	25 E	25. *	26. *	26. *	26. *
Max	25 W	13. *	12.6*	12.6*	12.6*
Min	25 W	27. *	27. *	27. *	27. *

Location 6

Flow Condition	Wind Condition	Historic	Existing	Extended	Island
Max	10 E	2.04	2.3	2.8	2.3
Min	10 E	20.0	19.9	20.5	19.9*
Max	10 W	4.4	4.4	4.4	4.4
Min	10 W	28. *	27.4	27.4	27.4*
Max	25 E	19. *	20.4	21.0	20.4*
Min	25 E	28. *	28. *	28. *	28. *
Max	25 W	24. *	23.3	23.3	23.3*
Min	25 W	28. *	28. *	28. *	28. *

*These values are estimated from the computations performed for similar conditions.

compared to the historic case, leads to change on the order of 2 - 5 ppt in the salinity in its immediate vicinity and less than 1 ppt at distances from 3.2 - 8.0 km (2 - 5 mi) away from it. The extended causeway is expected to lead to further changes on the order of 2 - 4 ppt in the immediate neighborhood of the causeway. Salinity patterns of the island option are similar.

EFFECT OF A 6.1-M (20-FT) BREACH

Two methods have been used to predict the flow through a 6.1-m (20-ft) breach located just north of the dog leg in the causeway. The first, which gives a low estimate, computes the flow by using the water velocity given by the model near the causeway in the absence of a breach and the cross-section of the breach. The second gives a more realistic estimate and is based on the predicted difference in water elevations on either side of the causeway due to current set up. Preliminary calculations of wave set up indicate that this factor would add slightly to the head differential but would not increase flow velocities predicted below by more than 25 percent. Velocities in the breach are related to the change in elevation H by the Bernoulli equation:

$$\frac{V^2}{2g} + \frac{P}{\rho g} + H = \text{Constant (neglecting head losses)}$$

or $$V = \sqrt{2g\Delta H}$$

Tables D-3 and D-4 show the different values of the flow in the breach and the associated flow in the lagoon for different wind conditions.

The flow in the breach represents 2 - 4 percent of the total flow in the lagoon and thus will have a small effect on the salinity.

<u>Example</u>: 13- m/s (25 knot) wind from the east.

TABLE D-3

A ROUGH ESTIMATE OF THE EFFECT OF A 6.1-M (20-FT) BREACH ON THE SALINITY AROUND THE CAUSEWAY - HIGH FLOW

		10E	10W	25E	25W
	(m)	0.00196	0.00232	0.0260	0.0396
$\overline{H}$ depth	(m)	1.8	1.8	1.8	1.8
V vicinity	(m/s)	0.09	0.003	0.029	0.10
V bernoulli	(m/s)	0.2	0.2	0.7	0.9
Q-low estimate	(m^3/s)	1	<1	3	1
Q-high estimate	(m^3/s)	80	80	260	320
Q-Simpson Lagoon	(m^3/s)	101	101	202	470
Max % change in flow		2.0%	2.2%	3.7%	1.9%
C in the Lagoon	(ppt)	7.9	3.4	16.4	11.5
C outside the Lagoon	(ppt)	5.0	12.3	12.2	20.8
C expected in the lagoon	(ppt)	7.8	3.6	16.2	11.7

TABLE D-4

A ROUGH ESTIMATE OF THE EFFECT OF A 6.1-M (20-FT) BREACH ON THE SALINITY AROUND THE CAUSEWAY - LOW FLOW

		10E	10W
	(m)	0.00189	0.00228
$\overline{H}$ depth	(m)	1.8	1.8
V vicinity	(m/s)	0.06	0.003
V bernoulli	(m/s)	0.2	0.2
Q-low estimate	(m^3/s)	1	<1
Q-high estimate	(m^3/s)	2	2
Q-Simpson Lagoon	(m^3/s)	101	101
Max % change in flow		2.1%	2.3%
C in the Lagoon	(ppt)	14.6	21.4
C outside the Lagoon	(ppt)	11.1	25.8
C expected in the lagoon	(ppt)	11.2	21.5

Without the breach, the predicted salinity in the lagoon near the causeway is 16.4 ppt; the predicted salinity on the opposite side of the causeway is 12.2 ppt. Using the second method mentioned above to estimate the flow through the breach, a value of 7.3 m^3/s (260 ft^3/s) is obtained. If the total flow in the lagoon is taken to be 202 m^3/s (7200 ft^3/s), the expected salinity in the lagoon with the breach is:

$$S = \frac{S_b Q_b + S_l Q_l}{Q_b + Q_l}$$

S = salinity

Q = flow rate

Subscript b refers to breach

Subscript l refers to lagoon

$$S \doteq \frac{12.2 \times 260 + 16.4 \times 7200}{260 + 7200}$$

S = 16.25 ppt

This indicates less than a 1 percent change with the existence of the breach.

7.0 CONCLUSIONS

Several cases of causeway options, wind conditions, and river discharge conditions were investigated to define the impact of the existing causeway and proposed modifications to the water quality in Prudhoe Bay and Simpson Lagoon. The investigations were of a preliminary nature and were primarily concerned with qualitative and comparative evaluation. The main conclusions drawn from the study are enumerated below.

1. The hydrodynamic simulations show that flow in the area of concern conforms to the bathymetric contours to a great extent. Current speeds seem to be approximately 2 - 3 percent of wind speeds. Boundary conditions do not exert their influence as far as the region of the causeway.

2. The effects of the existing causeway as compared to the historic case are as follows:

   -Simpson Lagoon

   a. East winds result in "saltier" waters. The effect is between 2 and 5 ppt up to 8 km (5 mi) into the lagoon and about 1 ppt beyond.
   b. West winds result in fresher water. The effect is limited to 1 ppt except in the immediate vicinity of causeway where it may be as much as 5 ppt.

   -Prudhoe Bay

   The effect is on the order of 4 ppt during both east (fresher) and west (saltier) on conditions in the immediate vicinity of the causeway (within one mile). There is very little effect beyond.

3. The effects of an extended causeway as compared to the existing causeway are as follows:

   -Simpson Lagoon

   a. East winds are likely to increase salinities by 2 - 4 ppt up to 8 km (5 mi) and on the order of 1 ppt beyond.

   b. West winds are likely to result in approximately 1 ppt decrease in the immediate vicinity.

1. The hydrodynamic simulations show that flow in the area of concern conforms to the bathymetric contours to a great extent. Current speeds seem to be approximately 2 - 3 percent of wind speeds. Boundary conditions do not exert their influence as far as the region of the causeway.

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-Prudhoe Bay

The effect is on the order of 4 ppt during both east (fresher) and west (saltier) on conditions in the immediate vicinity of the causeway (within one mile). There is very little effect beyond.

3. The effects of an extended causeway as compared to the existing causeway are as follows:

-Simpson Lagoon

a. East winds are likely to increase salinities by 2 - 4 ppt up to 8 km (5 mi) and on the order of 1 ppt beyond.

b. West winds are likely to result in approximately 1 ppt decrease in the immediate vicinity.

-Prudhoe Bay

The effect is likely to be on the order of 1 ppt in the immediate vicinity of the causeway.

4. The effects of an island as compared to the existing causeway - a minimal effect (less than 1 ppt) was found under all investigated conditions.

5. 6.1-m, (20-ft) breach likely to result in minimal change (about 0.2 ppt) over the existing conditions.

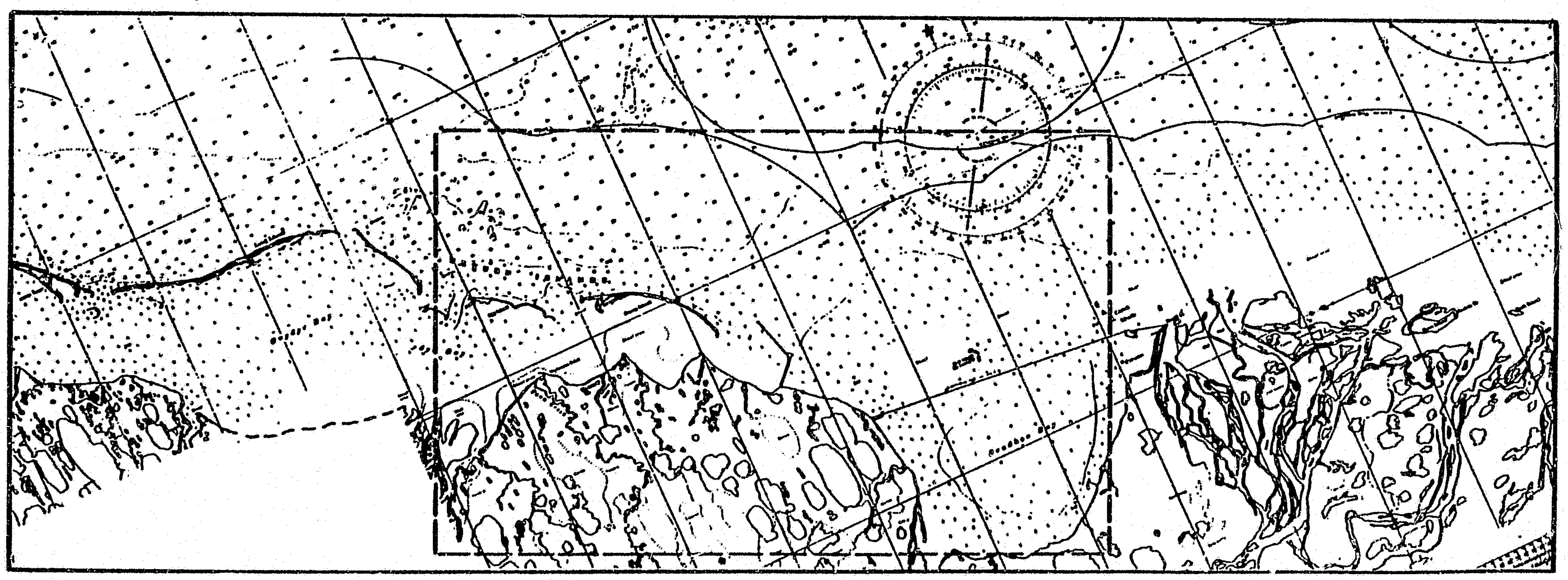
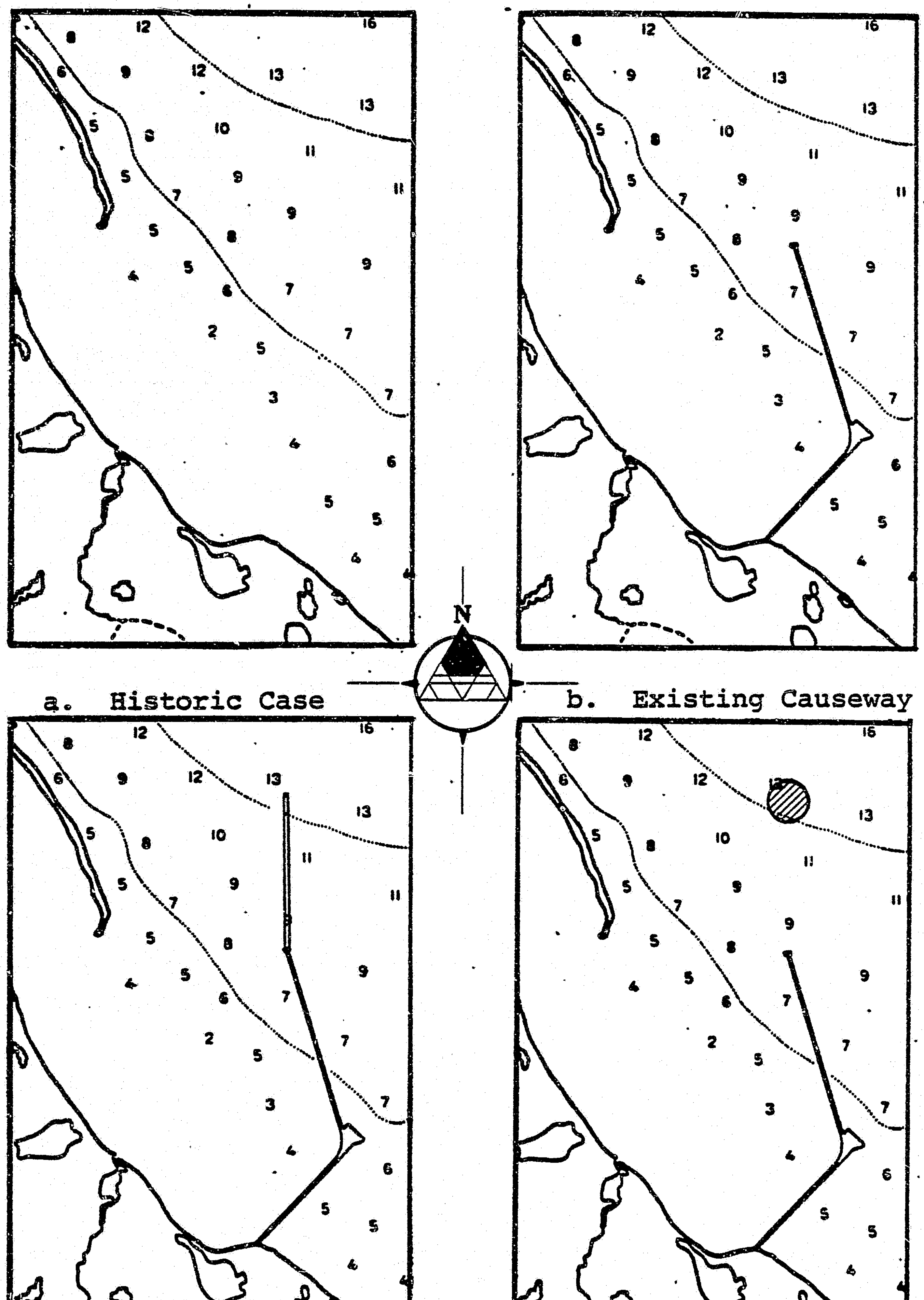


FIGURE D-1 Map of the Study Area



a. Historic Case

b. Existing Causeway

c. Extended Causeway

d. Causeway with Island

MODELED CAUSEWAY OPTIONS

PBU Waterflood Environmental Impact Statement	Figure D-2

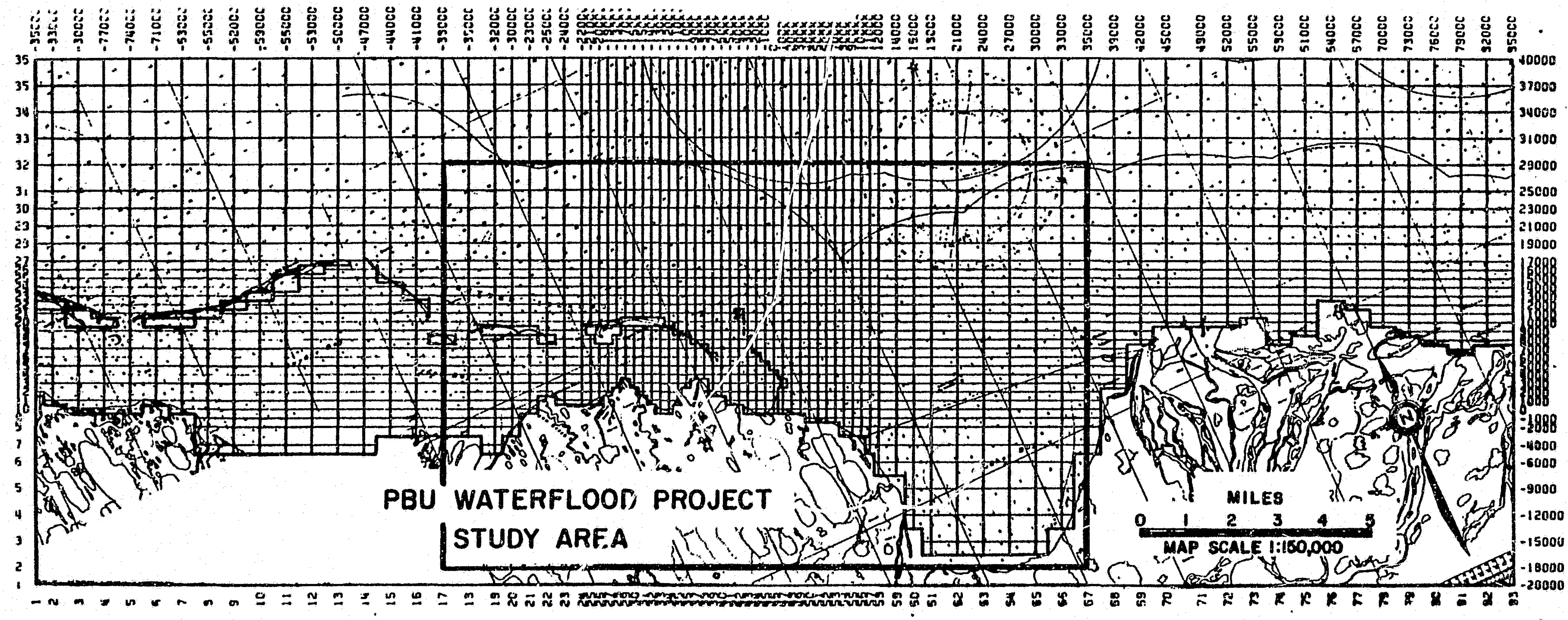


FIGURE D-3 Finite Difference Grid for Study Area

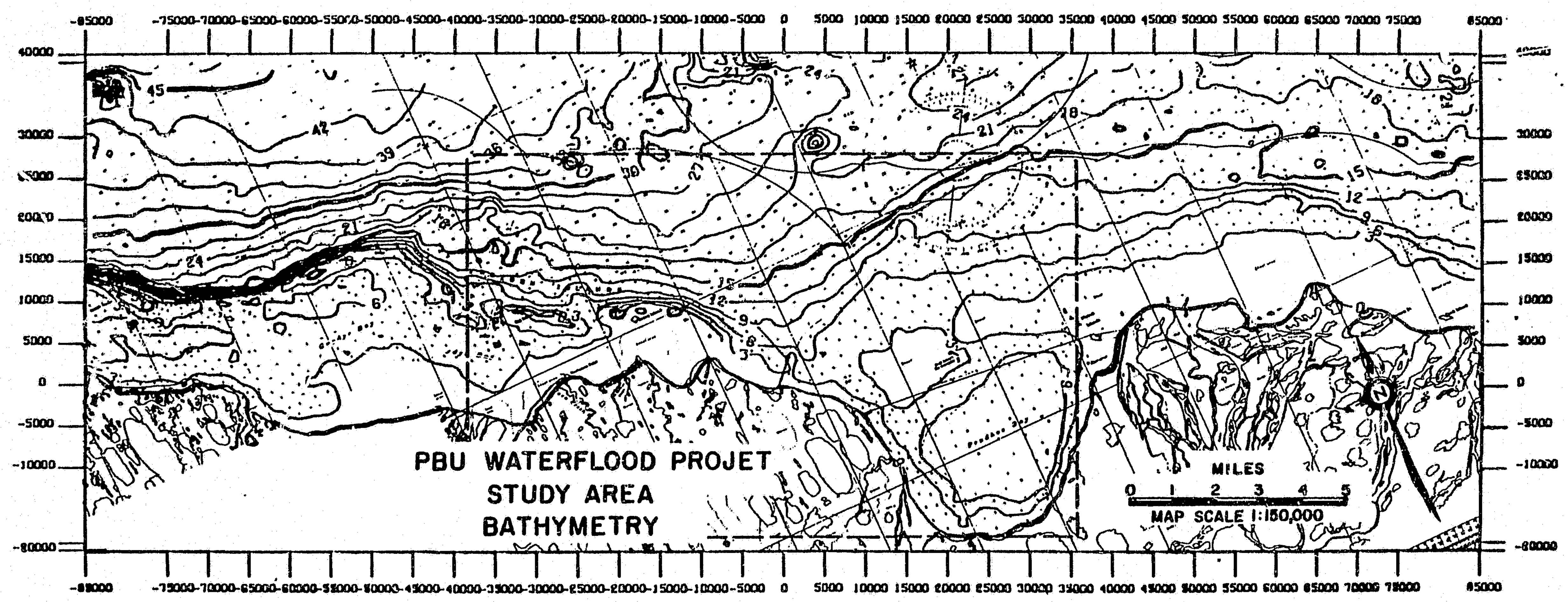


FIGURE D-4 Bathymetric Contours in Study Area

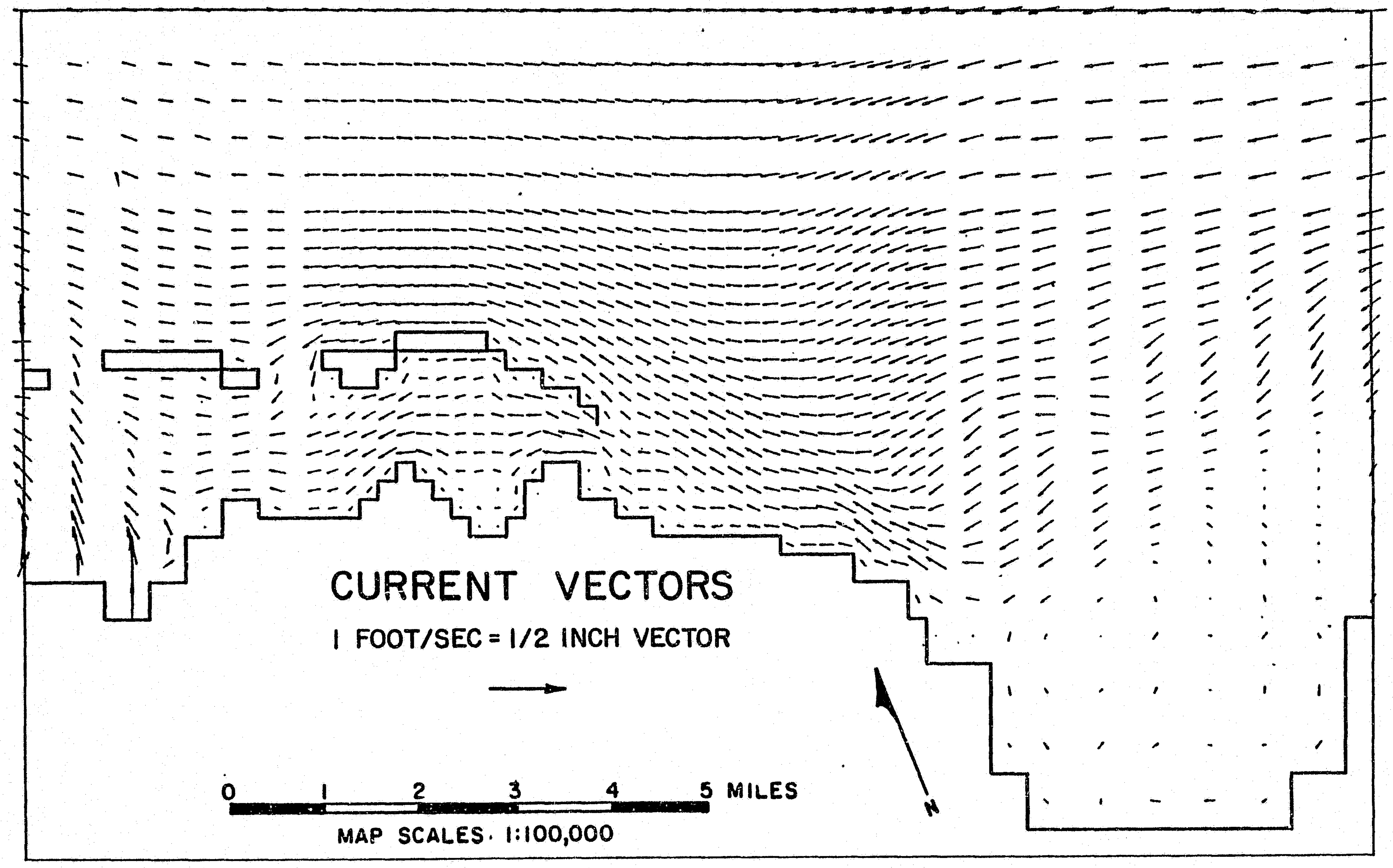


FIGURE D-6

HISTORIC CASE / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

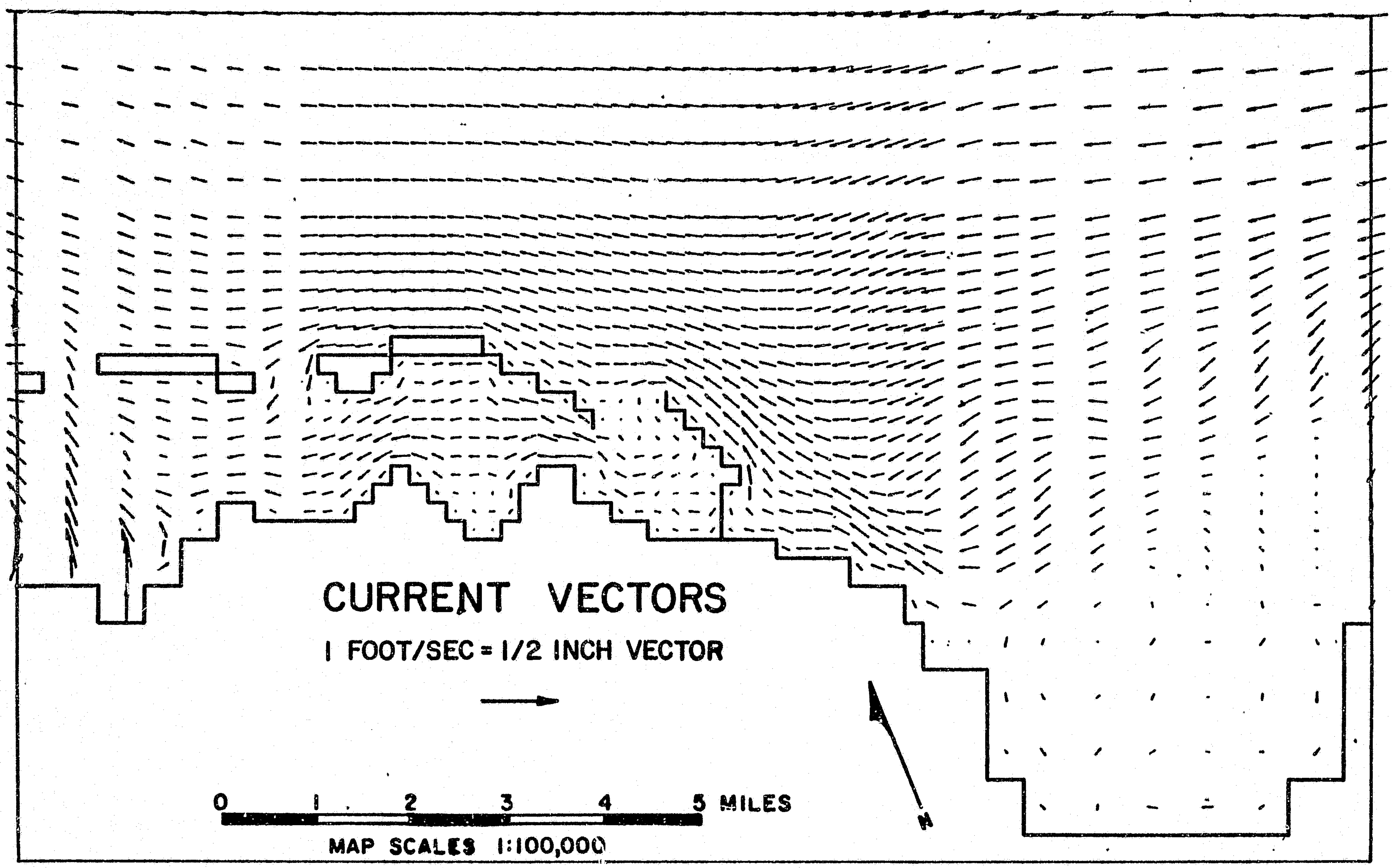


FIGURE D-5

EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

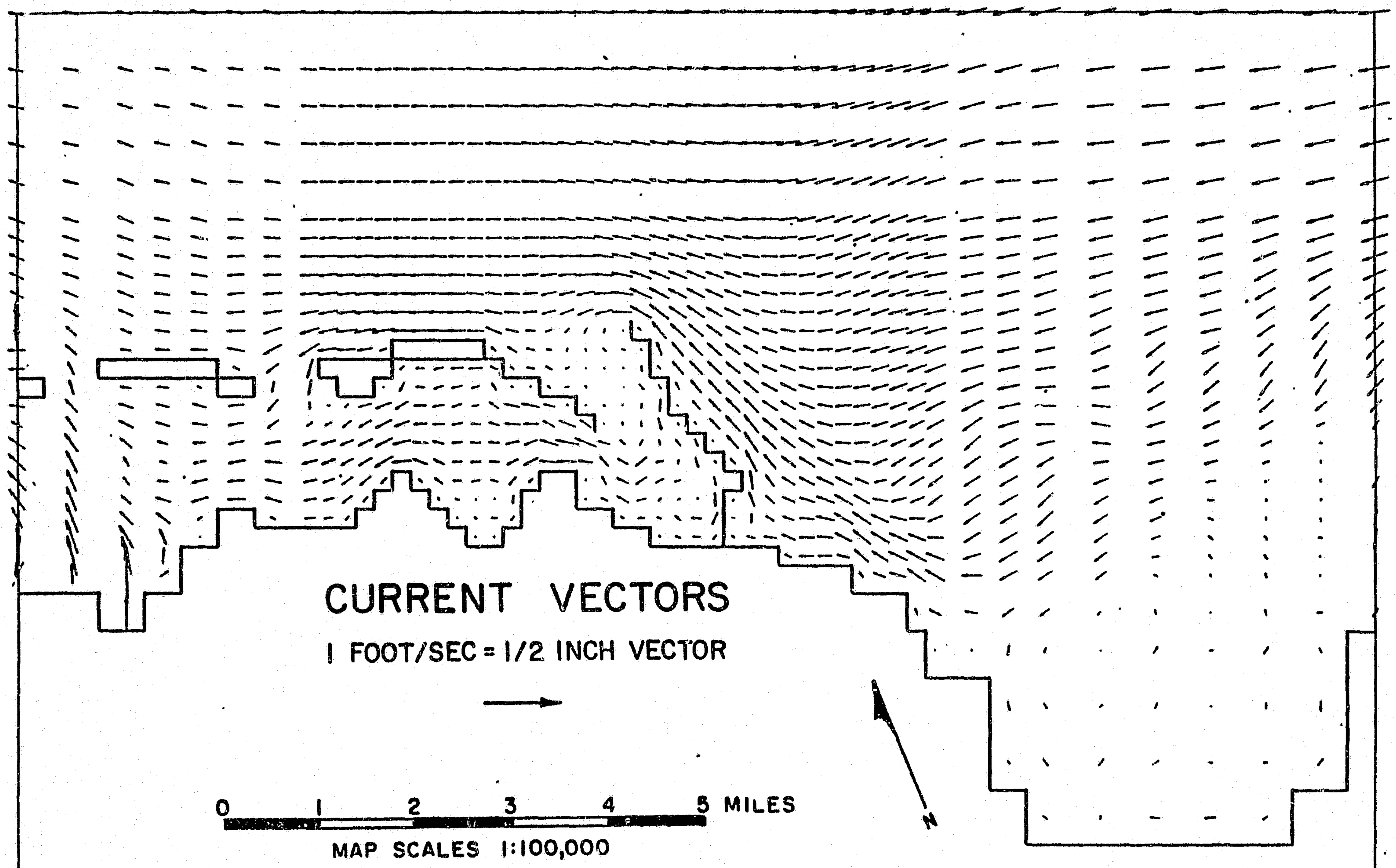


FIGURE D-7

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

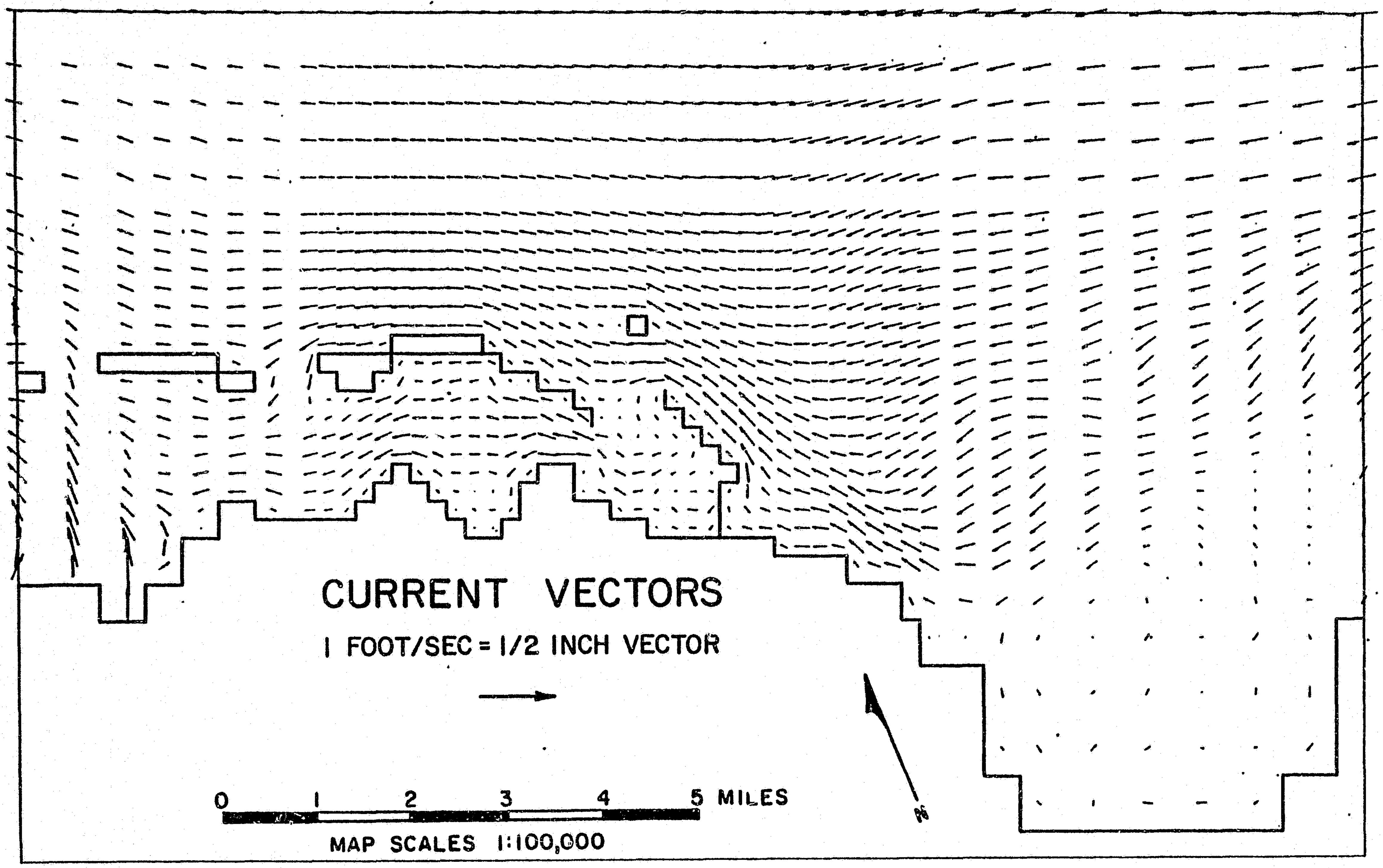


FIGURE D-8

CAUSEWAY WITH ISLAND / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

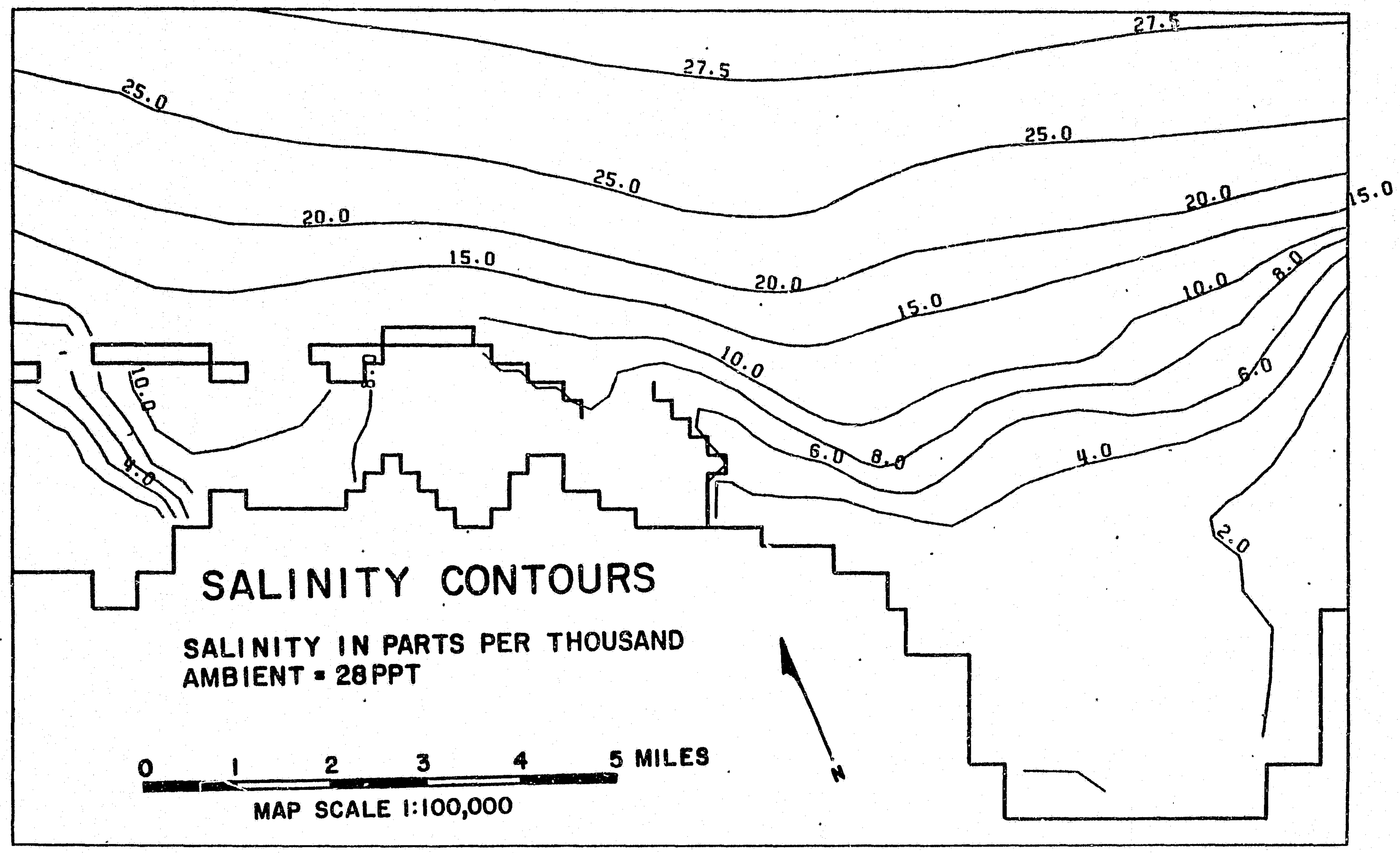


FIGURE D-9

EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

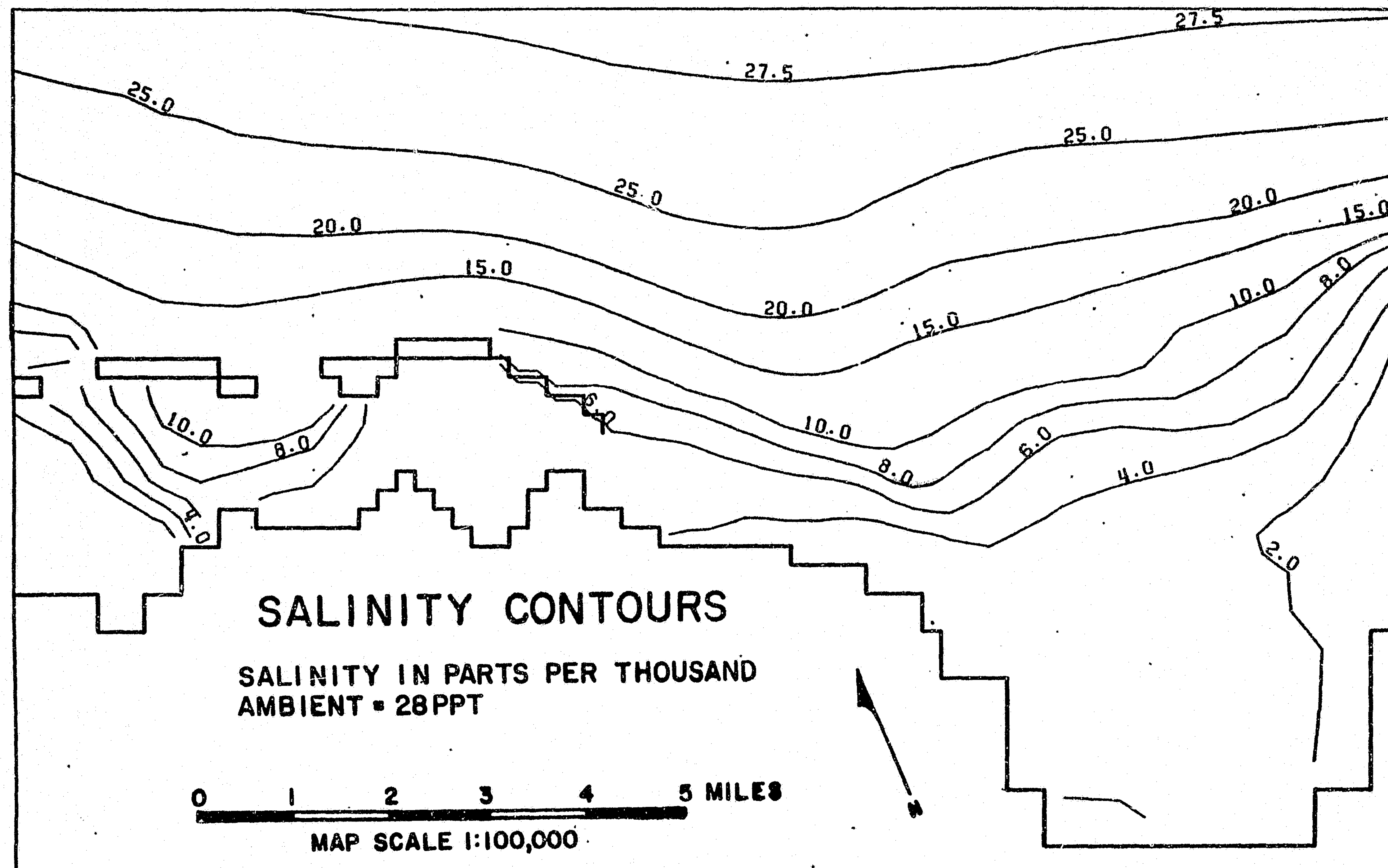


FIGURE D-10

HISTORIC CASE / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

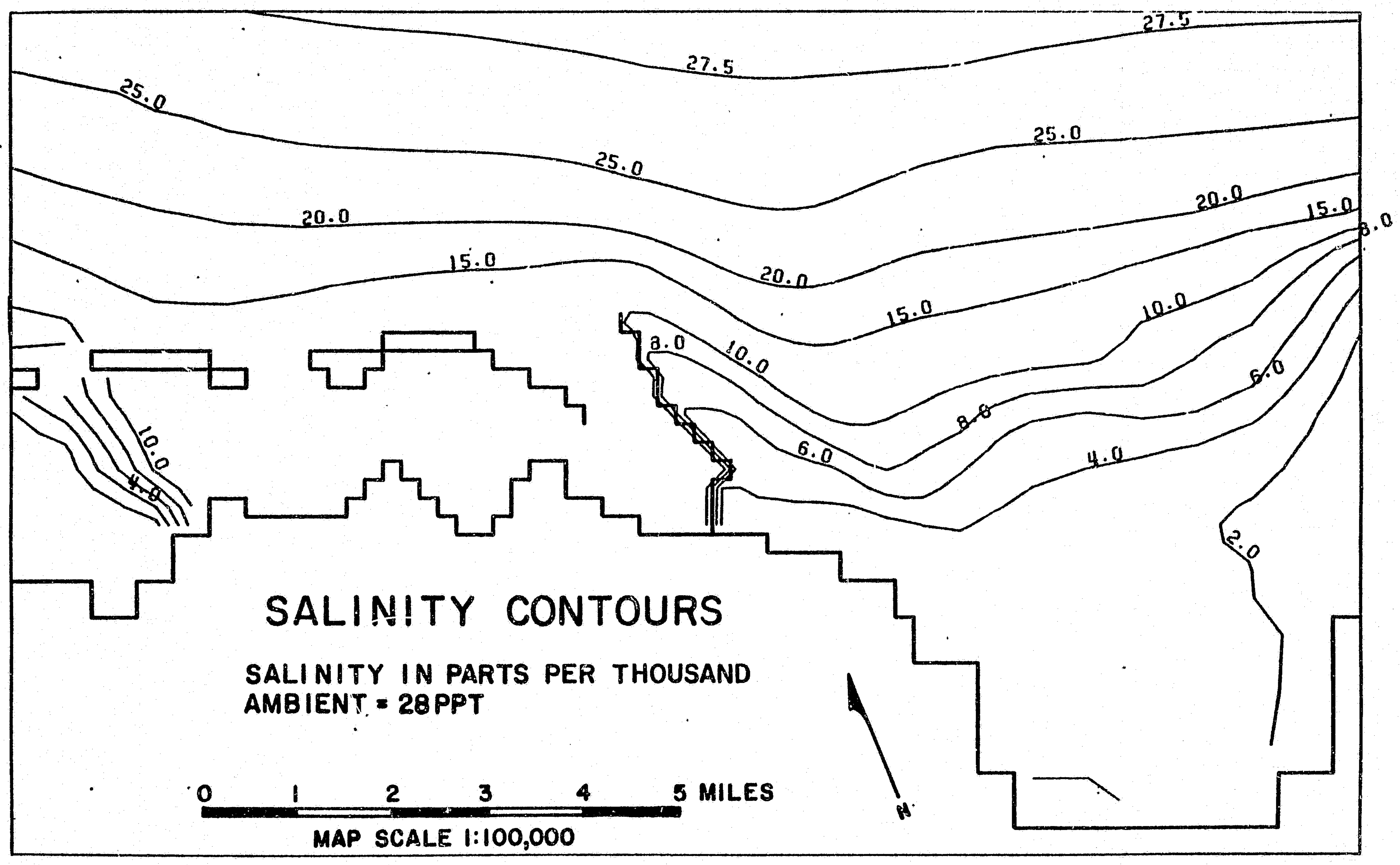


FIGURE D-11

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

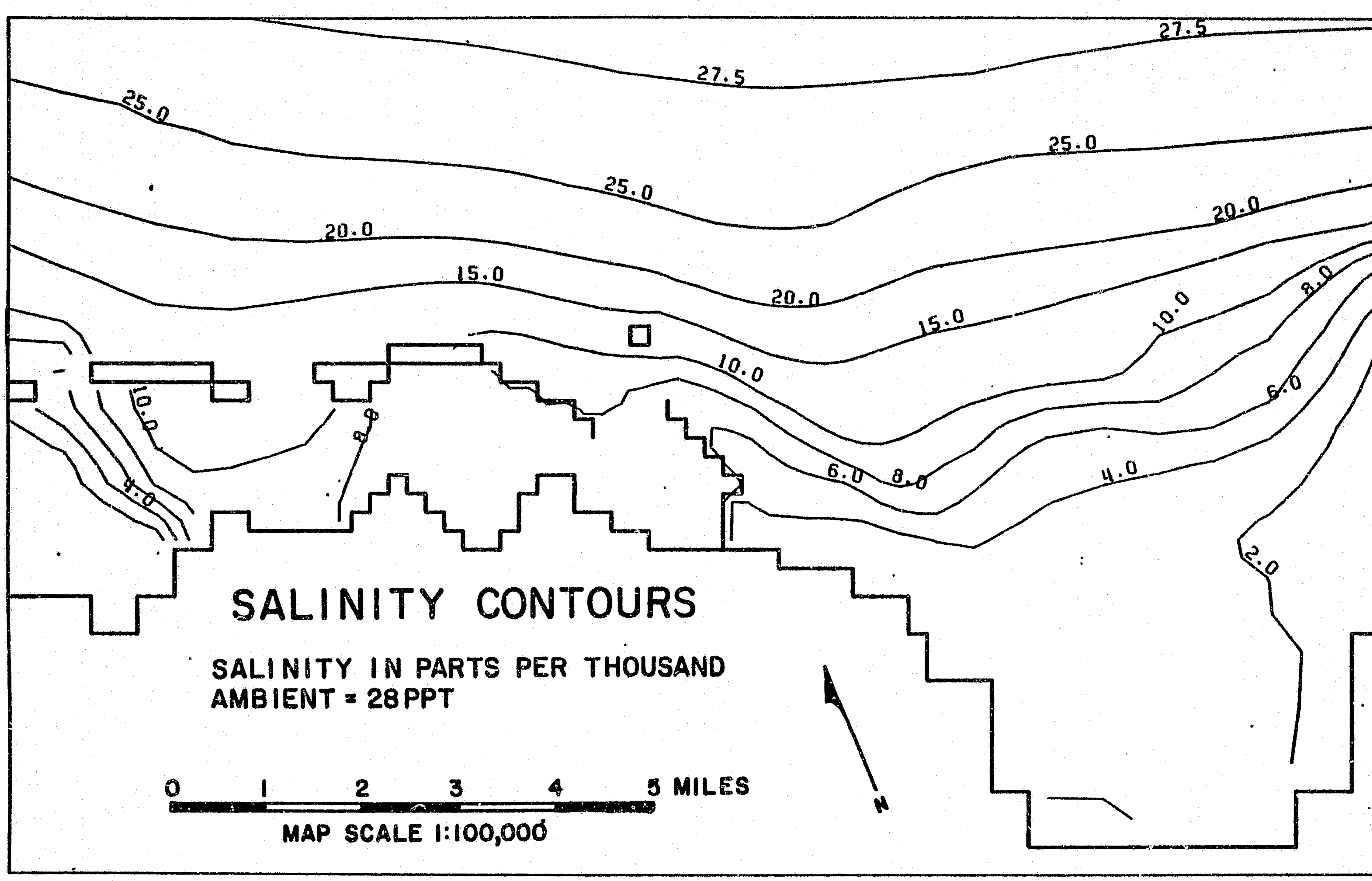


FIGURE D-12

CAUSEWAY WITH ISLAND / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

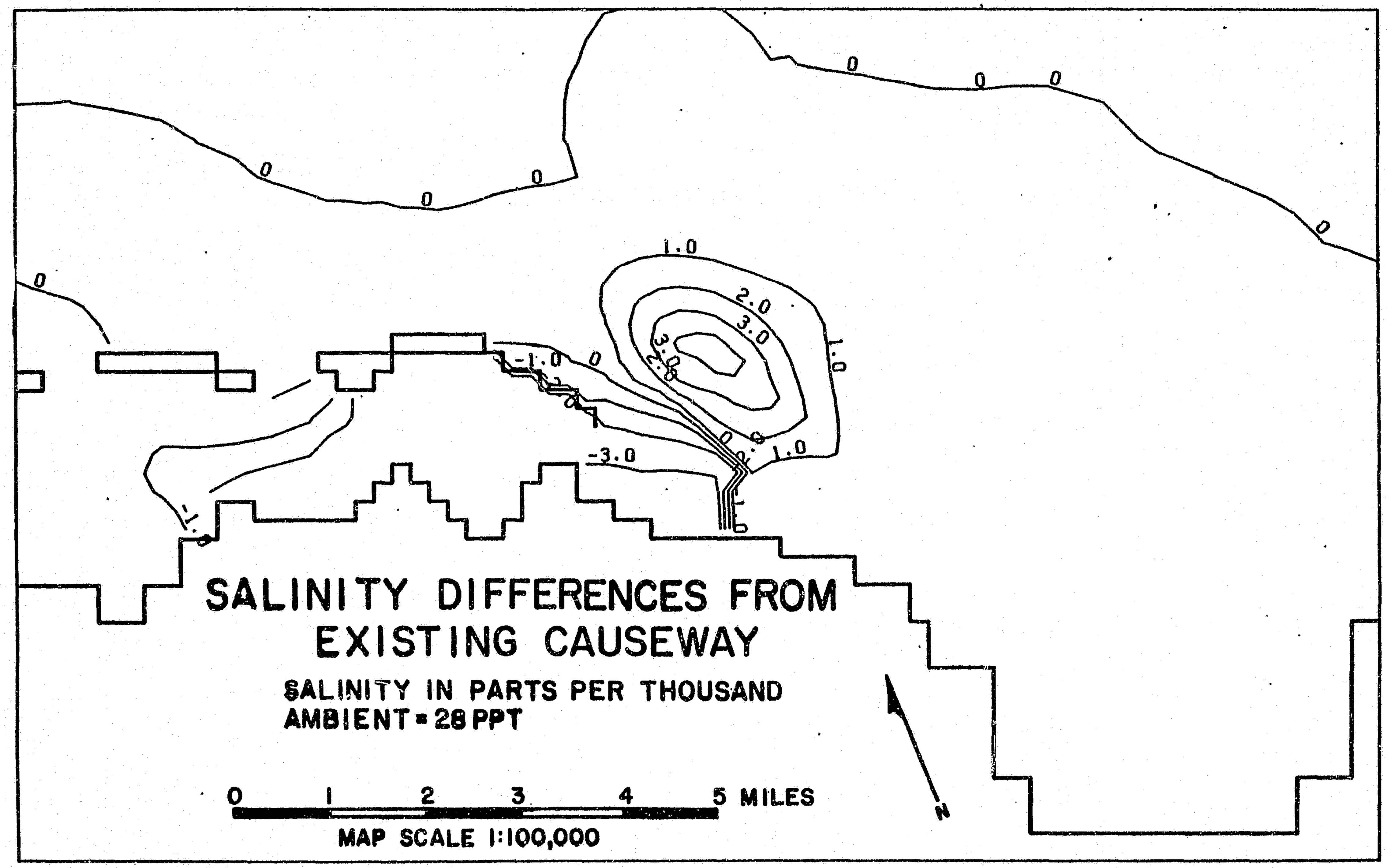


FIGURE D-13

HISTORIC CASE / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

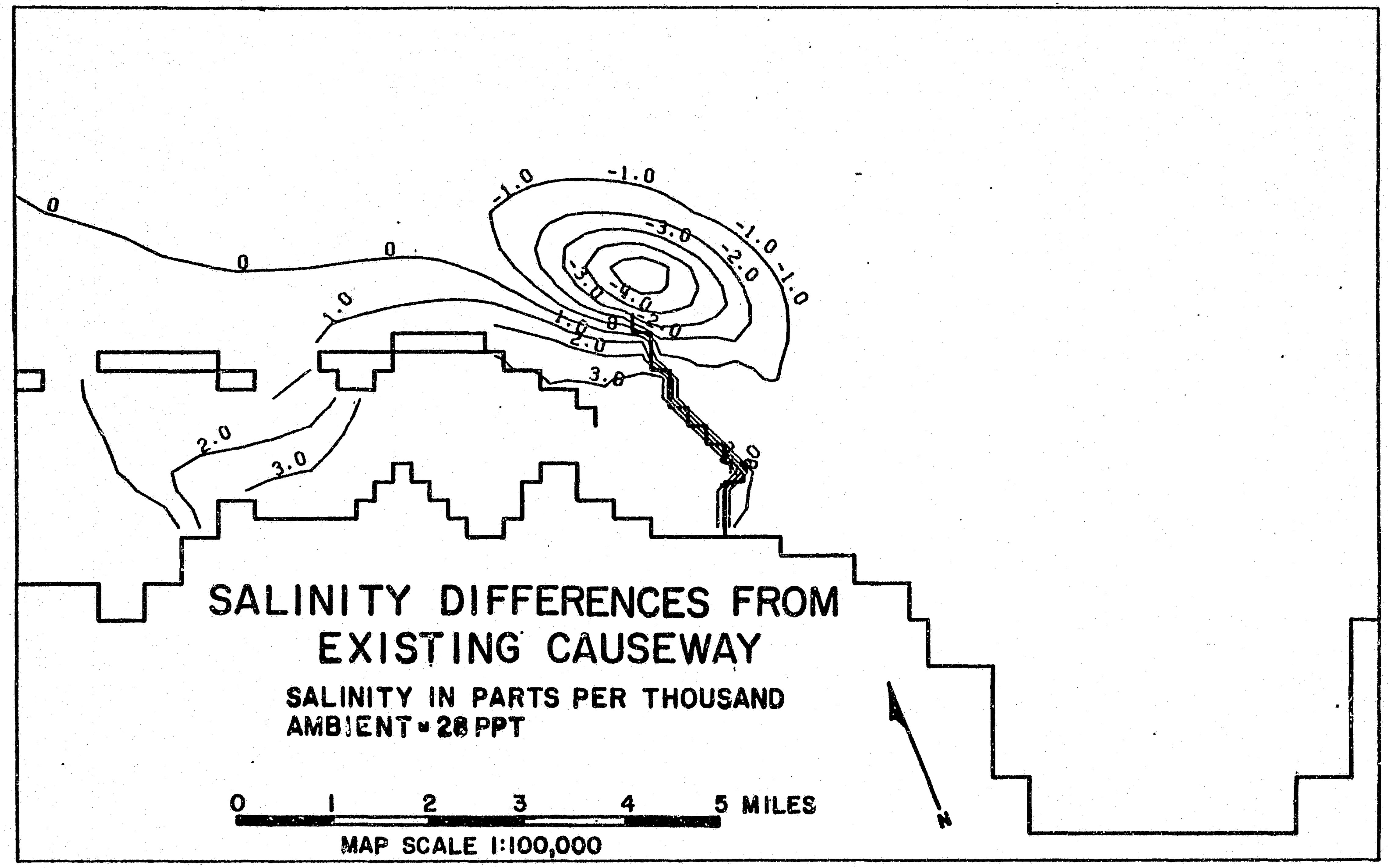


FIGURE D-14

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

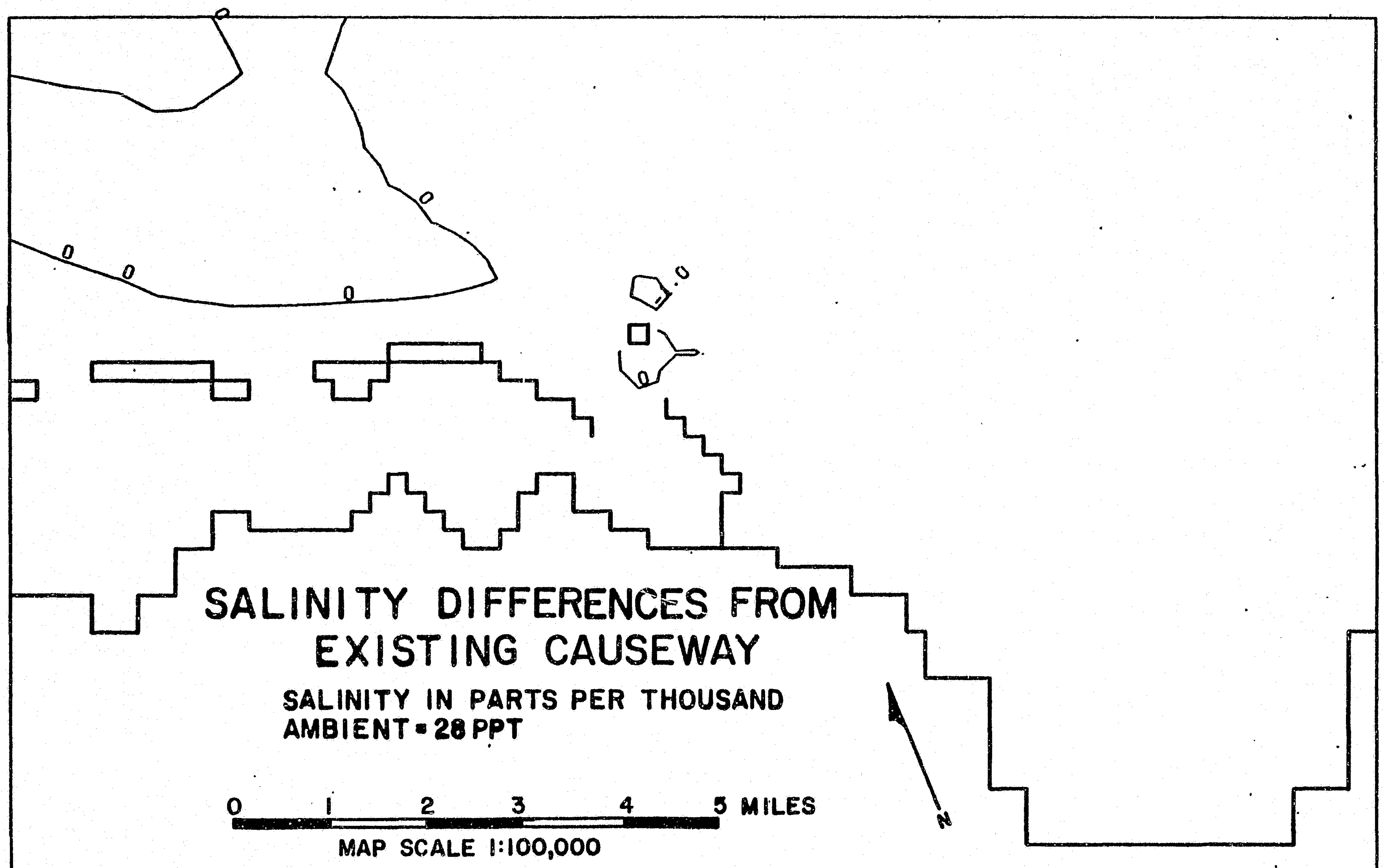


FIGURE D-15

CAUSEWAY WITH ISLAND / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 60 DEG

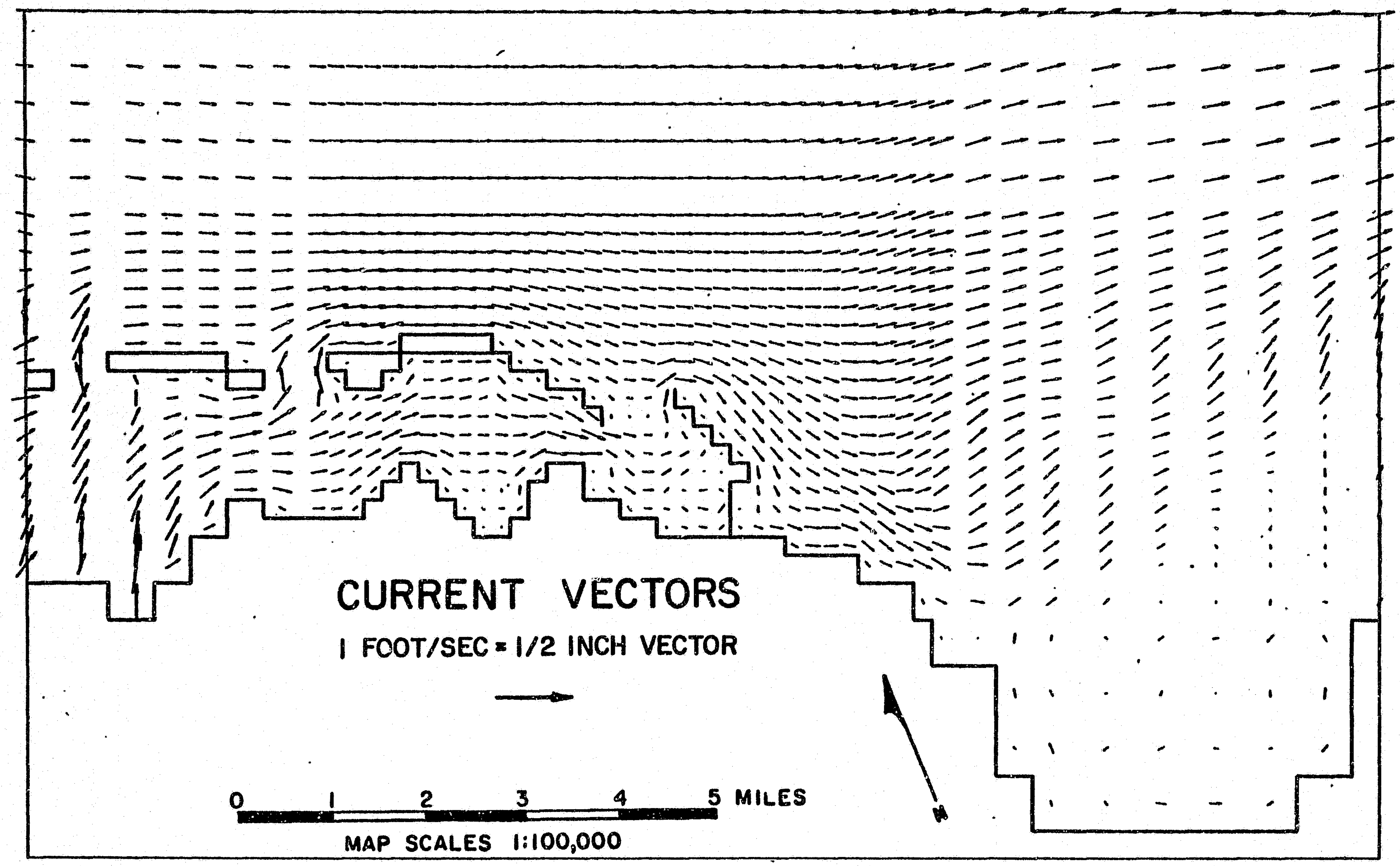


FIGURE D-16
EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

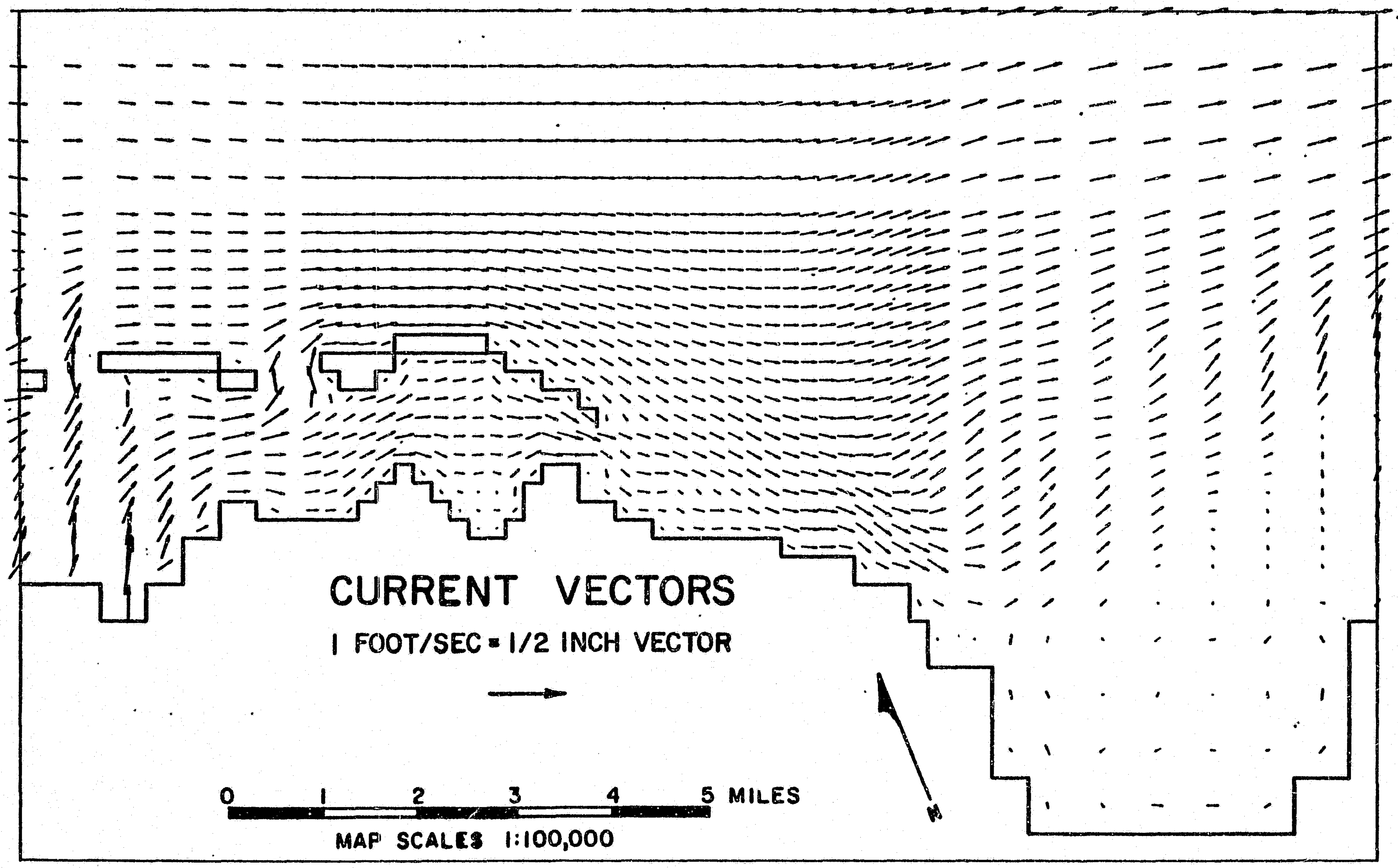


FIGURE D-17

HISTORIC CASE / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

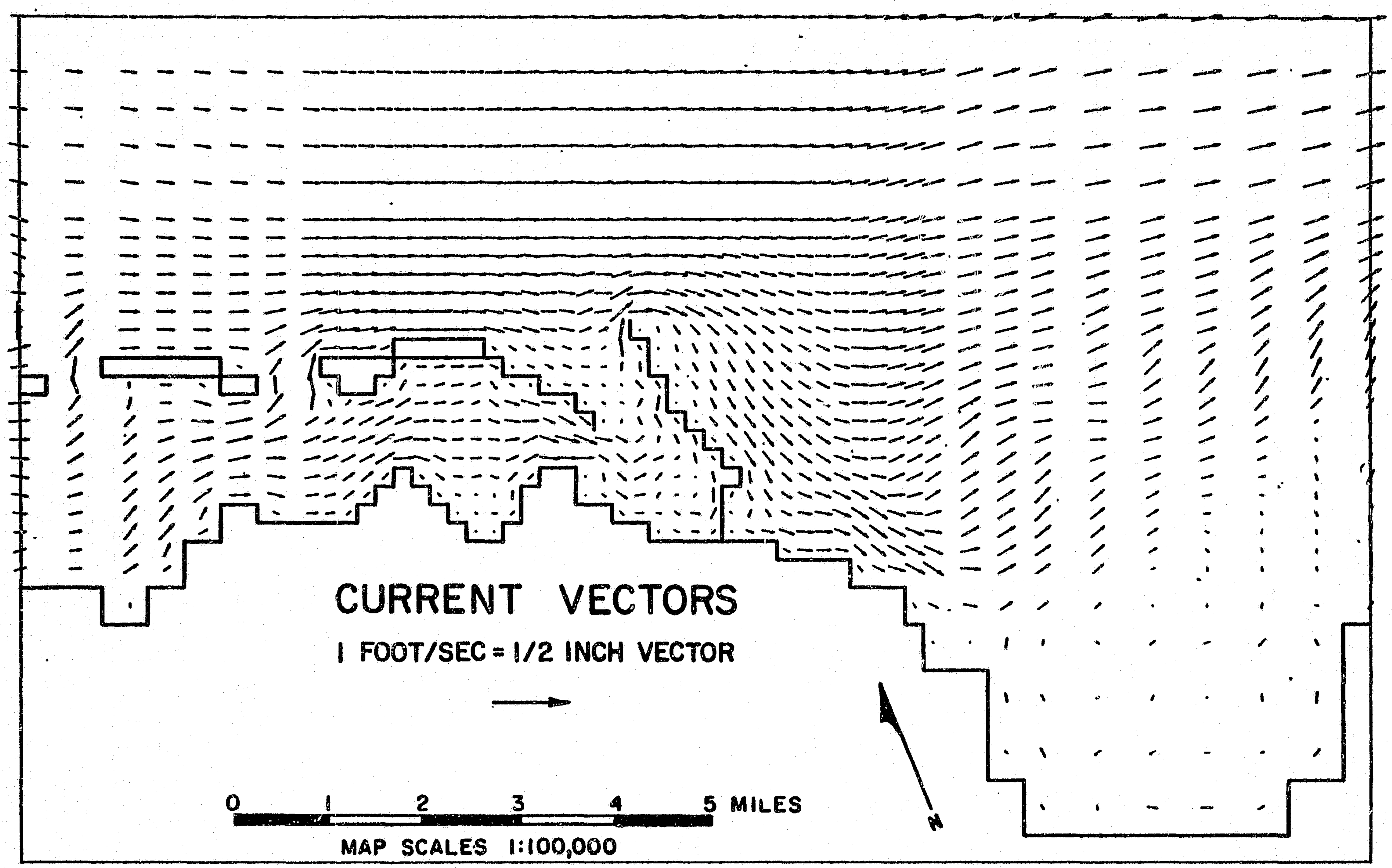


FIGURE D-18

EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 240 DEG

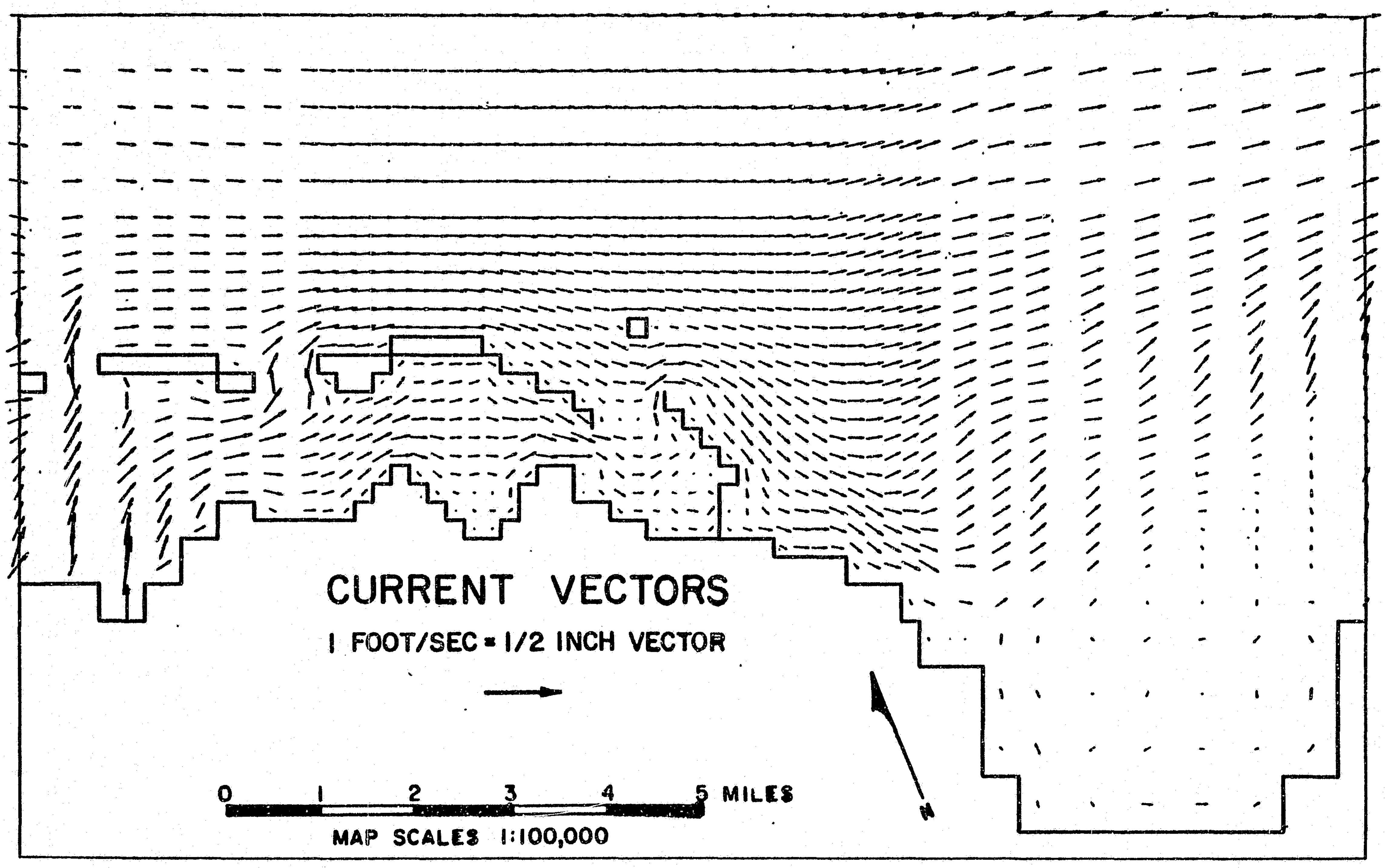


FIGURE D-19

CAUSEWAY WITH ISLAND / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

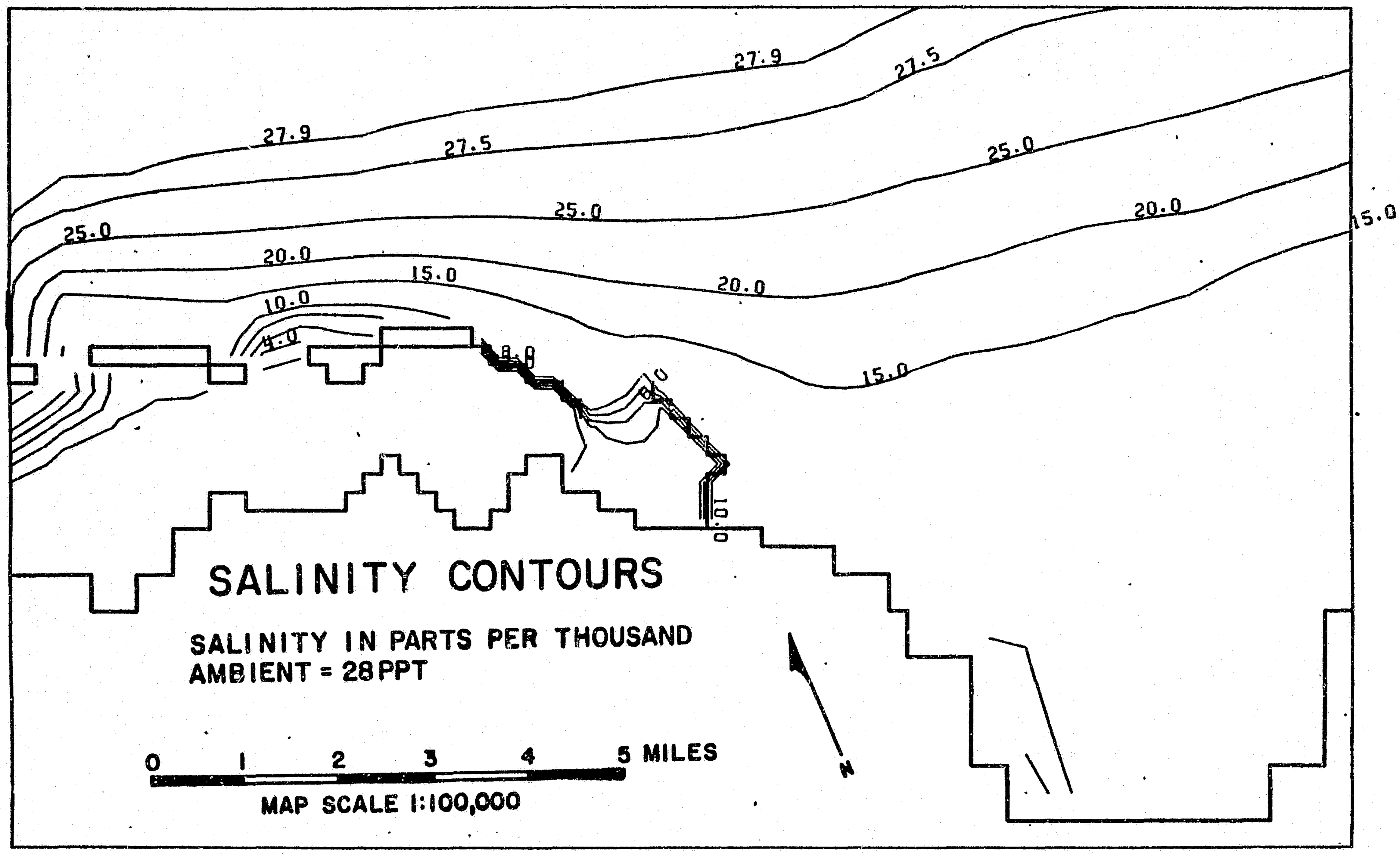


FIGURE D-20

EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

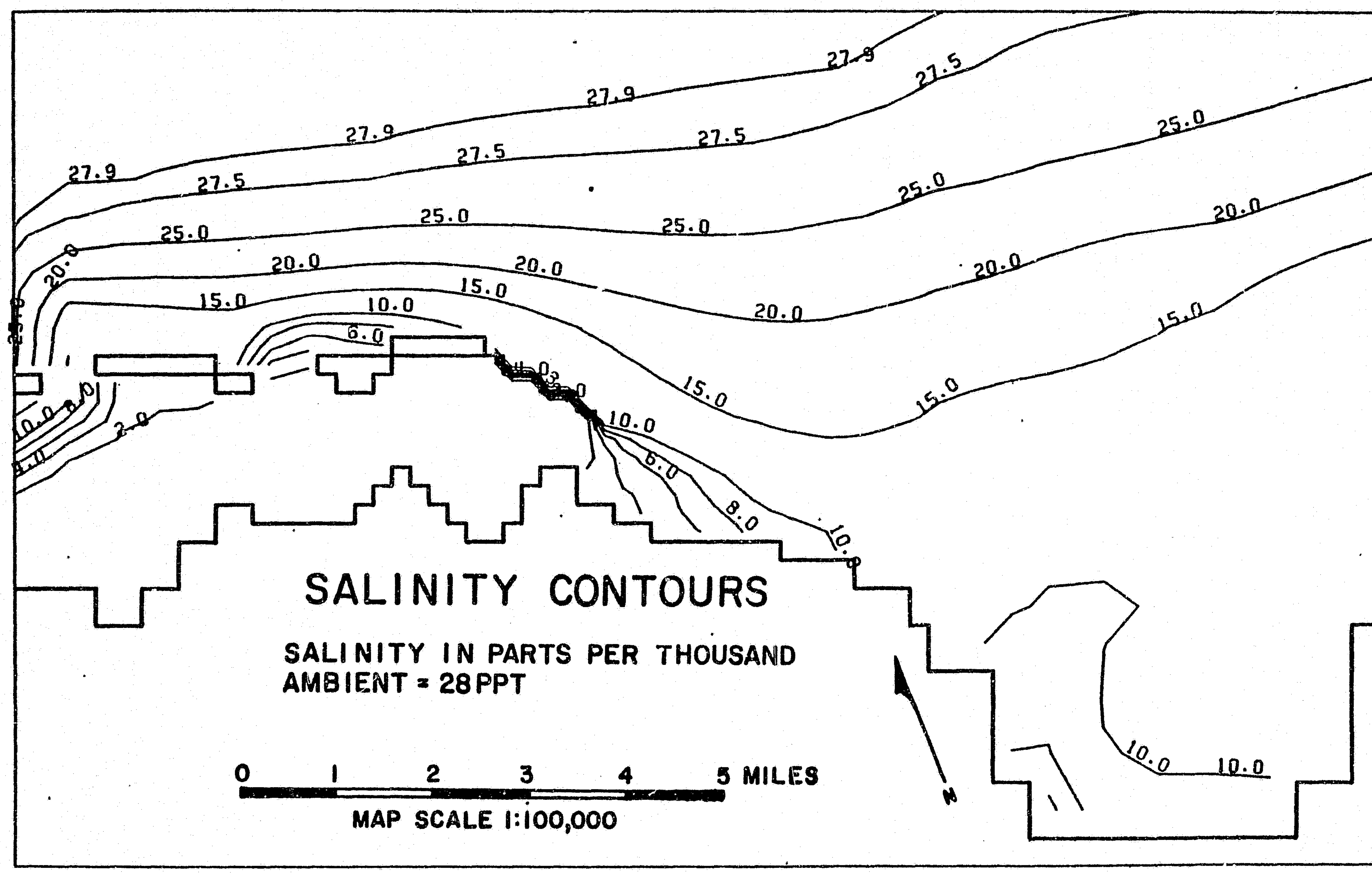


FIGURE D-21

HISTORIC CASE / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

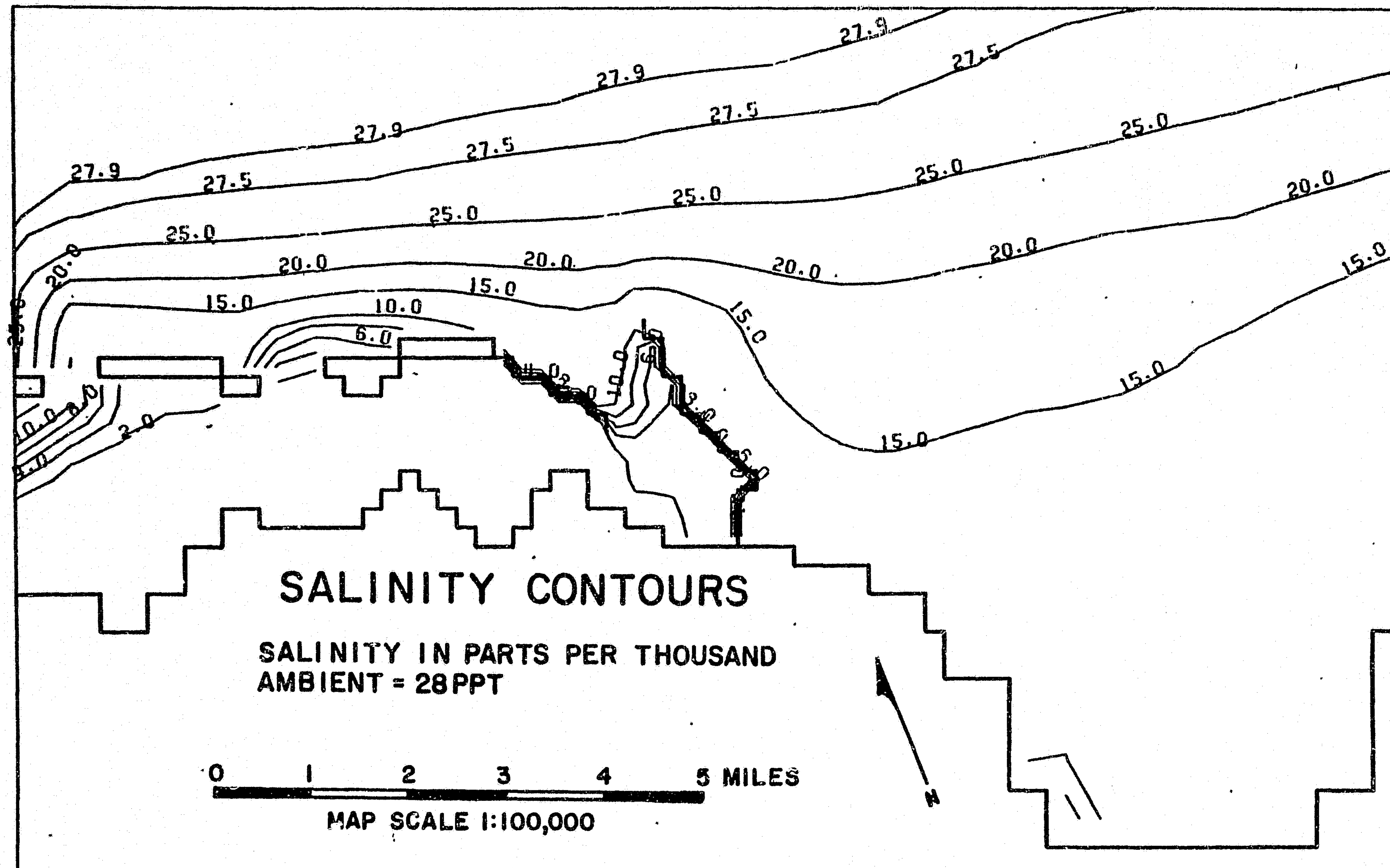


FIGURE D-22

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

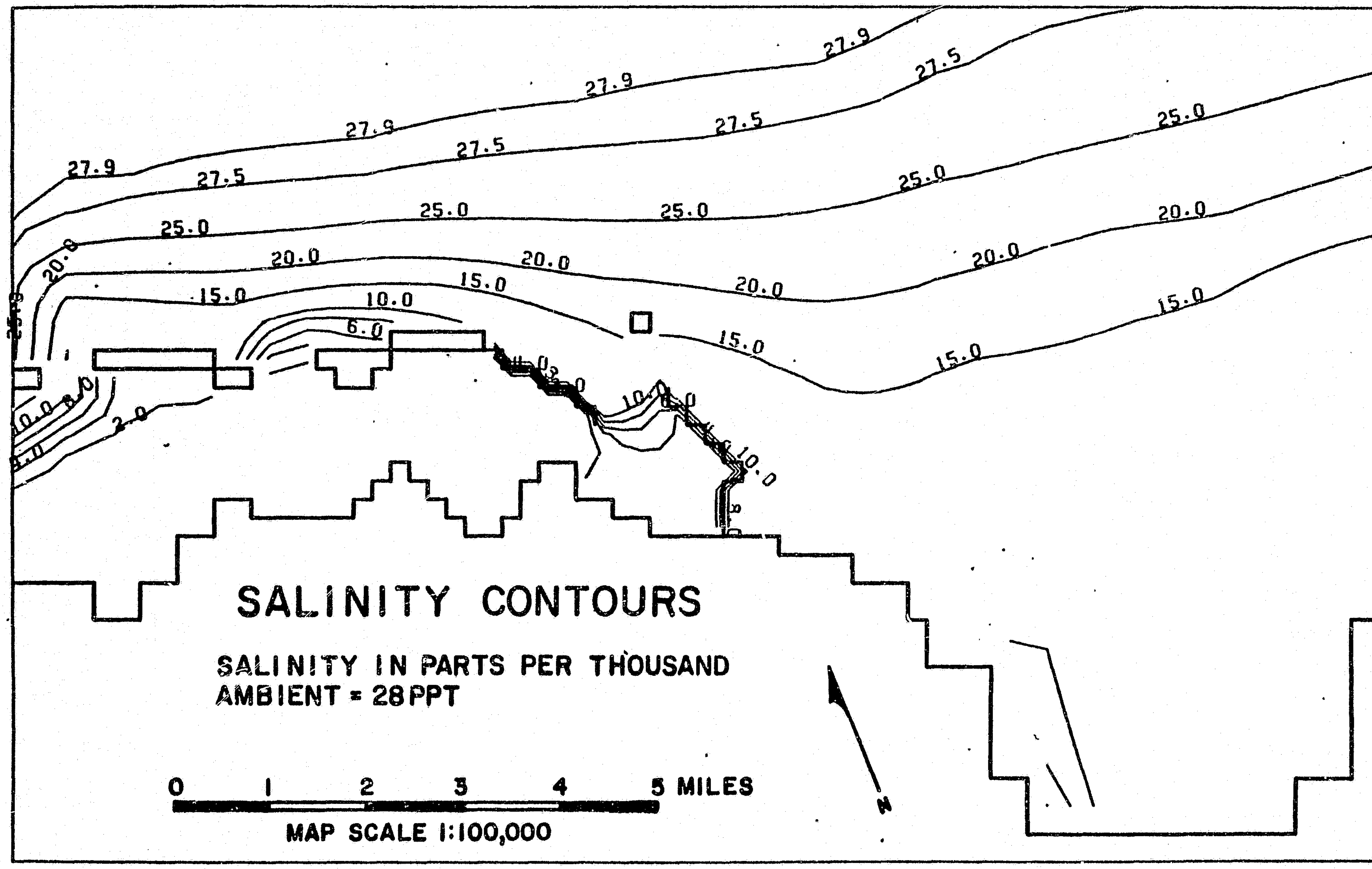


FIGURE D-23

CAUSEWAY WITH ISLAND / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

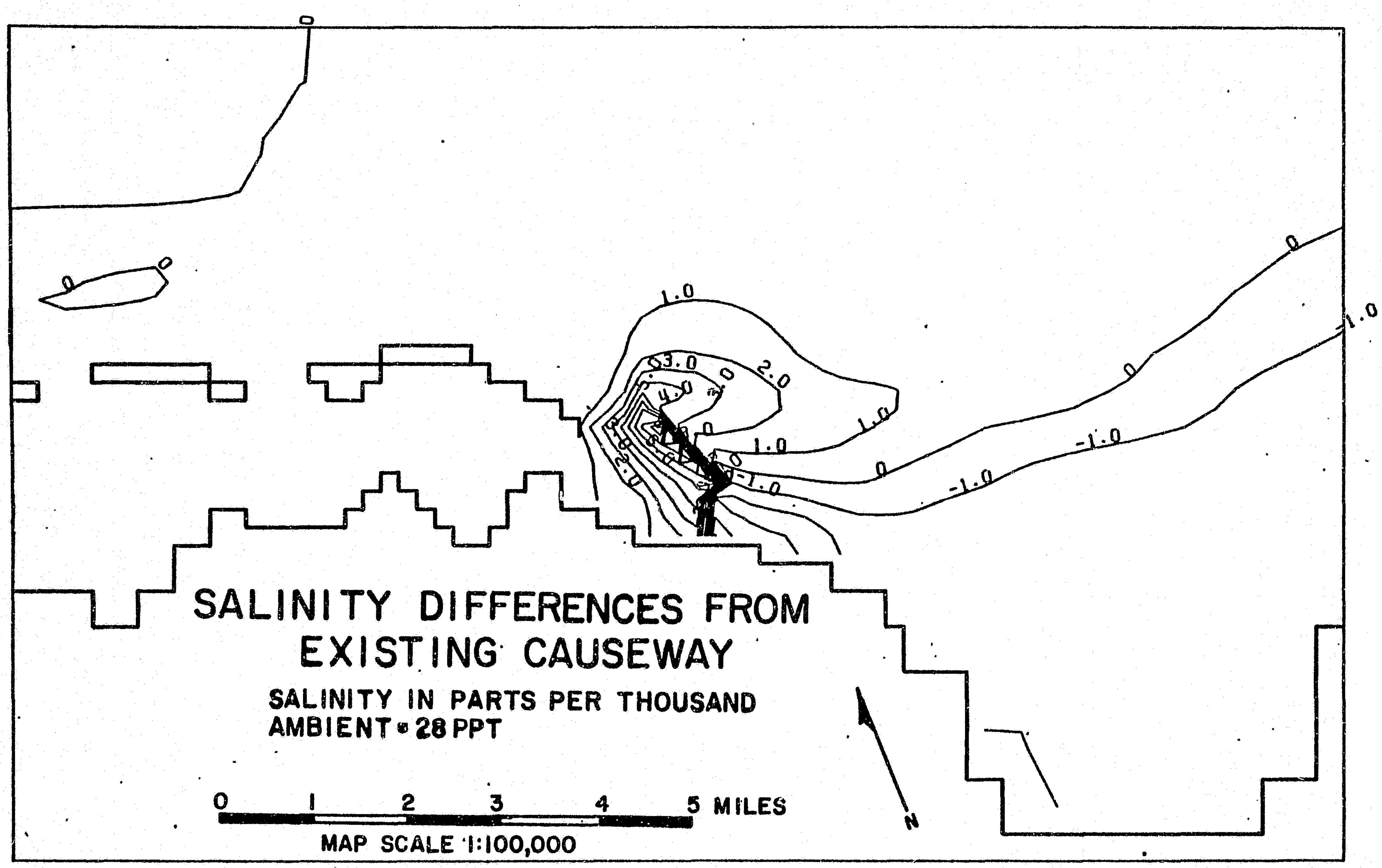


FIGURE D-24

HISTORIC CASE / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

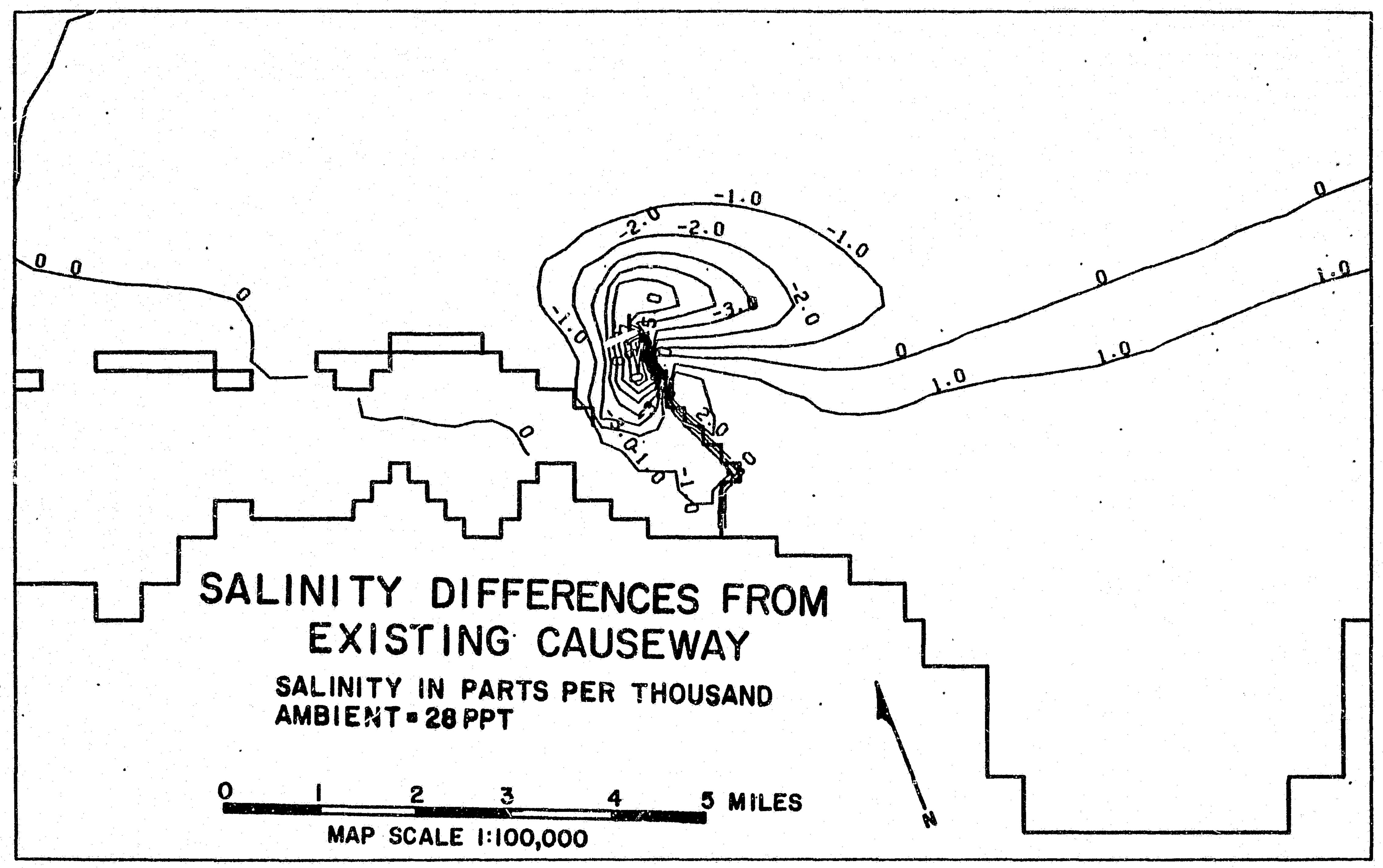


FIGURE D-25

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

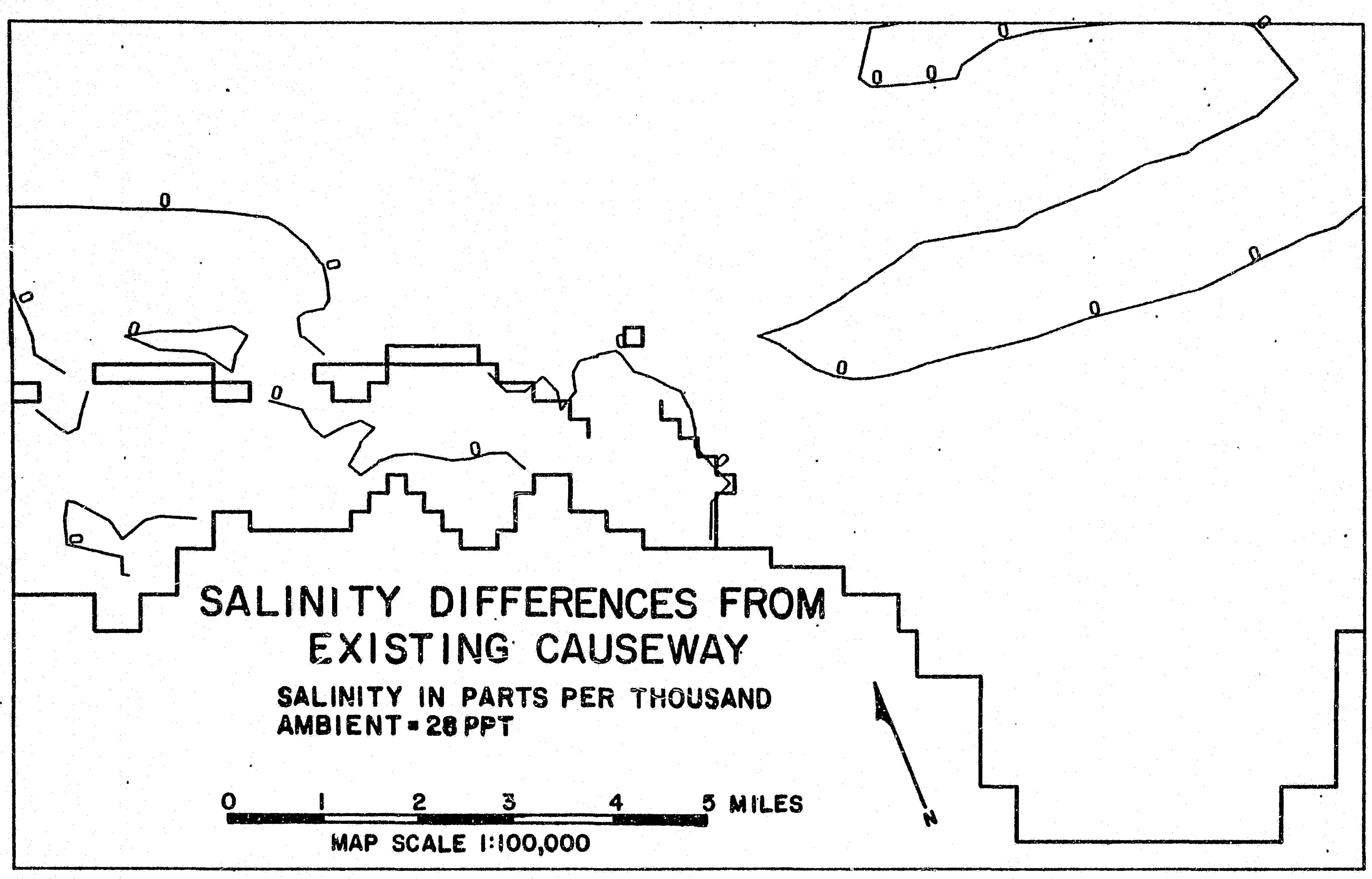


FIGURE D-26

CAUSEWAY WITH ISLAND / REPRESENTATIVE HI FLOW / WIND 10 KNOTS AT 240 DEG

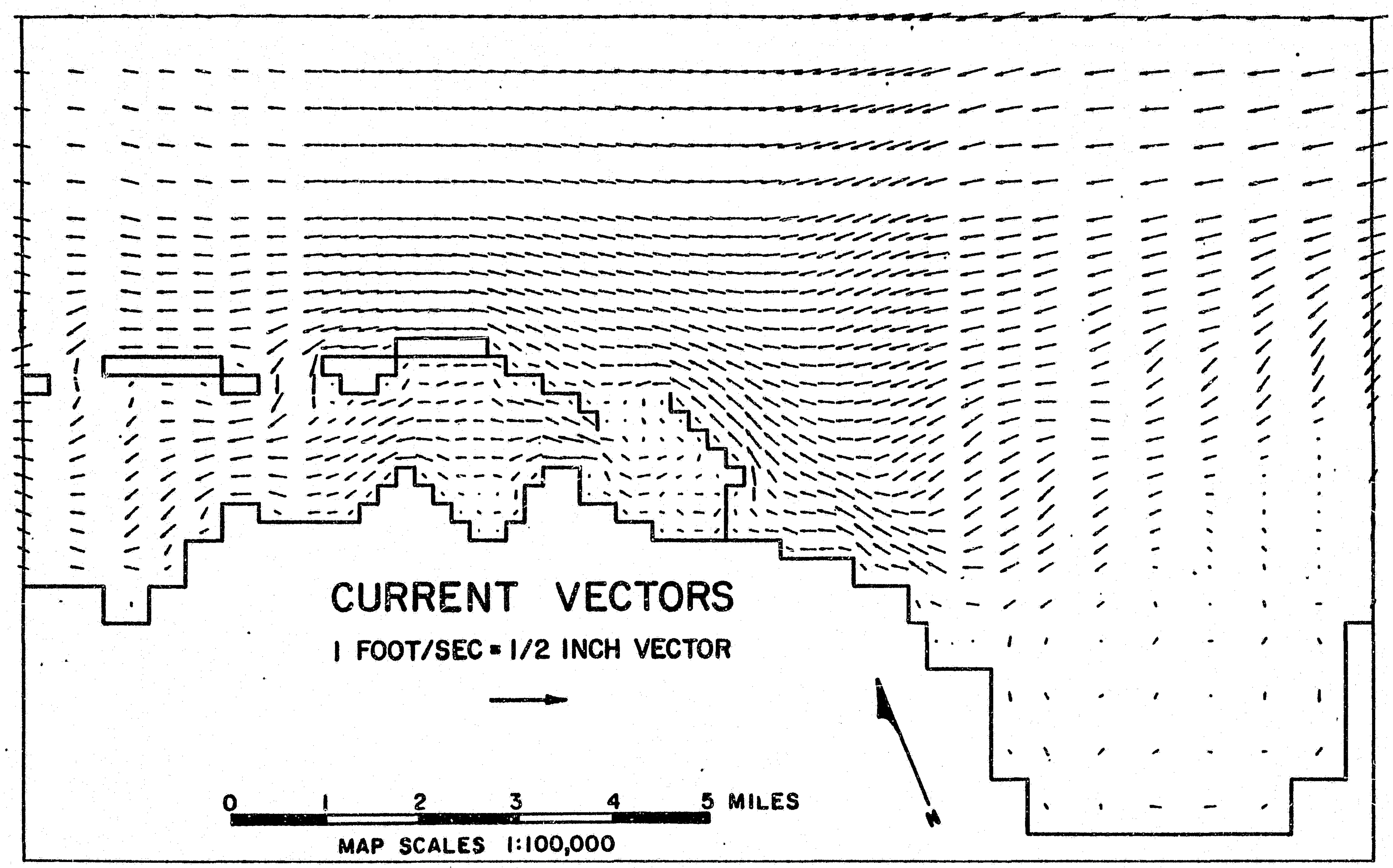


FIGURE D-27

EXISTING CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

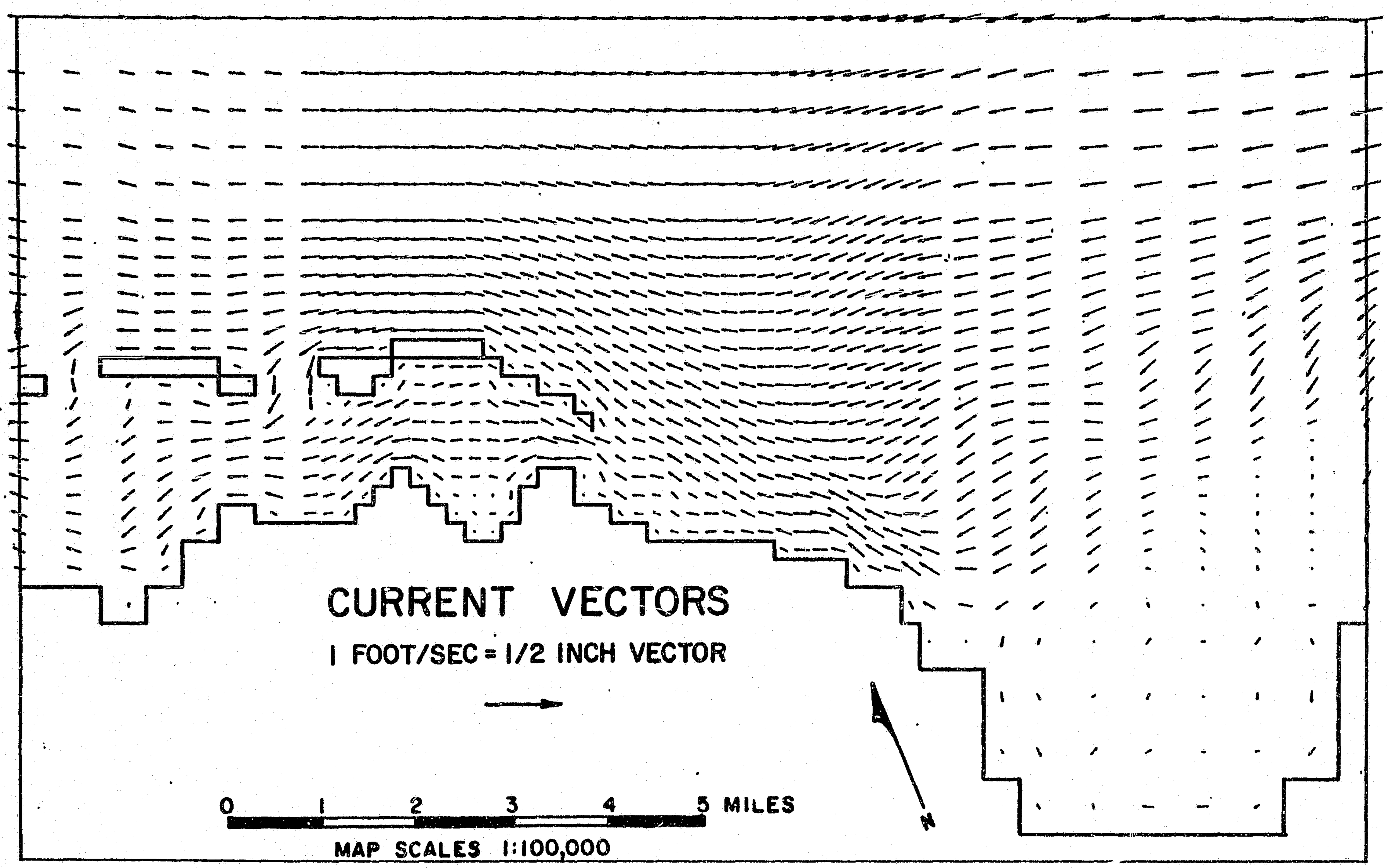


FIGURE D-28

HISTORIC CASE / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

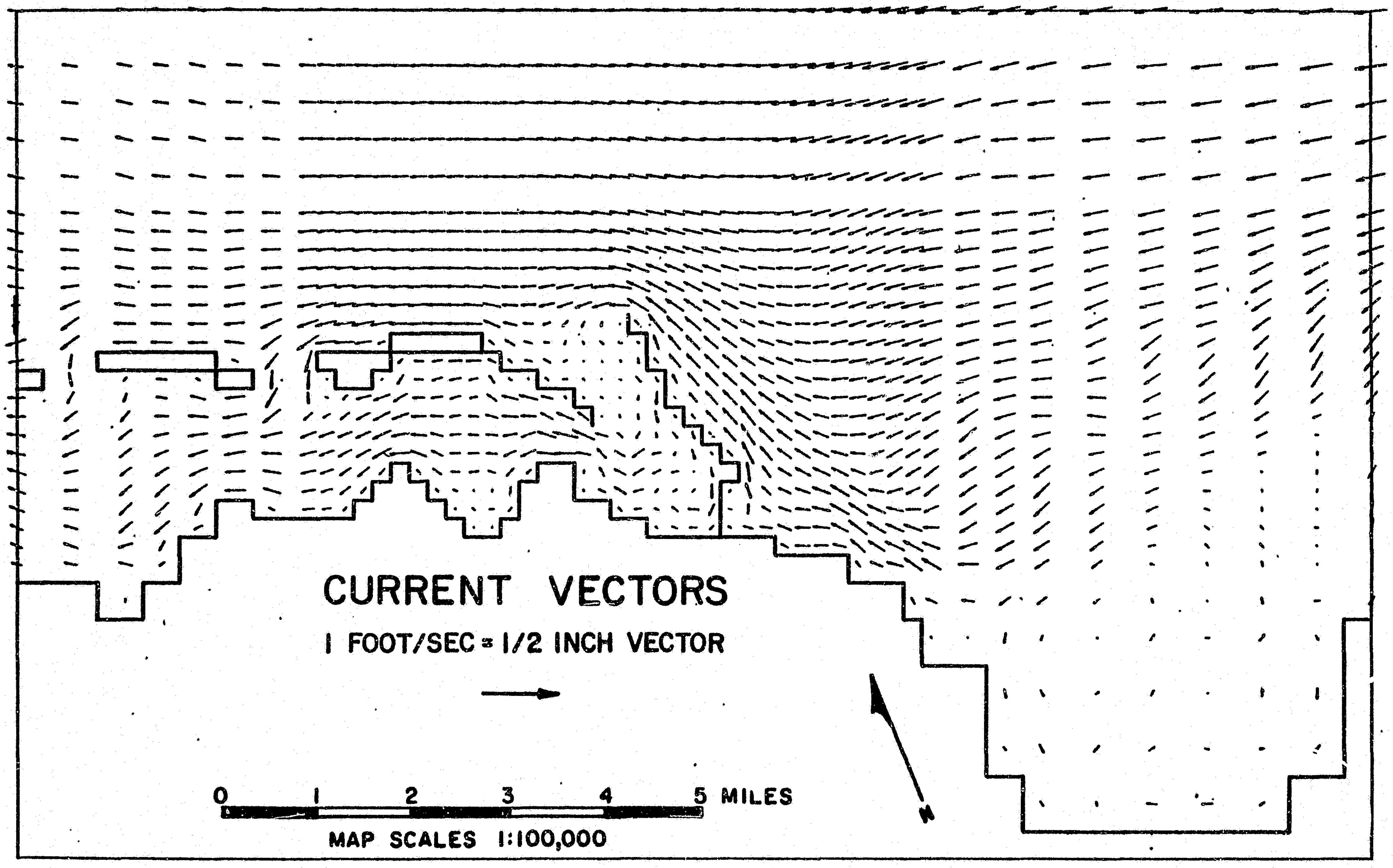


FIGURE D-29

EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

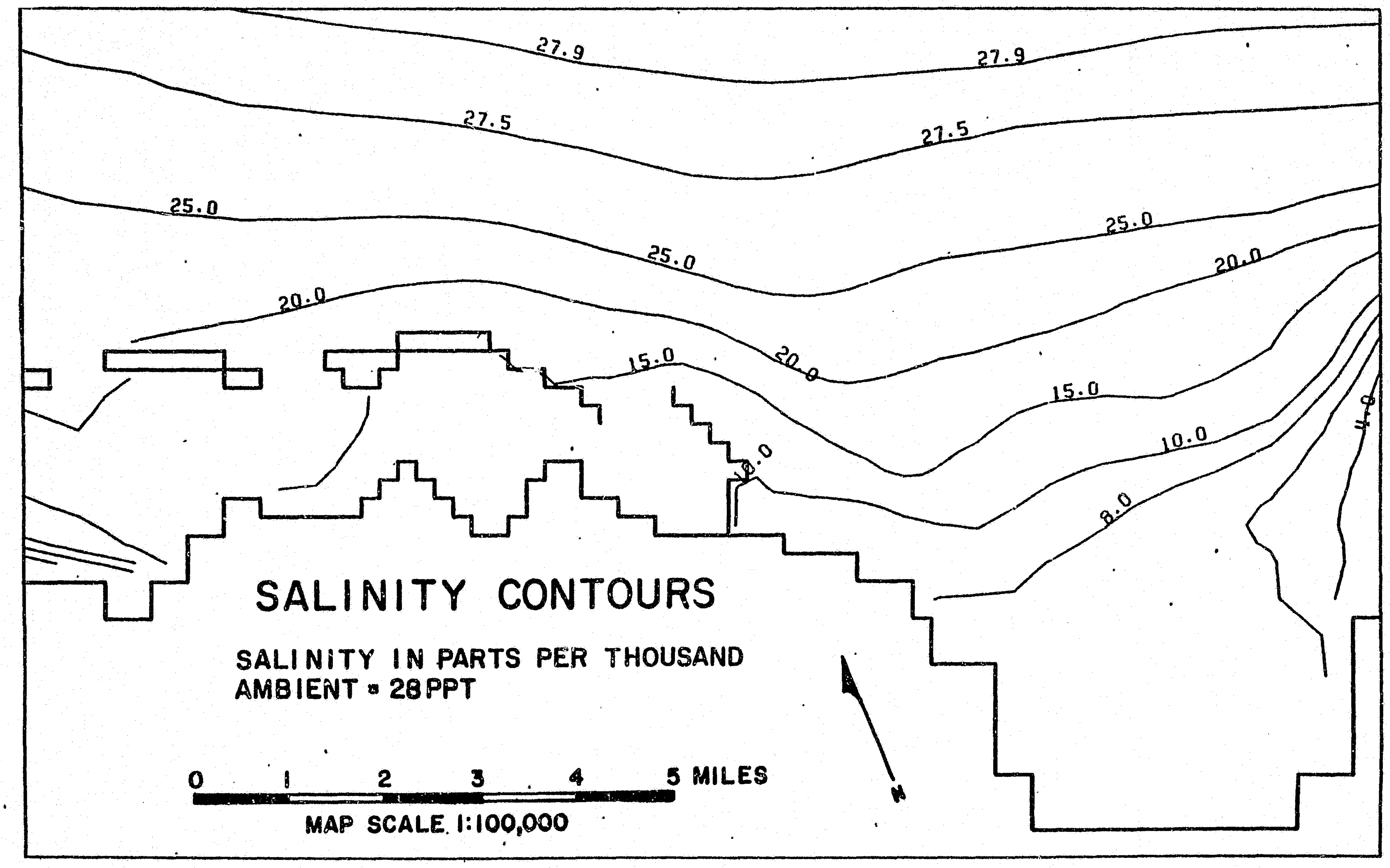


FIGURE D-30

EXISTING CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

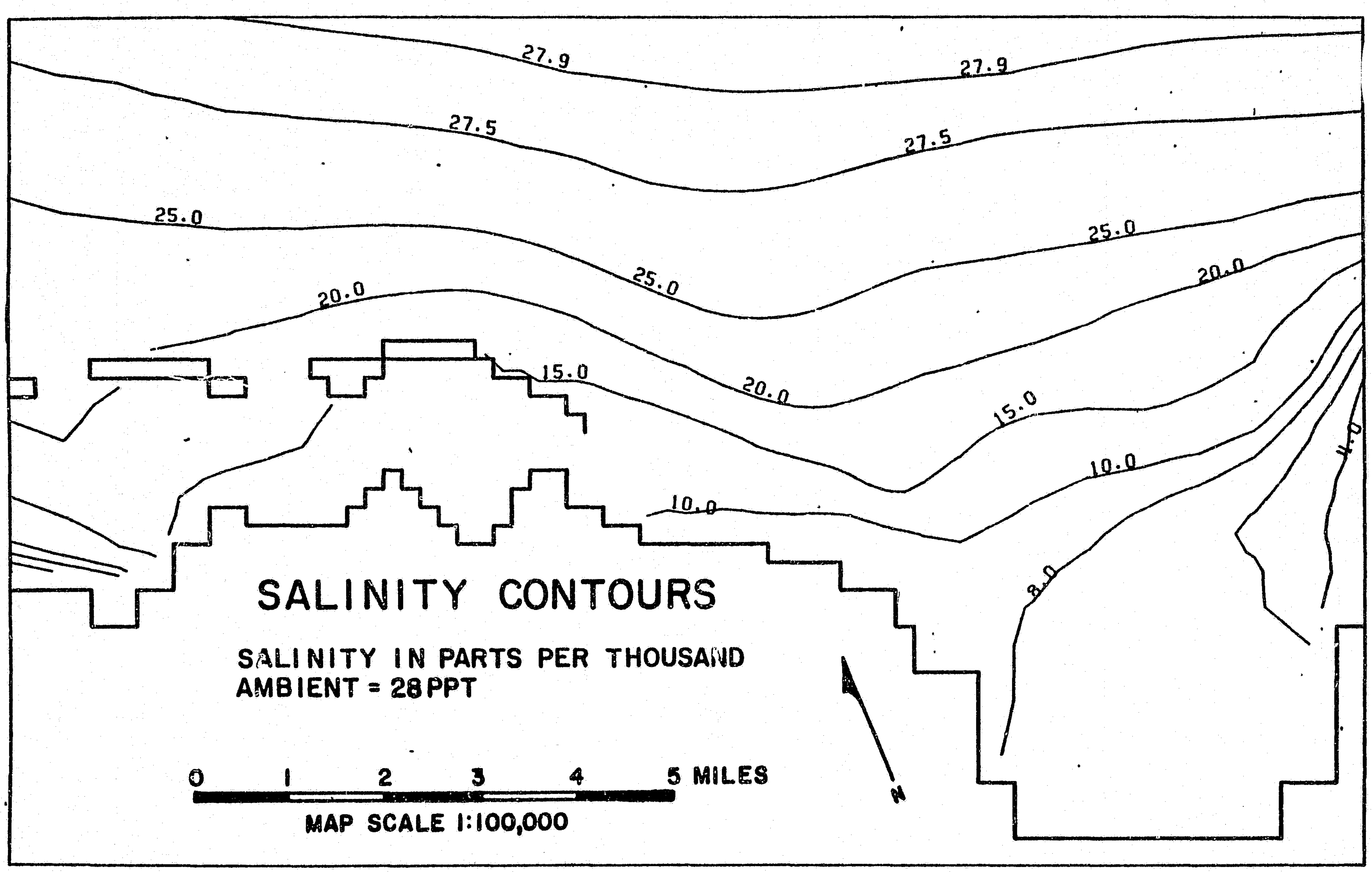


FIGURE D-31

HISTORIC CASE / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

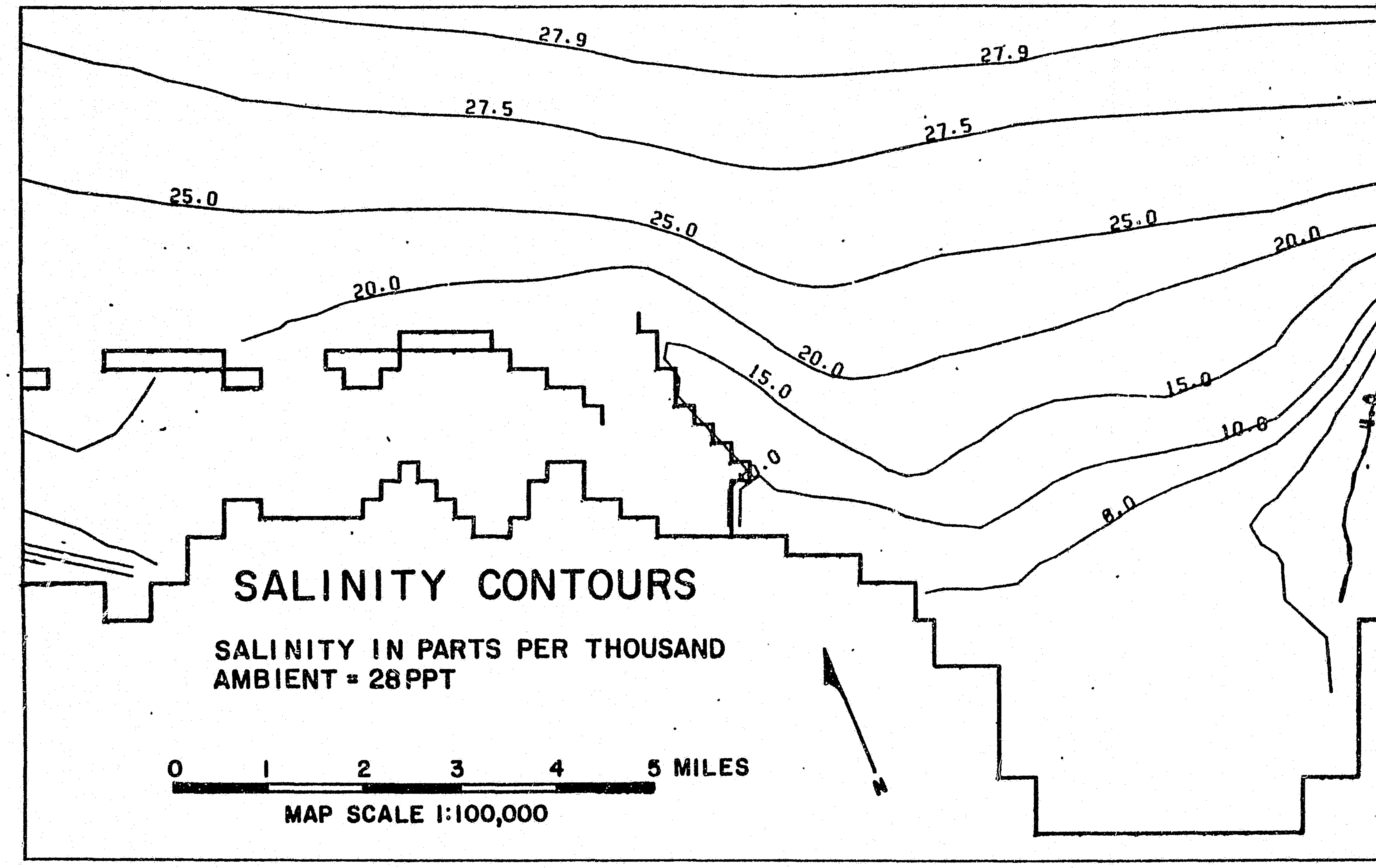


FIGURE D-32

EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

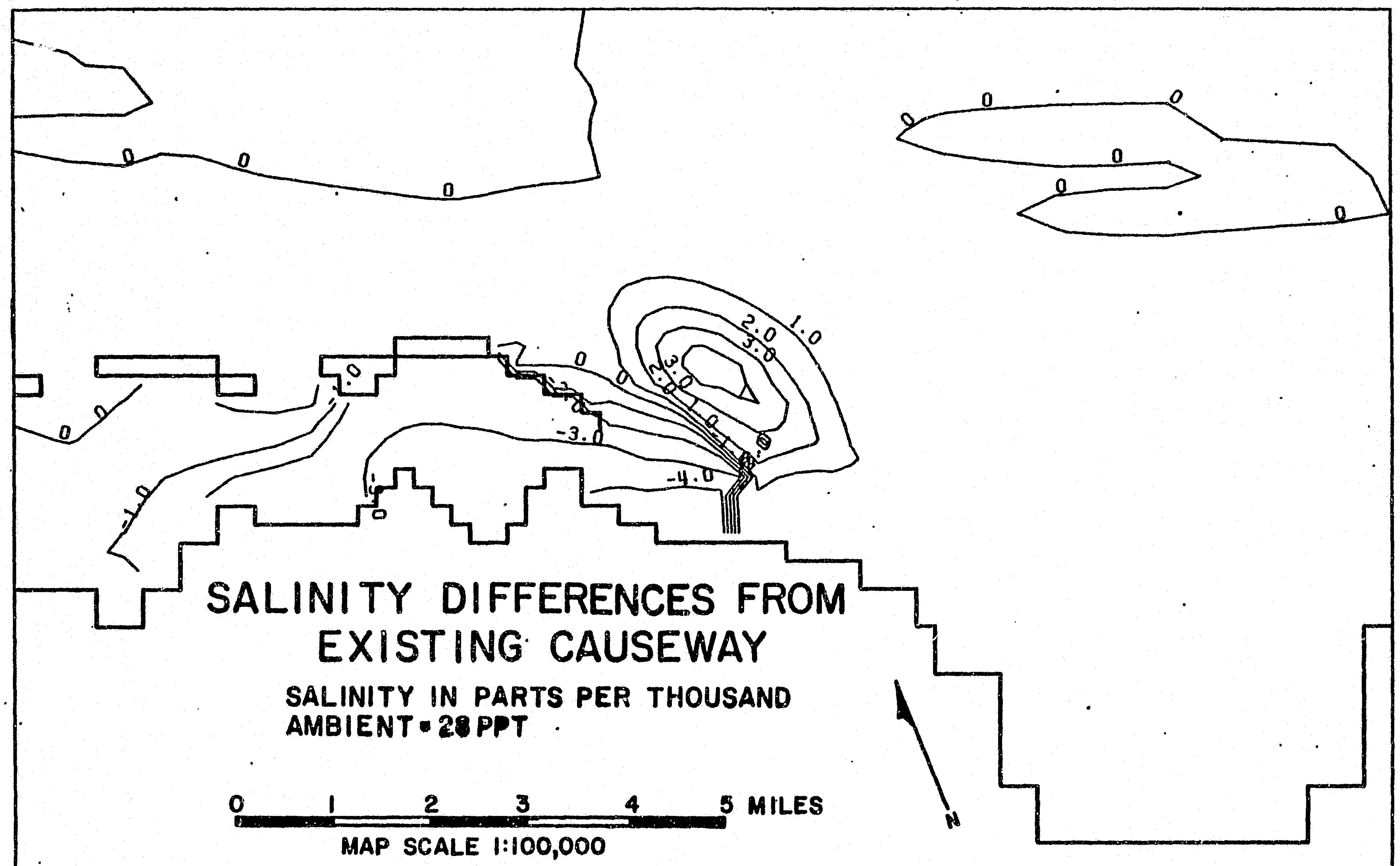


FIGURE D-33

HISTORIC CASE / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

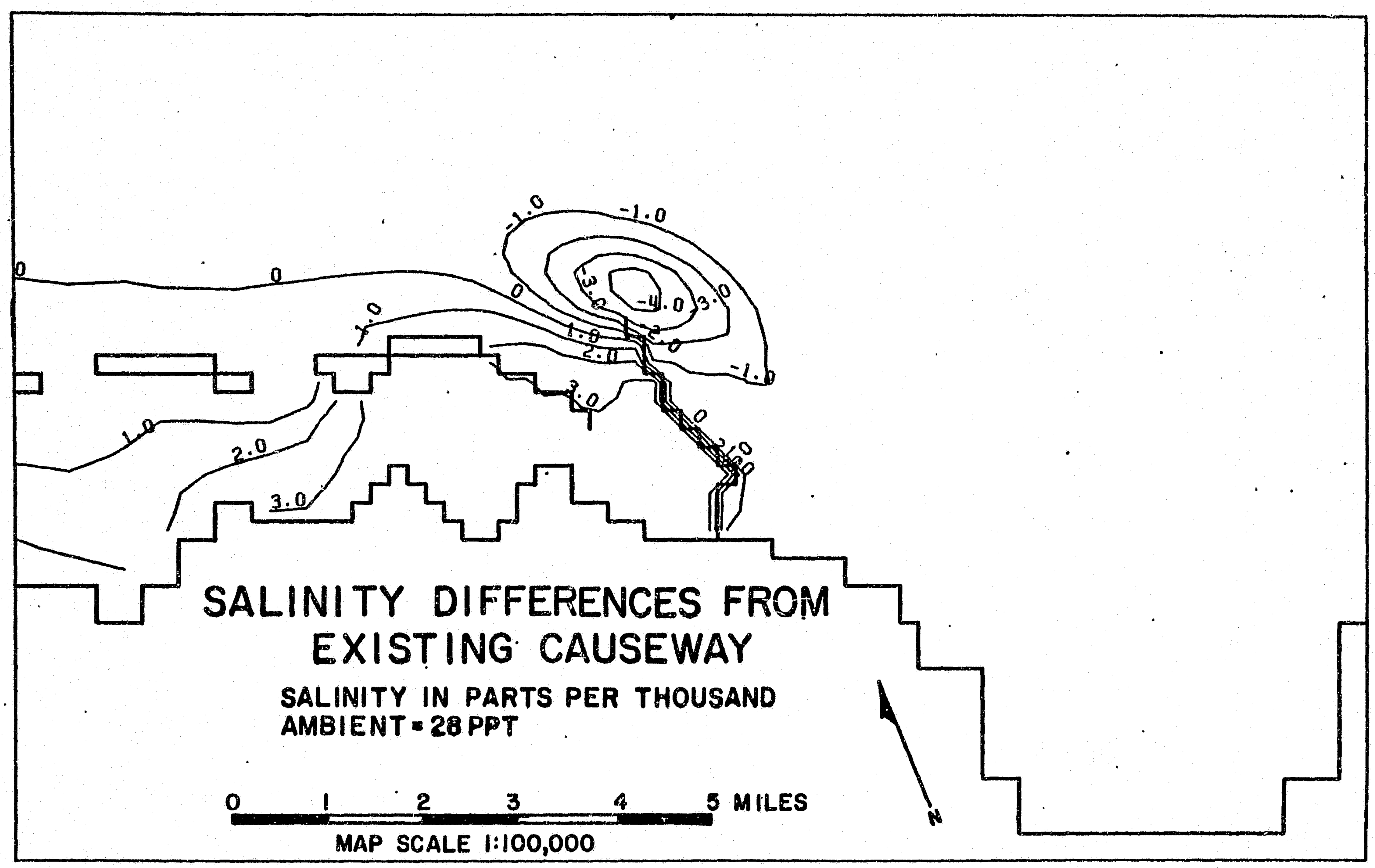


FIGURE D-34

EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 60 DEG

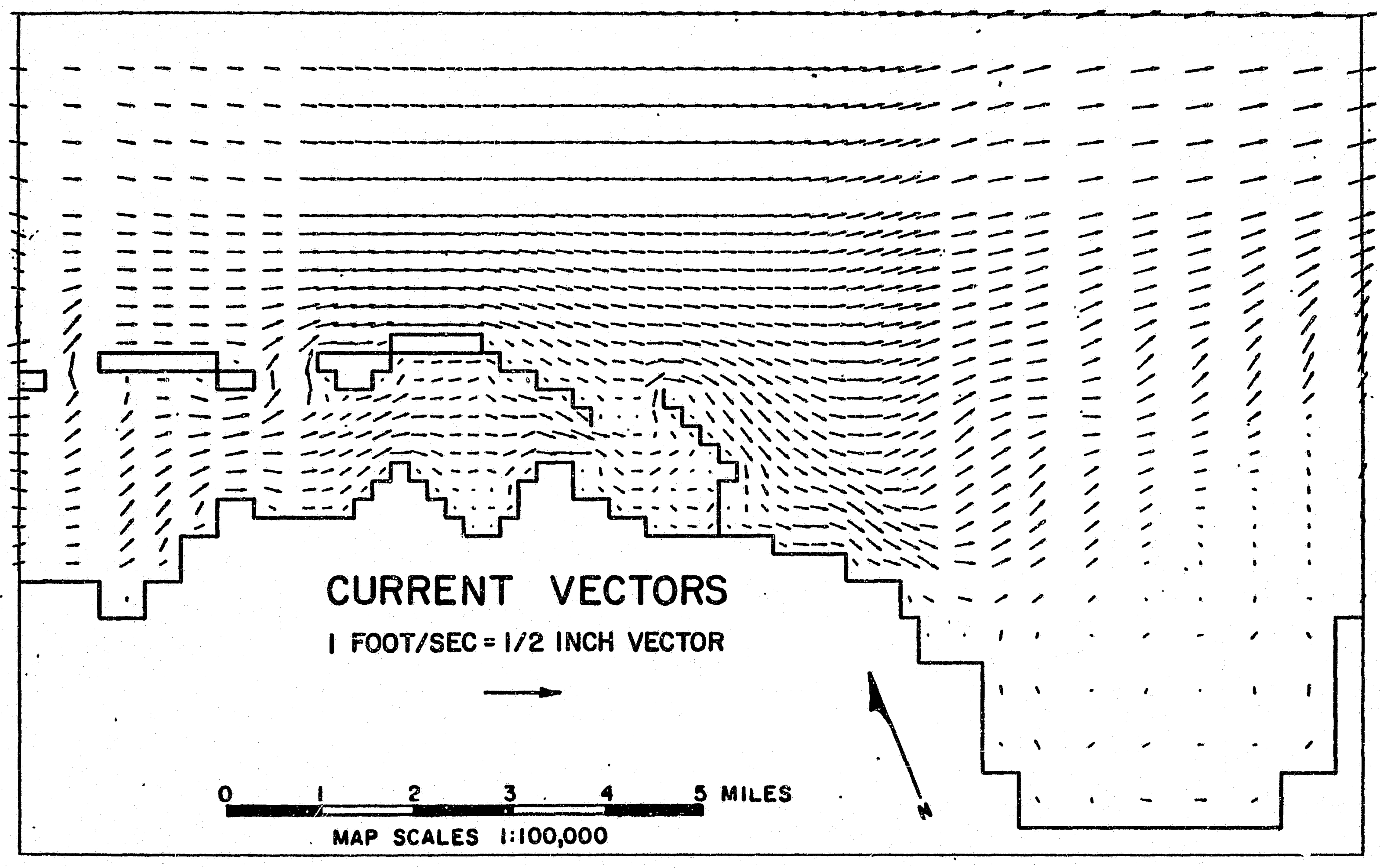


FIGURE D-35

EXISTING CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 240 DEG

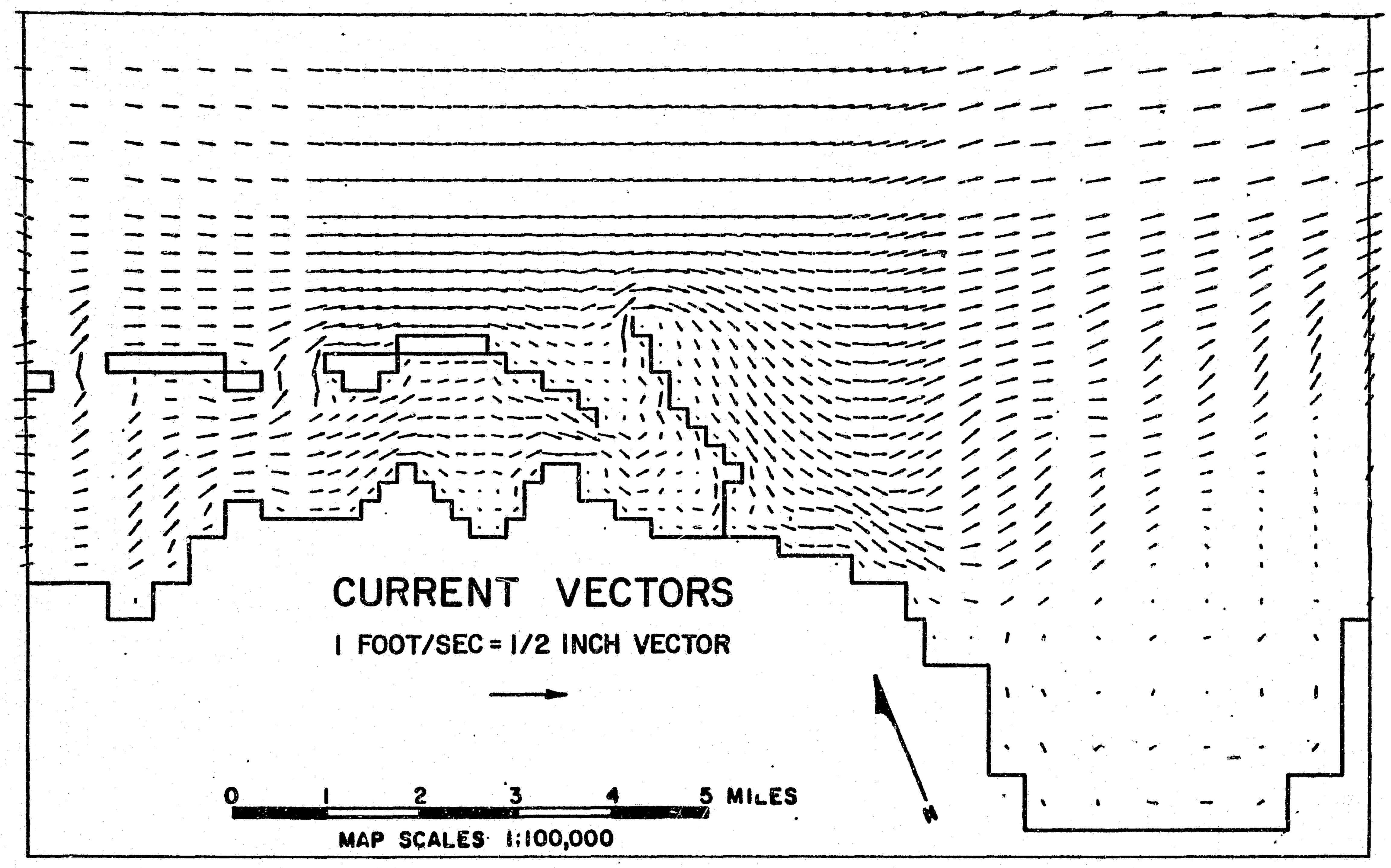


FIGURE D-36

EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 240 DEG

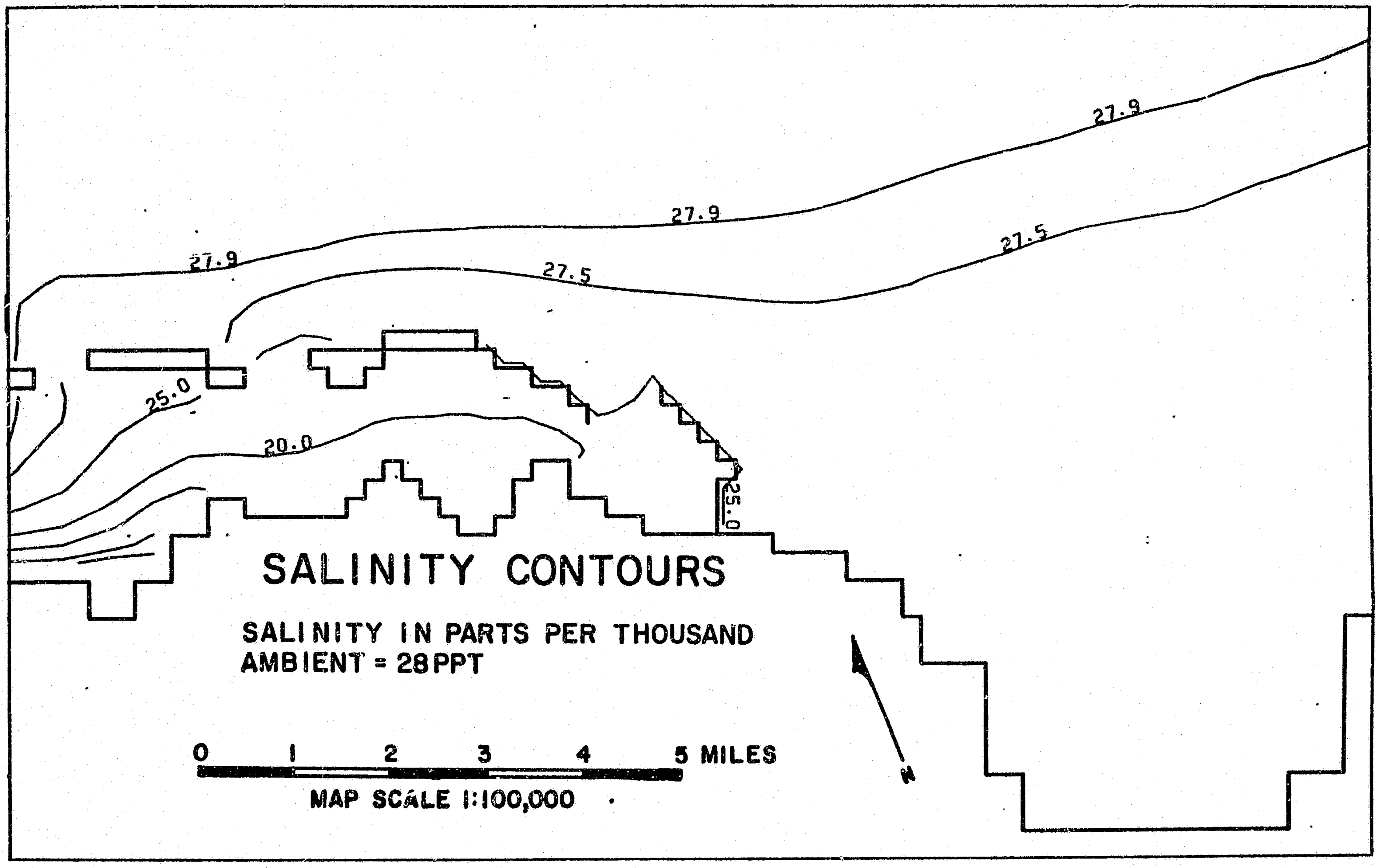


FIGURE D-37

EXISTING CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 240 DEG

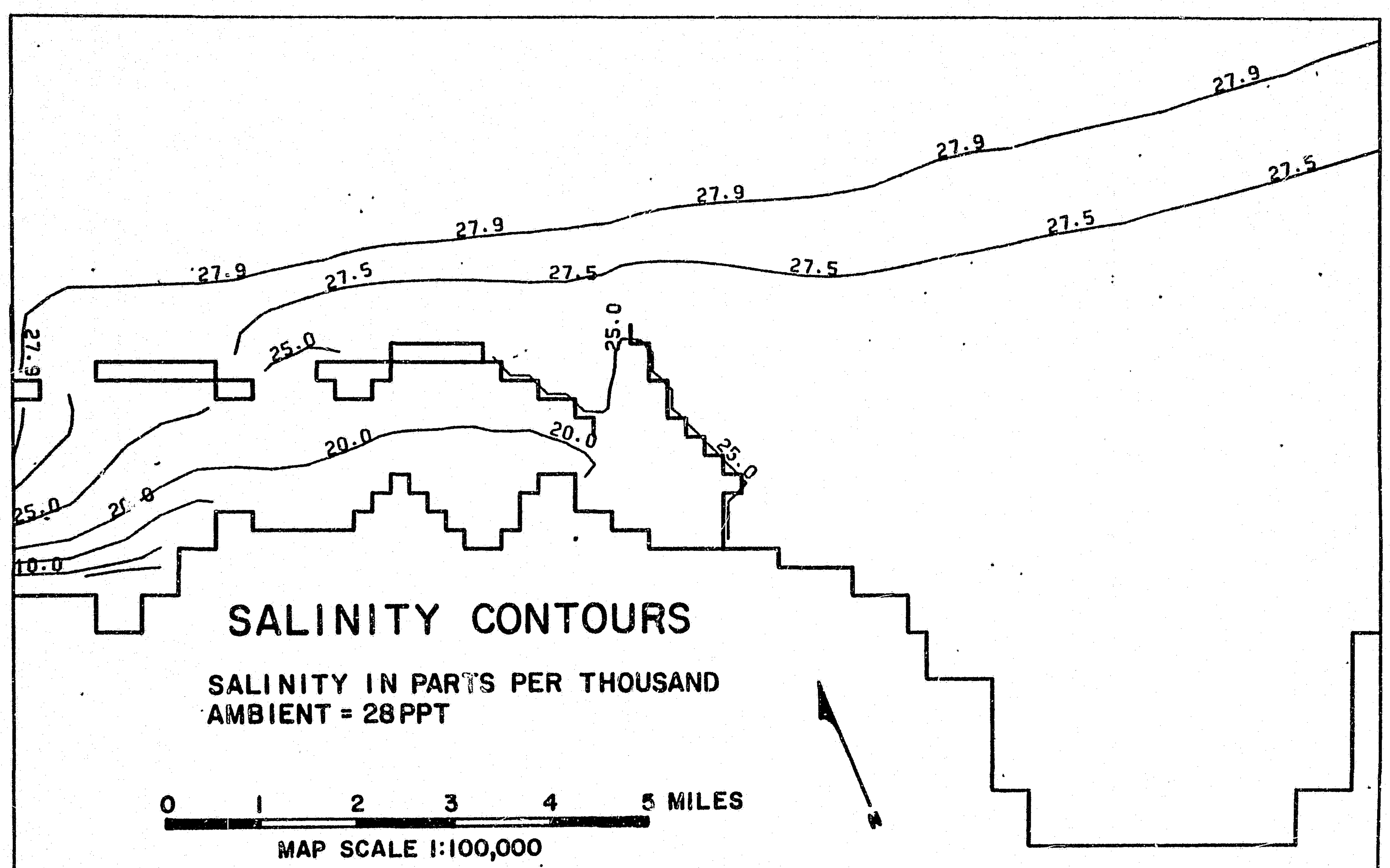


FIGURE D-38
EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 240 DEG

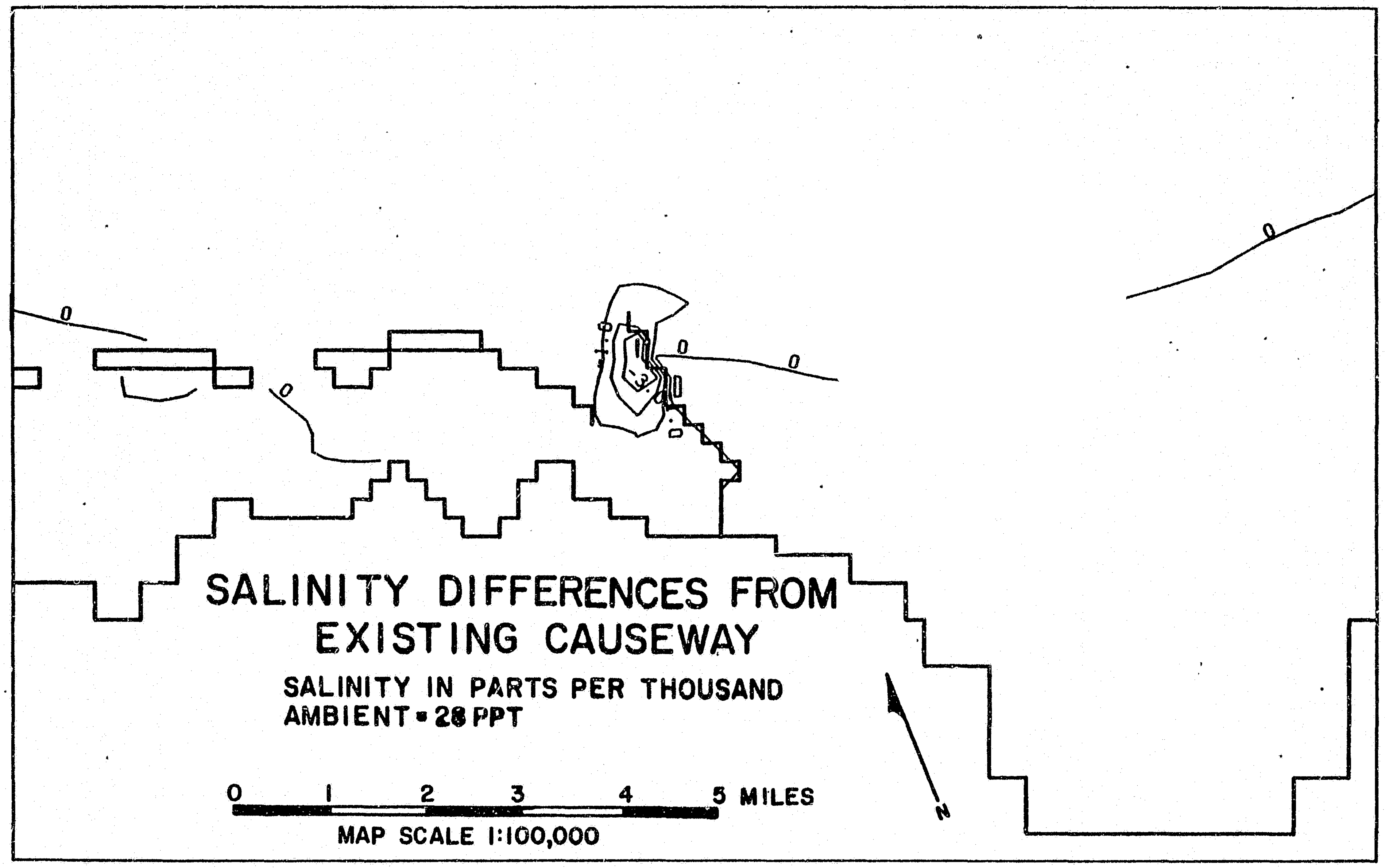


FIGURE D-39

EXTENDED CAUSEWAY / REPRESENTATIVE LO FLOW / WIND 10 KNOTS AT 240 DEG

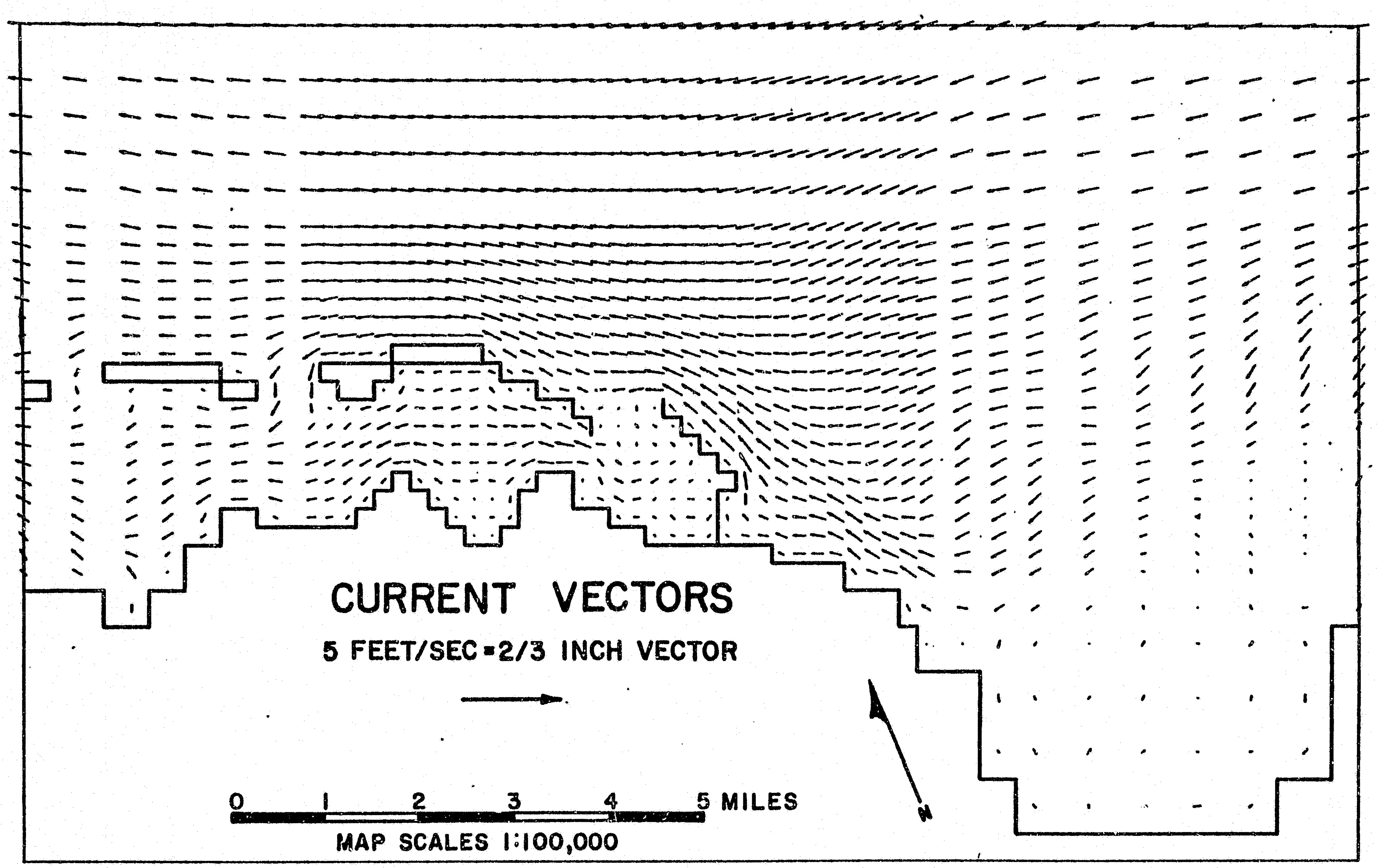


FIGURE D-40
EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 60 DEG

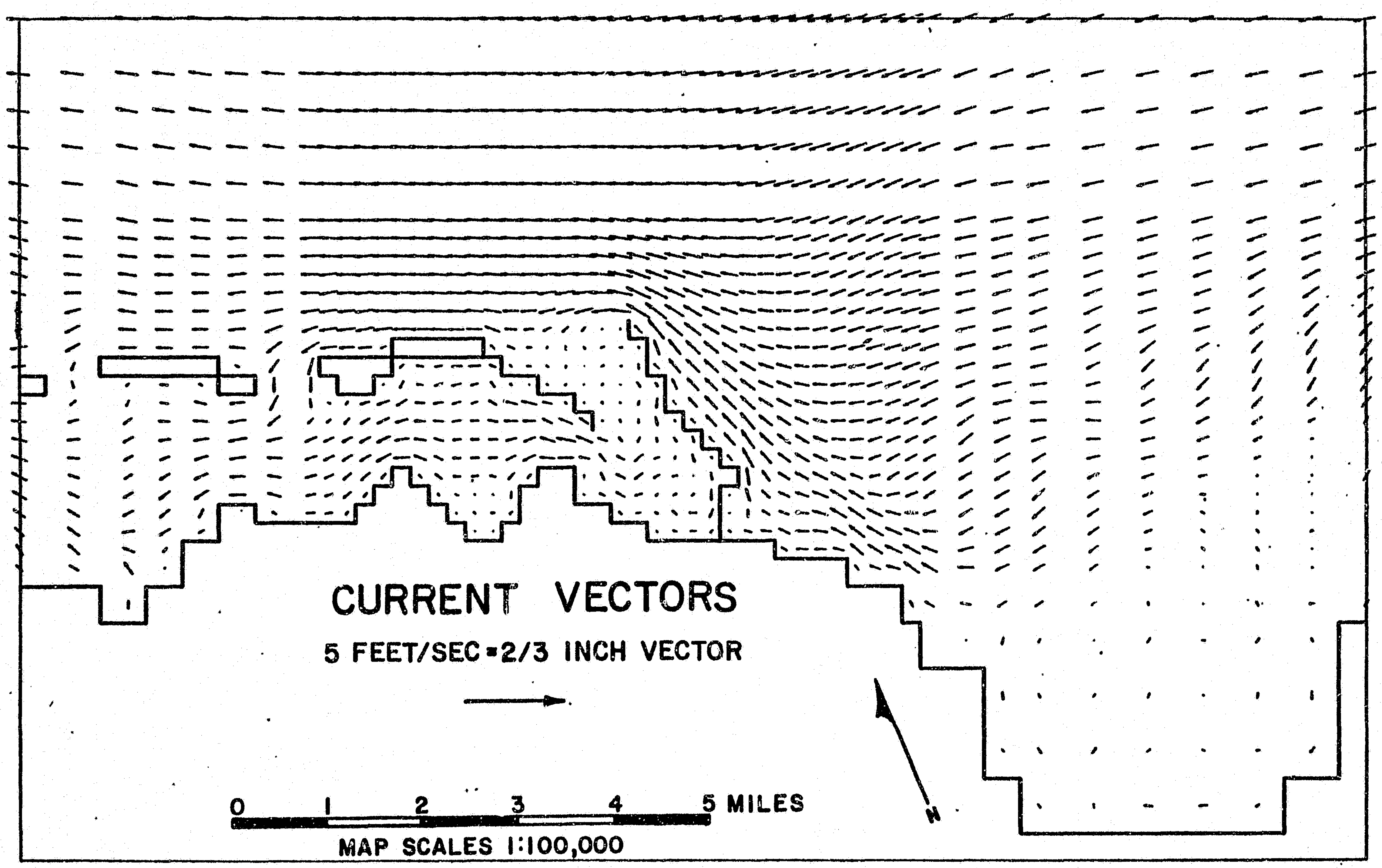


FIGURE D-41

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 60 DEG

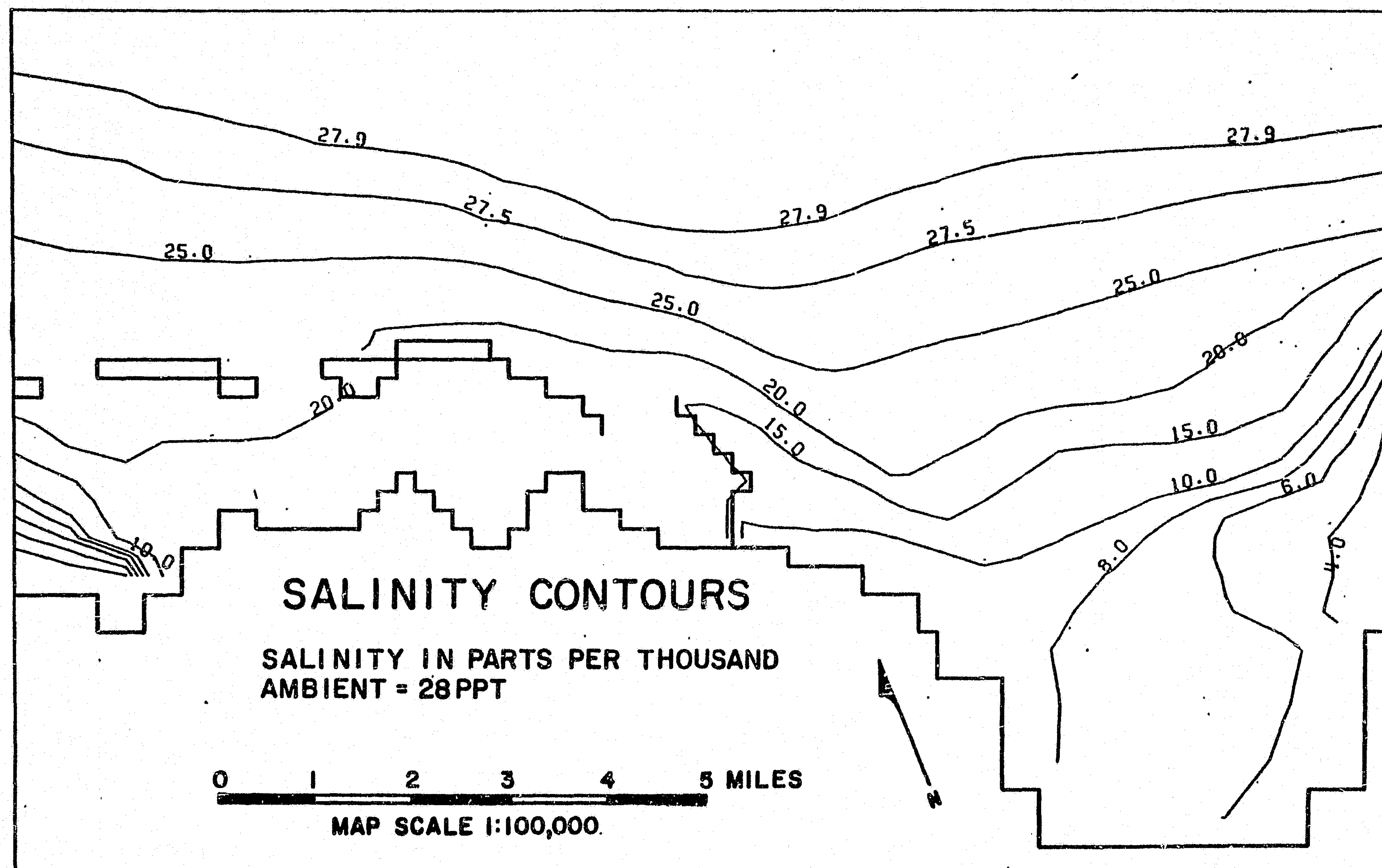


FIGURE D-42

EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 60 DEG

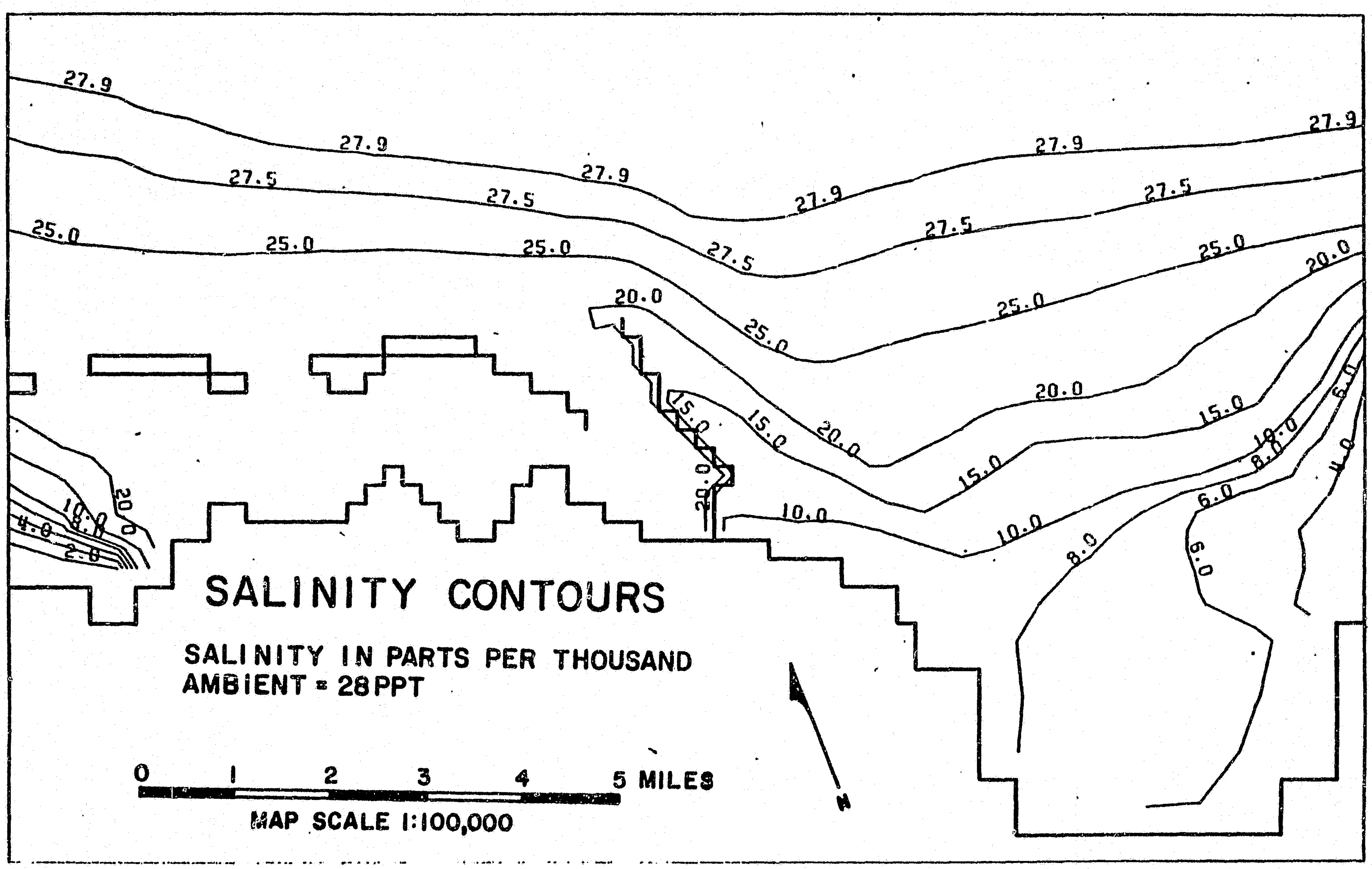


FIGURE D-43

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 60 DEG

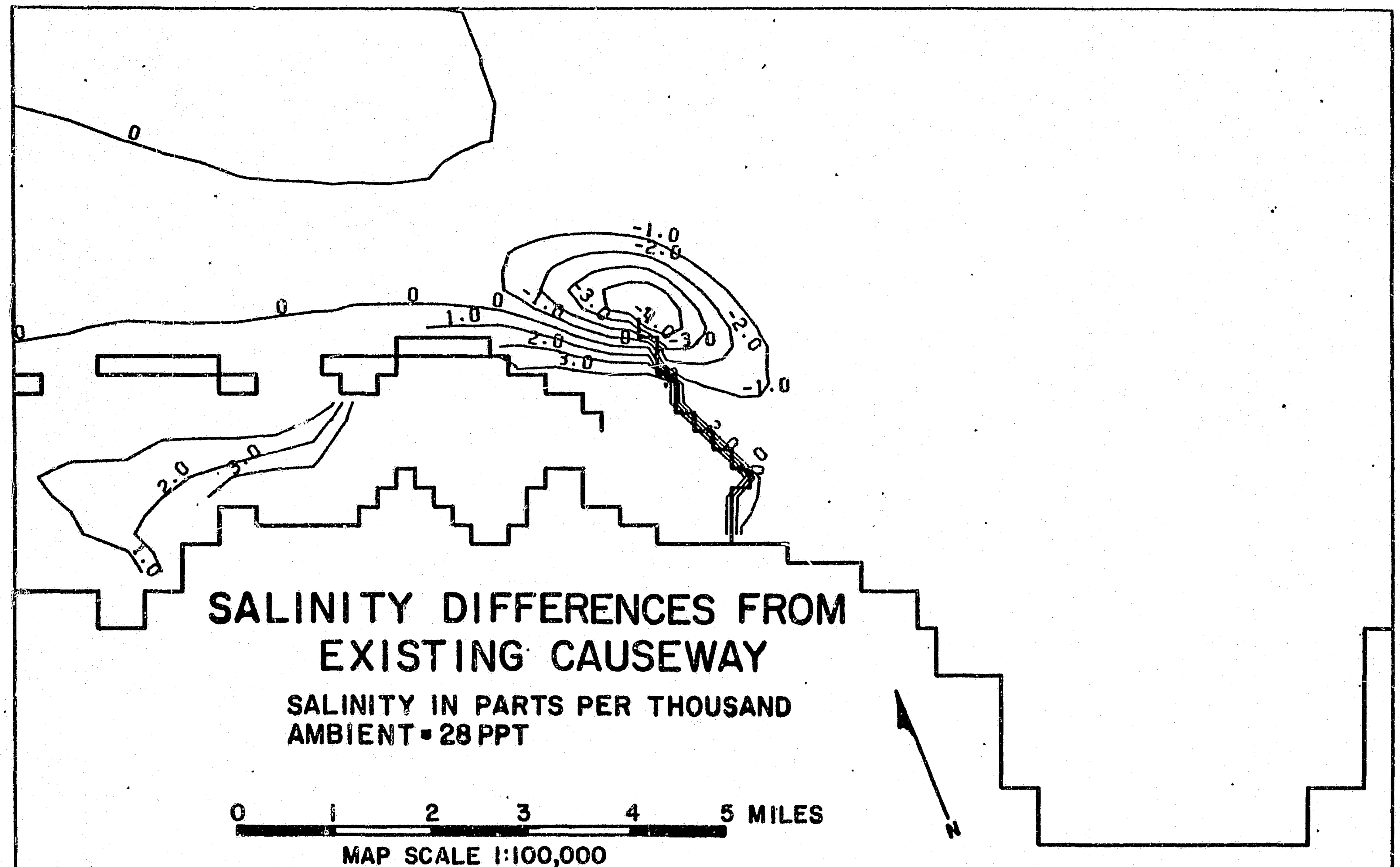


FIGURE D-44

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 60 DEG

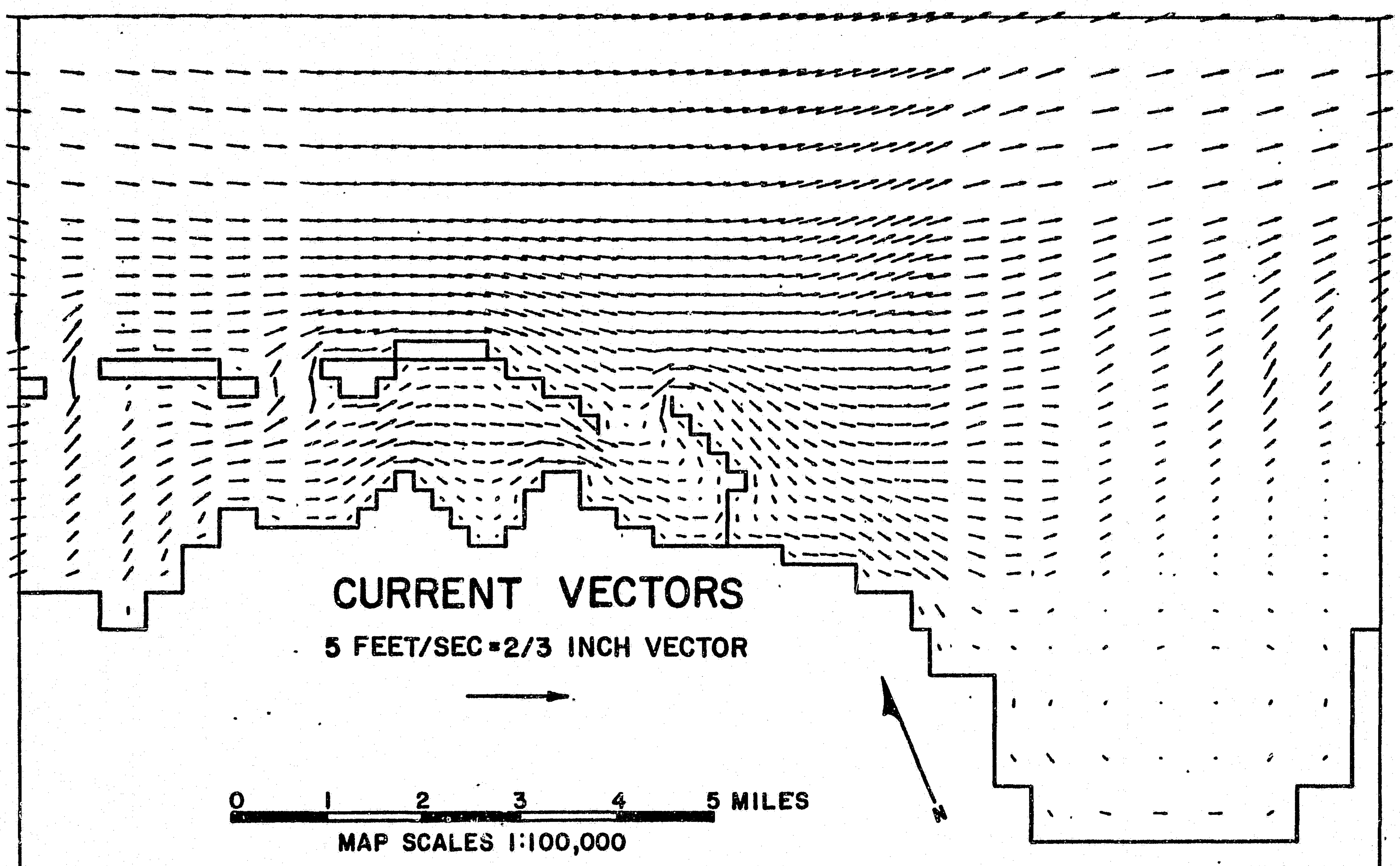


FIGURE D-45

EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 300 DEG

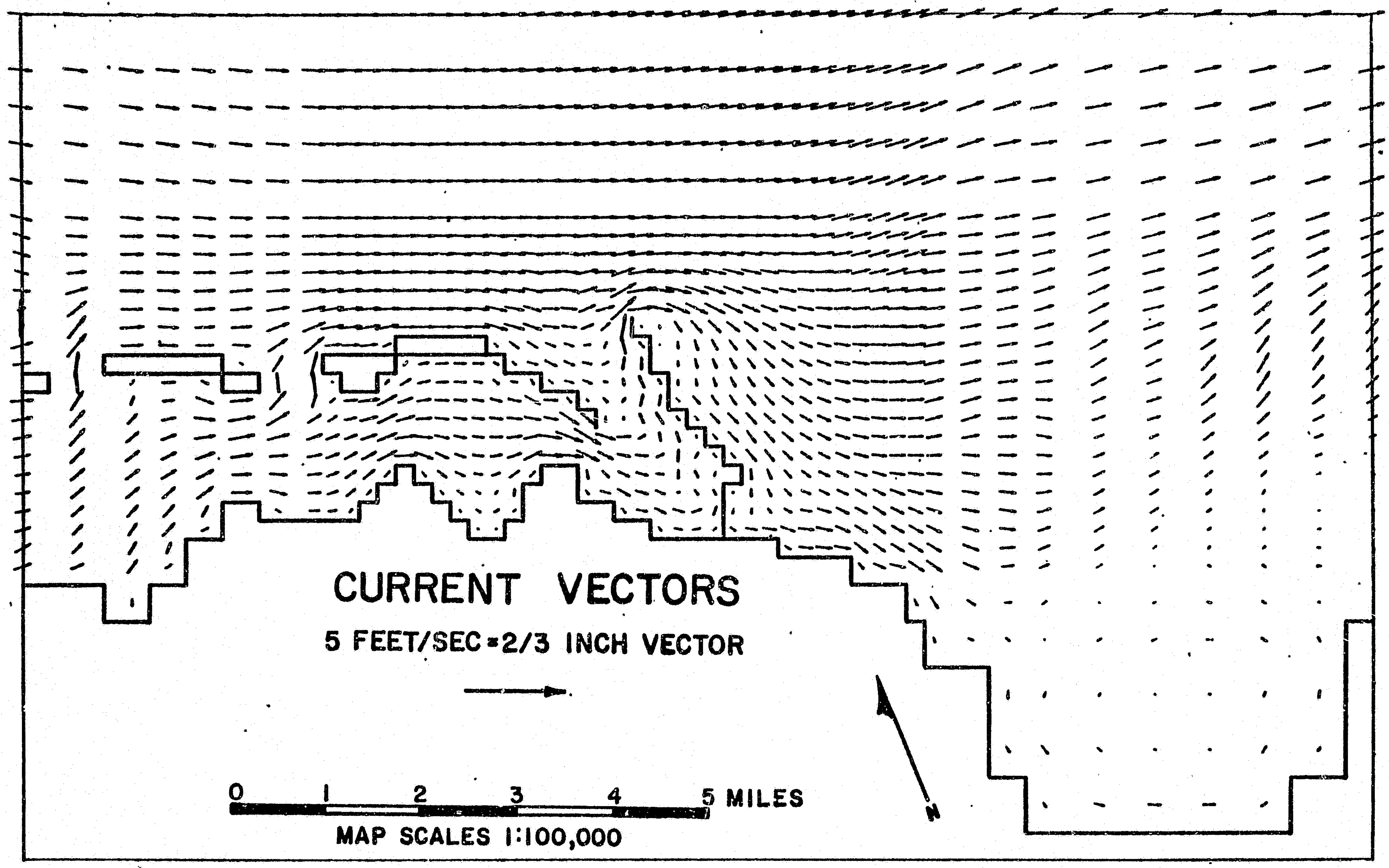


FIGURE D-46

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 300 DEG

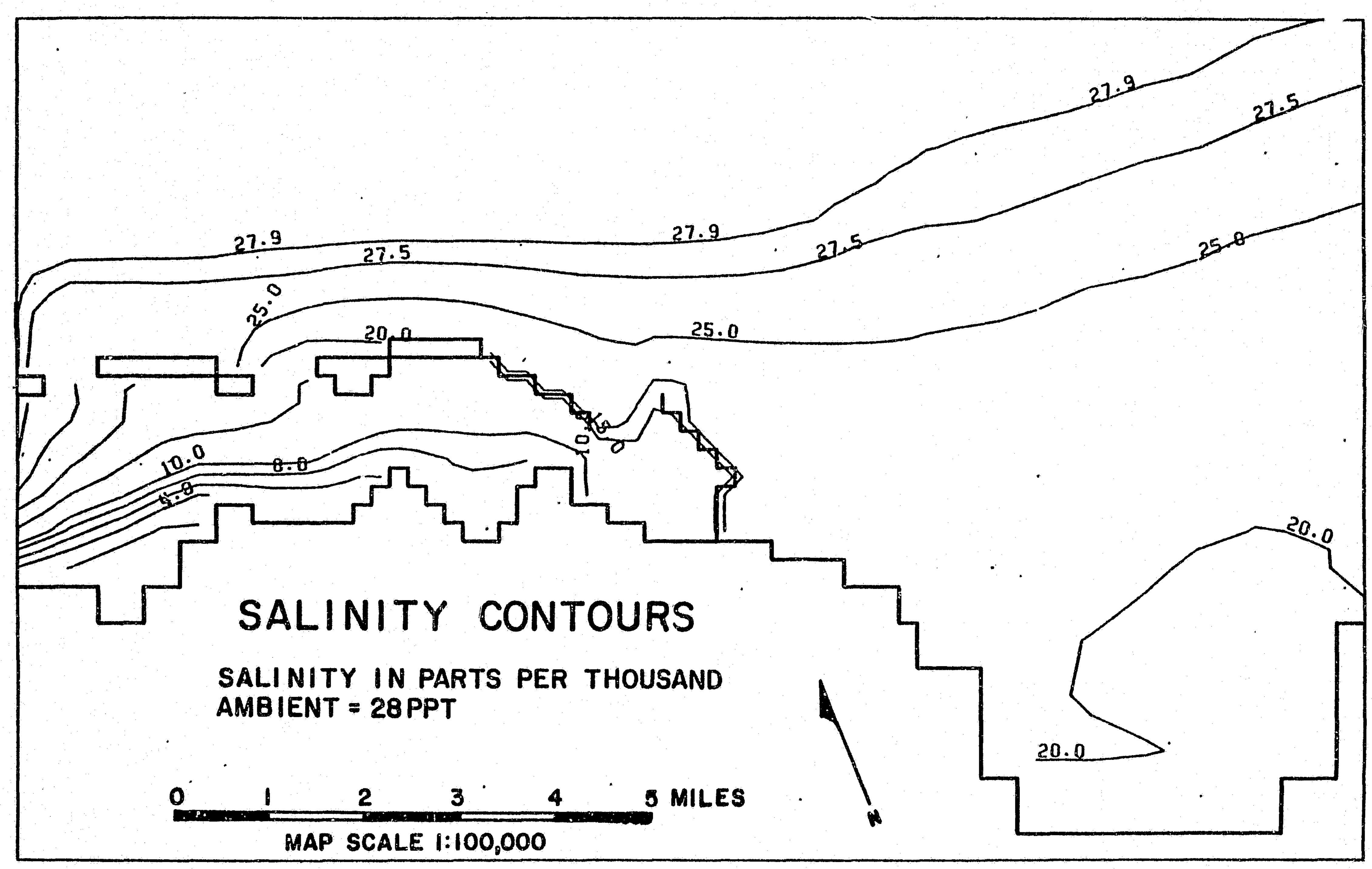


FIGURE D-47

EXISTING CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 300 DEG

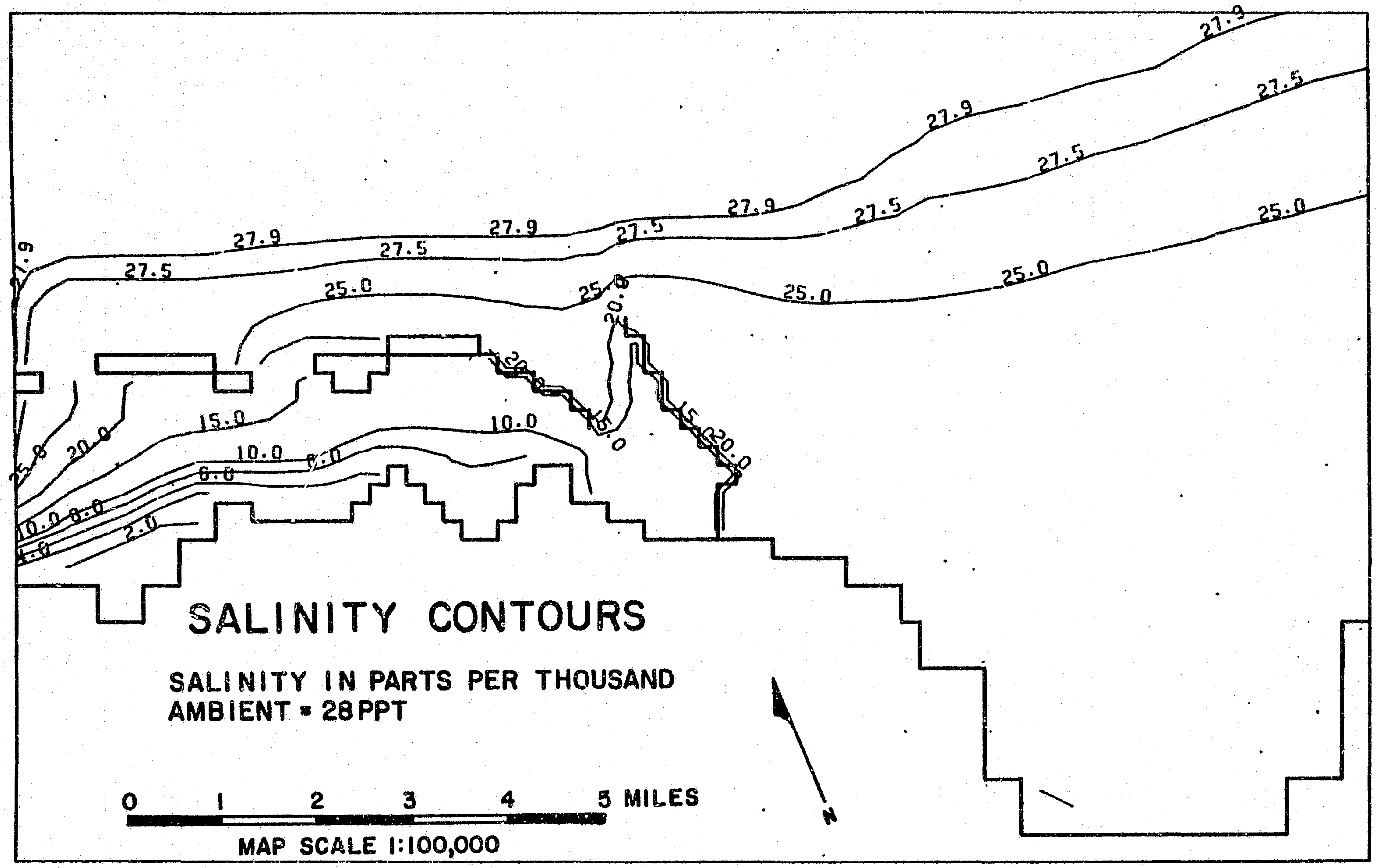


FIGURE D-48

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 300 DEG

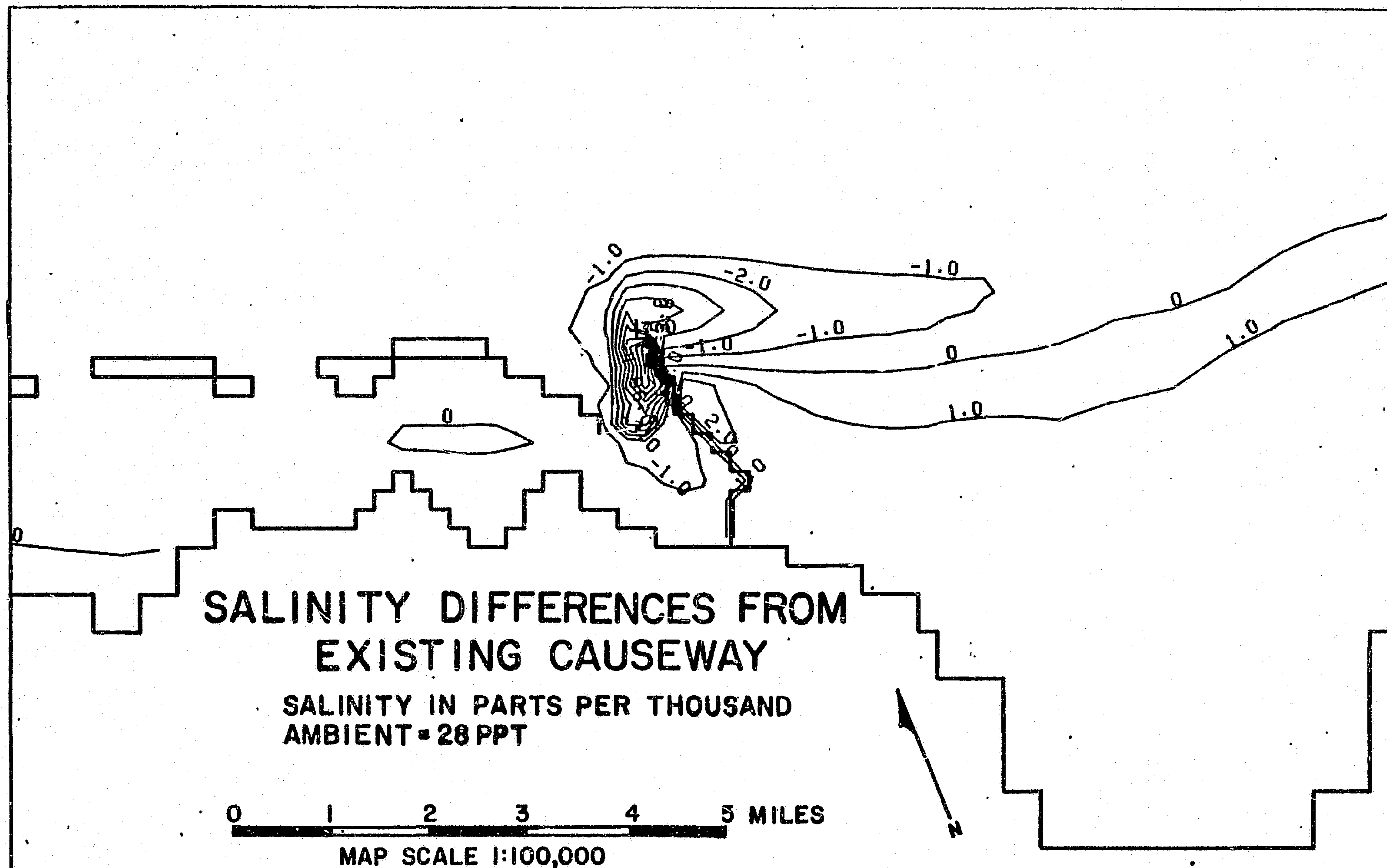
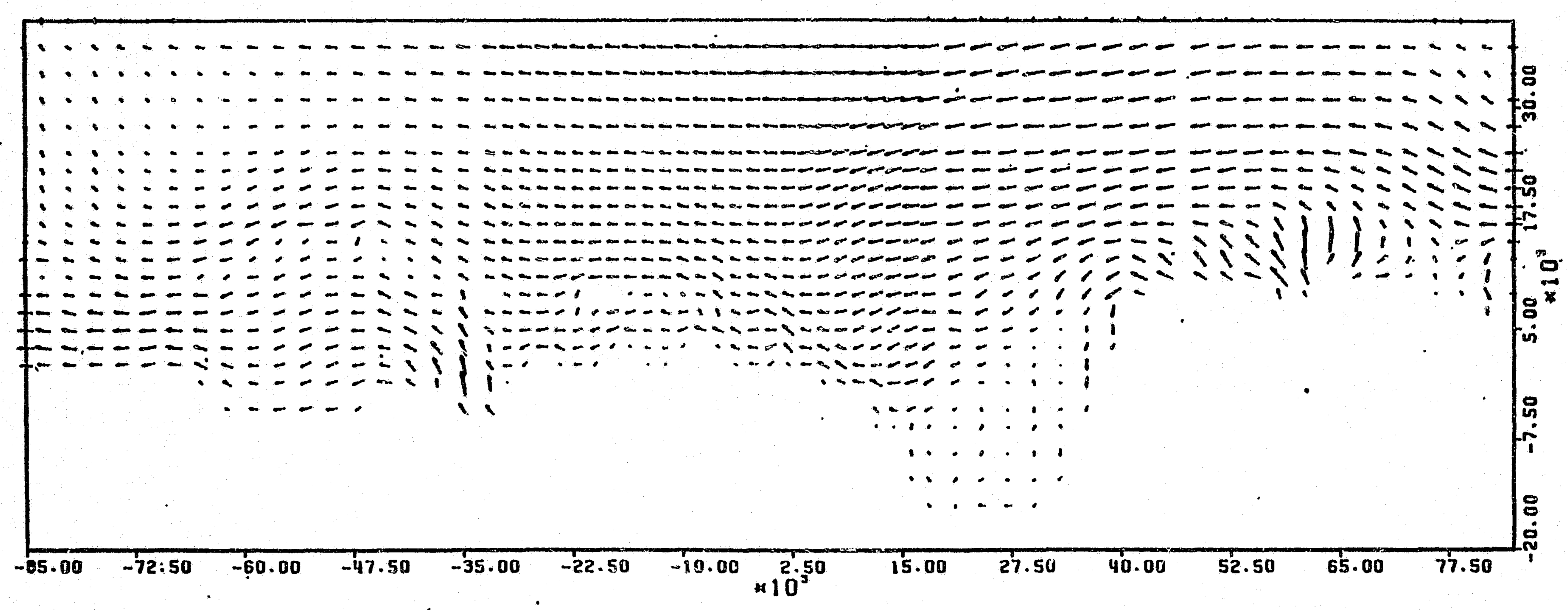


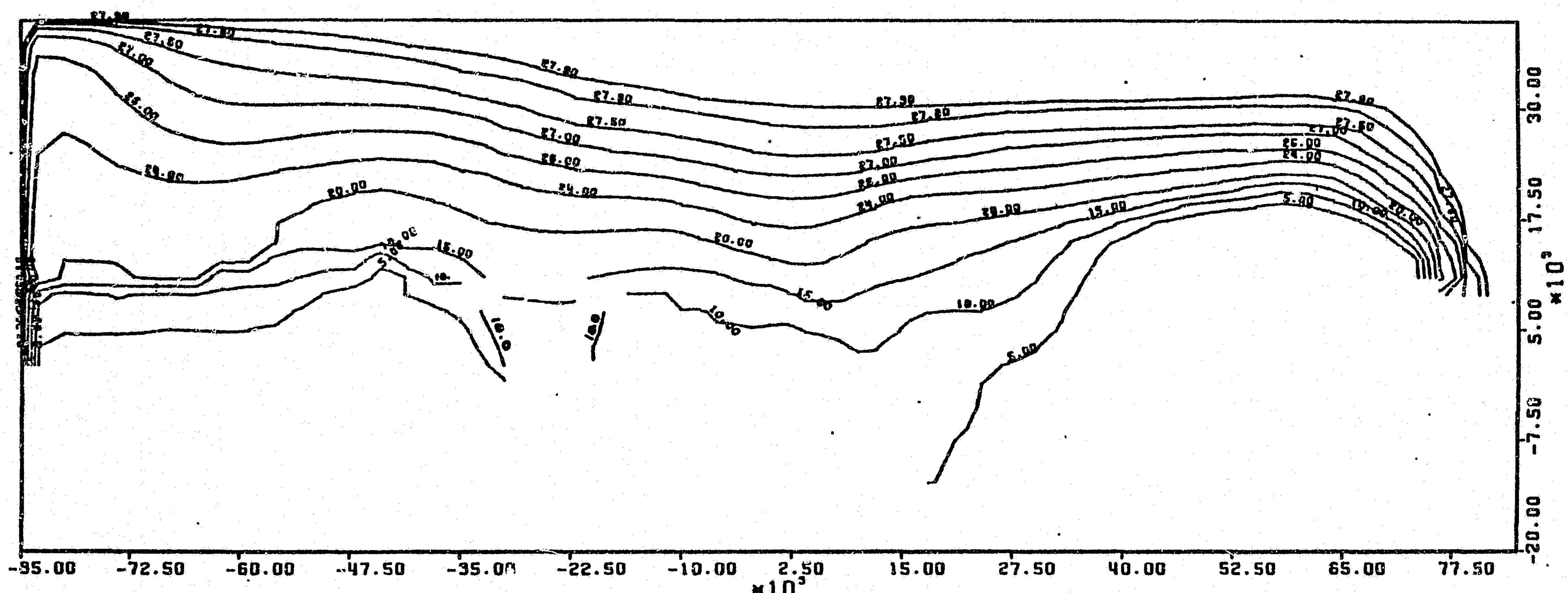
FIGURE D-49

EXTENDED CAUSEWAY / REPRESENTATIVE HI FLOW / WIND 25 KNOTS AT 300 DEG



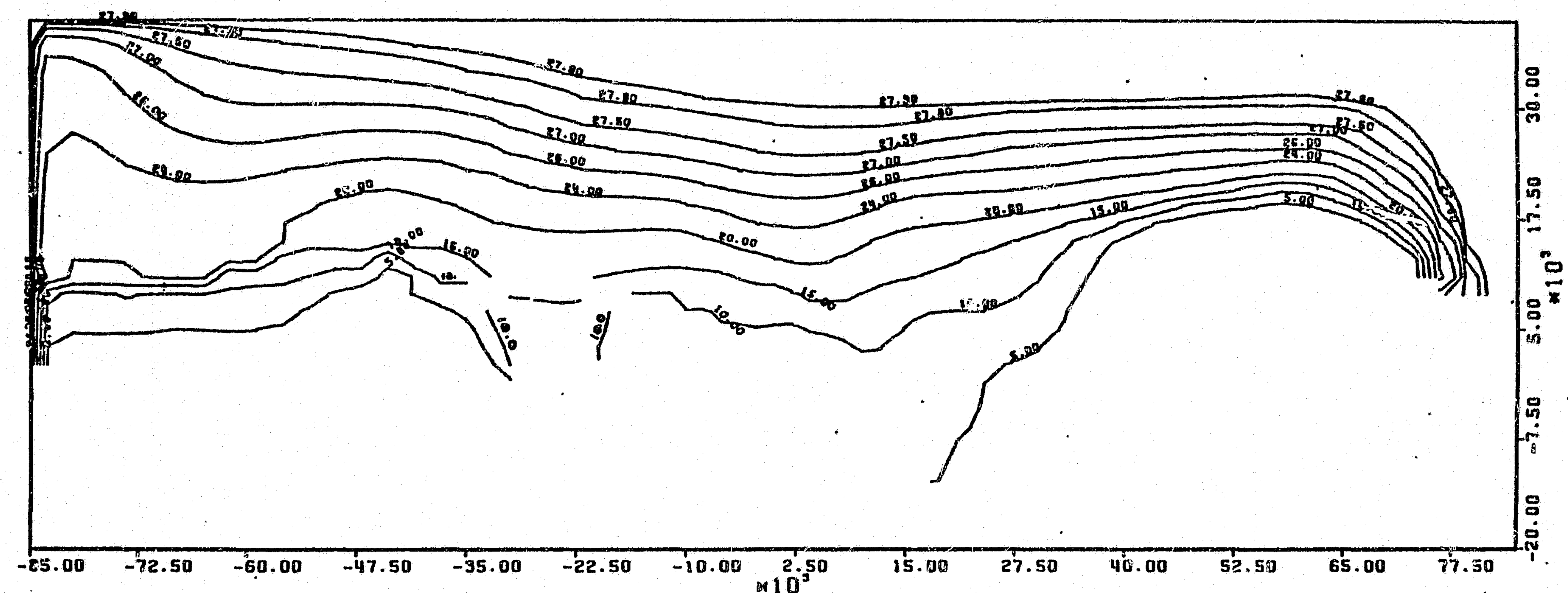
CURRENT VECTORS - BASE CASE

FIGURE D-50



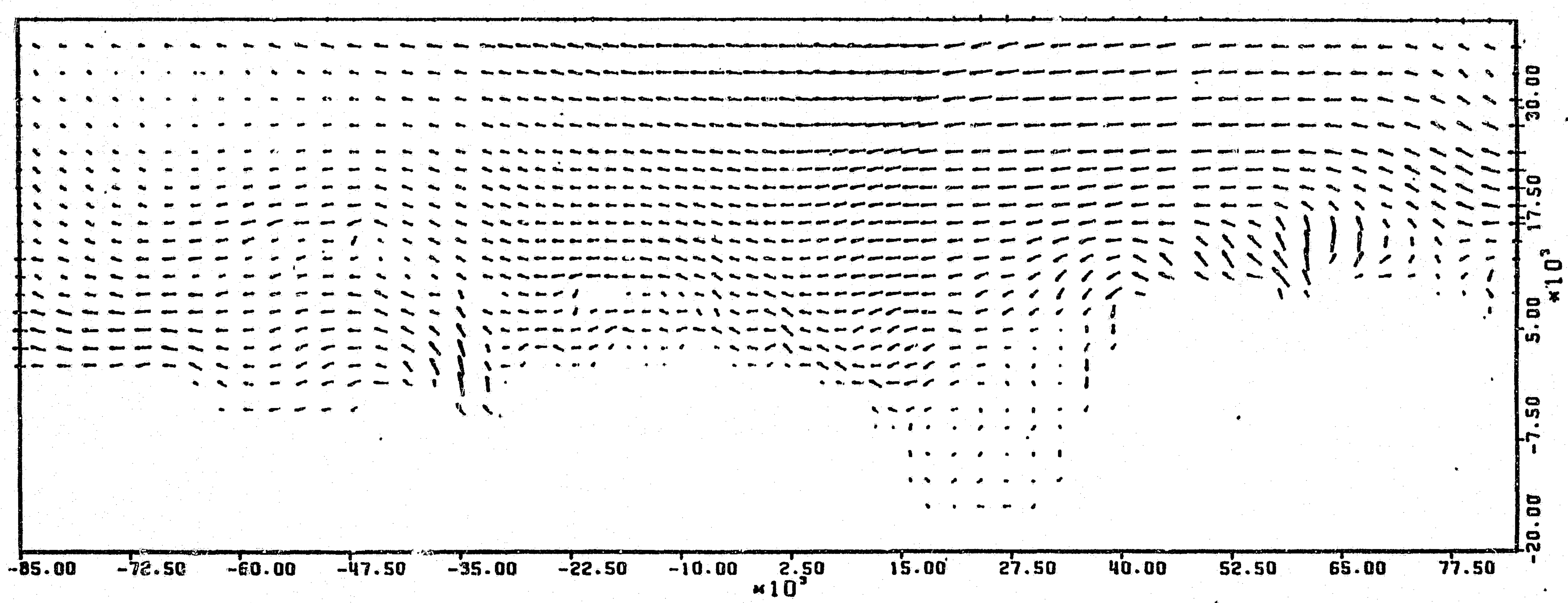
SALINITY CONTOURS - BASE CASE

FIGURE D-51



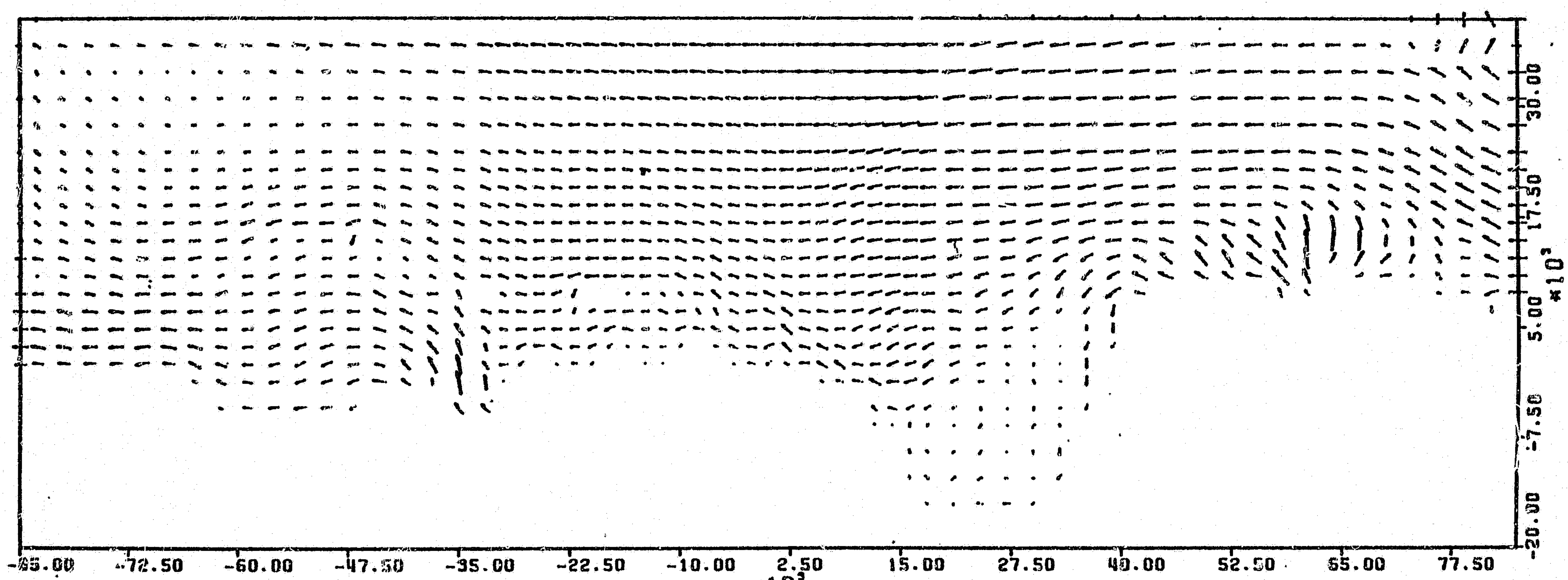
SALINITY CONTOURS - BASE CASE

FIGURE D-51



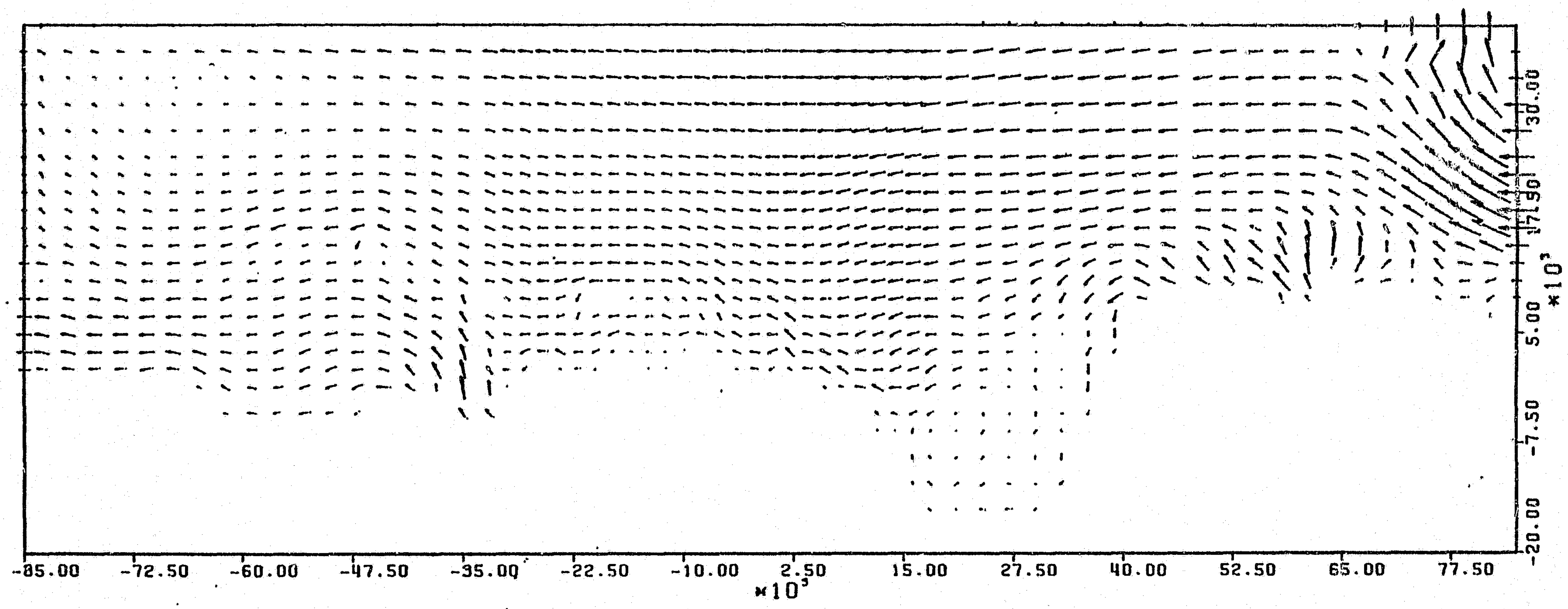
CURRENT VECTORS - MODIFIED BOUNDARY CONDITION - $\alpha = 0$, $\beta = 2$

FIGURE D-52



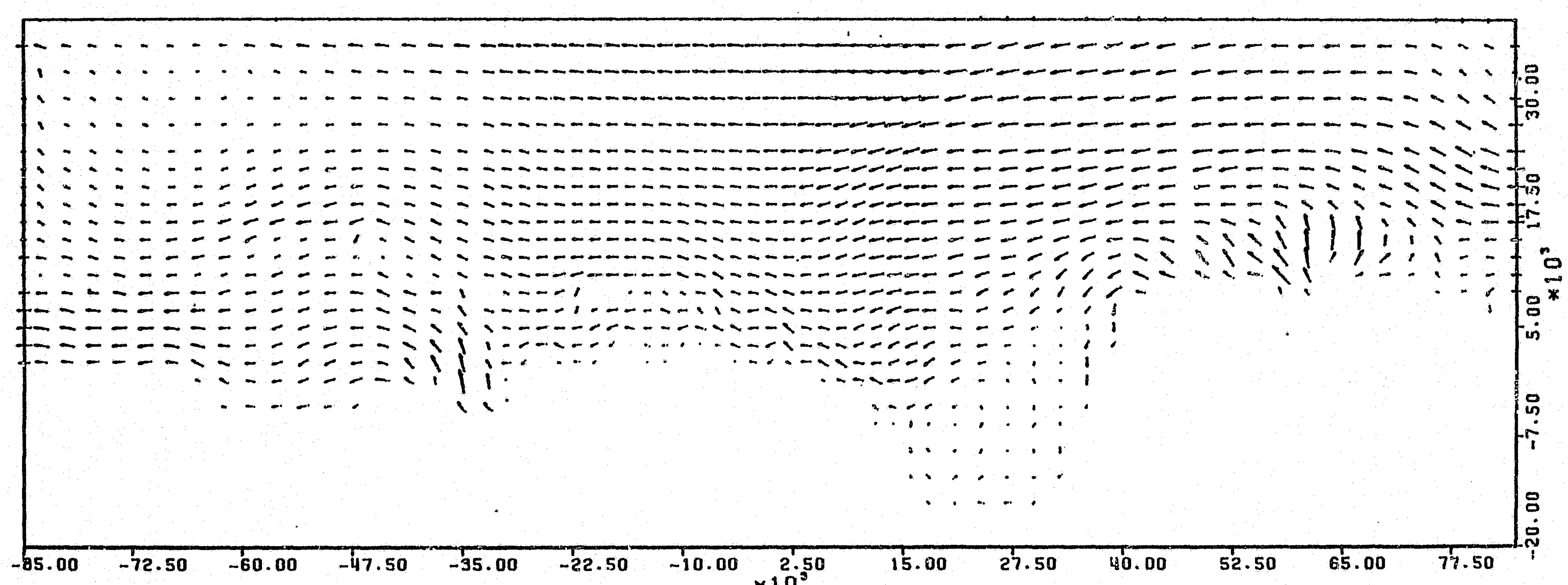
CURRENT VECTORS - MODIFIED BOUNDARY CONDITION - U = - 0.4 FEET/SEC AT RIGHT-HAND BOUNDARY

FIGURE D-53



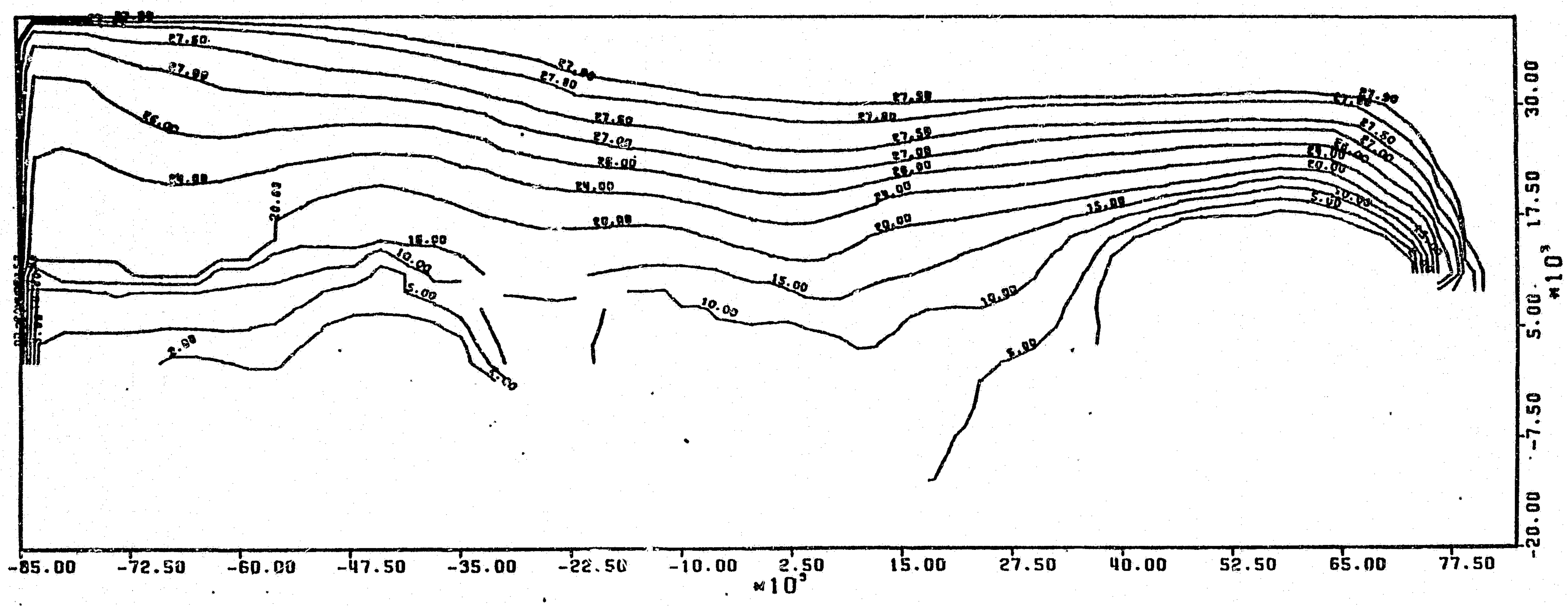
CURRENT VECTORS - MODIFIED BOUNDARY CONDITION - η FIXED AT RIGHT HAND BOUNDARY, η = 0.16 FEET AT THE COAST AND DECREASES LINEARLY TO 0 FEET AT THE LAST GRID POINT

FIGURE D-54



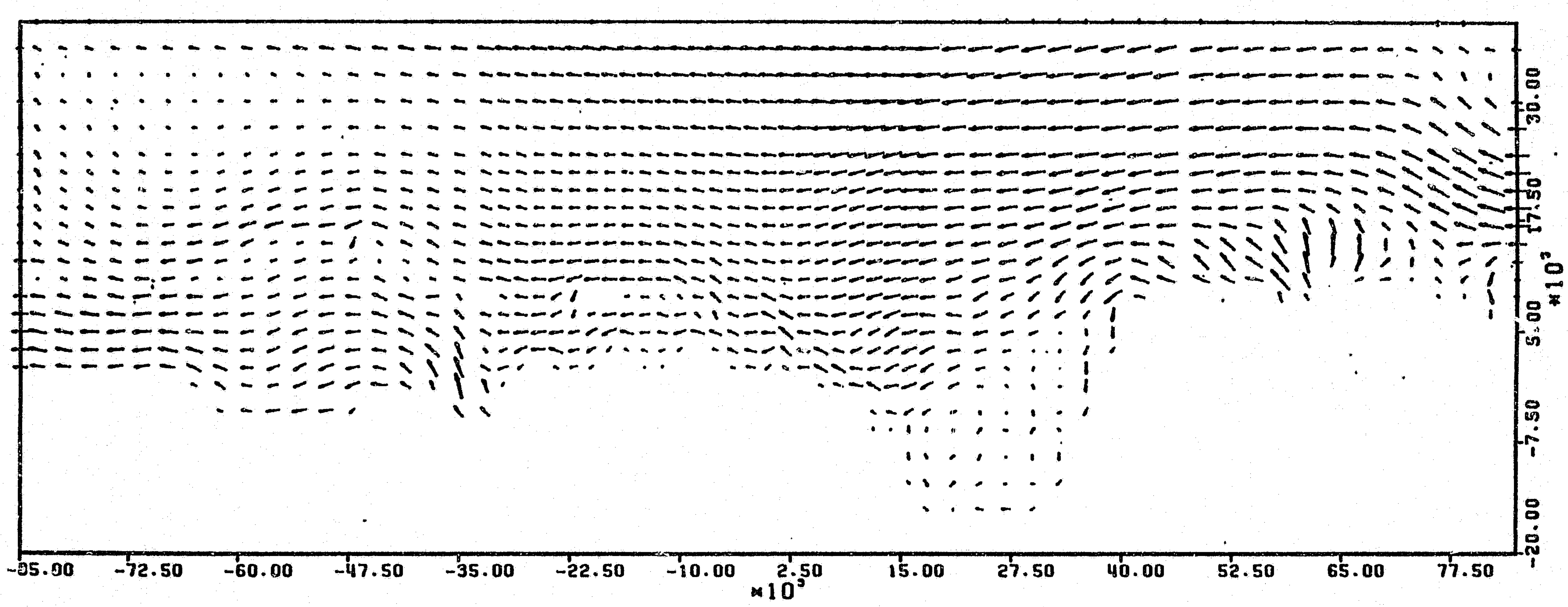
CURRENT VECTORS - MODIFIED BOUNDARY CONDITION - U = - 0.2 FEET/SEC AT THREE GRID POINTS CLOSEST TO COAST ON RIGHT-HAND BOUNDARY, AND V = 0.02 FEET/SEC AT EIGHT GRID POINTS ALONG UPPER-LEFT BOUNDARY

FIGURE D-55



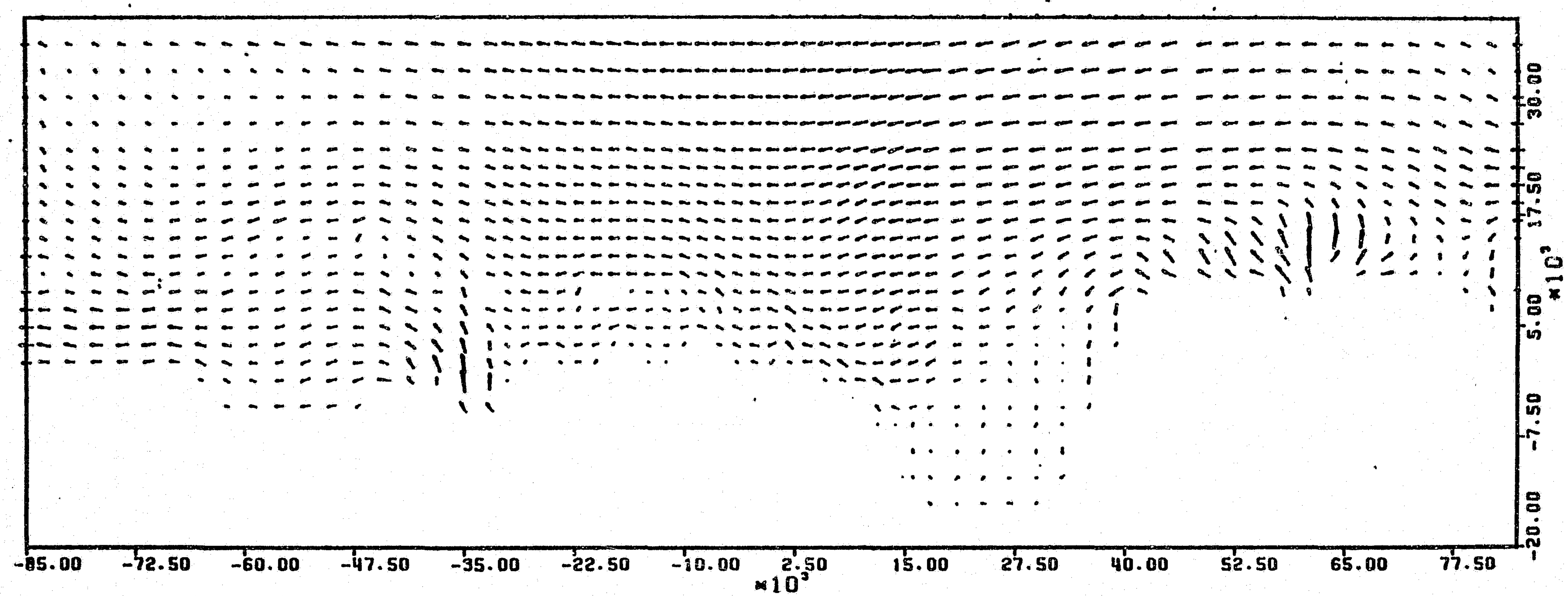
SALINITY CONTOURS - MODIFIED BOUNDARY CONDITION - $\alpha = 0$, $\beta = 2$

FIGURE D-56



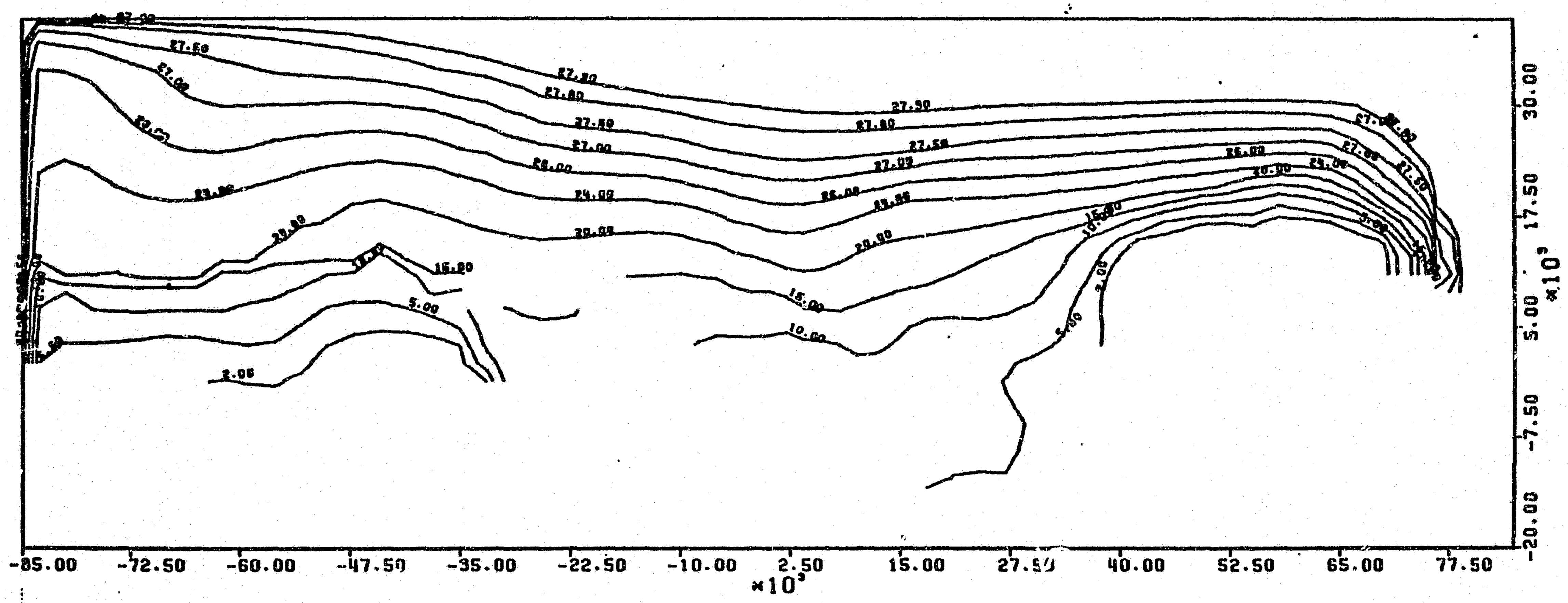
CURRENT VECTORS - BOTTOM FRICTION FACTOR = 0.016

FIGURE D-57



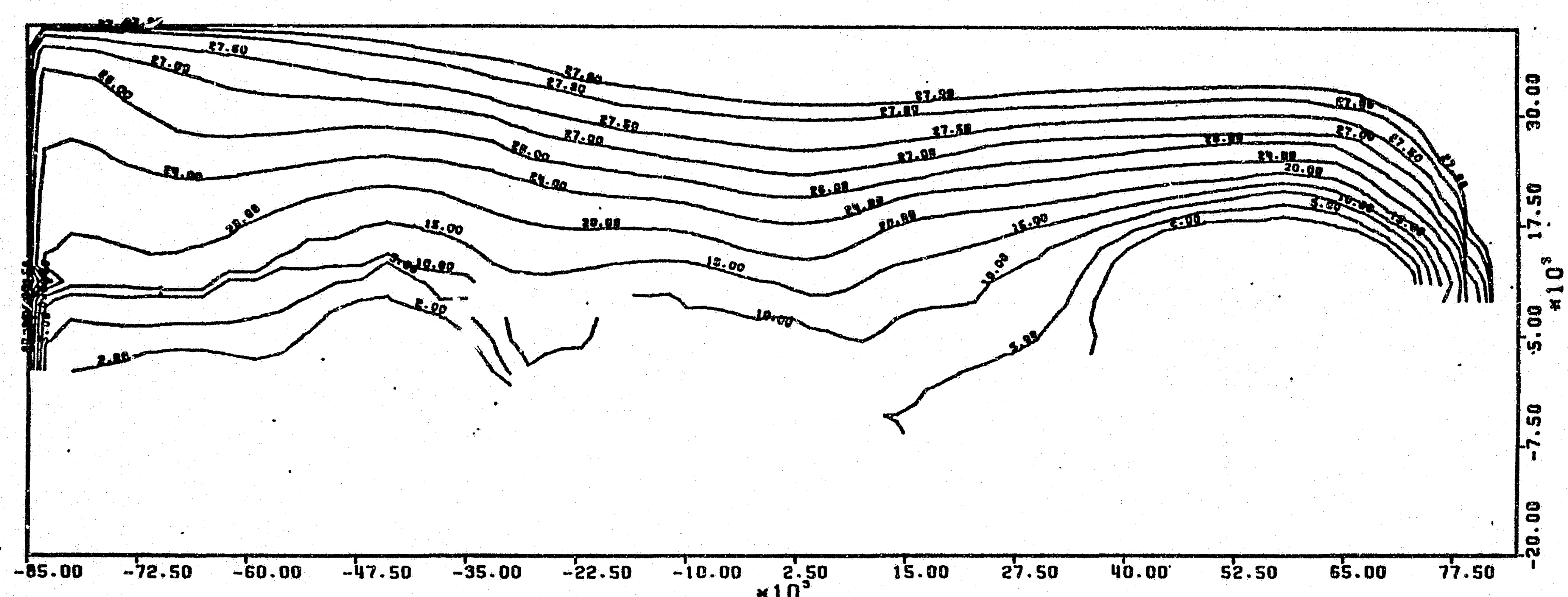
CURRENT VECTORS - BOTTOM FRICTION FACTOR = 0.025

FIGURE D-58



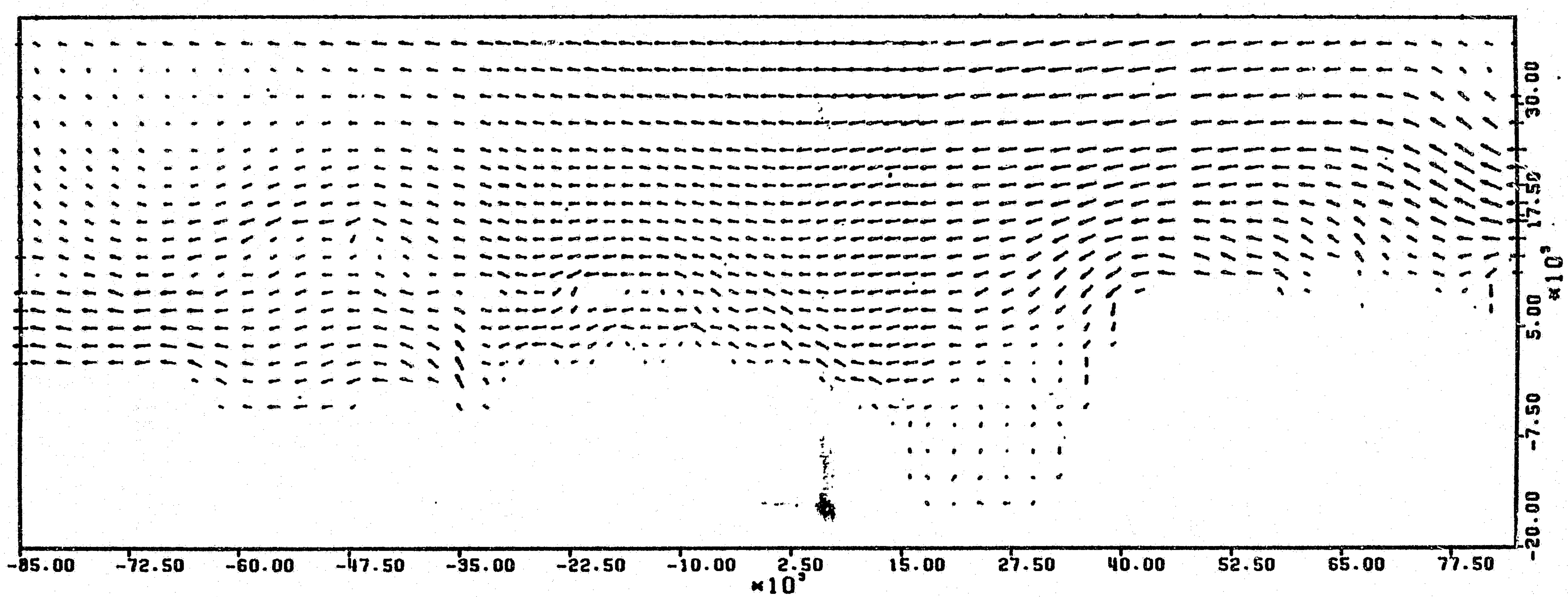
SALINITY CONTOURS - BOTTOM FRICTION FACTOR = 0.016

FIGURE D-59



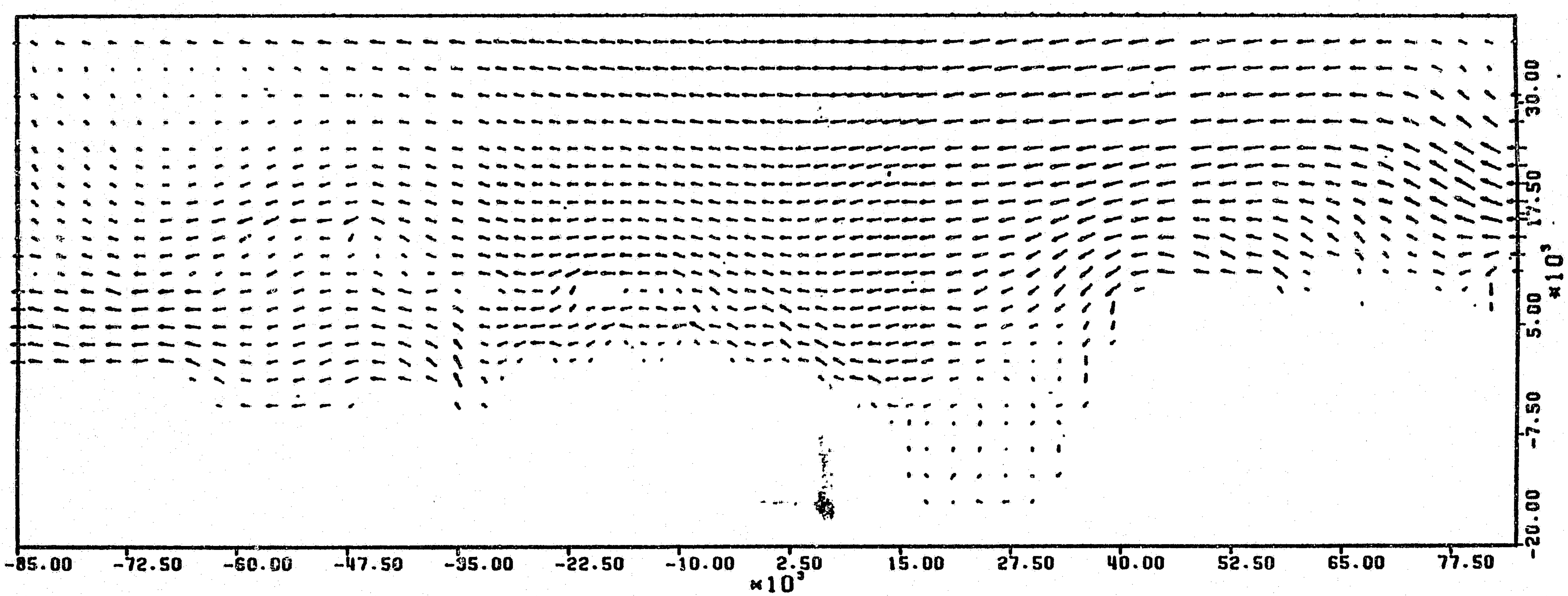
SALINITY CONTOURS - BOTTOM FRICTION FACTOR = 0.025

FIGURE D-60



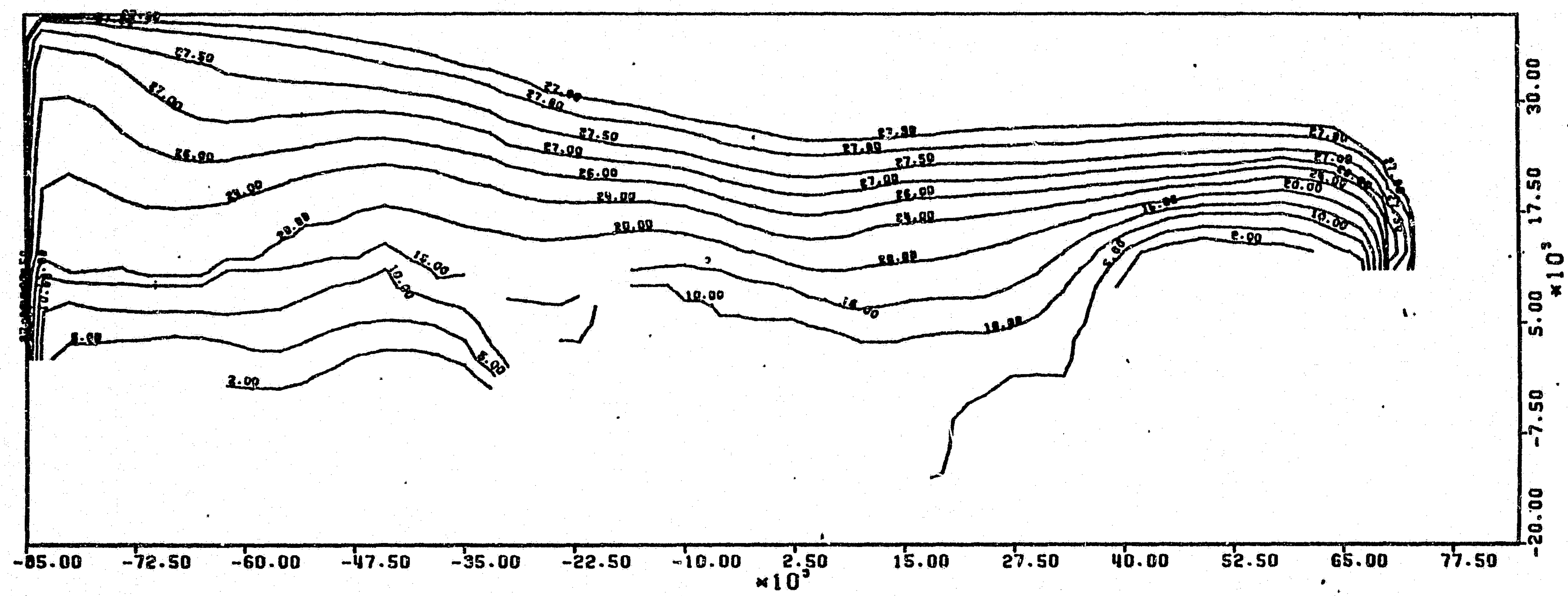
CURRENT VECTORS - ALL DEPTHS INCREASED BY 2 FEET

FIGURE D-61



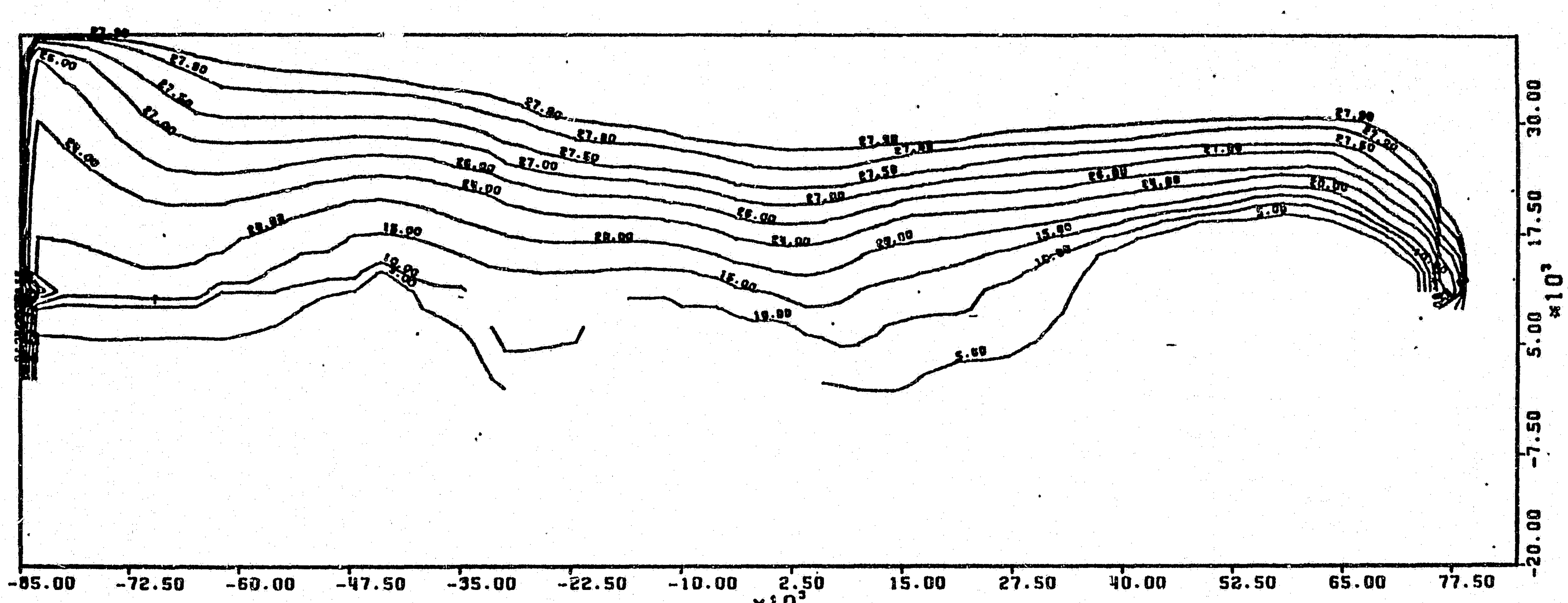
CURRENT VECTORS - ALL DEPTHS INCREASED BY 2 FEET

FIGURE D-61



SALINITY CONTOURS - ALL DEPTHS INCREASED BY 2 FEET

FIGURE D-62



SALINITY CONTOURS - DISPERSION COEFFICIENT = 5 FEET^2/SEC

FIGURE D-63

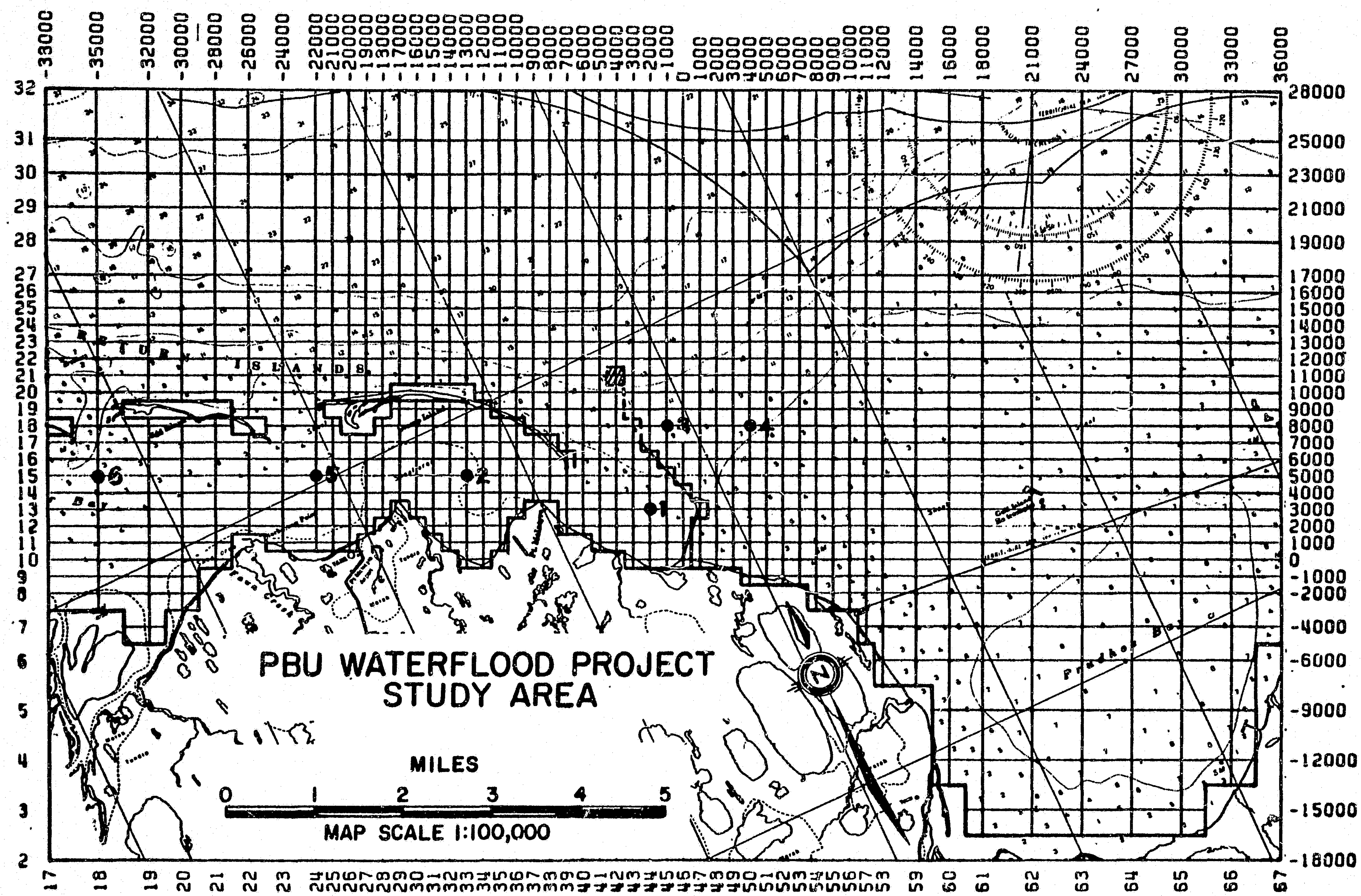

PBU WATERFLOOD PROJECT
STUDY AREA
MILES
0 1 2 3 4 5
MAP SCALE 1:100,000
ISLANDS

FIGURE D-64

REFERENCES

Bird, R. B., W. E. Stewart, and E. N. Lightfoot, 1960. Transport phenomena, John Willey & Sons, Inc., New York, London.

Callaway, R. J., 1976. Transport of pollutants in the vicinity of Prudhoe Bay, Alaska, NOAA, PB 261 410.

Chin, H., A. Niedoroda, and P. Mangarella, 1979. Addendum to 1978 summer environment studies associated with the Prudhoe Bay Dock: physical oceanography and benthic ecology, Draft report to ARCO Oil and Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska.

Chow, V. T., 1959. Open channel hydraulics, McGraw Hill Book Company, Inc.

Dames & Moore, 1977. Kaneohe Bay urban water resources study: computer modeling, Job Number 4401-034-11, July.

Dames & Moore, 1978. Draft mathematical modeling study for Seminole Electric Cooperative, Inc., Job No. 10359-044-09, February.

Dronkers, J. J., 1964. Tidal computations in rivers and coastal waters, North Holland Publishing Company, Amsterdam.

FSAR, Docket No. 50-302, 1973. Verification study of Dames & Moore's hurricane storm surge model With application to Crystal River Unit 3 Nuclear Plant, Crystal River, Florida, Florida Power Corporation, Florida, July.

Intersea Research Corporation, 1980. Surge height and current time histories, communication from J. W. Joy of Intersea Research to R. Schilling of ARCO on January 24, 1980.

Keulegan, G., 1951. Wind tides in small closed channels, Research Paper 2207, National Bureau of Standards, U.S. 1951.

Manning, R., 1891. On the flow of water in open channels and pipes, Transaction, Institution of Civil Engineers of Ireland, Vol. 20, pp. 161-207.

Mungall, J. C. H., R. W. Hann, Jr., D. J. Horne, R. E. Whitaker, and C. E. Abel, 1978. Oceanographic processes in a Beaufort Sea barrier island - lagoon system: numerical modeling and current measurements, Contract Number 03-7-022-35182, Department of Oceanography, Texas A & M University, College Station, Texas, March.

Ott Water Engineers, Inc., 1980. ARCO model input surge analysis, prepared for ARCO Gas & Oil Company, Dallas, February.

Runchal, A. K., 1978. Mathematical modeling of a large water body, Proceedings of the Symposium on Technical, Environmental, Socioeconomic and Regulatory Aspects of Coastal Zone Management, American Society of Civil Engineers, March 14-16, 1978.

Spight, T. M., 1979. Prudhoe Bay west dock extension: synthesis of environment studies 1974-1978. Draft report to ARCO Oil and Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska.

Stoker, J. J., 1957. Waterwaves, Interscience Publishers, New York.

U.S. Geological Survey, 1979. Flood characteristics of Alaska streams, Water Resources Investigations 78-129.

U.S. Geological Survey. Water-discharge records for the Arctic Slope, Alaska, Station 15896000, Kuparuk River Near Deadhorse, June 1971 to September 1977.

U.S. Geological Survey. Water-discharge records for the Arctic Slope, Alaska, Station 15910000, Sagavanirktok River near Sagwon, August 1970 to September 1977.

U.S. Geological Survey. Water-discharge records for the Arctic Slope, Alaska, Station 15896700, Putuligayuk River near Deadhorse, May 1970 to September 1977.

Van Dorn, W. G., 1953. Wind stresses on an artificial pond, Journal Marine Research, Vol. 12, pp. 216-249.

Wilson, B. W., 1960. Note on surface wind stresses over water at low and high speeds, Journal of Geophysical Records, 65(10):3377-3382, October.

Woodward Clyde Consultants. Draft Results of Processed Current Meter Data, July, 1979, and August, 1979, communication from K. E. Tarbox of Woodward Clyde Consultants to P. Hellstrom of ARCO Oil & Gas Company, on October 5, 1979.

APPENDIX E

MARINE BIOLOGY

1.0 INTRODUCTION

This appendix is a technical support and source document for statements made in Section 3.9 of the DEIS for the proposed Waterflood Project at Prudhoe Bay.

Marine biological communities in the Prudhoe Bay vicinity could be affected by several aspects of the proposed or alternative actions. Extension or modification of the existing causeway, operation of the intake and discharge and resultant changes to the regional and local physical and chemical environment are the major areas of concern (Section 4.2). Biological production in the study area is important locally in providing a subsistence resource for the Eskimo and limited commercial and sport fisheries as well as waterfowl and marine mammal harvest. On a broader scale, migratory species breeding and feeding here during the brief open-water period contribute to populations (waterfowl, anadromous fish, whales) of considerable importance elsewhere in the Beaufort Sea and as far south as South America.

The marine biological environment of the Prudhoe Bay vicinity is dominated by both static and dynamic physical features. The major static features are the shallow sloped bathymetry and the barrier islands. Major seasonal features include dynamic open-water/ice-cover periods and transitional periods, as well as the influx of fresh water, primarily from the Sagavanirktok River, in the thaw period. Winds operate on the variable open-water system to cause turbidity and other local water quality changes in the Prudhoe Bay marine environment. These features modify the local marine biological environment such that a system with low species diversity develops.

2.0 FIELD STUDY PROGRAMS

Studies of various marine biological features have only recently (past 10 years) begun in the Prudhoe Bay area in response to oil development. Seasonal observations have been limited due to the complexity of sampling under various forms of ice. Studies of the specific areas affected by the proposed causeway extension and other project facilities are limited to the summers of 1974 - 1979, with major field sampling occurring from July - September. However, signficant studies were accomplished during the winter of 1979 (Tarbox and Thorne 1979, Busdosh et al. 1979, Beehler et al. 1979, Robilliard and Bushdosh 1979, Tarbox et al. 1979). On a larger scale, the BLM-sponsored NOAA/OCSEAP program has covered both nearshore and offshore studies of all major components of the macrobiological system. Programs of major significance to the Waterflood Project are listed below.

Most of the earlier nearshore work along the Alaska coast has centered around the Barrow area. The first study, by MacGinitie (1955) at the Naval Arctic Research Lab was directed primarily at benthos (organisms associated with the bottom) but also discussed both phytoplankton and zooplankton. This study was followed by several studies on the phytoplankton (Bursa 1963, Horner 1969) and the zooplankton constituents (Johnson 1958, Redburn 1974), productivity of the ice algae (Horner 1972, 1973; Horner and Alexander 1972; Clasby et al. 1976), and productivity of the benthic diatoms (Matheke 1973, Matheke and Horner 1974).

Recent studies in and near the Colville River system, including Simpson Lagoon and Harrison Bay, of the primary productivity and biomass of phytoplankton, were conducted by the University of Alaska (Alexander et al. 1974) and were sponsored by State and Federal Sea Grant programs, EPA and various oil companies. The most specific work in the Prudhoe Bay region was done by Horner et al. (1974) and Coyle (1974). English and Horner (1976) studied phytoplankton and zooplankton populations offshore and in Prudhoe Bay under an OCSEAP-funded program. Additional offshore studies have continued under this same program (Horner 1978, 1979).

In conjunction with the proposed Waterflood Project, densities of major zooplankton species (including ichthyplankton) during the 1979 - 1980 winter and 1979 open-water periods have been conducted near the site (Tarbox et al. 1979, Tarbox and Moulton 1980).

Until recent years, little was known of the ecology of the benthic invertebrates of the Beaufort Sea region. The first comprehensive study of the nearshore benthos of the Alaska arctic coast was conducted by MacGinitie (1955) at Barrow. Only scattered work was done in the Beaufort Sea until oil was discovered on the North Slope in 1968. In 1970, the U.S. Coast Guard, Exxon U.S.A., and OCSEAP sponsored several offshore studies including benthic sampling (Carey and Ruff 1977; Carey 1977, 1978). A study of the nearshore benthos of the Simpson Lagoon region was conducted in conjunction with the University of Alaska study of the estuarine environment of the Colville River system (Alexander et al. 1974, Crane 1974).

OCSEAP has funded several programs to investigate the nearshore benthos of the Simpson Lagoon area (Griffiths et al. 1975, 1977; Griffiths and Craig 1978; Griffiths and Dillinger 1979) and the coast of the Beaufort Sea (Broad 1977; Broad et al. 1978, 1979). Investigations of the boulder patch habitat in Stefansson Sound have also been reported (Dunton and Schonberg 1979). Little work has been done on arctic benthic macrophytes. The first major report on an arctic kelp bed, located at Barrow, was by Mohr (1957). Studies documenting the kelp in the Stefansson Sound region and nearby areas have been conducted by OCSEAP investigators (Broad et al. 1979), and by PBU consultants (Beehler et al. 1979) in conjunction with the Waterflood Project.

Benthic studies were conducted to determine the effects of the PBU causeway construction on invertebrate populations near the causeway (Feder et al. 1976a,b). Similar investigations were continued through 1978 (Grider et al. 1977, 1978). The PBU owners have sponsored several benthic studies in conjunction with the proposed Waterflood Project, including a study of the biology of *Saduria entomon* (Robilliard and Busdosh 1979) and a study of motile amphipods (Busdosh et al. 1979).

Craig and McCart (1976) summarized much of the Beaufort Sea and adjacent freshwater fisheries research prior to 1976. Several reports (AINA 1974, Woodward-Clyde 1979, NOAA-BLM 1978) have synthesized available fisheries data in the Beaufort Sea and the project vicinity, respectively. Craig and Griffiths (1978) and Craig and Haldorson (1979) completed recent studies to the west of the project vicinity (Simpson Lagoon), and Griffiths et al. (1975 and 1977) and Kendel et al. (1975) completed studies to the east (Nunaluk Lagoon, Kaktovik Lagoon, and Yukon coast). Morrow (1979) summarized the life histories, distribution, and value of freshwater fishes in Alaska. Several site-specific reports provide details of the freshwater environments (Yoshihara 1972, 1973; USDI 1972; McCart et al. 1972; Craig and McCart 1974, 1976; Craig and Mann 1974; Craig 1977; Bain 1974; and Percy 1975). Specific fish studies in the project vicinity have been completed by Bendock (1977), Doxey (1977), NOAA-BLM (1978), Tarbox and Thorne (1979), Tarbox and Spight (1979), Moulton et al. (1980), and Tarbox and Moulton (1980). These latter studies have focused on dominant marine and anadromous fish with an emphasis on the abundance, distribution, and seasonality of nearshore fish species. The majority of sampling has occurred in the open-water, "summer," period, which can range from a few weeks to a few months in duration.

Limited data exists for the 9-month "winter" period when ice hinders fish sampling in the Beaufort Sea. Winter plankton pumping produced only two (unidentified) fish eggs (0.5/1000 m^3) (Tarbox et al. 1979). Fyke nets captured 19 fish (89 percent arctic cod, 11 percent bartail snailfish) in winter. Based upon diver observations, this sampling technique appeared to favor the pelagic community rather than the benthic community. Divers observed 43 fish (70 percent bartail snailfish, 16 percent fourhorn sculpin, 11 percent arctic cod, and 2 percent slender eelblenny). All arctic cod observed in winter were in the water column, although some were close to the bottom (Tarbox and Thorne 1979).

Hydroacoustic fish assessment under ice, while covering a limited area due to fixed upward and downward looking transducers, indicated low fish densities (Tarbox and Thorne 1979). However, the main pelagic species observed (arctic cod) is a schooling species, so it is possible that larger numbers of this species were present but undetected. Hydroacoustic monitoring under ice showed an unexpected diel pattern (fewer targets in the afternoon) that persisted even though the light regime changed from 10 - 20 hours of light. Bartail snailfish and fourhorn sculpin were observed by divers in this time period (in a presumed inactive mode) possibly indicating some pelagic inactivity was a result of these more bottom-associated species leaving the water column after actively feeding there. Hydroacoustic methods used cannot detect fish on the bottom. Hydroacoustic studies indicated an apparent attraction to structures placed under the ice although a small number of fish were apparently involved in the observations (Tarbox and Thorne 1979).

Recent marine mammal studies in the Beaufort Sea are annotated in Severinghaus (1979) with one exception (BLM 1979) involving marine mammal surveys in the proposed Beaufort Sea OCS lease area. NOAA-BLM (1978) provided a synthesis of OCSEAP marine mammal studies. Recent Beaufort Sea studies of the biology, distribution, abundance, and use by man of selected marine mammals include: bowhead whales (Braham et al. 1979, in press; Everitt and Krogman in press; Marquette in press); belukha whales (Fraker et al. 1978); ringed seals (Smith and Stirling 1975; Lowry 1978a, b); polar bears (Eley 1977, Marquette in press); and arctic fox (Underwood 1975, Battelle Pacific Northwest Laboratory 1979).

This appendix is based upon these and other available reports and personal communications with various experts. No field sampling was completed; all descriptions and conclusions are based on available data.

3.0 GENERAL ECOLOGY

The structure of the marine system in the vicinity of Prudhoe Bay generally appears to be relatively simple, i.e., the assemblages are not very diverse, interactions appear straightforward and the major physical factors influencing the biological components can be readily defined. Generally, forage species for the major top predators are confined to a small number of very abundant prey species. Although the dynamic properties of Beaufort Sea biological systems are poorly known, it appears likely that physical factors play the strongest role in determining the nature of the biological assemblages in the area of the proposed action. The relatively few species tolerant of this harsh physical environment have often been able to build very large populations, resulting in a total biomass comparable to that in more temperate habitats.

Most investigators of this area have commented on the severely rigorous nature of the environment, particularly referring to salinity changes, temperature regime, bottom-fast ice, ice impingement and scouring, storm surge, turbidity, and low concentrations of dissolved oxygen. They have described how these stresses result in the assemblages being impoverished in species. Some stresses to which this benthic fauna is subjected may be no more rigorous in terms of variability than many other shallow subtidal, exposed soft substrate habitats in arctic or temperate regions. The benthic assemblages do not appear less rich than exposed, soft-bottom assemblages in more temperate areas such as lower Cook Inlet (Dames & Moore 1979) or southern California (Lees 1975). In such habitats, the nature of the natural stresses may vary, but many exposed soft sediment habitats at temperate latitudes are also subjected to extreme disturbances annually. In Prudhoe Bay, the major stresses are storm surge, which can move tremendous amounts of sediment and leave large numbers of animals buried, suffocated or unearthed; bottom-fast ice; removal of sediments by ice scouring; and freezing of the upper layers of sediment. Except in the bottom-fast ice zone where the sediment freezes, temperature variation (about 7°C) is less in the

Arctic than in lower Cook Inlet (about 16°C) or southern California (about 25°C). The greatest variations in salinity are also incurred in inshore areas affected by bottom-fast ice. In deeper water, variations in salinity at the bottom are no greater than normally experienced by estuarine organisms. Turbidity is also generally no more of a problem than in an estuary. Ultimately, even if all animals are killed or displaced annually by storm surge, ice scour, or freezing, the area is no more rigorous than in analogous habitats farther south where factors such as storm surges also kill a great majority of organisms. Virtual annihilation of infauna is also known to occur in temperate areas ([illegible] 1975), but in the Beaufort Sea the open-water growing and recovery season is extremely short.

Food webs in the Prudhoe Bay area are apparently relatively simple, involving mainly terrigenous organic debris and phytoplankton, bacteria, several types of crustaceans, fishes, birds, and marine mammals. The dietary overlap among the major consumers is high. However, the dynamic characteristics of this ecosystem, which are little known at present, may introduce a level of complexity much greater than that currently perceived.

Terrigenous organic debris (TOD) comprises about 78 percent of the carbon available in the inshore and nearshore areas, and phytoplankton, about 22 percent (Schell 1978). The available data are not sufficient to accurately identify the energy pathways by which TOD might be utilized by marine organisms. Broad et al. (1978) has observed assimilation of organic carbon from peat by <u>Gammarus setosus</u> and peat has been observed in the stomachs of several other major detritivorous crustaceans (Griffiths and Dillinger 1979). The major detritivores appearing to link the detritus resources and bacteria to the secondary consumers (predators) are the isopod <u>Saduria entomon</u>, the gammarid amphipods <u>Gammarus setosus</u>, <u>Onisimus glacialus</u>, <u>Apherusa glacialis</u>, and <u>Gammaracanthus loricatus</u>, and the mysids <u>Mysis relicta</u> and <u>M. litoralis</u>. The main herbivores consuming phytoplankton and passing the energy along to secondary consumers are the copepods <u>Calanus glacialis</u>, <u>Derjuginia tolli</u>, <u>Acartia clausa</u> and <u>Pseudocalanus minutus</u>.

The main secondary consumers include the marine fishes Myoxocephalus quadricornis (fourhorned sculpin), Boreogadus saida (arctic cod), and the anadromous fishes Salvelinus alpinus (arctic char), Coregonus autumnalis and C. sardinella (arctic and least cisco), the sea ducks (oldsquaw and common eider), pinnipeds (ringed and bearded seals), and perhaps belukha whales. The sculpin, most abundant in the nearshore area (depth less than 2 m, 6.5 ft), feeds primarily on mysids, isopods, amphipods, juvenile arctic cod, Saduria and fish eggs. Arctic cod, abundant in schools throughout the area, feed largely on copepods and mysids. Arctic char, also dispersed throughout the lagoons, feed largely on arctic cod as well as mysids, isopods, amphipods, insects and fourhorn sculpin (e.g. Bendock 1977). Little has been reported on the diet of ciscoes living in the low-salinity inshore areas. However, they appear to eat mainly mysids, amphipods and dipterans with considerable vegetation and detritus also ingested (Bendock 1977).

The ringed seal feeds heavily on arctic cod, but supplements its diet with mysids, isopods and amphipods. Oldsquaw also feed on mysids, isopods and amphipods. The natives conduct commercial and subsistence fisheries on arctic cod, arctic char, arctic and least cisco, as well as the whitefish species, seals, waterfowl and belukha and bowhead whales. The ringed seal is fed upon by the polar bear, arctic fox and man.

In general, energy pathways involving infaunal organisms in the Prudhoe Bay area have not yet been identified. Plant energy from terrigenous or marine sources appears to pass primarily through several principal species of epibenthic amphipods, isopods or mysids to fish, birds, or seals, and ultimately to polar bears, arctic foxes and man.

4.0 DESCRIPTION OF ASSEMBLAGES AND ECOLOGICAL SIGNIFICANCE

PRIMARY PRODUCERS

Carbon fixed by phytoplankton is one of the three major sources of energy in the Beaufort Sea. Many of the phytoplankters common to this region have generally circumpolar distributions (Bursa 1963, Horner 1969, Coyle 1974, Horner et al. 1974, Hsiao 1976). Many species show pronounced seasonality both in abundance and diversity, largely as a result of varying light, hydrography and nutrient levels.

During the period of ice cover, several types of phytoplankters live within and on the under side of the ice. In the Prudhoe Bay region, this "epontic" community is made up of primarily pennate diatoms, but species composition and standing stocks are quite variable (Horner et al. 1974). *Fragilariopsis* spp, *Nitzschia frigida*, *N. grunowii*, and *Chaetoceros* sp are the common species. Many of the diatoms found in the ice also are found in the water column, but only *Nitzschia grunowii* appears to be a major component of both habitats (Horner et al. 1974). Other organisms associated with this ice community include dinoflagellates, flagellates from several algal phyla, ciliated protozoans, and several zooplankters (Horner and Alexander 1972).

The correlations among primary productivity, chlorophyll *a*, and diatom concentrations are positive and strong (English and Horner 1976). Primary productivity of the ice algae has been estimated to be about 5 grams carbon per square meter per year (g $C/m^2/yr$) at Barrow (Alexander et al. 1974). This figure may be valid for Prudhoe Bay, but lower chlorophyll *a* levels and the lateness of the bloom suggest that a more realistic level is 1 g $C/m^2/yr$ (Horner et al. 1974). The importance of the spring bloom of ice algae (which occurs prior to the bloom in the water column) may lie more in the fact that it prolongs the growing season than in the total amount of carbon fixed (Alexander et al. 1974). Ice algae may also represent an important source of algae for benthic organisms during and immediately following breakup (Schell 1978).

A second phytoplankton bloom occurs irregularly in the water column during the open-water period. Generally, the concentrations of chlorophyll *a*, an indicator of primary productivity, is higher in the deeper, clearer, more saline waters than in the brackish and generally turbid surface or nearshore waters.

There is evidence that, during relatively stable conditions, distinct phytoplankton communities are formed that are roughly segregated geographically by depth, and perhaps by salinity (Horner et al. 1974). Pennate diatoms, microflagellates and centric diatoms were the dominant forms in three such communities documented in 1974. However, later studies by English and Horner (1976) in the same area showed no discrete divisions, and most common species were distributed throughout the area. They concluded that this was probably a result of significant mixing from weather conditions, along with nutrient concentrations.

Estimates of the total primary productivity for the water column in the lagoon range between 13 - 23 g C/m^2/yr. The total annual primary production inside Prudhoe Bay probably does not exceed 10 g C/m^2/yr, including about 10 percent from ice algae (Horner et al. 1974); this is much lower than the maximum value of 7.8 g C/m^2/d reported between late April and August (approximately 1000 g C/m^2/yr) in the very productive environment of Kachemak Bay, lower Cook Inlet (Larrance 1978). The contribution of benthic microalgae to total system primary productivity is estimated to be approximately 60 percent near Barrow (Matheke 1973). It could also represent a significant contribution in the Prudhoe Bay area. An unmeasured additional contribution to the annual productivity of the Prudhoe Bay area is derived from benthic macroalgae that grow in patches of varying sizes and density (Beehler et al. 1979). Major species are the laminarian kelps (*Laminaria solidungula* and *L. saccharina*). Density of kelp patches was low near shore and tended to increase with depth.

ZOOPLANKTON

Zooplankton of the Beaufort Sea can be categorized into four general groupings: (1) fully planktonic (holoplanktonic) species occuring throughout the arctic basin, (2) expatriates from the Bering and Chukchi Seas, (3) expatriates characteristic of neritic, less-saline environments, and (4) partially-planktonic (meroplanktonic) forms

(English and Horner 1976). Meroplankton is composed of planktonic eggs and larvae of a variety of invertebrates and fish (ichthyoplankton) that are present in the water column for only finite periods in the course of developing into mature organisms. Thus, meroplankton is important both as a food resource for plankton feeding species and as a vital stage in the life history cycle of many species. Some primarily benthic forms, such as gammarid amphipods and mysids often swim short distances into the water column. While they are not true components of the plankton (Busdosh et al. 1979), they are often classed as "epibenthic zooplankton" and may in fact be vulnerable to entrainment by the proposed intake.

Horner et al. (1974) reported 30 zooplankton taxa from nine phyla in samples taken from the Prudhoe Bay region during August. Only six of these taxa were distributed throughout the region. Based on relative abundance and community structure, three areas were differentiated: (1) estuarine waters inside Prudhoe Bay, (2) marine waters seaward of the Midway Islands, and (3) the lagoon area between Pt. McIntyre and the Midway Islands, which exhibits intermediate characteristics.

The nearshore, neritic waters of Prudhoe Bay were dominated by the holoplanktonic copepods Acartia clausa and Pseudocalanus spp; mero-plankters were virtually absent (Horner et al. 1974). This area had the highest concentration of the small hydroid medusae, Perigonimus yoldia-arctica (bell height 5 - 25 mm). The holoplanktonic medusae, Aeginopsis laurentii, also occurred in this region (Horner et al. 1974). Broad et al. (1978), sampling in the littoral zone, found four additional species inshore.

Seaward of the Midway Islands, the zooplankton became more oceanic. In these more saline waters, the copepods Microcalanus spp, Pseudo-calanus spp, and Chiridius obtusifrons dominated. Five species of Hydrozoa were reported from this area by Horner et al. (1974). Obelia longissima ($\leq$0.5 mm in diameter) was the only hydrozoan species which favored the waters outside the Midway Islands. Samples taken much farther offshore indicated that medusae are not abundant in this area, but that densities increase to the west (English and Horner 1976). Hydrographic and weather conditions could conceivably increase concentrations in the vicinity of Prudhoe Bay. The major species occurring in the offshore water are Aglantha digitale (≤2.5 cm in height) and Rathkea octopunctata (≤4 mm in diameter) (Hand and Kan 1961, Horner and English 1976). The only scyphozoan, Cyanea capillata (≤30 cm in diameter), and a ctenophore, Beroe cucumis (≤30 cm long), also occur offshore (English and Horner 1976). In contrast with the area inside the barrier islands, meroplankters made up a more significant portion of the zooplankton of this region. Decapod, polychaete, and barnacle (Balanus) larvae, while more abundant, did not surpass the copepods numerically (Horner et al. 1974). However, in comparison to the Chukchi and Bering Seas, this region of the Beaufort Sea is generally poor in meroplankton (Johnson 1956).

The lagoon area between Prudhoe Bay and the Midway Islands had higher species diversity than the nearshore areas, corresponding with increased salinity and depth, and was dominated by the copepods Calanus glacialis and Pseudocalanus minutus. In samples taken during the winter and spring beneath the ice north of the causeway, the dominant species were P. minutus and an euryhaline, brackish water species, Derjuginia tolli (Busdosh et al. 1979). Copepods strongly dominated the holoplankton; other forms were encountered only infrequently. Although chaetognaths were found throughout the area, they were possibly a result of mixing between offshore and inshore water masses (Horner et al. 1974). Meroplankters, only a small portion of the zooplankton of this area, consisted of a few barnacle naupilii and cyprid larvae and a few crab zoea during August (Horner et al. 1974). Polychaete larvae were the major meroplankters in winter and spring samples but densities were very low (Busdosh et al. 1979).

Ichthyoplankton is discussed in the fish section below.

BENTHOS

Benthic organisms, especially epibenthic forms, are highly important in marine food chains and could be affected by direct project disturbance (burial) and by more subtle project-induced changes to the physical environment.

The benthos of the coastal region near the proposed development is characterized by low species diversity, density, and biomass in the shallow water, increasing with depth and distance from shore (Broad 1977; Feder et al. 1976a,b; Carey and Ruff 1977). The dominant infaunal forms are annelid worms, molluscs and arthropods. The patchy distribution of these species is largely determined by such physical factors as sediment type, ice stress, organic nutrient export, average and extreme bottom temperatures, and salinities. All are related generally to depth (Carey and Ruff 1977; Carey 1977, 1978; Feder 1976a,b; Grider et al. 1977, 1978). Many of the benthic invertebrates reproduce without planktonic development by producing demersal eggs or by brooding their larvae; thus replacement is accomplished by recruitment from local populations (Feder et al. 1976a) or adult immigrations, rather than through settlement of planktonic larvae. However, some very abundant species are widely dispersed by planktonic larvae, and dispersion by motile adults is common.

Three geographic areas can be used to describe the benthic assemblages of this region: (1) the nearshore areas less than 2 m (6.5 ft) in depth, (2) the inshore areas between 2 - 20 m (6.5 - 65.6 ft) in depth, and (3) the offshore areas over 20 m in depth.

Nearshore

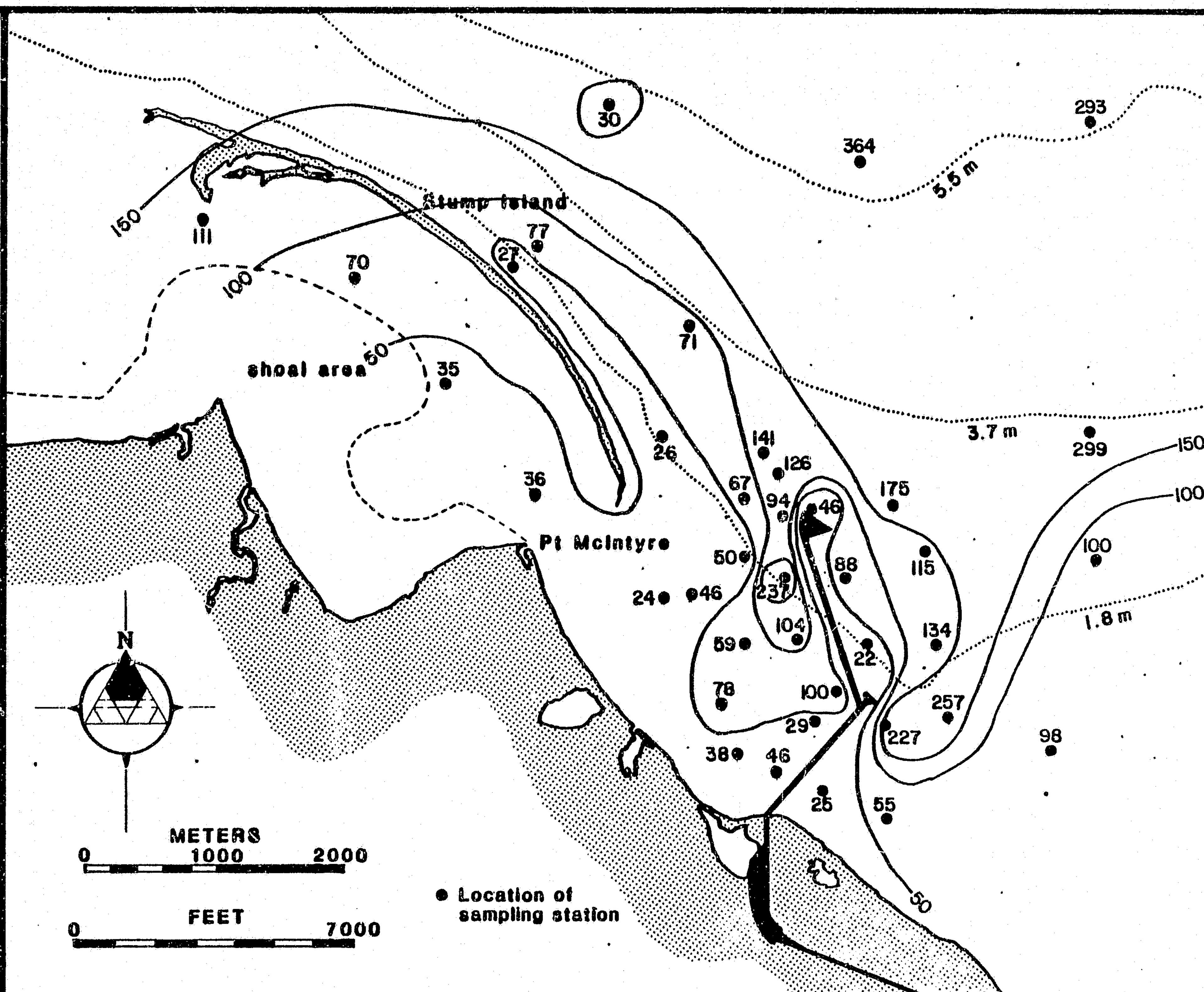
The shallow nearshore areas of the Prudhoe Bay region, from the intertidal zone to a depth of 2 m (6.5 ft), encompass most of Prudhoe Bay and the area behind Stump Island and generally approximate the area where the land-fast ice freezes to the substrate. These areas have rather low species diversity, density, and biomass (Broad et al. 1978; Feder et al. 1976a,b; Grider et al. 1977, 1978) (Figures E-1, E-2 and E-3). Areas shallower than 0.5 m (1.6 ft) have virtually no benthic infauna (Broad 1977, Feder et al. 1976a, Carey and Ruff 1977). Depth-related differences in this area are less pronounced than in deeper water and distribution of species is patchy (Broad et al. 1978).

The benthos is characterized by motile, opportunistic epifaunal forms capable of rapidly recolonizing the nearshore after the ice recedes in the spring, e.g., the mysids Mysis relicta and M. littoralis, the amphipods Pontoporeia affinis, Onisimus glacialis, and O. littoralis, and the isopod, Saduria entomon. Also found are small infaunal forms capable of over-wintering in the sediments or of rapid recolonization, e.g., the polychaete Pygospio elegans, tubificid and enchytraeid oligochaetes, and larvae of the midge Paraclinio alaskensis (Broad 1977; Broad et al. 1978; Feder et al. 1976a,b; Grider et al. 1977, 1978).

Inshore

The inshore area (2 - 10 m, 6.5 - 32.8 ft), including most of the lagoon between the outer barrier islands and the 2-m isobath (approximate limits of landfast ice), has moderately low species diversity, species richness, biomass, and density (Grider et al. 1977, 1978; Broad 1977; Chin et al. 1979a,b). The magnitude of these parameters exhibits a strong positive correlation with depth, but, on the west side of the causeway, the magnitude is characteristic of deeper water (a tongue of high values characteristic of deeper water intrudes into the shallow water near the causeway; Figures E-1, E-2 and E-3). Although motile epifaunal crustaceans are as common in the inshore area as in the nearshore area, sedentary infaunal species that are affected by the actions of bottomfast ice in the nearshore area become relatively more abundant here. Important epifaunal crustaceans include Mysis spp, Pontoporeia femorata, Onisimus galcialis, Saduria entomon, S. sibirica, Boeckosimis affinis, and Diastylis sulcata. Important infaunal

Figure E-1



MEAN NUMBER OF INDIVIDUALS OF BENTHIC INVERTEBRATES (5 REPLICATES/STATION/YEAR) IN 1976-1979

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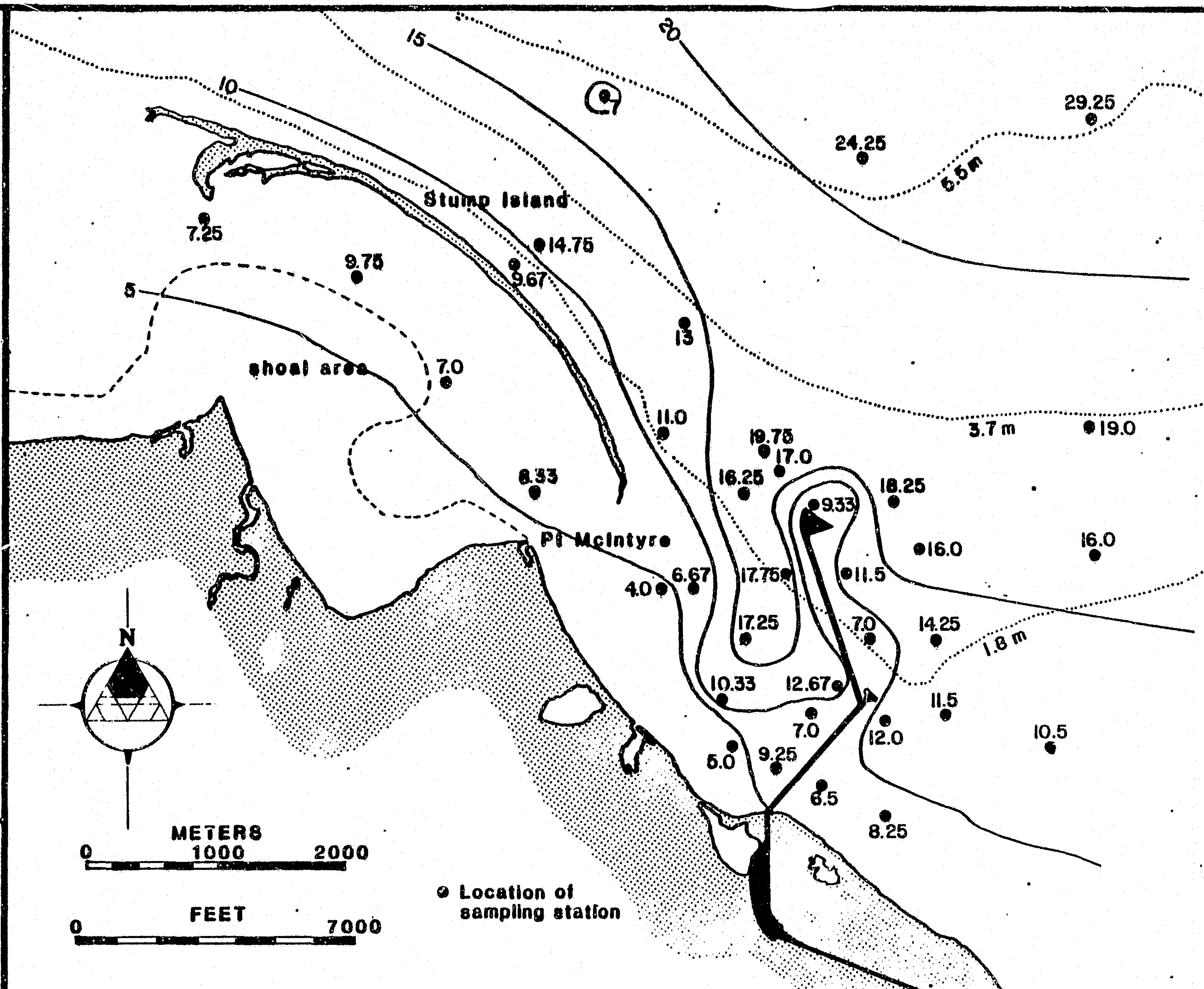
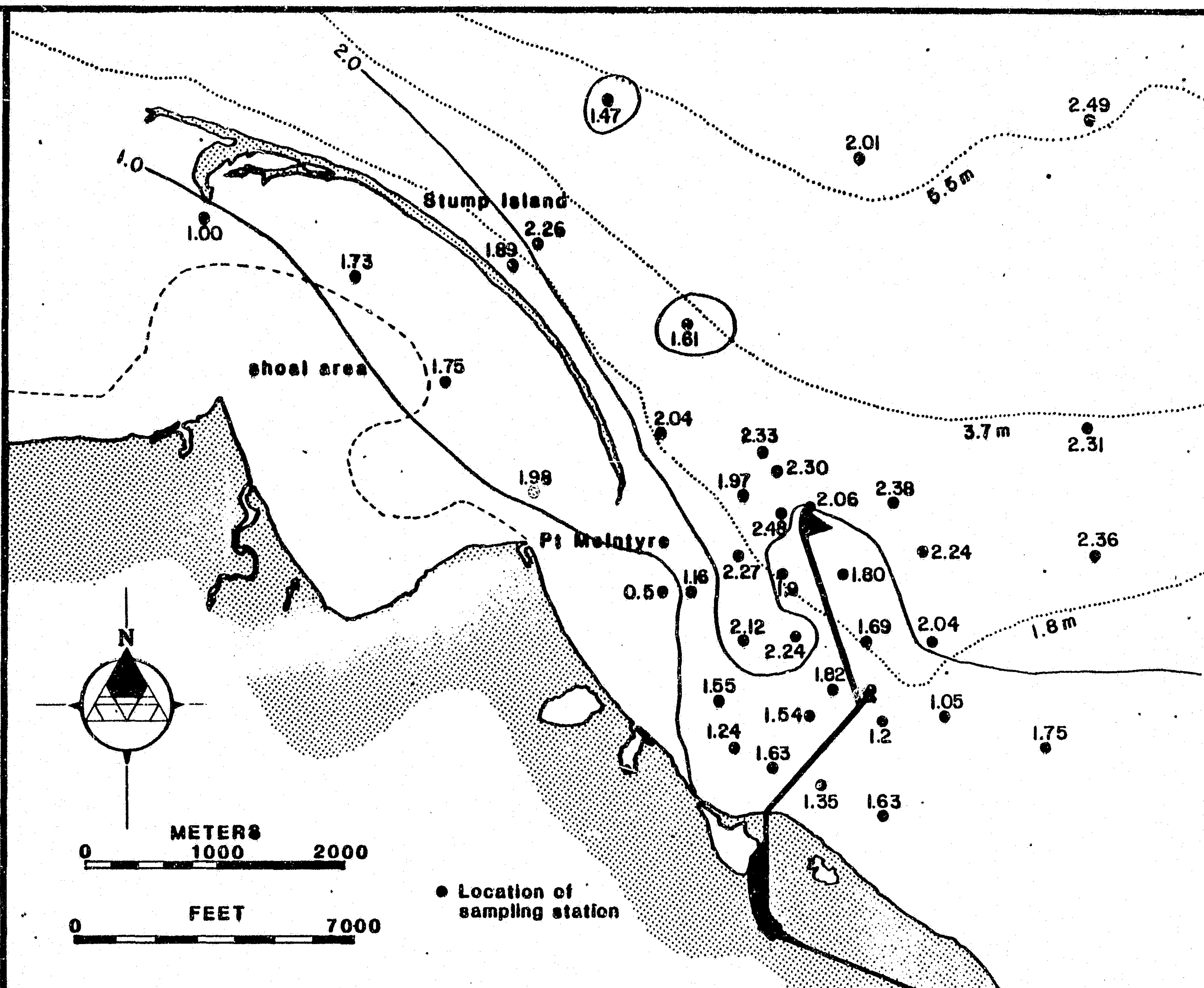
Figure E-2



MEAN NUMBER OF SPECIES OF BENTHIC INVERTEBRATES
(5 REPLICATES/STATION/YEAR) IN 1976-1979

PBU Waterflood Environmental Impact Statement

Figure E-3



SPECIES DIVERSITY (H') OF BENTHIC INVERTEBRATES IN 1976–1979 species include Ampharete vega, Chaetozone setosa, Halicryptus spinulosus, Chone sp, Cyrtodaria kurriana, Portlandia arctica, Scolecolepides arctus, Eteone longa, Tharyx spp, and Prionospio cirrifera. Most of these infaunal species are fairly long-lived, and most of the polychaetes are tubicolous. These characteristics suggest that the area is more stable than the nearshore zone. A wide variety of species were restricted to bottoms deeper than 6 m (20 ft) (Grider et al. 1977, 1978; Chin et al. 1979a,b).

Offshore

The offshore region (greater than 10 m, 33 ft), shows a significantly richer faunal composition than areas closer to shore (Carey and Ruff 1977). Polychaetes, represented by 37 families, make up the bulk of the infauna (Carey 1978). Gammarid amphipods are also a dominant component of the assemblage with over 100 species representing 24 families. The major physical factor determining distribution is related to depth (Carey 1978). Some of the more important species probably include the polychaetes Ampharete vega and A. acutifrons, Praxillella praetermissa, Cirrophorus sp, Prionspio cirrifera, Aricidea suecica, and the molluscs Liocyma fluctuosa and Polinices pallidus.

POTENTIAL FOULING COMMUNITY AT PRUDHOE BAY

Although the amount of hard substrate in the Prudhoe Bay area waters is limited, boulder patches and other types of hard substrate below the level of bottomfast ice do support epibenthic assemblages. This habitat probably would not be affected by the proposed action, but some of the sessile epifaunal filter-feeding organisms are potential foulers, and could pose a threat to efficient operation of the seawater treating plant.

Conditions inside both intake and discharge pipes frequently promote development of fouling assemblages; this can be a major problem for operations requiring seawater for heat exchange or other uses. The fact that such systems continuously move large volumes of water and entrained food particles makes them optimal for rapid growth of fouling organisms. In the vicinity of Prudhoe Bay, such pipeline systems would be especially favorable to fouling organisms since they would constitute a new, hard substrate protected from ice scour.

Information on potential fouling organisms in the Arctic is scanty. MacGinitie (1955) described hard-bottom assemblages off Point Barrow. A wide variety of those epifaunal animals are potential foulers. He stated that several species of the barnacle Balanus were among the most prolific organisms in rocky subtidal habitats around Barrow. Other potential foulers included the sea strawberry (Eunephtya rubiformis), a small mussel, (Musculus discors), several species of sponges, hydroids, and ascidians, along with several encrusting, digitate, foliose and head-forming bryozoans.

Information on potential fouling organisms in the Prudhoe Bay region has been provided by both OCSEAP and waterflood environmental studies. Many epifaunal forms reported by MacGinitie (1955) occur in the region and could act as "seed stock" for fouling assemblages in the intake and discharge systems associated with the seawater treating plant. Species composition of assemblages in the boulder patches near Cross Island was described by Dunton and Schonberg (1979). They observed encrusting, foliose and head-forming bryozoans, sponges, serpulid polychaetes, the sea strawberry, and the mussel Musculus. Furthermore, they reported that the hydroid Tubularia indivisa and the ascidian Dendrodoa aggregata, both important potential foulers, were common in the Cross Island area. Subsequently, Beehler et al. (1979) observed that several important potential foulers were common offshore of the West Dock in close proximity to Prudhoe Bay. Foremost among these were the sea strawberry, the mussel, and several sponges. Additionally, they observed several species of nudibranchs that feed on the epifaunal forms and that could be entrained into the intake and filtration system. Moreover, in the protection of the pipelines, brittle, erect, digitate or head-forming bryozoans, reported by MacGinitie (1955) but not yet observed at Prudhoe Bay, could become large enough to cause a substantial reduction in flow if they became established in the intake or discharge pipes. Redburn (1974) reported distinct hydrographic and biological differences as a function of depth, suggesting that not all fouling organisms in the Prudhoe Bay area would be able to successfully colonize the new habitat provided.

Barnacles were absent from all species lists examined from around Prudhoe Bay (Horner et al. 1974, Dunton and Schonberg 1979, Beehler et al. 1979). Barnacle naupilii and cyprid larvae also have been recorded as rare in plankton samples (Horner 1978). However, Tarbox and Robilliard (1980) indicated that barnacles have been observed encrusting concrete blocks dumped west of the existing PBU dock and living on cobbles in the lagoon between the Midway Islands and the mainland coast. In view of MacGinitie's report, the rarity of barnacles is rather puzzling. Based on the descriptions of Dunton and Schonberg (1979) and Beehler et al. (1979), neither sedimentation (smothering) nor poor circulation would appear to limit barnacles in the lagoon or the boulder patches. Thus, it appears that barnacles could pose a fouling problem.

FISH

Orientation

The study orientation is toward fish species that potentially could be impacted by the proposed action. These fish studies therefore focus on the nearshore (0 - 2 m, 0 - 7 ft) and inshore (2 - 20 m, 7 - 66 ft) marine waters and in the lower sections of the adjacent freshwater streams (Sagavanirktok, Kuparuk, and Putuligayuk Rivers).

The level of study is further focused on the early life history, diet, movements, distribution, and abundance of major fish species in the project vicinity. These parameters are of interest because early life history stages of fish (eggs, larvae, fry) are less able to avoid entrainment and impingement in the project intake, are distributed by currents influenced by causeway alternatives, and are more likely vulnerable than juvenile and adult forms to project discharges. Diets of major fish species are important to ascertain secondary impacts to fishes by possible project impacts on prey species. Fish movements are of interest, especially longshore migrations that could be further influenced by the proposed causeway extension. Temporal distribution and abundance information for dominant fish species based upon historical catches allows approximation of the numbers of fish in the project vicinity that could be impacted by the proposed action.

Prudhoe Bay Area Fish Populations

Descriptions of fishes in Alaska coastal areas have been traditionally broken down into three broad categories:

- Marine species, which remain in brackish or marine waters throughout their lives.

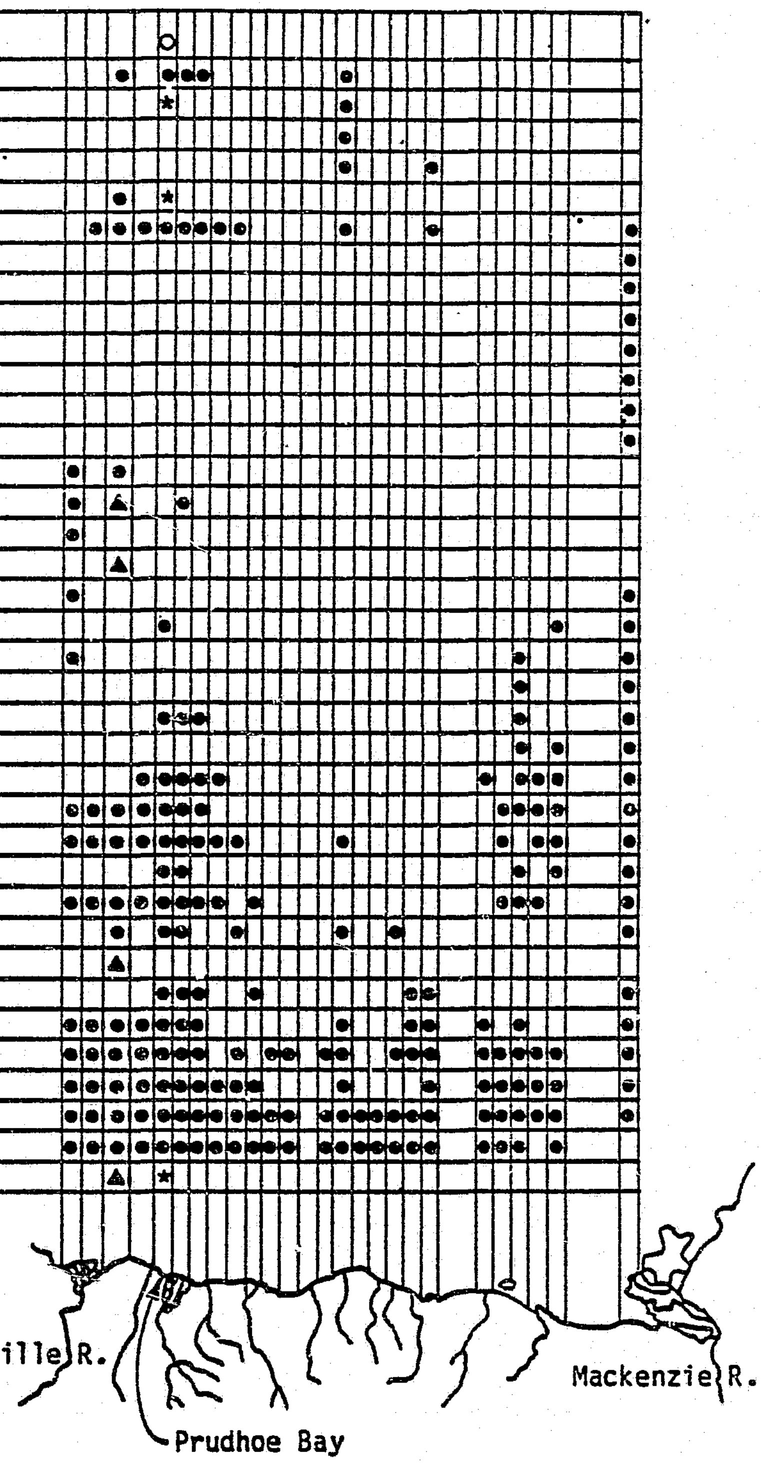
- Anadromous species, which tolerate a broad salinity range and undertake seaward migrations during their life cycle.

- Freshwater species, which occasionally occur nearshore when salinities are low.

Freshwater species entering low-salinity marine areas and marine species entering the lower reaches of streams under low-salinity conditions often overlap.

Figure E-4 presents a distributional array of the 38 fish species and general locations between the Colville and Mackenzie Rivers in marine and freshwater areas. Since two new fish species were taken in Prudhoe Bay in 1978 (Tarbox and Spight 1979a), four new species were found in Simpson Lagoon in 1978 (Craig and Haldorson 1979), and one new species

Common name	Scientific name
Bartail snailfish	Liparis herschelinus[b]
Unidentified snailfish	Liparid spp.
Slender eelblenny	Lumpenus fabricii
Stout eelblenny	Lumpenus medius
Arctic sculpin	Myoxocephalus scorpiodes
Capelin	Mallotus villosus
Pale eelpout	Lycodes pallidus
Trout-perch	Percopsis omiscomaycus
Pond smelt	Hypomesus olidus
Arctic lamprey	Lampetra japonica
Lake chub	Couesius plumbeus
Spoonhead sculpin	Cottus ricei
Longnose sucker	Catostomus catostomus
Lake trout	Salvelinus namaycush
Smelt spp.	Osmerus spp.
Pink salmon	Oncorhynchus gorbuscha
Chum salmon	Oncorhynchus keta
Sockeye salmon	Oncorhynchus nerka
Northern pike	Esox lucius
Burbot	Lota lota
Starry flounder	Platichthys stellatus
Pacific herring	Clupea harengus pallasi
Saffron cod	Eleginus gracilis
Inconnu	Stenodus leucichthys
Rainbow smelt	Osmerus mordax
Humpback whitefish	Coregonus pidschian
Arctic cod	Boreogadus saida
Round whitefish	Prosopium cylindraceum
Broad whitefish	Coregonus nasus
Ninespine stickleback	Pungitius pungitius
Threespine stickleback	Gasterosteus aculeatus
Arctic grayling	Thymallus arcticus
Arctic flounder	Liopsetta glacialis
Fourhorn sculpin	Myoxocephalus quadricornis
Least cisco	Coregonus sardinella
Arctic cisco	Coregonus autumnalis
Arctic char	Salvelinus alpinus
Pacific sand lance	Ammodytes hexapterus



Sources:

NOAA-BLM (1978), Craig and McCart (1976). Symbols: ●

Craig and Haldorson (1979). Symbols: ▲

Tarbox and Spight (1980). Symbols: *

Moulton et al. (1980). Symbols: ○

(a) Species records are approximate, since sampling efforts varied throughout the area. Most samples shown here were taken in nearshore, brackish water areas less than 3 m in depth.

(b) All fish names are according to American Fisheries Society (1970).

DISTRIBUTIONS OF FISH SPECIES RECORDED IN NEARSHORE AREAS BETWEEN THE COLVILLE & MACKENZIE RIVERS[a]

PBU Waterflood Environmental Impact Statement | **Figure E-4**

was taken in 1979 in Prudhoe Bay (Moulton et al. 1980), it is highly probable that more species will be located, particularly as more sampling is completed farther offshore in the Beaufort Sea and under winter conditions. In some cases these "new" species are species caught previously and only recently identified. The numerically dominant fish species will probably remain as has been seen in past sampling. The following were identified as "key" species by NOAA-BLM (1978):

Species		Anadromous	Marine
Arctic cisco	Coregonus autumnalis	X	
Least cisco	C. sardinella	X	
Arctic char	Salvelinus alpinus	X	
Fourhorn sculpin	Myoxocephalus quadricornis		X
Arctic cod	Boreogadus saida		X

Although the proportion of these five species varied from site to site, they collectively accounted for 91 - 98 percent of the fish enumerated at Simpson Lagoon (Craig and Griffiths 1978), Prudhoe Bay (Doxey 1977), Kaktovik Lagoon (Griffiths et al. 1977), Nunaluk Lagoon (Griffiths et al. 1975), and along the Yukon Territory coastline (Kendel et al. 1975). In some localities broad whitefish and humpback whitefish (both anadromous species) may also be important (NOAA-BLM 1978).

Intensive marine studies were undertaken in the Prudhoe Bay vicinity during the summers of 1978 and 1979 in anticipation of the proposed Waterflood Project (Tarbox and Spight 1979, Moulton et al. 1980, Tarbox and Moulton 1980). Table E-1 summarizes the relative fish abundance from these two periods and from other sampling efforts.

Limited winter sampling in Prudhoe Bay occurred from February - May 1979. Stations due north of DH 3 under the ice in water 4.6 - 6.7 m (15 - 22 ft) deep were sampled with hydroacoustic techniques, net sampling, baited traps, plankton pumping and SCUBA observation (Tarbox and Thorne 1979).

TABLE E-1

RELATIVE ABUNDANCE (%) OF FISH SPECIES CAPTURED IN THE VICINITY OF PRUDHOE BAY MODIFIED FROM TARBOX AND SPIGHT (1979)

	Simpson Lagoon[a]			Prudhoe Bay[b]	Prudhoe Bay[c]		Prudhoe Bay[d]			Colville[e] Delta Commercial Fishery
Species	Gill Net (781)[f]	Fyke Net (10,026)	Faber Net (366)	Fyke and Gill Nets (20,661)	9-m Seine (44)[g]	3-m Trawl (638)	Tow, Fyke and Gill Nets (1,081)	0.5-m Larval Fish Net (1,084)	3-m Trawl (3,390)	(57,483)
Arctic cisco	56.0	15.0	0.0	3.9	0.0	0.3	0.3	--	--	64.9
Arctic char	14.0	4.0	0.0	13.0	--	--	2.4	--	--	--
Least cisco	12.0	2.0	0.0	30.5	--	--	0.2	--	0.1	29.0
Fourhorn sculpin	9.0	70.0	0.0	29.0	76.0	2.2	2.6	3.1	0.2	--
Arctic cod	0.1	8.0	83.0	19.6	0.0	92.8	62.7	31.7	98.1	--
Broad whitefish	4.0	0.1	0.0	2.5	13.6	0.0				4.9
Humpback whitefish	2.0	0.0	0.0	0.6	--	--	0.2	--	--	1.2
Bering cisco	1.0	0.0	0.0	--	--	--	--	--	--	--
Capelin	1.0	0.02	0.0	0.02	9.1	1.6	27.3	--	0.1	--
Arctic flounder	0.4	1.0	0.0	0.1	--	--	--	--	--	--
Ninespine stickleback	0.0	0.2	0.0	0.01	--	--	--	--	--	--
Smelt	0.0	0.2	0.0	0.2[h]	--	--	--	--	--	--
Snailfish	0.0	0.1	16.6	0.2	0.0	1.6	3.3	65.1	1.2	--
Sculpin	0.0	0.0	0.5	--	--	--	--	--	--	--
Sand lance	--	--	--	--	2.3	1.3	0.1	--	0.1	--
Slender eelblenny	--	--	--	--	0.0	0.3	0.7	--	--	--
Round whitefish	--	--	--	0.04	--	--	--	--	--	--
Arctic grayling	--	--	--	0.1	--	--	--	--	--	--
Saffron cod	--	--	--	0.04	--	--	0.4	--	--	--
Rainbow smelt	--	--	--	--	--	--	--	--	0.3	--

(a) Craig and Griffiths (1978); summer data.
(b) Doxey (1977); summer data, mainly fyke net.
(c) Tarbox and Spight (1979)
(d) Tow net catches are 96 percent of the catches; Moulton et al. 1980; Tarbox and Moulton 1980.
(e) Commercial fishery data reported in Craig and Griffiths (1978); average annual catch.
(f) ( ) indicates total catch.
(g) Quarter hauls only.
(h) Boreal smelt.

The sampling periods of recent fisheries studies in the Prudhoe Bay region are:

Investigation	Sampling Period
Doxey (1977)	June 21 to September 22, 1976
Tarbox and Spight (1979)	August 16 to August 21, 1978
Moulton et al. (1980)	July 16 to September 1, 1979
Tarbox and Thorne (1979)	February 13 to May 5, 1979
Craig and Griffiths (1978)	June 19 to September 23, 1977
Craig and Griffiths (1979)	April 1978 to February 1979

As was the case for most other Beaufort Sea studies, Doxey (1977) sampled nearshore. Tarbox and Spight (1979) and Moulton et al. (1980) completed sampling out to a water depth of over 9 m (29 ft).

The abundance and location of Prudhoe Bay area fish during ice-cover periods is generally open to speculation due to insufficient data. Lack of equipment suitable to fish these shallow ice-infested waters under extremely difficult surface conditions complicates data gathering in the area. The continuing discovery of new species in each summer field season highlights this problem. This discovery is probably related to improved sampling techniques and increased effort rather than changes in fish distribution.

However, the background of summer sampling is thought sufficient to identify the species in the Prudhoe Bay vicinity most likely to be impacted by the proposed action since few fish were caught or seen in winter (February) sampling. A recent description by Tarbox and Spight (1979) summarizes these key fish species as follows.

General Description of Marine Species

Arctic Cod:

Arctic cod are abundant in the Beaufort Sea and widely distributed throughout the project area. They are a key species in the Arctic Ocean community, converting planktonic and nektonic crustaceans into a food resource exploited by arctic char, seals, walrus, whales, birds, and man.

Fourhorn Sculpin:

Sculpins are one of the most abundant fish in shallow nearshore waters around Prudhoe Bay. They harvest enormous quantities of small crustaceans and fish from the nearshore environment, and in turn, are probably an important diet item for larger predators.

Other Species:

Pacific sand lance, bartail snailfish, capelin, smelt, arctic flounder, slender eelblenny, and saffron cod have been captured in small numbers. Some of these are probably uncommon in the area, while others are seldom captured because appropriate gear types have not been utilized. Among these species, snailfish may prove to be an important element of the kelp bed community, and capelin and Pacific sand lance may be important forage species.

General Description of Anadromous Species

Arctic Char:

Arctic char are abundant and widely distributed throughout the study area. They are a major predator and an important object of subsistence and sport fisheries.

Arctic Cisco:

Arctic cisco were the most frequently captured anadromous fish in Simpson Lagoon, and are by far the most important fish in the Colville commercial fishery. These data are sufficient to identify this species as a key species.

Least Cisco:

Least cisco were the most commonly captured fish in Prudhoe Bay by Bendock (1977) and are the second most abundant fish in the Colville commercial fishery; therefore, they are a key species for impact assessment.

Broad Whitefish:

Broad whitefish were commonly encountered in Prudhoe Bay by Bendock (1977) and Doxey (1977) but were less common in Simpson Lagoon (Craig and Griffiths 1978); they are important in the Colville commercial fishery and therefore important for impact assessment.

Humpback Whitefish:

Humpback whitefish apparently do not stray far from spawning rivers' deltas, and are not particularly common in the study area. They do form a significant element of the Colville River commercial catch and are therefore included as important to the region.

Other Species:

Ninespine stickleback, arctic grayling, round whitefish, and Bering cisco have been reported occasionally. Most of these probably are strays from fresh water, rather than true anadromous forms. They do not form an appreciable element of the Prudhoe Bay community, and the individuals in Prudhoe Bay do not constitute a major portion of their respective species population.

In summary, at least two marine fish species and five anadromous species qualify as key species in the Beaufort Sea system. Aspects of their biology relevant to the proposed action will be discussed in the following sections.

Distributions and Life Histories of Marine Fish

Arctic Cod

Arctic cod are circumpolar in distribution and probably the most important species in the Prudhoe Bay vicinity in terms of abundance and role in the marine ecosystem of this area and of the Beaufort Sea. This species is the main plankton consumer in arctic seas (Bendock 1977). It is most numerous from inshore (2 - 20 m, 7 - 66 ft) to offshore waters. Fourhorn sculpin were more numerous in nearshore sampling (<2 m) completed by Doxey (1977). Arctic cod is an important food item of arctic marine mammals, birds, and other fish (Andriyashev 1954, Bain and Sekerak 1978). Coastal residents also take arctic cod for human consumption and dog food (Craig and Griffiths 1978).

Much of the arctic cod life history is undocumented. Beaufort Sea spawning locations are not known, but spawning is thought to occur under the ice in coastal waters during winter (Andriyashev 1954). Nikol'skii (1954) indicated that spawning occurs from November through February. The appearance of cod fry and mature adults indicates a January to February spawn in the Prudhoe Bay vicinity (outside the study area) (Tarbox and Moulton 1980). Sexual maturity typically is reached at 4 years of age (<200 mm total length), with fecundity ranging from 9000 to 21,000 eggs (Andriyashev 1964). In Simpson Lagoon, sexually mature males were seen at age 2 and at ages 3 - 4 for females; however, only 16 percent of the males and 11 percent of the females were mature when captured (Craig and Griffiths 1978). Gonad evaluations indicated that most mature arctic cod were in a resting stage in March 1979. Pelagic eggs are assumed. Larvae 5 - 9 mm were captured in May and toward fall they attain 20 - 32 mm in

TABLE E-2

AGE-LENGTH RELATIONSHIPS FOR ARCTIC COD

Site Source	Prudhoe Bay Bendock (1977)	Simpson Lagoon Craig and Griffiths (1978)	Bering Sea Andriyashev (1937) (in Andriyashev 1954)	Cheshskaya Bay Klumov (1949) (in Andriyashev 1954)
Age (years)		Length (mm)		
0	24		31	
1	99		100	
2	151		144-158	Q57
3	161	233	180-200	189
4		254	220-230	200
5		298		210

length in the Chukchi Sea (Andriyashev 1954). Young-of-the-year arctic cod averaged 15 - 24 mm in Prudhoe Bay in August (Bendock 1977, Tarbox and Moulton 1980). In Simpson Lagoon, mid-July catches of arctic cod larvae averaged 8.1 mm while later in mid-September they averaged 19 mm (Craig and Griffiths 1978). These authors also reported a 10-fold higher average larvae density inside the lagoon than offshore. Tarbox and Spight (1979) did not catch many arctic cod larvae in 1978, probably due to sampling limited to near-surface waters. Arctic cod larvae represented 35 percent of the catch in 1979 (Tarbox and Moulton 1980), and were more abundant in bottom samples than in surface samples. Moulton et al. (1980) provided arctic cod data that indicated bottom to surface catch ratios of larva densities ranging from 2:1 to 45:1, with a general increase in this ratio with increasing water depth. Arctic cod growth is slow (Table E-2).

Of the 14 arctic cod taken (68 - 135 mm) in winter, 38 percent were immature and most were males (3:1 sex ratio). Low densities were detected in hydroacoustic surveys (0.0006 - 0.0007 fish per m^3), compared to 0.07 arctic cod per m^3 from trawl sampling in August 1979 (Moulton et al. 1980). These observations, along with the low egg density and lack of small arctic cod fry, suggest that spawning did not occur in the sampling vicinity in March 1979 or had occurred prior to that date.

Arctic cod were previously reported as mainly distributed along ice edges and outside the coastal zone (Nikol'skii 1954). Recent studies during open-water periods (Moulton et al. 1980, Craig and Haldorson 1979) suggest a patchy distribution of individuals and schools of arctic cod in the Prudhoe Bay vicinity in summer. In July 1979 the highest catch rate was observed in the West Dock vicinity (Moulton et al. 1980):

The following arctic cod distributions were observed in the summers of 1978 (Tarbox and Spight 1979) and 1979 (Moulton et al. 1980):

- Localized areas of relatively high densities occurred in 1978 near the end of DH 3 (306 fish per ha), in Prudhoe Bay proper (163 fish per ha), and inshore of the Midway Islands at depths >5.5 m (18 ft) (106 fish per ha).

- The large numbers of fish at DH 3 in 1978 were attributed to a relatively large school. These fish were distributed from surface to bottom, and the school was at least 300 m (984 ft) in width.

- Catch data suggest similar sized schools were probably present in Prudhoe Bay and offshore to slightly greater than 5.5 m (18 ft) in depth.

- Using trawl data and a 20 and 10 percent efficiency, a rough estimate of 28 and 57 million arctic cod, respectively, was calculated for the Prudhoe Bay area in August 1978 (Tarbox and Spight 1979). Similar estimates have not been calculated for July-August 1979 data (Moulton et al. 1980).

- Nearshore waters (<2 m, 7 ft) generally had fewer arctic cod than offshore waters. Approximately 89 percent of the catch was offshore.

- Concentrations of arctic cod near DH 3 were seen under and near vessels and barges moored there during the survey period. This agrees with arctic cod attractions to structures suggested by Quast (1974). Arctic cod were found killed by the propellers of a vessel leaving DH 2.

- Arctic cod distribution was apparently associated with the leading edge of the marine water mass in 1979 (Moulton et al. 1980).

- In August 1978, Craig and Haldorson (1979) reported a massive school of "several million" arctic cod inside Pingok Island (roughly halfway between the Colville and Kuparuk Rivers).

Larval arctic cod were more dense inside Simpson Lagoon than at an outside station (Craig and Griffiths 1978). In summer 1979 sampling, arctic cod larvae were usually more dense in bottom stations and this trend increased with station depth (Tarbox and Moulton 1980). Larval to juvenile stage changes occurred in August in the Chukchi Sea (Quast 1974).

Arctic cod observations during the open-water sampling period indicate their distribution in the Prudhoe Bay area fluctuates with time. Bendock (1977) found low numbers of arctic cod in Prudhoe Bay from mid-July to mid-August, when catches increased. Young-of-the-year were abundant at times in Simpson Lagoon, and mature females were seen by mid-September (Craig and Griffiths 1978).

Arctic cod are a major element at the secondary consumer level (Quast 1974), as they are the main consumer of plankton in arctic seas (excluding coastal regions) (Bendock 1977). Arctic cod larvae and fry eat copepod eggs, nauplii and copepodites (Woodward-Clyde 1979). Bendock (1977) reported that Prudhoe Bay arctic cod fed primarily on mysids (based upon 12 stomachs analyzed). Of the 14 arctic cod stomachs examined by Tarbox and Thorne (1979) in winter, seven were 100 percent full in winter, with Mysidacea representing 90 percent of the biomass (Tarbox and Thorne 1979). Arctic cod are a major link between these planktonic organisms and the many consumers of this fish species (char, flounder, saffron cod, sculpin, seals, belukha whales, gulls, other sea birds, and man).

Fourhorn Sculpin

The fourhorn sculpin is another abundant marine species in the Prudhoe Bay vicinity. It is generally more numerous near shore than the arctic cod. This sculpin is circumpolar in distribution and is found in marine, brackish, and occasionally fresh water.

A Chukchi Sea subspecies related to the fourhorn sculpin spawns in late fall or in winter, when females prevail in catches (Andriyashev 1954). Fry hatch in the spring, and mass runs of the fry toward coasts have been noted in July (Andriyashev 1954). Mature fourhorn sculpin were found in Simpson Lagoon during August and September (Craig and Griffiths 1978).

The fourhorn sculpin grows slowly and does not grow very large. In 1978 fourhorn sculpin caught ranged from 18 - 169 mm in length, with most fish ranging from 20 - 40 mm (Tarbox and Spight 1979). In 1979, one larger individual (226 mm) was taken (Moulton et al. 1980). Age and average length in Simpson Lagoon were reported as follows: 1 - 63 mm, 2 - 94 mm, and about 226 mm at age 9 (Craig and Griffiths 1978). Andriyashev (1954) reported the age and average length of a related subspecies as: 5 - 6 years old (200 - 240 mm) and 7 - 8 years old (240 - 270 mm). Larger sized sculpins were less common in Simpson Lagoon as compared to Nunaluk and Kaktovik Lagoons to the east (Tarbox and Moulton 1980). In Prudhoe Bay, ages varied from 1 - 7 years with the majority being ages 2 and 3 (Bendock 1977). In contrast, 1 and 2-year old fish were dominant in Simpson Lagoon and numbers decreased gradually to age 6 (Craig and Griffiths 1978). In Simpson Lagoon, most males were mature by age 3 and most females by age 4 (Craig and Griffiths 1978).

Distribution of fourhorn sculpin was limited to nearshore areas and the deeper waters of Prudhoe Bay (Craig amd Griffiths 1978, Bendock 1977, Tarbox and Spight 1979). Distribution and relative abundance of this species in Prudhoe Bay and nearby areas are shown in Figure E-4 and Table E-1. No sculpins were collected offshore (water depth > 3 m, 10 ft) of Prudhoe Bay, the West Dock, or Stump Island, and none were collected along the western shore of Prudhoe Bay except at the mouth of the Putuligayuk River (Tarbox and Spight 1979). Bendock (1978, in Tarbox and Spight 1979) did capture sculpins off several of the outer barrier islands. This marine form may move some distance up streams.

Fourhorn sculpin use nearshore habitats as spawning and rearing grounds; their fry are often most abundant, if not the only fish found in these areas (Craig and McCart 1976). However, fourhorn sculpin larvae represented only 4 percent of the ichthyoplankton collected in the open-water season of 1979 (Tarbox and Moulton 1980). Young-of-the-year (18 - 26 mm) sculpins were most numerous 3 - 5 m (10 - 16 ft) from shore with abundance dropping toward shore and also abruptly in deeper water on the lagoon shore of Pingok Island (Craig and Griffiths 1978). In 1978 Prudhoe Bay area sampling, fourhorn sculpin density was generally low and uniform in all stations (Tarbox and Spight 1979). Prudhoe Bay area densities are much lower than reported by Craig and Griffiths (1978) for Pingok Island in Simpson Lagoon (Tarbox and Spight (1979).

Fourhorn sculpin was the most numerous fish species in studies by Craig and Griffiths (1978) and by Bendock (1977). This sculpin was the earliest marine species taken as sampling began (June 23, 1976) in Prudhoe Bay during breakup (Bendock 1977).

Bendock (1977) reported that these sculpins feed on immature isopods, amphipods, and juvenile arctic cod in Prudhoe Bay. Craig and McCart (1976) found small sculpins feeding on amphipods and copepods while larger fish prefer isopods (*Saduria entomon*). Fish eggs, amphipods, and mysids were also observed in sculpin diets.

Other Marine Fish

Bartail snailfish (*Liparis herochelinus*) were not taken in Prudhoe Bay proper but were common offshore (>2 m, 2 ft). Young-of-the-year snailfish (age 0) were caught in areas with attached algae (Tarbox and Spight 1979). Sixty-five percent of the ichthyoplankton caught in the summer of 1979 were snailfish (Tarbox and Moulton 1980). Ninety-three percent of the bartail snailfish observed in winter were associated with kelp habitat. This distribution is similar to that of a related species (*L. liparis*), which deposits its eggs on polyp colonies or subaquatic vegetation (Nikol'skii 1954). *L. liparis* spawns from December to February or later and larvae measuring 5.5 mm in length hatch 6 - 8 weeks following spawning (Nikol'skii 1954). If similar development occurs in bartail snailfish, a late March to late April spawning period is suggested in the Prudhoe Bay vicinity (Tarbox and Spight 1979).

Six snailfish (not positively confirmed as *L. herschelinus*) (53 - 116 mm) were examined in March 1979; some females had spawned while others were ripe. Eggs were observed attached to kelp fronds and in bottom depressions during February 1979 SCUBA observations. This snailfish and the fourhorn sculpin both have adhesive eggs, and it is probable that both spawn in this area. The six snailfish stomachs examined from winter sampling contained primarily amphipods (81 percent of biomass and 67 percent frequency of occurrence) and were nearly 50 percent full (Tarbox and Thorne 1980). Larval snailfish were very abundant in near-bottom waters off the PBU dock during the summer of 1979 (Tarbox and Moulton 1980). Densities peaked at 186/1000 m^3 in July and 590/1000 m^3 in August. By September, numbers dropped sharply to (<24/1000 m^3) as larger larvae (>15 mm) apparently settled to the benthic habitat.

Small numbers of Pacific sand lance (64 - 95 mm) were taken by trawl in 2 - 6 m (7 - 20 ft) deep stations in 1978 off Prudhoe Bay (Tarbox and Spight 1979). The difficulty of sampling this species suggests that its abundance may have been underestimated. Moreover, its presence in other arctic waters and in arctic char stomachs from Prudhoe Bay may mean its distribution and abundance may be extensive along the Beaufort Sea coast (Tarbox and Spight 1979).

Capelin (48 - 78 mm) were taken in Prudhoe Bay, offshore of Stump Island, and at the base of the West Dock in 1978, whereas no fish were taken in waters >6 m (20 ft) deep (Tarbox and Spight 1979). Bendock (1977) reported capelin spawning on gravel beaches in the Prudhoe Bay region during August 1976.

Distributions and Life Histories of Anadromous Fish

Anadromous Arctic Char:[1]

The arctic char in the project vicinity is the western Arctic-Bering Sea form (McPhail 1961). The Mackenzie River to the east is, for practical purposes, the dividing line between this form and the eastern arctic form (Craig and McCart 1976). The taxomony of the *Salvelinus alpinus* complex, as well as its life history, is complicated and not fully understood.

The anadromous char is the most prevalent life history pattern for this species in this area. The species is ecologically flexible, having nonanadromous forms including several isolated dwarf forms (Craig and McCart 1976).

In the Bering Sea, anadromous char spawn in the larger drainages with available perennial springs. In the Prudhoe Bay vicinity, the arctic char overwinter and spawn in certain areas of the Sagavanirktok River (Figure E-5). Adults move up rivers to spawning grounds from mid-August through November, with peak migrations occurring in September and October (Craig and McCart 1976).

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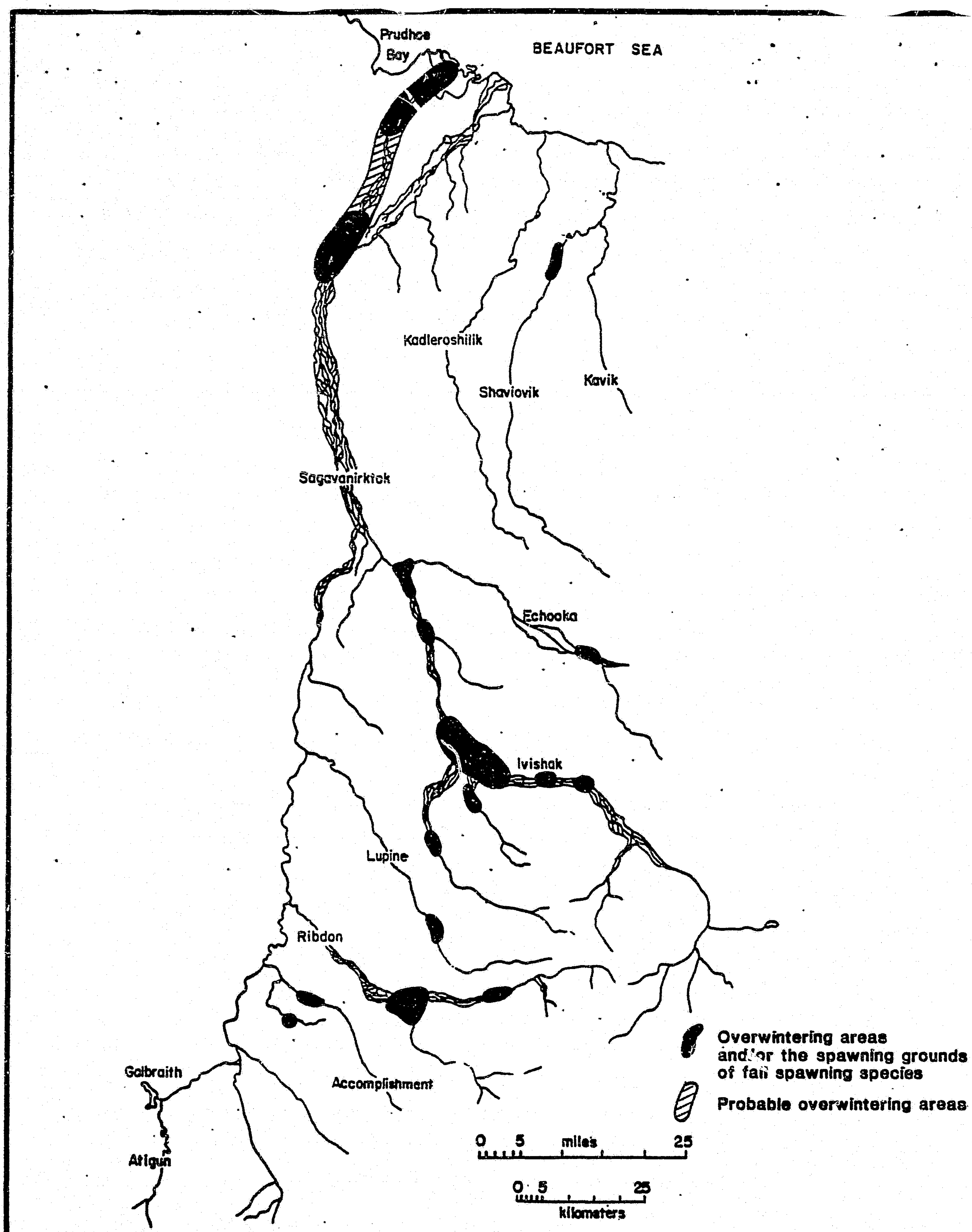
1 According to Morrow (1979), the anadromous char in Alaska is *Salvelinus malma* or a northern form of Dolly Varden, rather than the arctic char (also spelled charr), *S. alpinus*, which he claims in Alaska appear to be the freshwater, lake-dwelling type. This report will address the anadromous char form with the name arctic char, as used by most other investigators.



Source: Craig and McCart 1974

WINTER FISHERIES
IN THE SAGAVANIRKTOK RIVER AND SURROUNDING DRAINAGES

PBU Waterflood Environmental Impact Statement	Figure E-5

Eggs normally incubate in stream gravel at 0° - 4°C (32° - 39°F), but may develop in waters exceeding 10°C (50°F) (McCart and Bain 1974). Because eggs cannot tolerate freezing, all known spawning areas are near spring sources (McCart and Bain 1974). Young-of-the-year remain in the gravel from 7 - 9 months before emerging in the spring (McCart and Bain 1974), and spend 3 - 5 years in the streams, overwintering in special spring areas (Figure E-5) as juveniles before they become smolt and migrate to sea (Craig and McCart 1976). Most of these char enter the sea during spring breakup (June) and return to over-winter in the streams by mid-August or until freeze-up (Craig and McCart 1976). Char mature at 6 - 8 years of age (Craig and McCart 1976) to repeat the reproductive cycle. Tarbox and Moulton (1980) indicated that females mature at ages 7 - 8 and males mature at age 9.

Adult char apparently do not spawn in consecutive years; rather, most individuals spawn only every second year. Thus, at any given time, a population of arctic char will have a group preparing to spawn in the upcoming spawning period and others that will not spawn until the following period (adult nonspawners) (Craig and McCart 1976).

A further complexity may be that maturing char remain in fresh water the summer of the year in which they spawn, thus spending 20 months in fresh water prior to and after spawning. Between spawnings, the char would typically spend about 1 - 3 summer months in coastal marine waters and 9 - 11 months overwintering in fresh water.

In the Sagavanirktok drainage, two migrant types separate. Mature migrants entered all large mountain streams, while immature migrants were concentrated in mountain streams nearest the sea (McCart and Bain 1974). This coincides with the distribution of known spawning areas in the Sagavanirktok shown in Figure E-5. The Sagavanirktok River supports one of the largest North Slope char populations (Tarbox and Moulton 1980).

A significant characteristic related to project impact assessment is that females are significantly more abundant in nearshore waters than males because some members of anadromous char populations (mostly males) never migrate to the ocean (Craig and McCart 1976). The marine habitat of these char is not well described to date. Use of nearshore habitats is thought to be limited to periods when the char enter the sea at breakup (June) and when they ascend the streams before freeze-up (September). Char range widely in the ocean and spread out along the coast in plumes of fresh river water that flood the fast ice (Bendock 1977).

Larger char leave the Sagavanirktok River in early June, followed in late June and early July with age 3 and 4 smolts (Doxey 1977). Adults were most numerous in July and they began their return to fresh water during the first week of August (Tarbox and Moulton 1980). Juveniles (100 - 200 mm fork length) are present in Prudhoe Bay until freeze-up and enter the Sagavanirktok River in September (Bendock 1977). The distribution and relative abundance of char in various areas is given in Figure E-4 and Table E-1.

Homing success in arctic char is not known. Tag studies (which normally do not involve much effort in looking for tagged fish in other rivers) have indicated straying from the Sagavanirktok River as far as 300 km (186 mi) to the west (near Barrow) to 250 km (155 mi) to the east (Canning River) (Tarbox and Moulton 1980). At any given time in summer, the nearshore Prudhoe Bay environment may have char present from drainages anywhere on the Alaska and western Yukon (Mackenzie River) coast. Arctic char tagged in the Sagavanirktok drainage in the falls of 1971 and 1972 were recaptured in the central portion of Simpson Lagoon in 1978 by Craig and Haldorson (1979). Age groups of char in Prudhoe Bay range from 3 through 12 with most fish between 7 - 9 (Tarbox and Moulton 1980). Craig and Griffiths (1978) reported a bimodal length frequency in Simpson Lagoon (males at 220 mm and 540 mm) and an absence of intermediate-sized fish corresponding to juveniles aged 5 - 8 years. In Simpson Lagoon, about half the fish were mature and 46 percent of the mature females and 29 percent of the mature males were spawners (Craig and Griffiths 1978).

An important parameter related to the proposed Waterflood Project is that no arctic char less than 100 mm fork length have been taken to date in summer field studies in the Prudhoe Bay area (Bendock 1977, Craig and Griffiths 1978), indicating that their susceptibility to entrainment would be low in this area. However, fish of this size and larger would be susceptible to mortality and stress at the proposed intake.

Food of arctic char include a variety of epibenthic organisms and insect larvae and fish with frequencies as follows: amphipods (in 95 percent of char examined), arctic cod (42 percent), mysids (32 percent) and isopods (11 percent) (Bendock 1977). Doxey (1977) also found char that had eaten capelin. The diet of char has been shown to vary by area probably due to variation in food abundance. For example, fish, an important diet component, was mostly fourhorn sculpin in Nunaluk Lagoon but was mostly arctic cod in the Canning River vicinity (Craig and McCart 1976). Amphipods were the dominant food item (55 percent) in Simpson Lagoon followed by mysids (32 percent) and fish (only 5 percent) (Craig and Griffiths 1978).

Arctic char are in turn consumed by other marine species. Man uses the char in a subsistence fishery and an expanding sport fishery (Bendock 1977). Arctic char were often captured with empty stomachs (32.5 percent) and those stomachs containing food averaged only 24.8 percent in fullness (Griffiths et al. 1975).

Arctic Cisco

The arctic cisco has an anadromous form that is of great importance in local fisheries in some areas (Barter Island, and the Colville and Mackenzie River deltas) (Craig and McCart 1976). In Alaska waters this species ranges from Point Barrow to Demarcation Point (Bendock 1977), ranking as one of the most numerous and widespread nearshore fish between the Colville and Mackenzie Rivers (Craig and McCart 1976). Arctic cisco, like large arctic char, are distributed widely along the coastline and along the barrier islands.

A major difference between the arctic cisco and the arctic char is that the cisco apparently use only two of the largest drainages in the region (Colville and Mackenzie Rivers) as spawning and probably overwintering areas. Spawning migration timing and distances traveled upriver vary markedly between these two river systems, probably due to the greater length (6 times) of the Mackenzie River. Females typically mature by mid-July, and upstream migrations in the Mackenzie River occur from early July through September (Kendall et al. 1975). The arctic cisco undertake spawning migrations 2 months later into the Colville River (Griffiths et. al. 1975). Migrations extend as far as 725 km (450 mi) from the Mackenzie River mouth, while in the Colville River the spawning occurs in the lower reaches of the river (Craig and McCart 1976). The arctic cisco is a fall spawner, but spawning timing and locations are not definitely known (Craig and McCart 1976). After maturity is reached (5 - 8 years), arctic cisco are thought to spawn in alternate years (Griffiths et al. 1975).

The timing of fry dispersal is not known but may correspond to breakup of the coastal rivers (Kendall et al. 1975). Arctic cisco enter the Beaufort Sea at age 1 (Bendock 1977). Fry and juveniles (23 - 107 mm) were abundant in shallow shoreline catches near the Mackenzie River (Kendall et al. 1975). Hunter (1975) found arctic cisco at the Firth River mouth by June 30.

Doxey (1977) indicated an eastward trend in mid-July, with east-to-west movement in early August and from west to east in mid-August. Migrations are fast for the distances traveled. A fish tagged at Prudhoe Bay was taken 241 km (150 mi) east near Barter Island 19 days later (Bendock 1977). Of 21 recaptured arctic cisco tagged mostly in August in Prudhoe Bay, 19 were taken in the fall run in the Colville River (Bendock 1977).

Age/average length relationships in Prudhoe Bay arctic cisco were as follows: 1 - 110 mm, 2 - 127 mm, 3 - 197 mm, 4 - 212 mm, 5 - 231 mm, 6 - 264 mm, 7 - 272 mm, 8 - 296 mm, 9 - 309 mm, 10 - 319 mm, 11 - 320 mm, and 12 - 350 mm (Bendock 1977). The smallest individual taken by Bendock was 62 mm.

No sexually mature fish were taken in Prudhoe Bay by Bendock (1977). His samples (198 fish) had a male/female sex ratio of 9:1. In Simpson Lagoon, 57 percent of the males and 46 percent of the females were mature; males matured at ages 7 - 9 and females at ages 8 - 10 (Craig and Griffiths 1978). Either mature arctic cisco do not range into the Prudhoe Bay area or at least do not range as far from their natal streams as do younger age classes (Bendock 1977). The amount of straying from natal streams was not reported.

Prudhoe Bay arctic cisco first appeared in late June (Bendock 1977) and were seen in the bay until September 15 when they disappeared (Doxey 1977). Most spawners return to the Colville by mid-July; juveniles and mature nonspawners remain in coastal waters for a longer time (Craig and Griffiths 1978). Some arctic cisco may spend the entire winter in nearshore coastal waters (Craig and Griffiths 1978). The distribution and relative abundance of arctic cisco in various areas and years sampled are provided in Figure E-4 and Table E-1.

The arctic cisco feeds differently in various areas sampled. Bendock (1977) reported foods of arctic cisco as: mysids (60 percent of stomachs), amphipods (53 percent), and vegetation and detritus (40 percent). Craig and Griffiths (1978) found arctic cisco in Simpson Lagoon feeding on mysids (66 percent of items), amphipods (24 percent), and copepods (8 percent). McPhail and Lindsey (1970) report crustaceans and small fishes are the main food items of adult arctic cisco.

The arctic cisco's importance as a fishery is demonstrated by this species' constituting 60 - 70 percent (30,000 - 50,000 fish) in the winter commercial Colville Delta catch (Alt and Kogl 1973) and by its great importance in the diets of the native Inupiat population. Recent population estimates by Craig and Haldorson (1979) indicate a catchable population (>275 m in length) on the order of 250,000 fish in the Colville River.

Least Cisco

The least cisco is another whitefish with an anadromous form. This species was the most frequently captured whitefish in the Prudhoe Bay area (Bendock 1977) and was less abundant in Simpson Lagoon (Craig and Griffiths 1978). Least cisco range from Bristol Bay to arctic Alaska and eastward at least as far as Bathhurst Inlet and Cambridge Bay (McPhail and Lindsey 1970). Both anadromous and nonmigratory forms of least cisco exist in Alaska. The distribution and relative abundance of the least cisco are shown in Figure E-4 and Table E-1.

Sexual maturity was reached in 7 - 8 years, and of those mature individuals found in Prudhoe Bay, 20 percent had developing gonads and would not spawn in the year of capture, indicating that a portion of the population does not spawn every year (Bendock 1977). Spawning reportedly takes place during the fall in the lower reaches of major rivers (Bendock 1977). Bendock (1977) located no overwintering or spawning areas in the Prudhoe Bay vicinity, and tagging indicated that most least ciscos in the Prudhoe Bay area return to the Colville River. Least cisco can overwinter at sea (Gulf of Tazov) if food is available (Yukheva 1955, in Kogl and Schell 1974).

While age 1 and 2 least cisco were captured in Prudhoe Bay, it appears that most individuals enter brackish waters during their third year (about 139 - 210 mm). The absence of least cisco from the outer barrier islands indicates a strong affinity for brackish waters on the mainland coastline (Bendock 1977).

Based on limited tagging studies, the least cisco of Prudhoe Bay and Simpson Lagoon are from the Colville River stock. Some mixing of stocks is likely as one tagged fish from Simpson Lagoon was recaptured near Barrow (Craig and Griffiths 1978). One fish tagged in Prudhoe Bay was captured in the Colville River 7 days later (Bendock 1977). One tagged fish was recovered 250 km (155 mi) east (Griffin Point) (Doxey 1977). However, least cisco apparently do not migrate as far as the arctic cisco into the central region between the Colville and Mackenzie Rivers (Craig and McCart 1976).

In Prudhoe Bay, tagged fish had an eastward movement from breakup through mid-August and then a general westward movement until freeze-up with a haphazard movement of some individuals in the bay throughout July and August (Bendock 1977). Bendock (1977) reported least cisco as appearing in the bay in early July and being taken to the end of the study period (September 20).

Prudhoe Bay least cisco ranged from 82 mm - 364 mm (ages 1 through 12), with 7 through 10-year-old fish most frequently captured (Bendock 1977). Growth rates were lower in Prudhoe Bay than in the Mackenzie River and interior Alaska.

Age/average length relationships in Prudhoe Bay were reported by Bendock (1977) as follows: 1 - 110 mm, 2 - 127 mm, 3 - 197 mm, 4 - 212 mm, 5 - 231 mm, 6 - 264 mm, 7 - 272 mm, 8 - 296 mm, 9 - 309 mm, 10 - 319 mm, 11 - 320 mm, and 12 - 350 mm.

Least cisco in Prudhoe Bay feed on mysids (91 percent of stomachs), amphipods (45 percent), adult dipterans (27 percent), isopods (9 percent), and vegetation/detritus (9 percent) (Bendock 1977).

Least cisco are also taken in the Colville River commercial fishery and recent estimates indicate a catchable population on the order of 590,000 fish (Craig and Haldorson 1979).

Broad Whitefish

The broad whitefish also has an anadromous form and supports valuable commercial and subsistence fisheries in Alaska waters. This species ranges in North America from the Bering Sea to the Beaufort Sea as far east as the Perry River (Bendock 1977). A summer fishery in the Colville River delta harvests about 3000 broad whitefish annually (Alt and Kogl 1973). The distribution and relative abundance of broad whitefish are shown in Figure E-4 and Table E-1.

The broad whitefish matures at about age 9. Some mature fish with developing gonads were captured that would not spawn in the year of capture (Bendock 1977), indicating that some portion of the population does not spawn each year. Studies by Furniss (1975) indicate both Sagavanirktok and Colville River stocks may inhabit Prudhoe Bay.

Adults enter the Sagavanirktok River in late August and spawn in deep pools in the lower reaches of the delta, where the fish also overwinter (Bendock 1977). Adults and fry re-enter the sea when the larger rivers break up in early June, with fish caught in the Sagavanirktok delta on June 11 and in Prudhoe Bay on June 23 (Bendock 1977). Young-of-the-year and age 1 broad whitefish seldom traveled beyond the waters adjacent to the Sagavanirktok and Colville deltas (Bendock 1977). These fish forage in shallow bays and lagoons along the mainland coastline (Bendock 1977). Overwintering at sea may occur since Andriashev (1954) reported that broad whitefish spend the winter in the Ob Inlet.

Broad whitefish sizes captured in the Prudhoe Bay vicinity ranged from 40 mm - 560 mm. Ages 1 - 3 and 8 - 13 were represented in Prudhoe Bay catches (Doxey 1977).

Doxey (1977) indicated an eastward movement in August and September coinciding with the Sagavanirktok River spawing run. Some fish may be going the opposite direction if Colville River fish in fact come to Prudhoe Bay. Tag returns were insufficient to indicate any definite movement trends.

Of the 40 percent of the broad whitefish examined that had food in their stomachs, the predominant food organisms were chironomid larvae (Bendock 1977).

Humpback Whitefish

Humpback whitefish are another whitefish with an anadromous form. This species is among the most widely distributed in Alaska although they are generally in mainland drainages and not at sea (Bendock 1977). The Colville River is undoubtedly the major source of humpback whitefish to the Beaufort Sea. They spawn during the fall in the lower river reaches and they likely overwinter near the river delta (Bendock 1977). Bendock (1977) reported that this species was sparsely distributed between the Colville and Sagavanirktok deltas. No information was located on overwintering at sea by this species. The distribution and abundance of humpback whitefish are shown in Figure E-4 and Table E-1.

Humpback whitefish generally are mature at ages 7 - 10 years (310 - 463 mm) in the Colville River. In this study all males were spawners, but 68 percent of the females were nonspawners, possibly because they were immature (Kogl and Schell 1974). Kogl and Schell (1974) reported this species as the most numerous whitefish taken in the Colville River from late September to mid-November (peak at October 4 - 19). Spawning occurred under the ice in the river delta in October. Young presumably hatch in late winter and then move downstream (Morrow 1979).

Bendock (1977) captured humpback whitefish from 61 - 475 mm (fork length), in Prudhoe Bay from the first of July to the end of August. Habitation of brackish water is described by McPhail and Lindsey (1970), and Morrow (1979) reported that they have been taken several miles offshore off the Colville and Sagavanirktok Rivers.

Tag returns were insufficient to define trends in movement. Doxey (1977) and Furniss (1975) indicated a possible westward movement in early August.

Amphipods and shrimp were the main organisms consumed by humpback whitefish. In the fall spawning period few fish had empty stomachs and they continued to feed at 0.1°C (32°F) and 9 parts per thousand salinity (Kogl and Schell 1974).

A summer commercial fishery operates in the Colville Delta which took 1000 humpback whitefish (Alt and Kogl 1973).

Other Species

Other anadromous fish are not numerous enough to be of importance in impact assessment. Also, the species listed above are useful as indicators of the general habitat requirements of such species.

MARINE MAMMALS

Orientation

Sixteen species of marine mammals have been recorded in the Beaufort Sea and at least six additional species could enter the area (NOAA-BLM 1978). These species are listed as follows:

a. Year-Round Residents:
    - Ringed seals (*Phoca hispida*)[1]
    - Bearded seals (*Erignathus barbatus*)
    - Polar bears (*Ursus maritimus*)[2]

b. Summer Seasonal Visitors:
    - Bowhead whales (*Belaena mysticetus*)[1]
    - Belukha whales (*Delphinapterus leucas*)[1]
    - Spotted seals (*Phoca vituliua largha*)[1]

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[1] Currently under protection of the National Marine Fisheries Service.

[2] Currently under protection of the U.S. Fish and Wildlife Service.

c. Special cases

Walruses (Odobenus rosmarus)[2]

Gray whales (Eschrichtius robustus)[1]

Arctic foxes (Alopex logopus)[2]

d. Other mammals (rare or low numbers)

Killer whales (Orcinus orca)[1]

Harbor porpoises (Phocoena phocoena)[1]

Narwhals (Monodon monoceros)[1]

Fur seals (Callorhinus ursinus)[1,3]

Northern sea lion (Eumetopias jubata)[1]

Hooded seals (Cystophora cristata)[1]

Harp seals (Phoca groenlandica)[1]

e. Chukchi Sea mammals which conceivably enter the Beaufort Sea:

Humpback whales (Megaptera novaeangliae)[1]

Fin whales (Balaenoptera physalus)[1]

Sei whales (Balaenoptera borealis)[1]

Minke whales (Balaenoptera acutorostrata)[1]

Sperm whales (Physeter catadon)[1]

Ribbon seals (Phoca fasciata)[1]

Only limited marine mammal surveys have been conducted in the Prudhoe Bay project area. However, general observations of the Beaufort Sea area have indicated that the major species of concern in the Prudhoe Bay vicinity are:

Bowhead whales
Belukha whales
Bearded seals
Ringed seals
Polar bears
Arctic foxes

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[1] Currently under protection of the National Marine Fisheries Service.
[2] Currently under protection of the U.S. Fish and Wildlife Service.
[3] Harvest regulated by the North Pacific Fur Seal Commission.

The Marine Mammal Protection Act of 1972 (PL 92-522) has provided for research and management of selected species. The Federal-State interactions in management are discussed by Burns (1980). To date the management and research goals of the act have not been fully realized.

The bowhead whale is one of the most endangered species of great whales (NOAA-BLM 1978, Appendix 6). The gray whale is also classified as endangered (USDI 1979), may occur seasonally in the western Beaufort Sea (NOAA-BLM-1978, Appendix 6), and is apparently extremely rare in the Prudhoe Bay vicinity.

Descriptions of Selected Species

Bowhead Whale

The bowhead whales of the Beaufort Sea have been recently described by Smith (1974), Fiscus and Marquette (1975), Marquette (1976, 1977), Braham and Krogman (1977), Braham et al. (1977, 1977, in press), Fraker et al. (1978), Lowry et al. (1978b), Durham (1979), AEIDC (1979), Braham et al. (in press), Naval Ocean Systems Center (1980), Everitt and Krogman (in press). A synthesis of bowhead whale movements and biology was provided from available data by Rietze (1979) as follows:

> "Bowhead whales of the western Arctic Ocean occur seasonally from the central Bering Sea northward throughout the Chukchi and eastern Siberian Seas and eastward throughout the U.S. Beaufort Sea to Banks Island and Amundsen Gulf, Northwest Territories, Canada. Bowheads are thought to winter in the northern and central Bering Sea, timing their northward migration with the breakup of the pack ice, generally in April. The migration proceeds through the Bering Strait and the Chukchi Sea to Point Barrow. From Point Barrow the whales travel northeasterly in the Beaufort Sea through leads to Banks Island, Canada and Amundsen Gulf.

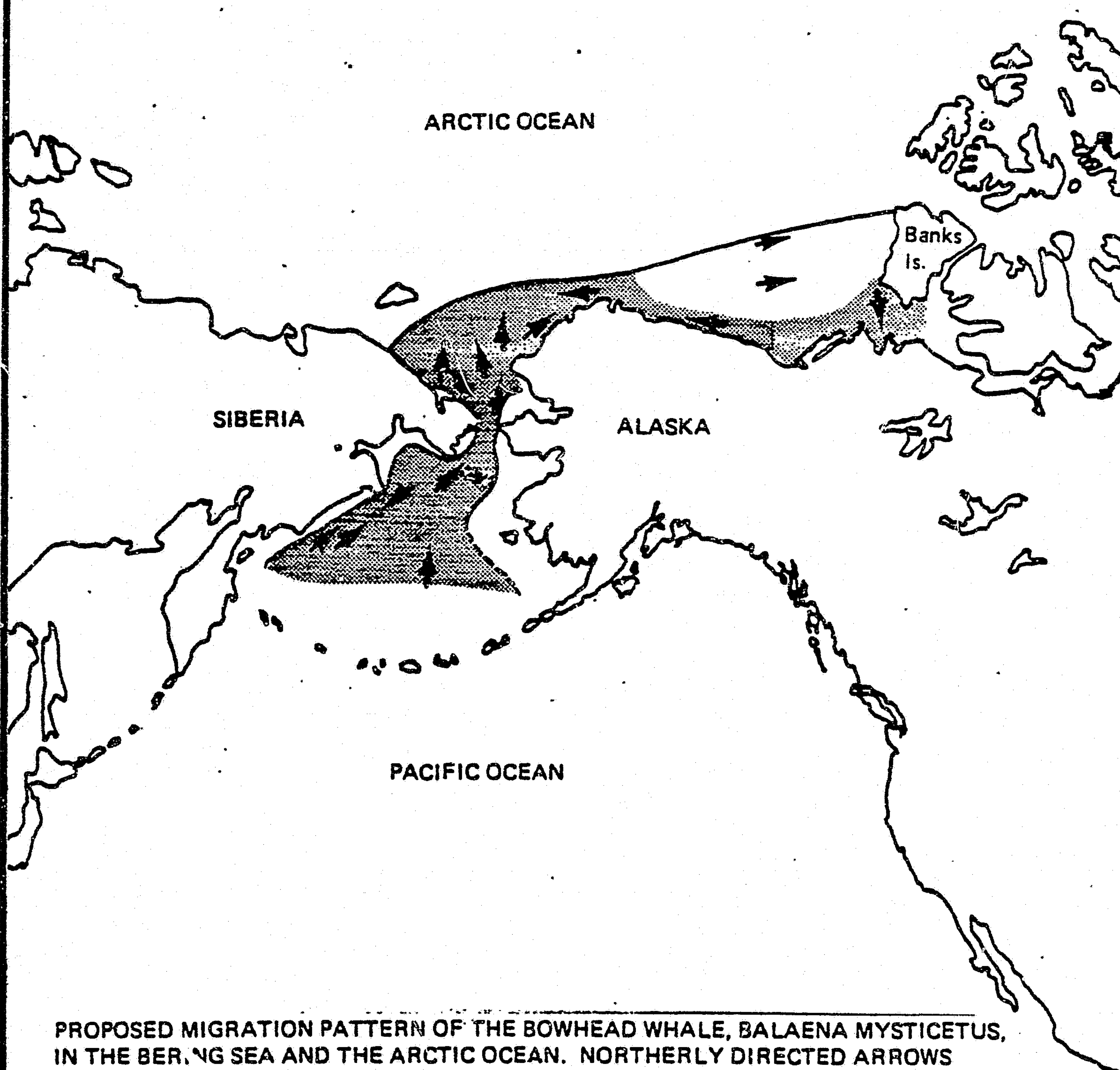
In August and September, bowheads begin to leave the eastern Beaufort sea on their fall migration back to the Bering Sea. The whales travel west through the southern Beaufort Sea to Point Barrow. During this migration, the whales are hunted by Alaskan Eskimos from the villages of Kaktovik, Nuiqsut, and Barrow. Suspected migration routes are shown in [Figure E-6].

Sightings made since 1974 indicate that bowheads occur in shallow coastal waters all the way out to the ice pack (beyond the 100 m [328 ft] contour), although their exact spatial distribution is not known. Nearshore areas in the western Beaufort Sea appear to be important to the bowhead in the fall since there have been numerous sightings in shallow water from Smith Bay to Point Barrow [see Figure E-7].

The current population estimate of bowhead whales in the western Arctic is 2,264, with a range of 1,783 to 2,865. This estimate is the result of three years of counting conducted by NMFS biologists. Key biological parameters (e.g., recruitment, mortality, and age structure) controlling the population of bowhead whales are virtually unknown.

Bowheads begin reaching sexual maturity after attaining lengths exceeding [12 m] 38 feet. Recent information obtained from harvested whales indicates that sexual maturity may not be reached in some whales until those animals have attained a length of [14 - 15 m] 45 - 50 feet. The breeding period of the bowhead is not well known. Some researchers maintain that breeding occurs in early April before the whales reach Point Hope, whereas other researchers have reported witnessing copulatory behavior in May near Point Hope and near Barrow.

Gestation is estimated to last about 1 year, and thus calving season corresponds with the time of breeding. Observations of cows with calves passing Point Hope and Point Barrow from mid-April to mid-June suggest that most bowheads are probably born in

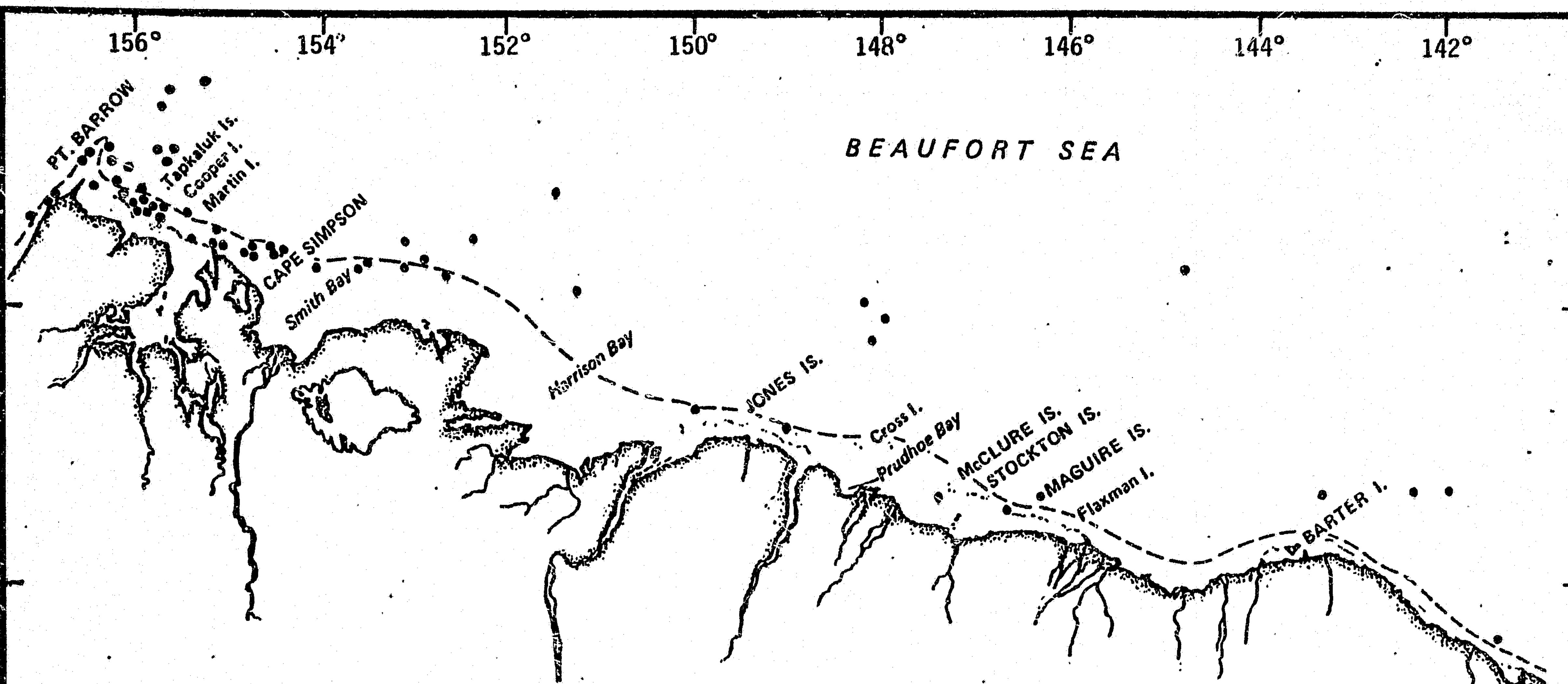


PROPOSED MIGRATION PATTERN OF THE BOWHEAD WHALE, BALAENA MYSTICETUS, IN THE BER..NG SEA AND THE ARCTIC OCEAN. NORTHERLY DIRECTED ARROWS DEPICT TH... ARCH TO JUNE MIGRATION AND SOUTHERLY DIRECTED ARROWS DEPICT THE SE... R TO DECEMBER MIGRATION. SHADED AREAS ARE WHERE DATA ARE AVAIL... ROM HISTORICAL ACCOUNTS OR FROM RECENT SIGHTINGS.

Source: Braham, Krogman & Fiscus 1977

SUSPECTED MIGRATION ROUTES

PBU Waterflood Environmental Impact Statement	Figure E-6



Bowhead whale sightings (•) in the Beaufort Sea, August through November, 1974-1978, made during NMFS aerial surveys, and from contributing scientists. Only sightings with a verified position data were used. Most sightings occurred in the last half of September. The dashed line represents the 12 m contour.

Source: Braham, Krogmen, & Carrol, Unpublished manuscript.

BOWHEAD WHALE SIGHTINGS

Figure E-7

the spring, either before February to March migration or during April to June migration.

One researcher classified the bowhead as a bottom skimmer in terms of its feeding habits, although it is probable that it feeds throughout the water column. A comprehensive food habits study has not been conducted, but available data indicate that pelagic arthropods (euphausiids, mysids, copepods, and amphipods) are the preferred food organisms, and that annelids, molluscs, and echinoderms are utilized to a lesser degree. Stomach contents of a whale taken by Point Hope Eskimos during a spring migration included the remains of polychaetes, molluscs, crustaceans, and echinoderms, whereas stomach contents of two whales taken at Point Barrow in the fall of 1977 contained (by volume) 90.3% euphasiids and 9.6% amphipods.

Researchers report whales moving past the NMFS ice camps in the spring at a rate of 1.0 - 4.0 knots, depending on the direction of the current. During the spring migration, whales do not travel in close association with one another. Of 2,406 bowhead observations recorded during 1976-1978, 1,818 (75.4%) were singles, 470 (19.5%) were in pairs, 105 (4.4%) were in groups of three, and 16 (0.7%) were in groups of four. During the fall migration, bowheads may travel in larger groups.

Bowheads' reaction to noise appears varied. A bowhead will leave the area when an outboard motor approaches. However, reaction to airplanes flying overhead seems mixed, the whales reacting vigorously in some instances and showing little reaction in other instances. It appears that fright reaction to noise varies greatly, depending upon the source, environmental conditions, and activity of the animals.

Bowheads are known to occur near Prudhoe Bay. Since 1974, 53 fall sightings have been made totaling approximately 323 animals for the entire Beaufort Sea. These sightings are the result of aerial surveys conducted mostly west of 150° W longitude. Although fewer animals were observed east of 150° W longitude, the paucity of sightings is thought to be directly proportional to the effort expended (i.e., less extensive aerial surveys). Numerous fall sightings have been made in nearshore shallow waters between Point Barrow and Smith Bay during the past 5 years, suggesting that this is an area of importance to bowheads. The whales appeared to be involved in feeding activity at the time of these sightings. It is not possible at this time to determine whether the western portion of the Beaufort Sea is more critical to the bowhead than the eastern portion. Limited surveys east of 150° W longitude have not established heavily utilized areas in the eastern Beaufort Sea, although it is certainly possible that these areas exist."

In October 1979 11 bowheads were sighted within an area 16.6 km (10.3 mi) north and 11 km (6.9 mi) northeast of Cross Island. In addition, one bowhead was sighted 5.5 km (3.4 mi) north of Narwhal Island (Naval Ocean Systems Center 1980).

Burns (1980) and Brewer (1980) reported that surveys by the Alaska Department of Fish and Game indicate no bowheads inside the barrier islands near Prudhoe Bay during spring migration because of extensive shorefast ice. The whales are well to the northeast by the time the shorefast sea ice melts in June. However, they indicated that whales do move closer to the barrier islands during fall migration and follow the "intermediate shelf." Bowheads are not to be expected inside the barrier islands at any time.

Belukha Whales

The belukha (also spelled beluga) whales of the Beaufort Sea have been recently described by Klinkhart (1966), Smith (1974), Sergeant and Brodie (1975), Braham and Krogman (1977), Braham et al. (1977, 1979), and Fraker et al. (1978). Braham et al. (1979) provided information used in a synopsis by Swope (1979) as follows:

Distribution

"The Bering Sea population of belukha whales consists of both resident and migratory components. One component is thought to winter in the Bering Sea and migrate into the eastern Siberia and western Canada waters in spring and summer. An unknown portion of this population summers in the Norton Sound-Yukon Delta area and Kotzebue Sound. Eschscholtz and Spafafief Bays, in Kotzebue Sound, provide possible breeding and calving areas. The Beaufort Sea probably serves mainly as a summer feeding area for belukha whales migrating from the Bering and Chukchi Seas. Overwintering in the Beaufort and Chukchi Sea, should it occur, would probably occur in open water during mild ice years. Spring migration occurs from March to early July, at which time whales follow nearshore and offshore leads along the west and north coast of Alaska and through the Bering and Chukchi Seas, a migration route corresponding closely to that of bowhead whales. A large number of individuals may congegate in the spring until breakup of the pack ice, at which time they may form smaller groups until the summering areas are reached. Braham (1979) indicated that those individuals summering in the Canada arctic waters cross the Beaufort Sea from May to June, using leads which normally occur 30 - 100 km (19 - 62 mi) offshore. The animals then move south along the west side of Banks Island to Amundsen Gulf and the Mackenzie delta. Although not well documented, individuals apparently begin to depart Canada waters in August or September, returning back to the Bering Sea in December or during the time of advancing ice.

Reproduction and Food Habits

Sexual maturity is reached in the female at an age of 5 years and in the male at about 8 years. Breeding generally occurs from late spring to early summer in the eastern Siberia and Canada arctic waters. Although data on breeding in Alaska waters is not available, it probably coincides closely with that in Canada arctic waters. Calving is believed to occur in May or June; however, Eskimos have reported seeing young calves as early as March. With a gestation period of 12 months and a lactation period of 24 months, the reproductive cycle of a belukha whale is estimated to last 3 years. Belukha whales feed primarily on fish as well as invertebrates in estuaries and bays at the mouth of rivers. Prey species utilized in the Beaufort Sea are unknown, but polar cod is an abundant and available potential prey species in the western Arctic. Whales residing in Bristol Bay feed upon all species of salmon, smelt, flounder, sole, sculpin, blenny, lamprey, mussels, and several types of shrimp during the summer. Their diet regime for the rest of the year is unknown."

Johnson (1979) reported sighting schools of belukhas swimming westward offshore of the west end of Pingok Island during September of 1977 and 1978. None was ever observed inside the barrier islands.

Bearded Seals

Bearded seals in the Beaufort Sea have been studied recently by Burns (1967), Stirling et al. (1975), Burns and Eley (1977), and Burns and Frost (1979).

The bearded seal is an ice-associated marine mammal. Annual differences in ice conditions and bottom contours relative to preferred feeding depths in the Beaufort Sea make the region a marginal habitat for this seal (Burns and Frost 1979). They report a low abundance relative to the Chukchi and northern Bering Seas. Burns and Eley (1977) report about 0.1 animal per km^2 in the Beaufort Sea. Some bearded seals are present in all seasons in the Beaufort Sea; thus, all annual and life cycle events take place in this area (Burns and Frost 1979).

Bearded seals can make and maintain breathing holes in relatively thin ice. However, they avoid regions of continuous, thick, shorefast ice and they are not common in regions of unbroken, heavy, drifting ice (Burns and Frost 1979). The bearded seal inhabits areas of shallow water where ice is in constant motion producing leads, polynya and other openings along transition zones, which are very limited in the Beaufort Sea relative to the Chukchi and northern Bering Seas (Burns and Frost 1979).

Movements occur from the Chukchi Sea to the western Beaufort in summer and the bearded seals occupy ice remnant areas close to shore (Burns and Frost 1979). Movement from the Chukchi Sea to the eastern Beaufort Sea is not thought to be great, due to the low densities in summer (Burns and Frost 1979).

Bearded seal pups are born on top of the ice from late March through May and then breeding and molting follows (NOAA-BLM 1978). Although some pups are born in the Beaufort Sea, most are born in the Bering and Chukchi Seas. Pups can swim shortly after birth and are weaned in 12 - 18 days (Burns 1967).

Major prey species of bearded seals in the Beaufort basin in order of importance are the spider crab (Hyas coarctatus), shrimp (Sabinea septemcarinata) and arctic cod (Boreogadus saida) (Lowry et al. 1978a). Bearded seals are primarily benthic feeders, but their diet changes both as the seals move and as prey species in a given area change with time. In spring and summer, invertebrates comprised 95 percent of the stomach contents; in November and February, fish were of greater importance for bearded seals taken near Barrow. Arctic cod were taken in substantial quantities and their appearance in the winter diet may coincide with an onshore spawning migration during early winter (Burns and Frost 1979).

Ringed Seals

Ringed seals are the most common and widespread seal in the Beaufort Sea (NOAA-BLM 1978). Recent reports on ringed seals include those of

Burns and Harbo (1972), Burns and Eley (1977), Smith and Stirling (1975), and Lowry (1978 a,b).

Ringed seals are ice-associated marine mammals usually found close to shore in the landfast ice. The change to summer ice results in seasonal concentrations of ringed seals along the edge of the pack ice and in ice remnants along shore; in the fall, these seals redistribute to the south as ice cover increases (NOAA-BLM 1978). They are numerous and important as food for man and other animals, such as polar bears and arctic foxes. They are the most numerous seal taken by Eskimo seal hunters (NOAA-BLM 1978).

Beaufort Sea ringed seal densities declined about 50 percent between 1970 and 1977, apparently due to heavy ice in 1975 and 1976 (Stirling et al. 1975, Burns and Eley 1977). It has been theorized that a net westward and southern displacement of ringed seals from the Beaufort and northern Chukchi Seas has occurred. A gradual return to the Beaufort Sea is anticipated if better ice years (1977 and 1978) continue to occur (NOAA-BLM 1978).

Ringed seal densities are higher on landfast ice than on pack ice (Burns and Harbo 1972, Burns and Eley 1977). Stable landfast ice is the preferred breeding habitat (NOAA-BLM 1978). Ringed seal pups are born from late March to late April in lairs in snowdrifts and pressure ridges. They remain in natal dens for 4 - 6 weeks (Smith and Stirling 1975, Eley 1978). Breeding follows and adults are less mobile on landfast ice in this pupping and breeding period and depend on a few holes and cracks for breathing (Smith and Stirling 1975). Molting follows from May through early July. Within the Prudhoe Bay area, Burns (1980) estimates densities of about one seal per km^2 in the spring.

Feeding is reduced in the pupping, breeding, and molting periods and blubber is metabolized (NOAA-BLM 1978). From summer through fall feeding becomes intensive (NOAA-BLM 1978).

Arctic cod is the most important single prey species in the Beaufort Sea, where they are eaten year-round. This fish species is a predominant food in fall and winter and is possibly also a major food in offshore areas during the summer. Off Prudhoe Bay in November 1977, large quantities of arctic cod were found in ringed seal stomachs. Amphipods and mysids were major food items in late winter and spring in the western Beaufort Sea. Nearshore prey species vary by area. Nearshore Barrow ringed seals ate euphausiids, isopods, and gammarid amphipods in late spring and summer, with euphausiids dominating particularly in August 1977. North of Prudhoe Bay in August 1977, hyperiid amphipods dominated, while east of Prudhoe Bay small amounts of gammarid amphipods, mysids, and shrimp were eaten in summer (NOAA-BLM 1978).

Apparently the ringed seal feeds on the most abundant and available suitable species (Lowry et al. 1977). Ringed seals appear to forage very heavily on temporally and spacially dispersed zooplankton blooms, which are probably critical for attaining an adequate annual food intake (NOAA-BLM 1978).

REFERENCES

AINA, 1974. The Alaska arctic coast: a background study of available literature. U.S. Army Corps of Engineers, Alaska District.

Alexander, V., R. Horner, and R.C. Clasby, 1974. Metabolism of arctic sea ice organisms. University of Alaska, Inst. of Marine Science. Rep. R74-4. 120 pp.

Alt, K.T., and D.R. Kogl, 1973. Notes on the whitefish of the Colville River, Alaska. J. Fish. Res. Bd. Canada 30(4):554-556.

American Fisheries Society, 1970. Common and scientific names of fishes. Special publication No. 6, Washington, D.C.

Andriyashev, A.P., 1954. Fishes of the northern seas of the U.S.S.R. Izdatel'stvo. Akad. Nauk. SSR, Moskva-Leningrad. Translation from Russian, Israel Program for Scientific Translations. Jerusalem, 1964. 617 p.

AEIDC, 1979. Status of bowhead whales, bowhead research and Alaska Eskimo whaling: A report to the State Legislature. University of Alaska, Anchorage.

Bain, L.H., 1974. Life histories on systematics of arctic char in the Babbage River System, Yukon Territory. Canadian Gas Study Ltd. Biological Report Series 18(1):1-156.

_____, and A. Sekera, 1978. Aspects of the biology of arctic cod, Boreogadus saida, in the central Canadian Arctic. Report by LGL Limited for Polar Gas Project, Toronto. 104 p.

Battelle Northwest Laboratory, 1979. Alaska environmental research. In: Annual report for 1978 to the DOE Assistant Secretary for Environment, Part 2 supplement - ecological sciences, pp. 12.0 - 12.24.

Beehler, C., M. Busdosh, K. Tarbox, and G. Robilliard, 1979. Occurrence of kelp offshore of Prudhoe Bay, Alaska. In: Environmental studies of the Beaufort Sea - Winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska, 36 pp.

Bendock, T., 1977. Beaufort Sea estuarine fishery study. Alaska Dept. Fish and Game. Final report to NOAA/BLM. Contract No. 03-5-022-69. 61 p.

Braham, H.W., 1979. Personal communication with J. Isakson, Dames & Moore.

_____, H.W., and B.D. Krogman, 1977. Population biology of bowhead (Balaena mysticetus) and beluga (Delphinaterus leucas) whale in the Bering, Chukchi and Beaufort Seas. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Fish. Serv., Northwest and Alaska Fish. Cent., Mar. Mammal Div., Seattle, Wash., Processed Rep., 29 p.

_____, B.D. Krogman, and C. Fiscus, 1977. Bowhead (Balaena mysticetus) and beluga (Delphinapterus leucas) whales in the Bering, Chukchi and Beaufort Seas. In: Environmental assessment of the Alaskan continental shelf, annual reports of principal investigators for the year ending March 1977, Vol 1, receptors - mammals, p. 134-160. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo.

_____, B.D. Krogman, S. Leatherwood, W. Marquette, D. Rugh, M. Tillman, J. Johnson, and G. Carroll. In press. Preliminary report of the 1978 spring bowhead whale research program results [SC/30/Doc. 36]. Rep. Int. Whaling Comm. 19. 57 p.

_____, B.K. Krogman, W. Marquette, D. Rugh, J. Johnson, M. Nerini, S. Leatherwood, M. Dahlheim, R. Sonntag, G. Carroll, T. Bray, S. Savage, and J. Cubbage, 1979. Bowhead whale (Balaena mysticetus) preliminary research results, June through December 1978. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish Serv., Northwest and Alaska Fish. Cent., Natl. Mar. Mammal Lab., Seattle, Wash., NWAFC Processed Rep. 79-8, 40 p.

Brewer, M. (USGS/NPR-A), 1980. Personal communication to J. Hemming, Dames & Moore.

Broad, A.C., 1977. Environmental assessment of selected habitats in the Beaufort and Chukchi Sea littoral system. Annual Report RU #356. In: Environmental Assessment of the Alaska Continental Shelf, Annual Report, OCSEAP, Boulder, Col.

_____, A. Benedict, K. Dunton, H. Koch, D.T. Mason, D.E. Schneider, and S.V. Schonberg, 1979. Environmental assessment of selected habitats in the Beaufort and Chukchi littoral system. Annual report. OCSEAP, Boulder, Col.

_____, H. Koch, D.T. Mason, G.M. Petrie, D.E. Schneider, and R.J. Taylor, 1978. Environmental assessment of selected habitats in the Beaufort Sea littoral system. In: Environmental assessment of the Alaskan continental shelf. Annual report. Nat. Oceanic Atmos. Admin., Boulder, Co. 86 p.

Burns, J.J., 1967. The Pacific bearded seal. Alaska Dep. Fish Game, Fed. Aid Wildlife Restoration Proj. Rep. Vol. 8, 66p.

_____, (ADF&G), 1980. Personal communication to J. Hemming, Dames & Moore.

_____, and T.J. Eley, 1977. The natural history and ecology of the bearded seal (Erignathus barbatus) and the ringed seal (Phoca hispida). Annual report, OSCEAP, Boulder, Co.

_____, and K.J. Frost, 1979. The natural history and ecology of the bearded seal (Erignathus barbatus). Final report. OSCEAP, Boulder, CO.

_____, and S. J. Harbo, Jr., 1972. An aerial census of ringed seals, northern coast of Alaska. Arctic 25(4):279-290.

Bursa, A., 1963. Phytoplankton in the coastal waters of the Arctic Ocean at Point Barrow, Alaska. Arctic 16:239-262.

Busdosh M., K. Tarbox, and G. Robilliard, 1979. Attraction of amphipods by baited traps. In: Environmental studies of the Beaufort Sea - Winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska, 36 pp.

Carey, A.G., Jr., 1977. Summarization of existing literature and unpublished data on the distribution, abundance, and life histories of benthic organisms, Annual Report Vol. 6, Receptors - fish, littoral, benthos. OCSEAP, Boulder, Co.

_____, 1978. The distribution, abundance, diversity and productivity of the western Beaufort Sea benthos. Annual Report RU #6. In: Environmental assessment of the Alaskan continental shelf. Annual report. OCSEAP, Boulder, Co.

_____, and R.E. Ruff, 1977. Ecological studies of the benthos in the western Beaufort Sea with special reference to bivalve molluscs. In: M.J. Dunbar (Ed.), Polar oceans. Arctic Institute of North America, Calgary, Alberta.

Chin, H., M. Busdosh, G.A. Robilliard, R. Firth, 1979a. Environmental studies associated with the Prudhoe Bay dock: physical oceanography and benthic ecology. Final report prepared for Atlantic Richfield Company by Woodward-Clyde Consultants, Anchorage, Alaska.

_____, A. Neirdoroda, G. Robilliard, and M. Busdosh, 1979b. Related studies. In: Biological effects of impingement and entrainment from operation of the proposed intake. Draft report for ARCO Oil and Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska.

Clasby, R.C., V. Alexander, and R. Horner, 1976. Primary productivity of sea ice algae. In: D.W. Hood and D.C. Burrell (Eds.), Assessment of the arctic marine environment: selected topics. Univ. of Alaska, Inst. Mar. Sci. Oceas. Publ. 4.

Coyle, K.O., 1974. The ecology of the phytoplankton of Prudhoe Bay, Alaska, and the surrounding waters. M.S. thesis, Univ. of Alaska, Fairbanks, 265 pp.

Craig, P.C., 1977. Ecological studies of anadronous and resident populations of arctic char in the Canning River drainage and adjacent coastal waters of the Beaufort Sea, Alaska. Canadian Arctic Gas Study Limited, Biological Report Series 41:1-116.

_____, and W. Griffiths, 1978. Ecology of fishes in Simpson Lagoon. In: Beaufort Sea barrier island-lagoon ecological process studies. LGL Ltd.-U.S., Inc., Annual Report, Research Unit 467. NOAA/OCSEAP, Boulder, Co. 318 p.

_____, and L. Haldorson, 1979. Ecology of fishes in Simpson Lagoon, Beaufort Sea, Alaska. In: Beaufort Sea barrier island-lagoon ecological process studies. LGL Ltd.-U.S., Inc., Annual Report, Research Unit 467. NOAA/ OCSEAP, Boulder,Co.

_____, and P. McCart, 1974. Fall spawning and overwintering areas of fish populations along routes of proposed pipeline between Prudhoe Bay and the Mackenzie Delta, 1972 to 1973. In: P. McCard (Ed.), Fisheries research associated with proposed gas pipeline routes in Alaska, Yukon, and Northwest Territories. Arctic Gas Biological Report Series, Vol. 15(3). 36 p.

_____, and P. McCart, 1976. Fish use of nearshore coastal waters in the western Arctic: emphasis on anadromous species. In: D.W. Hood and D.C. Burrell (Eds.), Assessment of the arctic marine environment: selected topics. Occas, Publ. No. 4, Inst. Mar. Sci., Univ. of Alaska, Fairbanks.

_____, and G.J. Mann, 1974. Life history and distribution of the arctic cisco (Coregonus autumnalis) along the Beaufort Sea coastline in Alaska and the Yukon Territory. Canadian Arctic Gas Study Ltd., Calgary, Alberta. Biol. Rept. Ser. 17(1):47 p.

Crane, J.J., 1974. Ecological studies of the benthic fauna in an arctic estuary. M.S. thesis, Univ. of Alaska, Fairbanks, 105 pp.

Dames & Moore, 1979. Ecological studies of intertidal and shallow subtidal habitats in lower Cook Inl t. Report prepared for NOAA-OCSEAP.

Doxey, M., 1977. Fishery impact survey of the ARCO causeway. Alaska Dept. Fish and Game, Unpubl. Rpt. to Atlantic Richfield Co. 38 p.

Dunton, K. and S. Schonberg, 1979. An arctic kelp community in Stefanson Sound, Alaska; a survey of the flora and fauna. In: Broad, A.C., Reconnaissance characterization of littoral biota, Beaufort and Chukchi Seas. Environmental assessment of the Alaskan continental shelf. October 1978.

Durham, F.E., 1979. The catch of bowhead whales (Balaena mysticetus) by Eskimos, with emphasis on the western arctic. Contrib. Sci. Nat. Hist. Mus., Los Angeles Cty. 314:1-14.

Eley, T.J., 1977. An analysis of polar bear predation on ice-inhibiting pinniped populations of Alaska, abstract only. In: Proclamation 2nd Conference on Biol. Marine Mammals, San Diego, Calif., 12-15 December 1977, p. 18.

_____, 1978. The ringed seal in Alaska. Wildlife Notebook Series, Alaska Dept. Fish and Game, Juneau, Alaska.

English, T.S., and R.A. Horner, 1976. Beaufort Sea plankton studies, pp. 593-671. In: Environmental assessment of the Alaska continental shelf., Vol. 7, fish, plankton, benthos, littoral. RU #359. Principal Investigators Reports for the year ending March 1976, OCSEAP, Boulder, CO.

Everitt, R.D., and B.D. Krogman, in press. Sexual behavior of bowhead whales observed off the north coast of Alaska. Arctic 32(3), 4 p.

Feder, H.M., D.G. Shaw and A.S. Naidu, 1976a. The arctic environment in Alaska, the nearshore marine environment in Prudhoe Bay, Alaska. Institute of Marine Science, Grant Report 76-3, Vol. I, University of Alaska, Fairbanks.

_____, D. Schamel, E.R. Shaw, and A.S. Naidu, 1976b. Environmental study of the marine environment in Prudhoe Bay, Alaska. Institute of Marine Science, University of Alaska, Fairbanks.

Fiscus, C.H., and W.M. Marquette, 1975. National Marine Fisheries Service field studies relating to the bowhead whale harvest in Alaska, 1974. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Cent., Seattle, Wash., Processed Rep., 23 p.

Fraker, M.A., D.E. Sergeant, and W. Hoek, 1978. Bowhead and white whales in the southern Beaufort Sea. Beaufort Sea Tech. Rep. #4, Department of Fisheries and the Environment (Can.), Beaufort Sea Project, Sidney, B.C., 114 p.

Frost, K., L. Lowry and J. Burns, 1978. Offshore demersal fishes and epibenthic invertebrates of the northern Chukchi and western Beaufort Seas. Alaska Dept. Fish and Game. Annual Report. NOAA/OCCSEAP, Boulder, Co., 39 p.

Furniss, R.A., 1975. Inventory and cataloging of arctic area waters. Alaska Dept. Fish and Game. Annual Report 16:1-47.

Galbraith, D., and D. Fraser, 1974. Distribution and food habits of fish in the eastern coastal Beaufort Sea. Interim Report of Beaufort Sea Project Study B1 (Eastern). Fish. and Marine Serv., Environ. Canada. 48 p.

Grider, G.W., G.A. Robilliard, and R.W. Firth, 1977. Environmental studies associated with the Prudhoe Bay dock: coastal processes and marine benthos. Final report prepared for Atlantic Richfield Company by Woodward-Clyde Consultants, Anchorage, Alaska.

_____, G.A. Robilliard, and R.W. Firth, 1978. Environmental studies associated with the Prudhoe Bay dock: coastal processes and marine benthos. Final report prepared for Atlantic Richfield Company by Woodward-Clyde Consultants, Anchorage, Alaska.

Griffiths, W. and P.C. Craig, 1978. Invertebrates. In: J. Truett (Ed.), Beaufort Sea barrier island-lagoon ecological process studies. LGL Ltd., Environ. Research Assoc. RU #467. Annual report to OCSEAP, Boulder, CO.

_____, P.C. Craig, G. Walder and G. Mann, 1975. Fisheries investigations in a coastal region of the Beaufort Sea (Nunaluk Lagoon, Y.T.). Canadian Arctic Gas Study Ltd., Calgary, Alberta, Biol. Rept. Ser. 34(2):219 p.

_____, J. DenBeste and P.C. Craig, 1977. Fisheries investigations in a coastal region of the Beaufort Sea (Kaktovik Lagoon, Barter Island, Alaska). Canadian Arctic Gas Study Ltd., Calgary, Alberta. Biol. Rept. Ser. 40(2): 190 p.

_____, and R.E. Dillinger, 1979. Ecology of invertebrates in Simpson Lagoon, Beaufort Sea, Alaska. In: Beaufort Sea barrier island-lagoon ecological process studies. Annual Rep. by LGL Limited for NOAA/OCSEAP, Boulder, CO., 119 p.

Hand, C. and L.B. Kan, 1961. The mudusae of the Chukchi and Beaufort Seas of the Arctic Ocean including the description of a new species of Eucodonium. Arctic Institute of North America Tech. Paper #6.

Horner, R.A., 1969. Phytoplankton studies in the coastal waters near Barrow, Alaska. Ph.D. thesis, Univ. Washington, Seattle, 261 pp.

_____, 1972. Ecological studies on arctic sea ice organisms. Progress Report to the Office of Naval Research for the period 1 May 1971 - 30 April 1972. Univ. of Alaska, Inst. Mar. Sci. Rep. No. R72-18. 176 pp.

_____, 1973. Studies on organisms found in arctic sea ice. Final Report to the Arctic Institute of North America. No report number.

_____, 1978. Beaufort Sea plankton studies, Annual Rept. RU#359. OCSEAP, Boulder, CO.

_____, 1979. Beaufort Sea plankton studies. Annual Report RU#359. OCSEAP, Boulder, CO.

_____, 1972. Algal populations in arctic sea ice: an investigation of heterotrophy. Kimnol. Oceanogr. 14:454-458.

_____, K.O. Coyle and D.R. Redburn, 1974. Ecology of the plankton of Prudhoe Bay. Alaska Inst. Mar. Sci. Rept. R74-2, Univ. of Alaska, Fairbanks. 78 pp.

Hsiao, S.I.C., 1976. Biological productivity of the southern Beaufort Sea: phytoplankton and seaweed studies. Dept. Environment, Beaufort Sea Project Tech. Report 12-C, Victoria, B.C.

Hunter, J.G., 1975. Fishery resources of the western arctic. Manuscript Rep. Ser. Fishery Research Board of Canada #1335, 33 pp.

Johnson, M.W., 1956. The plankton of the Beaufort and Chukchi Sea areas of the Arctic and its relations to the hydrography. Arctic Inst. N. Amer. Tech. Pap. No. 1. 32 pp.

_____, 1958. Observations on inshore plankton collected during summer 1957 at Point Barrow, Alaska. J. Mar. Res. 17:272-281.

Johnson, S.R., 1979. Fall observations of westward migrating white whales (Delphinapterus leucas) along the central Alaskan Beaufort Sea coast. Arctic, 32(3):275-276.

Kendel, R.E., R.A.C. Johnston, U. Lobsiger, and M.D. Kozak, 1975. Fishes of the Yukon coast. Beaufort Sea Project Technical Report No. 6. Victoria, B.C.

Klinkhart, Edward, 1966. The beluga whale in Alaska. Alaska Dep. Fish Game, Fed. Aid Wildl. Restoration Proj. Rep., Vol. 7, 11 p.

Kogl, D.R., and D.Schell, 1974. Colville River delta fisheries research. In: Baseline data study of the Alaskan arctic aquatic environment. Institute of Marine Science, University of Alaska, College, Alaska. Final Report.

Larrance, J.D. and A.J. Chester, 1979. Source, composition, and flux of organic detrities in lower Cook Inlet. Final Report. Pacific Marine Environment Laboratory, NOAA, for NOAA-OCSEAP, Boulder, Co.

Lees, D.C., 1975. City of Oxnard predischarge receiving water monitoring study - results of biological study. Final report prepared for City of Oxnard by Environmental Quality Analysts, Inc. and Marine Biological Consultants, Inc.

Lowry, L.G., K.J. Frost, and J.J. Burns, 1977. Trophic relationships among ice inhabiting phocid seals. OSCEAP final report. Boulder, CO.

_____, 1979a. Trophic relationships among ice inhabiting plocid seals. OSCEAP final report. Boulder, CO.

_____, 1978b. Food of ringed seals and bowhead whales near Point Barrow, Alaska. Can. Field-Nat. 92(1):67-70.

McCart, P., and H. Bain, 1974. An isolated population of arctic char (Salvelinus alpinus) inhabiting a warm mineral spring above a waterfall at Cache Creek, N.W.T. J. Fish. Res. Board Can. 31(8):1408-1414.

_____, P. Craig and H. Bain, 1972. Report on fisheries investigations in the Sagavanirktok River and neighboring drainages. Report to Alyeska Pipeline Service Co., Bellevue, Washington. 186 pp.

McPhail, J.D., 1961. A systematic study of the Salvelinus alpinus complex in North America. Fish. Res. Bd. Canada 18(5):793:816.

_____, and C.C. Lindsey, 1970. The freshwater fishes of north-western Canada and Alaska. Fish. Res. Board Can. Bull. 173:381 p.

MacGinitie, G.E., 1955. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. Smithsn Misc. Collns. 128(9): 1-201.

Marquette, W.M., 1976. Bowhead whale field studies in Alaska, 1975. MFR Paper 1195. Mar. Fish. Rev. 38(8):9-17.

_____, 1977. The 1976 catch of bowhead whales (Balaena mysticetus) by Alaskan Eskimos, with a review of the fishery, 1973-1976, and a biological summary of the species. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent., Mar. Mammal Div., Seattle, Wash., Processed Rep., 79 p + app.

_____, in press. 1977 catch of bowhead whales (Balaena mysticetus) by Alaskan Eskimos [SC/30/DOC-35]. Rep. International Whaling Commission No. 29. 26 pp.

Matheke, G.E.M., 1973. The ecology of the benthic microalgae in the sublittoral zone of the Chukchi Sea near Barrow, Alaska. M.S. thesis, Univ. of Alaska, Fairbanks. 132 pp.

_____, and R. Horner, 1974. Primary productivity of the benthic microalgae in the Chukchi Sea near Barrow, Alaska. J. Fish. Res. Bd. Can. 31:1779-1786.

Mohr, J.L., N.J. Wilimousky, and E.Y. Dawson, 1957. An arctic Alaskan kelp bed. Arctic 10:45-52.

Morrow, J.E., 1979. Freshwater fishes of Alaska: their biology, distribution and value. Report for EPA. NTIS No. PB 294879. University of Alaska, College, Alaska.

Moulton, L., K. Tarbox, and R. Thorne, 1980. Beaufort Sea fishery investigations. Summer 1979. In: Environmental studies of the Beaufort Sea. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

Naval Ocean Systems Center, 1980. Aerial surveys of bowhead whales, North Slope, Alaska, February 1980. Technical Document 314. Prepared for Bureau of Land Management.

Nikol'skii, G.V., 1954. Special ichthyology. Israel Program for Scientific Translations, National Science Foundation, Washington, D.C., OTS 60-21817, 538 pp.

NOAA-BLM, 1978. Environmental assessment of the Alaskan continental shelf. Interim synthesis: Beaufort/Chukchi. National Oceanic and Atmospheric Administration. 362 p.

Percy, R., 1975. Fishes of the outer MacKenzie delta. Beaufort Sea Project Technical Report No. 8. Victoria, B.C., Can.

Quast, J.C., 1974. Density distribution of juvenile arctic cod, Boreogadus saida, in the eastern Chukchi Sea in the fall of 1970. Fish. Bull. U.S. 72(4):1094-1105.

Redburn, D.R., 1974. The ecology of the inshore marine zooplankton of the Chukchi Sea near Point Barrow, Alaska. M.S. thesis., Univ. of Alaska, Fairbanks. 172 p.

Rietze, H.L., 1979. Letter from NMFS of December 13 to Colonel L.R. Nunn (Alaska District Corps of Engineers).

Robilliard, G. and M. Busdosh, 1979. Biology of the isopod (Saduria entomon) at Prudhoe Bay, Alaska. In: Environmental studies of the Beaufort Sea - Winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska, 124 pp.

Schell, D.M., 1978. Nutrient dynamics in nearshore under-ice waters. Annual report. NOAA/BLM-OCSEAP, Boulder, CO. 25 pp.

Sergeant, D.E., and P.F. Brodie, 1975. Identity, abundance, and present status of populations of white whales, Delphinapterus leucas, in North America. J. Fish. Res. Board Can. 32:1047-1054.

Severinghaus, N.C., 1979. Selected annotated references on marine mammals of Alaska. NMFS NWAFC processed report 79-15.

Smith, T.G., 1974. Biology of the Beaufort region. Northern Perspectives, Can. Arctic Resour. Comm. 2(2):11-12.

_____, and I. Stirling, 1975. The breeding habitat of the ringed seal (Phoca hispida): the birth lair and associated structures. Can. J. Zool. 53:1297-1305.

Stirling, I., R. Archibald, and D. DeMaster, 1975. Distribution and abundancce of seals in the eastern Beaufort Sea. Dep. Environ. [Can.], Beaufort Sea Project, Victoria, B.C., Can., Beaufort Sea Tech. Rep. #1, 58 p.

Swope, R., 1979. New results in marine mammal research. Population biology of the bowhead whale (Balaena mysticetus) II: Migrations, distribution and abundance in the Bering, Chukchi and Beaufort Seas, with notes on the distribution and life history of white whales (Delphinapterus leugas). A summary of September 1979 OCSEAP final report: H. Brauham, B. Krogman, G. Carroll (R.U. 69/70) National Marine Mammal Laboratory. Bering Sea - Gulf of Alaska Newsletter (9):5-7, November.

Tarbox, K., M. Busdosh, D. LaVigne, and G. Robilliard, 1979. Under-ice plankton in the Beaufort Sea near Prudhoe Bay, Alaska - February - May 1979. In: Environmental studies of the Prudhoe Bay Unit. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska, 52 pp.

_____, and L. Moulton, 1980. Larval fish abundance in the Beaufort Sea near Prudhoe Bay, Alaska. In: Environmental studies of the Beaufort Sea - Summer 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

_____, and G.A. Robilliard, 1980. Personal communication to D. Lees, Dames & Moore.

_____, and T. Spight, 1979. Beaufort Sea fishery investigations. In: Biological effects of impingement and entrainment from operation of the proposed intake. Draft report prepared for ARCO Oil and Gas Company by Woodward-Clyde Consultants, Anchorage, Alaska.

_____, and R. Thorne, 1979. Measurements of fish densities under the ice in the Beaufort Sea near Prudhoe Bay, Alaska. In: Environmental studies of the Beaufort Sea - Winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska, 111 pp.

Underwood, L.S., 1975. Notes on the arctic fox (Alopex lagopus) in the Prudhoe Bay area of Alaska. In: J. Brown (Ed.), Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biol. Papers of the University of Alaska, Special Report No. 2., pp. 145-149.

USDI, 1972. Final environmental impact statement proposed trans-Alaskan pipeline. Prepared by a special interagency task force for the Federal Task Force on Alaska Oil Development.

U.S. Dept. of Interior, 1979. Endangered and threatened wildlife and plants. Federal Register. 44(12):3636-3653, January 17.

Yoshihara, H.T., 1972. Monitoring and evaluation of arctic waters with emphasis on the North Slope drainages. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, Project F-9-4, 13(G-III-A):1-49.

_____, 1973. Monitoring and evaluation of arctic waters with emphasis on the North Slope drainages. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, Project F-9-5, 14 (G-III-A):1-83.

Woodward-Clyde Consultants, 1979. Prudhoe Bay waterflood project, Volume II, environmental, July 1979. Prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

APPENDIX F

FRESHWATER RESOURCES

1.0 INTRODUCTION

Thousands of shallow lakes and ponds, wide braided rivers, and small meandering streams dominate the Arctic Coastal Plain. The hydrology of this area is dominated by high flow in the spring, a gradual decrease in flow thoughout summer, and a virtual cessation of flow during the winter. Water quality parallels hydrology in a general sense. Spring breakup provides abundant fresh water. The quality changes throughout summer, and more rapidly as the winter ice cover thickens on lakes and streams. Free water is scarce by late winter in the natural system.

This section presents a discussion of discharge and quality in streams, water quality of lakes, ponds, and wetlands, and water availability and use.

2.0 STREAMS

The major streams in the Prudhoe Bay Development Area (PBDA) include the Putuligayuk, Kuparuk, and Sagavanirktok Rivers. The Putuligayuk, a tundra stream, arises within the Arctic Coastal Plain. When compared to mountain streams, tundra streams are relatively small, obtain flow from surface runoff, carry less sediment, are more stable, and form small deltas. The Kuparuk and Sagavanirktok headwater in the Brooks Range and are wide, braided rivers. Their flow comes from surface runoff, ground water, and springs.

The average and range of discharge for the Putuligayuk, Kuparuk, and Sagavanirktok are presented in Table F-1. The U.S. Geological Survey (USGS) maintains gaging stations on these rivers which measure flow from 96.4 percent of the Putuligayuk basin, 82.7 percent of the

TABLE F-1

AVERAGE AND EXTREME DISCHARGE OF MAJOR RIVERS IN PBDA

River	Period of Record	Drainage Area km/s	Average 3/s	Discharge ft^3/s	Maximum 3/s	Discharge ft^3/s	Minimum 3/s	Discharge ft^3/s
Putuligayuk near Deadhorse	May 1970 to Present	456	1.119	39.5	141	4980	0	0
Kuparuk near Deadhorse	June 1971 to Present	8107	36.11	1275	2320	82,000	0	0
Sagavanirktok near Sagwon	August 1970 to Present	5719	47.38	1673	838	29,600	0	0

Source: USGS 1978

38.4 percent of the Sagavanirktok. These percentages were calculated using total drainage areas of 473 km^2 (183 mi^2) for the Putuligayuk, 9802 km^2 (3784 mi^2) for the Kuparuk, and 14,898 km^2 (5752 mi^2) for the Sagavanirktok as presented by FERC (1979) and the drainage areas above the gaging stations presented by USGS (1978).

Streamflow records for the Sagavanirktok, Kuparuk, and Putuligayuk indicated mean annual flow rates of 0.02, 0.01, and 0.005 m^3/km^2 (0.8, 0.5, and 0.2 ft^3/mi^2) of contributing drainage basin, respectively (USGS 1972, 1973, 1974). These rates reflect the flow conditions of streams in the three physiographic provinces of the North Slope--mountains, foothills, and coastal plain. Kane and Carlson (1973) indicate that roughly half of the Sagavanirktok River drainage area lies above 600 m (1968 ft) in elevation, whereas less than 10 percent of the Kuparuk River basin lies above this elevation in the foothills and Brooks Range. The Putuligayuk River lies entirely within the coastal plain.

Generally, river breakup occurs in early June. The active layer is usually frozen to the surface during the initial stages of breakup; therefore, most water released by snowmelt reaches the river channels.

During pre-breakup flooding, bottomfast ice protects the river channel from scour. As flow increases, this ice is lifted and carried downstream. During the recession of the spring flood, ice is likely to become stranded, thus increasing the likelihood of ice jamming, localized flooding, and erosion.

Flows decline gradually throughout the summer with some fluctuations from rainstorms.

The sudden June breakup floods represent 60 - 80 percent of total annual flow (BLM 1979), and approximately 80 percent of the total annual discharge of coastal plain streams (Oceanographic Institute of Washington 1979).

For the 8 years of record, the Putuligayuk River starts flowing between May 27 and June 9, and stops between September 29 and October 10 (FERC 1979). Peterson (in press) indicates that 90 percent of the annual flow of the Putuligayuk River, and 78 percent of the Kuparuk River annual discharge occur during June. The Sagavanirktok releases 34 percent of its annual flow (at Sagwon) in June. As summer advances, discharge in the Putuligayuk and Kuparuk is significantly reduced compared to June flows. Summer flow reduction in the Sagavanirktok is gradual until September. USGS records for water years 1971 - 1977 (USGS 1972, 1973, 1974, 1975, 1976, 1977, 1978) indicate zero flow in the Putuligayuk River from November through April. The Kuparuk River flowed throughout the winter during water years 1972 - 1974, but had zero flow for at least 3 months during water years 1975 - 1977. Nauman and Kernodle (1973) indicate that the Sagavanirktok River sometimes continues to flow until mid-November. However, USGS records show some flow at Sagwon for water years 1972 - 1976. Zero flow was recorded during February, March, and April, 1977.

The water quality characteristics noted below indicate the Sagavanirktok, Kuparuk, and Putuligayuk Rivers have high quality during the open-water period. Some parameters display poor quality under ice, however, this is the natural state -- not pollution caused by man's activity.

Dissolved oxygen in rivers remains at or near saturation during the open-water season and becomes reduced in stagnant pools under ice cover. Schallock and Lotspeich (1974) note that severe oxygen depletion can occur in the Sagavanirktok River near Deadhorse during winter. Schallock (1975) measured dissolved oxygen concentrations as low as 1.2 mg/l, which was 8.2 percent saturation. He also measured a summer range of 9.9 mg/l (92 percent saturation) to 13.3 mg/l (95 percent saturation). USGS measurements at Sagwon display a range of 6.7 - 11.3 mg/l dissolved oxygen (USGS 1976), which is 47 - 95 percent saturation. The USGS measured a dissolved oxygen range of 1.4 - 14.6 mg/l in the Kuparuk River (USGS 1976). This range represents 9.6 - 103 percent saturation.

River pH is usually slightly basic. USGS measurements in the Sagavanirktok River at Sagwon indicate a range of 7.4 - 8.0 (USGS 1976, 1977). Schallock (1975) notes a summer range of 7.6 - 8.1 and a winter range of 7.2 - 7.7 near Deadhorse. The Kuparuk River displays a range of 6.4 - 7.8 (USGS 1976, 1977, 1978), and the Putuligayuk River pH has been measured between 7.7 - 8.0 (USGS 1976, 1977).

Conductivity, in micromhos/cm, has been measured in the three major rivers of the PBDA by the USGS. The following ranges are reported: Sagavanirktok River, 145 - 310 (USGS 1976, 1977); Kuparuk River, 29 - 426 (USGS 1976, 1977, 1978); and Putuligayuk River, 148 - 290 (USGS 1976, 1977). Schallock (1975) measured conductivity in the Sagavanirktok River near Deadhorse during summer (80 - 840) and winter (660 - 1700).

Small streams exhibit warmer summer temperatures than larger streams. Temperatures in the Putuligayuk River have ranged from 0°- 19°C (32° - 66°F), whereas the Sagavanirktok River at Sagwon displays a range of 0.5° - 14°C (33° - 57°F) (USGS 1976, 1977). The Kuparuk River has ranged from 0° - 13.5°C (32° - 56°F) (USGS 1976, 1977, 1978).

Nutrients are generally low in arctic streams. According to Hobbie (1973), phosphorus concentrations are always low, but nitrate may be high. Nitrate concentrations are usually lower than 0.20 mg/l in the Sagavanirktok River. Schell (1975) indicates that fresh water in rivers is primarily phosphate limited. Schallock (1975) measured nutrients in the Sagavanirktok River near Deadhorse. His data appear below in mg/l:

Parameter	Summer Range	Winter Range
Nitrate	0.05 - 0.15	0.09 - 0.76
Ammonia	0.02 - 0.09	0.01 - 0.18
Total Phosphate	0.01 - 0.05	0.01
Silica	0.6 - 2.7	3.6 - 12.5

The USGS (1976) measured total nitrogen in the Putuligayuk River on one occasion at 0.95 mg/l and total phosphate at 0.00 mg/l. The Kuparuk River has displayed a range of total nitrogen (as N) of 0.03 - 0.97 mg/l and a range of total phosphate (as P) of 0.00 - 0.07 mg/l (USGS 1976, 1977, 1978, 1979).

Streams generally have dissolved solids concentrations less than 120 mg/l (Feulner et al 1971), but local areas under ice can become brackish or saline. For example, Sherman (1973) found a saltwater aquifer beneath the lower Sagavanirktok River.

Dissolved solids concentrations also vary with season. Concentrations of calcium and potassium increase in small streams during summer but remain relatively constant in large rivers (Douglas and Bilgin 1975). Schallock (1975) measured some components of dissolved solids in the Sagavanirktok River during summer and winter. These data are reported below in mg/l:

Parameter	Summer Range	Winter Range
Calcium	10.0 - 42.0	89.0 - 95.0
Potassium	0.15 - 0.75	0.7 - 1.97
Sodium	0.40 - 1.3	2.6 - 9.0

USGS measurements of hardness and sodium indicate the following ranges in mg/l:

	Hardness	Sodium	
Sagavanirktok River	63 - 156	0.8 - 3.5	(USGS 1976)
Putuligayuk River	55 - 57	3.8 - 5.8	(USGS 1976)
Kuparuk River	18 - 180	0.9 - 4.7	(USGS 1976,1977,1978)

Suspended solids and turbidity are measures of the amount of particulate matter carried in the water column. These parameters reach their highest levels during periods of peak flow, primarily during spring breakup and secondarily during summer rain storms. As an example, it was estimated that in 1962 approximately 75 percent of the annual sediment load of the Colville River was transported during a 3-week period in June (Walker 1973). USGS measurements of suspended sediment have ranged from 1 - 139 mg/l in the Sagavanirktok River and from 1 - 45 mg/l in the Putuligayuk River (USGS 1976, 1977). The Kuparuk River displays a wider range, 1 - 336 mg/l (USGS 1976, 1977, 1978). Turbidity has generally been low: 1 - 2 Nephelometric Turbidity Unit (NTU) in the Putuligayuk River, 1 - 15 NTU in the Sagavanirktok River (USGS 1976), and 0 - 20 NTU in the Kuparuk River (USGS 1976, 1977, 1978).

Few measurements of total organic carbon have been made in these rivers. There are no data for the Sagavanirktok River and only one measurement in the Putuligayuk River, which was 8.9 mg/l (USGS 1976). The Kuparuk River displays a range of 3.7 - 18 mg/l (USGS 1976, 1978).

Trace elements have been measured in the Kuparuk River by the USGS (1976, 1977, 1978). All elements exhibited low concentrations during all three years except cobalt and lead, which were 0.2 mg/l and 0.1 mg/l, respectively, during water year 1977 (USGS 1978). Both of these elements were below the detection limits (cobalt, 0.05 mg/l; and lead, 0.1 mg/l) during water years 1976 and 1977.

3.0 LAKES, PONDS, WETLANDS

The Prudhoe Bay area is dotted with numerous lakes and ponds, and wetlands cover much of the northwest portion of the PBDA. Sellmann et al. (1975) indicate that 10 - 15 percent of the PBDA is covered by small to intermediate lakes, and Gatto (1980) indicates that 25 - 30 percent of the area is covered by lakes. Regional slope and relief control lake size with the largest lakes occurring on flat terrain (Sellmann et al. 1975). Most lakes are shallow, 1 - 2 m (3 - 6 ft) in depth and freeze to the bottom (Childers et al. 1977). Deep lakes are underlain by a talik, or thawed zone. According to Ward and Peterson (1976), taliks may be as deep as 91 m (300 ft).

An ice cover isolates tundra lakes and ponds from outside influences for 9 - 10 months of the year. Lakes and ponds generally freeze over by mid- to late September, remaining so until late June or July (Brewer 1958, Sater 1969). Water bodies less than 2 m (6 ft) freeze solid each winter.

During spring breakup, lakes act as natural catchments for meltwaters, and often flood past their normal shoreline. Ice on shallow lakes melts earliest, whereas deep lakes will have the longest period of summer ice cover (Sellmann et al. 1975). Lake levels decrease following breakup, often to levels below their outlet elevation, and can become stagnant by freeze-up. Arctic lakes are generally ice free for 2 - 3 months (Brewer 1958, Boyd 1959).

The water quality in lakes and ponds is generally high after breakup subsides and remains high until freeze-up approaches. Aesthetically, the waters may be objectionable because of high color, odor, and iron.

Arctic lakes are normally at, or near, complete saturation of dissolved oxygen during the open-water season and in the fall (Howard and Prescott 1979). Dissolved oxygen remains close to saturation in lakes and ponds due to the low level of biological activity (Sater 1969) and wind mixing. From mid-winter until breakup, dissolved oxygen decreases, often to levels less than 5 mg/l (Howard and Prescott 1971); severe deoxygenation may take place under ice so that some waters become anaerobic (Hobbie 1973). However, in lakes where photosynthesis occurs under ice, dissolved oxygen may reach supersaturation levels (Howard and Prescott 1973).

In ponds and lakes, pH generally ranges from slightly below neutral to about 8.0 (Howard and Prescott 1971). Kalff (1968) measured pH ranges of 6.7 - 8.4 in six lakes, and 6.7 - 7.2 in two ponds. Water in deep lakes that do not freeze solid during winter will exhibit essentially 0°C (32°F) temperatures. Shallow tundra lakes may reach

15°C (59°F), and ponds may reach 18°C (64°F) (Hobbie 1973) at the height of the warming period.

Nutrients in arctic waters are present in small quantities (Sater 1969, Hobbie 1973). Phosphate concentrations are low in lakes and ponds (Barsdate 1971, Hobbie 1973), whereas nitrate concentrations are low in lakes and high in ponds (Hobbie 1973). In a study of six lakes and two ponds, Kalff (1968) reported phosphate ranging from 0.002 - 0.019 mg/l with little difference between ponds and lakes. Nitrate ranged from less than 0.01 - 0.02 mg/l in lakes and from 0.05 - 0.17 mg/l in ponds. Barsdate (1971) reported that nitrate ranged from less than 1 ug/l to 0.09 mg/l in three ponds. According to Kalff (1971), there is an ammonia deficiency during the spring thaw.

Generally, fresh waters of the North Slope are dilute calcium bicarbonate waters (Kalff 1968). Lakes and ponds near the coast have higher salt levels than those farther inland, presumably from salt spray (Howard and Prescott 1971, Childers et al. 1977). Many lakes have high chloride values (Kalff 1968, Holmquist 1975). Dissolved solids concentrations fluctuate seasonally. Low solids concentrations in tundra ponds and lakes occur during breakup (Sater 1969). Salts in ponds and small lakes are somewhat concentrated during summer due to evaporation (Hobbie 1973). Douglas and Bilgin (1975) measured an increase in the concentrations of calcium and potassium during summer in small lakes. Solids are more concentrated during winter, largely because of solids rejection during freezing (Sater 1969, Hobbie 1973). Boyd (1959) reports a seasonal peak in chloride, alkalinity and hardness during April and May. Water in shallow lakes that do not freeze to the bottom is unusable for most purposes by late winter because of the concentration of dissolved solids. Conductivity (a measure of dissolved solids) ranged from 126 - 273 micromhos/cm at 25°C (77°F) in two tundra ponds and six lakes in a study by Kalff (1968).

Suspended solids and turbidity values are high in lakes and ponds during spring breakup, and may remain relatively high during summer. Wind mixing keeps particulates suspended in ponds and shallow lakes (Sater 1969, Hobbie 1973).

Some lakes may be high in iron and organics released from vegetative decay (Greenwood and Murphy 1972), and lake water is commonly characterized by objectionable color and odor and the presence of iron (Balding 1976). Tundra water color is a result of the leaching of organic material, which is enhanced by poor drainage on the coastal plain. Also, the bottom sediments of tundra ponds are highly organic (Hobbie 1971). Livingstone (1963) measured color as high as 250 platinum-cobalt (Pt) units in small tundra ponds, and Kalff (1968) measured a color range of 20 - 30 Pt units in six lakes, but noted that lakes usually contain 10 - 30 Pt units of color. Boyd (1959) noted that the concentration of organic material increases as the ice thickens during the fall.

Wetlands in the PBDA display characteristics similar to shallow lakes and ponds. They are completely frozen until late May or early June. Shallow wetlands melt from the top to the bottom within a few days (Bergman et al. 1977). Spring breakup completely inundates and flushes the wetlands, and as summer advances the water elevation drops. Coastal plain wetlands remain isothermal in summer because of the constant wind mixing (Bergman et al. 1977). The magnitude of diurnal temperature fluctuations in wetlands is inversely related to basin volume, the largest and deepest wetland exhibits the smallest diurnal temperature change.

Wetland water chemistry displays a seasonal variation similar to shallow lakes and ponds. Water quality is generally good until a complete ice cover forms, isolating the water from atmospheric influences. The conductivity increases during summer (Bergman et al. 1977). Low values are evident during spring breakup when wetlands become diluted with relatively pure meltwater. Conductivity increases as water levels decline throughout the summer. Summer variation in some water quality characteristics has been measured in wetlands by Bergman et al. (1977). Their data appear below showing both mean and (range).

	1 June - 14 June		15 June - 14 July		15 July - 8 Aug	
pH	6.9	(6.2-7.9)	7.6	(6.2-8.5)	8.0	(6.7-8.7)
Total hardness, ppm $CaCO_3$	66	(17-139)	95	(51-154)	207	(103-974)
Alkalinity, ppm $CaCO_3$	44	(17-103)	68	(34-103)	109	(68-137)
Dissolved oxygen, ppm	14.1	(13-15)	13.9	(10-15)	13.8	(13-15)
Free CO_2, ppm	7.8	(5-15)	6.6	(5-15)	8.5	(5-20)

Conductivity and pH values in wetlands are correlated to the distance inland from the Beaufort Sea. Bergman et al. (1977) note that waters of the loastal lowlands have a pH of 8.9, the same as coastal Beaufort Sea water. They also note that basins connected to the sea or periodically flooded by seawater contain brackish or subsaline water. Wetlands of the coastal uplands (lying within a few meters of the coast, but situated above sea level) were slightly brackish and had lower pH values (8.5 - 8.9). Fresh to slightly brackish water with a pH range of 6.2 - 9.0 occurred in wetlands approximately 1.5 km (0.9 mi) inland from the coast.

REFERENCES

Balding, G.O., 1976. Water availability, quality and use in Alaska. U. S. Geological Survey Open-File Report 76-513, 236 pp.

Barsdate, R. J., 1971. Nutrient metabolism and water chemistry in lakes and ponds on the arctic coastal plain. U. S. Tundra Biome, Vol I, Progress Report and Proposal Abstracts-1971.

Bergman, R. D., R. L. Howard, K. F. Abraham, and M. W. Weller, 1977. Water birds and their wetland resources in relation to oil development at Storkersen Point, Alaska. U. S. Department of the Interior, Fish and Wildlife Service, Resource Publication 129, Washington, D. C., 38 pp.

BLM, 1979. Final environmental impact statement, proposed federal/state oil and gas lease sale Beaufort Sea. U. S. Department of the Interior, Bureau of Land Management.

Boyd, W. L., 1959. Limnology of selected arctic lakes in relation to water supply problems. Ecology, 40(1):49-54.

Brewer, M. C., 1958. The thermal regime of an arctic lake. American Geophysical Union Transactions, 39(2):278-284.

Childers, J. M., C. E. Sloan, J. P. Meckel, and John W. Nauman, 1977. Hydrologic reconnaissance of the eastern North Slope, Alaska, 1975. U. S. Geological Survey, Open-file Report 77-492, 65 pp.

Douglas, L. A., and A. Bilgin, 1975. Nutrient regimes of soils, landscapes, lakes, and streams, Prudhoe Bay, Alaska. In: Jerry Brown (ed), Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report Number 2, pp. 61-70.

FERC, 1979. Prudhoe Bay project draft environmental impact statement, construction and operation of a sales gas conditioning facility at Prudhoe Bay, Alaska. Federal Energy Regulatory Commission, Washington, D.C., 259 pp.

Feulner, A. J., J. M. Childers, and V. W. Norman, 1971. Water resources of Alaska. U. S. Geological Survey, Open-file Report 1971, 60 pp.

Gatto, L.W., 1980. Letter dated April 25, 1980 from CRREL to Corps of Engineers regarding the Prudhoe Bay Waterflood Project.

Greenwood, J. K., and R. S. Murphy, 1972. Factors affecting water management on the North Slope of Alaska. Institute of Water Resources, IWR-19, University of Alaska, Fairbanks, 42 pp.

Hobbie, J. E., 1973. Arctic limnology: a review. In: Alaskan arctic tundra. The Arctic Institute of North America, Technical Paper Number 25, pp. 127-168.

Holmquist, C., 1975. Lakes of northern Alaska and northwestern Canada and their invertebrate fauna. Zool. Jb. Syst. Bd, 102, S. 333-484.

Howard, H. H., and G. W. Prescott, 1971. Primary production in Alaskan tundra lakes. American Midland Naturalist, Vol. 85, No. 1, pp. 108-123.

Kalff, J., 1968. Some physical and chemical characteristics of arctic freshwaters in Alaska and northwestern Canada. Journal Fisheries Research Board Canada 25(12):2575-2587.

Kane, D. L., and R. F. Carlson, 1973. Hydrology of the central arctic river basins of Alaska. Institute of Water Resources, IWR-41, University of Alaska, Fairbanks, 51 pp.

Livingstone, D. A., 1963. Alaska, Yukon, Northwest Territories, and Greenland. In: D. G. Frey (ed), Limnology in North America, University of Wisconsin Press, pp. 559-574.

Nauman, J. W., and D. R. Kernodle, 1973. Field water-quality information along the proposed trans-Alaska pipeline corridor September 1970 through September 1972. U. S. Geological Survey, Basic-Data Report, 22 pp.

Oceanographic Institute of Washington, 1979. Alaska North Slope wetlands study, part one biological considerations, part two soil and hydrology. Prepared for U. S. Army Corps of Engineers Alaska District.

Peterson, L.A., in press. North Slope water problems.

Sater, J. E., 1969. The arctic basin. The Arctic Institute of North America, Washington, D. C., 337 pp.

Schallock, E. W., 1975. Implications of resource development on the North Slope of Alaska with regard to water quality on the Sagavanirktok River. Symposium-Freshwater Quality Criteria Research, U. S. Environmental Protection Agency, Corvallis, Oregon, August 19, 1975, 17 pp.

__________, and F. B. Lotspeich, 1974. Low winter dissolved oxygen in some Alaskan rivers. U. S. Environmental Protection Agency, 66013-74-008.

Schell, D., 1975. Seasonal variation in the nutrient chemistry and conservative constituents in coastal Alaskan Beaufort Sea waters. In: V. Alexander et al., Environmental studies of an arctic estuarine system: final report. U. S. Environmental Protection Agency, pp. 233-296.

Sellmann, P. V., J. Brown, R. I. Lewellen, H. McKim, and C. Merry, 1975. The classification and geomorphic implications of thaw lakes on the arctic coastal plain, Alaska. Research Report 344, Cold Regions Research and Engineering Laboratory, Hanover, NH, 21 p.

Sherman, R. G., 1973. A groundwater supply for an oil camp near Prudhoe Bay, arctic Alaska. Proceedings--International Conference on Permafrost, 2nd, Yakutsk, Siberia, 1973, pp. 469-472.

USGS, 1971. Water resources data for Alaska, 1970, Part 1. Surface water records, Part 1. Water quality records, U.S. Geological Survey, 263 pp.

__________ 1972. Water resources data for Alaska, 1971, Part 1. Surface water records, Part 2. Water quality records, U. S. Geological Survey, 318 pp.

__________ 1973. Water resources data for Alaska, 1972, Part 1. Surface water records, Part 2. Water quality records, U. S. Geological Survey, 387 pp.

__________ 1974. Water resources data for Alaska, 1973, Part 1. Surface water records, Part 2. Water quality records, U. S. Geological Survey, 298 pp.

__________ 1975. Water resources data for Alaska, 1974, Part 1. Surface water records, Part 2. Water quality records, U. S. Geological Survey, 322 pp.

__________ 1976. Water resources data for Alaska, water year 1975, U. S. Geological Survey, Water-Data Report AK-75-1, 410 pp.

__________ 1977. Water resources data for Alaska, water year 1976, U. S. Geological Survey, Water-Data report AK-76-1, 401 pp

__________ 1978. Water resources data for Alaska, water year 1977. U. S. Geological Survey, Water-Data Report AK-77-1, 439 pp.

Walker, H. J., 1973. Morphology of the North Slope. In: Alaskan arctic tundra. The Arctic Institute of North America, Technical Paper Number 25, pp. 49-92.

Ward, D. L., and L. A. Peterson, 1976. A summary of water use problems related to North Slope petroleum development. Proceeding--27th Alaska Science Conference, Resource Development--Processes and Problems, Vol II, pp. 53-57.

APPENDIX G

ACOUSTICS

1.0 NOMENCLATURE

The range of sound pressures that can be heard by humans is very large. This range varies from two ten-thousand-millionths (2×10^{-10}) of an atmosphere for sounds barely audible to humans to two thousandths (2×10^{-3}) of an atmosphere for sounds which are so loud as to be painful. The decibel notation is used to present sound levels over this wide physical range. Essentially, the decibel unit compresses this range to a workable range using logarithms. It is defined as:

$$\text{Sound pressure level (dB)} = 20 \log_{10} \frac{(P)}{P_o}$$

where P_o is a reference sound pressure required for a minimum sensation of hearing.

Zero dB is assigned to this minimum level and 140 dB to sound which is painful. Thus a range of more than one million is expressed on a scale of 0 - 140.

The human ear does not perceive sounds at low frequencies in the same manner as those at higher frequencies. Sounds of equal intensity at low frequency do not seem as loud as those at higher frequencies. The A-weighted network is provided in sound analysis systems to simulate the human ear. A-weighted sound levels are expressed in units of dB. These levels in dB are used by the engineer to evaluate hearing damage risk (OSHA) or community annoyance impact and are also used in federal, state, and local noise guidelines and ordinances. The term "sound level" as used in this report, is understood to represent the A-weighted sound level unless otherwise noted.

Sound is not constant in time. Statistical analysis is used to describe the temporal distribution of sound and to compute single number descriptors for the time-varying sound. This report contains the statistical sound levels:

L_{eq} - This is the equivalent sound level which provides an equal amount of acoustical energy as the time-varying sound.

L_x - This is the level exceeded "x" percent of the time during the sample period where $L_{"x"}$ is:

L_1 - the maximum sound level;

L_{10} - the "intrusive" sound level;

L_{50} - the "median" sound level;

L_{90} - the "residual" sound level;

L_{99} - the minimum sound level;

L_d - Day Sound Level, L_{eq}, for the daytime period (0700-2200) only.

L_n - Night Sound Level, L_{eq}, for the nighttime period (2200-0700) only.

L_{dn} - Day-Night Sound Level, defined as:

$$L_{dn} = 10 \log_{10} ([15 \times 10^{L_d/10} + 9 \times 10^{(L_n+10)/10}]/24)$$

Note: A 10 dB correction factor is added to the nighttime equivalent sound level when computing L_{dn}.

2.0 CONSTRUCTION EQUIPMENT SOUND LEVELS

Tables G-1 through G-7 show equivalent sound levels for construction equipment during gravel placement and grading, pipeline construction, and module placement.

TABLE G-1

CONSTRUCTION EQUIPMENT, USAGE FACTORS AND
SOUND LEVELS FOR SHEET PILE AND CAUSEWAY EXTENSION AND EXPANSION ACTIVITIES

Equipment[a]	Sound Level @15 m (50 ft) - dB[f]	Number[a] of Units	Usage[e] Factor	Reference
Pile Driver	101	1	.04	(d)
Gravel Hauler	88	2	.04	(b)
D-6 Angle Dozer	88	1	.31	(b)
14-G Motor Grader	85	1	.05	(d)
Fuel Truck	88	1	02	(d)
Lube Truck	80	1	.02	(c)
Mechanics Truck	80	1	.02	(c)
3/4 ton Carry All	80	2	.02	(c)
Front End Loader	85	1	.10	(b)

Leg (total) @15 m = 89.1 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: U.S. Army 1977
(c) Reference: Dames & Moore files
(d) Reference: EPA 1977
(e) Usage factors represent the time equipment is operating at its noisiest mode
(f) Sound levels are based on equipment containing mufflers or other typical noise mitigation measures

TABLE G-2

CONSTRUCTION EQUIPMENT, USAGE FACTORS AND SOUND LEVELS
FOR CAUSEWAY PIPELINE AND STP PLATFORM FOUNDATION CONSTRUCTION

Equipment[a]	Sound Level @15 m (50 ft) - dB[g]	Number[a] of Units	Usage[f] Factor	Reference
Clam Shell Dredge	82	1	.07	(d)
14 G Motor Grader	85	1	.05	(d)
50 Ton Crane	83	1	.07	(b)
6 Ton Truck Tractor	88	2	.04	(b)
3 Ton Flat Bed Truck	88	4	.04	(b)
Fuel Truck	88	1	.02	(d)
Lube Truck	80	1	.02	(c)
3/4 Ton Carry-All	80	4	.02	(c)
3/4 Ton "A" Frame Truck	88	1	.04	(c)
Mechanics Truck	80	1	.02	(c)
3/4 Ton Pick-ups	80	4	.02	(c)
4x4 Blazer	80	1	.02	(c)
300 Amp Welding Machine	75	7	.40	(c)
185 CFM Air Compressor	71	1	.05	(e)

Leg (total) @15 m = 85.3 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: U.S. Army 1977
(c) Reference: Dames & Moore files
(d) Reference: EPA 1977
(e) Reference: EPA 1975
(f) Usage factors represent the time equipment is operating at its noisiest mode
(g) Sound levels are based on equipment containing mufflers or other typical noise mitigation measures

TABLE G-3

CONSTRUCTION EQUIPMENT, USAGE FACTORS AND SOUND LEVELS FOR MODULE GRAVEL PAD AND SUPPORT PILE INSTALLATIONS

Equipment[a]	Sound Level @15 m (50 ft) - dB[f]	Number[a] of Units	Usage[e] Factor	Reference
Texoma Drill	90	1	.50	(c)
Vibrator	76	1	.20	(b)
D-6 Angle Dozer	88	1	.31	(b)
14 G Motor Grader	85	1	.05	(d)
20 Ton Crane	83	1	.07	(b)
60 Ton Low Bed Trucks	88	1	.04	(b)
Fuel Truck	88	1	.02	(d)
Lube Truck	80	1	.02	(c)
Mechanics Truck	80	1	.02	(c)
Welding Truck	83	1	.40	(c)
3/4 Ton Carry-Alls	80	2	.02	(c)
3/4 Ton Pick-ups	80	2	.02	(c)

Leg (total) @15 m = 89.4 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: U.S. Army 1977
(c) Reference: Dames & Moore files
(d) Reference: EPA 1977
(e) Usage factors represent the time equipment is operating at its noisiest mode
(f) Sound levels are based on equipment containing mufflers or other typical noise mitigation measures

TABLE G-4

CONSTRUCTION EQUIPMENT, USAGE FACTORS AND
SOUND LEVELS FOR MAIN FIELD PIPELINE CONSTRUCTION

Equipment[a]	Sound Level @15 m (50 ft) - dB[f]	Number[a] of Units	Usage[e] Factor	Reference
D-7 Dozer	89	1	.10	(b)
D-6 Dozer	88	1	.10	(b)
14 G Motor Grader	85	1	.05	(d)
235 Hydraulic Excavator	85	1	.10	(d)
50 Ton Trucks	88	3	.04	(b)
20 Ton Crane	83	1	.07	(b)
6 Ton Truck Tractors	88	8	.04	(b)
3 Ton Flat Bed Trucks	88	16	.02	(b)
Fuel Truck	88	1	.02	(d)
Lube Truck	80	1	.02	(c)
3 Ton "A" Frame Truck	88	3	.04	(c)
Mechanics Truck	80	1	.02	(c)

Leq (total) @15 m = 88.9 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: U.S. Army 1977
(c) Reference: Dames & Moore files
(d) Reference: EPA 1977
(e) Usage factors represent the time equipment is operating at its noisiest mode
(f) Sound levels are based on equipment containing mufflers or other typical noise mitigation measures

TABLE G-5

CONSTRUCTION EQUIPMENT, USAGE FACTORS AND SOUND LEVELS FOR TREATING PLANT PLACEMENT

Equipment[a]	Sound Level @15 m (50 ft) - dB[f]	Number[a] of Units	Usage[c] Factor	Reference
10,000 hp Tug	90	3	.50	(b)
Derrick Barge	76	1	1.00	(b)

Leq (total) @15 m = 91.9 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: Dames & Moore files
(c) Usage factors represent the time equipment is operating at its noisiest mode.

TABLE G-6

CONSTRUCTION EQUIPMENT, USAGE FACTORS
AND SOUND LEVELS FOR BERM RAISING OPERATIONS

Equipment[a]	Sound Level @15 m (50 ft) - dB[g]	Number[a] of Units	Usage[f] Factor	Reference
Gravel Haulers	88	10	.02	(b)
D-6 Angle Dozer	88	1	.10	(b)
14 G Motor Grader	85	1	.05	(d)
Fuel Truck	88	1	.02	(d)
Lube Truck	80	1	.02	(c)
Mechanics Truck	80	1	.02	(c)
3/4 Ton Carry-All	80	34	.01	(c)
955 Front-End Loaders	85	1	.10	(b)
Welding Trucks	83	4	.20	(c)
3/4 Ton Pick-ups	80	24	.01	(c)
4x4 Blazer	80	8	.01	(c)
60 Ton Low-Bed Trucks	88	2	.02	(b)
300 Amp Welding Machines	75	54	.02	(c)
185 CFM Air Compressor	71	1	.40	(d)
1200 77M Air Compressor	77	4	.05	(e)

Leg (total) @15 m = 90.3 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: U.S. Army 1977
(c) Reference: Dames & Moore files
(d) Reference: EPA 1977
(e) Reference: EPA 1975
(f) Usage factors represent the time equipment is operating at its noisiest mode
(g) Sound levels are based on equipment containing mufflers or other typical noise mitigation measures

TABLE G-7

CONSTRUCTION EQUIPMENT, USAGE FACTORS
AND SOUND LEVELS FOR MAIN FIELD MODULE ERECTION

Equipment[a]	Sound Level @15 m (50 ft) - dB[g]	Number[a] of Units	Usage[f] Factor	Reference
6x6 Trucks	80	1	.02	(c)
3 Ton "A" Frame Trucks	88	3	.04	(c)
3/4 Ton Pick-ups	80	2	.02	(c)
3/4 Ton Carry-All	80	2	.02	(c)
3 Ton Flat Bed Trucks	88	3	.04	(b)
Fuel Truck	88	1	.02	(d)
Lube Truck	80	1	.02	(c)
Mechanics Truck	80	1	.02	(c)
300 Amp Welding Machines	75	7	.40	(c)
185 CFM Air Compressor	71	1	.05	(e)

Leg (total) @15 m = 84.3 dB

Notes:

(a) Reference: COE, January 17, 1980
(b) Reference: U.S. Army 1977
(c) Reference: Dames & Moore files
(d) Reference: EPA 1977
(e) Reference: EPA 1975
(f) Usage factors represent the time equipment is operating at its noisiest mode
(g) Sound levels are based on equipment containing mufflers or other typical noise mitigation measures

REFERENCES

U.S. Army Corps of Engineers, 1977. U.S. Army Corps of Engineers construction site noise control cost - benefit estimating (Draft). Construction Engineering Research Laboratory, Champaign, Illinois.

__________, 1980. Responses to Dames & Moore's letter to Waterflood Task Force. January 17, 1980.

U.S. Environmental Protection Agency, 1975. Noise emission standards for construction equipment: background document for portable air compressors. EPA 550/9-76-004, Office of Noise Abatement and Control; Washington, D.C.

__________, 1977. Characterization of construction site activity, Phase I Interim Report. Office of Noise Abatement and Control, Washington, D.C.

APPENDIX H

ENTRAPMENT, IMPINGEMENT AND ENTRAINMENT IMPACTS

1.0 INTRODUCTION

Impacts of operating the water withdrawal intakes would be those primarily concerned with the entrapment and subsequent impingement or entrainment of marine life.

In this analysis, entrapment refers to the entry of marine life into the intake structure and emphasizes the prevention of the escape of organisms (USEPA 1977). Impingement is the blocking of larger organisms by a barrier, generally the screening system (USEPA 1977). Impingement is often lethal to fish due to stress (including exhaustion, starvation, and reimpingement), descaling (caused by screen contact or screen wash), or asphyxiation. Asphyxiation can occur due to removal from water (USEPA 1976) during rotation of traveling screens or when fish are forced against the screen for prolonged periods. Entrainment of organisms refers to those smaller organisms that are drawn through intake screening devices into pumps, strainers and water treatment sections of the plant. It is assumed for all alternative intake designs that entrainment of organisms through the primary screening system would result in 100 percent mortality.

For all design alternatives, the intake would be designed to withdraw 4.25 m^3/s (67,430 gal/min) of water. Reliability of the intake is a concern in the adverse and rather extreme operating environment of the Prudhoe Bay area.

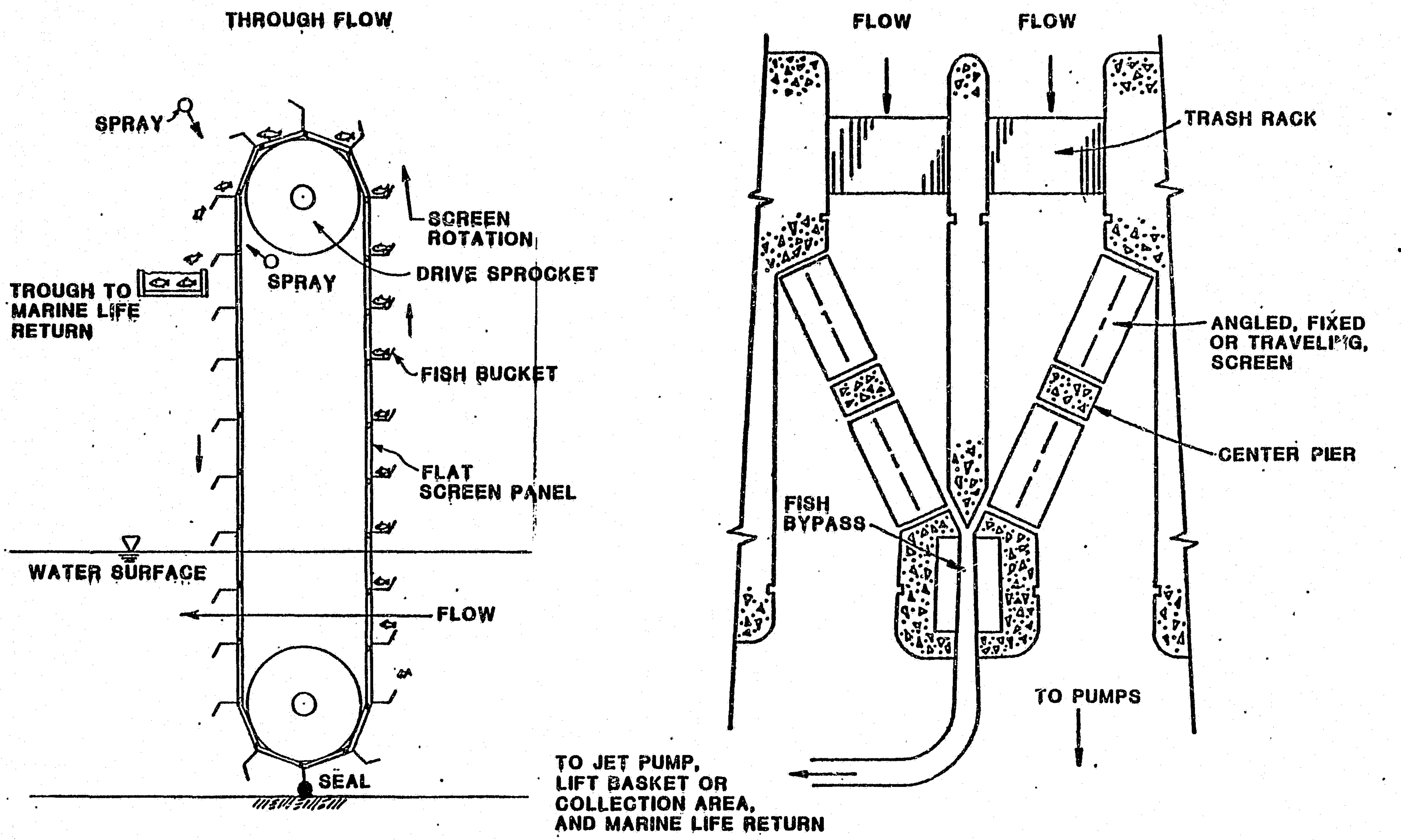
2.0 DESCRIPTION OF PROPOSED DESIGN

The proposed intake structure consists of nine bays, each of which would withdraw water at a rate of 0.47 m^3/s (7490 gal/min) through an underwater opening 2.9 m (9.5 ft) wide by 1.52 m (5 ft) deep. A set of "trash bars" designed to block entrance of large submerged objects and ice would be situated in the underwater opening. These bars should not affect fish passage but might be heated to prevent icing. The bottom of the opening would be approximately 0.3 m (1 ft) above the seabed. Water velocity through this opening would be less than 15 cm/s (0.5 ft/s).

The entrance to each of the intake screen channels would be smaller than the channel itself. Therefore, the velocity at the "mouth" of the channel would be higher than that within the channel. The velocity within each channel would be approximately 5 cm/s (0.16 ft/s). Each channel would be 2.9 m (9.5 ft) wide by 3.7 m (12 ft) deep by 15.2 m (50 ft) long. Normal water depth would be 3.7 m (12 ft). Warm water (21°C, 70°F) would be mixed into each channel through diffusers at a rate of about 0.06 m^3/s (2 ft^3/s) during much of the year to control ice buildup.

One set of vertical traveling screens would be located at the interior end of each channel (Figure H-1, Alternative A). The screen would be 2.9 m (9.5 ft) wide and extend from the channel bottom to a vertical height of 12.2 m (40 ft). The screening surface would be composed of panels of 9.5-mm (3/8-in) by 25.4-mm (1-in) mesh made of T316 grade stainless steel. Velocity through the screens would be 7 cm/s (0.24 ft/s). Water withdrawal pumps would be located sufficiently far back from the screens to assure uniform velocities and flow through each screen set.

The screen panels would be fitted with fish buckets and the screens would operate continuously. Depending upon the debris loading conditions experienced, one of two available screen speeds would be used: either 0.76 m/min (2.5 ft/min) or 3.05 m/min (10 ft/min). A dual screen wash system would be utilized. A fish removal wash, consisting of a 20 lb/in^2 gauge water jet, would wash marine life into a marine



ALTERNATIVE A

PROPOSED VERTICAL TRAVELING SCREENS (TYPICAL)

ALTERNATIVE B

FISH BYPASS SYSTEM WITH ANGLED SCREENS (TYPICAL)

Figure H-1

ALTERNATIVE INTAKE DESIGN CONCEPTS

life return line. A 70 lb/in^2 wash would remove debris from the screens into a separate sluice for return to the water body.

Specific numbers, dimensions, etc. given in this section reflect the applicant's preliminary design and may be altered somewhat during final design stages.

3.0 BIOLOGICAL IMPLICATIONS

ENTRAPMENT

The USEPA (1976) has recognized the potential for adverse impacts associated with approach channel intakes similar to that proposed, particularly when escape passages are not provided. They note that setting screens back in a channel increases the potential for entrapment as does the use of a wall ("skimmer wall") of the type envisioned to allow water withdrawal from under the ice near the bottom. USEPA (1976) states that these walls create non-uniform velocities and entrapping dead spaces. They further state, "fish will not usually swim back under the wall to safety." USEPA (1976) recommends a fish guidance and bypass system as an alternative.

The overall potential for fish entrapment by the proposed design is not clearly known. Behavioral entrapment would be more significant than velocity entrapment. Entrapment would vary seasonally and among species. Organisms would be exposed to highest velocities at the entrances to the intake channels. However, the major fish species present at the proposed intake location are not expected to be vulnerable to velocity-induced entrapment as adults or large juveniles.

The velocity at each channel entrance would be no greater than 15 cm/s (0.5 ft/s). This velocity has been cited as a swimming speed attainable by many species of small fish and the mean cruising speed of all young salmon at low temperatures (USEPA 1976). In addition, tests on several species of cod and the longhorn sculpin (same genus as fourhorn sculpin) determined that they had sustained swimming capacities substantially greater than 15 cm/s (Beamish 1978). Temperature has also been shown to have little or no effect on burst speed (the highest speed fish can maintain for 20 s or less) (Beamish 1978). Almost all fish tested had burst speeds of at least 15 cm/s.

In particular, anadromous fish would be less vulnerable to intake entrapment than marine species. Anadromous fish are present in the Beaufort Sea primarily during the open-water season, usually as 3-year old or larger fish. Therefore, when it is possible for these fish to encounter the intake, their sustained swimming capacity would be well in excess of 15 cm/s (0.5 ft/s).

Smaller fish (particularly larvae), plankton and meroplanktonic macroinvertebrates would probably pass more or less passively into the intake channels. These organisms would probably enter in roughly the same concentrations as their density in the water column. Motile benthic macroinvertebrates (e.g. Saduria) would move freely on the hard substrate provided by the intake structure and could move into and out of the entrance to the intake channel along that substrate.

Some larger fish may enter the intake channels "voluntarily." Fish have been found to orient to intake structures (Lifton and Storr 1977), and have been observed swimming around many kinds of submerged structures and into and out of water withdrawal intakes. Tarbox and Thorne (1979) indicate fish in the project area are attracted to structures. Fish entering the intake may be drawn to the traveling screens by the low velocity present, although some may swim along the channels to that point or avoid it entirely. The opening to the bay from the intake channels is small compared to the size of the channel; therefore, some fish may become "behaviorally entrapped" within the intake.

Since the opening to the intake channel would be near the bottom, pelagic species would be less likely than demersal fish to enter and become entrapped. However, if pelagic species should enter the intake, they would be less likely to find the low entrance and escape.

Schooling species, such as arctic cod, may have a greater potential for entrapment than non-schooling fish, as schooling fish would likely enter the intake in greater numbers at a given time.

IMPINGEMENT

Once fish enter the intake channel they would either leave through the opening or become entrapped. Entrapped fish would remain within the intake channel until they tired or otherwise became impinged upon the traveling screens. The traveling screens would provide the only other exit from each of the intake channels. The velocity of water flowing though the traveling screens would be low (7 cm/s, 0.24 ft/s). Smaller fish that generally have lower swimming capacities and physiologically impaired fish are more likely to become impinged.

A substantial number of the arctic cod found near the proposed intake site were relatively small in size (<70 mm in length) (Moulton et al. 1980, Tarbox and Moulton 1980, Tarbox and Spight 1979). This would tend to make them more vulnerable to impingement if they were large enough to be retained upon the screens. Although tests of retention on mesh screens indicated that the body depth of a fish was the factor most responsible for determining if a fish was retained on a screen (Tomljanovich et al. 1978), existing fish size distribution data from the Prudhoe Bay area are based on length. Studies by Dames & Moore (1979) indicated that fish more than several centimeters long could pass through a 9.5-mm (3/8-in) screen. Kerr (1953) found that 9.5-mm (3/8-in) woven square mesh screening could retain chinook salmon or striped bass as small as 51 mm (2 in) long. A review by Sonnichsen et al. (1973) indicated that fish of lengths between about 58 - 84 mm (2.3 - 3.3 in) are the smallest fish that would be retained by a 9.5-mm (3/8-in) screen, depending upon the body length to depth ratio of the fish.

It is therefore probable that fish smaller than 50 - 60 mm (2 - 2.3 in) in length reaching the screens would be entrained. Fish over 100 mm (3.9 in) are usually retained on the screens. Fish between 60 - 100 mm in length (2.3 - 3.9 in) may fall into either category, depending upon general fish body shape and, in particular, body depth.

FISH RETURN SYSTEM

Those fish that become impinged would be carried upward by the vertical movement of the screens. Fish buckets or extended lips mounted at the lower part of each screen panel would retain the fish on the screen system and prevent them from falling off. Fish that fell off would be reimpinged and thus subject to additional stress and mortality. The screen system would be in constant motion; therefore, fish would not be retained against the screens for long periods and the potential for asphyxiation would decrease. Since the water depth would be 3.7 m (12 ft) and screen travel would be between 0.76 - 3.05 m/min (2.5 - 10 ft/min), impingement time would vary between 1.2 - 4.8 min. Once the screen panels have been lifted clear of the water surface, a low-pressure wash would gently move the fish into the fish bucket area of the panel. This would reduce the potential for descaling and asphyxiation.

It is important to limit impingement time. Tomljanovich et al. (1978) found a strong inverse relationship between impingement duration and survival, particularly for impingement times in excess of 4 min. Once the fish have been moved into the fish bucket portion of the screen panel, they would be retained in a sufficient depth of water to prevent asphyxiation. These fish would be gently washed into a fish return sluice for return to the water body.

For later life stages, survival of an impingement and return system has been shown to be relatively high. At the VEPCO installation at the Suney Station, survivals average 93.3 percent (White and Brehmer 1976). Murray and Jinnette (1978) have found survivals of 86 percent of older fish and invertebrates in a center-flow screen system. Therefore, it may be conservatively expected that 80 percent or more of those older fish and larger invertebrates impinged upon the screens would survive and be returned alive to the water body.

The marine life return system would utilize a water velocity of 30 cm/s (1 ft/s) maintained by an impeller-type fish pump. This velocity should be sufficient to transport juvenile and smaller fish. Larger fish, however, might be able to maintain themselves against the flow for a period of time, increasing possibilities of stress and resultant mortality. Passage through the return system (152.4 m, 500 ft long) would require 500 - 610 s for passively moving fish. This is due to the time required for passage from the screen wash through the marine life return system and out to sea, there being a distance of 33.5 m (110 ft) between the screen set closest to the return outfall and the one most distant. An additional 10 percent mortality of fish entering the intake has been assumed to occur in the marine life return system.

ENTRAINMENT

The entrainment of smaller organisms through the screens would be in proportion to their density in the water body. In general, data are not sufficent to estimate year-round losses of phytoplankton and zooplankton (other than ichthyoplankton). It should be pointed out, however, that only a small percentage of the water present in the intake vicinity would be withdrawn. This would insure a relatively small entrainment loss.

Since some data on ichthyoplankton abundance are available (Tarbox et al. 1979, Tarbox and Moulton 1980, Tarbox and Spight 1979), a quantitative estimate of entrainment losses was made based on the volume of water withdrawn from the Beaufort Sea and the density of fish eggs and larvae found in the vicinity of the proposed intake. The actual entrainment of the ichthyoplankton by the intake would vary depending upon weather conditions, and consequent hydrographic conditions. The presence of various offshore water masses of differing salinities greatly affects the numbers and taxa of organisms present (Tarbox and Moulton 1980), and therefore estimates prepared in this manner should be utilized as a guide to the expected level of entrainment and not as definitive answers.

Calculation of Potential Entrainment

The results of an estimate of potential entrainment of fish eggs and larvae are shown in Table H-1. These estimates are based upon a flow of 4.25 m^3/s (67,430 gal/min) through the intake. This volume represents a daily intake of about 0.09 percent of the volume of water inside the 6-m (20-ft) isobath between the mouths of the Sagavanirktok and Kuparuk Rivers (based on surface area calculations of Tarbox and Spight 1979). It was assumed that all larvae present in water drawn through the intake would be entrained. Densities of eggs and larvae present in the proposed intake area were based upon data presented by Tarbox and Moulton (1980) and Tarbox et al. (1979). Tarbox et al. (1979) collected pump samples periodically from the site of the proposed intake from February 13 through May 3, 1979. Eggs were the only early life history stage of fish collected. Tarbox and Moulton (1980) collected ichthyoplankton and zooplankton with a tow net at six stations near the proposed intake periodically from July 17 through September 1, 1979. Fish larvae only were analyzed. Of the stations sampled, Stations 1 and 3 were located nearest the site of the proposed intake; therefore, the averages of near-bottom densities at these two stations were used in calculating potential entrainment.

To calculate the potential number of eggs and larvae entrained, the time covered by the two programs was broken into a number of periods. These periods corresponded to sampling dates and time spans between sampling dates. In both studies, samples were not taken on a daily basis; therefore, ichthyoplankton density in a period between sampling dates was estimated as the average of densities on the end-point dates for that period. Near-bottom densities in each period were multiplied

TABLE H-1

POTENTIAL 6.5-MONTH ENTRAINMENT OF FISH EGGS AND LARVAE BY THE PROPOSED INTAKE BASED UPON DATA COLLECTED FROM FEBRUARY 13 THROUGH SEPTEMBER 1, 1979

Taxon	Estimated Number Entrained
Eggs	5,856
Larvae:	
Arctic Cod[a]	239,648
Fourhorn Sculpin	163,220
Snailfish[b]	397,179
Unidentified Larvae	6,076
Total Larvae	806,122

[a] Includes larvae definitely and tentatively identified as arctic cod

[b] Includes larvae definitely and tentatively identified as snailfish

by the number of days in a period times the daily intake volume of 409,536 m^3 (14,462,625 ft^3); this yielded the numbers of eggs and larvae entrained during each period. These quantities were summed over the time span covered by the sampling programs to yield total potential entrainment from February 13 through September 1, 1979.

By these estimates, 239,648 arctic cod larvae would have been entrained by the proposed intake during the 6.5-month period for which these estimates were made. Using data for North Sea cod cited by Cushing (1973), 1 percent is a reasonable estimate of survival from larvae to age 2. Assuming 1 percent survival from larvae to reproducing adult, 2396 adults would potentially have been removed from the arctic cod population present in the Prudhoe Bay area. This represents less than 0.01 percent of the conservatively estimated 28 million arctic cod present in the Prudhoe Bay area in 1978 (Tarbox and Spight 1979). These data are based on only one-half year's sampling as an additional measure of conservatism for the reasonable worst case, and because of the known preference of arctic cod larvae and juveniles for near-bottom waters and for artificial structures, an order of magnitude safety factor has been added to increase the estimated loss rate to 0.1 percent of the standing stock in the area. Even at this rate, cropping by entrainment should not noticeably reduce the numbers of arctic cod present in the Prudhoe Bay area. Although calculations were not made, a similar loss rate due to entrainment can be assumed for other marine species, such as bartail snailfish and fourhorned sculpin, that have planktonic larvae.

4.0 SYSTEM ALTERNATIVES

PRIMARY SYSTEM DETAILS

For the proposed traveling screen system utilizing fish buckets and a conventional vertical traveling screen, two types of dual wash-screen systems are commercially available. One system has a front wash where marine life would be washed off the ascending or front side of the screen into the marine life return system. The other system carries the fish to the rear or descending side of the screen system, where they are washed into the marine life return system. Both systems are in commercial use and are useful in protecting marine life. There are some advantages unique to each system.

The number and location of wash spray-nozzles are not known. This will be determined in the detailed engineering design process after the actual wash type has been selected.

SCREENING SIZE

The size of fish that may be retained upon the screens and returned to the water body via the marine life return system will depend on the screening size. In order to protect as many fish as feasible it would be desireable to utilize screening with a smaller opening size. Screens with finer openings to retain smaller juveniles and adults as well as larger larvae have been investigated for use with traveling screens by Murray and Jinnette (1978), Tomljanovich et al. (1977), Sazaki et al. (1972), and Skinner (1974) and it has been shown that high survival of even delicate species is obtainable. However, in the project area, icing is expected to be greater for smaller screen sizes and reliability correspondingly reduced.

ALTERNATIVE TRAVELING SCREEN SYSTEM

An alternative traveling screen system that is used commercially in Europe and at one power plant in the United States is the center-flow type screen. This screen system is described by USEPA (1976). Each center-flow screen would be oriented parallel to the approaching water flow. Water would enter the screens through a central "keyhole" or entrance port and would exit through both the ascending and descending screen faces. The system consists of a series of semi-circular screen baskets that increase the filtering area of the screen and allow easily installed fish buckets. This system utilizes an overhead wash system that washes debris and organisms into the return sluice. The center wash makes it possible to retrieve organisms more gently than with many other systems. In operation, this system has been shown to allow high fish survivals (Murray and Jinnette 1978). Laboratory tests also have indicated that high survivals of juveniles and larvae may be expected (Tomljanovich et al. 1977, 1978).

Due to the geometry of these screens, the highest water velocities occur at the screen entrance port or "keyhole". Depending upon the geometry of the specific screen installation, the "keyhole" velocity may be 2 - 3 times greater than the intake channel velocity or the approach velocity to the screens. In some installations this would be a disadvantage; however, in the proposed application this would provide a means of removing entrapped fish from the intake channels and sending them to the marine life return system with less stress and subsequently lower mortality. This system would be considerably more efficient than the proposed screen design at removing fish. There are other mechanical, engineering and cost advantages to the use of this system as well.

MARINE LIFE RETURN SYSTEM

Use of a jet pump, rather than the proposed impeller to induce flow in the marine life return system would greatly reduce the chances of mechanical damage to fish. As discussed previously, the 30 cm/s (1 ft/s) water velocity in the marine life return life has the disadvantage of not being high enough to overcome the expected swimming capacities of several of the species that may be expected to be placed in the system. In addition, the time spent in the system, 8 - 10 min, may be excessive. Studies of usable fish return line velocities (Taft et al. 1976) showed that minimal mortality was suffered by fish in a return system utilizing velocities up to 2.4 m/s (8 ft/s). At these velocities, maximum residence time in the marine return line would be 76 s and the system would be capable of quickly removing all species encountered. Another advantage to higher velocities would be a reduction in the potential for biofouling in the return line due to high velocity scouring.

DETERRENCE

It may be possible to deter fish from actually entering the intake channel entrance by use of a behavioral device such as an air bubble curtain. These devices have been used at several locations to divert fish and have had mixed success. The efficency of these systems may vary according to temperature, light intensity and fish species. Research by Bibko et al. (1974) and Stone and Webster (1976a) showed that an air bubble curtain could be effective in deterring fish from entering an intake. Studies at other types of intakes under turbid water conditions (Lieberman and Muessiy 1978) have indicated no effect on impingement.

An air bubble curtain may, however, have an additional use of keeping certain types of ice out of intake channel entrances.

FISH DIVERSION

It is important to remove entrapped fish from the various intake channels and with as low stress and mortality to the fish as practical. The proposed method relies on impingement of fish on traveling screens with subsequent release into fish buckets. An alternative method is a fish guidance system, such as louvers or angled screens (Figure H-1, Alternative B). This is a much more desirable method of handling fish since fish are not impinged and therefore suffer considerably less stress.

In this system a set of louvers, a traveling screen, or a fixed screen is placed at an angle to the flow of water. Fish travel along the screens rather than become impinged and are led to a bypass area where they are returned to the water body with much reduced handling.

Louvers have been shown to be somewhat limited at guiding younger and smaller life stages (Skinner 1974), however, guidance efficiences up to 85 percent have been obtained (Taft and Mussalli 1978).

Studies of both fixed and traveling angled screens have indicated that these devices are highly effective in diverting fish at many life stages. Studies of bypass by fish 25 - 150 mm (1 - 6 in), were conducted for a number of large power plants (Taft et al. 1976). It was found that an angled 9.5-mm (3/8-in) screen oriented at 25° to the flow was able to bypass 100 percent of the fish tested. Of the fish bypassed, there was 96 percent one-week latent survival (Taft et al. 1976). Studies of other species, including Atlantic tomcod (Microgadus tomcod), 50 - 150 mm (2 - 6 in) in length, also achieved 100 percent bypass (Stone and Webster 1976b). Angled screens have also been utilized at a number of hydroelectric facilities. Gunsolus and Eicher (1970) reported on the screens at the Northfork Project. At the Mayfield Dam (Washington State), Thompson and Paulik (1967) reported that they obtained 100 percent guidance efficiencies by covering the louver system with woven mesh screening.

Guidance of younger life stages and smaller fish is obtainable also. Work by Prentice and Ossiander (1974) with angled horizontal screens showed that they could achieve 97 percent diversion of 70 - 170-mm (3 - 7-in) salmonoid fingerlings.

Work by Heuer and Tomljanovich (1979) showed that for very small larvae (mean length less than 15 mm, 0.6 in), substantial numbers could bypass fine opening screens, even when not set at an angle. Work reviewed by Pavlov and Pakhorukov (1973) in the USSR included studies on fine-mesh fish diversion screens employed in both laboratory and prototype studies. These showed that bypass of 10 - 40-mm (0.4 - 1.6-in) fish could be achieved with up to 97.6 percent efficiency, depending upon approach velocity and bypass flow.

It is therefore believed that an angled screen system (using either fixed or traveling screens), utilizing a bypass and marine life return system, would significantly increase the level of protection to marine life over the proposed system, provided that such a system is feasible for the Waterflood Project. It would also alleviate any significant fish entrapment problem.

REFERENCES

Beamish, F.W.H. 1978. Swimming capacity. In: Hoar, W.S. and D.J. Randall (Eds.), Fish physiology, Vol. VII locomotion. Academic Press, N.Y. pp. 576.

Bibko, P.N., Wirtman, L. and P.E. Keuser, 1974. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (Morone saxitalis) and the gizzard shad (Dorsoma epedianum). In: Jensen, L.D. (Ed.), Entrainment and intake screening. Proceedings of the second entrainment and intake screening workshop. EPRI publication No. 74-049-055 Electric Power Research Institute, Palo Alto, Calif.

Cushing, D.H., 1973. The possible density-dependence of larval mortality and adult mortality in fishes. In: Blaxter, J.H.S. (Ed.), The early life history of fish, Springer-Verlag, New York. 765 pp.

Dames & Moore, 1979. Seminole Plant Units No. 1 and No. 2 316b study and report. Report for Seminole Electric Cooperative, Inc. Tampa, Fla.

Gunsolus, R.T., and G.J. Eicher, 1970. Evaluation of fish passage facilities at the North Fork project on the Clackamas River in Oregon. The Fish Commission of Oregon and Portland General Electric Co.

Heuer, J.H., and D.A. Tomljanovich, 1979. A further study on the protection of fish larvae at water intakes using wedgewire screens. Tennessee Valley Authority Technical Note B33.

Kerr, J.E., 1953. Studies on fish preservation at the Confra Costa steam plant of the Pacific Gas and Electric Company. State of California, Department of Fish and Game, Fish Bulletin No. 92.

Lieberman, U.T., and P.M. Muessig, 1978. Evaluation of an air bubble to mitigate fish impingement at an electric generating plant. Estuaries 1(2):129-132.

Lifton, W.S., and J.E. Storr, 1977. The effect of environmental variables on fish impingement. In: Jenso, L.D., 1977. Fourth national workshop on entrainment and impingement. E.A. Communications. Melville, N.Y.

Moulton, L., K. Tabox, and R. Thorne, 1980. Beaufort Sea fishery investigations, summer 1979. In: Environmental studies of the Beaufort Sea. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

Murray, L.S. and T.S. Jinnette, 1978. Survival of dominant estuarine organisms impinged on fine-mesh traveling screens at the Barney M. Davis Power Station. In: Sharma, R.K. and J.B. Palmer, 1978. Larval exclusion systems for power plant cooling water intakes. Argonne National Laboratory. Argonne, Ill.

Pavlov, D.S., and A.M. Pakhorukov, 1973. Biological basis of protecting fish from entry into water intake structures. In: Pischchevaya promyshlennost, 208 p. (Translated by: S. Pearson, NMFS, NW Fisheries Center, 1974).

Prentice, E.F., and F.N. Ossiander, 1974. Fish diversion systems and biological investigation of horizontal traveling screen, Model VII. In: Jensen, L.D. Proceedings of the second workshop on entrainment and intake screening EPRI No. 74-049-005, Electric Power Research Institute. Palo Alto, Calif.

Sazaki M., Heubach, W. and J.E. Skinner, 1972. Some preliminary results on the swimming ability and impingement tolerance of young-of-the-year steelhead trout, king salmon, and striped bass. Final Report for Anadromous Fisheries Act Project. Calif. AFS-13.

Sonntchsen, Jr., J.C., B.W. Bentley, G.F. Bailey, and R.E. Nakatani, 1973. A review of thermal power plant intake structure design and related environmental considerations. Hanford Engineering Development Laboratory. Richland, WA.

Skinner, J.E., 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects. In: Jensen, L.D., (Ed.), Proceedings of the second workshop on entrainment and intake screening. John Hopkins University Baltimore, Maryland. February 5-9, 1973.

Stone and Webster Engineering Corporation, 1976a. Studies to alleviate potential fish entrapment at power plant cooling water intakes. Report prepared for Niagra Mohawk Power Corporation and Rochester Gas and Electric Corporation.

______, 1976b. Final report - Indian Point flume study. Prepared for Consolidated Edison Company of New York, Inc.

Taft, E.P. and Y.G. Mussalli, 1978. Angled screens and louvers for directing fish at power plants. Proceedings of the American Society of Civil Engineers Journal of the Hydraulics Division.

______, P. Hofmann, R.J. Eisle and T. Horst, 1976. An experimental approach to the design of systems for alleviating fish impingement at existing and proposal power plant intake structures. In: Jensen, L.D. (Ed.), Third national workshop on entrainment and impingement. EA Communications, Melville, N.Y.

Tarbox, K., M. Bushdosh, D. La Vigne, and G. Robilliard, 1979. Under-ice plankton in the Beaufort Sea near Prudhoe Bay, Alaska--February - May 1979. In: Environmental studies of the Beaufort Sea-winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants Anchorage, Alaska.

_______, and L. Moulton, 1980. Larval fish abundance in the Beaufort Sea near Prudhoe Bay Alaska. In: Environmental studies of the Beaufort Sea-summer 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

_______, and T. Spight, 1979. Beaufort Sea fishery investigations. In: Biological effects of impingement and entrainment from operation of the proposed intake. Draft report prepared for ARCO Oil and Gas Co. by Woodward-Clyde Consultants, Anchorage, Alaska.

_______, and R. Thorne, 1979. Measurements of fish densities under the ice in the Beaufort Sea near Prudhoe Bay, Alaska. In: Environmental studies of the Beaufort Sea-winter 1979. Report prepared for Prudhoe Bay Unit by Woodward-Clyde Consultants, Anchorage, Alaska.

Thompson, J.S., and G.J. Paulik, 1967. An evaluation of louvers and bypass facilities for guiding seaward migrant salmonids past Mayfield Dam in west Washington. Washington Department of Fisheries, Olympia, Wash.

Tomljanovich, D.A., J.H. Heuer, and C.W. Viogtlander, 1977. Investigations on the protection of fish larvae at water intakes using fine mesh screening. Tennessee Valley Authority Tech. Note No. 1322, 36 p.

_______, J.H. Heuer, and C.W. Voigtlander, 1978. Investigations on the protection of fish larvae at water intakes using fine-mesh screening. In: Sharma, R.R. and J.B. Palmer (Eds.), Larval exclusion systems for power plant cooling water intakes. Argonne National Laboratory, Argonne, Ill.

USEPA, 1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. Effluent Guidelines Division, Office of Water and Hazardous Materials. USEPA, Washington, D.C. pp. 263.

_______, 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment. Section 316(b) P.L. 92-500. U.S. Environmental Protection Agency, Office of Water Enforcement, Permits Division, Washington, D.C. 58 pp.

White, J.C. and M.L. Brehmer, 1976. Eighteen month evaluation of the Ristroph traveling fish screens. In: Jensen, L.D. (Ed.), Proceedings of the third national workshop on entrainment and impingement, New York City, February 24, 1976. E.A. Communications.

APPENDIX I

COASTAL PROCESSES

1.0 INTRODUCTION

The shoreline along any body of water subject to wave action is very dynamic. The interaction of the prevailing wind and wave climate with the geology of an area produces a system in some degree of dynamic equilibrium. Any major structure introduced into this system will necessarily result in changes. This appendix assesses possible changes in littoral transport patterns and subsequent effects resulting from the proposed action.

2.0 REFRACTION ANALYSIS

Two important factors determining sediment transport at the project site are the height of breaking waves and the angle these wave crests make with the shoreline. These two parameters were determined by using a computer program to model the waves as they propagate shoreward from deep water to shallow water.

As a wave approaches shallow water, its propagation speed decreases. Thus if the wave approaches the beach an an angle, one "end" of the wave will reach shallow water and decrease its speed. This will tend to bend the wave so that it approachs along a path more perpendicular to the shore.

The model examines the shoreward propagation of waves by analyzing wave properties along a series of lines perpendicular to the wave crests, called orthogonals. At finite intervals along each orthogonal, calculations are made to yield wave speed, wave length, and water depth. As these parameters change, the degree that the orthogonal changes direction (corresponding to the "bending" of the wave crest) is determined from Snell's law:

$$\frac{\text{SIN}\alpha_1}{C_1} = \frac{\text{SIN}\alpha_2}{C_2}$$

where:

- α_1 is the angle a wave crest makes with the bottom contour over which the wave is passing,
- α_2 is a similar angle measured as the wave crest passes over the next bottom contour,
- C_1 is the wave velocity corresponding to α_1,
- C_2 is the wave velocity corresponding to α_2.

Plotting each of these orthogonals depicts the interaction between bathymetry and waves of a given period and initial direction, and yields information concerning the angle the wave crests make with the shoreline at breaking.

Shoaling is the other major phenomenon associated with deep-water waves approaching a shoreline. The shoaling coefficient is a ratio of the wave height in any depth with the wave height in deep water, eliminating effects of refraction, percolation and bottom friction.

Bathymetry for the refraction analysis was digitized from NOAA nautical chart number 16061. Interpolation of these randomly-spaced data points was performed to construct a regularly-spaced grid. Two grids were generated. A 10,000-ft grid was used for the initial runs of the longer period waves (Figure I-1). A smaller 2000-ft grid was used for a more detailed analysis of the project area (Figure I-2).

Refraction analyses were run based on a no-causeway assumption. The shoreline was idealized as a series of straight lines. The bathymetry was smoothed slightly to eliminate any rapid changes in depth, as such sharp transitions violate the assumptions of Snell's law. Cases were analyzed for waves with periods of 1.5, 2, 3, 4, 5, 6, and 8 s. Heights ranged from 0.2 - 3.7 m (0.5 - 12 ft). Waves from three directions were analyzed: 150°(T), 180°(T), and 210°(T).

Available data suggest that most waves during the three open-water months of July, August and September are less than 0.6 m (2 ft) in height, have periods of 3 s or less, and arrive from the east or northeast. A 10-year storm has been hindcast as having a significant period of 5.8 s with a significant wave height of 2.4 m (8 ft). A 100-year storm has been calculated to have a significant period of 6 s with a significant wave height of 3.7 m (12 ft). Although the prevailing winds and waves are from the east and northeast, severe storms can come from the west.

The results of the refraction analyses are presented in Figures I-5 through I-19.

3.0 LONGSHORE CURRENT VELOCITIES

As waves approach a shoreline at an angle and break, a current is established parallel to the shore. Waves in shallow water, especially breaking waves, set sediments in motion. These sediments are transported with the longshore current until the current velocity dissipates.

An analysis of the longshore current velocities generated at a site can indicate the capacity of these forces to transport sediments. The model used to generate the longshore currents is a modified version of the model proposed by Longuet-Higgins (1970). This modified model (Madsen et al. 1978) depends upon:

the bottom slope (β),
a friction factor (f),

a lateral eddy viscosity constant (Γ),
the ratio of wave height to depth at breaking (α),
the wave period (T),
the breaking wave height (H_B),
and the angle between the wave crest and the shoreline at breaking (Θb).

The wave parameters at the breaker zone were determined from the refraction analysis. The bottom slope, taken as 0.002, was determined from the bathymetry, and the values for f and Γ were taken from available literature.

The highest longshore current velocities for a system in which the waves break only once are just inside the surf zone. In this particular case, since the bottom is so flat, waves may break, reform, and break several times before ultimately losing all of their energy on the beach. This provides a wide cross-sectional area through which sediment may be transported. Figure I-3 presents a comparison of the longshore current velocities for the typical wave regime and for possible storms from the east and west. Both the distribution and magnitude of velocity are much greater for the storm. Thus, one severe storm can erase the accumulated effects of several years' normal wave activity. Hume and Schalk (1967) indicated that during one storm near Barrow, Alaska, over 153,000 m^3 (200,000 yds^3) of sediment were moved compared to the average yearly littoral transport of approximately 7650 m^3 (10,000 yds^3). Longshore current patterns can be envisioned by examining this circulation model.

4.0 SEDIMENT TRANSPORT

Sediment transport calculations were based upon an empirical formula developed by Komar and Inman (1977). This formula is somewhat dependent upon sediment size, but primarily dependent upon breaking wave height and the angle of wave incidence. It establishes the sediment transport as a function of the square of the breaker height; consequently, larger waves have considerably greater potential for transporting sediments.

Five representative sites were selected in the area of interest: three along Stump Island, one along the shoreline at the causeway (prior to causeway construction), and one farther east along the Prudhoe Bay shoreline (Figure I-4). Transport rates (yds^3/day) were calculated for a variety of wave heights and periods at each of the five sites. Average potential transport rates for each wave height, period, and direction were calculated from these values (Table I-1).

These values may represent overestimates of the actual transport rates by at least an order of magnitude. This possible discrepancy arises primarily from variation in the availability of sediment. Most of the beaches modeled have only limited quantities of sediment and much of that is organic matter, the transport of which has not been adequately modeled. The mild slope of these beaches enables the longshore current to effectively move sediment over a large cross-sectional area perpendicular to the coastline. However, once having broken on such a slope, waves would not break continuously (as defined by the ratio of the water depth to the wave height) all the way to uprush limit. The result would be a complex velocity distribution considerably lower overall than the model predicts.

TABLE I-1

POTENTIAL TRANSPORT RATES AT AVERAGE SITE
(yds^3/day)

T	H	Westerly Winds angle 112°	Westerly Winds angle 107°	Easterly Winds angle 112°	Easterly Winds angle 107°
	1	-5,120	-4,480	1,280	2,880
	2	-19,840	-17,920	5,120	11,520
	3	-51,200	-46,720	11,840	26,560
	4	-94,720	-87,360	19,520	43,520
4	1	-6,080	-5,120	2,240	3,520
	2	-25,280	-21,440	11,840	17,600
	4	-108,160	-92,800	41,280	59,440
	6	-295,040	-267,520	84,160	151,680
5	4	-97,600	-80,960	24,640	48,320
	6	-243,200	-208,640	58,240	114,560
	8	-523,520	-471,360	105,600	208,000
6	6	-196,160	-168,320	100,480	223,360
	8	-394,560	-345,920	175,520	434,240
	12	-1,126,080	-1,030,080	356,160	938,880

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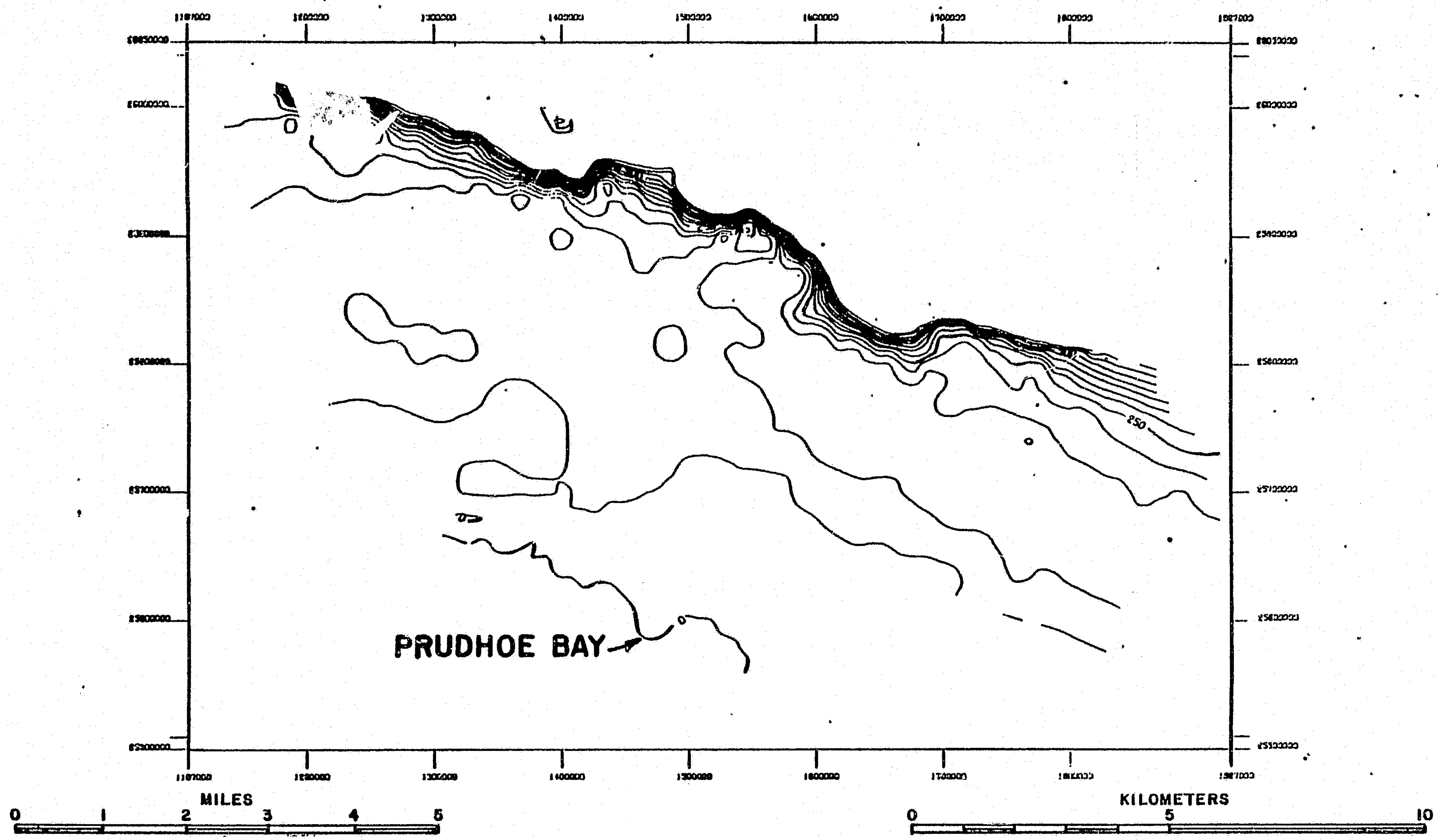

Figure I-1

OFFSHORE BATHYMETRY

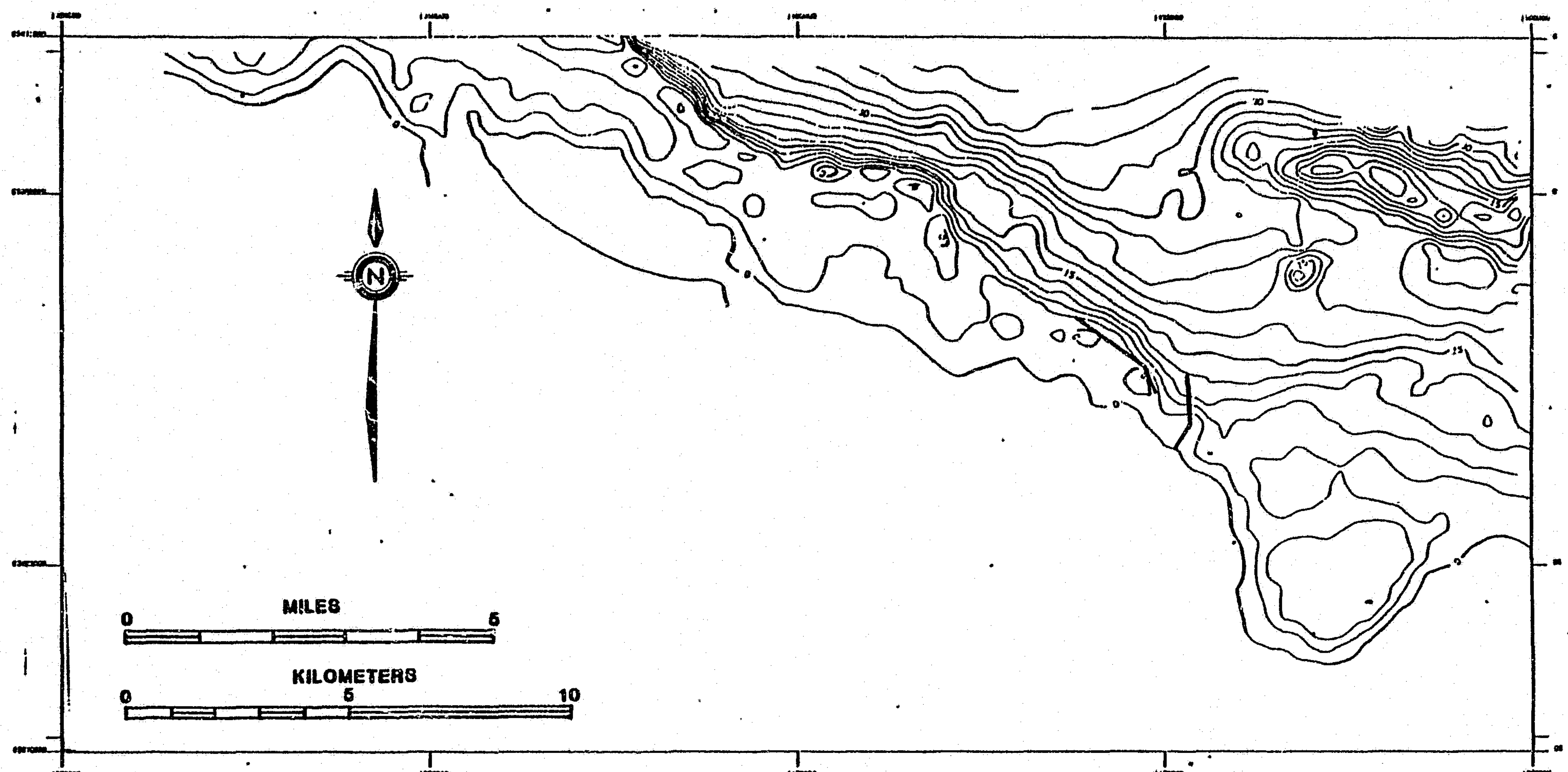

Figure I-2

PRUDHOE BAY, NEARSHORE BATHYMETRY
(WITH EXTENDED CAUSEWAY AND IDEALIZED STUMP ISLAND INSERTED)

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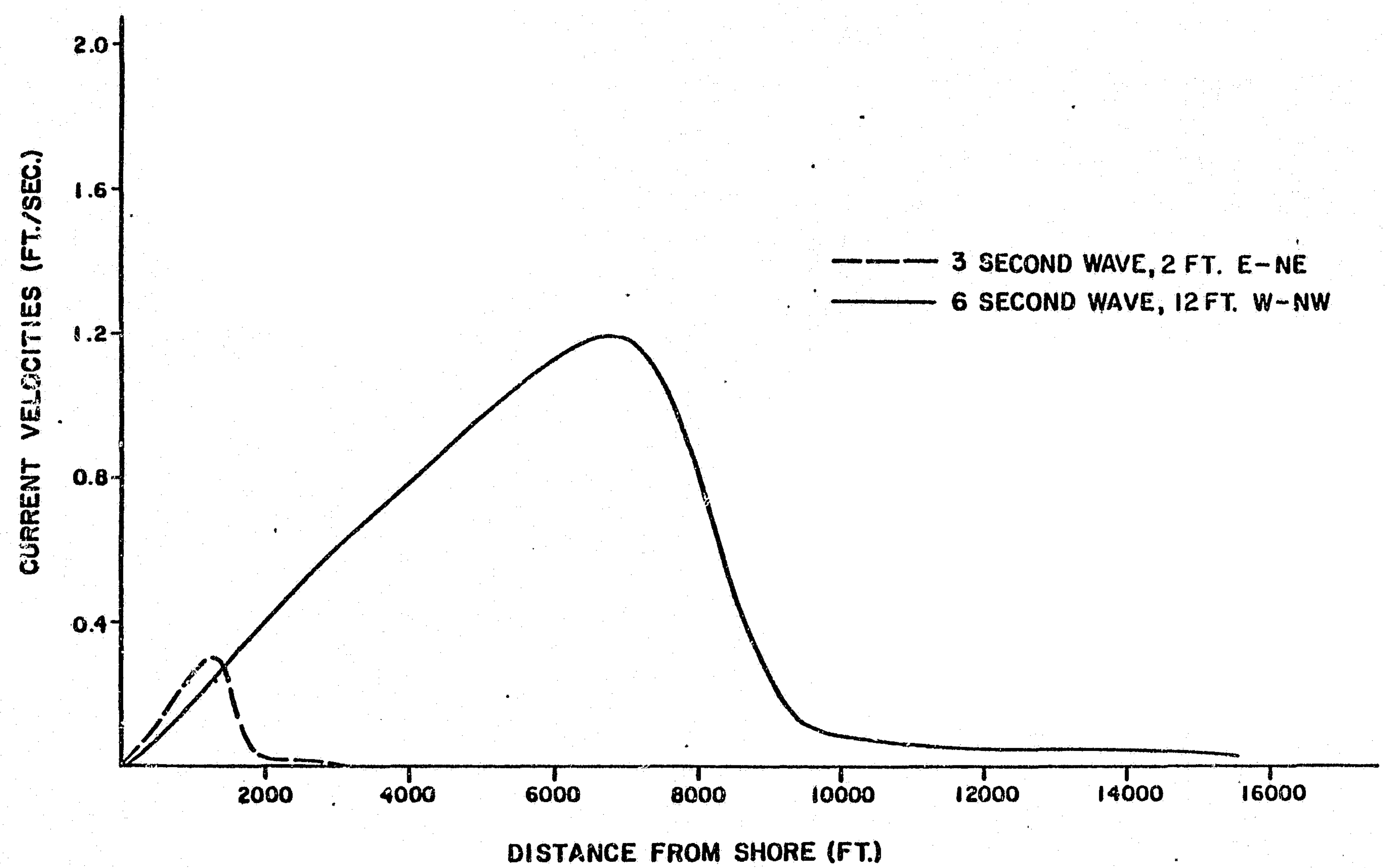

Figure I-3

LONGSHORE CURRENT VELOCITIES

(SLOPE) M = 0.002

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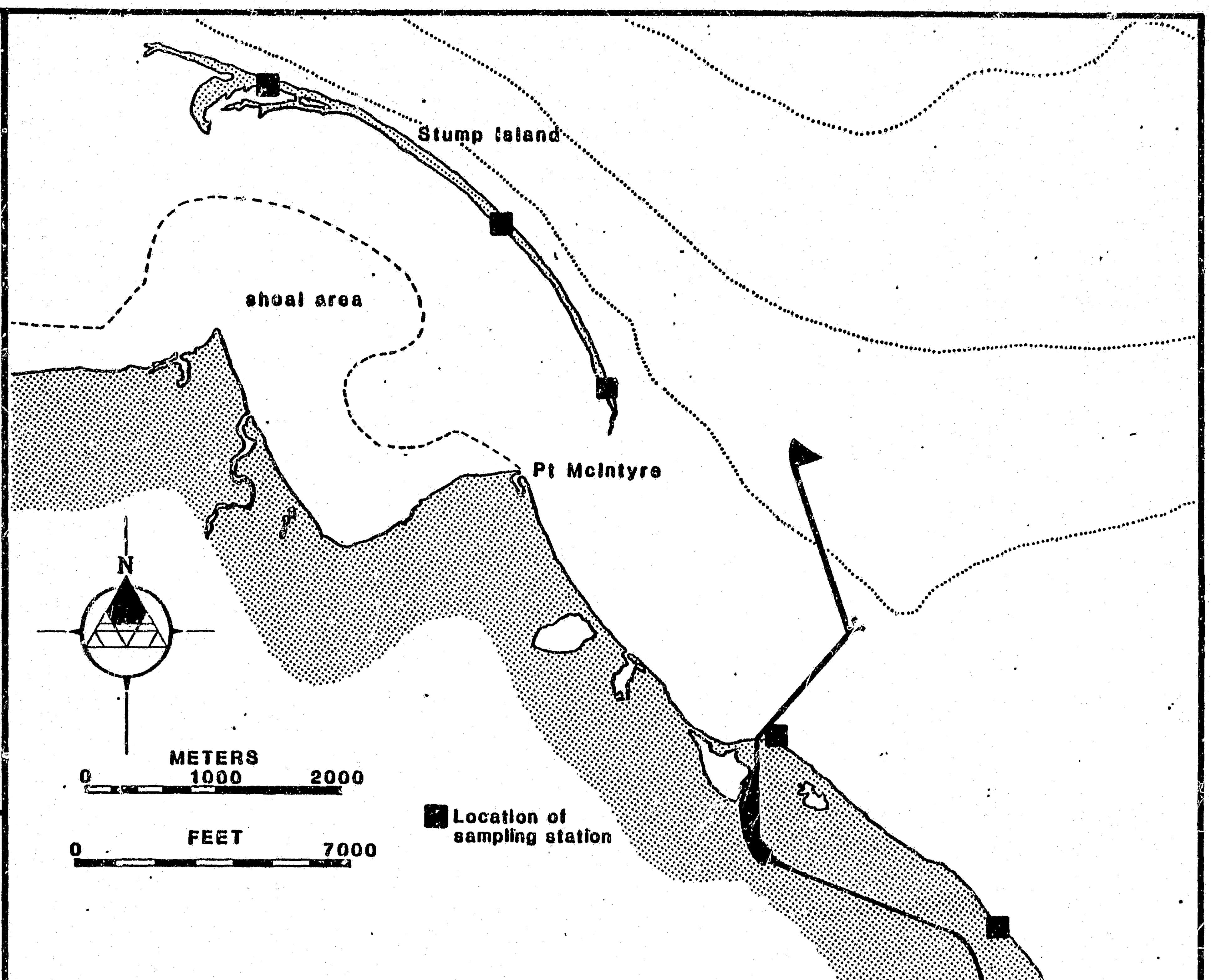
Figure I-4



SEDIMENT TRANSPORT SITES

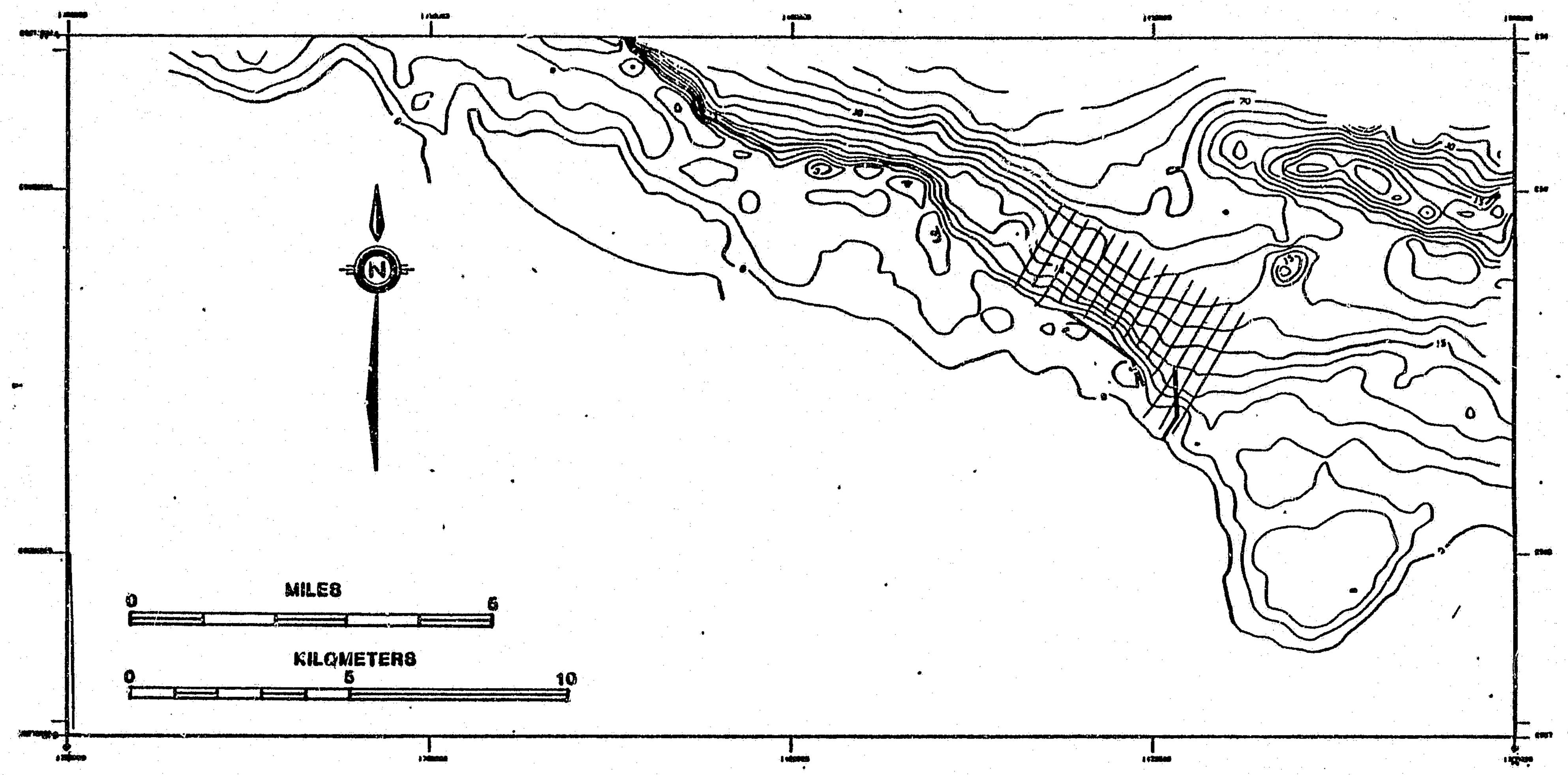
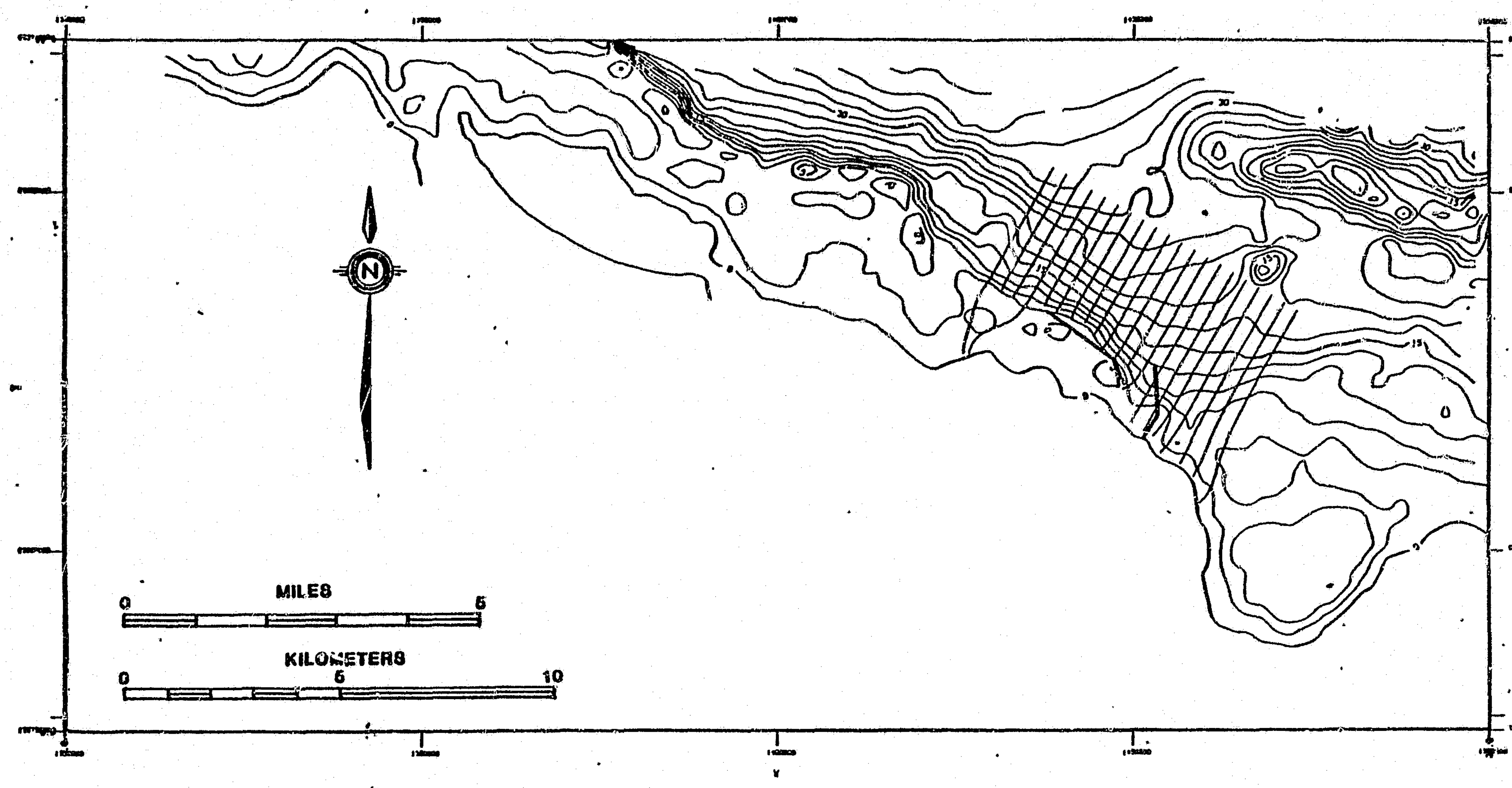


Figure I-5

1.5 SECONDS, 210° (T)

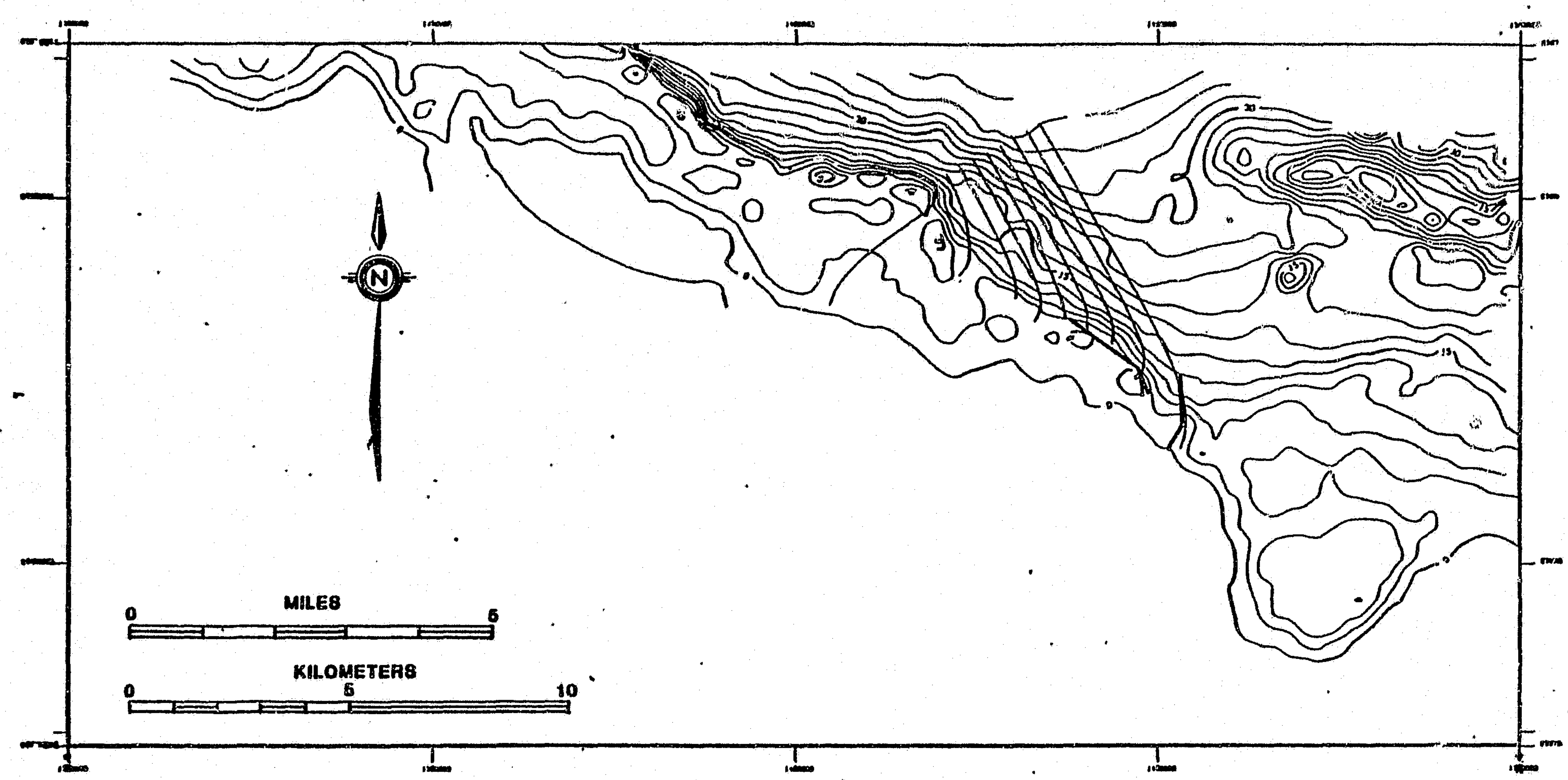
WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION



2.0 SECONDS, 210° (T)

WAVE REFRACTION   SELECTED WAVE PERIOD, DIRECTION

Figure I-6



3.0 SECONDS, 150 (T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

Figure I-7

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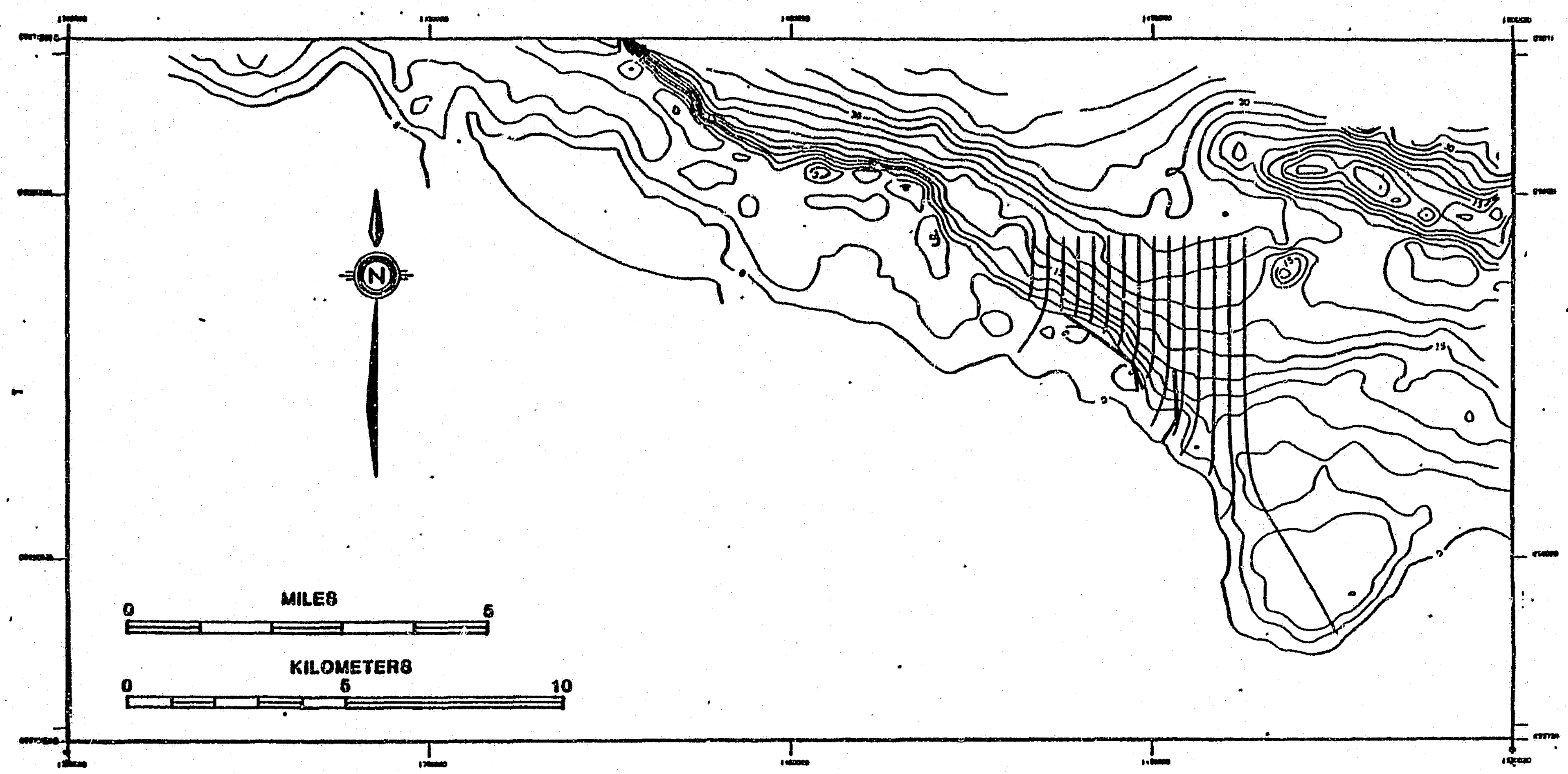
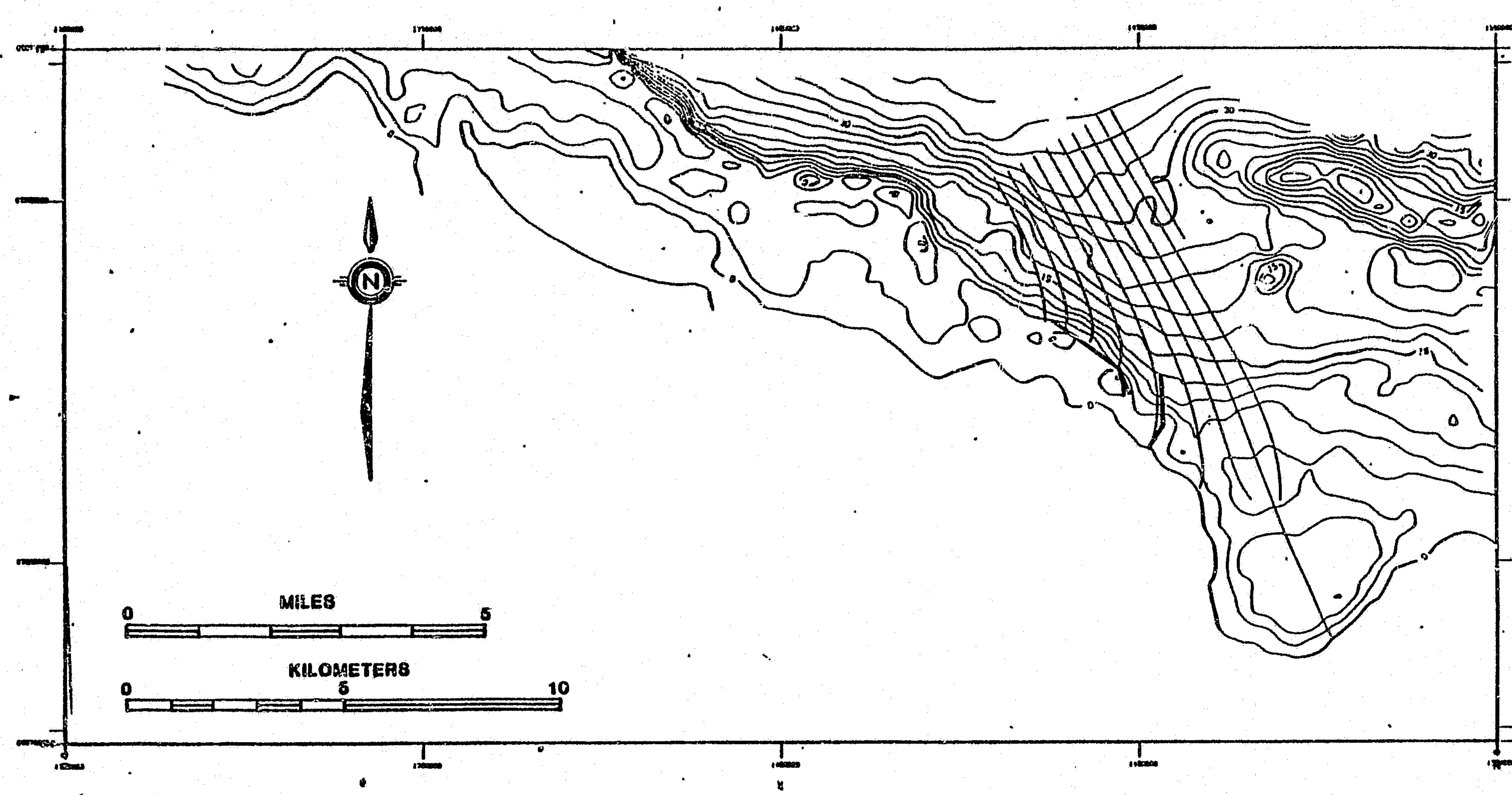


3.0 SECONDS, 180°(T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

Figure I-8



4.0 SECONDS, 150° (T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

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Figure I-9

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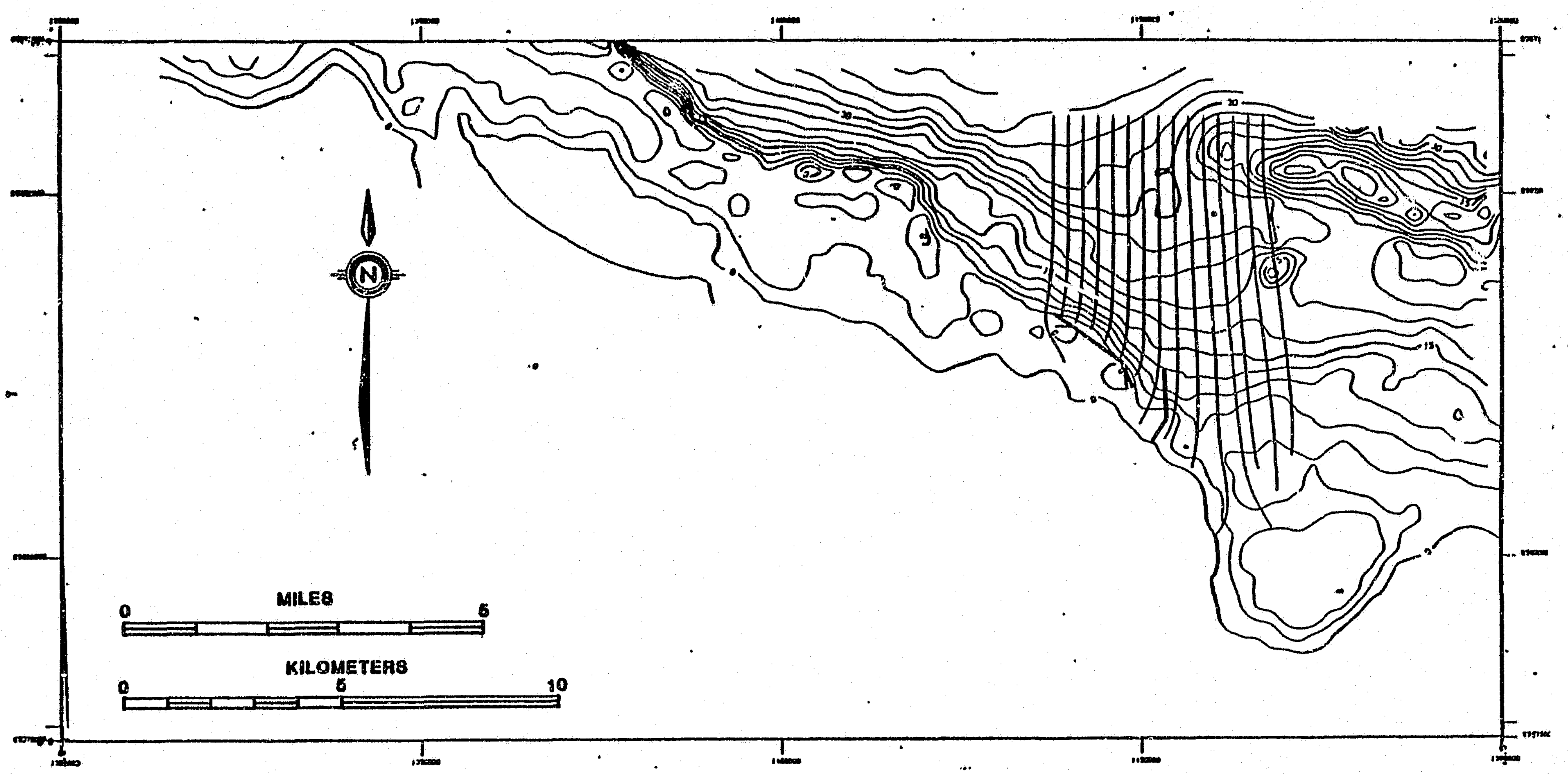

Figure I-10

4.0 SECONDS, 180° (T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

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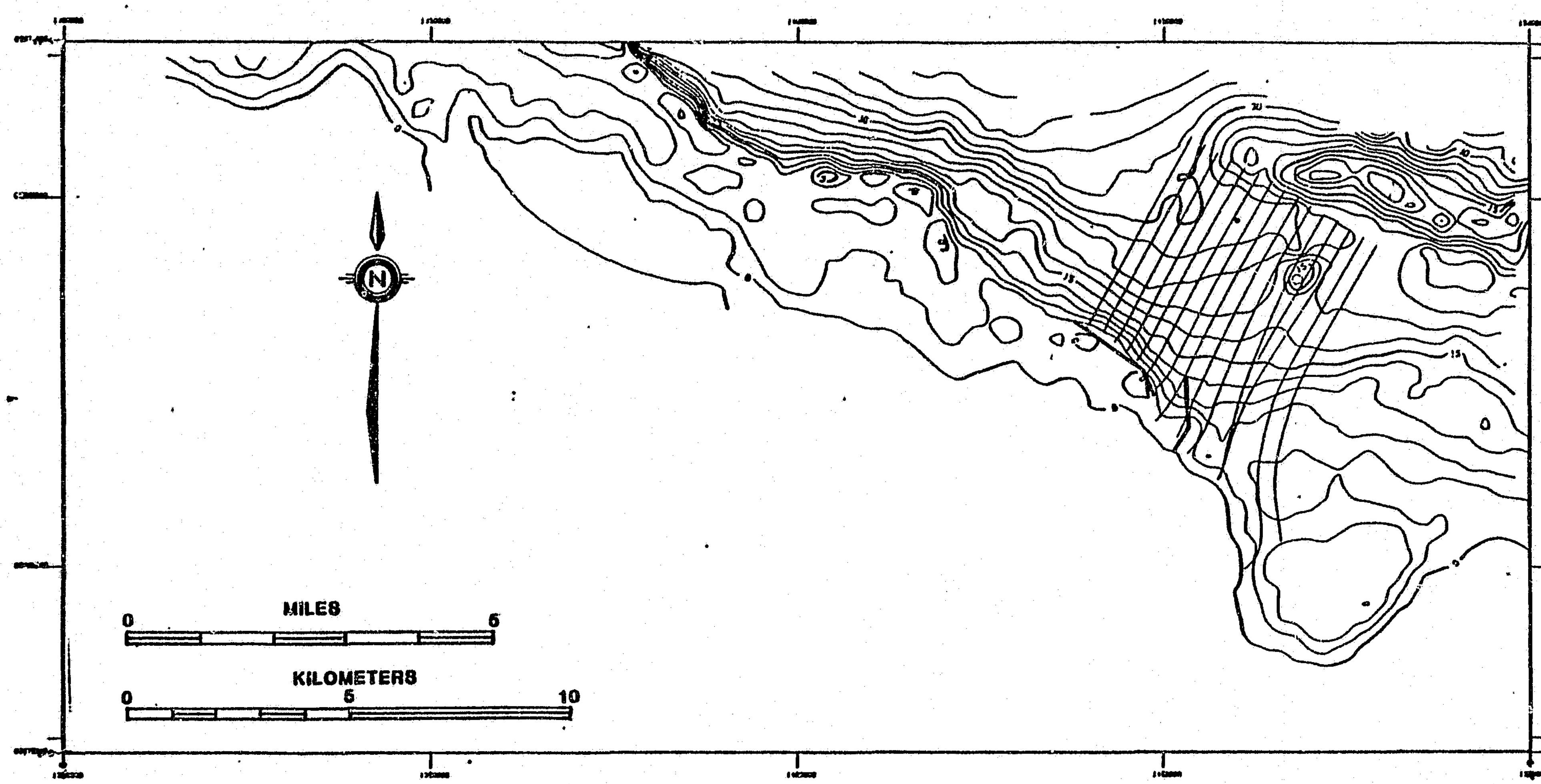
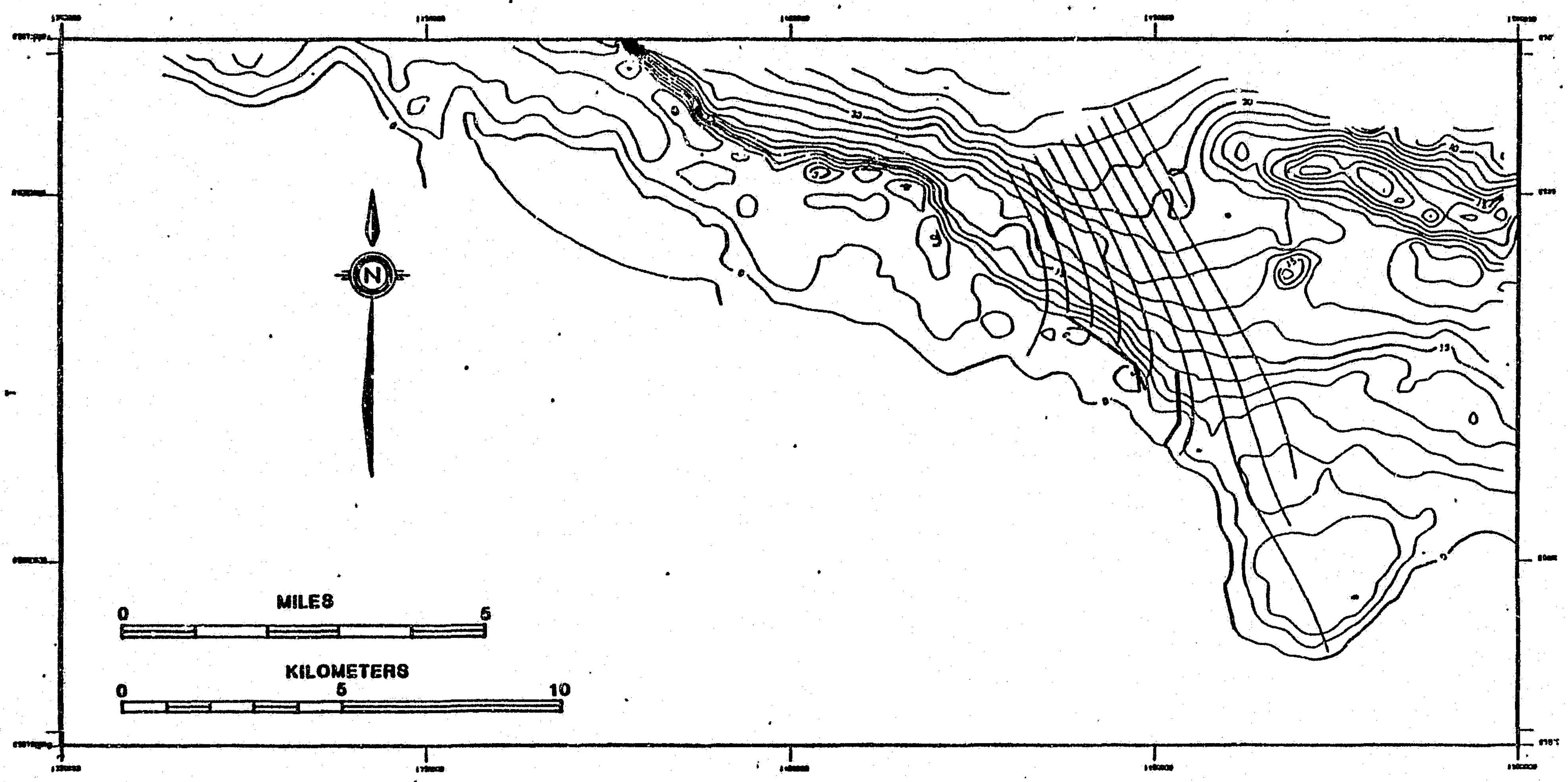


Figure I-11

4.0 SECONDS, 210°(T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION



5.0 SECONDS, 150°(T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

Figure I-12

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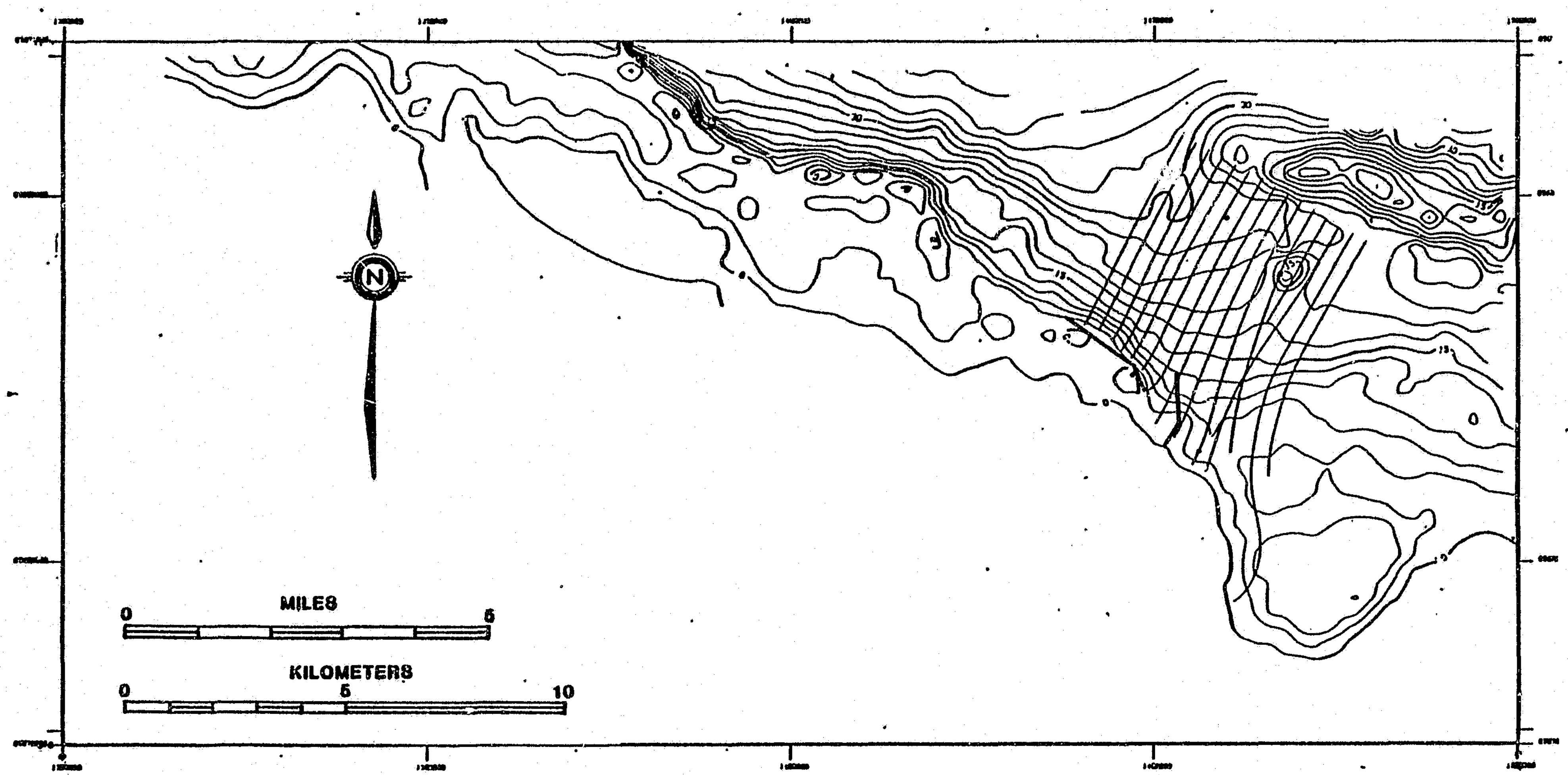

Figure I-13

5.0 SECONDS, 210°(T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

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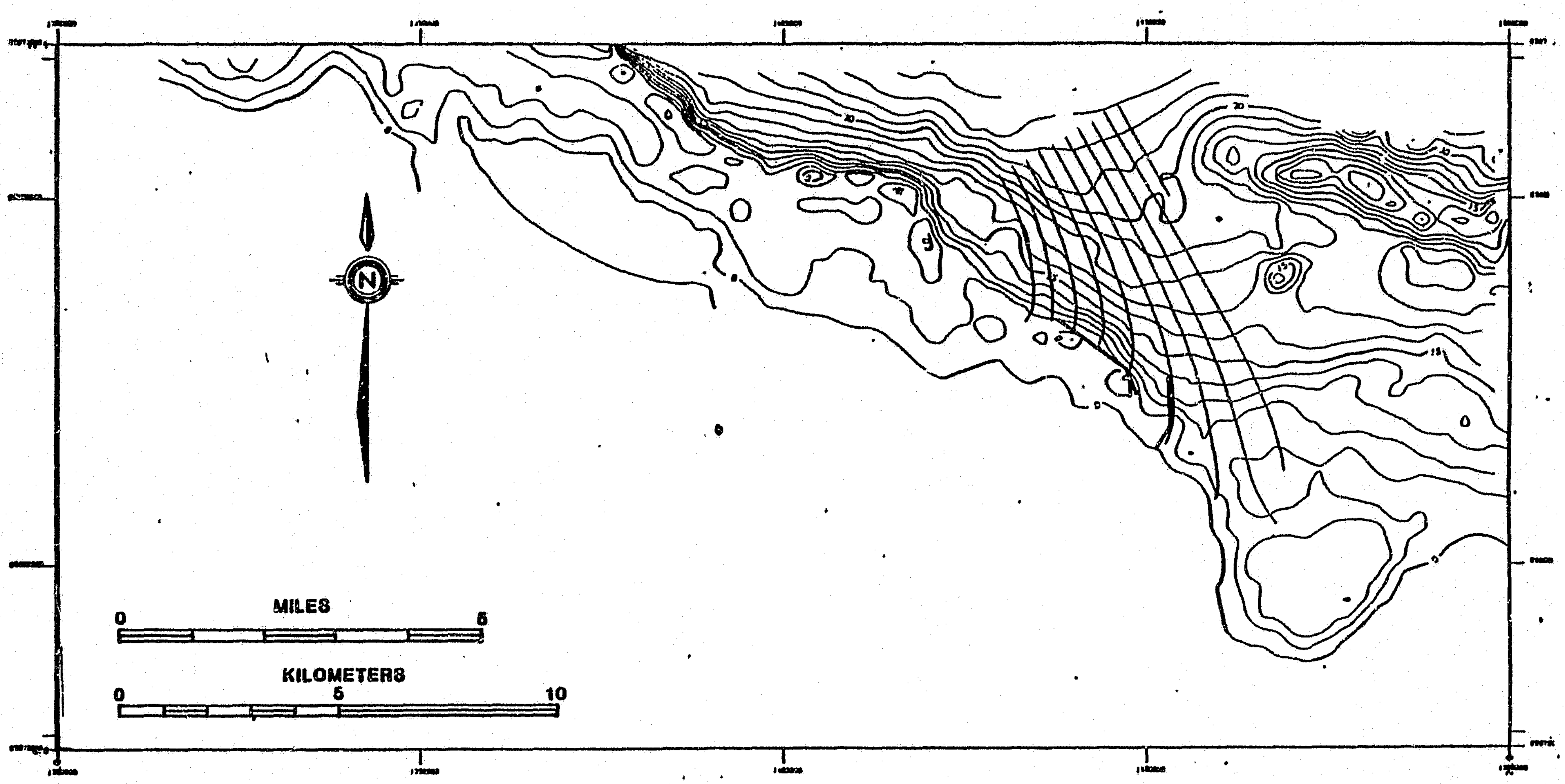

6.0 SECONDS, 150° (T)

WAVE REFRACTION   SELECTED WAVE PERIOD, DIRECTION

Figure I-14

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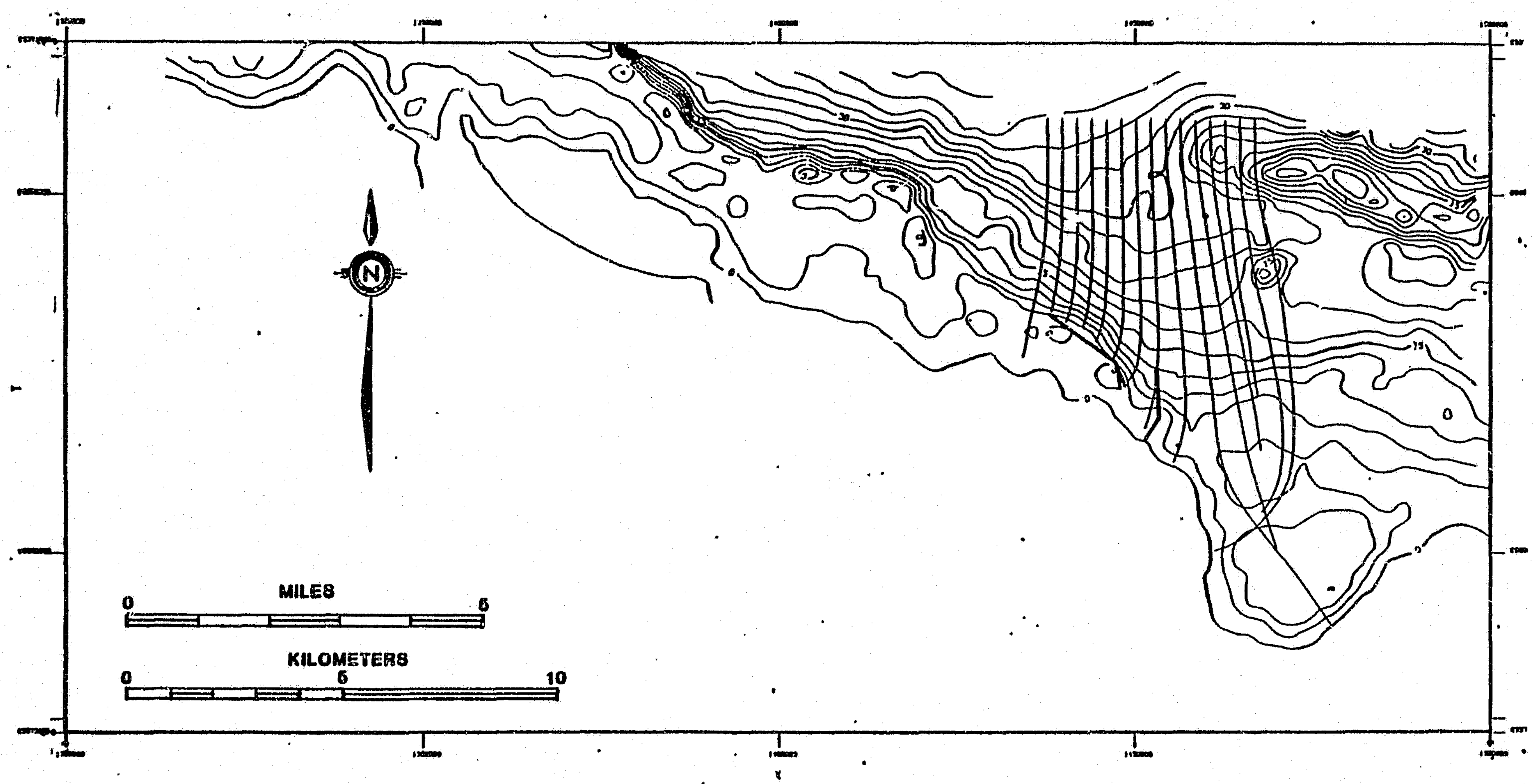

Figure I-15

6.0 SECONDS, 180°(T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

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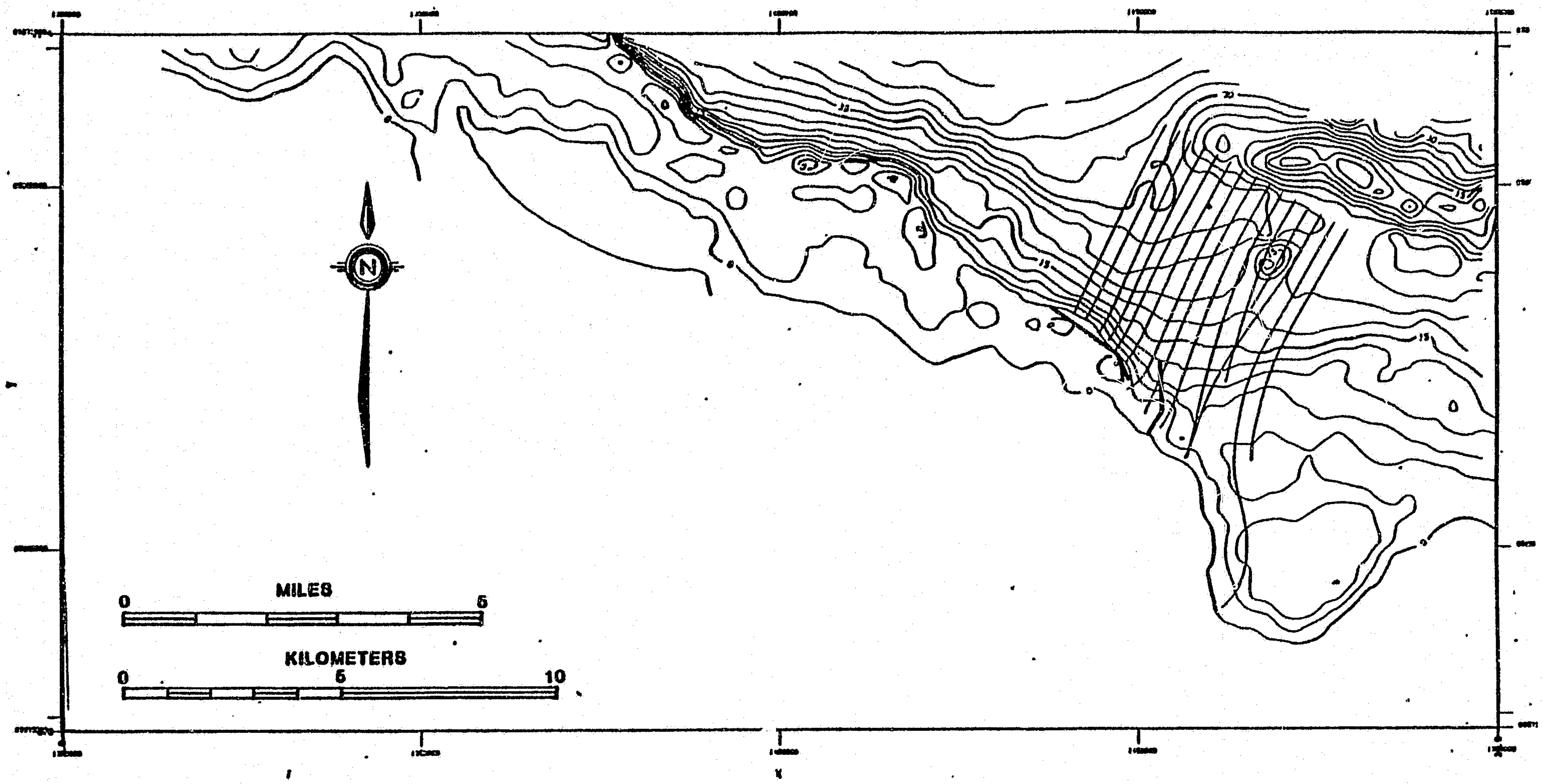

Figure I-16

6.0 SECONDS, 210° (T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

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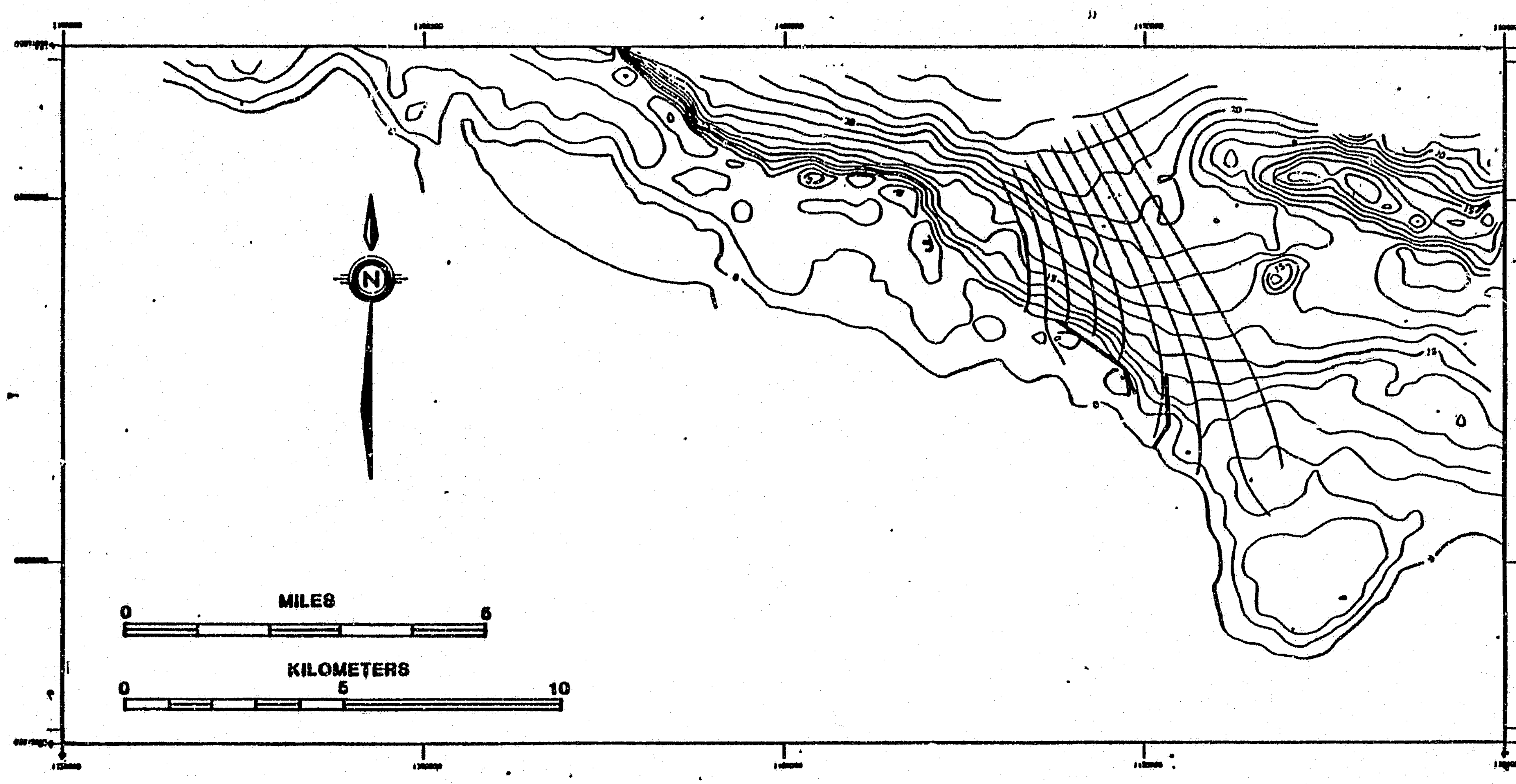


8.0 SECONDS, 150° (T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

Figure I-17

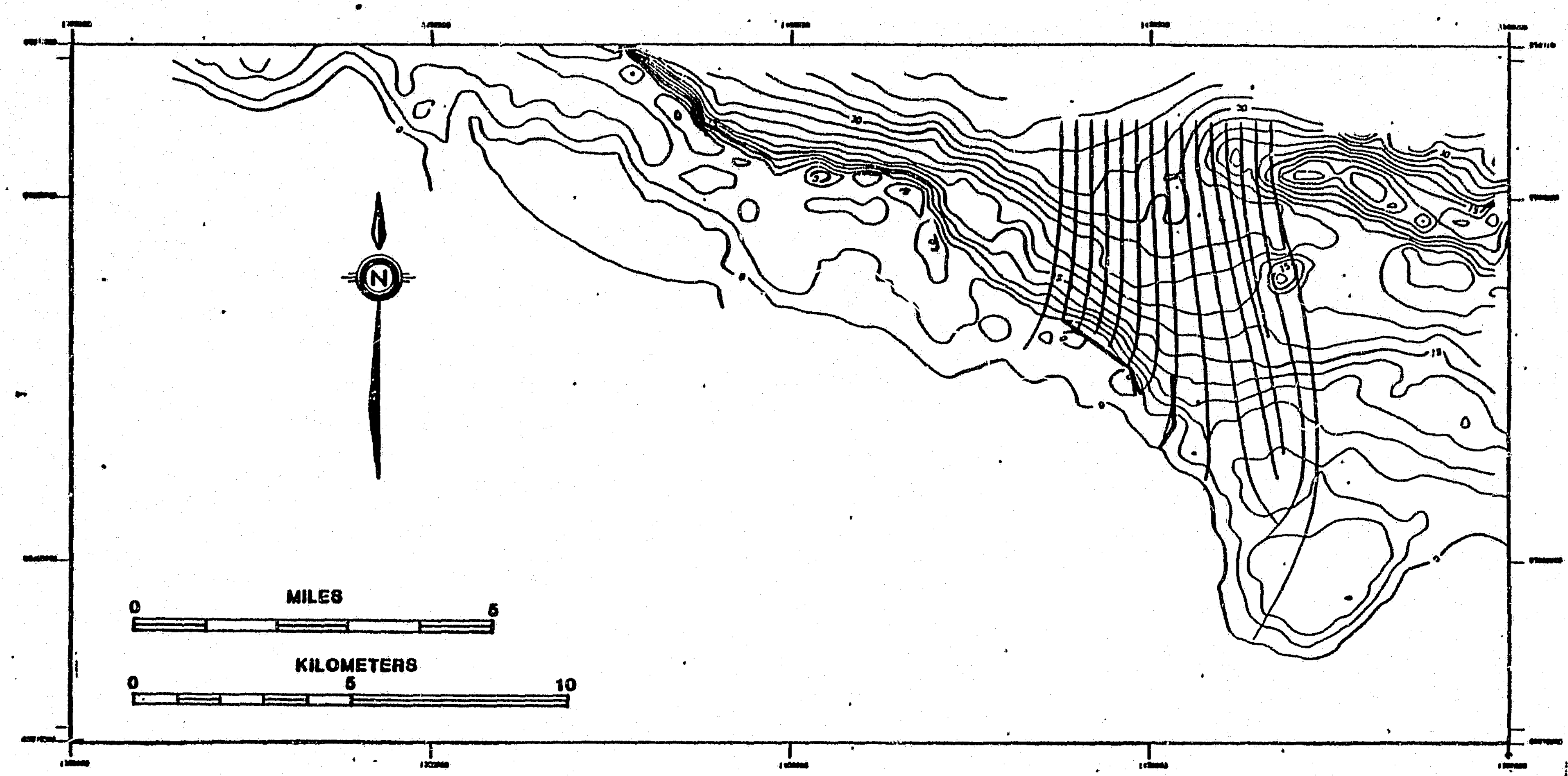
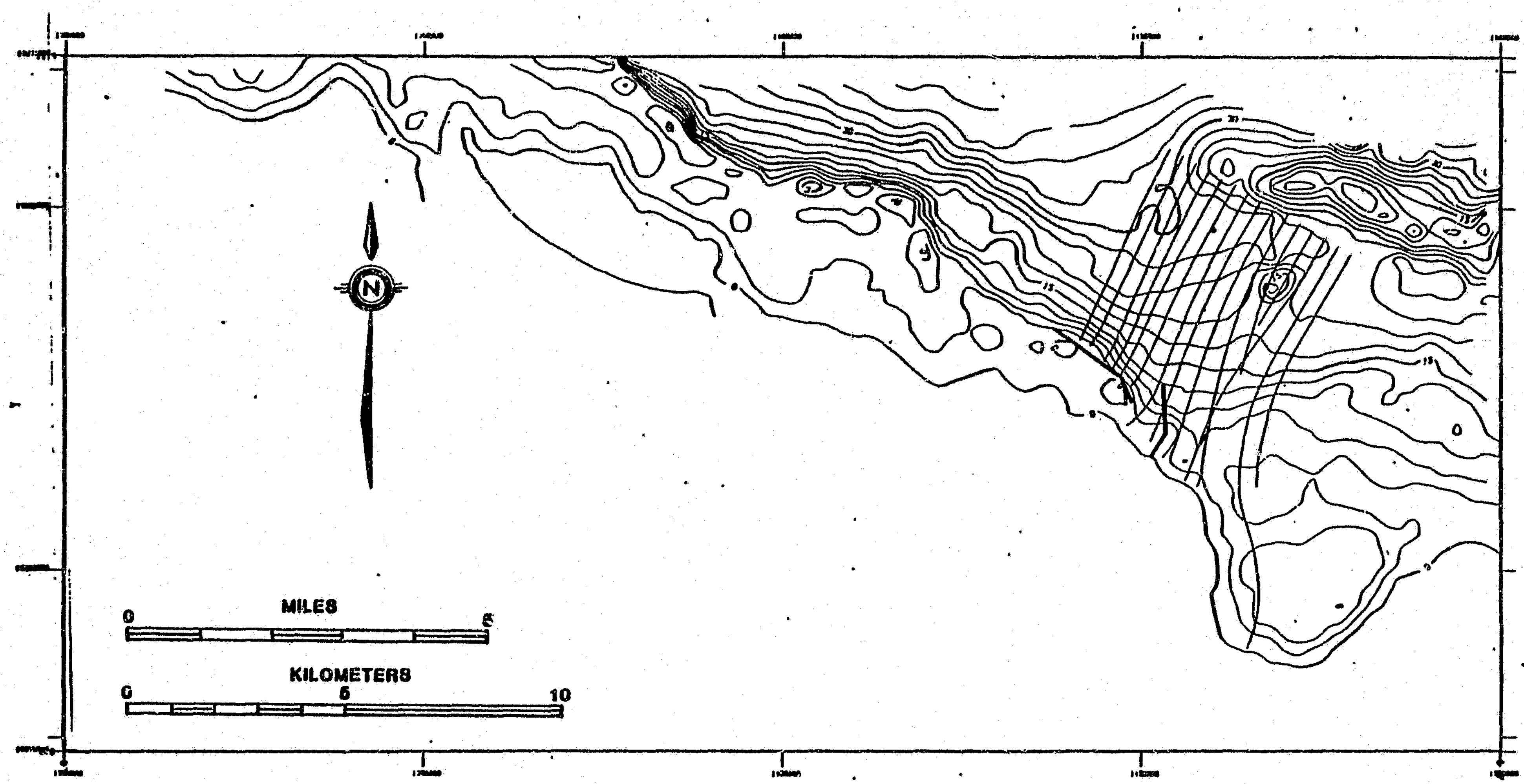


Figure I-18

8.0 SECONDS, 180°(T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION



8.0 SECONDS, 210° (T)

WAVE REFRACTION SELECTED WAVE PERIOD, DIRECTION

Figure I-19

REFERENCES

Longuet-Higgins, M.S., 1970. Longshore curents generated by obliquely incident sea waves, parts 1 and 2. Journal of Geophysical Research, 75 (33):6778-6801.

Hume, J.D., and M. Schalk, 1967. Shoreline processes near Barrow, Alaska: a comparison of the normal and catastrophic. Arctic 20(2): 86-103.

Komar, P., and D. Inman, 1967. Longshore sand transport on beaches. J. Geophys. Res. 75(30):5914-27.

APPENDIX J

ASSESSMENT OF ICE FORCES, ICE OVER-RIDE AND EMBANKMENT STABILITY[1]

1.0 INTRODUCTION

The waterflood facilities would involve a causeway extending 1125 m (3700 ft) out to the 3.7-m (12-ft) contour of the Beaufort Sea, with a seawater treating plant at the end. This appendix addresses concerns regarding the risk associated with ice forces and ice override and includes a review of available literature relating to the interaction of bottom-founded structures with ice-sheets, particularly related to ice forces, ice override, and stability of the structure.

2.0 ENVIRONMENTAL FORCES ON ICE SHEETS AND GENERAL ICE CONDITIONS

DRIVING FORCES

Ice action on artificial structures should be considered in two categories (Croasdale and Marcellus 1978). First, the structure has to withstand the lateral forces imposed by the moving ice, and second, the ice must not encroach on the working surface. Both of these types of ice action depend on the pattern of ice movement, its thickness, and its strength.

Ice forces are limited either by the environmental forces moving the ice or by the force that would cause the ice to fail against a bottom-founded structure. Whether or not ice will ride up an embankment slope is determined by relating the ice forces to the resistance offered by the slope.

[1] Derived from Hardy Associates (1978) Ltd., 1980. Assessment of ice forces, ice over-ride and embankment stability, Prudhoe Bay waterflood project. Report prepared for Dames & Moore.

The driving forces on an ice sheet exerted by wind and current depends on the square of the wind velocity and current velocity respectively, and are also directly proportional to the fetch area of the ice sheet involved (Braun and Johannesson 1971, Croasdale and Marcellus 1978). Due to the potential for extremely large fetch areas involved in coastal locations, environmental driving forces theoretically can achieve very high values. Consequently, the forces exerted by large coastal ice sheets usually are considered to be limited to the strength of the ice sheet itself by whatever mode of failure. Therefore, there is little to be gained by making specific calculations of the potential thrust that could be exerted on an ice sheet by environmental forces.

ICE CONDITIONS

A brief summary of ice conditions used as a base for this discussion is shown in Table J-1.

The most critical period from the viewpoint of maximum ice force will occur when ice thickness, strength and movement are greatest. This would appear to be the period around mid-October, when ice thickness may approach 1 m (3 ft) and storm activity is highest, or in the November-January/February period when ice movement may still occur, and the ice thickness can approach 2 m (7 ft). After this period, the ice is essentially static in this zone. During breakup, thicker ice will be in motion but is unlikely to have high strength due to warmer temperatures. Ice pile-up is likely to become a more important issue at this time.

3.0 ICE FORCES AND MODE OF FAILURE

Croasdale and Marcellus (1978) have shown that a crushing or ductile flow failure mode is more likely to occur than either a buckling failure of the ice sheet, or failure of the adfreeze bond formed between the ice sheet and the embankment. Whether crusing or ductile flow will occur depends on the strain rate. Slow, persistent movements

TABLE J-1

SUMMARY OF ICE CONDITIONS

Time	Process	Ice Thickness (m)		Comments
early October	New sea-ice forms	0 - 0.2 (?)	(0.7 ft)	Forces small
mid October	First shore fast ice	0.2 - 1.0 (?)	(0.7 ft)	Period of max. storm activity. Ice very mobile
Nov-Jan-Feb	Extension and modification	1 - 2	(3 - 7 ft)	Ice less active
Feb - May	Static ice sheet	2	(7 ft)	Little movement
late May	River flooding of fast ice	2	(7 ft)	Little movement
mid June	Opening and movement	?		Breakup
August 1	Nearshore area ice-free	0		-

of the ice sheet give rise to a ductile failure of the ice sheet, and generally smaller forces on the embankment. Large, faster movements of the ice sheet give rise to a crushing mode of failure, and may cause a buildup of ice rubble around the structure. This rubble, if it becomes thick enough and grounds, may assist in armouring the embankment against the ice sheet. Initially, however, the structure has to be capable of withstanding the crushing strength of the ice during periods of large ice movement. Ice force loadings suggested by Jahns (1979) and Ralston (1979) for drilling and production islands correspond to design ice strengths of 122 kg/cm^2 (270 lb/in^2). Ralston (1979) further suggests that based on experience with the Netserk F-14 island, "Ice pressures of 68 kg/cm^2 (150 lb/in^2) can be expected annually. . ." in the Mackenzie Bay area. These pressures correspond to movements of up to 0.4 m/hour (17 in/hour).

The crushing strength of ice depends mainly on strain rate, salinity and sample size. Allen (1970) shows data for thin ice sheets acting on wide structures in the range of 91 - 113 kg/cm^2 (200 - 250 lb/in^2). Fredeking and Gould (1975) have reported laboratory studies on the edge loading of ice plates, and obtain ice strengths in the range of 113 - 136 kg/cm^2 (250 - 300 lb/in^2) for ice sheets at -10°C (14°F) where the loaded area is very wide when compared with the thickness of the ice sheet. Data specific to the ice type and temperature conditions at Prudhoe should be obtained to develop a more rational basis for quantifying the strength of the ice sheet. Crushing strength is also related to ice crystal size and c-axis azimuth orientation. Tests have shown that the crushing strength may be two to five times higher perpendicular to the c-axis versus 45° to the c-axis. Since the load direction/c-axis effect is significant, it needs to be addressed. However, based on data available from other sources, a value for ice crushing strength of between 91 - 136 kg/cm^2 (200 - 300 lb/in^2) will be used for illustrative purposes. For example, an ice sheet moving at a high enough velocity to cause crushing or brittle failure of an ice sheet 0.9 m (3 ft) thick will induce a force on a structure of 48,924 kg/m (108,000 lbs/ft) run if the ice strength is 113 kg/cm^2

A 1.8-m (6-ft) sheet would induce twice this loading (97,848 kg/m, 216,000 lbs/ft) run. The velocity at which the ice sheet must travel to achieve the peak (crushing) strength relates to the strain rate in the ice sheet. A strain rate of about 1.5 $hour^{-1}$ is sufficient to obtain the maximum strength of an ice sheet, where strain rate, $\dot{\varepsilon}$, is given by:

$$\dot{\varepsilon} = v/h \qquad [hour]^{-1}$$

where v = ice sheet velocity (m/hour, ft/hour)

and h = characteristic dimension parallel to ice sheet (m,ft)

The characteristic dimension, h, is difficult to assess, but for the treatment structure at the end of the causeway, it likely to be in the range of 152 m (500 ft). When considering the 0.9-m (3-ft) thick ice sheet above, a velocity of 229 m/hour (750 ft/hour) would be required to provide a strain rate of 1.5 $hour^{-1}$, and a peak crushing strength would then be obtainable. At strain rates much lower than this, a ductile (creep) mode of failure would predominate, and generally lower strengths would be obtained. This is likely to be the case later in the winter season, when the ice sheet becomes less mobile and small rates of movement are generally observed. Ice strengths at this time can be approximately quantified using the known ratios between strength and strain rate. Generally, strength is proportional to the strain rate cubed. If the strain rate is reduced by three orders of magnitude, the ice strength will be reduced by one order of magnitude (i.e. a factor of 10).

At spring breakup, the ice is thick but is also relatively warm. Consequently, the competency of the ice sheet is greatly reduced. Michel (1970) suggests a design strength for the impact loading of spring ice of 34 kg/cm^2 (75 lb/in^2). The accuracy of this design strength is not known; however, the reduced ice competency coupled with the much higher movement rates common at this time may conceivably control ice loads on irregular boundaries.

Design to resist the lateral ice forces described in this section is accomplished by sizing the structure to achieve the necessary shearing resistance within the earth structure, and ensuring that a sufficient safety factor against shearing is available. The geotechnical aspects of earth structure stability are reviewed later.

4.0 ICE RIDE-UP

When an ice sheet moves against a shallow slope, it is normally subject to bending stresses that cause it to break into a number of pieces. These broken pieces continue to be pushed against the slope by the advancing ice sheet. For wide structures with small freeboards, such as embankments or artificial islands, there is a risk that the ice will advance up the beach and onto the embankment surface. Therefore, whether the ice will ride-up a slope or create a rubble pile is an important consideration in the design of embankments such as that proposed for the causeway extension.

In general, ice ride-up will occur if the resistance to ice sliding up the beach is less than the ice push (Croasdale et al. 1978). The ice push is limited by such factors as ice sheet size, winds, current, ice thickness, ice strength and modulus; whereas the beach resistance is governed by friction, slope angle and height.

Ice ride-up has been reported several times in the literature. Shapiro (1976) described how a 1.2-m (4-ft) thick ice sheet was pushed ashore near Barrow, Alaska to a distance of 24 m (80 ft) up the beach. Hanson (1978) described another occurrence, also near Barrow, where ice was pushed to an elevation of 2.4 - 2.7 m (8 - 9 ft) above sea level at different beach slopes. Braun and Johannesson (1971) and Allen (1970) discuss ice pilings and methods of predicting their maximum height, but the mechanics of ice pilings are less relevant than the prediction of ice ride-up, which may impinge on a working surface. Although a major concern at the design stage, no sigificant ice ride-up has been reported at the many artificial islands constructed in shallow water in the Canada Beaufort Sea in Mackenzie Bay. However, the ice or climatic conditions at these locations may not be as severe as may be experienced in the Prudhoe Bay area.

Croasdale et al. (1978) have examined the theoretical criteria necessary for ride-up, and offer some simple and approximate design methods for prevention. Ride-up can only occur if the capacity of the ice sheet to push is greater than the resistance to movement of ice up the slope. Ice push will be limited either to the environmental driving force (wind, current) or by the strength of the ice sheet immediately in front of the structure. Resistance to sliding up the embankment side slope can be obtained by sliding or jamming, or by an ice pile-up caused by instability of broken ice pieces. If the ice sheet is not sufficiently strong to push broken ice pieces up the side of the slope, then a rubble pile or ice piling will form at the bottom of the slope, and ice ride-up will cease. Figure J-1 shows the statics of the ice ride-up problem. Using the notation of this figure, the force required in the ice sheet per unit width to push the ice over the crest of the embankment slope is:

$$= Lt\gamma_i \, (\sin\beta + \mu \cos\beta) \tag{1}$$

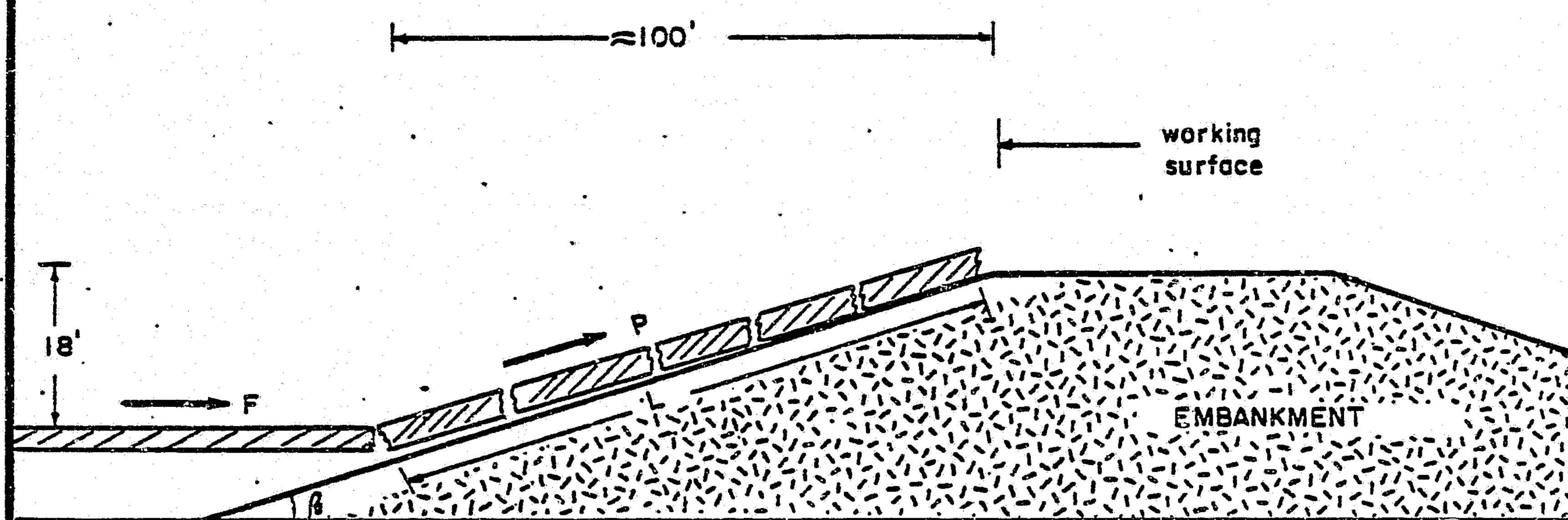
where L = sloping length of ice sheet

t = ice thickness

γ_i = ice density

β = embankment angle

and μ = ice/embankment friction coefficient



P = Ice force per unit width on slope.

F = Ice force per unit width (horizontal).

STATICS OF ICE RIDE UP

PBU Waterflood Environmental Impact Statement | Figure J-1

It should be noted that this value may be a lower bound force as it does not account for the weight of the ice sheet in contact with the sea floor or the force required to break the ice at the bottom of the slope. The actual force could be 20 to 30 percent higher.

If the ice stress gives rise to a horizontal force per unit width in the floating ice sheet, F, such that

$$F \geq P \cos \beta \qquad (2)$$

then ice ride-up will occur.

Referring to the proposed causeway extension, and considering an ice sheet 1 m (3 ft) thick, the following are the required parameters to assess ice ride-up.

Coefficient of friction		0.3[1]
Slope		1:5 (11.3°)
Slope length, L	=	approximately 30 m (100 ft)
γ_{ice}	=	24 kg/m^3 (56 lb/ft^3)
Force required, P	=	3728 kg/m (8230 lbs/ft) run.

The horizontal stress required in the ice sheet is obtained from Equation (2), i.e.:

$$F \geq 3656 \text{ kg/m (8070 lbs/ft) run.}$$

In a 0.9-m (3-ft) thick ice layer, this represents a compressive stress in the ice of 8.4 kg/cm^2 (18.7 lb/in^2), which is far below the maximum compressive stress that the floating ice sheet could achieve. Therefore, the possibility for ice ride-up for this embankment configuration appears very likely at first sight. However, the available

1 If the ice is riding upon ice that previously rode up slope, or is riding over a snow-covered slope, the coefficient of friction will be in the range of 0.03 to 0.1.

analysis indicates that a moving (non frozen-in) ice sheet is quite weak in flexure.

Croasdale et al. (1978) provide a theoretical relationship between the sliding resistance and the condition for flexural failure in the ice sheet, and derive the necessary condition for ice ride-up to be:

$$0.68 \ \frac{\sigma}{Z} \frac{(t)}{E}^{0.25} \quad (\gamma_{ice})^{-0.75} \quad (\sin\beta - \mu \cos)^{-1} \ \geq 1 \qquad (3)$$

where Z is the embankment freeboard

σ is the critical flexural stress

and E is the Young's Modulus for the ice

Of the parameters in the above equation, the flexural stress is clearly the most important. The other material property, E, may not be well-defined and enters the expression under a fourth root; therefore, errors in this property will not be as important. The following typical material properties and geometric embankment properties were assumed:

$E = 453{,}600$ kg/cm^2 (1,000,000 lb/in^2)
$\sigma = 45$ kg/cm^2 (100 lb/in^2)
$Z = 5.4$ m (18 ft)
$t = 0.9$ m (3 ft)
$\gamma_{ice} = 25$ kg/m^3 (56 lb/ft^3)
$\beta = 1.5$ (11.3°) $\mu = 0.3$

The left hand side of Equation (3) is calculated to be 0.66, which is less than 1, indicating that for a failure stress inflexure of 45 kg/cm^2 (100 lb/in^2) ice ride-up is not possible for the parameters selected. However, bearing in mind that this criterion is directly proportional to the flexural failure stress, and also varies inversely with the friction coefficient, u, small changes in these parameters could increase the left-hand side of Equation (3) to greater than unity. The above analysis is not presented as a design calculation, but rather to illustrate some of the more important design parameters involved, and to indicate that ice ride-up is a possibility for the proposed embankment configuration.

The criterion expressed by (3) suggests that low angle slopes and low freeboards favor the occurrence of ice ride-up. This is consistent with observations of ride-up on beaches to heights of 1.8 - 2.7 m (6 - 9 ft) above sea level. The higher freeboard and steeper slope proposed for the causeway extension are certainly less favorable for ice ride-up than conditions at natural beaches where ride-up has been observed. However, in view of the fact that the above calculations indicate that conditions for ice ride-up to the crest of the embankment could be achieved with a reasonable combination of input parameters, it is advisable to consider some of the design alternatives available to inhibit ice ride-up.

5.0 DESIGN TO LIMIT ICE RIDE-UP

Conceptually, several methods of limiting ice ride-up might be considered. Practically, however, only one or two of these may receive further consideration because of economic considerations or a need for further study of local ice conditions.

Increasing the freeboard and steepening side slopes are geometric changes suggested by the ride-up criteria discussed in the previous section. These are particularly expensive, however, in view of the considerable extra volumes of fill required, and may not be as cost-effective as some of the methods considered below.

A compression instability in the ice can be caused by constructing a "bump" in the slope. If the ice pieces are disturbed sufficiently out of the plane of the slope as they ride up, an instability and resulting pile-up can be induced. The height of the bump, e, can be calculated from an expression given by Croasdale et al. (1978):

$$e = \frac{L^2 \gamma_{ice}}{2\,\sigma_c} \tag{4}$$

where L = length of ice pieces

σ_c = stress in ice sheet due to sliding resistance on slope

Unfortunately, this expression depends on the square of the length of ice pieces, and is therefore difficult to use in practice. As an example, for ice pieces up to 4 m (12 ft) long and 0.9 m (3 ft) thick, the following calculations can be carried out for these parameters:

L = 4 m (12 ft)

γ_{ice} = 25 kg/m^3 (56 lb/ft^3)

The stress in the ice sheet for a 30 m (100 ft) long sloping 1:5 embankment has been calculated previrusly to be 3728 kg/m (8230 lbs/ft) run, and this translates to a stress, σ_c, equal to 8.6 kg/cm^3 (19 lb/in^2) for a 0.9 m (3-ft) thick ice sheet. Equation (4) gives the required height of "bump" in the embankment slope e = 45 cm (17.7 in) or approximately 0.4 m (1.5 ft). Therefore, a bump of this height, if suitably armoured against the action of sliding ice, would cause a compression instability in ice pieces up to 4 m (12 ft) long as they rode up the embankment slope.

Jamming of the ice can be caused by a sudden increase in embankment slope angle. This is caused by the sudden increase in slope resistance. The required angle of the steeper slope, λ, for jamming to occur is given by:

$$\lambda = \tan^{-1} \frac{(1)}{\mu}$$

where is the coefficient of friction at the ice/embankment contact as before.

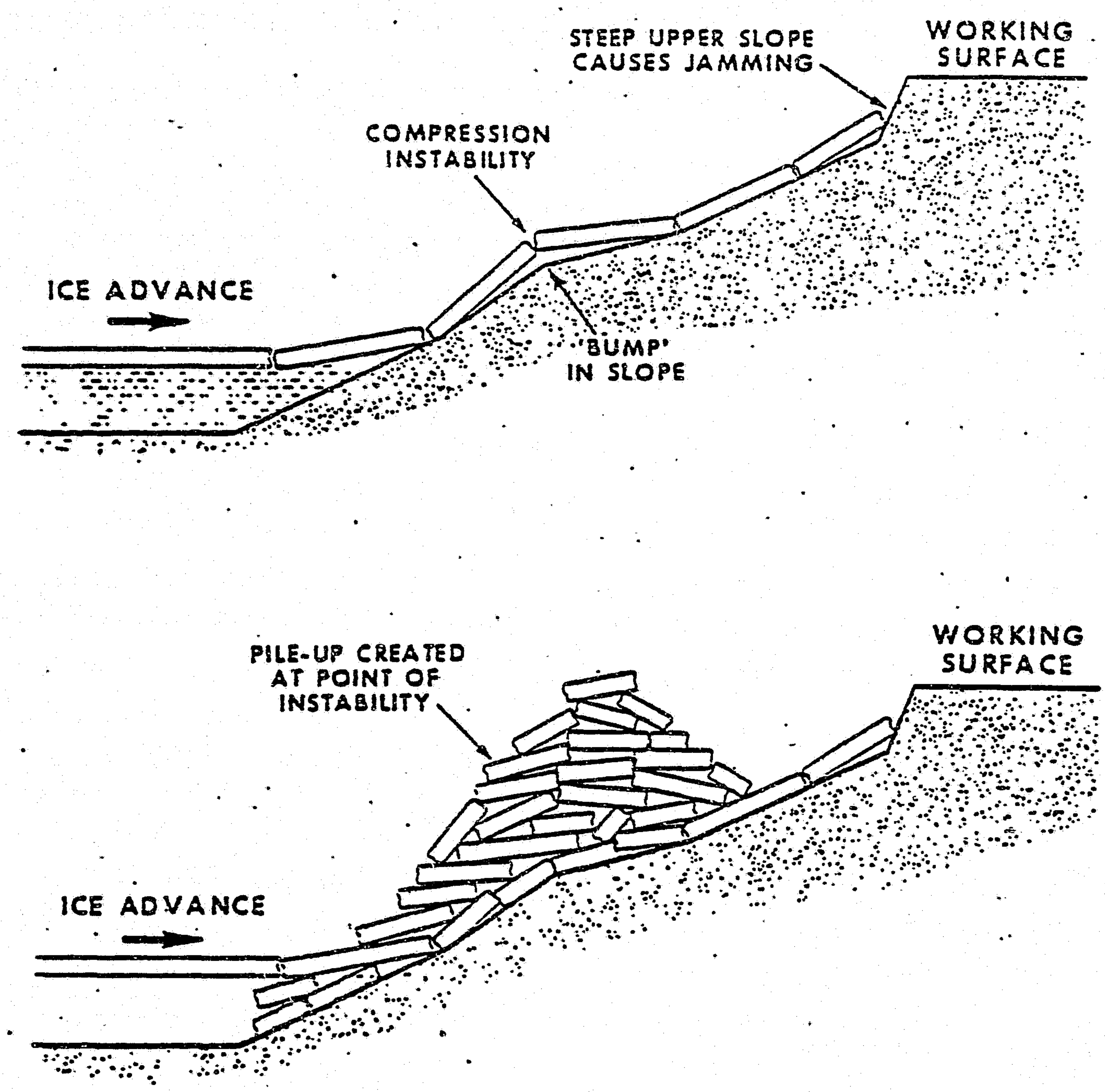
This does not appear to be a practical design measure on its own, however, because of the high slope angle required. For example, for a typical sliding resistance of $\mu = 0.3$, the slope angle λ would have to be 73°. As it is difficult to maintain stable slopes in gravel in the long term much above 30°, it is difficult to see how this measure could be employed without introducing some vertical caisson or concrete structure into the embankment design.

Obstacles can be placed on a side slope to discourage ice ride-up. Steel piles have been placed on the beach of an artifical drilling island in the Beaufort Sea by Imperial Oil to protect the drilling rig during spring breakup. In that case, however, the ice was weak and an ice rubble pile formed at the water line and the piles were not required. If vertical steel piles were considered as a measure to inhibit ride-up, they would have to be designed as a group to resist the flexural strength of the ice sheet developed at the water line.

In summary, the most feasible method of limiting the possibility of ice over-riding the working surface of the embankment would appear to involve a slope change somewhere in the central area of the side slope, possibly coupled with a steep upper slope formed with gravel, rip-rap or sheet piling. As shown on Figure J-2, the measures would be designed to cause a pile-up at some distance away from the working surface. This method may have practical limitations, nonetheless, such as:

- Snow may fill the depressions and be relatively hard by breakup, the time of major concern.

- Ice has over-ridden rubble piles in areas of rapid ice movement and therefore could conceivably ride up over itself if movements were large enough.



(after Croasdale et al, 1978)

DESIGN TO RESIST RIDE-UP

PBU Waterflood Environmental Impact Statement | Figure J-2

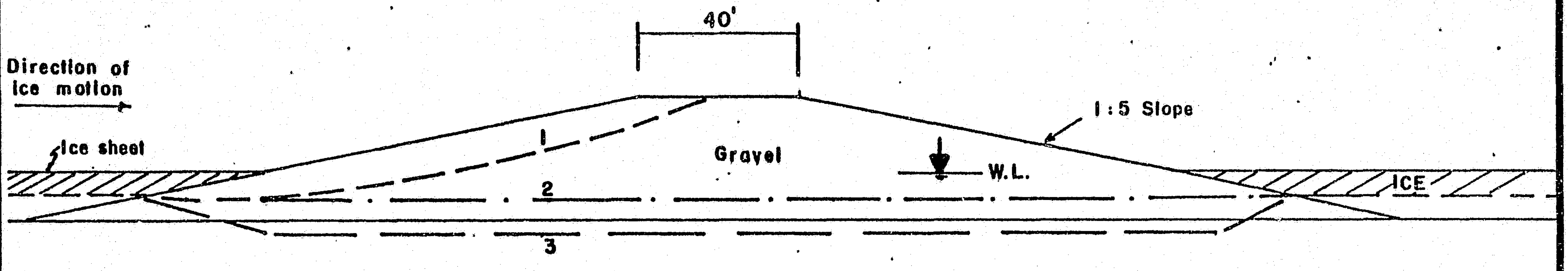
- Summer maintenance would be required to insure the integrity of the slope angle and slope change.

The proposed design as it stands combines certain features of merit in limiting ice ride-up, namely a long embankment side-slope and high freeboard. However, the possibility of ice ride-up affecting the working surface is present, based on the simplified analysis and typical parameters used earlier. Whether or not the design measures described above should be implemented will depend on a more complete study of ice properties and local ice conditions.

6.0 EMBANKMENT STABILITY AND GEOTECHNICAL ASPECTS

EMBANKMENT STABILITY

Assuming that the ice sheet will fail in a crushing or ductile flow mode, and that a value for ice compressive strength can be assigned to the ice sheet, it is necessary to consider the stability of the embankment from a purely geotechnical standpoint. Figure J-3 shows three possible failure modes in the embankment: edge slope failure, basal failure through the embankment, and a foundation failure in the soils beneath the embankment. Each can be assessed using well-established limit equilibrium techniques, provided the effective strength parameters for the granular fill and the foundation soils are known. After about one season, the possibility of edge failure (Mode No. 1) will be greatly reduced due to natural freezeback in the embankment. After some years, the possibility of basal embankment failure (Mode No. 2) will also be greatly reduced for the same reason. The possibility of a foundation failure occurring depends largely on the nature of the foundation soils. If they exhibit strength properties similar to the fill, then the possibility of this mode of failure is remote. However, if they are fine-grained silty clay or clay soils, their strength properties are considerably weaker than the fill material and this mode of failure may be a cause for concern.



POSSIBLE MODES OF FAILURE IN CAUSEWAY

1 Edge slope failure

2 Basal failure through embankment

3 Foundation failure beneath embankment

Figure J-3

POSSIBLE MODES OF FAILURE IN CAUSEWAY

Very preliminary estimates indicate that if the fill material has an effective friction angle of 35°, and the water table is at the elevation of the ice surface, the embankment resistance to a lateral ice sheet is on the order of 220 kips/ft run of embankment when considering the edge slope failure mode. Using the same assumption, a basal failure surface parallel to the base of the ice sheet provides a resistance of about 280 kips/ft, which is greater than Mode 1. Therefore the edge slope failure mode is more critical, but will only remain so perhaps during the first winter or two of operation. The foundation failure mode will only provide a lower resistance than the edge failure mode if the effective friction angle of the foundation soils is less than about 23° (i.e. tan $\emptyset'$ less than 0.42). This would be realized only if the foundation soils are silty clay or clay.

These estimated values for embankment resistance can be placed in perspective by considering an ice sheet 1.8 m (6 ft) thick, and imposing an average stress of 91 kg/cm^2 (200 lb/in^2) either due to crushing failure in the ice or ductile yielding (creep) of a slowly moving ice sheet. This would give rise to an ice sheet force of 172 kips/ft on the side of the embankment. These forces are in the same order and slightly below the embankment resistance values estimated above, and therefore the possibility of embankment instability is a definite concern, if an ice sheet of this thickness can show appreciable movement during the winter season.

SETTLEMENT OF EMBANKMENT

The nature of the foundation soils will also govern the amount and rate of settlement that the causeway and the supported facilities will experience following construction. This may be of concern from two standpoints, namely: (a) the amount of extra fill that may have to be placed either initially or later to maintain the design grades in the embankment, and (b) the possibility of damage or disruption to facilities that could result from time-dependent (consolidation) settlements in the near surface soil layers.

FROST EFFECTS

Exposure of the embankment surface above water level will cause an aggradation of permafrost into the embankment at this location. Depending on the percentage of fine particle sizes in the gravel fill, some relatively minor movements due to frost heave in the re-freezing embankment may occur for the first few years following construction. After several years, depending on the rate of freezeback in the embankment, the frost line will penetrate to the seabed materials. If the seabed soils are gravels, sands or silty sands, the 9-m (30-ft) thick overburden will limit the resulting frost heave to a relatively minor amount. However, if the seabed soils have a high percentage of silt and clay-sized particles, a concern for frost action may exist. Depending on the sensitivity of the supported facilities to the surface expresssion of deep-seated movements, frost heave in the subsoils may prove a concern several years after the causeway is in service. Movements of several centimeters would not be unreasonable in later years if the seabed soils are generally fine-grained. Careful design may be required to ensure the integrity of the treating plant and utility lines embedded in the embankment.

REFERENCES

Allen, J.L., 1970. Effective force of floating ice on structures Nat. Res. Council, Tech. Memo 98. p. 41.

Bruun, P.M., and P. Johannesson, 1971. The interaction between ice and coastal structures. Proc. 1st Intl. Conf. on Port and Ocean Energy and Arctic Conditions. University of Trondheim, Norway.

Croasdale, K.R., and R.W. Marcellus, 1978. Ice and wave action on artificial islands in the Beaufort Sea. Canadian Journal of Civil Engineering 5, p. 98.

________, M. Metge, and P. H. Verity, 1978. Factors governing ice ride-up on sloping beaches. Pt. I, Proc. IAHR Symposium on Ice Problems, Lulea, Sweden, August.

Frederking, R. and L. Gould, 1975. Experimental study of edge loading of ice plates. Can/. Geotech. J. 12, p. 456.

Hanson, A., 1978. Private communication cited by Croasdale et al. (1978). Naval Artic Research Laboratory, Barrow, Alaska.

Hayley, D.W. and R.H. Sangster, Geotechnical aspects of offshore drilling islands. Proc. 27th Can. Geotech. Conf. November, Edmonton, Alberta.

Jahns, H.O., 1979. Production islands. In: Technical seminar on Alaskan Beaufort Sea gravel island design. October, 1979, Anchorage.

Michel, B., 1970. Ice pressure on engineering structures. U.S. Army CRREL Monograph III-B1b.

Ralston, T.D., 1979. Sea ice loads. In: Technical seminar on Alaskan Beaufort Sea gravel island design. October, 1979, Anchorage.

Shapiro, L. and W. Harrison, 1976. Mechanics of origin of pressure ridges, shear ridges and hummock fields in landfast ice. Annual report, Contract No. 03-5-022-55, Geophysical Inst. University of Alaska, Fairbanks, March 1976.

APPENDIX K

RESERVOIR ENGINEERING[1]

1.0 INTRODUCTION

The Prudhoe Bay oil field was discovered in 1968, but production did not commence until completion of pipeline facilities in June 1977. In January 1980, the 1 billion bbl mark was reached for cumulative oil production.

Production horizons in the field range from Mississippian to Jurassic in age with the most important being a sandstone belonging to the Sadlerochit formation or early Triassic age. Hydrocarbon accumulations in the Sadlerochit reservoir are at sub-sea depths of 2438 - 2743 m (8000 - 9000 ft). Within the formation, the oil column reaches a maximum of 140 m (460 ft), with a gas cap that overlies approximately two-thirds of the oil column. The productive limits of the reservoir encompass approximately 65,561 ha (162,000 acres). Hydrocarbon volumes contained in the reservoir are estimated at 0.6 trillion m^3 (21.2 trillion ft^3) of gas in the gas cap, 400 million m^3 (13.9 trillion ft^3) of solution gas, 729 million bbl of gas cap condensate, and 20.5 billion bbl of oil.

2.0 PRODUCTION POTENTIAL

Any oil reservoir is a complex system containing a variety of fluids, rock properties, and energies inherent in the fluids (FERC 1979). The Sadlerochit reservoir is made even more complex by the sheer magnitude of its size. The apparent size of the Prudhoe Bay field and the potential impact it could have on the U.S. domestic energy supply made

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1 Derived from Helton Engineering and Geological Consultants (1980), Prudhoe Bay Unit waterflood project reservoir engineering. Prepared for Dames & Moore.

it almost mandatory that an elaborate and intensive geologic and engineering study be conducted, utilizing some form of numerical simulation in order to accurately describe the reservoir and project its producing potential. Work of this nature has been in progress for approximately the last 10 years (Wadman et al. 1979).

Studies have been conducted independently by the Prudhoe Bay Unit owners and by the Alaska Oil and Gas Conservation Commission (AOGCC). In each of these studies, an attempt was made to build a mathematical model based on acceptable engineering fundamentals encompassing the entire reservoir and accounting for all known or estimated variables. Ultimately, the models evolved as three-dimensional, three-phase (oil, gas and water), comprehensive re-constructions of the reservoir. To date, all have arrived at approximately the same conclusions.

Briefly stated, the more pertinent of these conclusions are as follows:

1. The main Prudhoe Bay field, Sadlerochit formation, contains about 20.5 billion bbl of oil and 1.1 trillion m^3 (40 trillion ft^3) of gas (gas cap and gas in solution).

2. Primary recovery, or natural depletion, should produce about 35 percent of the oil-in-place, or 7 billion bbl. This assumes injection of produced water and injection of gas not sold, assuming gas sales of 56 million m^3/day (2 billion ft^3/day).

3. Gas production through natural depletion would be about 65 percent of the gas-in-place or 731 million m^3 (26 trillion ft^3). This represents sales gas taken at a rate of 56 million m^3/day (2 billion ft^3/day), commencing 5 years after initial production.

4. Economic life of the field, after a maximum initial production rate of 1.5 million bbl/d, with a natural decline and under the above conditions, would be about 26 years.

5. Well recompletions could improve both oil rate and ultimate recovery, and consequently extend field life. However, this factor is believed to have little bearing on the magnitude of additional oil recovery attainable by source water injection.

6. Source water injection would increase oil production by 5 - 9 percent of the oil-in-place, or 1 - 1.8 billion bbl, and gas production or sales by about 15 percent of the gas-in-place, or 170 million m^3 (6 trillion ft^3). These figures assume gas sales to commence as stated above and source water injection of 2 million bbl/d to commence 5 - 10 years after initial production.

7. Improvement in oil recovery could be as much as 3 percent of the oil-in-place, or 600 million bbl, by commencing source water injection prior to initiation of substantial gas sales. Delaying water injection beyond early 1985 would become a progressively serious consequence by as much as 0.5 - 1.0 percent per year of the oil-in-place. Gas sales should not commence prior to start-up of source water injection.

3.0 PRIMARY RECOVERY

Primary recovery, or natural depletion, at the Prudhoe Bay field is principally through the mechanism of gravity drainage (Wademan et al. 1979). Under the proper reservoir conditions, this can be the most efficient means of depletion by natural causes (Frick 1962). In addition, an expanding gas cap can be most beneficial in the early stages of oil production as its energy can be used to push oil to the principal oil producing areas of the field. Available data indicate that this is the case in many portions of the Prudhoe field. The producing formation appears to be of the type that has historically provided highly efficient oil production by gravity drainage. Examples of note would be Wilcox Reservoir, Oklahoma (estimated to yield 57 percent of the oil-in-place under gravity drainage) and the Lakeview Pool, California (estimated to have a 63 percent recovery factor)

(Frick 1962). While these examples may be extremes, they illustrate that a 35 - 36 percent primary recovery factor for Prudhoe Bay is a reasonable estimate.

Efficient recovery under the conditions existing in this reservoir, however, requires proper management of fluid withdrawals. Rapid or uncontrolled withdrawals from the oil or gas cap zone can create an excessive pressure drop that can reduce ultimate oil recovery. The results of such fluid withdrawals include:

1. Migration of the gas-cap into a lower pressure oil zone resulting in high gas-oil ratios and possible premature shut-in of oil producing wells.

2. Gas in solution in the oil zone is held in solution by pressure, providing energy to the oil phase and assisting its movement to the well bore. As pressure declines, this gas breaks out of solution and its value as an oil producing agent can be lost.

3. Oil that migrates to the gas cap zone is lost for production purposes, due to its dispersion in the gas.

These situations can never be completely avoided; however, certain steps can be taken to postpone their premature occurrence and consequently improve the ultimate oil recovery. The most prominent and widely used techniques are injection of gas and/or water (Interstate Oil Compact Commission 1974).

Injection of produced gas at the Prudhoe field has been underway since production commenced and will continue until a gas sales pipeline is completed (tentatively estimated for mid-1985) (AOGCC 1980). Approximately 57 million m^3/day (2 billion ft^3/day) would be committed to the pipeline. The remainder, after fuel usage, would be injected. Under these circumstances, over 50 percent of the gas-in-place would be sold. With approximately 10 percent (15 percent to date) being consumed as fuel or lost in process, relatively little of the original gas-in-place would be left in the reservoir. The benefit to the reservoir during its early stages of production with this gas injection program is significant. Pressure is maintained for a considerable time at a level conducive to aiding oil recovery by keeping gas in solution and assisting the gas cap expansion process. When gas sales commence, however, at the projected rate, it appears that it would be prudent to commence with a water injection program.

4.0 SECONDARY RECOVERY

Injection of water in substantial quantities could accomplish pressure maintenance and secondary recovery.

Waterflood is a secondary recovery method in which water is injected into a reservoir to obtain additional oil recovery by displacing oil with water and supplementing the natural energy indigenous to the reservoir.

At Prudhoe Bay, oil recovery will be increased primarily by the displacement mechanism and to a lesser extent by the reduction of overall reservoir pressure decline. Water would be injected in those portions of the reservoir where the primary recovery mechanisms will be less efficient.

Waterflooding, as an oil producing mechanism, has existed for over 100 years; however, it was not until the early 1940's that the technique made significant gains. Virtually every oil field of significant size that does not have a natural water drive, has been, is being, or will be waterflooded. It has been recently estimated that over 50 percent of the domestic U.S. oil production is a result of water injection programs (Interstate Oil Compact Commission 1974).

In determining the suitability of a given reservoir to waterflooding or pressure maintenance the following factors must be considered:

- Reservoir geometry
- Lithology
- Reservoir depth
- Porosity
- Permeabilities
- Fluid properties
- Continuity of reservoir properties
- Magnitude and distribution of fluid saturations

The influence of these factors on ultimate recovery, rate of return, and ultimate economic return must be considered collectively to evaluate the economic feasibility of conducting waterflooding and/or pressure maintenance operations in a particular reservoir. Factors other than reservoir characteristics will also have a great influence. These would include the price of oil, marketing conditions, operating expenses, and availability of water (Frick 1962).

All the preceding factors and conditions have been subjected to extensive in-depth analysis and review, subsequently becoming integral parts of various reservoir simulation models. Modeling results conclude that water injection at the Prudhoe Bay field can be economically beneficial in improving oil recovery by approximately 5 percent of the original oil-in-place, or 1 billion bbl.

Achieving this additional oil recovery will depend to a great extent on the accuracy of current appraisals, which only additional drilling, production performance, and other technical analyses can provide. To date, the original performance projections conducted prior to June 1977, are well within acceptable range of actual field performnce (DNR 1980).

There are, however, some areas of concern that could be of increasing significance. These being:

SHALE BREAK CONTINUITY

The producing formation is broken up in certain areas of the field by four major layers of shale (Wadman et al. 1979). If these shale zones ultimately prove to be continuous over wide areas of the field, the gravity drainage mechanism, so important to the primary recovery phase, could be seriously restricted. Vertical permeability (the transmissibility of fluids in a vertical direction) is an extremely important factor with thick oil columns (such as exist at Prudhoe Bay) that depend on a gravity drainage process for oil recovery. Additional drilling and production performance, along with periodic pressure surveys, will provide the information needed to assess this potential problem. For the present, breaks have been incorporated in various model studies, based on current data, and no serious detrimental effect is foreseen (Wadman et al. 1979). Should time and more information indicate otherwise, then the importance of water injection would become even more significant. If the effect of gravity drainage is substantially reduced, and the gas sales proceed as scheduled, the only practical method of providing the energy necessary to move oil to the producing wells would be with water injection displacement. A need for water injection is already anticipated in those areas of the field where shales are known to exist (Wademan et al. 1979).

WITHDRAWAL RATES

The high gas-oil ratios in the eastern portion of the field (drill site 9), could be evidence of excessive withdrawal rates that could result in the dissipation of gas cap or solution gas energy and a subsequent loss of oil production. It has been reported, however, that the geology in this area may be responsible for this situation (DNR

1980). Pressure surveys reported in August 1978 and again in August 1979 would indicate this to be the case, as no serious deterioration in pressure in that particular area occurred in the several months of production that took place.

START-UP TIME FOR A WATER INJECTION PROGRAM

As currently scheduled, water injection would commence during the second quarter of 1984 (PBUWTF 1979), approximately 7 years after initial production, or after a cumulative oil production of about 3.5 billion bbl. While the optimum time for water injection start-up is highly debatable, it would appear that any substantial delay could be extremely detrimental to maximum oil recovery. However, this depends, to a large degree, on the timing of gas sales. As long as produced gas is re-injected into the gas cap, the effects of gravity drainage and the expanding gas cap would prevail and oil production would be highly efficient. In fact, premature water injection could be detrimental to a gravity drainage mechanism (Frick 1962). Once gas sales commence, however, the decline of reservoir pressure would accelerate and the timing for the start of water injection would become more critical. If water injection were delayed until 1990 and gas sales commenced in 1985, the reservoir would be well into its natural decline, some 30 percent of the oil-in-place would have been produced, and oil recovery would be increased only 2 - 3 percent. In addition, some areas of the field will not respond as expected to the gravity drainage/gas-cap-expansion mechanism. Therefore, water injection capability would be needed for selective areas before the 1984 scheduled time as available quantities of produced water would be insufficient for any extended injection program.

5.0 ALTERNATE RECOVERY METHODS

Several other methods of oil recovery exist (most of which are still considered to be in a developmental stage) but most are generally considered as tertiary recovery techniques. That is, applicable to a given reservoir after primary and secondary recovery (waterflooding) has been completed.

POLYMER FLOODING

Actually an adjunct to waterflooding, this method involves the mixing of polymeric chemicals with the injection water. This results in the water being more viscous than the oil and thereby improves the displacement efficiency of the water. The best applications are in reservoirs containing more viscous crudes than found at Prudhoe Bay. The minimum concentrations usually recommended are 0.04 kg/bbl (0.1 lbs/bbl) of injection fluid. In this case, with a planned injection rate of 2 million bbl/d, upwards of 90,720 kg/d (200,000 lbs/d) of chemical would be required for approximately 5 years. This would not be feasible from a logistical or economical standpoint when the degree of increased oil recovery would likely be minimal.

CARBON DIOXIDE

As much as 12 percent of the gas produced at Prudhoe is carbon dioxide. This CO_2 would be processed out of the gas when gas sales commence. Most previous instances of CO_2 injection have been as secondary recovery mechanisms in conjunction with water injection and its merits are still being evaluated. The quantities of CO_2 available at Prudhoe are substantial relative to sizeable projects being presently conducted in the U.S. (Herbeck et al. 1976, Kane 1979) and it is possible that this product could improve ultimate recovery. It would appear, however, that the true benefits of CO_2 injection are best utilized in reservoirs with low primary recovery factors and relatively low operational costs (Herbeck et al. 1976), which is certainly not the case at Prudhoe Bay. Highly corrosive carbonic acid is formed when CO_2 is combined with water, necessitating special metal alloys and coatings for facilities. When alternate injection of CO_2 and water is used, dual injection systems are required - one for CO_2 and one for water (Herbeck et al. 1976). The case for CO_2 injection at Prudhoe appears doubtful because the CO_2 would not be miscible with the oil, making the potential for incremental recovery quite small.

CAUSTIC FLOODING

Caustic has been utilized largely on an experimental basis with no reported outstanding success. Its function is primarily to alter the characteristics of the reservoir rock to permit the flow of oil preferential to water. Since Prudhoe reservoir rock is already preferential to oil flow, it is doubtful that any significant benefit can be gained with this technique.

STEAM INJECTION

Injected steam is used primarily to heat the reservoir to a temperature that lowers the viscosity of the oil, thereby allowing it to move more easily to the well bore. The practical application of steam is limited to low gravity (less than 20° API) crude oils in relatively shallow depths (less than 914 m, 3000 ft) (Interstate Oil Compact Commission 1974). These conditions do not exist at Prudhoe. The economical and environmental consequences of steam generation and injection through a layer of permafrost would seem to preclude its consideration.

IN-SITU COMBUSTION

This is a process whereby the oil zone is actually ignited. A burning front is maintained and propagated through the reservoir by pumping compressed air down the wells. Oil viscosity ahead of the flame front is lowered, allowing the oil to move more freely to the producing wells while being pushed along by the injection of the compressed air. There is little evidence in available technical literature supporting the economic viability of this process, although undoubtedly there are some successful projects currently in progress. The Glen Hummel Field in Wilson County, Texas, has been referred to as a successful project although no economics have been reported. The Battrum Field in Saskatchewan, Canada, has been reported as a commercial application of the process (Interstate Oil Compact Commission 1974). For the Battrum project, it is estimated that the initial investment for compressor stations was 22 times that for waterflood stations. Operating expense for the stations was estimated at 7 times that for waterflood stations. Also, the investment needed for fireflood wells and surface facilities are considerably greater than those for waterflooding due to handling fluids that are foaming, emulsified, and corrosive (Coleman and Walker 1967). In both of these fields, primary recovery was low (less than 15 percent of oil-in-place) and they produced a low gravity, viscous, crude oil (18° - 21° API).

MICELLAR SOLUTION (CHEMICAL FLOODING)

This is primarily a tertiary process that can be successfully applied to reservoirs that have been successfully waterflooded. The micellar, or chemical, solution is actually a surfactant (surface-active-agent) type material. These agents are petroleum based or manufactured from hydrocarbons, and act on the reservoir rock like a detergent, or soap. They are effective in removing oil from the reservoir rock, but to efficiently move that oil to the well bore the solution must be followed by a polymer solution. This means that large quantities of two expensive chemicals, directly related in cost to the price of crude oil, must be made available. However, in order to provide some basis for conjecture, it might be well to discuss a hypothetical situation. Assume that after waterflooding some 12 billion bbl of oil are still in the ground at Prudhoe. It has been stated that a 40 percent recovery factor of the oil-in-place might be acheived in certain reservoirs of this type with this process (Herbeck et al. 1976). That could imply an additional 4.8 billion bbl at Prudhoe. Projected cost, assuming a somewhat limited chemical and polymer slug, could be in the range of $20 billion for the chemical solution and an additional $10 billion for the polymer solution. There is currently no surfactant available that is suitable for the high temperatures in the Prudhoe field (180 - 210°F). Logistics would also pose a problem, since up to 10 millions lb/d could be needed to treat a million bbl/d of water.

GAS INJECTION

Gas injection is already in effect at Prudhoe and will continue until a gas pipeline is ready to accept deliveries. The additional oil recovery that might be gained by continuing gas injection with no sales to the pipeline would probably not outweigh the benefits of the 56 million m^3/d (2 billion ft^3/d) of 1000 BTU gas, or 731 million m^3 (26 trillion ft^3) total that would have been sold during the life of the oil rim. While gas injection maintains significant importance to this reservoir in its early life, its usefulness reaches a point of diminishing returns when gas is cycled in and out of the reservoir with very little oil movement. Because gas is also more mobile in reservoir rock than water, it is a less effective displacement mechanism. Energy requirements to re-inject gas with no gas sales would equal or exceed 100 million bbl of oil.

REFERENCES

Coleman, D.M., and E.L. Walker, 1967. Battrum fire flood encourages Mobil, Canadian Petroleum, December.

AOGCC (Alaska Oil and Gas Conservation Commission), 1980. Personal communications with personnel of the Division of Oil and Gas.

FERC (Federal Energy Regulatory Commission), 1979. Environmental impact statement, draft, sales gas conditioning facility, Prudhoe Bay Unit, Appendix 'A'.

Frick, Thomas C., 1962. Petroleum Handbook, Vol. II.

Herbeck, E.F., R.C. Heintz, and I.R. Hastings, 1976. Fundamentals of tertiary oil recovery, Petroleum Engineer.

Interstate Oil Compact Commission, 1974. Secondary and tertiary oil recovery porcesses, Sept., 1974.

Kane, A.V., 1979. Performance review of a large scale CO_2 -wag enhanced recovery project, Sacroc Unit, Kelly-Snyder field. Journal of Petroleum Technology, February.

PBUWFT (Prudhoe Bay Unit Waterflood Task Force), 1979. Overview, Vol. I., Dec.

Wadman, D.H., D.E. Lamprecht, and I. Mrosovsky, 1979. Joint geologic engineering analysis of the Sadlerochit Reservoir, Prudhoe Bay Field, Journal of Petroleum Technology, July.

APPENDIX L

TERRESTRIAL HABITAT MAPPING AND EVALUATION

1.0 INTRODUCTION

Terrestrial resources within the primary and secondary Waterflood Project impact zones are of national significance because of their combined values to migratory birds, caribou and small mammals, and because of the beneficial functions of wetlands.

Substantial research has been conducted in relation to various aspects of the Prudhoe Bay terrestrial environment including studies of the distribution of plant communities, plant ecology, and wildlife habitat preference. In order to accomplish the environmental planning and impact analysis stages of the EIS process, this information was consolidated into an explicit assessment method. The approach relied heavily on vegetation and soils mapping as a basis of information. Various data, along with professional judgement, were applied to evaluate resource and impact significance. Using an interdisciplinary approach, project elements were modified to lessen adverse environmental effects, and unavoidable resource losses were documented.

It should be noted that the method developed in this appendix was designed to be used only as an aid in assessing ecological impacts and planning site locations. Other values and approaches are also applicable to environmental assessment and siting aspects of the Waterflood Project and should not be excluded by these procedures.

2.0 MASTER HABITAT MAPS

The most comprehensive attempt to classify and map landscape features in the Prudhoe Bay region has been developed by the Institute of Arctic and Alpine Research (INSTAAR) in cooperation with the scientists at the U.S. Army Cold Regions Research and Engineering Laboratory

(CRREL) and Ohio State University. This mapping effort, combined related mapping elements (landform units, soils characteristics, and plant communities) in the production of detailed master habitat maps (Everett 1975; Webber and Walker 1975; Everett et al. 1978; Walker et al. in press). Substantial portions of the Prudhoe Bay development area were mapped according to this system prior to the Waterflood Project permit application. A specific study was initiated to apply the existing mapping to those areas within the Waterflood Project zone of influence and to expand the mapping to include project facilities outside the mapped area. The mapping zone included an area of about 500 m (1520 ft) around each site where terrain disturbance was anticipated. In addition a zone of 500 m (1520 ft) on either side of proposed pipeline/road corridors was mapped (Figure L-1).

For those project sites within the area already mapped according to the detailed master map system, the legends were adapted directly from the Geobotanical Atlas of the Prudhoe Bay Region (Walker et al. in press). The landform-soil-vegetation boundaries on these maps were extracted from the maps contained in the atlas. Cultural features and disturbance boundaries were updated using 1979 color photography of the region. Information codes on the master maps were expressed in fraction form:

$$\frac{\text{Vegetation Stand Type(s)}}{\text{Soil Unit, Landform Unit, Slope}}$$

The numerator consisted of one or more letter-number complexes which denoted the plant communities present (Table L-1). On the maps more than one vegetation code may appear as part of a master map fraction. This indicates a mosaic of vegetation (a vegetation complex) with the first code denoting the dominant plant community. Additional codes indicate other communities covering more than 20 percent of the map unit. The denominator was usually composed of a three number and/or letter code that from left to right indicates soil type, landform type and slope (Table L-2). When the slope was relatively flat (0 - 2 percent), the third number was omitted from the fraction.

Disturbed areas, outlined by a dotted line, were commonly given two designations: one indicating the plant community that was originally present, and one indicating the type of disturbance that has since affected the areas. Disturbances, such as the presence of gravel or construction debris, vehicle tracks, winter roads and ponding were included (Table L-1).

Detailed habitat mapping was not available for 18 out of a total of 34 drill sites, manifold pads and gravel sites or for the major portion of the east and west pipeline corridors (Table L-3). Therefore, master habitat maps were created for these sites based on interpretation of aerial photographs. A slightly modified landform legend was utilized and the vegetation legend is based only on site moisture and vegetation physiognomy. No slope codes are contained in the master map fractions. Also, the symbols denoting undercut river banks and excavated areas have not been incorporated on these maps. The vegetation legend is based on land cover categories proposed for a LANDSAT mapping program on the Alaskan Arctic Slope (Walker 1980). These categories are more general than the vegetation designations used in the previously mapped areas in that no floristic information is contained in the unit names. However, the legend does contain a general description of each vegetation category along with equivalent stand types from Walker et al. (in press). These general cover categories and their equivalents in terms of the detailed plant community units are listed in Table L-4. Field verification of the photo interpretation will take place during the summer of 1980 and necessary corrections will be made at that time.

A complete set of master maps (Figures L-2 through L-35) is included with this appendix (with wetland communities indicated; Section 3.0).

3.0 RESOURCE VALUE AND SENSITIVITY MAPS

Five categories of resource value or sensitivity were selected for specific consideration: wetland contributions, primary productivity, saltwater sensitivity, bird habitat value, and mammal habitat value. The categories were chosen on the basis of statutory requirements (e.g. wetlands), ecological importance, and applicability to Waterflood Project impact analysis. Each of the categories was analyzed utilizing the master habitat information and thematic maps were prepared for each on the same map base as was used for the master maps.

WETLAND AND OPEN WATER HABITATS

Specific plant assemblages including wetland types in the vicinity of pads, drill sites and corridor areas are shown on the master habitat maps. Specific wetland communities have been combined to produce generalized categories based on the amount of moisture present. These categories are: moist meadows (coastal and river/stream/floodplain communities), wet meadows (non-saline and saline graminoids), lake/pond communities (*Carex aquatilis* and *Arctophila fulva*), open-water zones, and flooded areas resulting from disturbance. This wetland classification is according to terminology adopted by the U.S. Army Corps of Engineers, Alaska District.

Table L-5 describes site characteristics and species composition of the general wetland categories and provides the corresponding detailed and general classifications that were used for wetland mapping purposes. Wetlands of 16 drill pads and gravel sites were mapped in detail at the plant community level and another 18 pads and gravel sites along with east and west road and pipeline corridors were mapped according to the more general land cover category groupings. A complete set of wetland community maps was prepared on the master map bases and is included in this appendix (Figures L-2 through L-35).

PRIMARY PRODUCTIVITY

One indicator of the potential relative value of plant communities is net primary productivity, i.e. the rate at which a plant community produces organic matter over and above that required to maintain its metabolic requirements. As with most coastal plain tundra there is a strong positive correlation between increasing site moisture and production. There is no simple relationship between productivity and standing crop. The most productive communities are wet graminoid meadows that have no woody plants. Conversely, dwarf and prostrate shrub communities have a much lower productivity, but a greater standing crop. Productivity in the Prudhoe area has been rated as intermediate between that for Barrow (Webber 1979) and Meade River (Komarkova and Webber 1980).

Productivity is lowest at the coast and progressively increases inland, corresponding to the warming climatic gradient. Thus, on sites with similar moisture regimes, there is an increase in productivity southwards away from the coast. In mesic sites, increased productivity is reflected in the increased abundance and stature of erect deciduous shrubs and associated broad-leaved herbs (Walker et al. in press).

Community net primary productivity and standing crop figures used in the evaluation were estimated based on values in the literature (Webber 1974, 1979; Alexandrova 1970; Bliss 1977; Komarkova and Webber 1980) (Table L-6). Productivity is expressed in terms of annual values for above and below ground production for all taxa. Standing crop values are for peak season and above ground material only. The standing crop comprises live and dead fractions including wood and litter of all taxa.

Plant communities in the vicinity of pads and road corridors were then rated in g/m^2/yr on a scale of 3 according to their relative amounts of annual productivity (Table L-7) and mapped. All pads and corridors were mapped at the general land cover category level (Table L-4) to maintain consistency in the data. The productivity map for the western pipeline/ road corridor is presented in Figure L-36. Productivity maps for the remaining project sites can be viewed at the Corps' Alaska headquarters.

SALTWATER SENSITIVITY

One aspect of habitat sensitivity that is especially applicable to an analysis of potential impacts from the Waterflood Project is the sensitivity of flora to saltwater. If a leak or break should occur in either the low or high-pressure pipelines, a substantial saltwater spill would result. Volumes of up to 16,500 m^3 (4 million gal) of heated (4.4°C, 40°F) saltwater could be spilled from low-pressure pipelines if the break occurred near the module staging area and 1400 m^3 (370,000 gal) could be lost from the high-pressure pipelines.

No definitive studies have been carried out on the tolerance of tundra plants to saltwater spills. However, the effects of storm surges on terrestrial communities at Prudhoe Bay give some indication of the relative sensitivities of the various plant forms and sites. Based on observations of vegetation types typical of the project area, a brine sensitivity scale was devised that rates plant communities according to their relative sensitivities to saltwater during the growing season. This scale was then used to rate the major vegetational communities of the Prudhoe Bay area according to their loss of vigor and their ability to recover (Table L-8).

Saltwater sensitivity ratings were mapped for the locations in the project area where spills are most likely to occur, i.e. the east and west pipeline corridors. Pipeline manifold and drill pad areas were not mapped for brine sensitivitiy, since these facilities have emergency dump areas and the risk of any uncontrolled spill is extremely low.

Mapping was done at the general community grouping category level to maintain consistency in the data (Table L-4). The saltwater sensitivity map for the western pipeline/road corridor is presented in this appendix (Figure L-37). Sensitivity maps for the remaining project sites can be viewed at the Corps' Alaska headquarters.

BIRD HABITAT VALUE

Numerous studies of the bird life of Prudhoe Bay have been conducted. The most significant of these studies from the habitat evaluation standpoint is a study of water birds conducted by Bergman et al. (1977). The Bergman system of water bird habitat classification was relied on heavily during this evaluation because of its relative simplicity and because the system has been used by resource managers for several years. Bergman's studies emphasized waterfowl and very wet habitats. In order to expand the scope to drier habitats, this information was supplemented by data on shorebird nesting densities (Table L-9) collected by Myers and Pitelka (unpublished data). Table L-10 presents the habitat rating system that was developed and relates it to the master map vegetation types and to the Bergman system. Translation of the master maps into the Bergman classification types was assisted by a key prepared by the U.S. Fish and Wildlife Service.

It should be noted that bird habitat value depends not only on vegetation types but also on the pattern of communities. For example, perhaps the most valuable water bird habitat on the Arctic Coastal Plain consists of a complex mixture of community types usually found within drained lake basins. Essential elements of this type include a mixture of emergent vegetation, open water, and drier types in proportions that are favorable to birds. Therefore, the habitat rating system employed in this appendix is to some degree subjective in that objective criteria were combined with judgments regarding community patterns.

Bird habitats were mapped for all project site areas. The map for the western pipeline/road corridor is presented in this appendix (Figure L-38). Bird habitat maps for the remaining sites can be viewed at the Corps' Alaska headquarters.

MAMMAL HABITAT VALUES

Mammal habitat requirements in the Prudhoe Bay area are less well known than bird habitat requirements. Most of the applicable information is summarized in Table L-11 for those mammals that are common residents. Patterns of mammal use are based to a large degree on soil moisture. High, dry terrain is rare on the Arctic Coastal Plain and is essential for those mammals that inhabit underground burrows or dens, such as ground squirrels and foxes. Caribou also favor high areas for insect relief. Therefore, this kind of terrain is probably important or directly limiting to these three common mammals. In this situation, landform is more important than vegetation type.

There is some evidence that caribou selectively feed on certain vegetation types (White et al. 1975); however, these trends are not distinct and caribou can generally be found in almost all habitat areas (Cameron 1980). The desire for insect relief is probably a more important motivating factor during the thawed season than is food availability.

Table L-12 rates the various community types according to their value to mammals. Mammal habitat quality was mapped for all project site areas. The map for the western pipeline/road corridor is presented in this appendix (Figure L-39). Mammal habitat maps for the remaining sites can be viewed at the Corps' Alaska headquarters.

4.0 OVERALL HABITAT VALUE/SENSITIVITY

In order to gain insight into overall habitat quality and vulnerability to impact, information from the previous analyses of individual habitat elements was combined with other evaluation criteria. Table L-13 summarizes the habitat element information.

No attempt was made to apply a strictly quantitative approach to habitat value, because it was felt that the data did not warrant such an analysis. Of the five habitat elements considered in Chapter 3.0, only one (primary productivity) was rated solely on the basis of empirical data. Other complications relative to a quantitative approach included:

- Difficulty in weighting habitat elements to provide proper emphasis according to their relative importance.
- The presence of many other habitat elements that could be considered.
- The fact that plant community distribution patterns as well as vegetation types were considered to be an important determinant of habitat value.

Therefore, an approach combining objective criteria and judgemental factors was used to devise an overall rating system for the basic land cover categories (Table L-14). The following criteria or considerations were employed in the analysis leading to the Table L-14 ratings:

- The habitat element information as summarized in Table L-13.
- Consideration of community distribution patterns as they relate to wildlife values.
- Consideration of habitat scarcity.

Overall habitat value/sensitivity maps were prepared on the master map bases. Additionally, the proposed waterflood facility sites were added to the maps to allow a direct comparison of siting vs. environmental value (Section 5.0). A complete set of these maps is included with this appendix (Figures L-40 through L-73). Several of the above maps are presented in color (Figures L-40 (north), L-45, and L-68) in order to provide an example of how the method can be applied and to illustrate another means of contrasting the various habitat values.

5.0 HABITAT VALUES WITHIN AREAS DIRECTLY ALTERED BY THE WATERFLOOD PROJECT

Following completion of the overall habitat value/sensitivity maps, a process of environmental planning was initiated, whereby, preliminary site locations were overlayed upon the value maps. Areas where the preliminary sites conflicted with high or high moderate habitat values were outlined for further consideration. Planning sessions involving Corps' personnel, industry staff and consultants were held to consider the conflicts and most site locations were modified to accommodate the environmental values identified by this approach. In a few cases technical constraints limited siting flexibility and, therefore, resulted in unavoidable conflicts with high value areas.

The overall habitat value/sensitity maps (Figures L-40 through L-73) illustrate the locations of existing or already permitted facilities as well as locations of projected pad expansions, roads, and pipelines that would be required for the Waterflood Project. Drill pad facilities represent an integration of production and injection equipment, thus making it difficult to identify a specific area of waterflood impact. The potential expansion area for the injection well pads, therefore, includes the total area that might be needed in the future for all uses, including waterflood. The percentage of the expanded area that would actually be dedicated to the Waterflood Project requirements has been estimated and is indicated on Table L-15.

Surface areas of habitats that potentially would be altered by gravel fill were analyzed for each of the Waterflood Project sites illustrated on the master maps. Each of the evaluation elements discussed in Section 3.0, plus overall habitat value/sensitivity, was considered separately. Areas in hectares were calculated for the variously rated habitat types within impacted zones using a polar planimeter. Accuracy of the area measurements was within about ± 0.07 hectares (700 m^2, 7535 ft^2) for all sites except the pipeline corridors. Areas too small to be measured by the planimeter (less than 700 m^2) were estimated visually.

A somewhat modified method was used to determine habitat areas altered by roads and pipelines. The routes within the corridors were only roughly delineated and the actual width of the fill was too narrow to allow effective use of the planimeter; therefore, habitat areas were determined by planimeter within a 50-m (164-ft) swath overlaying the proposed routes. The resulting habitat areas were then reduced proportionally to correspond with the actual areas affected (i.e., an 18-m, 59-ft, width for the west corridor road/pipeline and a 13-m, 43-ft, width for the east corridor pipeline). The results are only an estimation of potential habitat loss contingent on the final alignment of roads and pipelines.

Tables L-15 through L-20 present the results of the area calculations for each habitat evaluation element and each rating category. Table L-21 summarizes this information for all project sites combined.

The minor discrepancies in the total area calculations between Tables L-15, L-18, L-19, and L-20 are due to planimeter and rounding errors. Also, because of rounding errors the percentages for each category in Table L-21 do not necessarily add up to exactly 100 percent.

TABLE L-1

MASTER MAP VEGETATION CODES USED IN AREAS MAPPED IN DETAIL BY WALKER ET AL. (In Press)

Code (Numerator)	Community	Characteristic Microsite
B=Dry sites		
B1	DRY Dryas integrifolia, Carex rupestris, Oxytropis nigrescens, Lecanora epibryon PROSTRATE SCRUB	Pingos, ridges, high polygon centers
B2	DRY Dryas integrifolia, Saxifraga oppositifolia, Lecanora epibryon PROSTRATE SCRUB	Similar to Stand Type B1, but less exposed to wind
B3	DRY Saxifraga oppositifolia, Juncus biglumis FROST BOIL BARREN	Frost boils
B4	DRY Epilobium latifolium, Artemisia arctica RIVER BAR BARREN	River gravel bars
B5	DRY Dryas integrifolia, Salix ovalifolia, Artemisia borealis SANDY FLATS BARREN	Sandy river terraces, stabilized
B6	DRY Dryas integrifolia, Astragalus alpinus RIVER BANK PROSTRATE SCRUB	River banks
B7	DRY Braya purpurascens, Anemone parviflora, Arctagrostis latifolia SLUMPING RIVER BLUFF COMPLEX	Slumping river bluffs
B14	DRY Dryas integrifolia, Salix reticulata, Cetraria richardsonii SNOW PATCH PROSTRATE SCRUB	Dry, early-thawing snowbanks with hummocky terrain
U=Moist sites		
U1	MOIST Carex aquatilis, Ochrolechia frigida GRAMINOID MEADOW	Polygon rims and aligned hummocks in acidic tundra region
U2	MOIST Eriophorum vaginatum, Dryas integrifolia, Tomenthypnum nitens, Salix arctica GRAMINOID MEADOW	Well-drained upland sites
U3	MOIST Eriophorum angustifolium, Dryas intergrifolia, Tomenthypnum nitens, Thamnolia vermicularis GRAMINOID MEADOW	Well-drained upland sites, polygon rims, aligned hummocks
U4	Moist Carex aquatilis, Dryas integrifolia, Tomenthypnum nitens, Salix Arctica GRAMINOID MEADOW	Moister upland sites, centers of drier low polygon centers, polygon rims, aligned hummocks
U6	DRY Dryas integrifolia, Cassiope tetragona SNOW PATCH DWARF SCRUB	Well-drained snowbanks
U7	MOIST Salix rotundifolia SNOW PATCH PROSTRATE SCRUB	Late-thawing snowbanks
U8	MOIST Salix lanata,Carex aquatilis STREAM BANK DWARF SCRUB	Stream banks, lake margins
U10	MOIST Festuca baffinensis, Papaver macounii GRAMINOID MEADOW	Pingo tops, bird mounds and animal dens
M=Wet Sites		
M1	WET Carex aquatilis, Carex rariflora, Saxifraga foliolosa GRAMINOID MEADOW	Wet microsites in acidic tundra areas primarily associated with aligned hummocks
M2	WET Carex aquatilis, Drepanocladus brevifolius GRAMINOID MEADOW	Wet polygon centers and troughs, lake margins
M3	WET Carex aquatilis, Dupontia fisheri, Calliergon richardsonii GRAMINOID MEADOW	Wet polygon centers and meadows in sand dune region and along Kuparuk River
M4	VERY WET Carex aquatilis, Scorpidium scorpioides GRAMINOID MEADOW	Low, wet sites, polygon centers, drained lakes, lake margins
M5	WET Carex aquatilis, Salix rotundifolia STREAM BANK GRAMINOID MEADOW	Moist stream banks
E= Emergent sites		
E1	VERY WET Carex aquatilis GRAMINOID MEADOW	Water to about 30 cm (9 in)
E2	VERY WET Arctophila fulva GRAMINOID MEADOW	Water to about 100 cm (39 in)
E3	VERY WET Scorpidium scorpioides AQUATIC MOSS MEADOW	Water to about 100 cm in sand dunes region
W=Open Water		
W1	None	Lakes and ponds
W2	None	Streams and rivers
W3	Varies	Flooded areas caused by roads or pads

TABLE L-1 (continued)
MASTER MAP VEGETATION CODES USED IN AREAS MAPPED IN DETAIL BY WALKER ET AL. (In Press)

Code (Numerator)	Community or Type of Disturbance
D=Disturbed sites	
D1	Bare earth with pioneering species, e.g. *Braya purpurascens*, *Leptobryum pyriforme*, *Marchantia polymorpha*
D2	Foreign gravel or construction debris
D3	Dust-covered areas adjacent to roads
D4	Vehicle tracks - deeply rutted
D5	Vehicle tracks - not deeply rutted
D6	Winter road
D7	Excavated areas primarily in river gravels
W3	Flooded areas caused by roads or pads

TABLE L-2

SOIL, LANDFORM AND SLOPE UNITS FOR WATERFLOOD MAPPING*

I. SOILS

Unit 1st Code No.	Taxonomic Name	Identifying Field Characteristics
1	Pergelic Cryoboroll	A cold, freely drained soil underlain by permafrost with a dark humus, rich granular textured surface horizon
2	Pergelic Cryaquoll	A cold, dark colored wet soil, permanently mottled in the lower part of the humus, with weakly granular surface horizon
3	Complex of: 1) Histic Pergelic Cryaquept	A cold wet gray mineral soil, commonly mottled, having a surface horizon 25 cm (9.8 in) thick, composed of predominantly organic material
	2) Pergelic Cryohemist	A cold wet dark colored soil consisting of moderately decomposed organic material to depths of 40 cm (15.7 in)
32	Complex of Soils 3 and 2	
4	Complex of: 1) Histic Pergelic Cryaquept	A cold wet gray mineral soil, commonly mottled, having a surface horizon 25 cm thick, composed of predominantly organic material
	2) Pergelic Cryofibrist	A cold, wet, reddish to yellowish soil consisting of little decomposed fibrous organic materials to depths of 40 cm
5	Pergelic Cryorthent	A cold, freely drained gravelly soil lacking significant horizon development and generally free of organic matter
6	Pergelic-Ruptic Aqueptic Cryaquoll	
7	Pergelic Cryopsamment	A cold, well-drained sandy soil associated with sand dunes and exhibiting little or no profile development
8	Pergelic Cryaquept	Cold, wet, gray colored and mottled mineral soil, lacking a significant organic horizon

II. LANDFORM

Unit 2nd Code No.	Landform
1	High-Centered Polygons (Center-Trough Relief >0.5 m, 1.6 ft)
2	High-Centered Polygons (Center-Trough Relief ≤0.5 m)
3	Low-Centered Polygons (Rim-Center Relief <0.5 m)
4	Low-Centered Polygons (Rim-Center Relief >0.5 m)
5	Mixed High- and Low-Centered Polygons in Intricate Pattern
6	Frost Boil Tundra (non-sorted)
7	Strangmoor and/or Disjunct Polygon Rims
8	Hummocky Terrain Associated with Dissected Slopes
9	Reticulate-Patterned Ground
0	Non-Patterned Ground or with Pattern Occupying Less than 20%
S	Sand Dunes
A	Alluvial Floodplain
P	Pingo

Steep embankment

Undercut river bank

Excavated

Stream

Roads and Pads

III. SLOPE/DEGREE

Unit 3rd Code No.	Slope/Degrees
None	0 - 2
2	2 - 6
3	7 - 12
4	13 - 20
5	Greater than 20

*From Walker et al. (in press)

TABLE L-3

WATERFLOOD PROJECT SITES AND HABITAT MAPPING DETAIL EMPLOYED FOR EACH

Project Site	Mapped According to the detailed Geobotanical System as per Walker et al. (in press)	Mapped According to Generalized Cover Categories as per Walker (1980)
Injection Well Sites - West Side: A		X
B	X	
D	X	
E		X
F		X
H	X	
M		X
N	X	
Q	X	
R		X
S		X
X		X
Y		X
WF-1		X
Injection Well Sites - East Side:		
2	X	
3		X
4		X
5	X	
7	X	
9		X
11	X	
12	X	
13	X	
14		X
15		X
16		X
17		X
18		X
Intermediate Manifolds:		
2 - W	X	
3 - W	X	
2 - E	X	
3 - E	X	
West Low-Pressure Pipeline Corridor		X
East Low-Pressure Pipeline Corridor		X
Gravel Sites:		
Put. North		X
Put. South	X	

TABLE L-4

GENERALIZED COVER CATEGORIES USED IN MAPPING OF PRUDHOE BAY AREA

LAND COVER CATEGORIES[2]	CORPS OF ENGINEERS TERMINOLOGY[3]	DESCRIPTION OF VEGETATION	SITE DESCRIPTION	DETAILED COMMUNITY CATEGORIES[1]
I DRY PROSTRATE-SHRUB TUNDRA	--	Mostly mat-forming or creeping woody shrubs (e.g. Dryas). Lichens, sedges, mat and cushion form non-woody dicotyledons, and bare soil may form large components.	Dry, exposed but well-vegetated sites, mostly along bluffs, ridge tops, kames, pingos and some stabilized dunes.	B1, B2, B3, B6, B14, U7
II MOIST DWARF-SHRUB TUNDRA	--	Dwarf shrubs 10-50 cm (4-20 in) tall. Caespitose monocotyledons such as Eriophorum vaginatum may form a large component, but shrubs are clearly dominant. Typical dominants include Salix, Betula nana, Ledum decumbens, and Cassiope tetragona.	Snow patches	U6
IV MOIST GRAMINOID TUNDRA (includes Tussock Graminoid Tundra without a large shrub component)	Moist Upland Community	Single monocotyledons or caespitose monocotyledons (e.g. Eriophorum vaginatum, Carex bigelowii) clearly dominate. Dwarf shrubs, mosses and lichens may form a major component.	Moist graminoid tundra common near coast on well drained upland sites, also in polygonal terrain on higher microsites. Tussock tundra on similar sites inland.	U1, U2, U3, U4, U10,
V WET GRAMINOID TUNDRA	Wet Meadow Community	Dominated by single monocotyledons. Mosses may form a major component.		
Va Non-Saline	--	Dominated by wet tundra plants such as Carex aquatilis and Eriophorum angustifolium	Dominant vegetation in low-centered polygon complexes, wet sites often drained of standing water by mid-summer, but that remain saturated; and very wet sites with shallow (<10cm) of water all summer.	M1, M2, M3, M4, M5
Vb Saline	--	Dominated by wet shoreline plants such as Carex subspathacea, Puccinellia phryganodes, Dupontia fisheri and Stellaria humifusa	Coastal lagoons, estuaries, and salt flooded areas.	--

TABLE L-4 (Continued)

GENERALIZED COVER CATEGORIES USED IN MAPPING OF PRUDHOE BAY AREA

LAND COVER CATEGORIES[2]	CORPS OF ENGINEERS TERMINOLOGY[3]	DESCRIPTION OF VEGETATION	SITE DESCRIPTION	DETAILED COMMUNITY CATEGORIES[1]
VI AQUATIC TUNDRA	Lake/Pond Community	Dominated by true aquatic vegetation	Mostly shallow (up to 1 m deep) sublittoral shelves of thaw lakes (Arctophila fulva). Also partially drained lake basins with shallow water (Carex aquatilis and Arctophila fulva).	
VIa Carex	--	Dominated by Carex aquatilis		E1, E3
VIb Arctophila	--	Dominated by Arctophila fulva		E2
VII RIPARIAN SCRUB	River/Stream/ Floodplain Community	Shrubs generally greater than 50 cm tall. Near the coast and in alpine areas, dwarf shrubs (<50cm tall) occur. Dominant taxa include Salix and Alnus	Mostly medium height (0.5-2 m) shrub along streams inland from coast	U8
VIII RIVER BANK or COASTAL BARRENS	River/Stream/ Floodplain Community	Non-vegetated areas are clearly dominant but many pioneering plants such as Epilobium latifolium, Cochlearia officinalis, Salix spp., Dryas may be present with up to 50% cover.	Coastal bluffs, beaches, barren river bars barren bluffs, sand dunes	B4, B5, B7,
X DEEP WATER	Open Water	Non-vegetated	Water generally >1 m deep	W1, W2

[1] From Walker et al. (in press)
[2] From Walker (1980)
[3] From U.S. Army Corps of Engineers (1979)

TABLE L-5

WETLAND AND OPEN WATER COMMUNITIES OF WATERFLOOD PROJECT AREA

Wetland[1] Community	Site Description	Vegetation Description	Land Cover Categories (Walker 1980)	Detailed Community Categories (Walker et al. in press)
Coastline Community	Moist coastal meadows and saline meadows below highest strand line	Fresh meadow dominated by Carex aquatilis, Salix planifolia spp. pulchra. Saline meadow characterized by Dupontia fisheri and Cochlearia officinalis.	Moist graminoid tundra IV[2] (partial correspondence only)	M9, U12, U13
River/Stream/ Floodplain Community	Upland stream banks which are inundated by spring flood	Dominated by Dryas integrifolia, Eriophorum angustifolium, Tomenthypnum nitens, Didymodor asperifolius	Moist graminoid tundra IV (partial correspondence only)	U9
Wet Meadow	Coastal Plain: Dominant vegetation in low-centered polygon complexes, wet sites often drained of standing water by mid-summer, but that remain saturated; and very wet sites with shallow (<10 cm) water all summer.	Dominated by single monocotylendons (e.g. Carex aquatilis. Mosses may form a major component.	Wet graminoid tundra V a) non-saline b) saline	M1, M2, M3, M4, M5, M6, M7, M8, M10, M11
Lake/Pond Community	Coastal Plain: Mostly shallow (up to 1 m deep) sublittoral shelves of thaw lakes (Arctophila fulva). Also partially drained lake basins with shallow water (Carex aquatilis and Arctophila fulva).	Dominated by true aquatic vegetation or emergents (e.g. Arctophila fulva, Menyanthes trifoliata).	Aquatic tundra VI a) Carex aquatilis b) Arctophila fulva	E1, E2, E3, E4
Disturbed Sites	May or may not have vegetation. Possible breakdown of original vegetation community.	Flooded areas caused by road or pads	--	W3
Open-water	Non-vegetated	Water generally >1 m deep	Deep Water X	W1, W2

[1]Adapted from U.S. Army Corps of Engineers (1979) and Walker (1980)

[2]The Moist Graminoid Tundra community may also contain other wetland communities not distinguishable from aerial photography.

TABLE L-6

PRODUCTION AND STANDING CROP FOR THE MAJOR VEGETATION UNITS OF THE WATERFLOOD PROJECT AREA

Detailed Plant Community Category	Production $g/m^2/yr$	Peak Season Standing Crop g/m^2
DRY TYPES		
B1	50	190
B2	55	205
B3	10	25
B4	5	15
b5	20	180
B6	20	180
B7	10	35
B14	50	230
MOIST TYPES		
U1	90	150
U2	90	150
U3	90	150
U4	70	130
U6	60	200
U7	50	170
U8	80	120
U10	25	165
WET TYPES		
M1	110	185
M2	120	190
M3	130	195
M4	80	120
M5	120	200
EMERGENT TYPES		
E1	120	180
E2	130	185
E3	80	120
GENERAL COVER CLASSES		
I	50	200
II	60	200
III	Does not occur near coast	
IV	80	140
V	120	190
VI	125	180
VII	80	120
VIII	10	30

TABLE L-7

PRODUCTION RATING SCALE FOR PLANT COMMUNITIES
OF THE WATERFLOOD PROJECT AREA

Rating Scale	Annual Productivity $g/m^2/yr$	Detailed Plant Communities	Generalized Land Cover Classes
Low	0-50	B1, B3, B4, B5, B6, B7, B10	I, VIII
Moderate	51-100	B12, U1, U2, U3, U4, U6, U4, U8, M4, E3	II, III, IV, VII
High	101-150	M1, M2, M3, M5, E1, E2	V, VI

TABLE L-8

BRINE SPILLAGE SENSITIVITY OF VEGETATION TYPES
OF THE WATERFLOOD PROJECT AREA

Detailed Plant Community Category	Sensitivity
DRY TYPES	
B1	3
B2	3
B3	2
B4	1
B5	2
B6	1
B7	1
B14	3
MOIST TYPES	
U1	2
U2	2
U3	2
U4	2
U6	3
U7	3
U8	1
U10	2
WET TYPES	
M1	1
M2	1
M3	1
M4	1
M5	1
EMERGENT TYPES	
E1	1
E2	0
E3	0
GENERAL COVER CLASSES	
I	3
II	3
III	unit not presented in waterflood region
IV	2
V	0 in intertidal areas, 1 other sites
VI	1
VII	1
VIII	0 on coastal barrens, 1 other sites

Key:
- 0 - no detectable effects
- 1 - small reduction in vigor of some plants; complete recovery after one growing season
- 2 - moderate reduction in vigor of several plants with some death; recovery taking several growing seasons
- 3 - death of most plants; recovery after many years

TABLE L-9

DENSITY OF BREEDING SHOREBIRDS ON THE PRUDHOE BAY TUNDRA DURING THE THIRD WEEK IN JUNE

Habitat	Number of Birds/Ha
Frost boil tundra (Type B3 mixed with others)	0.9
Upland tundra (Types U2, U3, U4)	1.2
Upland tundra complex (Types U3 and U4 with M2)	1.7
Upland tundra pond or lake margin (Types M2 or M4)	1.8
Lowland tundra (wet facie) (Type M2 complex)	2.9
Pingo complex (Types B1, U10, U6, U7, etc.)	3.9
Stream complex (Types M5, U8, etc.)	3.9
Lowland tundra (very wet facie) (Type M4 complex)	4.2
Mixed ponds and polygons (Types E1 and E2 mixed with others)	5.7

Source: Myers and Pitelka (unpublished data)

TABLE L-10

BIRD HABITAT VALUE RATINGS AND CORRESPONDING COMMUNITY DESCRIPTIONS

Habitat Value Rating	Habitat Description	Classification from Bergman et al. 1977 (Wetlands only)	Vegetation Codes from Walker et al.	Generalized Land Cover Category	Bird Use
High	Mixed moist & wet habitats within a former lake basin including associated ponds and small lakes	Basin - complex (VI)	Mixed E2, E1, W1, M4, M2 with some U1 or U4	Mixed Wet Graminoid Tundra (V), Aquatic Tundra (VI) and Deep Water (X)	Heavily utilized by most Prudhoe Bay water birds for breeding and/or feeding
	Ponds or lakes with a continuous margin of emergent Arctophila fulva	Deep - Arctophila (IV)	W1 with E2	Aquatic Tundra (VIb) with Deep Water (X)	Breeding and feeding habitat for most waterfowl and loons
	Wetland with nearly continuous emergent vegetation (Arctophila fulva	Shallow - Arctophila (III)	E2	Aquatic Tundra (VIb)	Breeding and feeding habitat for most waterfowl and loons
	Salt or brackish water marsh	Coastal wetland (VIII)	M9	Wet Graminoid Tundra-Saline (Vb)	Feeding habitat for black brant and various shorebirds
High moderate	Wetland with nearly continuous emergent vegetation (Carex aquatilis)	Shallow - Carex (II)	E1	Aquatic Tundra (VIa)	Breeding and feeding habitat for ducks, loons and shorebirds
	Some lakes adjacent to high quality wetlands	Deep - open (V) adjacent to shallow - Arctophila (III) and shallow-Carex (II)	W1 adjacent to E2 or E1	Deep Water (X) with Aquatic Tundra (VI)	Breeding, feeding and nesting habitat for waterfowl and loons
	Stream channels with frequent ponds	Beaded streams (VII)	Channel designation with E1 or E2	--	Utilized by ducks and loons
	Very wet tundra complex	Flooded tundra (I)	M4 with some U1, U2, U3 or U4	Wet Graminoid Tundra (V) - partial correspondence only	High density shorebird nesting
	Stream bank complex	--	B6, U8, M5	Riparian Scrub (VII)	High density shorebird nesting
Low Moderate	Wet tundra complex	Flooded tundra (I)	M1, M2, M3 with some U1, U2, U3 or U4	Wet Graminoid Tundra (V)	Shorebird nesting, pintail feeding
	Open-water lakes and ponds	Deep - open (V)	W1	Deep Water (X)	Used by waterfowl and loons after nesting for resting, feeding and molting
	Pingo complex	--	B1, B2, U6, U10	Dry Prostrate-Shrub Tundra (I); Moist Dwarf Shrub Tundra (II)	Shorebird nesting habitat
	Sparsely vegetated areas	--	B4, B5	River or Coastal Barrens (VIII)	Shorebird nesting habitat

TABLE L-10 (Continued)

BIRD HABITAT VALUE RATINGS AND CORRESPONDING COMMUNITY DESCRIPTIONS

Habitat Value Rating	Habitat Description	Classification from Bergman et al. 1977 (Wetlands only)	Vegetation Codes from Walker et al.	Generalized Land Cover Category	Bird Use
Low	Moist upland complex	--	U2, U3, U4 with some M2	Moist Graminoid Tundra (IV)	Low density shorebird nesting
	Dry upland complex	--	B1, B2, B3	Dry Prostrate - Shrub Tundra (I)	Passerine bird nesting
	Flooded areas caused by man's activities	--	W3	--	--
	Disturbed areas (roads work pads, etc.)	--	--	Cultural Barrens (XI)	--

TABLE L-11

UTILIZATION OF THE MAJOR VEGETATION UNITS BY MAMMALS

Land Cover Category	Detailed Plant Community	Mammal Use: Caribou	Ground Squirrel	Fox	Collared Lemming	Brown Lemming
I Dry Prostrate-Shrub Tundra	B1	G1	D,F	D	D,F	
	B2	G1	D,F		D,F	
	B3	G1				
	B6	G1	F		D,F	
	B14	G1	D		D,F	
	U7	G2	D,F		D,F	
II Moist Dwarf-Shrub Tundra	U6	G2	D,F		D,F	
IV Moist Graminoid Tundra	U1	G2			D,F	D,F
	U2	G2	F		D,F	D,F
	U3	G2	F		D,F	D,F
	U4	G2	F			F
	U10	G2	D	D		
V Wet Graminoid Tundra	M1	G2	F			F
	M2	G2	F			F
	M3	G2				
	M4	G1				
	M5	G3				F
VI Aquatic Tundra	E1	G1				
	E2	G1				
	E3	G1				
VII Riparian Scrub	U8	G3				D,F
VIII River Bank or Coastal Barrens	B4	G2				
	B5	G2	F			
	B7	G1	D,F		D,F	

Legend: D - denning site
G1 - low caribou grazing use
G2 - moderate grazing use
G3 - high grazing use
F - feeding area

Sources: White et al. (1975), Underwood (1975), Hanson and Eberhardt (1979), Feist (1975), and personal observation of the authors

TABLE L-12

MAMMAL HABITAT VALUE RATINGS AND CORRESPONDING COMMUNITY DESCRIPTIONS

Habitat Value Rating	Habitat Description	Land Cover Category	Detailed Plant Community Types	Mammal Use
High	Well drained, elevated features - coastal bluffs, stream banks, pingos, lake margins, dunes	Dry prostrate-shrub tundra (I); River bank or coastal barrens (VIII)	B1, B2, B5, B6, B7, B9, B10, B11, B13, B14, U10	Ground squirrel, fox, and polar bear denning; caribou and ground squirrel feeding
	Floodplains of major rivers	River bank or coastal barrens (VIII)	B4	Caribou insect relief and travel corridor
	Moist stream banks	Riparian scrub (VII)	U8, U9, M5	Caribou feeding
Moderate	Moist uplands	Moist graminoid tundra (IV); Moist dwarf-shrub tundra (II)	U1, U2, U3, U4, U6, U7	Small mammal denning and feeding
Low	Most wet sites	Wet graminoid tundra (V); Aquatic tundra (VI); Deep water (X)	M1, M2, M3, M4, E1, E2, W1	Caribou and fox feeding

TABLE L-13

SUMMARY OF HABITAT VALUE/SENSITIVITY RESULTS FOR EACH EVALUATION ELEMENT AND LAND COVER CATEGORY

Land Cover Category	Wetland Contribution[1]	Primary Productivity	Saltwater Sensitivity	Bird Habitat Value	Mammal Habitat Value
I. Dry prostrate-shrub tundra	Low	Low	High	Low Moderate	High
II Moist dwarf-shrub tundra	Low	Moderate	High	Low	Moderate
IV Moist graminoid tundra	Low	Moderate	High Moderate	Low	Moderate
V Wet graminoid tundra					
Va Non-saline	High	High	Low Moderate	Low Moderate	Low
Vb Saline	High	High	Low	High	Low
VI Aquatic tundra					
VIa *Carex*	High	High	Low Moderate	High Moderate	Low
VIb *Arctophila*	High	High	Low	High	Low
VII Riparian scrub	Low	Moderate	Low Moderate	High Moderate	High
VIII River bank or coastal barrens	Low	Low	Low Moderate	Low Moderate	High
X Deep Water	--	Low	--	Low Moderate	Low
XI Cultural barrens	Low	Low	Low	Low	Low

[1] Judgement regarding the potential transfer of nutrients and energy to lake, stream, and marine systems.

TABLE L-14

OVERALL HABITAT VALUE/SENSITIVITY RATINGS AND CORRESPONDING COMMUNITY DESCRIPTIONS

Habitat Value Rating	Habitat Description	Land Cover Category	Detailed Plant Community Types	Resource Value/ Sensitivity
High	Wet with emergent Arctophila, including associated open water	VIb. Aquatic tundra - Arctophila	E2	High value to waterbirds, high primary productivity, wetland values, limited in area
	Selected mixed wet and moist habitats with some emergent vegetation usually within a drained lake basin	Closely associated Aquatic tundra (VI), Wet graminoid tundra (V), and Moist graminoid tundra (IV) communities	Mixed E2, E1, W1, M4, M2 with some U1 or U4	High value to waterbirds, wetland values
	Salt marsh, including associated open water	Vb. Wet graminoid tundra - Saline	--	High value to waterfowl
	Minor stream channels	--	--	Important in maintaining linked wetlands
	Pingo complex	--	B1, B2, U6, U10 P	High value to mammals, rare plants, sensitive to disturbance
	Abrupt river banks	--	B6, B7	High value to mammals, rare plants
High Moderate	Moist stream banks	VII. Riparian scrub	U8, M5	Caribou feeding, shorebird & passerine bird nesting habitat
	High, dry shrub areas; vegetated alluvium	I. Dry Prostrate-shrub Tundra	B1, B2	High value to mammals and passerine birds, sensitive to saltwater spills
	Wet with emergent Carex, including associated open water	VIa. Aquatic tundra - Carex	E1, E3	High value to waterbirds, high primary productivity
	Selected open water adjacent to high quality wetlands	X. Deep Water (partial correspondence only)	W1 (partial correspondence only)	High value to waterbirds

TABLE L-14 (Continued)

OVERALL HABITAT VALUE/SENSITIVITY RATINGS AND CORRESPONDING COMMUNITY DESCRIPTIONS

Habitat Value Rating	Habitat Description	Land Cover Category	Detailed Plant Community Types	Resource Value/ Sensitivity
Low Moderate	Moist shrub areas	II. Moist Dwarf-shrub tundra	U6	Sensitive to saltwater spills
	Wet tundra, including associated open water	Va. Wet graminoid tundra - Non-saline	M1, M2, M3, M4	High primary productivity, shorebird values
	Dry barren terrain; river gravel	VIII. River Bank or Coastal Barrens	B4, B5	Caribou insect relief and travel corridor, some shorebird use
	Deep open water	X. Deep water	W1	Waterfowl staging and resting
Low	Moist tundra	IV. Moist graminoid tundra	U1, U2, U3, U4 U10,	Some shorebird use, moderately sensitive to saltwater spills
	Roads, workpads, gravel pits	XI. Cultural Barrens	--	Occasional shorebird use
	Areas flooded due to roads and workpads	--	W3	--

TABLE L-15

SURFACE AREA OF WETLAND AND OPEN-WATER HABITATS DIRECTLY ALTERED BY WATERFLOOD PROJECT FACILITIES

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Wetlands	Open Water	Non-Wetland	Total
Injection Well Sites West Side					
A	50	0.4[b]	0.4	0	0.8
B	25	1.3	0.3	1.7	3.3
D	30	1.4	0.2	0.2	1.8
E	--	0	0	0	0
F	20	0.7	T[c]	0	0.8
H	--	0	0	0	0
M	30	1.7	T	0.1	1.9
N	10	0.2	T	0.1	0.4
Q	--	0	0	0	0
R	--	0	0	0	0
S	100	5.8	0.2	3.8	9.8
X	35	1.7	0.2	0	1.9
Y	35	1.5	0.4	0	1.9
WF1	100	11.0	0	0.2	11.2
Injection Well Sites East Side					
2	10	0.9	T	0.7	1.7
3	12	0.6	0	0.3	0.9
4	10	2.1	0	0	2.1
5	14	0.4	T	0.4	0.9
7	13	0.6	T	0.3	1.0
9	12	2.0	0.2	0.4	2.6
11	1	0.2	0	0.1	0.3
12	23	0.9	0	0	0.9
13	12	0.8	0.1	0.5	1.4
14	13	1.0	0.1	0.7	1.8
15	11	0.6	T	0.2	0.9
16	15	2.1	0.1	0.2	2.4
17	19	1.6	0.3	0.4	2.3
18	17	1.2	0	0.2	1.4

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Wetlands	Open Water	Non-Wetland	Total
Intermediate Manifolds					
2W	100	0.8	0	0	0.8
3W	100	0.5	0	0.3	0.8
2E	100	0.2	0	0	0.2
3E	--	0	0	0	0
West Low-Pressure Pipeline Corridor	100	6.6	0.2	4.4	11.2
East Low-Pressure Pipeline Corridor	100	3.9	1.6	4.0	9.5
Gravel Sites					
Putuligayuk North	100	0	6.3	28.4	34.7
Putuligayuk South	100	5.5	T	10.8	16.3
West Injection Plant	100	1.6	0	1.0	2.6
Totals		60.1	11.0	59.4	130.5

(a) Estimated percent of the mapped pad expansion areas that would be dedicated to Waterflood Project facilities.
(b) Calculated areas equal total area for all future uses x the percent dedicated to Waterflood Project facilities.
(c) T = trace -- less than 0.05 hectares.

TABLE L-16

SURFACE AREAS DIRECTLY ALTERED BY WATERFLOOD PROJECT FACILITIES--PRIMARY PRODUCTIVITY
(OPEN-WATER, PONDED AREAS, AND AREAS DISTURBED BY GRAVEL MINING NOT INCLUDED)

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Productivity Rating High	Moderate	Low	Total
Injection Well Sites West Side					
A	50	0.4[b]	0	0	0.4
B	25	0.5	1.8	0	2.3
D	30	1.3	0.1	0.1	1.5
E	--	0	0	0	0
F	20	0.5	0.2	0	0.7
H	--	0	0	0	0
M	30	1.7	0	0.2	1.9
N	10	0.2	0.2	0	0.4
Q	--	0	0	0	0
R	--	0	0	0	0
S	100	5.8	3.8	0	9.6
X	35	1.7	0	0	1.7
Y	35	1.5	0	0	1.5
WF1	100	11.0	0.2	0	11.2
Injection Well Sites East Side					
2	10	0.8	0.6	T[c]	1.4
3	12	0.3	0	0.4	0.7
4	10	0.6	0.1	0	0.6
5	14	T	0.8	0	0.8
7	13	0.4	0.3	T	0.7
9	12	0.6	0.3	0.1	1.0
11	1	0.2	T	T	0.2
12	23	0.3	0	0	0.3
13	12	0.3	0.4	0	0.7
14	13	0.8	0.3	0	1.1
15	11	0.6	0.2	0	0.8
16	15	2.1	0.2	0	2.3
17	19	1.6	0.5	0	2.1
18	17	1.2	0.1	0	1.3
Intermediate Manifolds					
2W	100	0	0	0	0
3W	100	0.5	0.3	0	0.8
2E	100	0.2	0	0	0.2
3E	--	0	0	0	0
West Low-Pressure Pipeline Corridor	100	6.6	4.1	0.3	11.0
East Low-Pressure Pipeline Corridor	100	3.4	4.0	0.1	7.5
Gravel Sites					
Putuligayuk North	100	0	0	34.7	34.7
Putuligayuk South	100	0	1.4	0	1.4
West Injection Plant	100	3.7	2.3	0	6.0
Totals		48.9	22.3	35.1	106.3

(a) Estimated percent of the mapped pad expansion areas that would be dedicated to Waterflood Project facilities.
(b) Calculated areas equal total area for all future uses x the percent dedicated to Waterflood Project facilities.
(c) T = trace -- less than 0.05 hectares.

TABLE L-17

SURFACE AREAS DIRECTLY ALTERED BY WATERFLOOD PROJECT FACILITIES--SALTWATER SENSITIVITY (OPEN-WATER NOT INCLUDED)

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Sensitivity Rating: High	High Moderate	Low Moderate	Low	Total
Injection Well Sites West Side						
A	50	0[b]	0	0.5	0	0.5
B	25	0	1.8	0.5	0.7	3.0
D	30	0	0.1	1.4	T[c]	1.6
E	--	0	0	0	0	0
F	20	0	0.1	0.5	0.2	0.8
H	--	0	0	0	0	0
M	30	0.2	0	1.7	0	1.9
N	10	0	0.2	0.2	0	0.4
Q	--	0	0	0	0	0
R	--	0	0	0	0	0
S	100	0	3.8	5.8	0	9.6
X	35	0	0	1.7	0	1.7
Y	35	0	0	1.5	0	1.5
WF1	100	0	0.2	11.0	0	11.2
Injection Well Sites East Side						
2	10	T	0.5	0.8	0.2	1.5
3	12	0.4	0	0.2	0.6	1.2
4	10	0	0.1	0.6	1.1	1.8
5	14	0	0.4	0.4	0	0.8
7	13	T	0.2	0.4	0.2	0.9
9	12	0.1	0.3	0.5	1.5	2.4
11	1	T	T	0.2	T	0.4
12	23	0	0	0.3	0.7	1.0
13	12	0	0.3	0.3	0.5	1.1
14	13	T	0.3	0.7	0.5	1.5
15	11	0	0.2	0.6	0	0.8
16	15	0	0.2	2.1	0	2.3
17	19	0	0.5	1.6	0	2.1
18	17	0	0.1	1.2	0	1.3

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Sensitivity Rating: High	High Moderate	Low Moderate	Low	Total
Intermediate Manifolds						
2W	100	0	0	0	0.8	0.8
3W	100	0	0.3	0.5	0	0.8
2E	100	0	0	0.2	0	0.2
3E	--	0	0	0	0	0
West Low-Pressure Pipeline Corridor	100	0.3	4.4	6.3	0.3	11.3
East Low-Pressure Pipeline Corridor	100	0.1	4.0	3.4	0.5	8.0
Gravel Sites						
Putuligayuk North	100	0	0	0	28.5	28.5
Putuligayuk South	100	0	1.4	0	14.8	16.2
West Injection Plant	100	0	1.0	1.6	0	2.6
Totals		1.3	20.5	46.7	51.2	119.7

(a) Estimated percent of the mapped pad expansion areas that would be dedicated to Waterflood Project facilities.
(b) Calculated areas equal total area for all future uses x the percent dedicated to Waterflood Project facilities.
(c) T = trace -- less than 0.05 hectares.

TABLE L-18

SURFACE AREAS DIRECTLY ALTERED BY WATERFLOOD PROJECT FACILITIES--BIRD HABITAT VALUES

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Habitat Value Rating: High	High Moderate	Low Moderate	Low	Total
Injection Well Sites West Side						
A	50	0	0	0.8[b]	0	0.8
B	25	0	0	0.8	2.5	3.3
D	30	0	0.3	1.3	0.2	1.8
E	--	0	0	0	0	0
F	20	0	T[c]	0.5	0.2	0.9
H	--	0	0	0	0	0
M	30	0	0.3	1.4	0.2	1.9
N	10	0	0	0.4	0	0.4
Q	--	0	0	0	0	0
R	--	0	0	0	0	0
S	100	0	0	6.0	3.8	9.8
X	35	0	0	1.9	0	1.9
Y	35	0	0	1.9	0	1.9
WF4	100	0	0	11.0	0.2	11.2
Injection Well Sites East Side						
2	10	0.1	0.2	0.6	0.8	1.7
3	12	0.2	0	0	0.7	0.9
4	10	0	0	0.6	1.2	1.8
5	14	T	0.4	0	0.4	0.9
7	13	0	0.1	0.3	0.4	0.8
9	12	T	0	0.7	1.8	2.6
11	1	0	T	0.2	T	0.3
12	23	0	0	0.3	0.7	0.9
13	12	T	0	0.9	0.4	1.4
14	13	T	0	0.9	0.8	1.8
15	11	T	0	0.4	0.4	0.9
16	15	T	0.2	1.9	0.2	2.4
17	19	0	0.9	0.9	0.5	2.3
18	17	0	0	1.3	0.1	1.4

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Habitat Value Rating: High	High Moderate	Low Moderate	Low	Total
Intermediate Manifolds						
2W	100	0	0	0	0.8	0.8
3W	100	0	0.5	0	0.3	0.8
2E	100	0	0	0.2	0	0.2
3E	--	0	0	0	0	0
West Low-Pressure Pipeline Corridor	100	2.5	0.7	3.5	4.7	11.2
East Low-Pressure Pipeline Corridor	100	2.3	0	2.9	4.3	9.5
Gravel Sites						
Putuligayuk North	100	0	0	0	34.7	34.7
Putuligayuk South	100	0	0	0	16.3	16.3
West Injection Plant	100	0	0	1.6	0	2.6
Totals		5.5	3.7	43.2	77.7	130.1

(a) Estimated percent of the mapped pad expansion areas that would be dedicated to Waterflood Project facilities.
(b) Calculated areas equal total area for all future uses x the percent dedicated to Waterflood Project facilities.
(c) T = trace -- less than 0.05 hectares.

TABLE L-19

SURFACE AREAS DIRECTLY ALTERED BY WATERFLOOD PROJECT FACILITIES--MAMMAL HABITAT VALUES

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Habitat Value Rating High	Moderate	Low	Total
Injection Well Sites West Side					
A	50	0	0	0.8[b]	0.8
B	25	0	2.5	0.8	3.3
D	30	0	0.2	2.8	3.0
E	--	0	0.1	0.7	0.8
F	20	0	0	0	0
H	--	0	0	0	0
M	30	0.2	0	1.7	1.9
N	10	0	0.2	0.2	0.4
Q	--	0	0	0	0
R	--	0	0	0	0
S	100	0	3.8	6.0	9.8
X	35	0	0	1.9	1.9
Y	35	0	0	1.9	1.9
WF1	100	0	0.2	11.0	11.2
Injection Well Sites East Side					
2	10	T[c]	0.4	1.2	1.7
3	12	0.4	0	0.8	1.2
4	10	0	0.1	1.7	1.8
5	14	0	0.4	0.5	0.9
7	13	T	0.3	0.7	1.1
9	12	0.1	0.3	2.2	2.6
11	1	T	T	0.2	0.3
12	23	0	0	0.9	0.9
13	12	0	0.4	0.9	1.3
14	13	0	0.3	1.5	1.8
15	11	0	0.2	0.6	0.8
16	15	0	0.2	2.1	2.3
17	19	0	0.5	1.8	2.3
18	17	0	0.2	1.2	1.4

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Habitat Value Rating High	Moderate	Low	Total
Intermediate Manifolds					
2W	100	0	0	0.8	0.8
3W	100	0	0.3	0.5	0.8
2E	100	0	0	0.2	0.2
3E	--	0	0	0	0
West Low-Pressure Pipeline Corridor	100	0.3	3.4	7.5	11.2
East Low-Pressure Pipeline Corridor	100	0.1	4.0	5.4	9.5
Gravel Sites					
Putuligayuk North	100	0	0	34.7	34.7
Putuligayuk South	100	0	1.4	14.8	16.2
West Injection Plant	100	0	1.6	1.0	2.6
Totals		1.3	21.5	109.0	131.8

(a) Estimated percent of the mapped pad expansion areas that would be dedicated to Waterflood Project facilities.
(b) Calculated areas equal total area for all future uses x the percent dedicated to Waterflood Project facilities.
(c) T = trace -- less than 0.05 hectares.

TABLE L-20

SURFACE AREAS DIRECTLY ALTERED BY WATERFLOOD PROJECT FACILITIES--OVERALL HABITAT VALUE/SENSITIVITY

Project Site	Waterflood[a]	Affected Area (Hectares) Habitat Value/Sensitivity Rating High	High Moderate	Low Moderate	Low	Total
Injection Well Sites West Side						
A	50	0	0	0.8[b]	0	0.8
B	25	0	0	0.8	2.5	3.3
D	30	0	0.3	1.3	0.2	1.8
E	--	0	0	0	0	0
F	20	0	T[c]	0.5	0.2	0.8
H	--	0	0	0	0	0
M	30	0.2	0.3	1.4	0	1.9
N	10	0	0	0.4	0	0.4
Q	--	0	0	0	0	0
R	--	0	0	0	0	0
S	100	0	0	6.0	3.8	9.8
X	35	0	0	1.9	0	1.9
Y	35	0	0	1.9	0	1.9
WF1	100	0	0	11.0	0.2	11.2
Injection Well Sites East Side						
2	10	0.1	0.1	0.8	0.6	1.6
3	12	0.1	0.3	0	0.5	0.9
4	10	0	0	0.6	1.2	1.8
5	14	T	0	0.4	0.4	0.9
7	13	0.1	0.1	0.4	0.4	1.0
9	12	T	0.1	0.7	1.8	2.7
11	1	0.1	0.1	1.9	0.2	2.3
12	23	0	0	0.3	0.7	1.0
13	12	T	0	0.9	0.4	1.4
14	13	T	0	0.9	0.8	1.8
15	11	T	0	0.4	0.4	0.9
16	15	T	0.2	1.9	0.2	2.4
17	19	0	0.9	0.9	0.5	2.3
18	17	0	0	1.3	0.1	1.4

Project Site	Percent Waterflood[a]	Affected Area (Hectares) Habitat Value/Sensitivity Rating High	High Moderate	Low Moderate	Low	Total
Intermediate Manifolds						
2W	100	0	0	0	0.8	0.8
3W	100	0	0	0.5	0.3	0.8
2E	100	0	0	0.2	0	0.2
3E	--	0	0	0	0	0
West Low-Pressure Pipeline Corridor	100	2.6	1.0	3.5	4.1	11.2
East Low-Pressure Pipeline Corridor	100	2.3	0.1	2.8	4.3	9.5
Gravel Sites						
Putuligayuk North	100	0	0	6.3	28.5	34.8
Putuligayuk South	100	0	0		16.3	16.3
West Injection Plant	100	0	0	1.6	1.0	2.6
Totals		5.8	3.6	52.3	69.6	131.3

(a) Estimated percent of the mapped pad expansion areas that would be dedicated to Waterflood Project facilities.
(b) Calculated areas equal total area for all future uses x the percent dedicated to Waterflood Project facilities.
(c) T = trace -- less than 0.05 hectares.

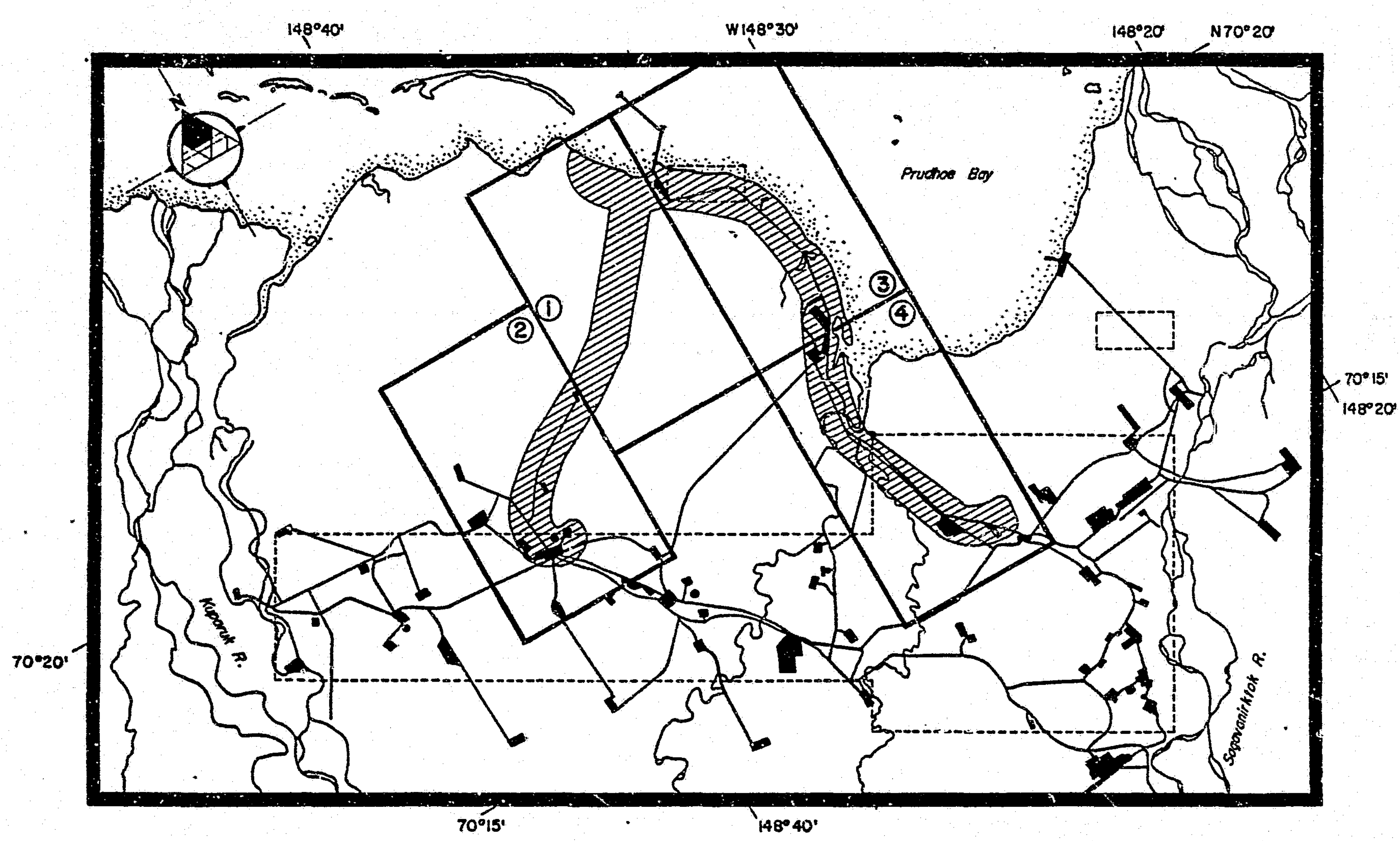
TABLE L-21

SUMMARY OF RELATIVE HABITAT VALUE AND/OR SENSITIVITY OF TERRAIN DIRECTLY ALTERED BY ALL WATERFLOOD PROJECT FACILITIES COMBINED

Category	Habitat Value/Sensitivity: High	Moderate: (High Moderate)	Moderate: (Low Moderate)	Low
Primary Productivity	48.9[a] (37.2%)[b]	22.3 (17.0%)		35.1 (26.7%)
Saltwater Sensitivity	1.3 (1.0%)	20.5 (15.6%)	46.7 (35.6%)	51.2 (40.0%)
Bird Habitat Value	5.5 (4.2%)	3.7 (2.8%)	43.2 (32.9%)	77.7 (59.2%)
Mammal Habitat Value	2.7 (2.1%)	21.6 (16.5%)		109.0 (83.0%)
Overall Habitat Value/ Sensitivity	5.8 (4.4%)	3.6 (2.7%)	52.3 (39.8%)	69.6 (53.0%)
	Wetland	Open Water		Non-Wetland
Wetlands and Open Water Habitats	60.1 (46.1%)	11.0 (8.4%)		60.2 (46.1%)
Total Area Affected				131.3

(a) Area in hectares
(b) Percent of total area

CORRIDOR MAP LOCATION



WESTERN CORRIDOR { ① NORTHERN PORTION
② SOUTHERN PORTION }

EASTERN CORRIDOR { ③ NORTHERN PORTION
④ SOUTHERN PORTION }

KEY TO HABITAT MAPPING

WETLAND AND OPEN WATER COMMUNITIES (FIGURES L-2 to L-35)

- WETLAND
- OPEN WATER
- NON-WETLAND

OVERALL HABITAT VALUE/SENSITIVITY (FIGURES L-41 to L-44,L-46 to L-67,L-69 to L-73)

- HIGH
- HIGH MODERATE
- LOW MODERATE
- LOW

FACILITIES (FIGURES L-36 to L-73)

- EXISTING FACILITIES AS OF JULY 1979
- EXPANSIONS PERMITTED OR APPLIED FOR BETWEEN JULY 1979 AND APRIL 1980
- PROPOSED FACILITIES

FIGURE L-1

Figure L-2 (North)

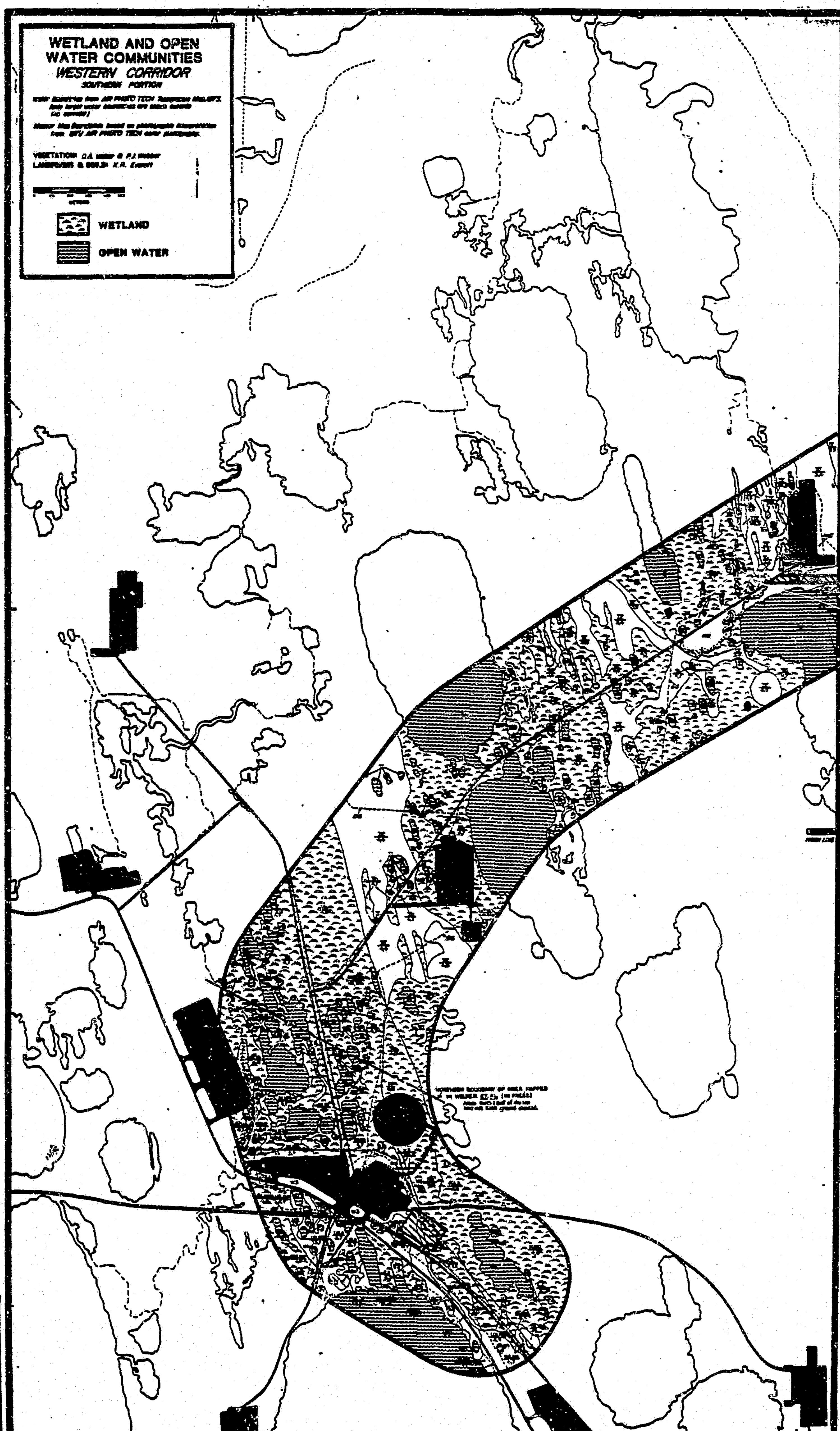


Figure L-2 (South)

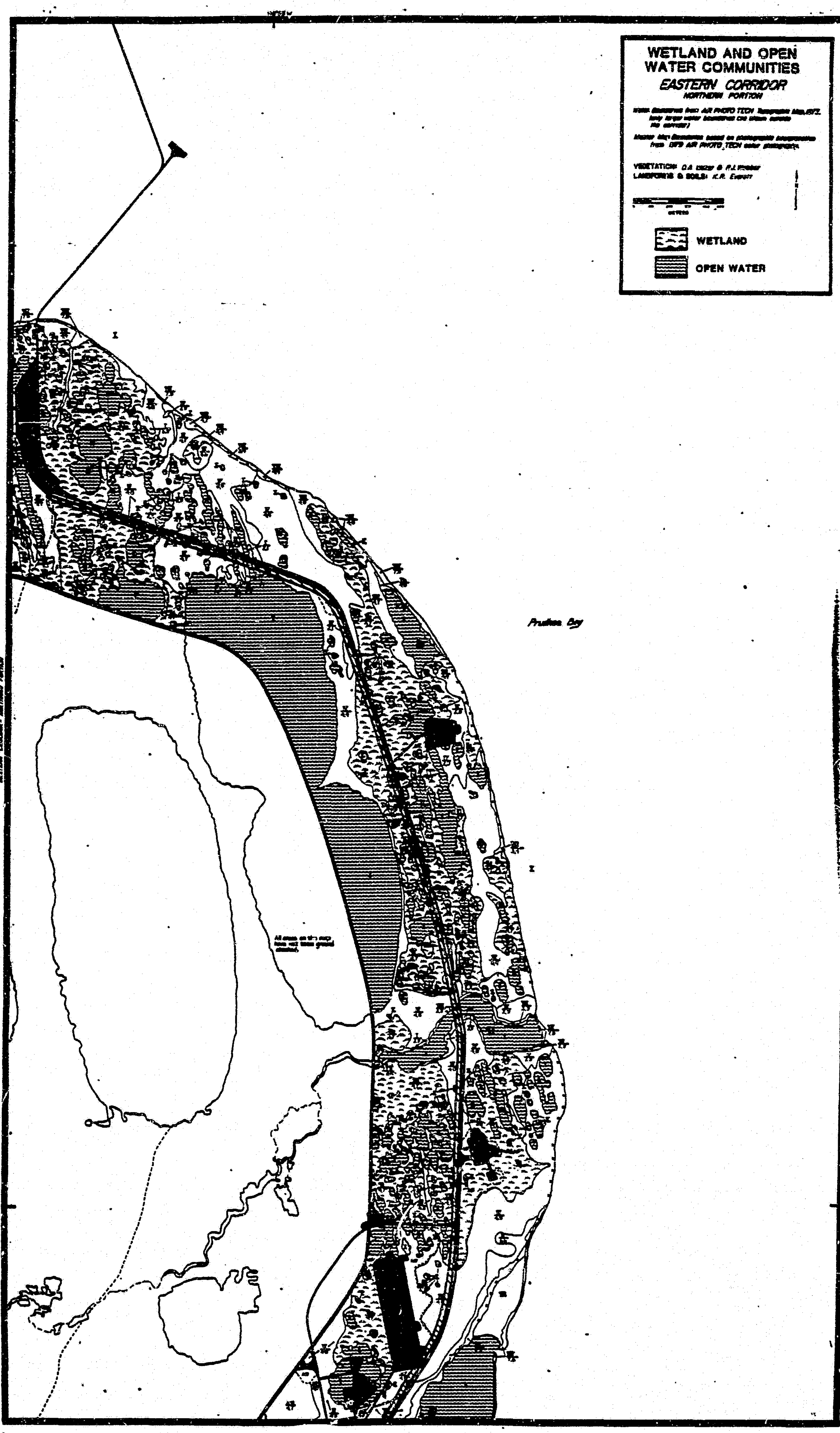


Figure L-3 (North)

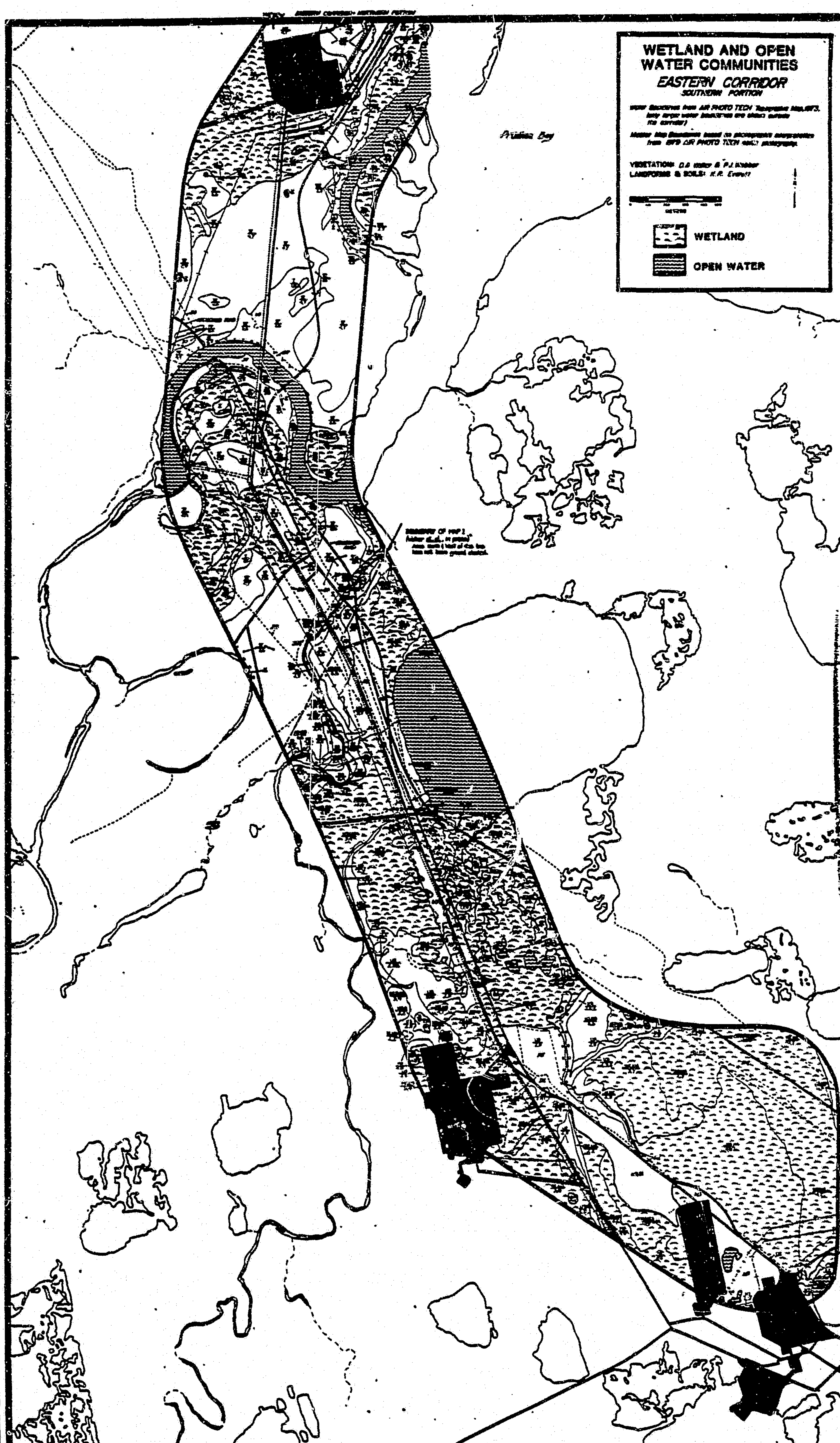
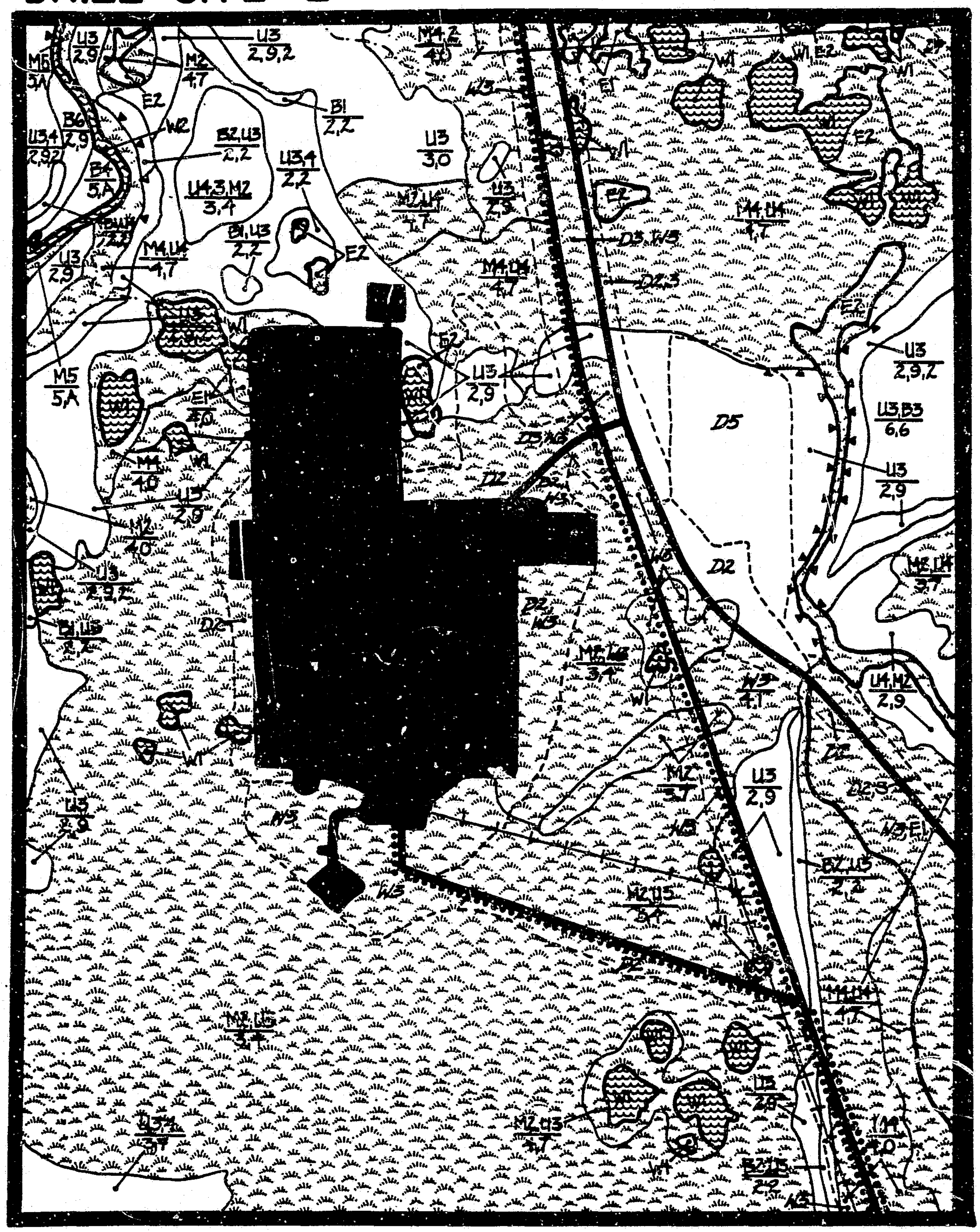


Figure L-3 (South)

DRILL SITE 2



0 100 200 300 400 500
METERS

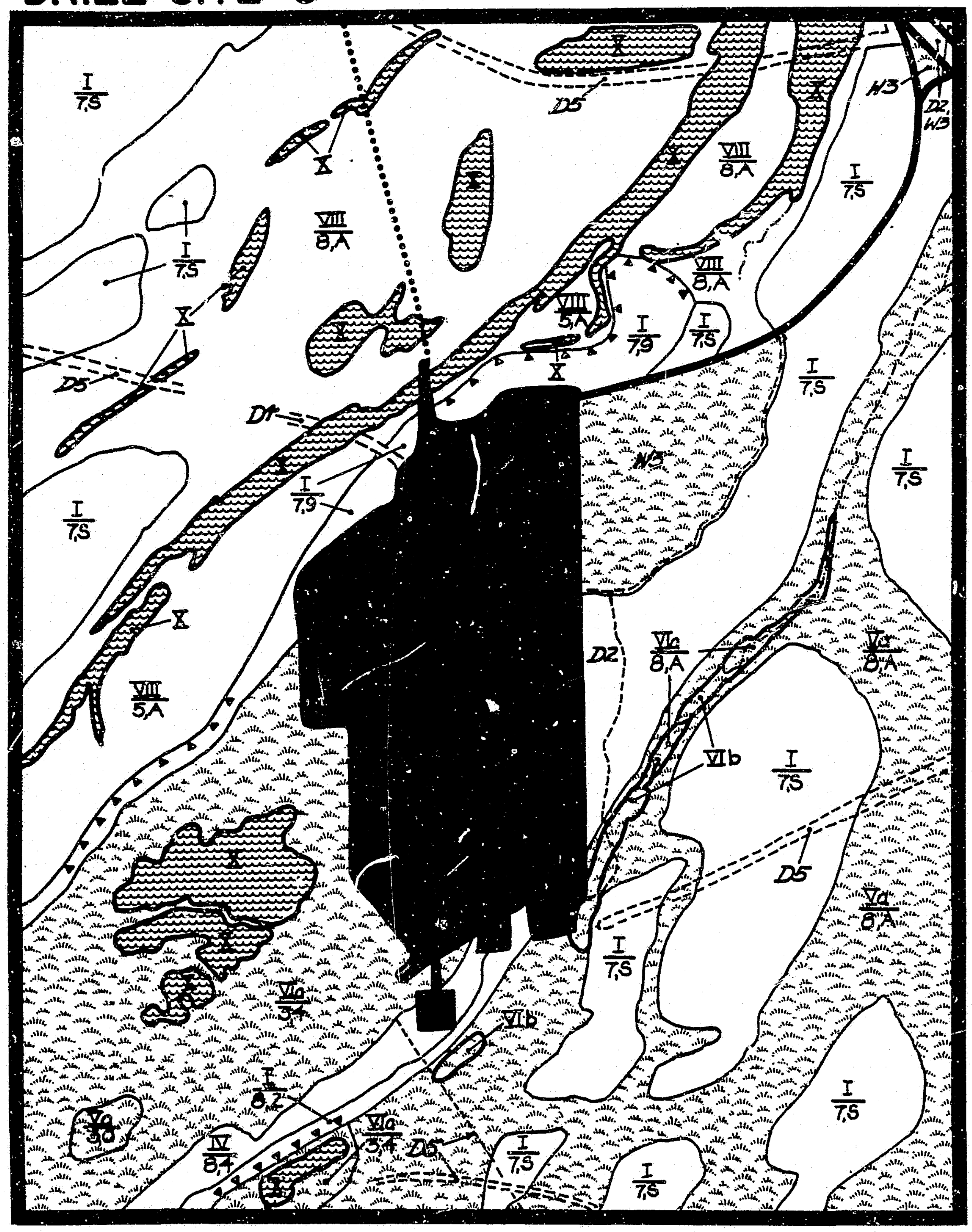
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-15
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-4

DRILL SITE 3



0 100 200 300 400 500

METERS

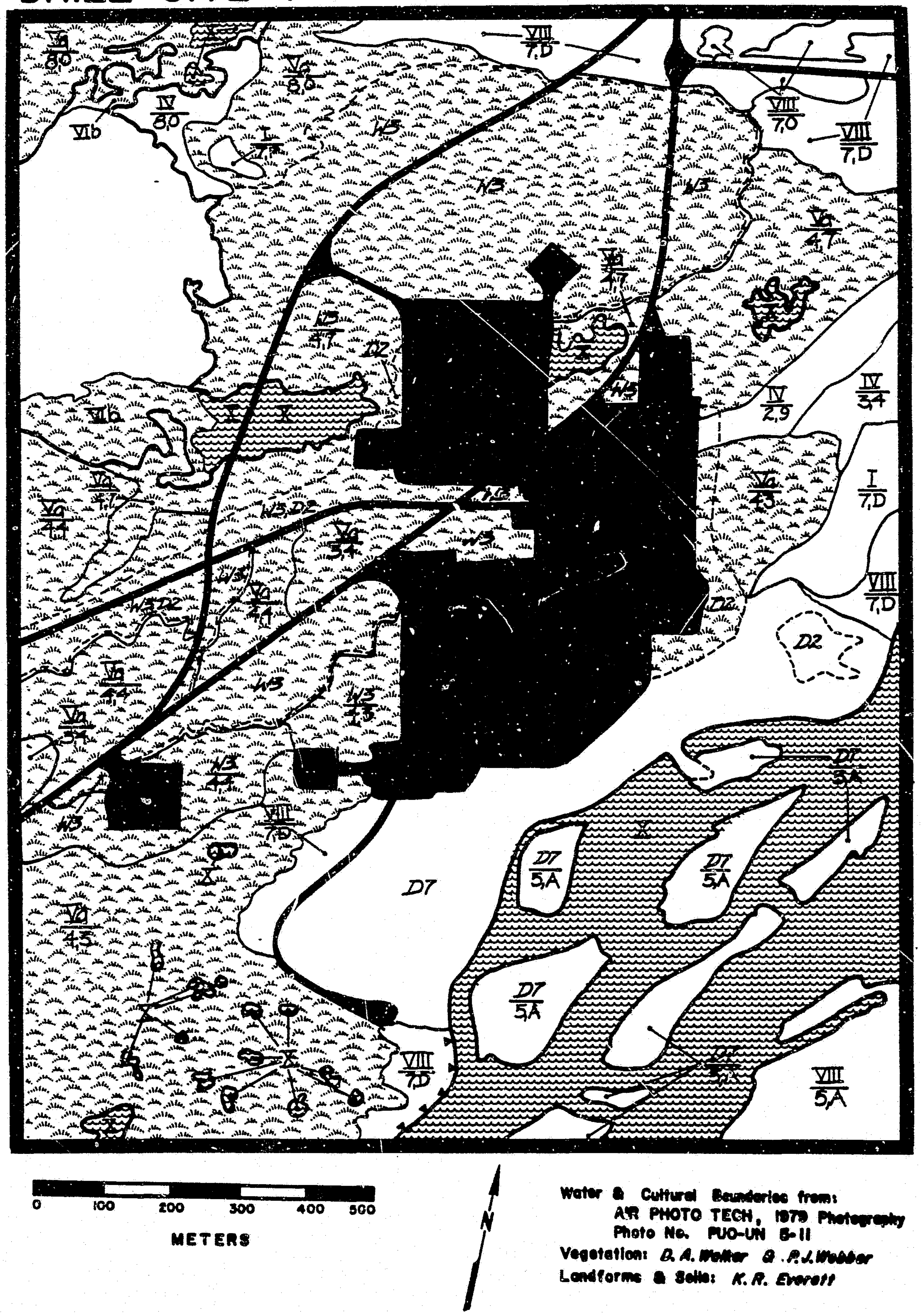
N

Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 7-10
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-5

DRILL SITE 4

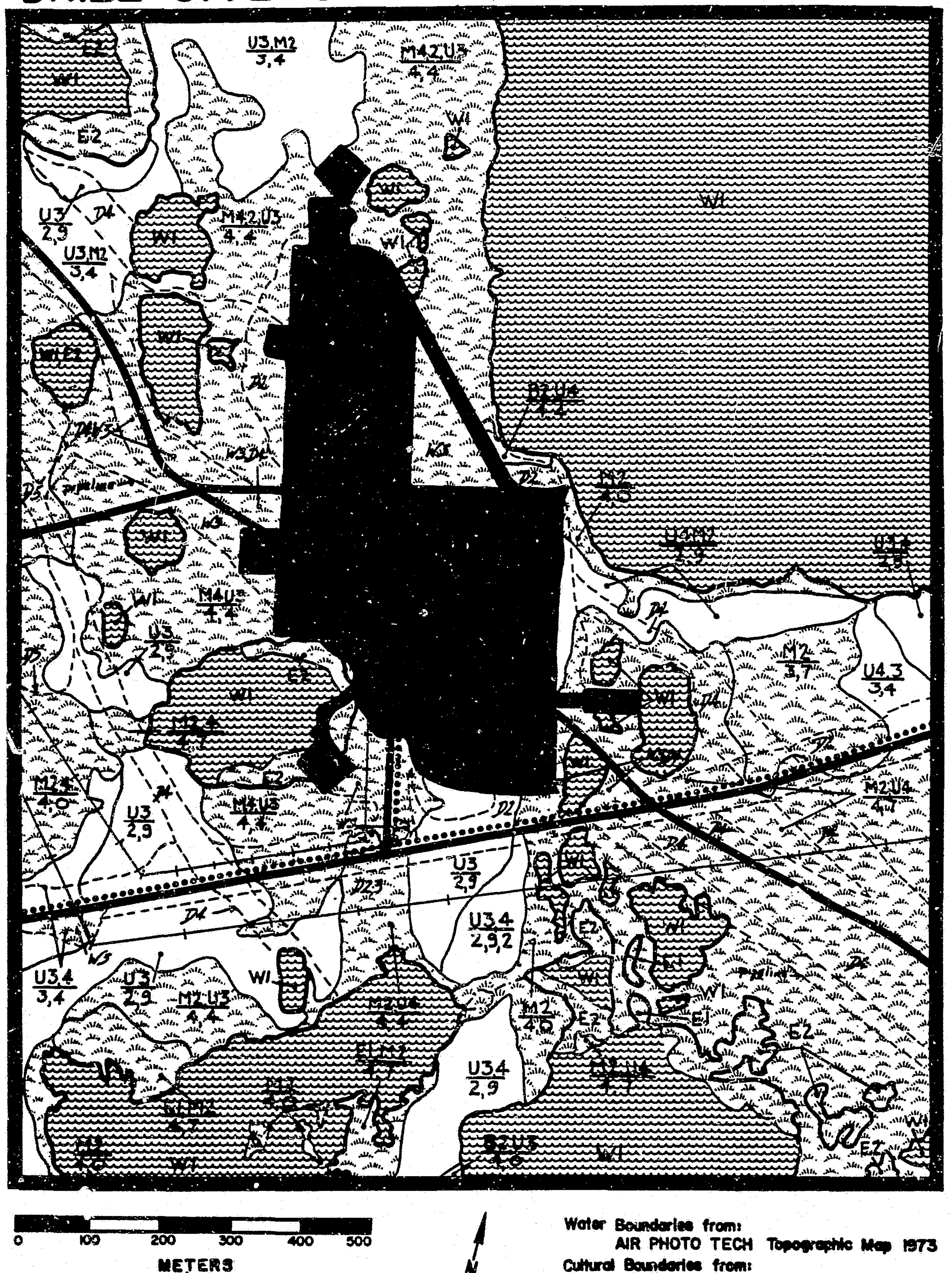


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 5-11
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-6

DRILL SITE 5

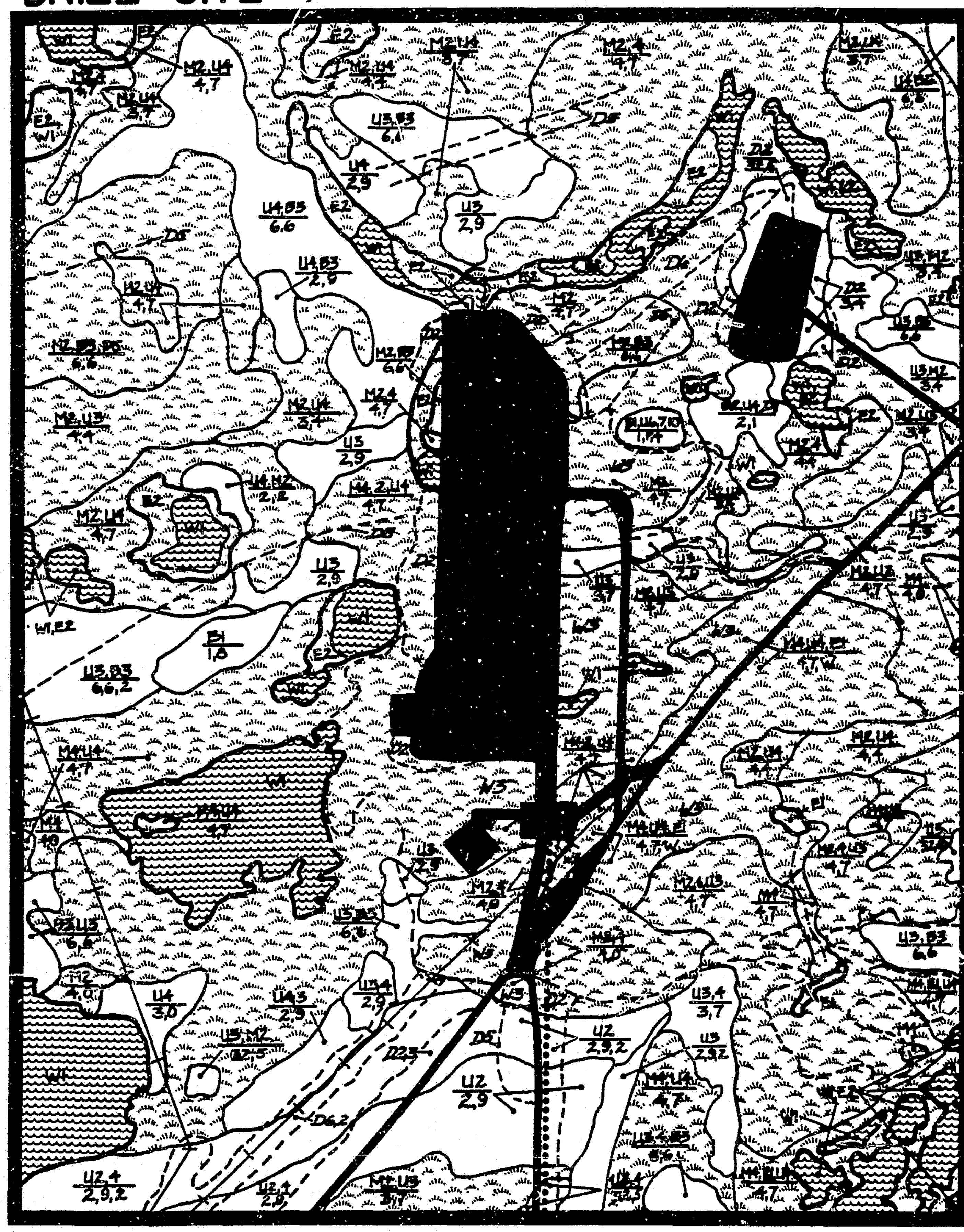


Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 6-13
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L–7

DRILL SITE 7



0 100 200 300 400 500
METERS

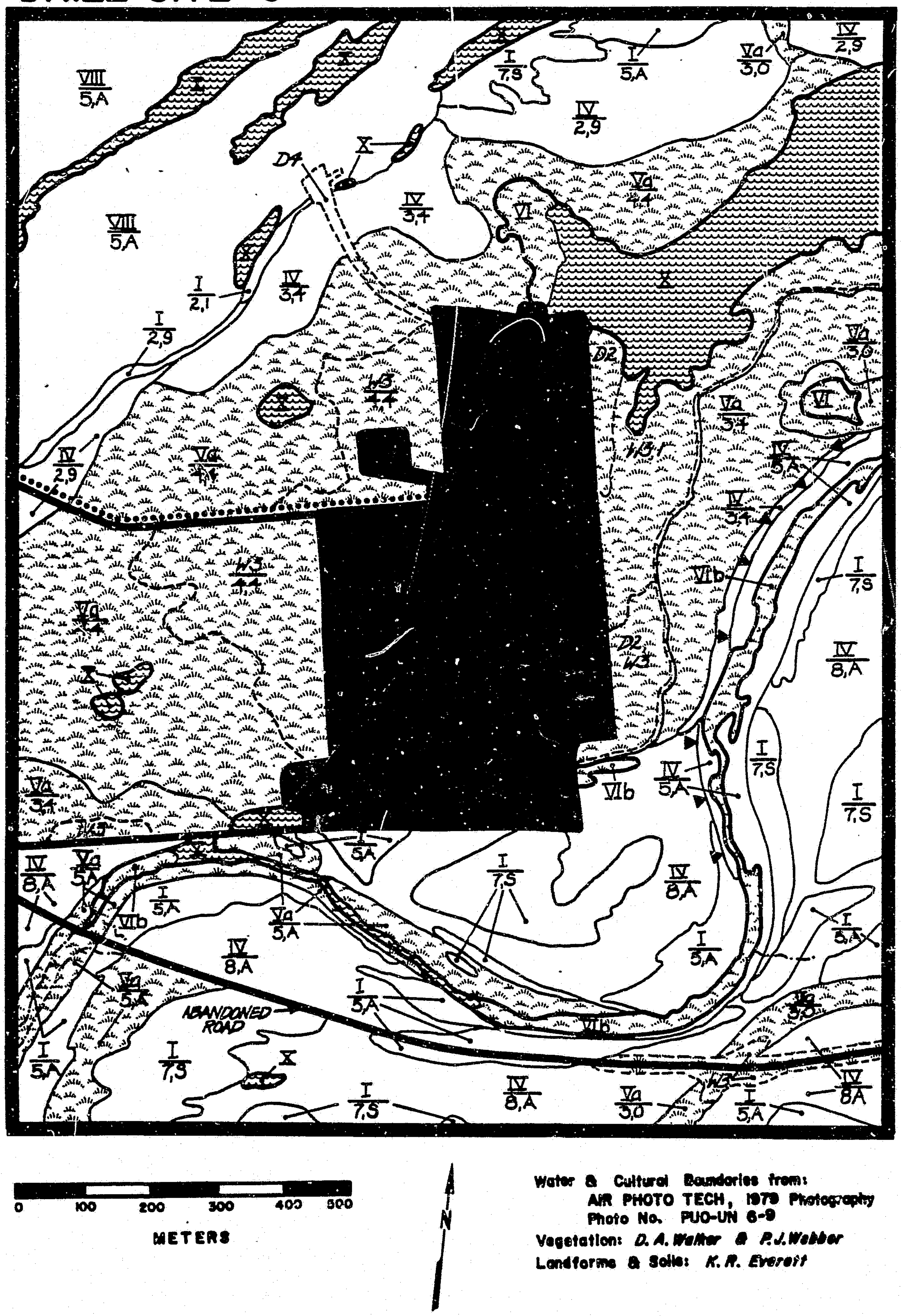
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-17
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-8

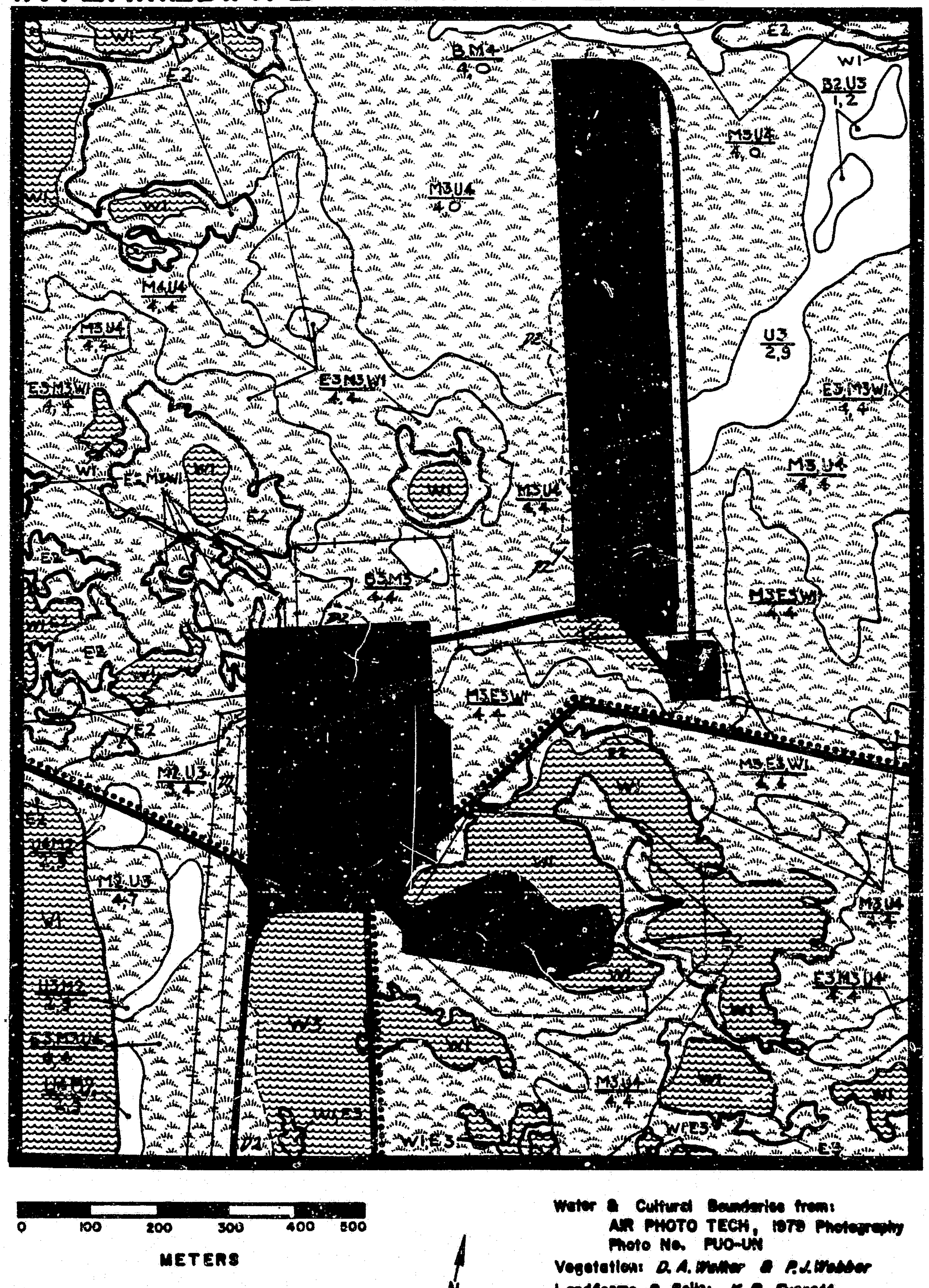
DRILL SITE 9



WETLAND AND OPEN WATER COMMUNITIES

Figure L-9

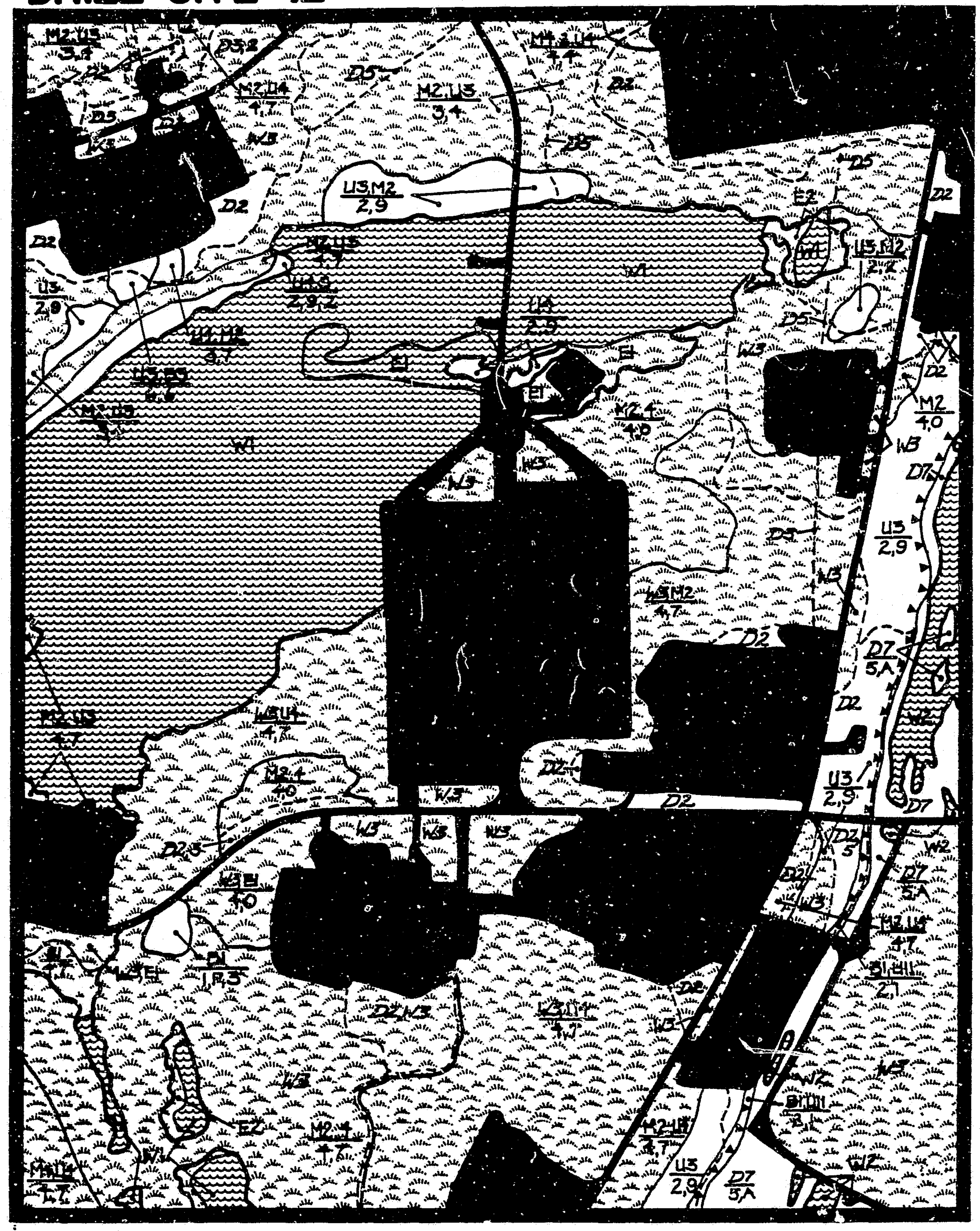
DRILL SITE 11 & INTERMEDIATE MANIFOLD 2 EAST



WETLAND AND OPEN WATER COMMUNITIES

Figure L-10

DRILL SITE 12



0 100 200 300 400 500

METERS

N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973

Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-12

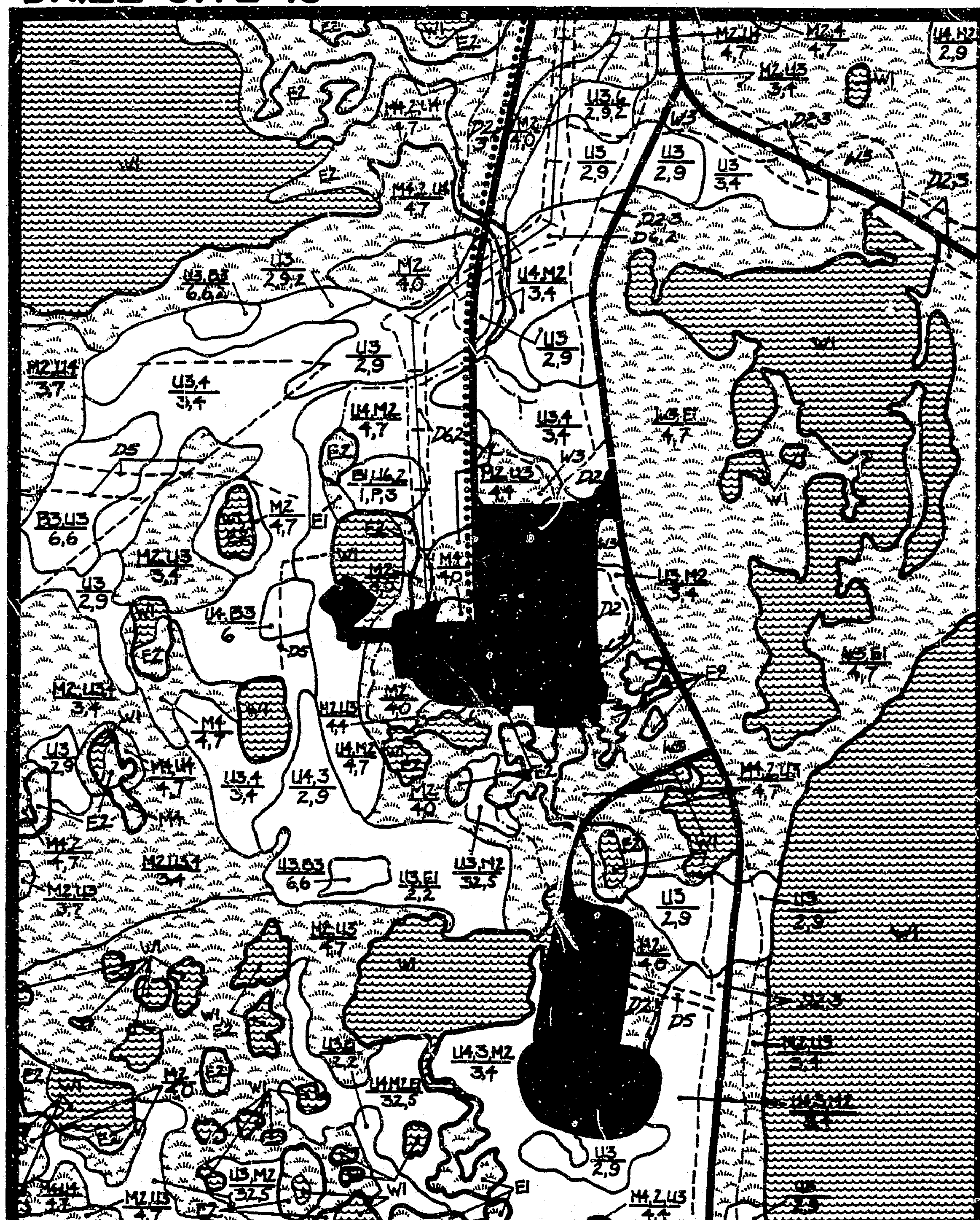
Vegetation: *D.A. Walker & P.J. Webber*

Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-11

DRILL SITE 13



0 100 200 300 400 500
METERS

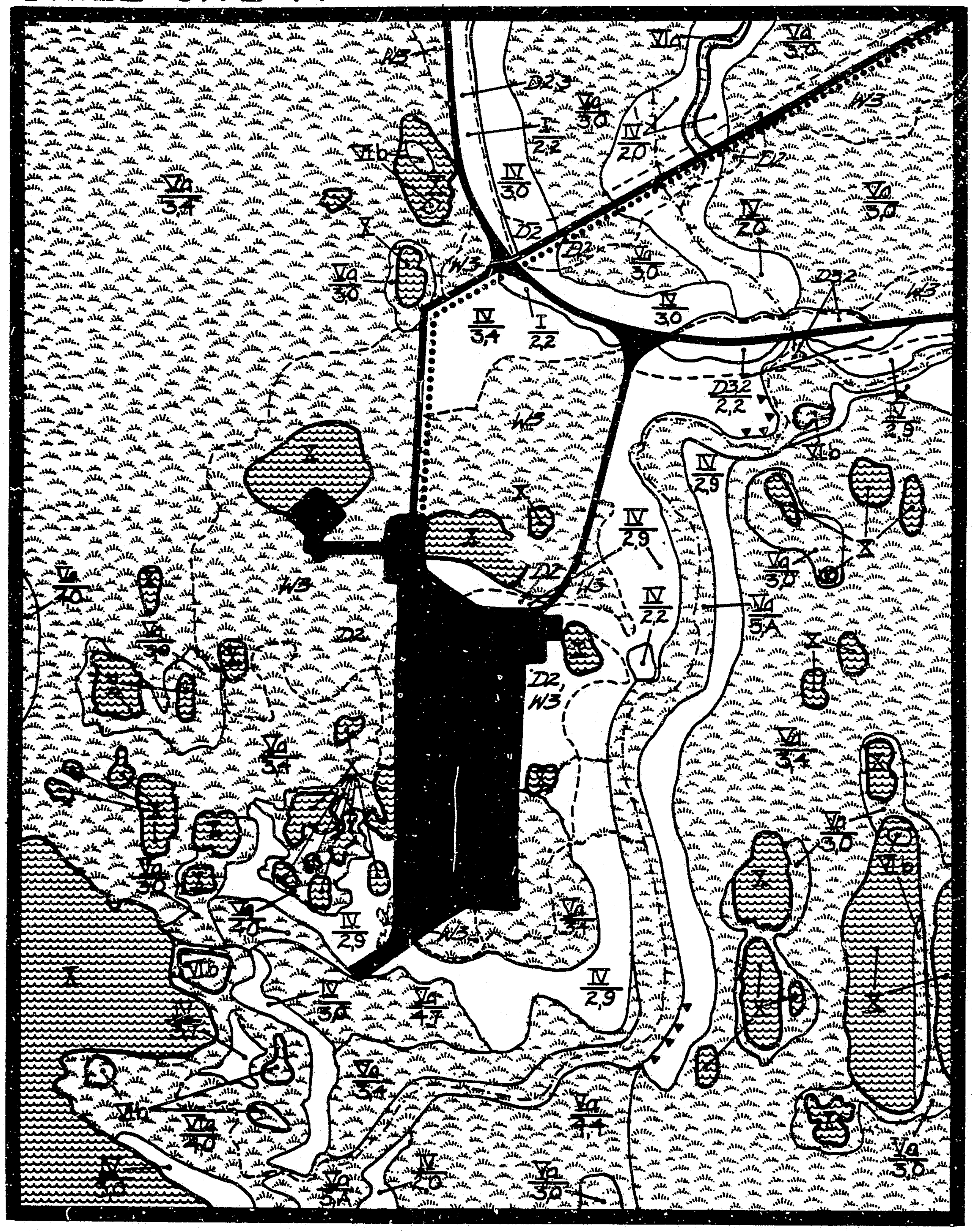
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 9-14
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-12

DRILL SITE 14



0 100 200 300 400 500

METERS

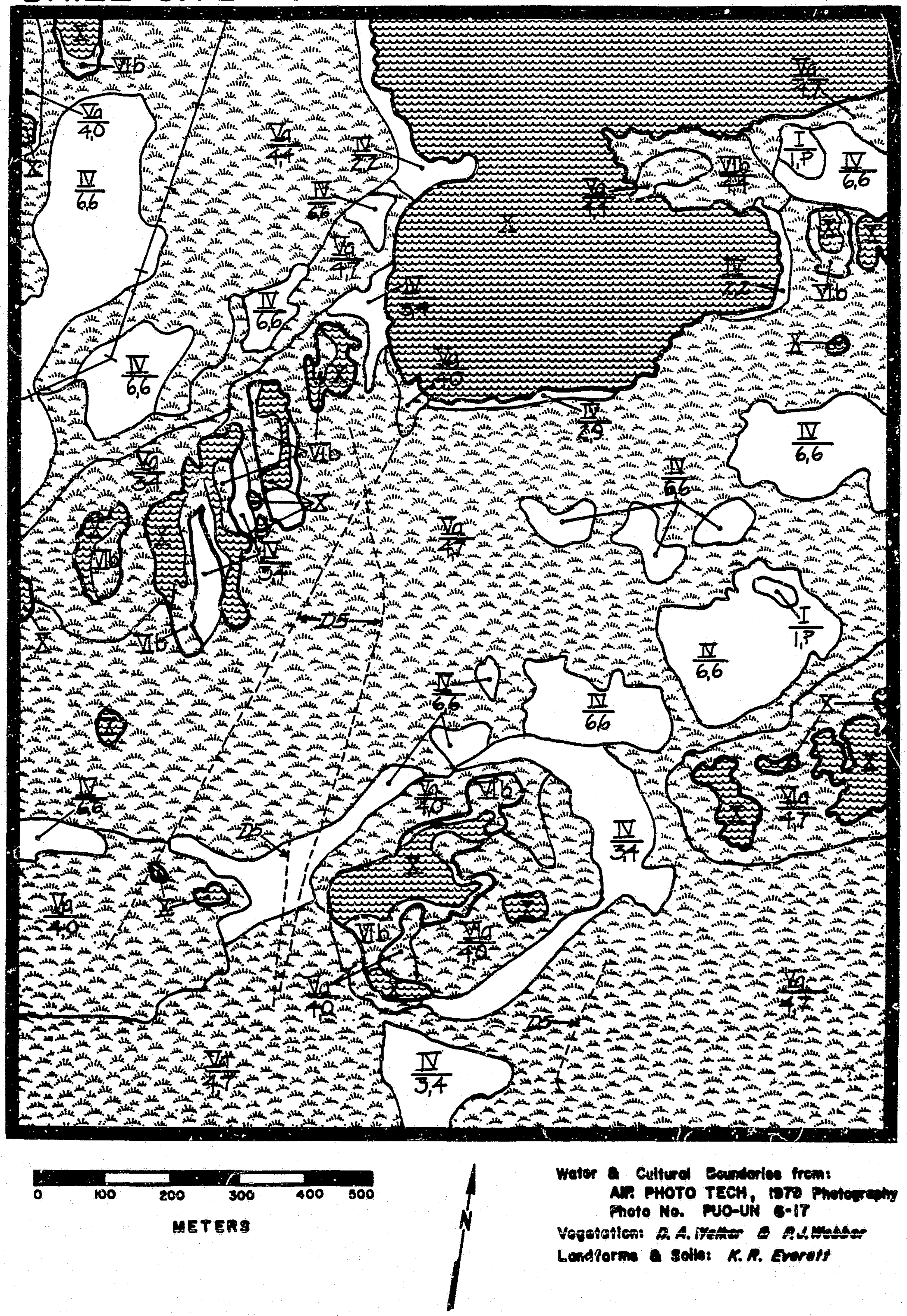
N

Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 8-16
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUITIES

Figure L-13

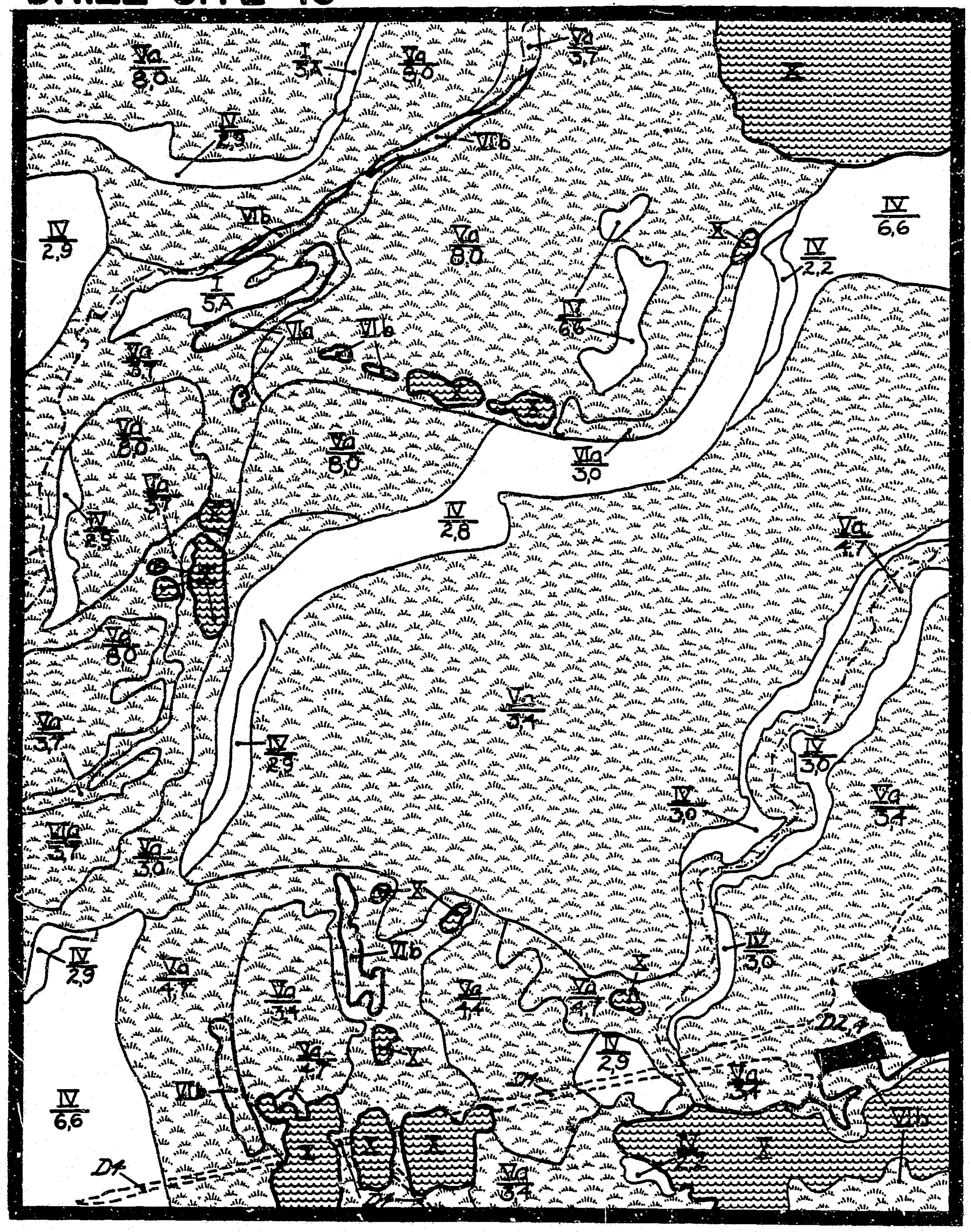
DRILL SITE 15



WETLAND AND OPEN WATER COMMUNITIES

Figure L-14

DRILL SITE 16



0 100 200 300 400 500

METERS

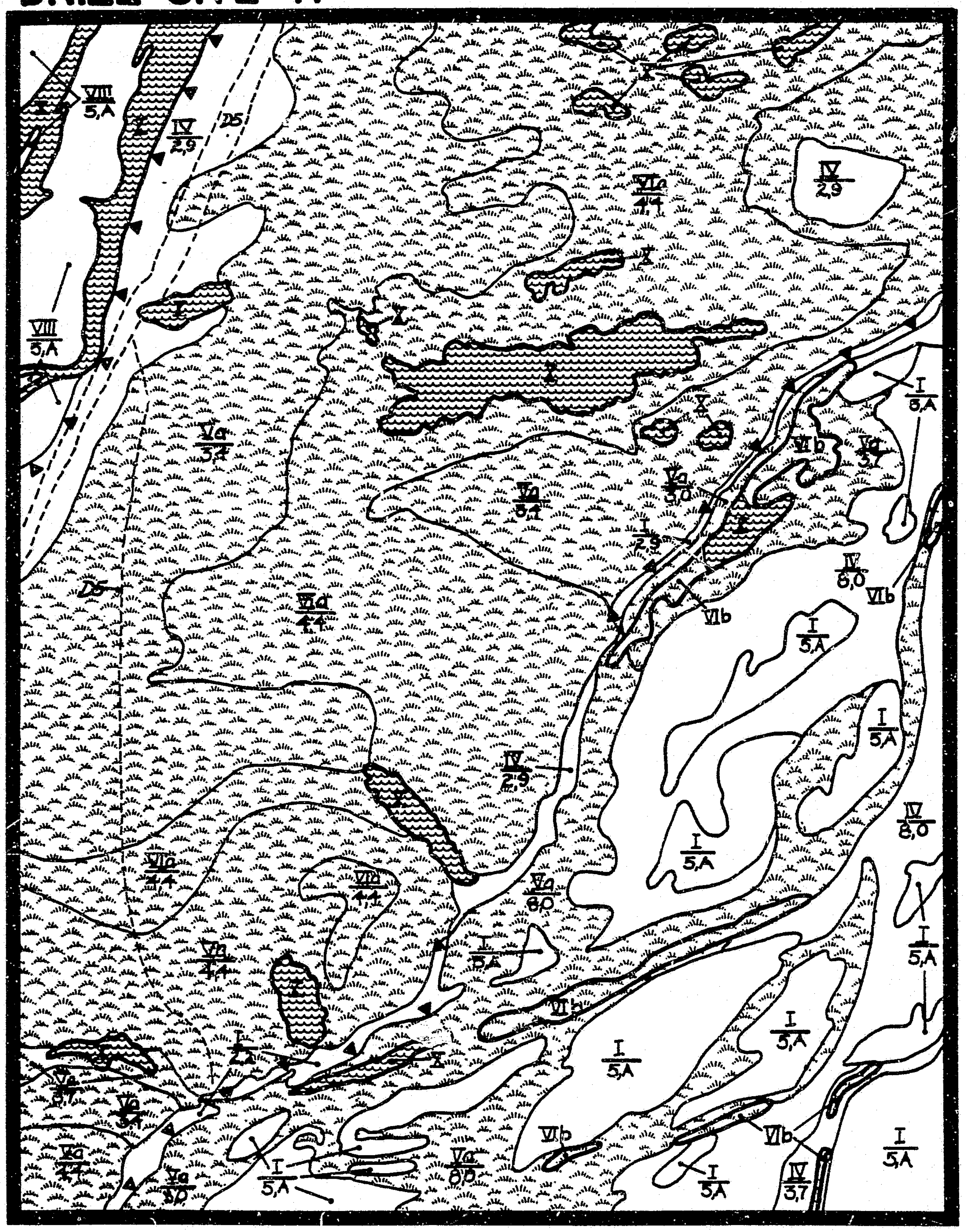
N

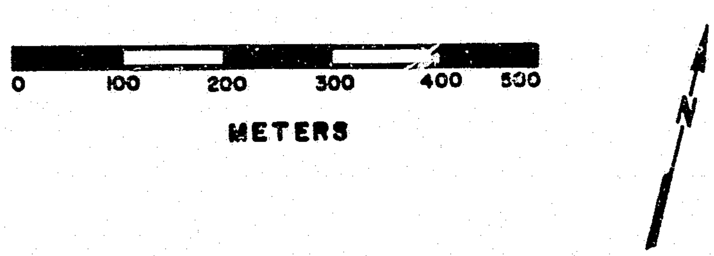
Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 7-8
Vegetation: *D. A. Walker* & *P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L–15

DRILL SITE 17



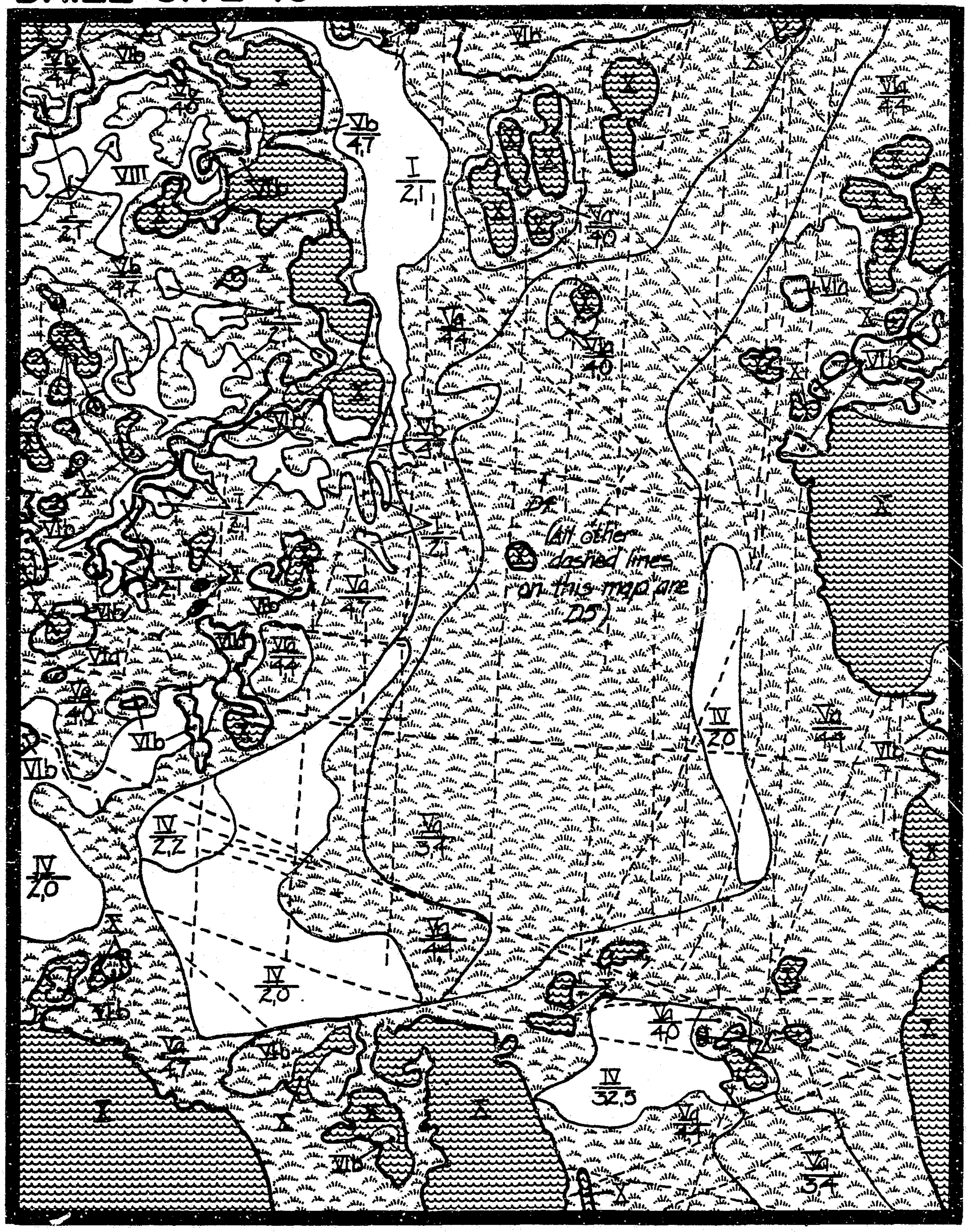


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 8-10
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-16

DRILL SITE 18



0 100 200 300 400 500

METERS

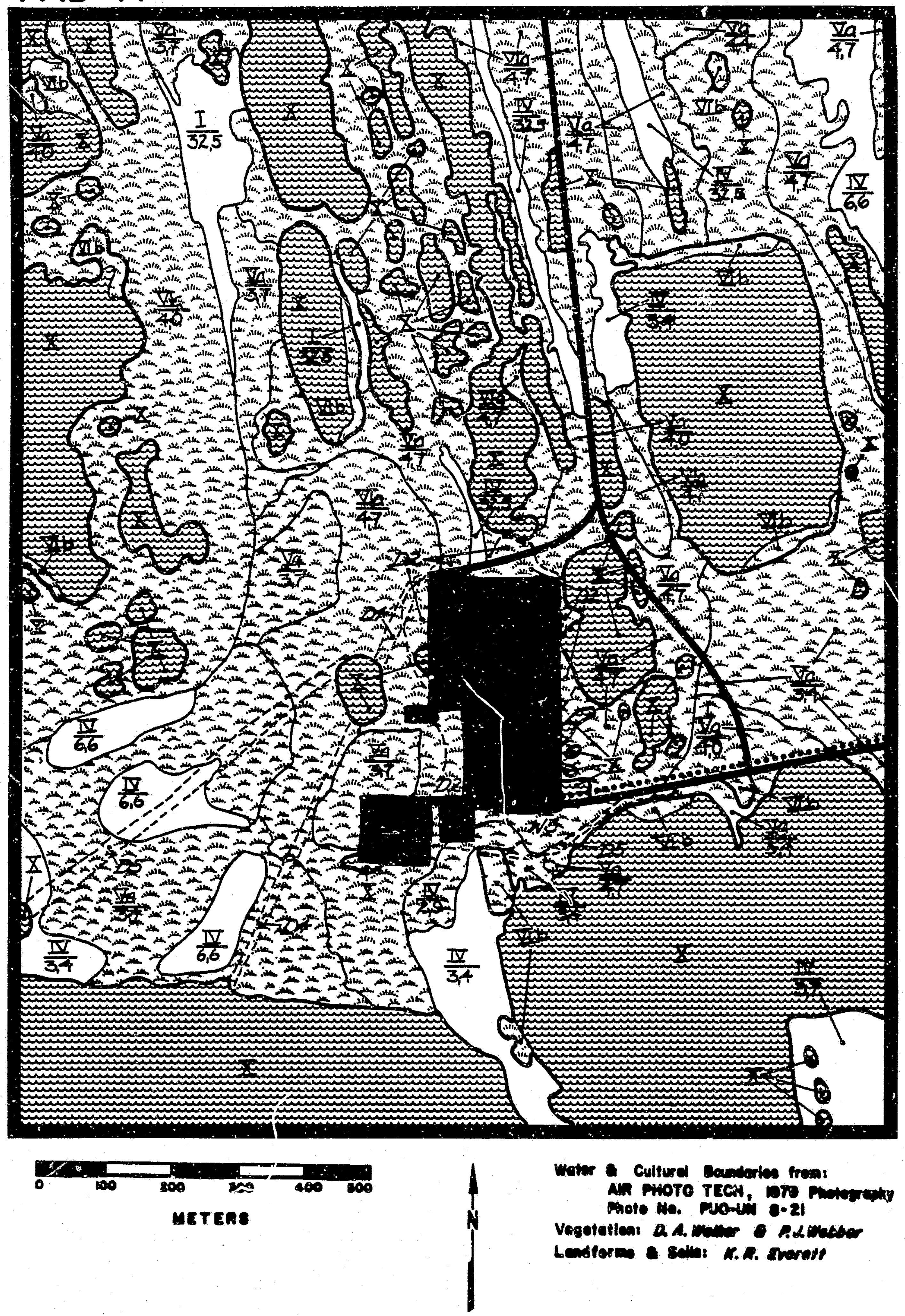
N

Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 5-15
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-17

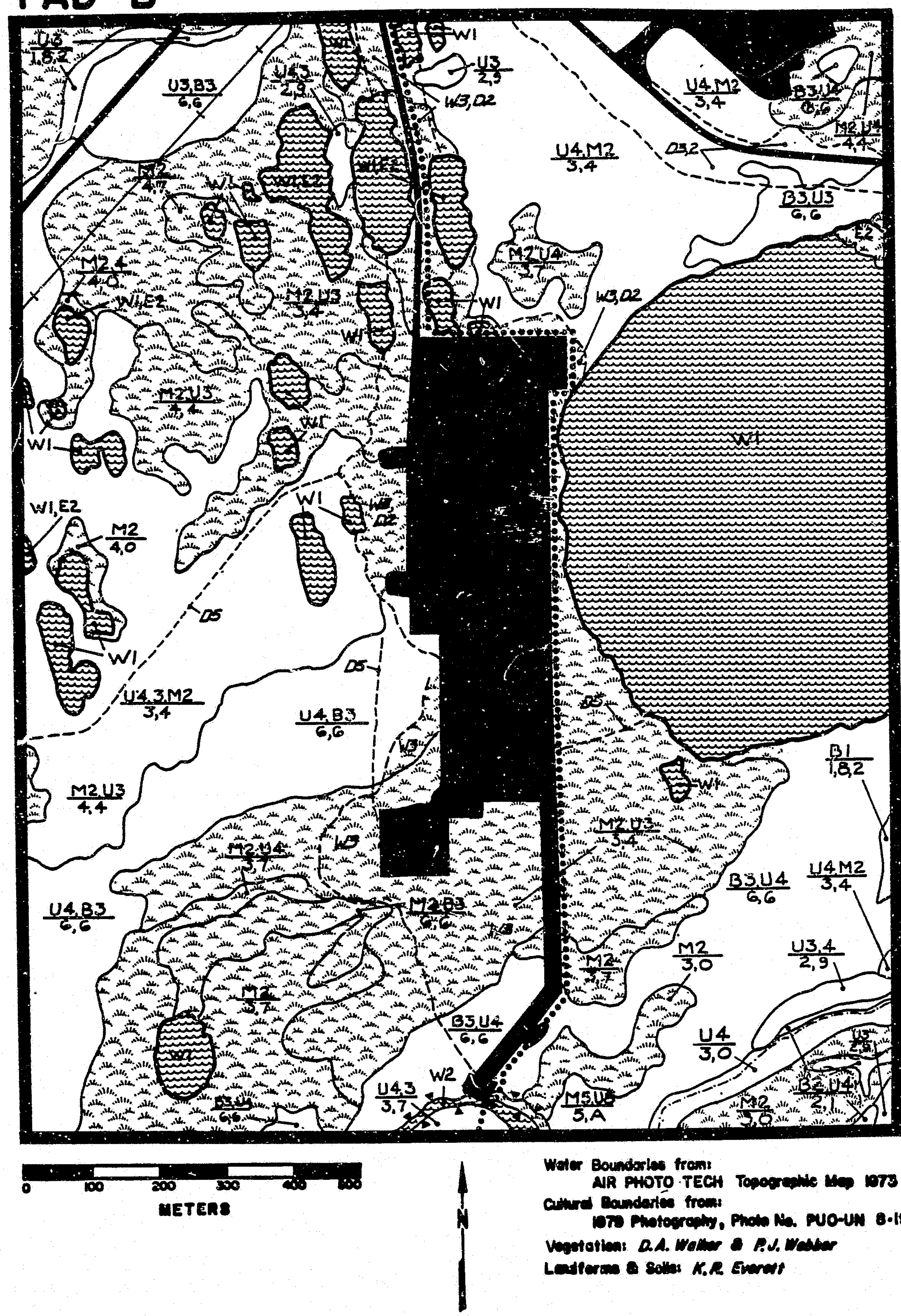
PAD A



WETLAND AND OPEN WATER COMMUNITIES

Figure L-18

PAD B

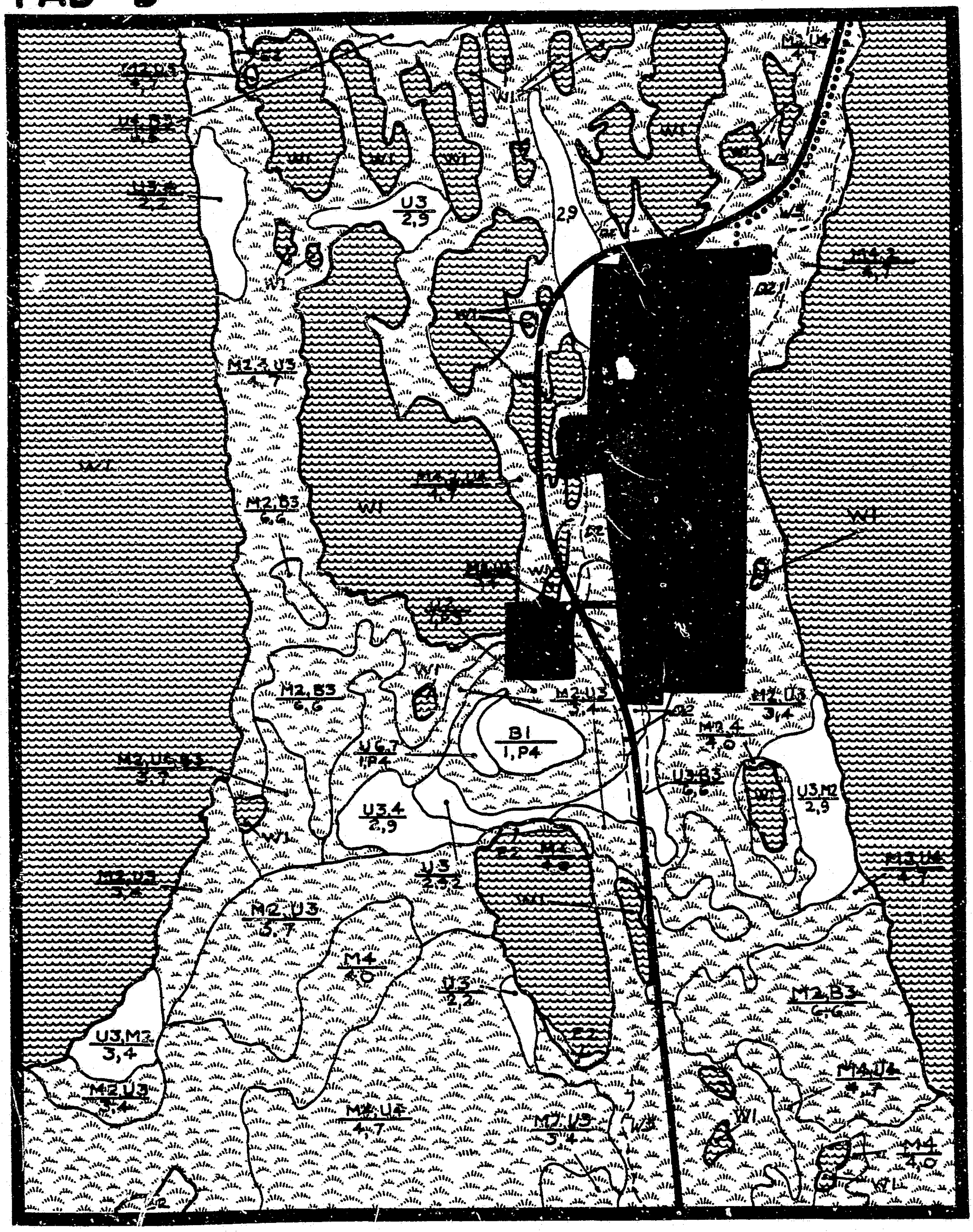


Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-19
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-19

PAD D



0 100 200 300 400 500
METERS

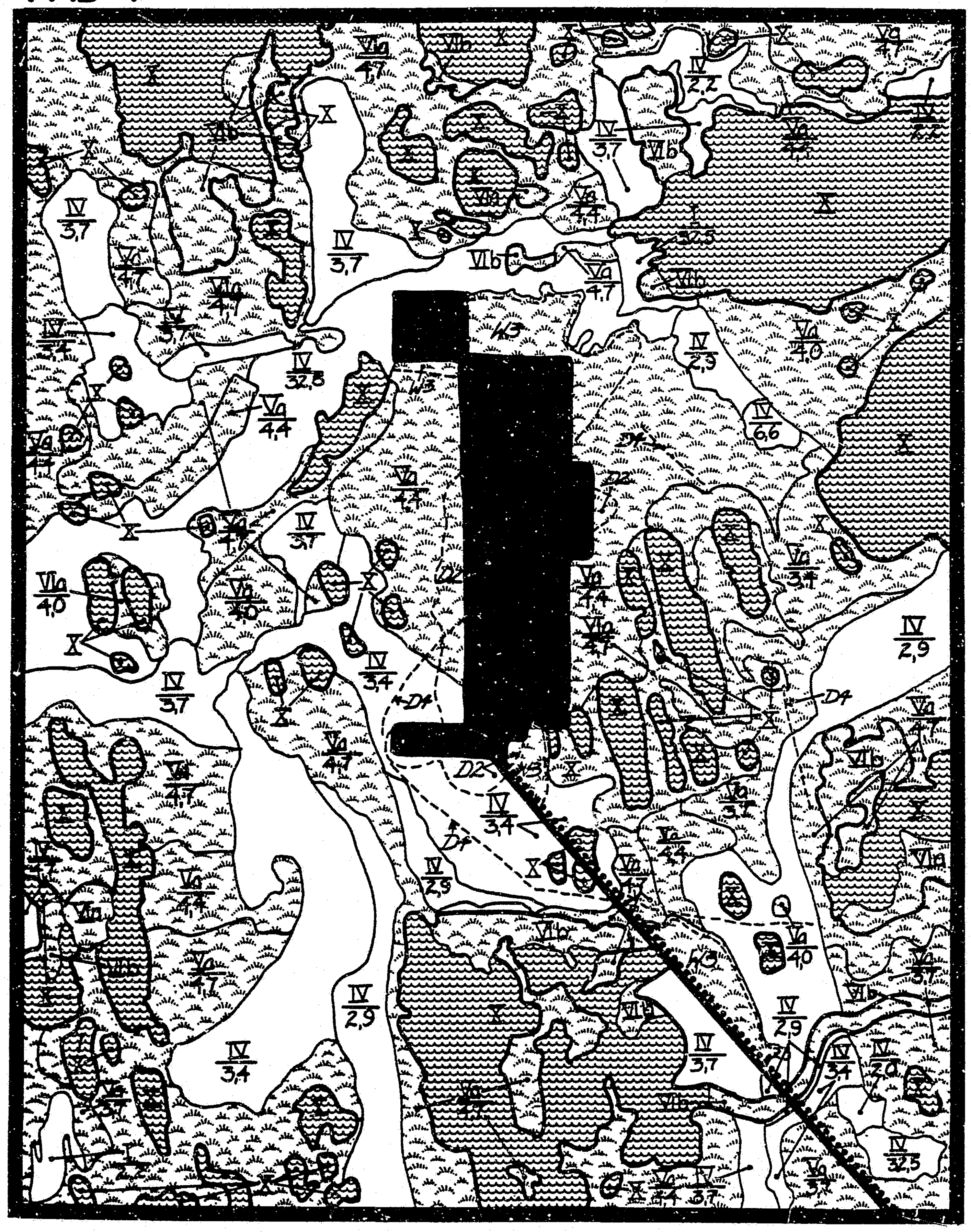
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-22
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-20

PAD F



0 100 200 300 400 500
METERS

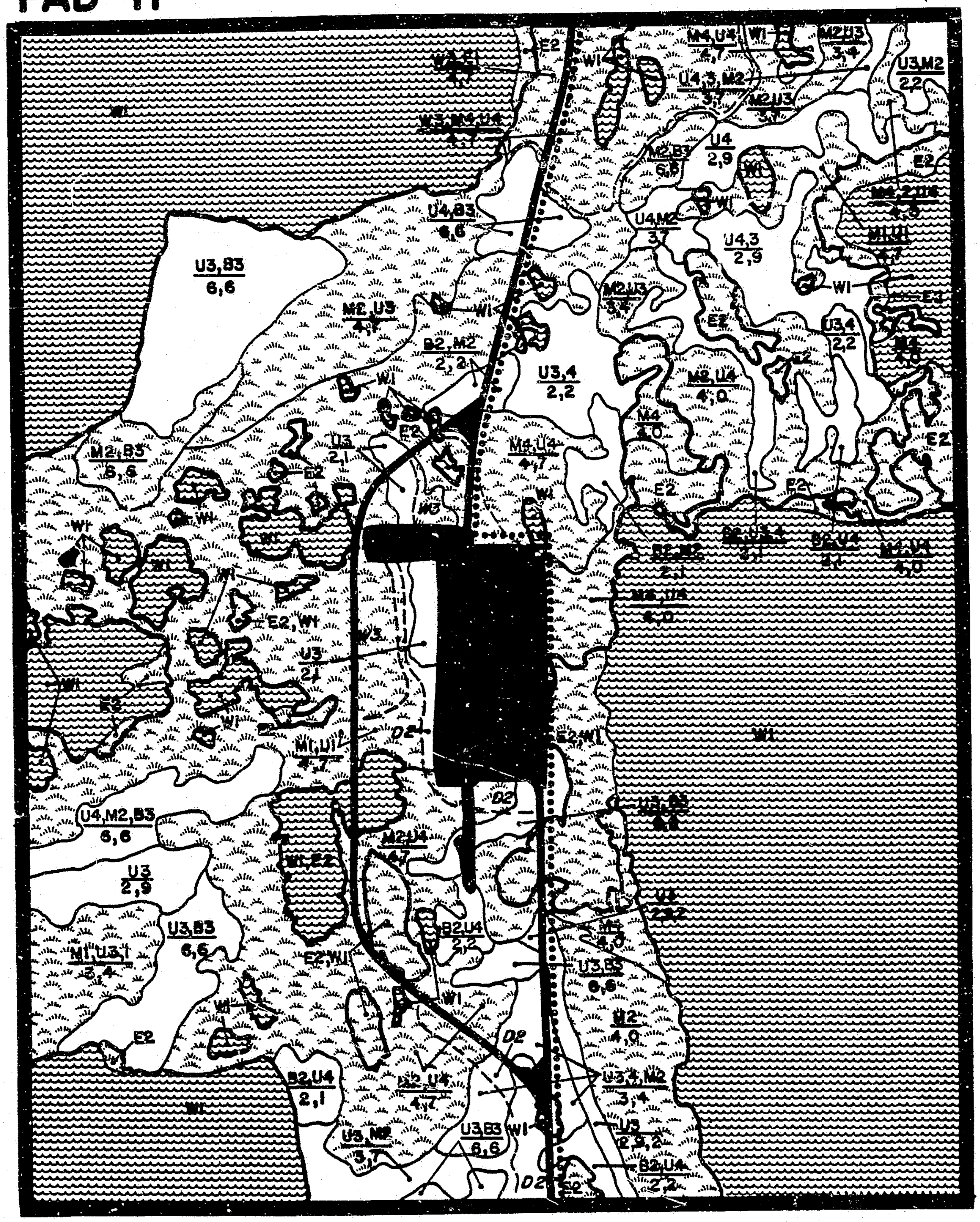
N

Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 6-23
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-21

PAD H



0 100 200 300 400 500
METERS

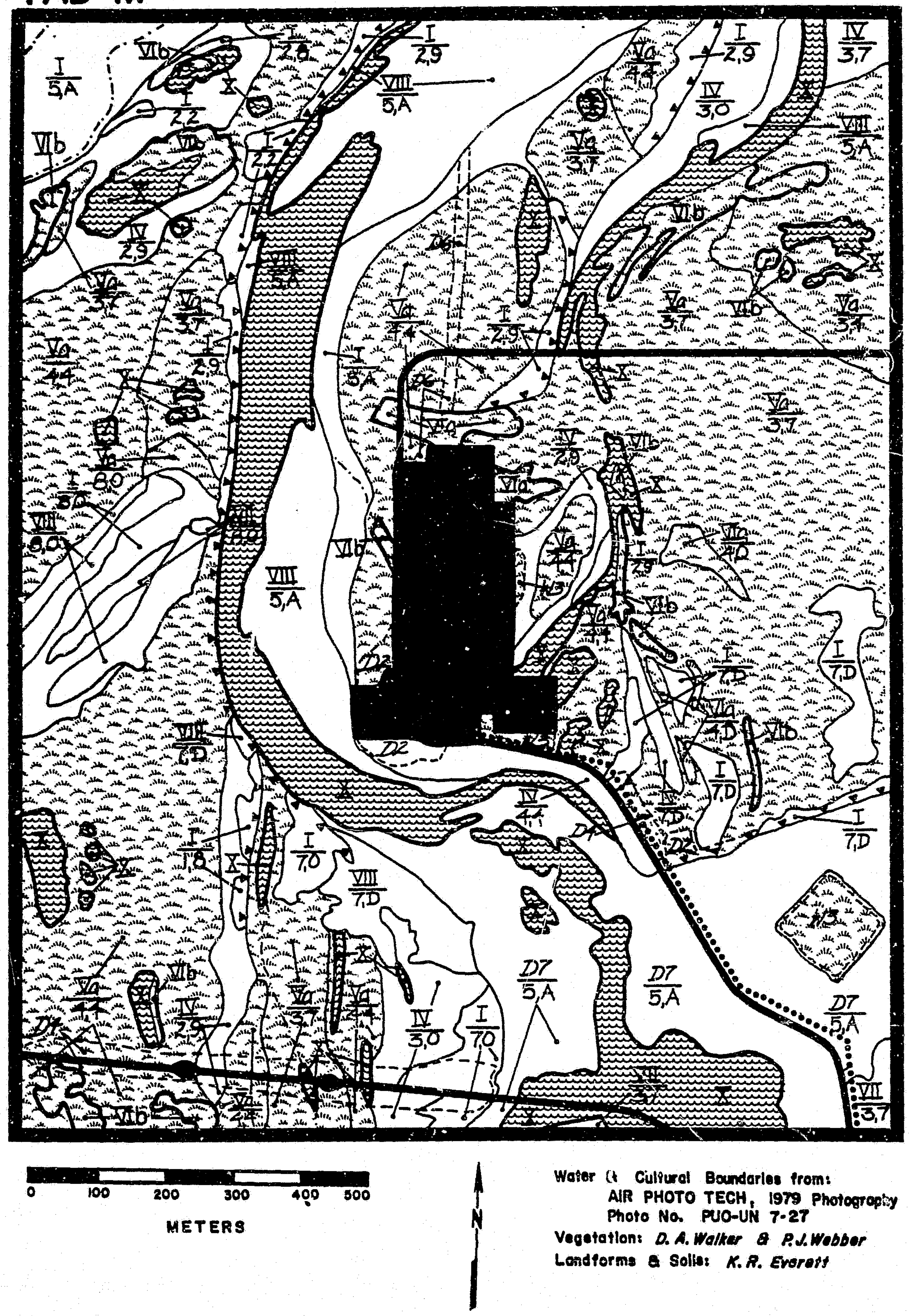
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-24
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L–22

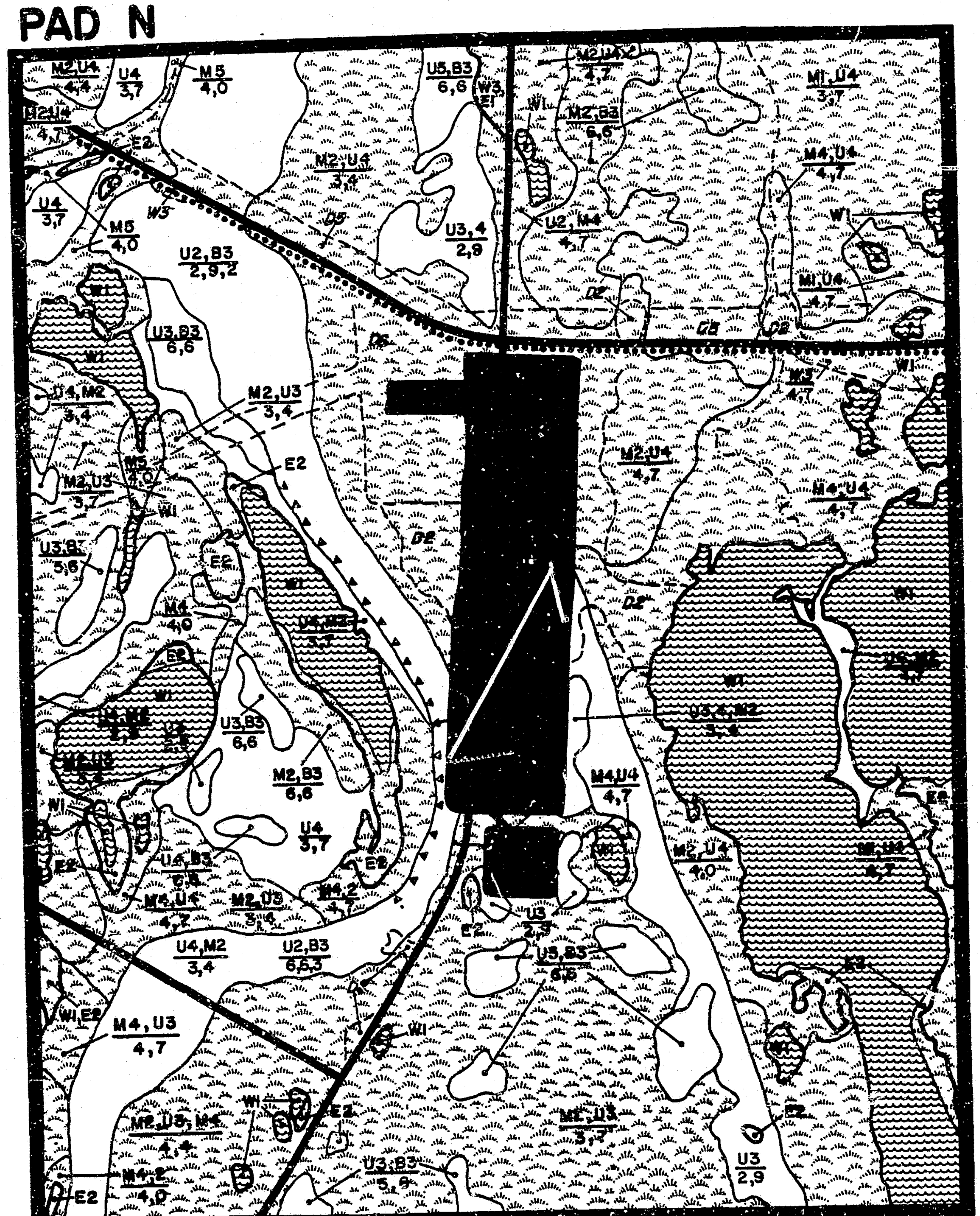
PAD M



WETLAND AND OPEN WATER COMMUNITIES

Figure L-23

PAD N



0 100 200 300 400 500

METERS

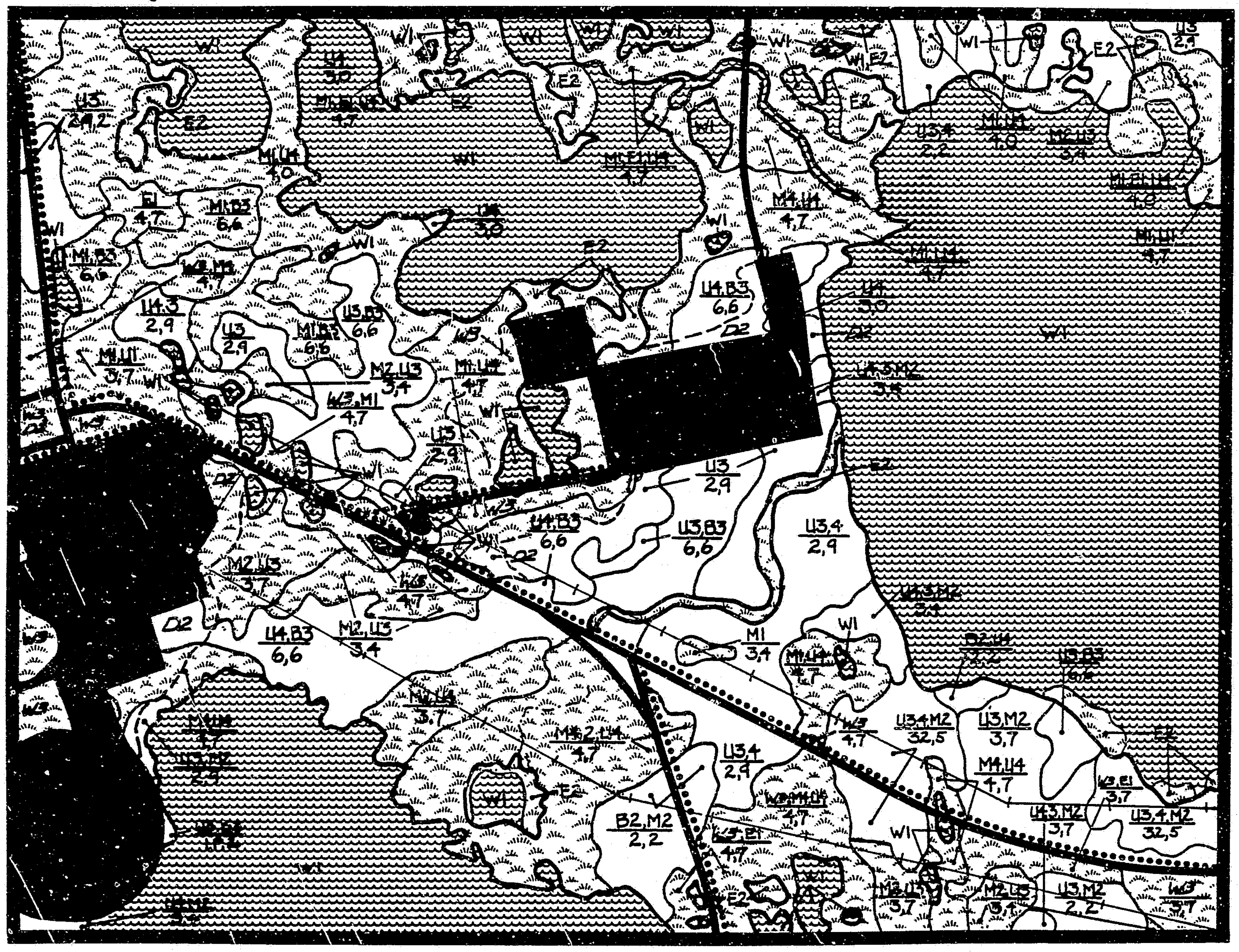
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 6-26
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-24

PAD Q



0 100 200 300 400 500
METERS

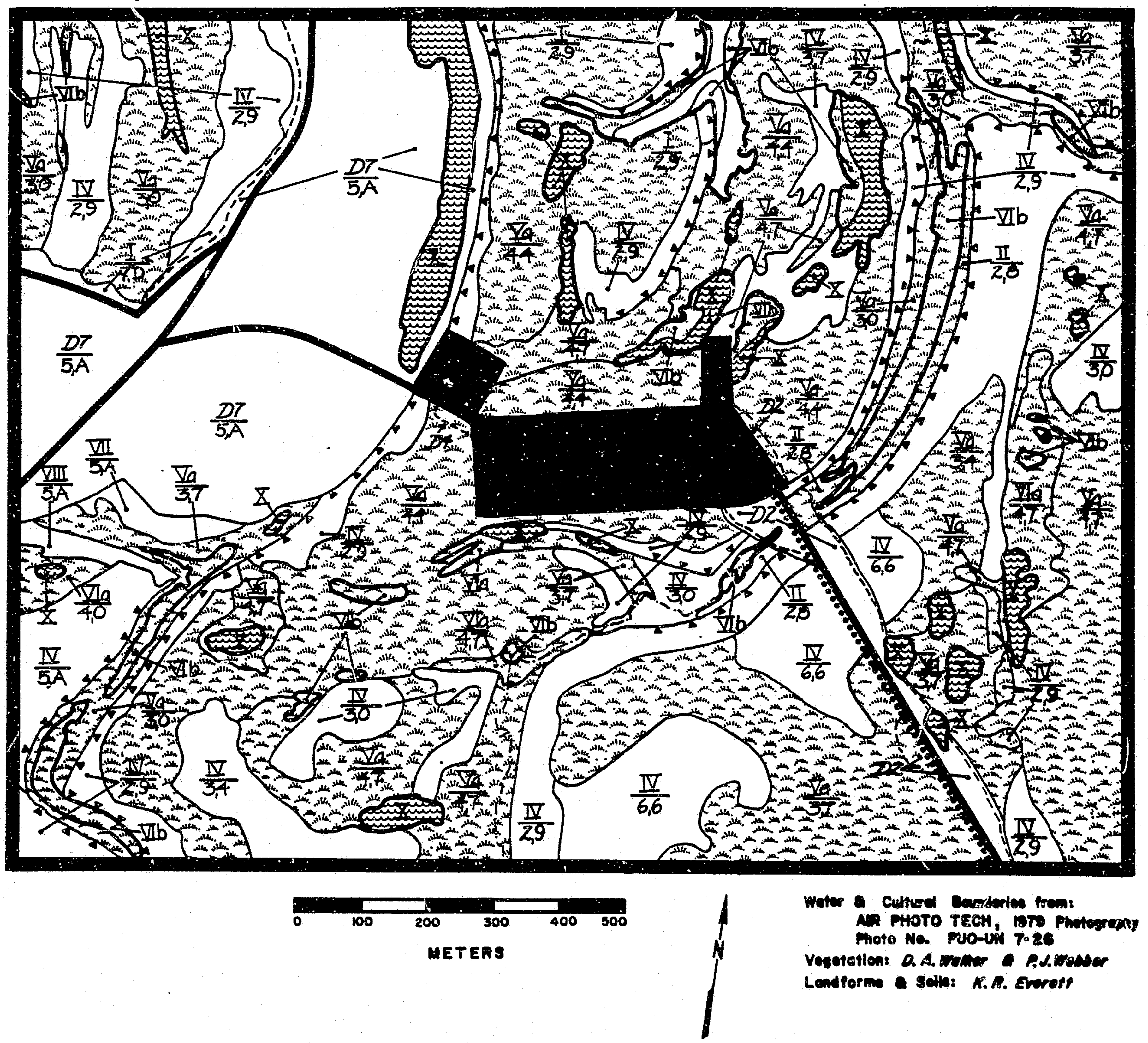
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-24
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-25

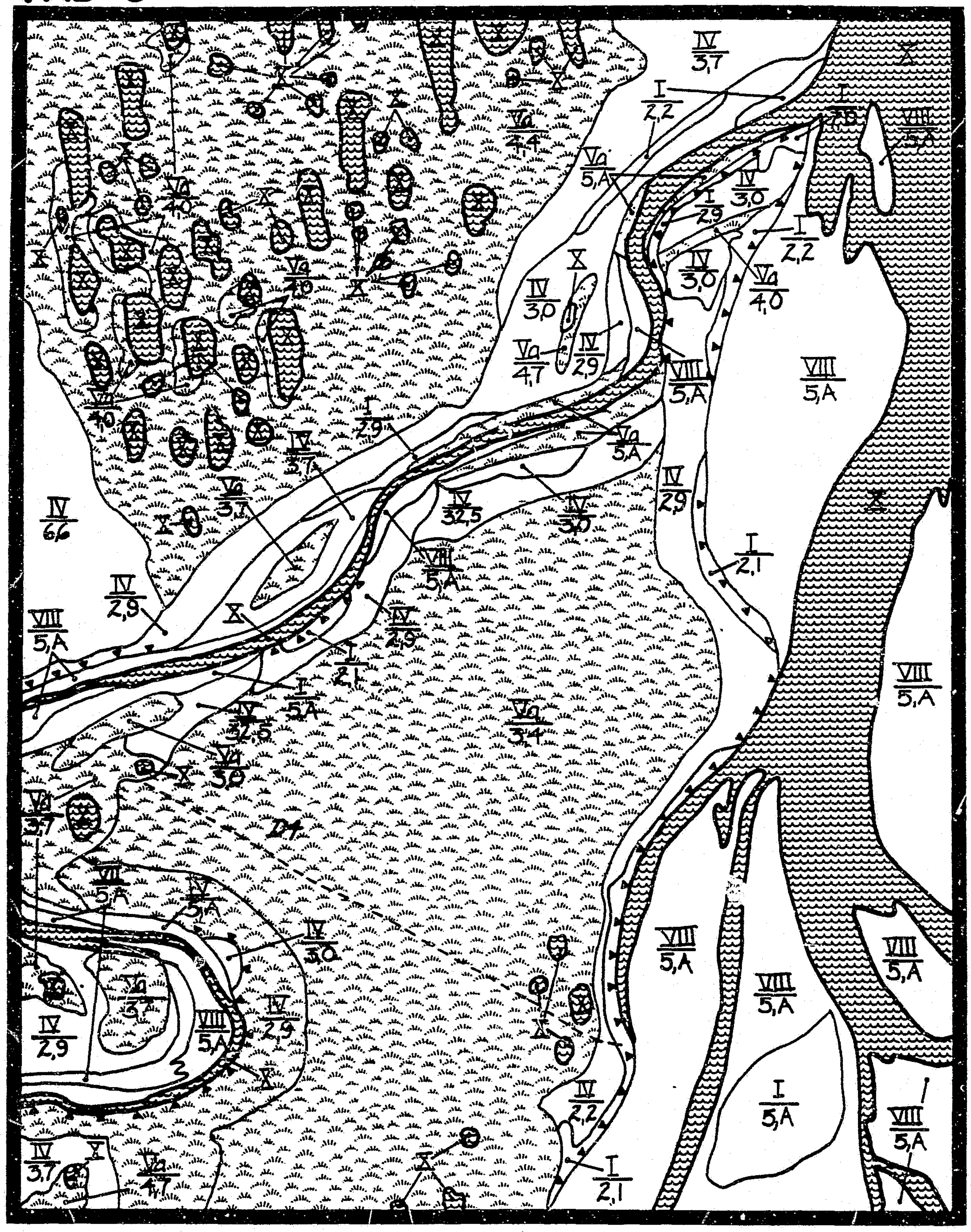
PAD R

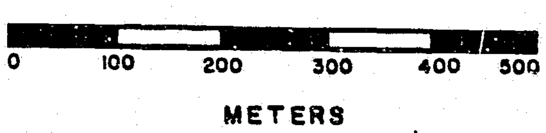


WETLAND AND OPEN WATER COMMUNITIES

Figure L–26

PAD S



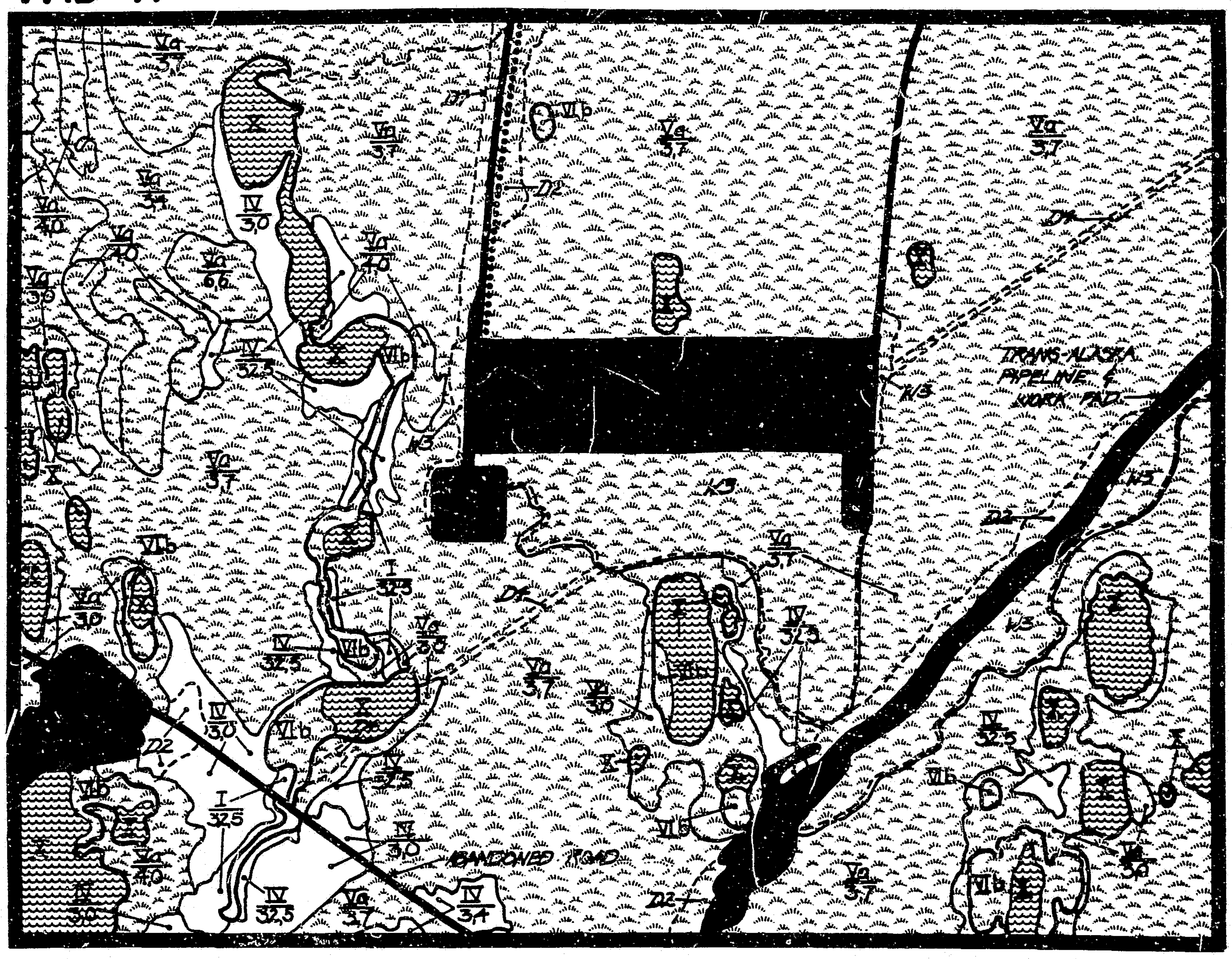


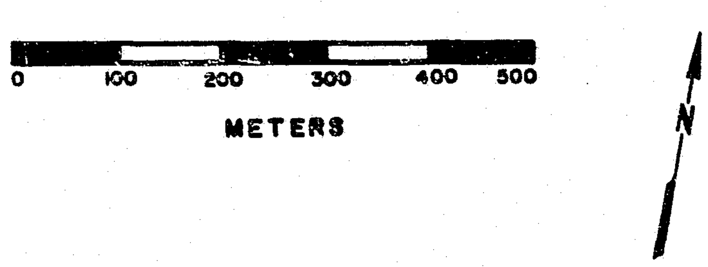
Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 7-29
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L–27

PAD X



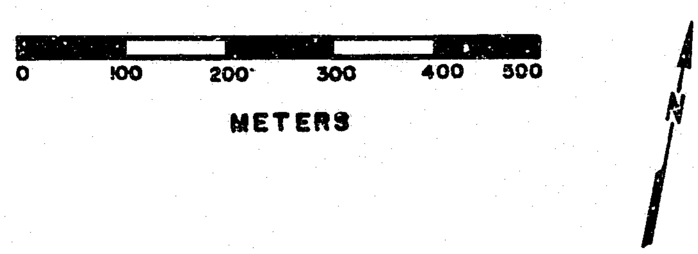


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 8-19
Vegetation: D. A. Walker & P. J. Webber
Landforms & Soils: K. R. Everett

WETLAND AND OPEN WATER COMMUNITIES

Figure L-28

PAD Y

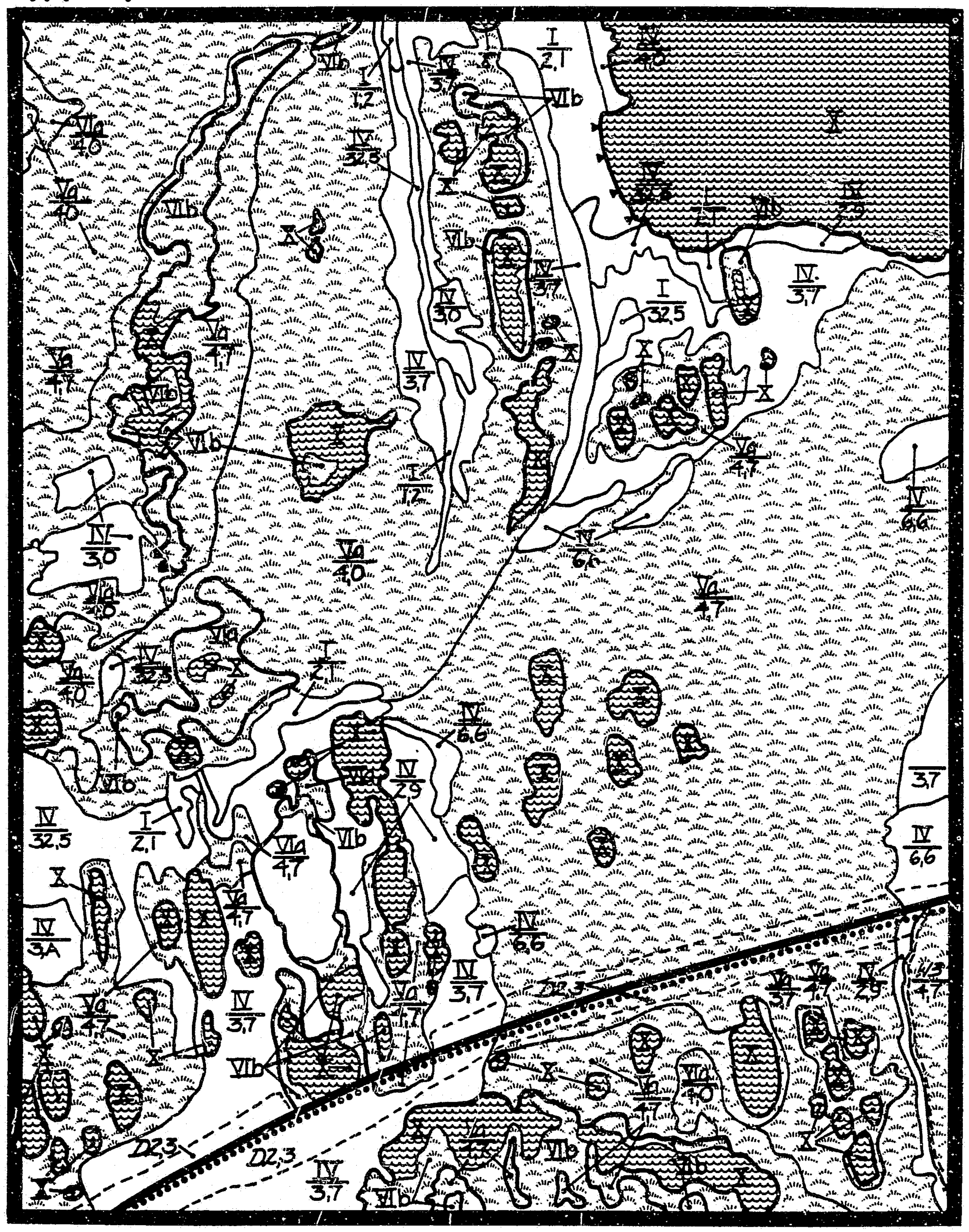


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 9-23
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L–29

WF I



0 100 200 300 400 500

METERS

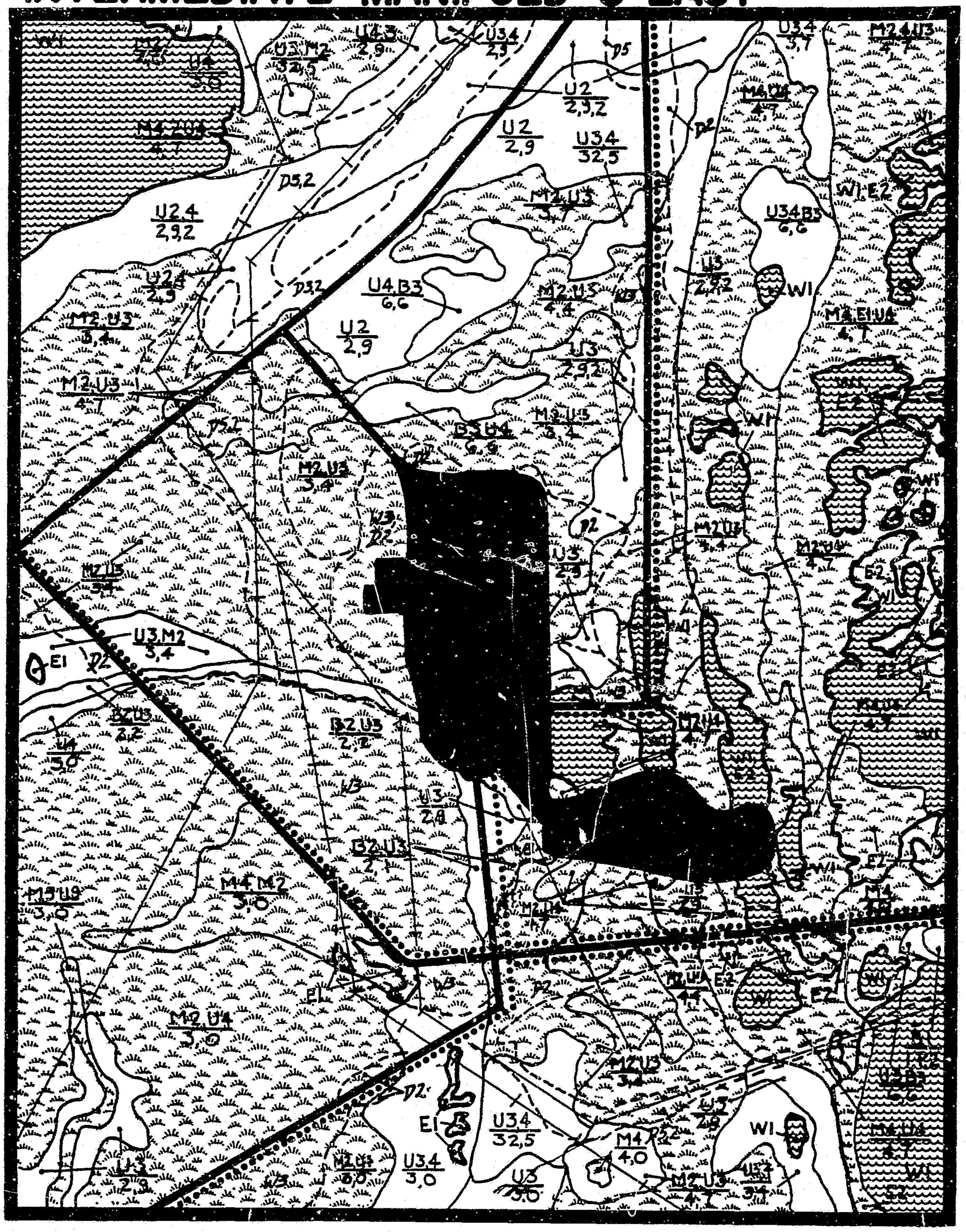
N

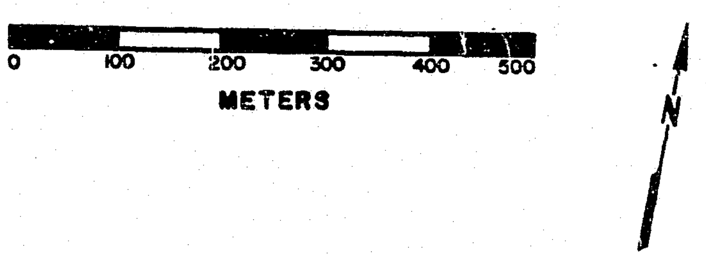
Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 6-19
Vegetation: *D. A. Walker* & *P.J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-30

INTERMEDIATE MANIFOLD 3 EAST



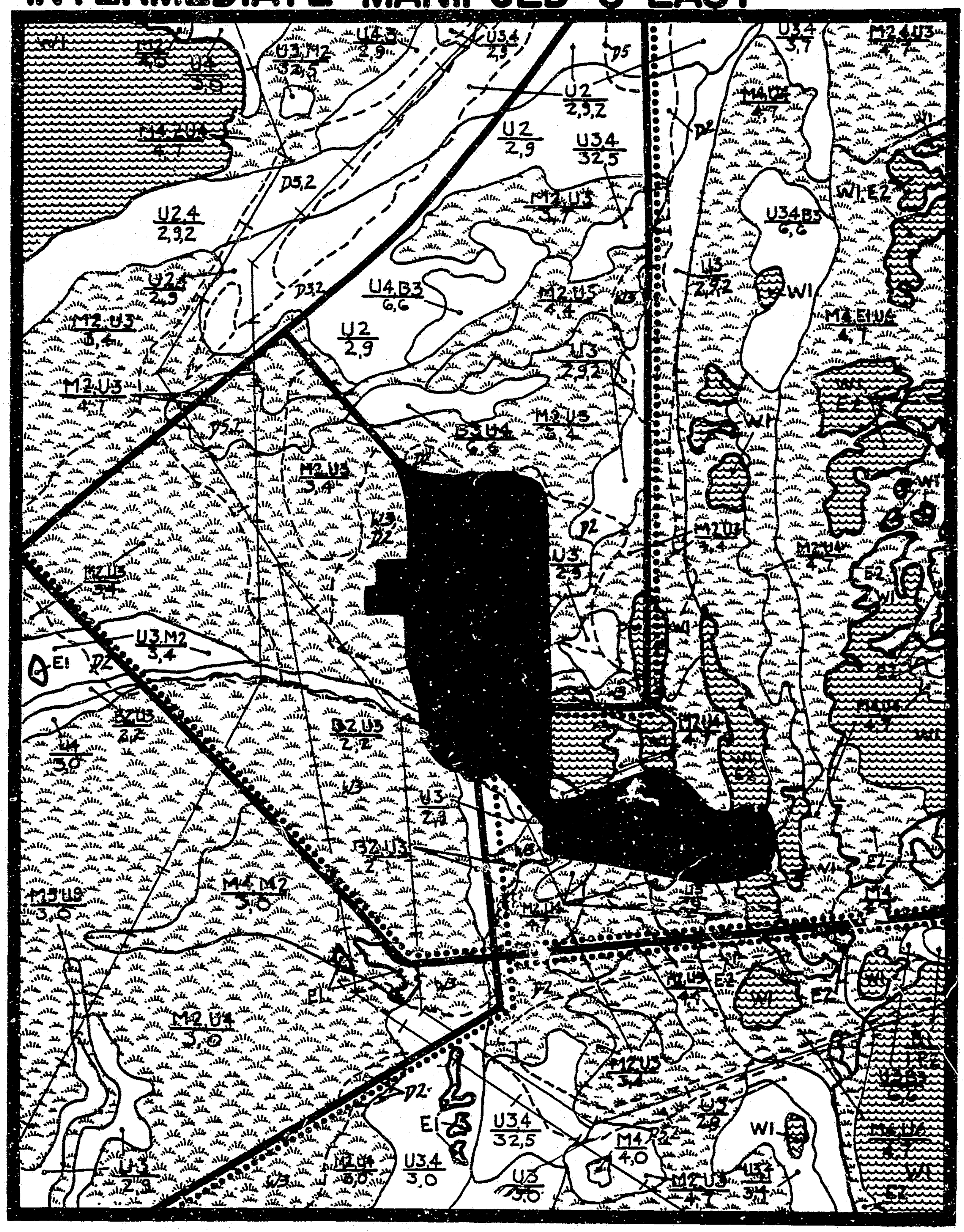


Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UH 8-17
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-31

INTERMEDIATE MANIFOLD 3 EAST



0 100 200 300 400 500
METERS

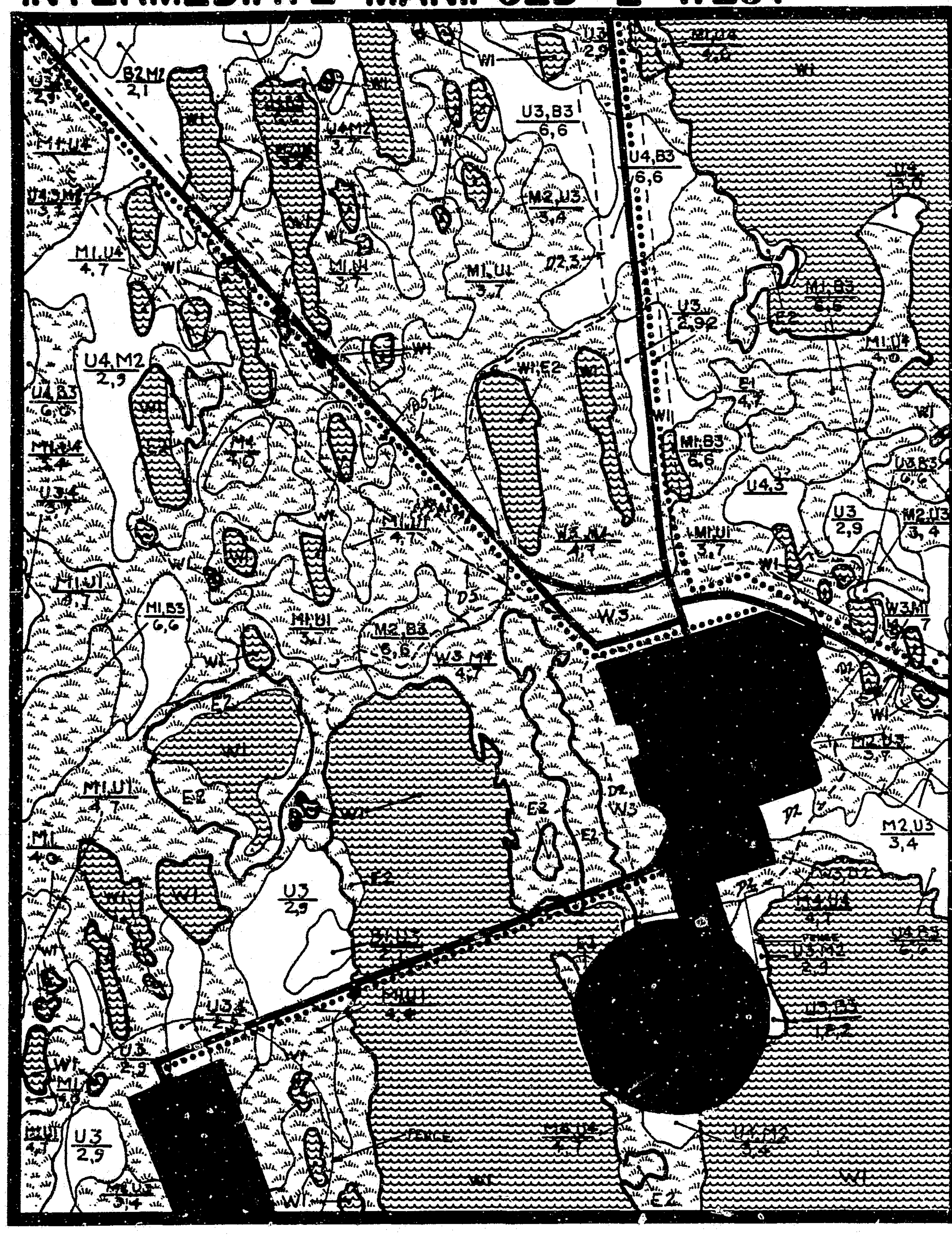
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-17
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-31

INTERMEDIATE MANIFOLD 2 WEST



0 100 200 300 400 500
METERS

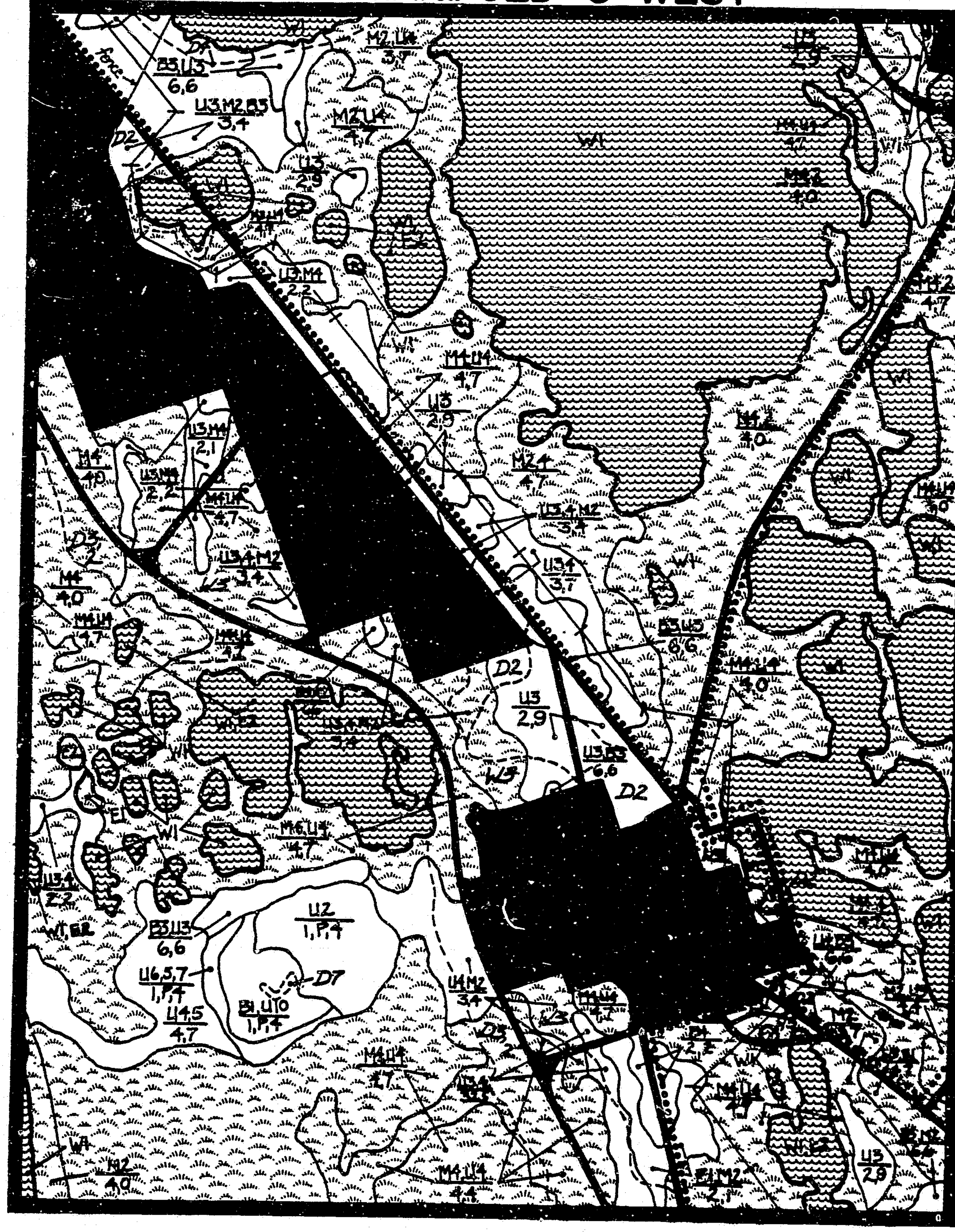
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-25
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L–32

INTERMEDIATE MANIFOLD 3 WEST



0 100 200 300 400 500
METERS

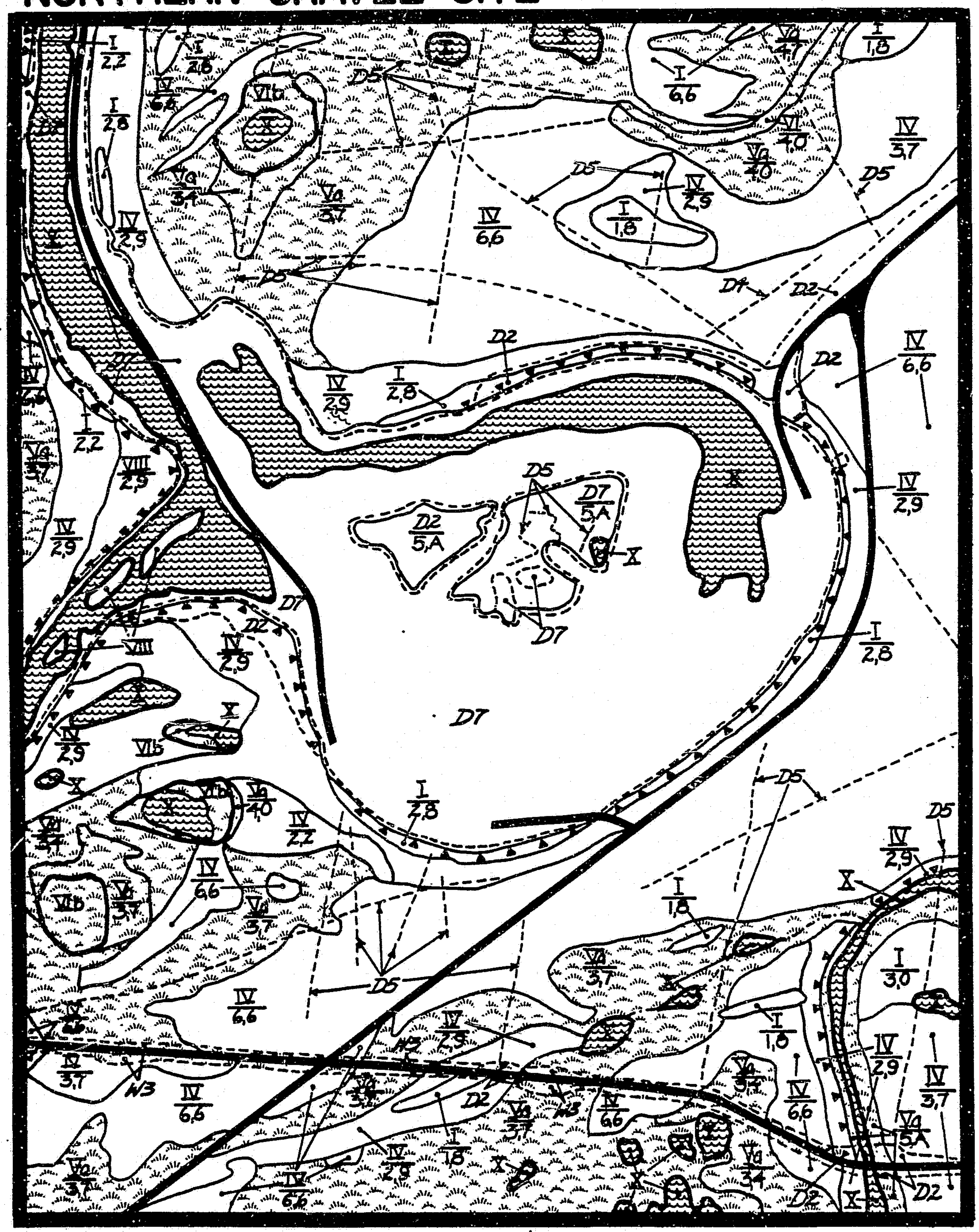
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-20
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-33

NORTHERN GRAVEL SITE



0 100 200 300 400 500

METERS

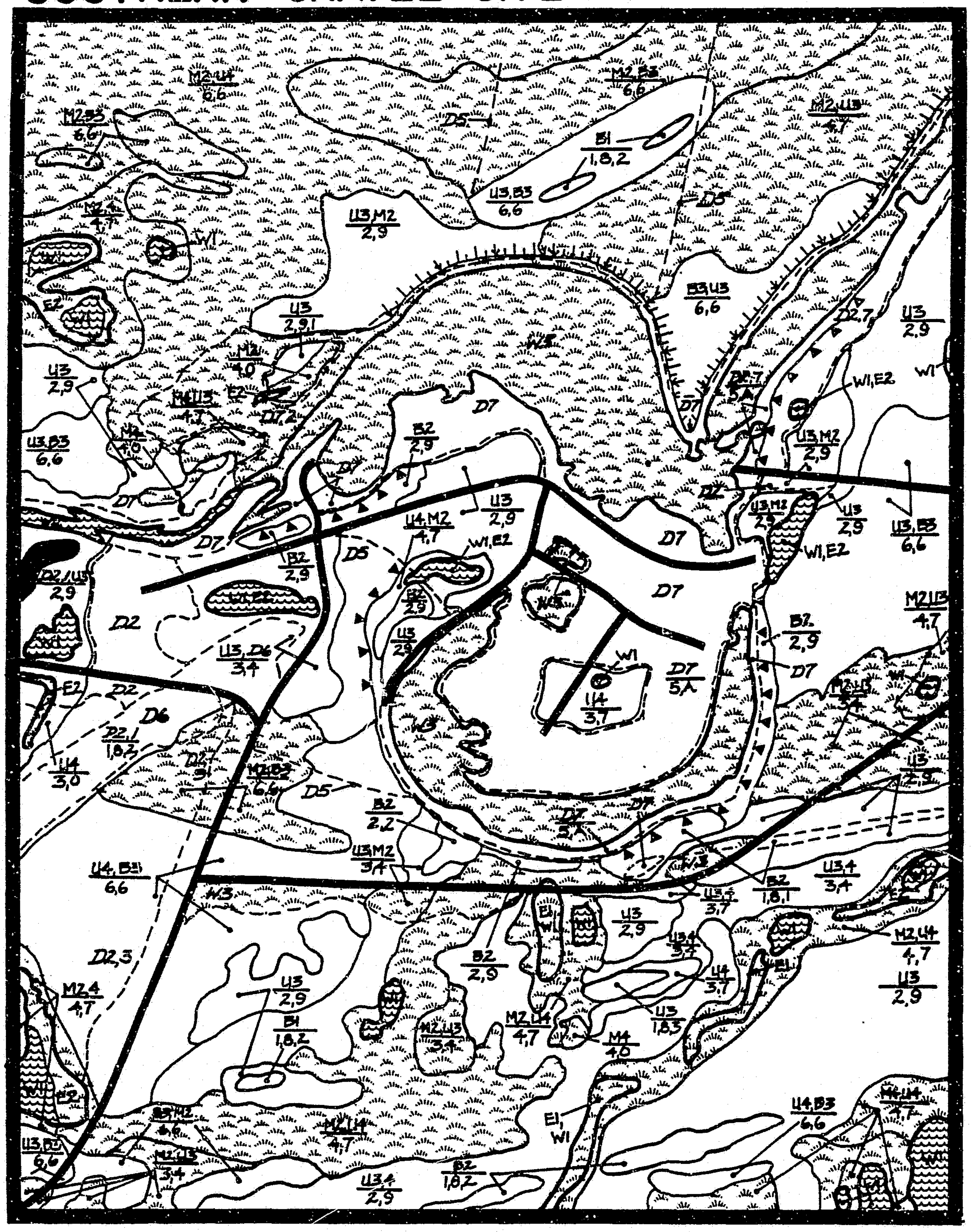
N

Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 6-18
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-34

SOUTHERN GRAVEL SITE



0 100 200 300 400 500
METERS

N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-17
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

WETLAND AND OPEN WATER COMMUNITIES

Figure L-35

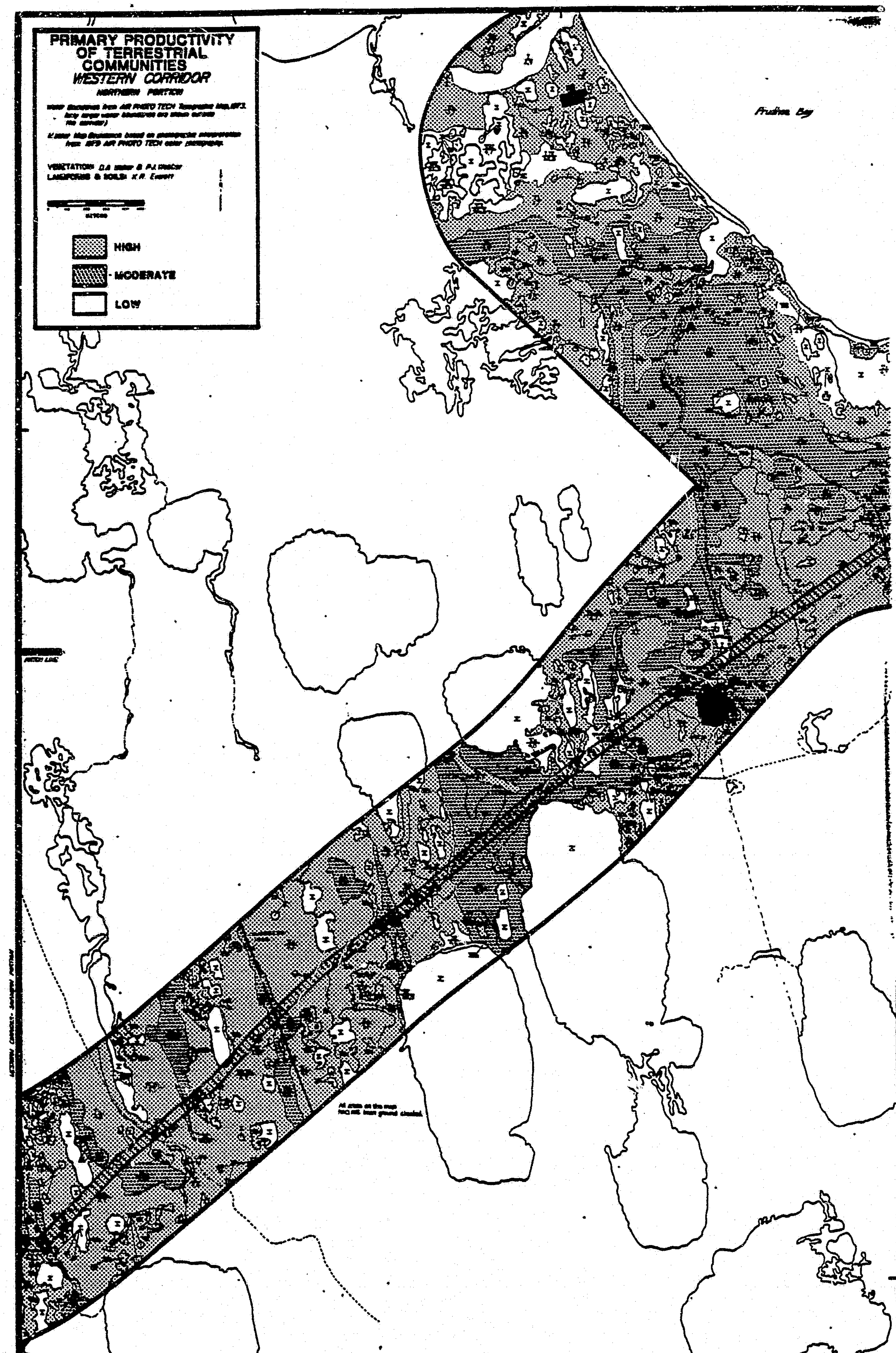


Figure L-36 (North)

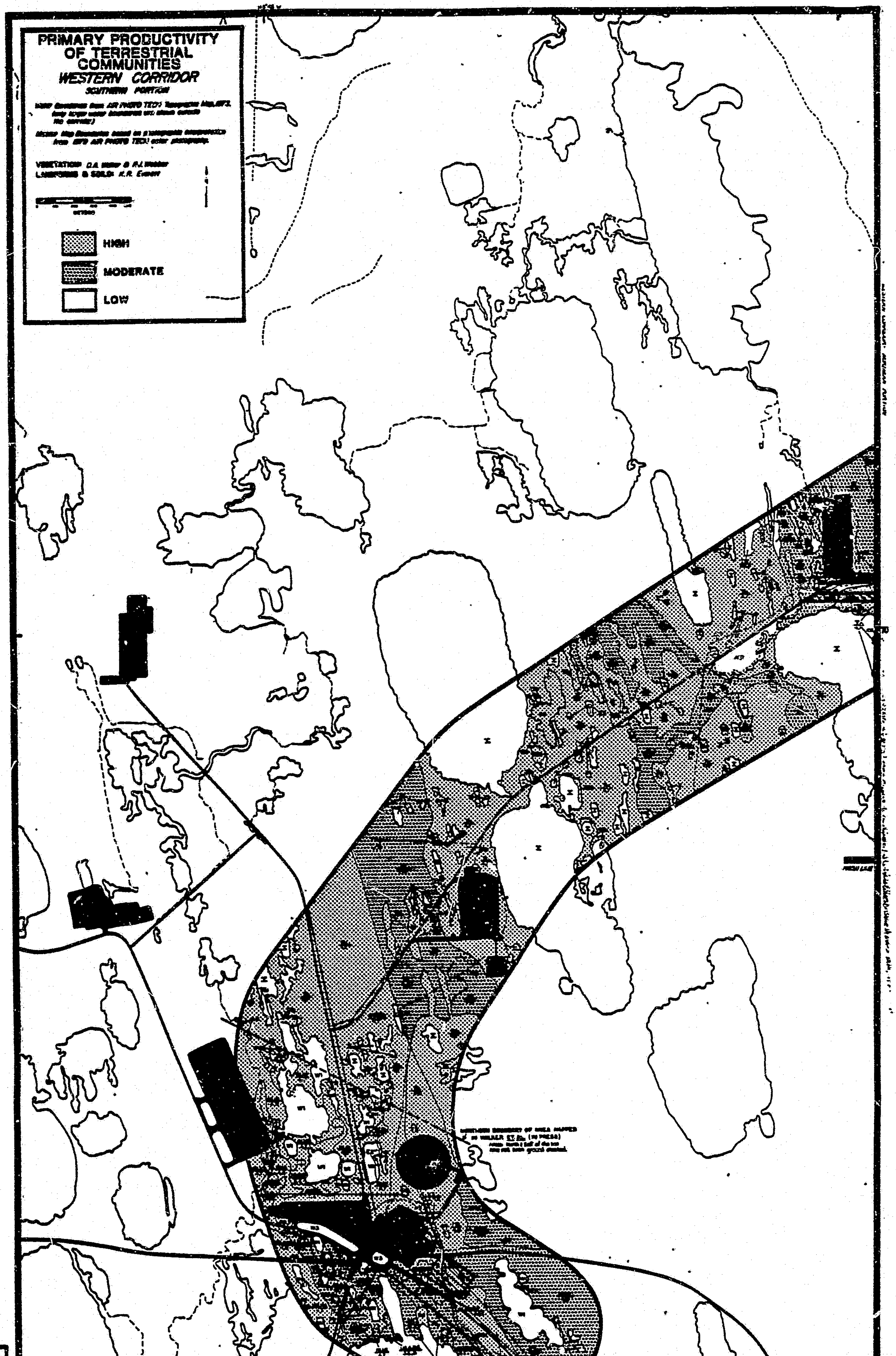


Figure L-36 (South)

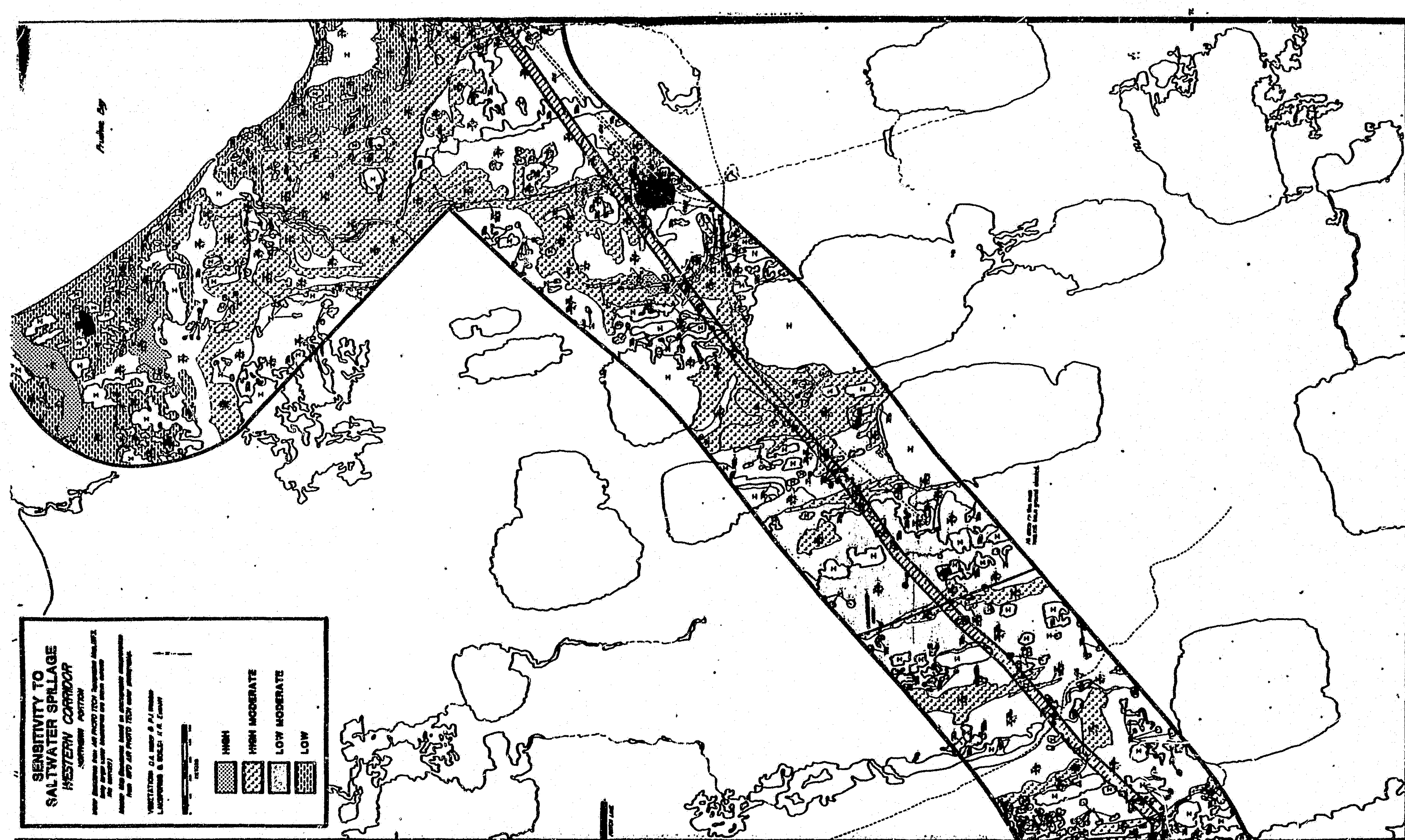


Figure L-37 (North)

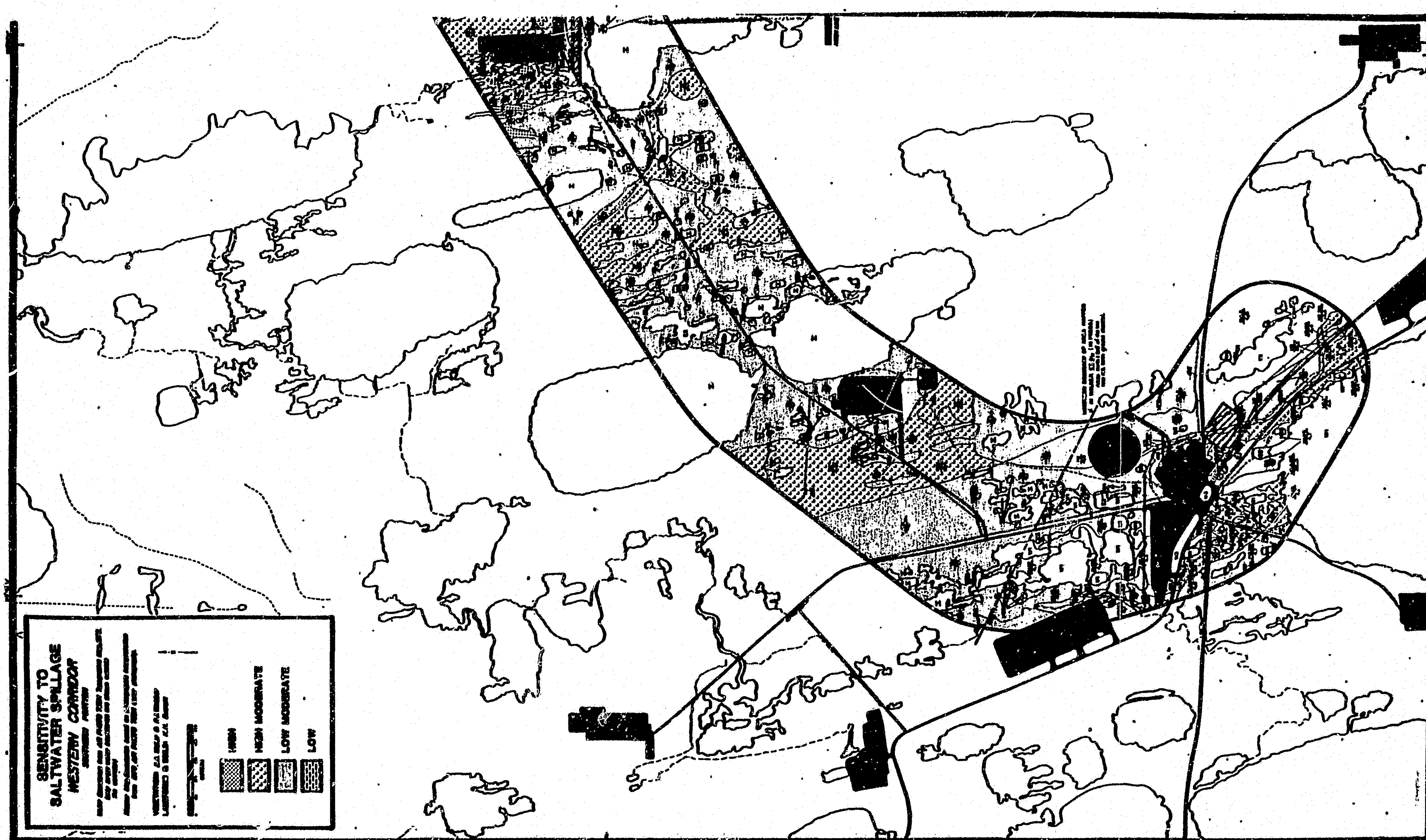


Figure L-37 (South)

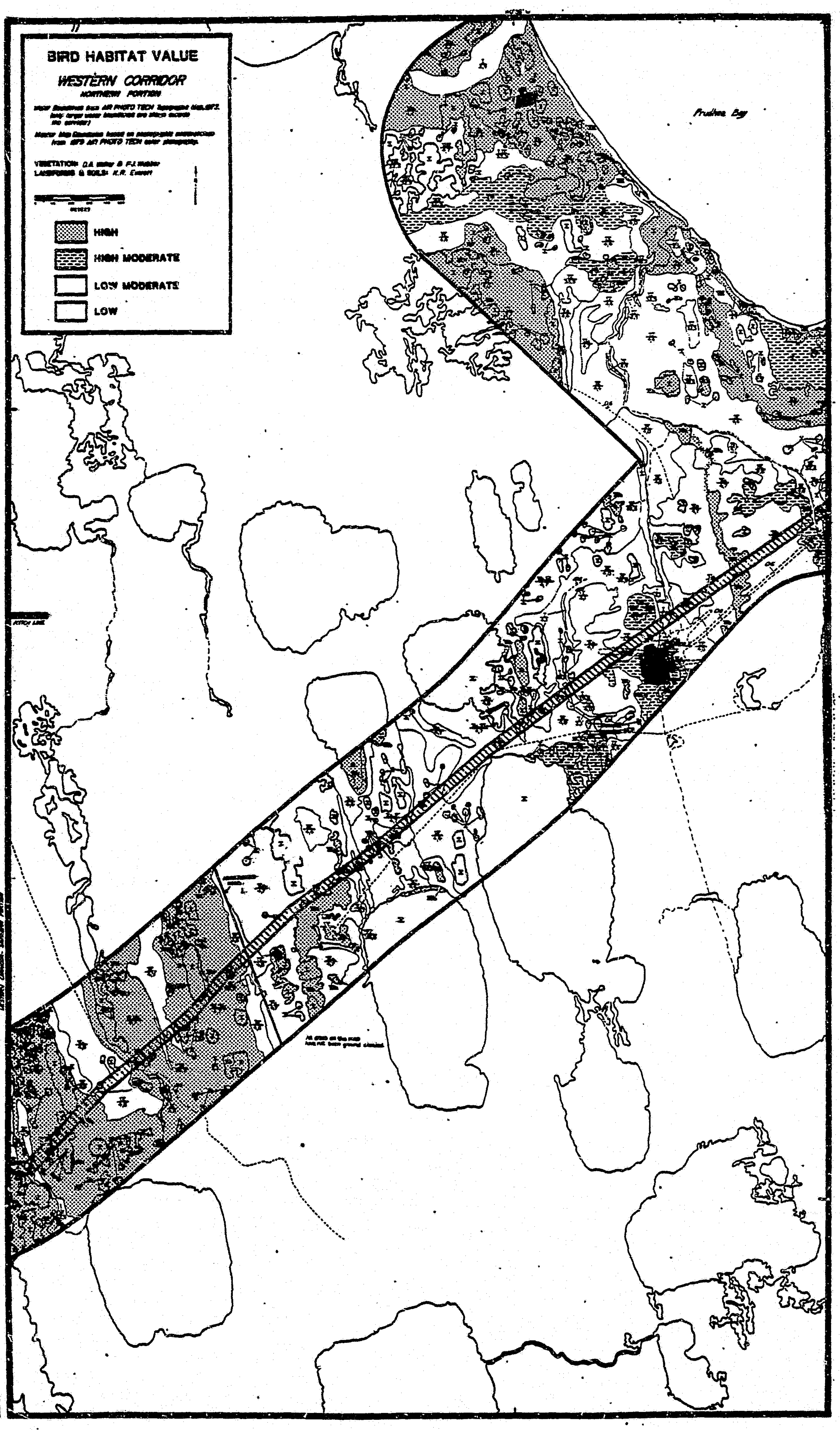


Figure L-38 (North)

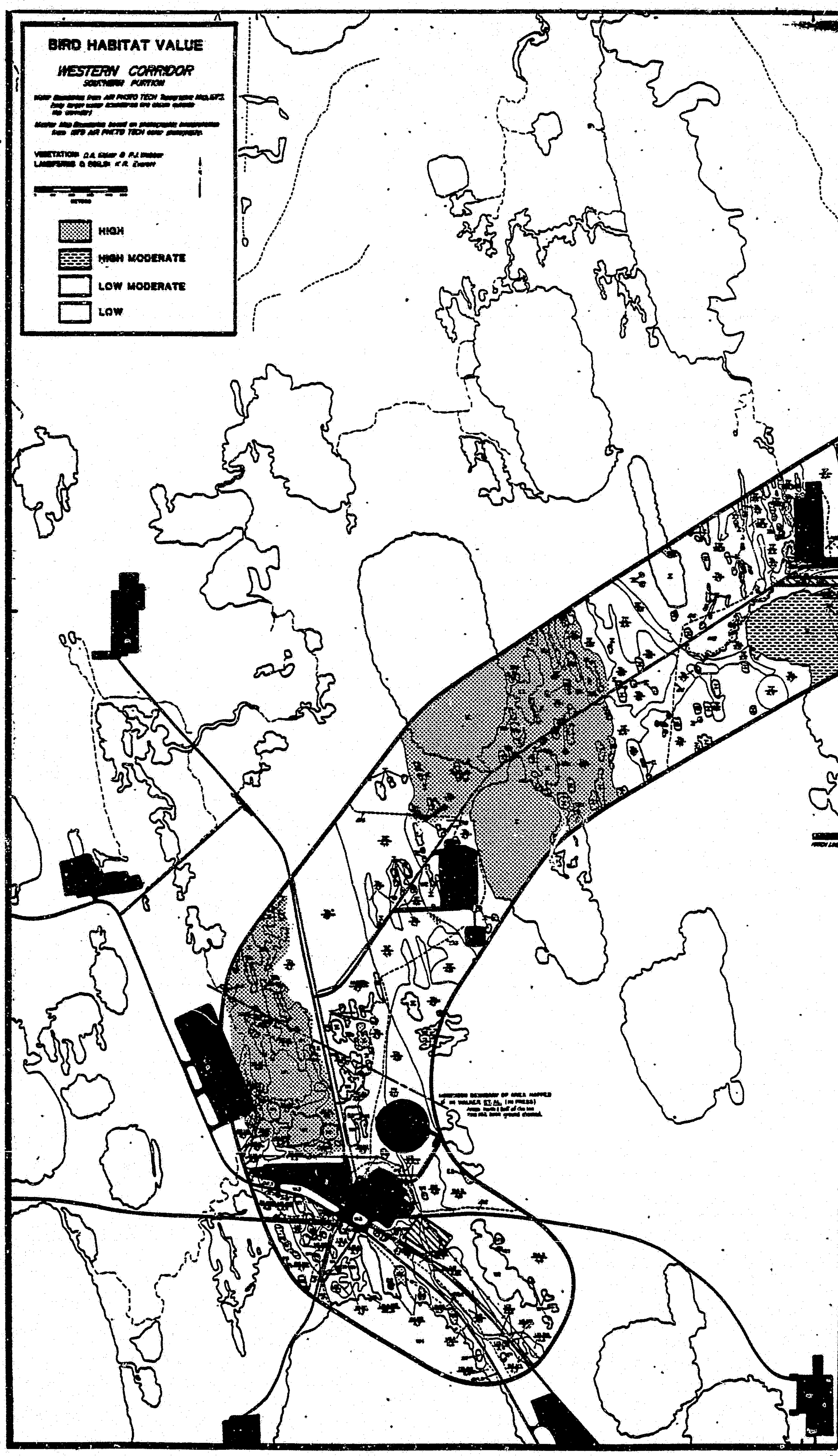


Figure L-38 (South)

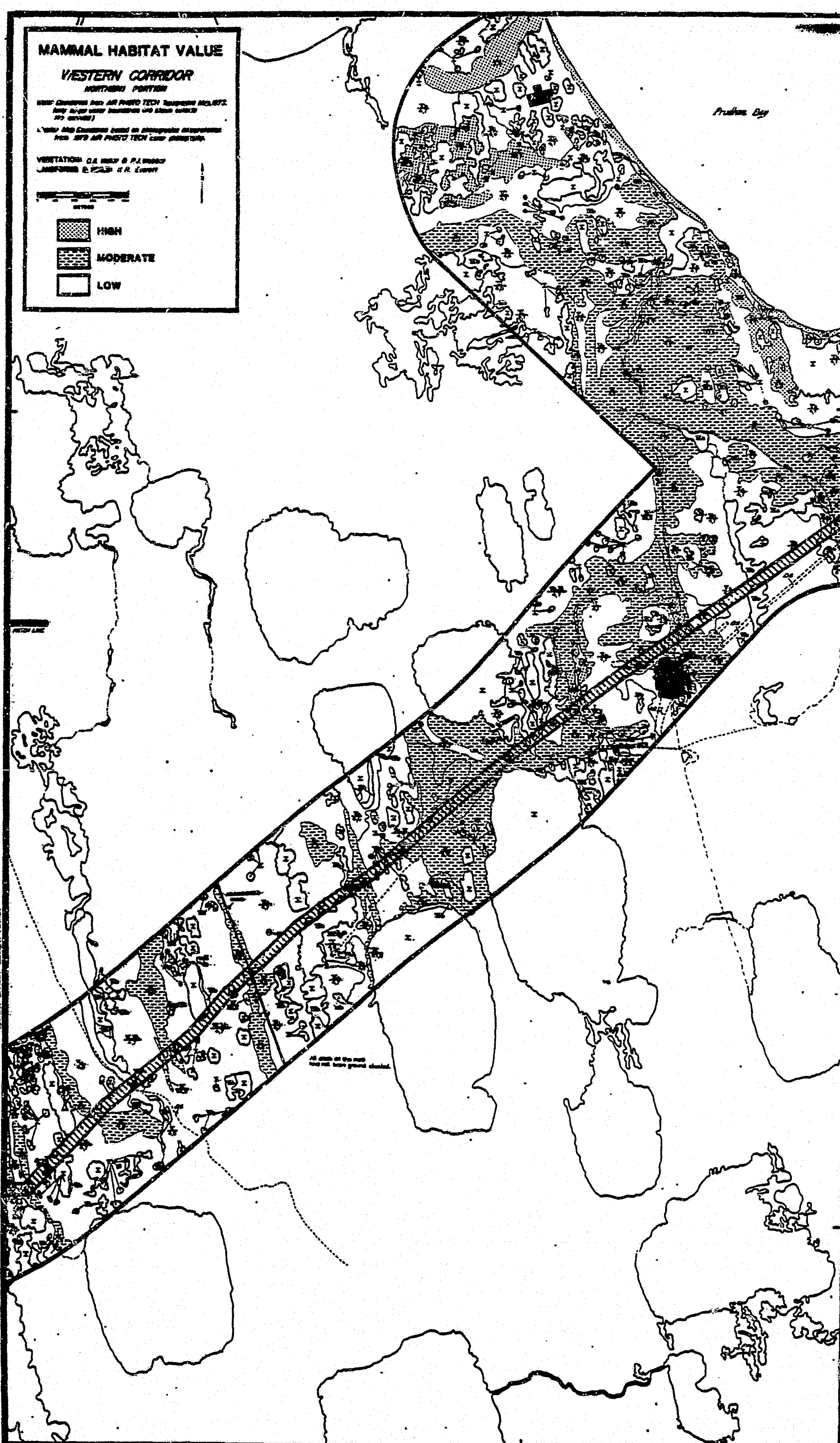


Figure L-39 (North)

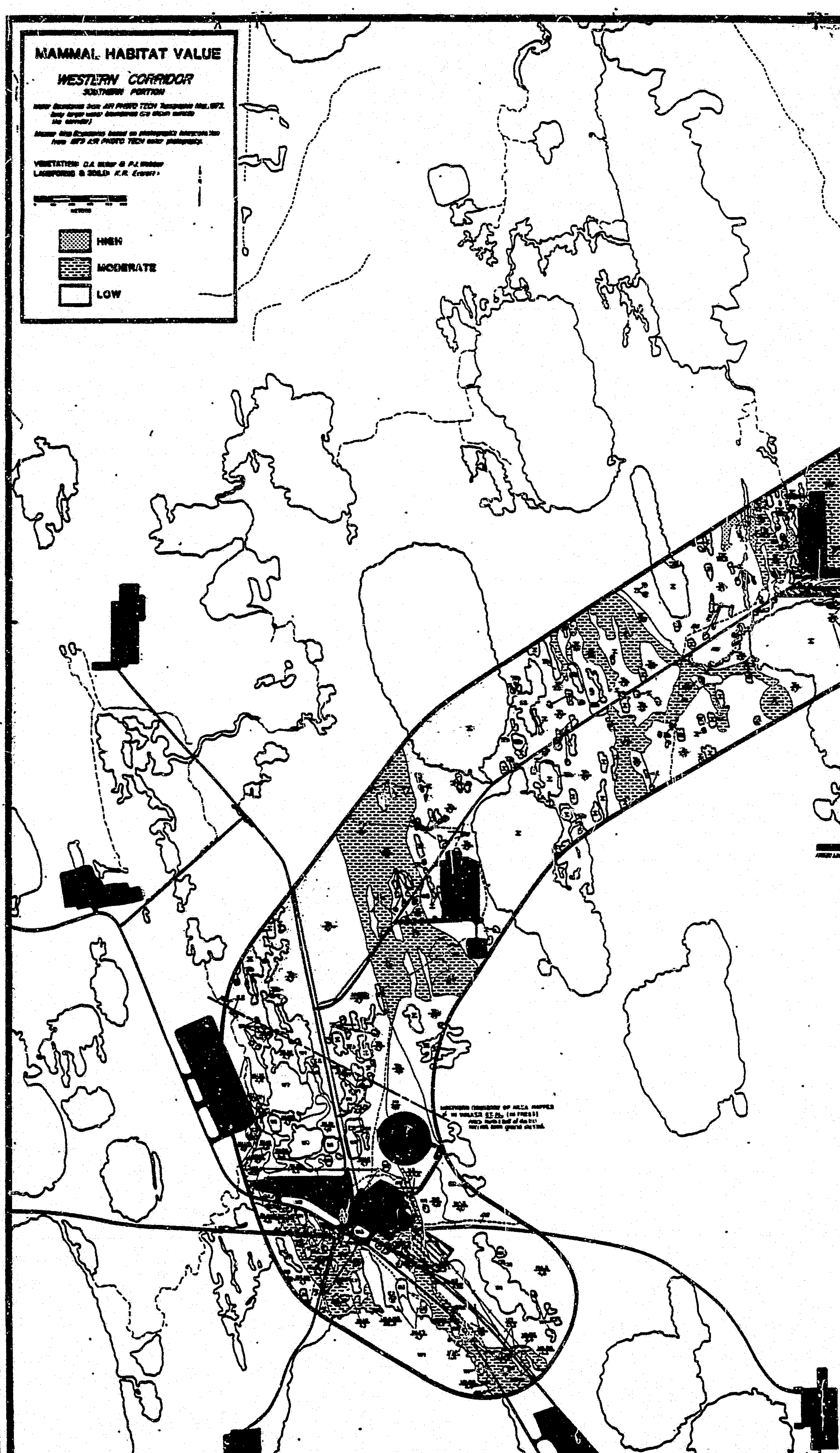


Figure L-39 (South)

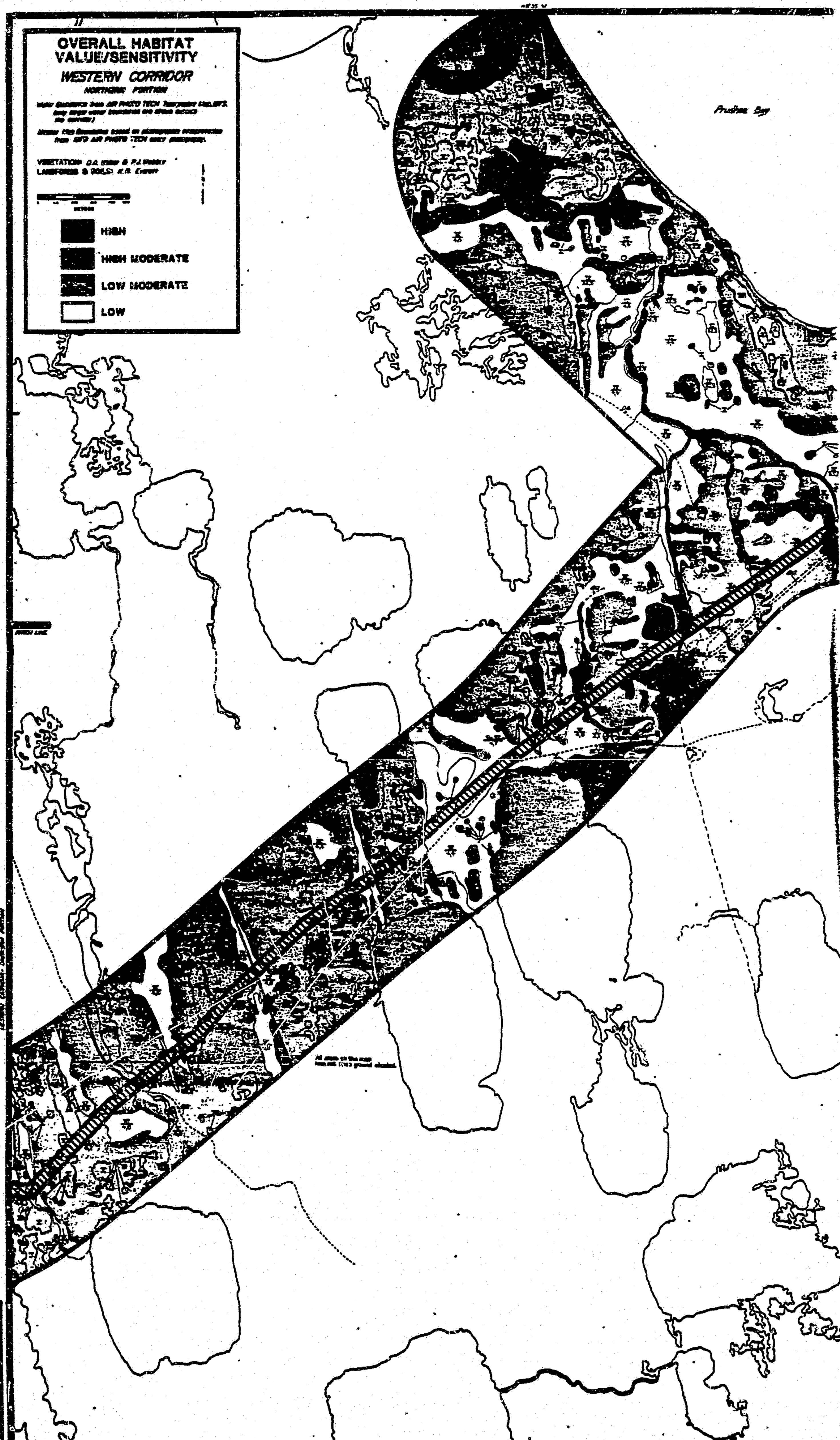


Figure L-40 (North)

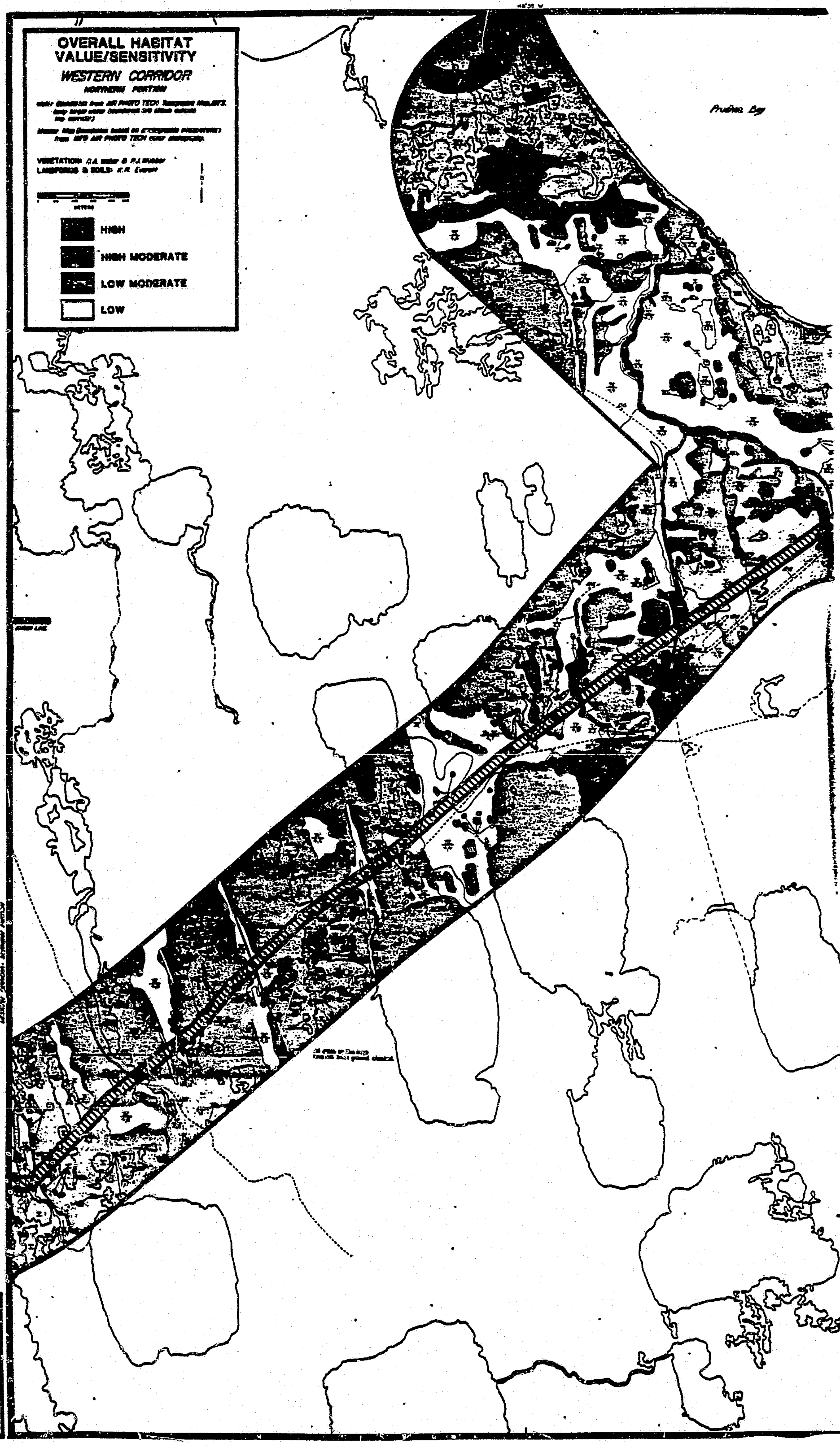


Figure L-40 (North)

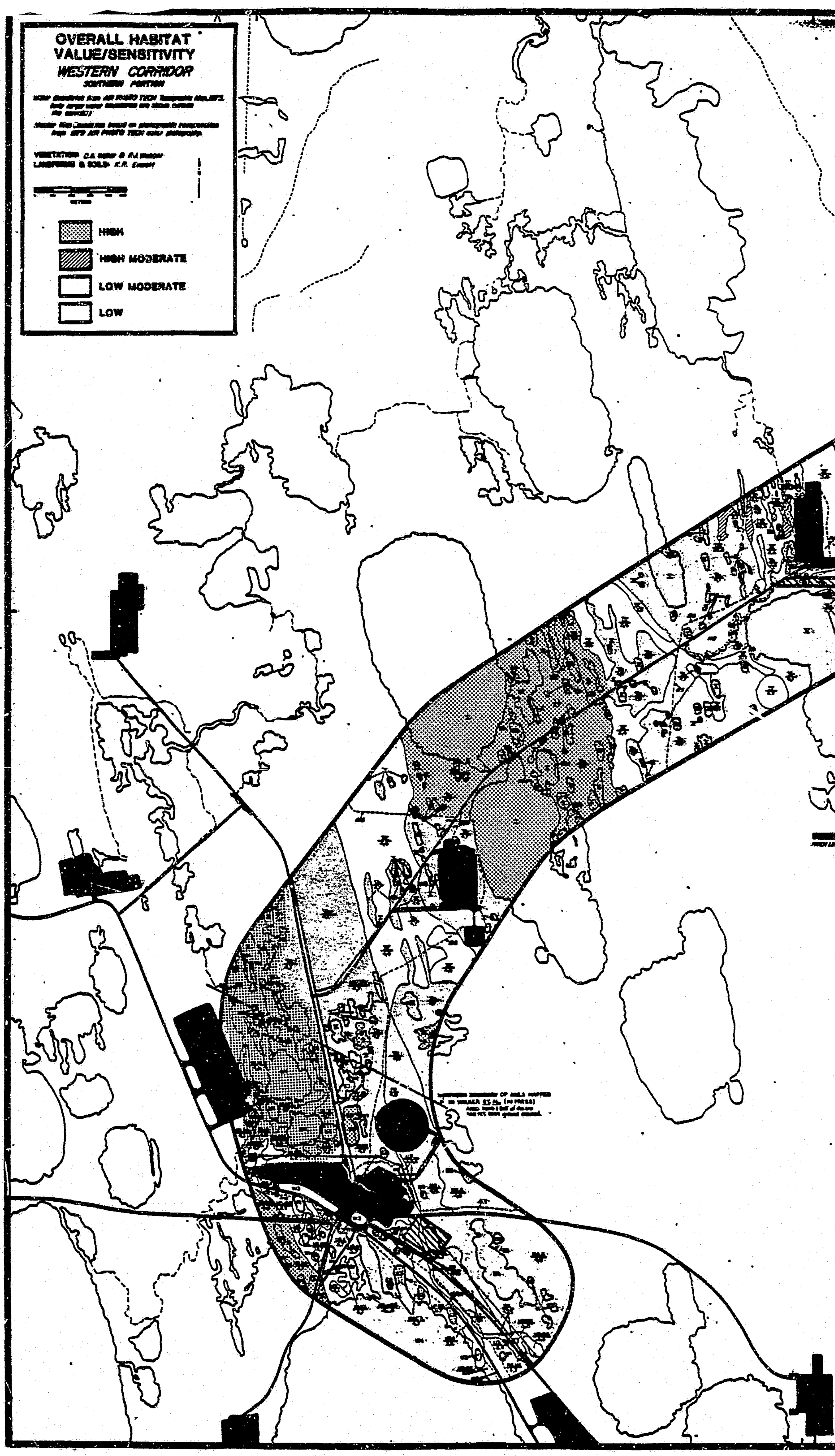


Figure L-40 (South)

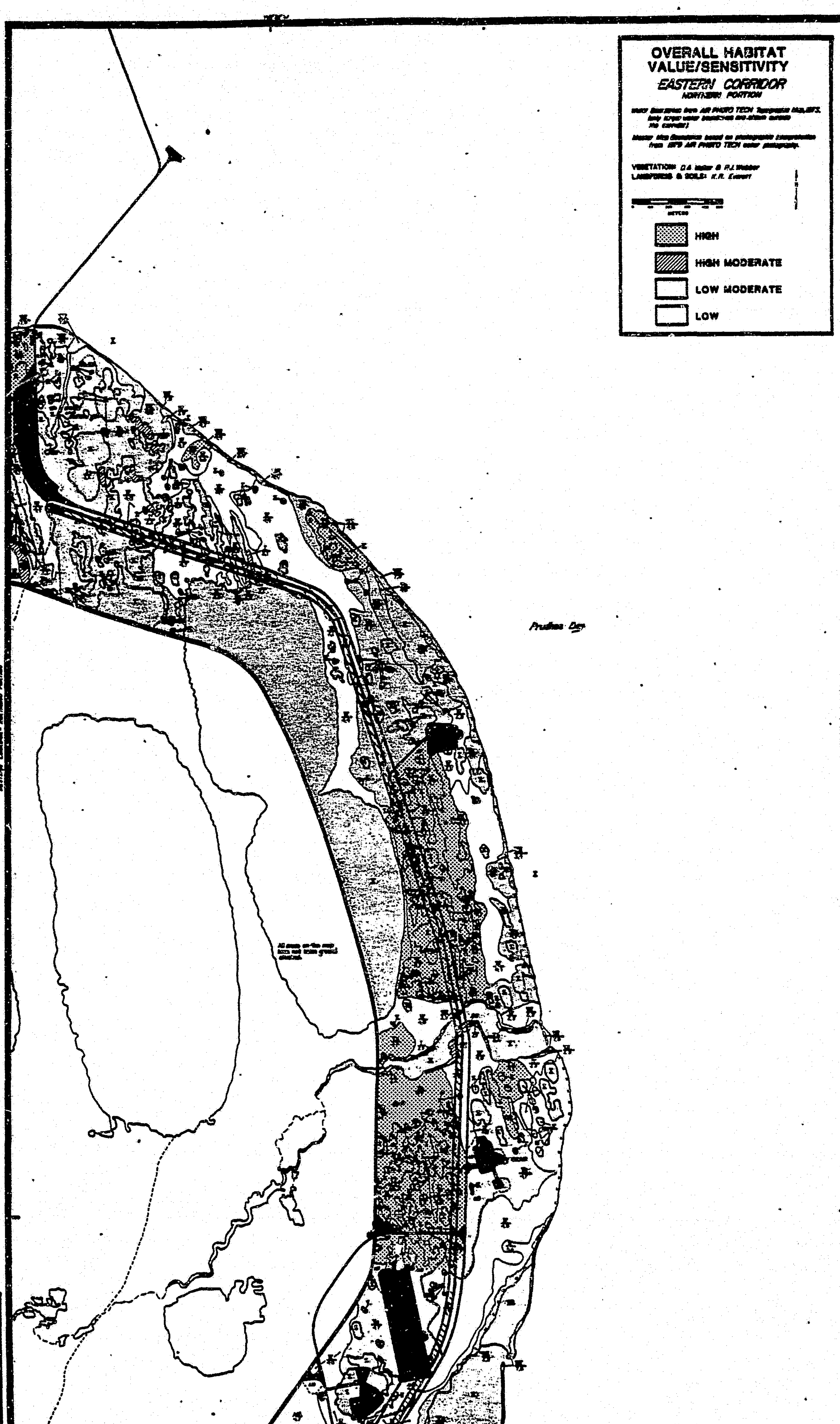


Figure L-41 (North)

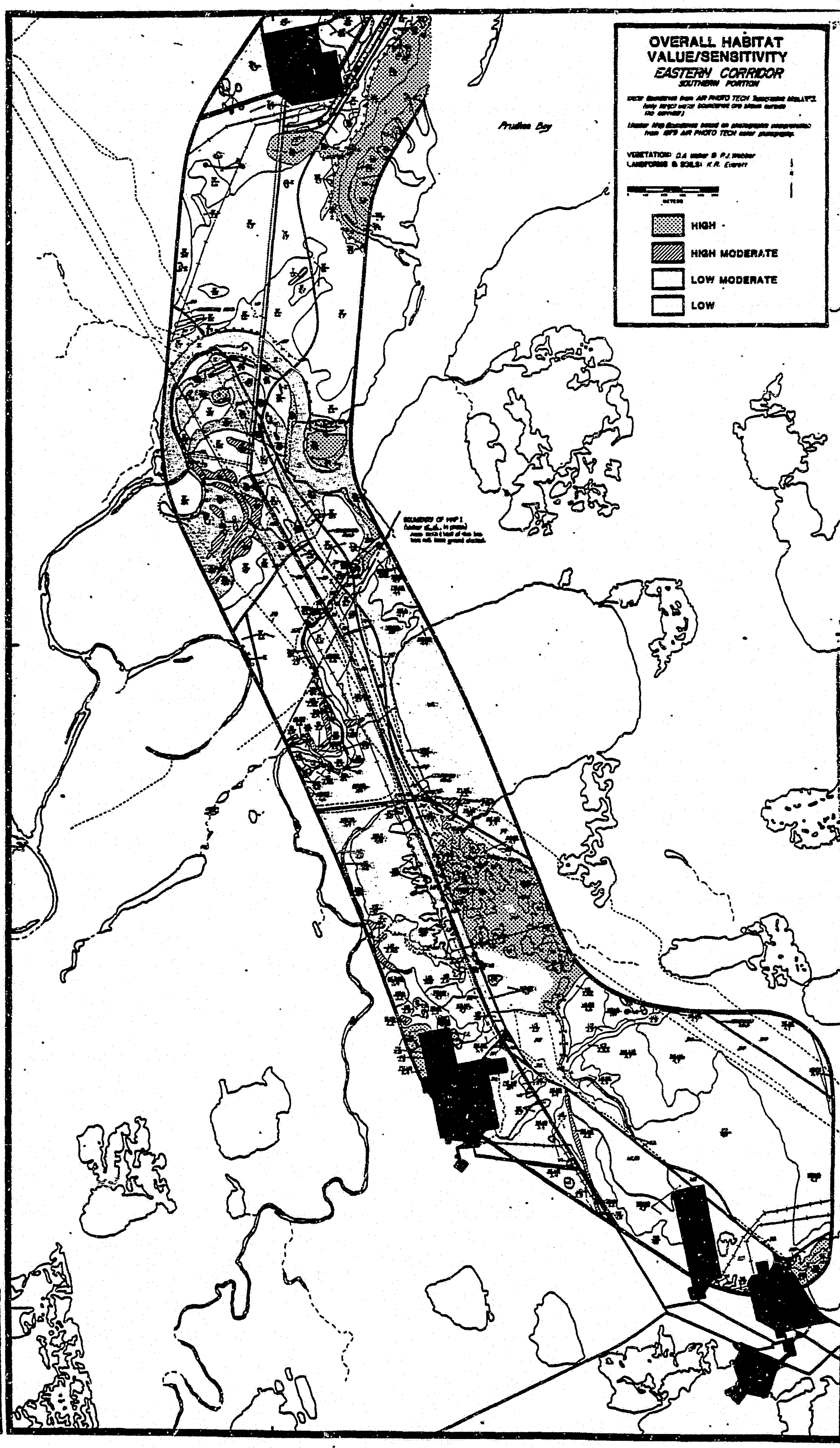
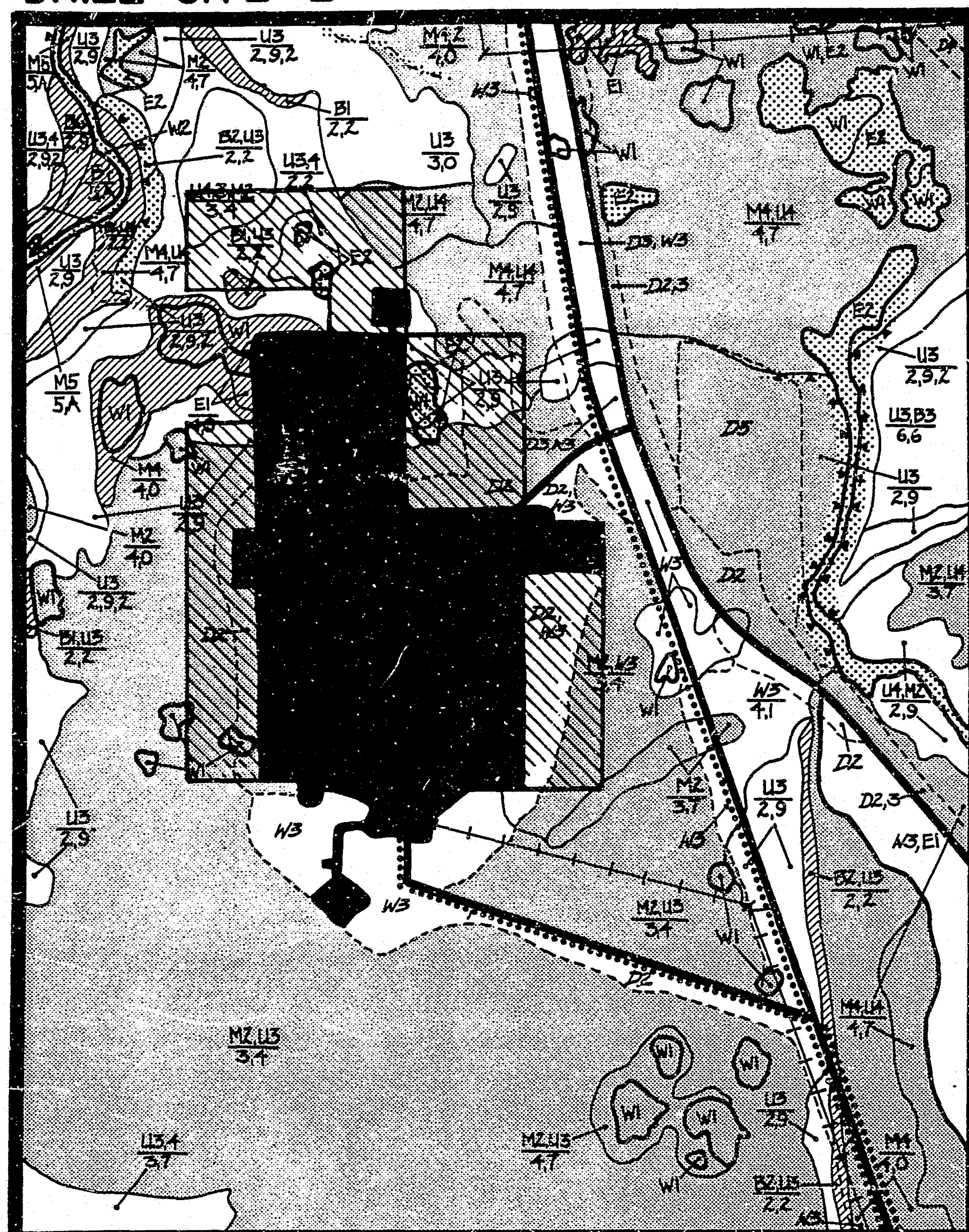


Figure L-41 (South)

DRILL SITE 2



0 100 200 300 400 500
METERS

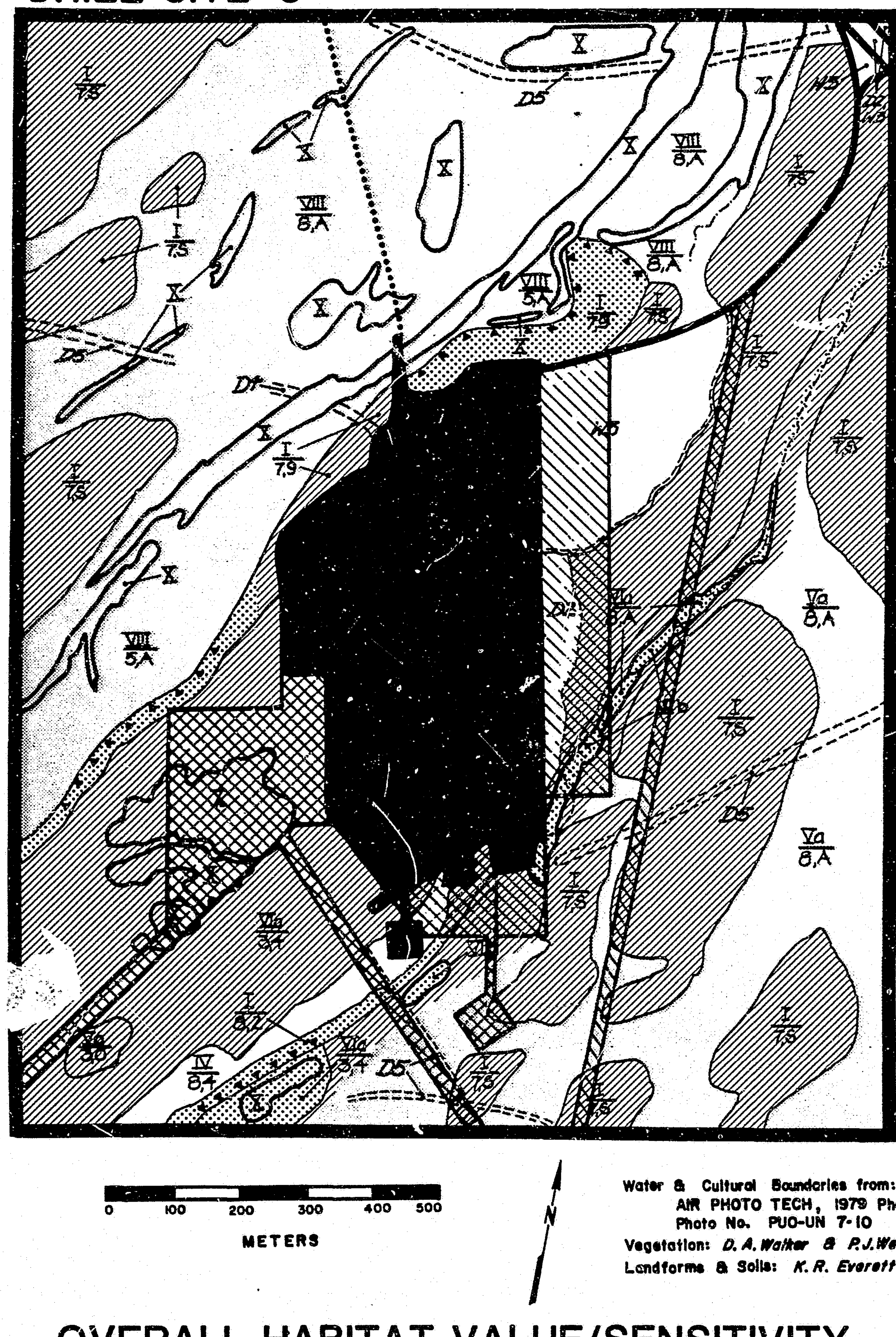
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-15
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-42

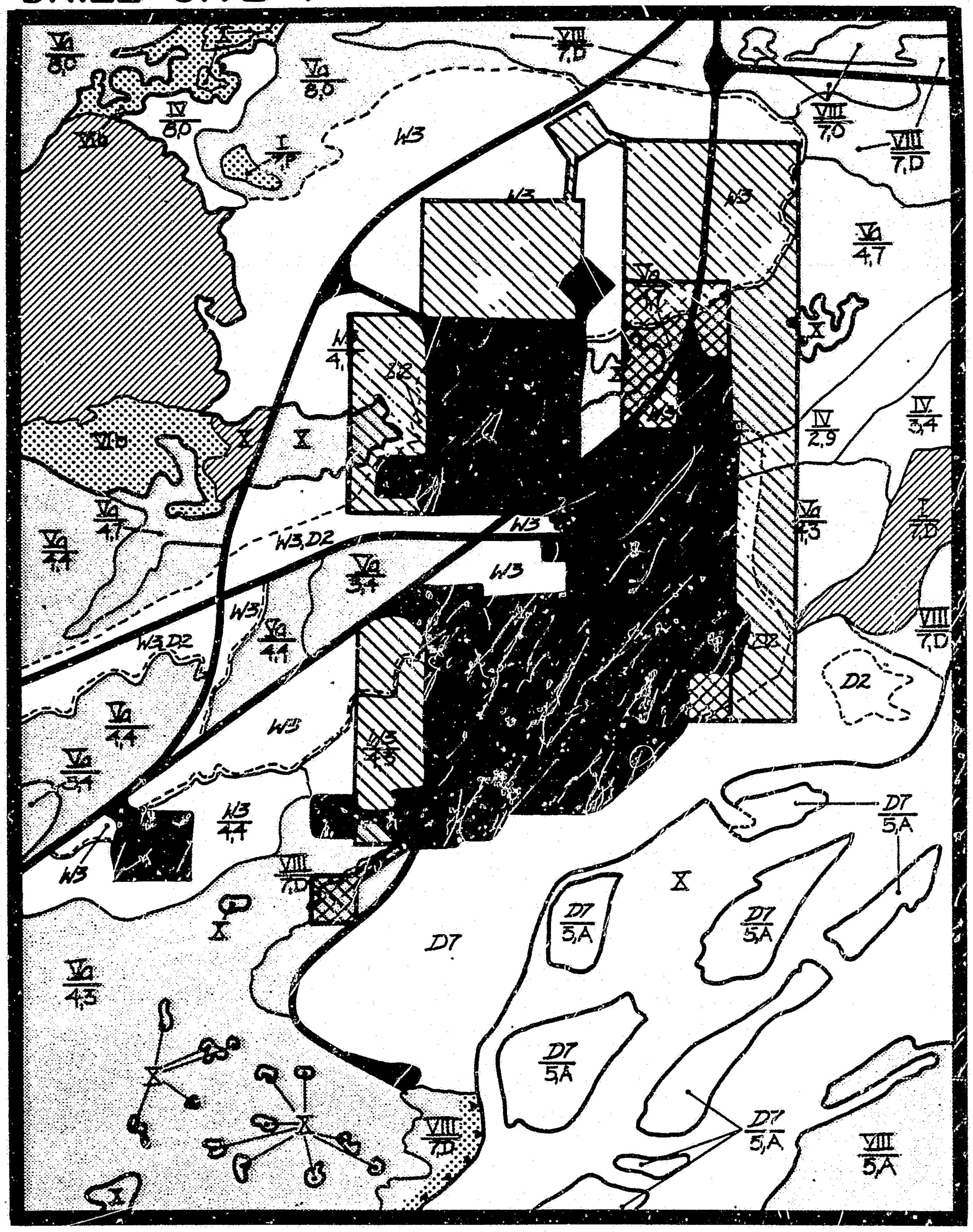
DRILL SITE 3

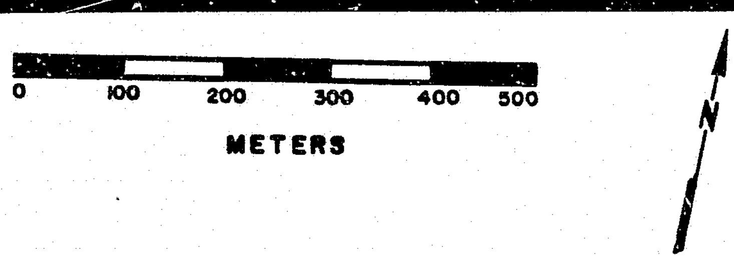


OVERALL HABITAT VALUE/SENSITIVITY

Figure L-43

DRILL SITE 4



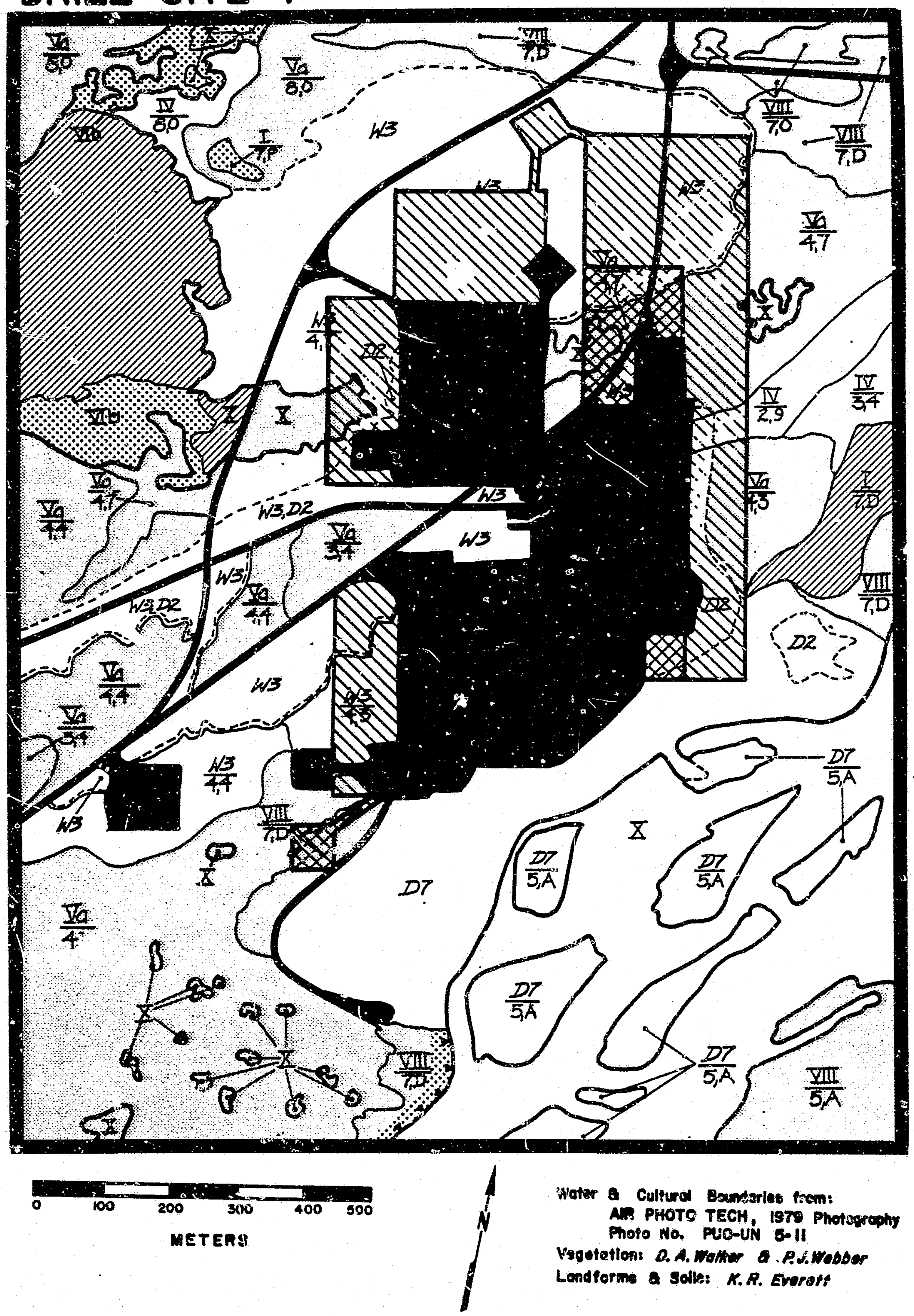


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 5-11
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-44

DRILL SITE 4



Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 5-11
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-44

DRILL SITE 5

0 100 200 300 400 500
METERS

N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 6-15
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

HIGH

HIGH MODERATE

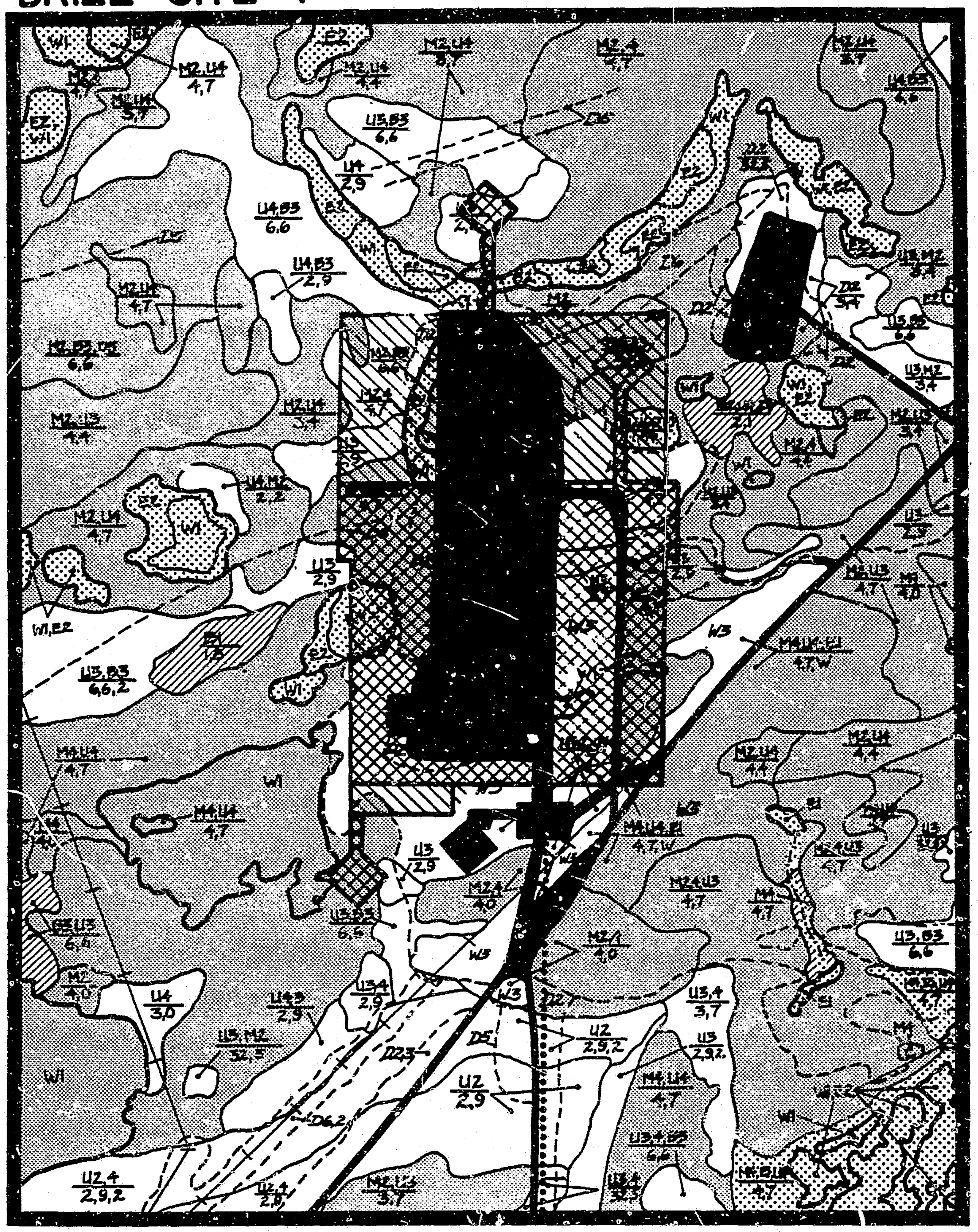
LOW MODERATE

LOW

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-45

DRILL SITE 7



0 100 200 300 400 500
METERS

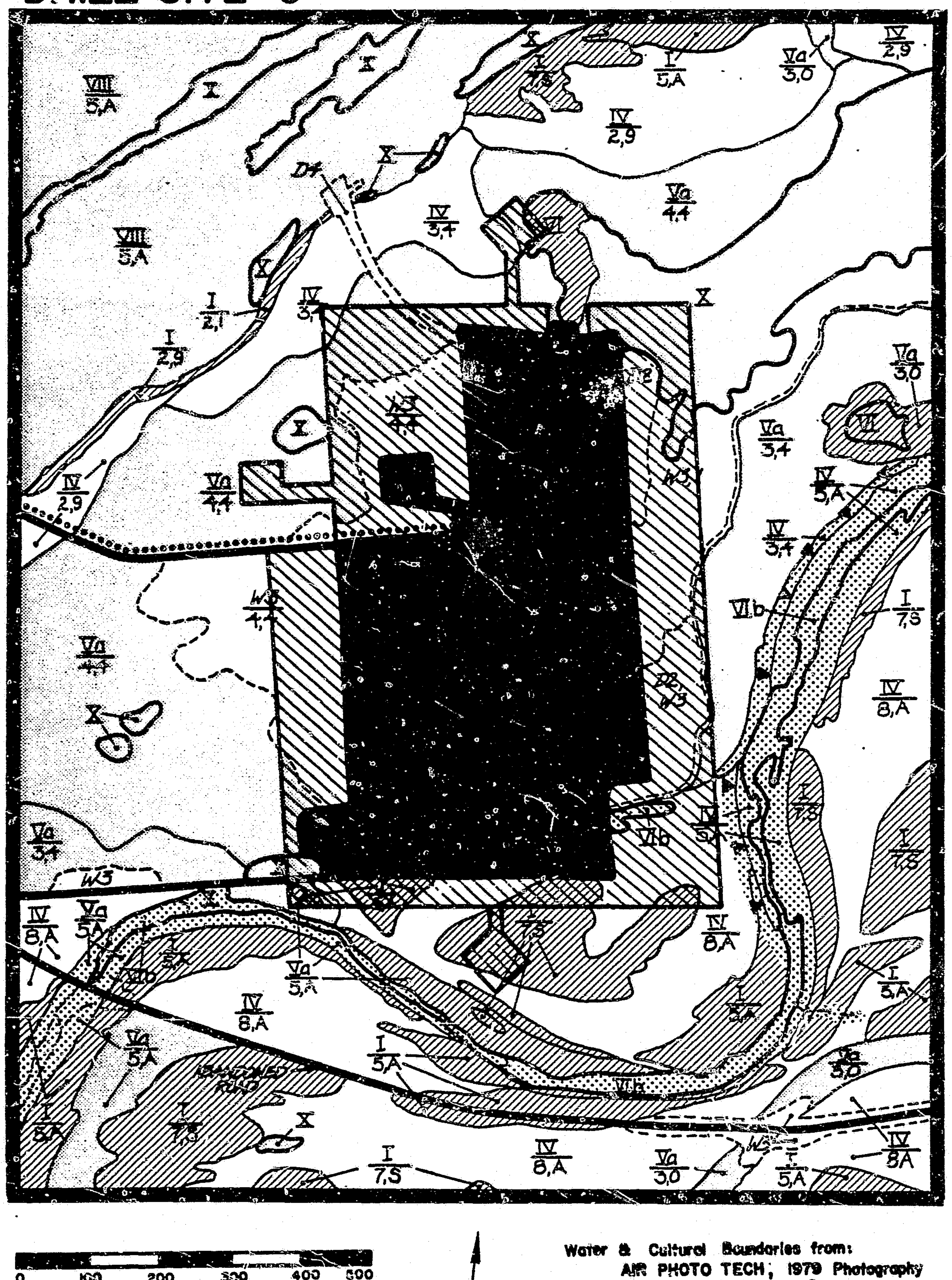
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUG-UN 7-17
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-46

DRILL SITE 9

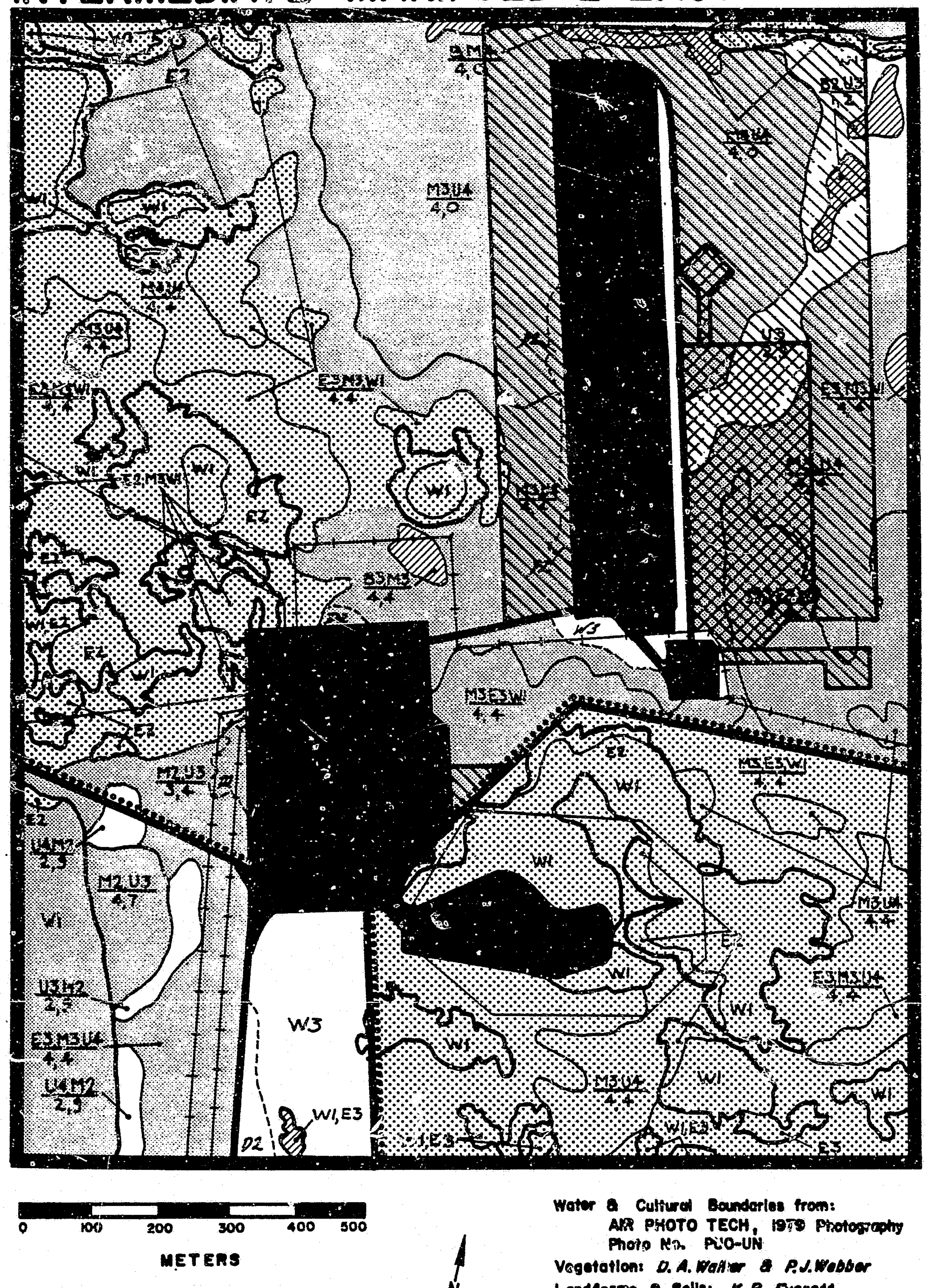


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 6-9
Vegetation: D. A. Walker & P. J. Webber
Landforms & Soils: K. R. Everett

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-47

DRILL SITE 11 & INTERMEDIATE MANIFOLD 2 EAST

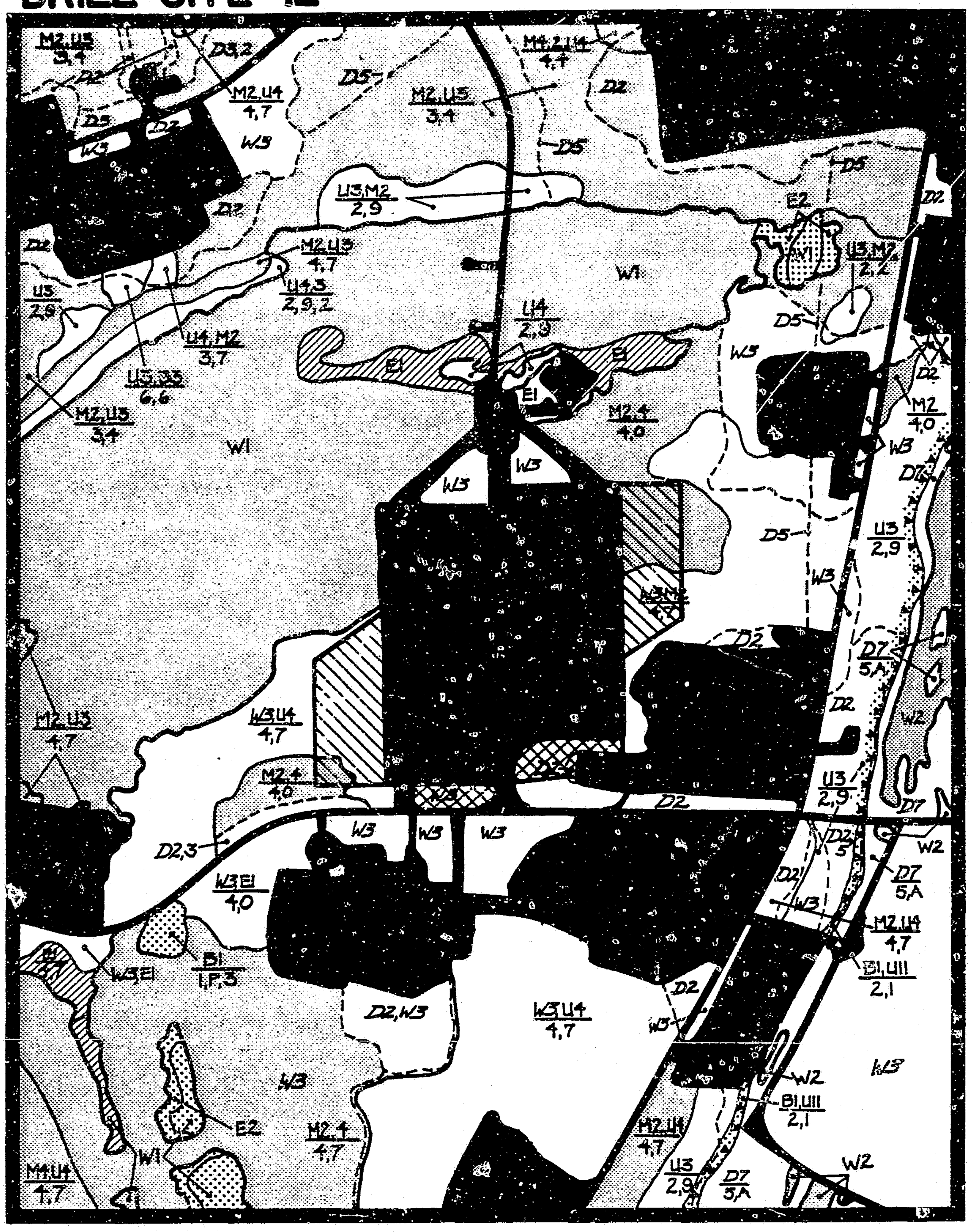


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSIVITY

Figure L–48

DRILL SITE 12



0 100 200 300 400 500
METERS

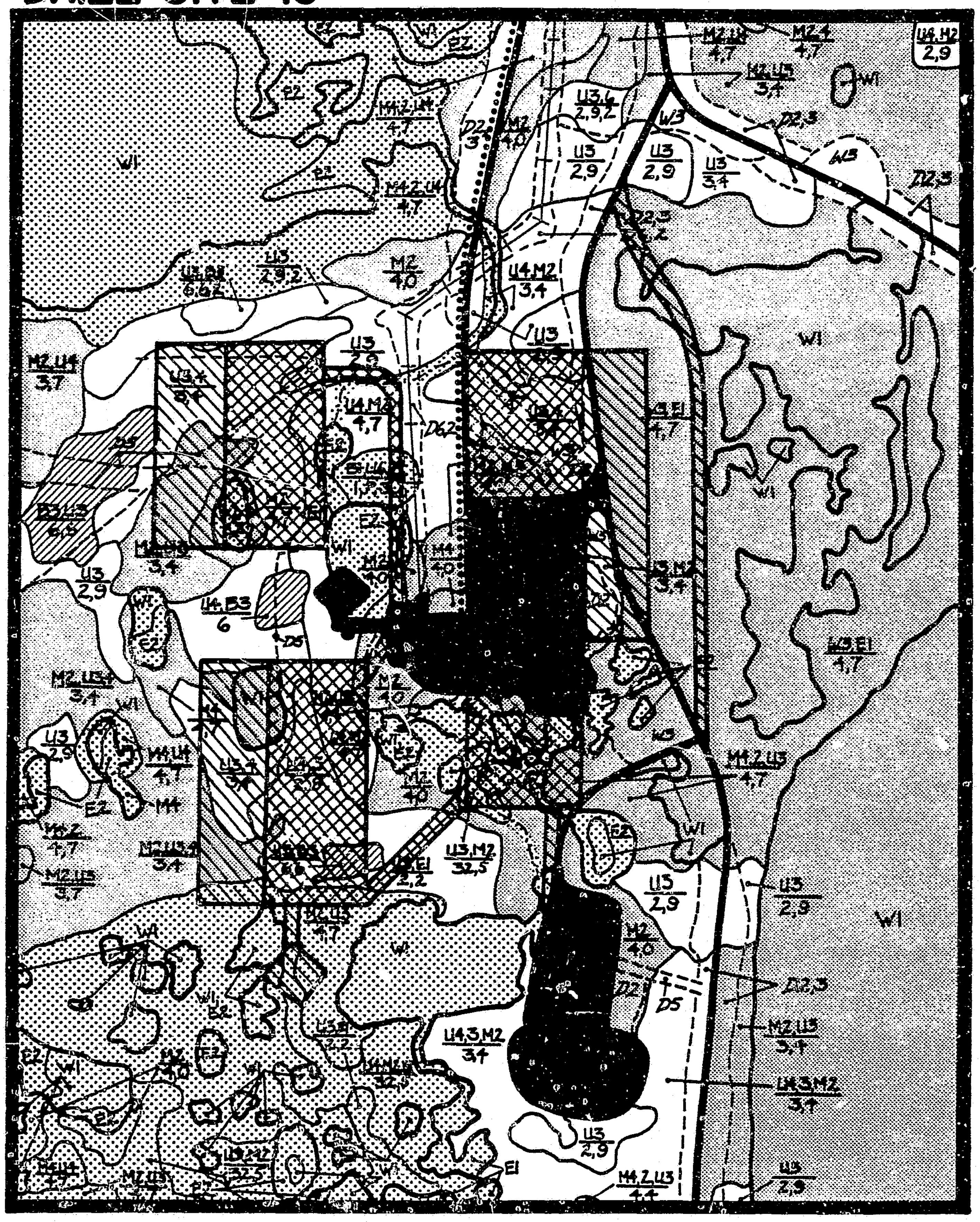
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 6-12
Vegetation: D.A. Walker & P.J. Webber
Landforms & Soils: K.R. Everett

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-49

DRILL SITE 13



0 100 200 300 400 500
METERS

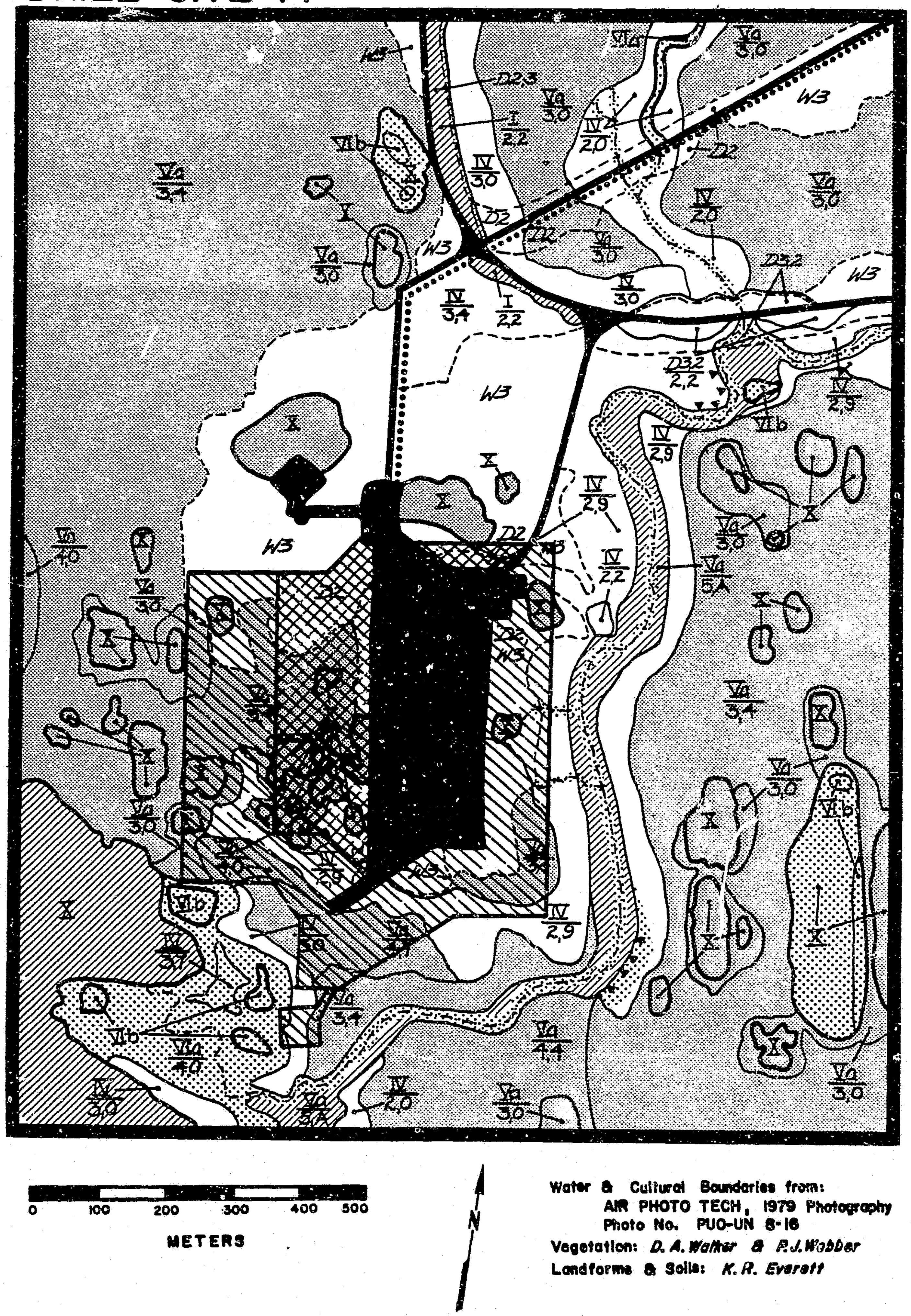
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. ?UO-UN 9-14
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-50

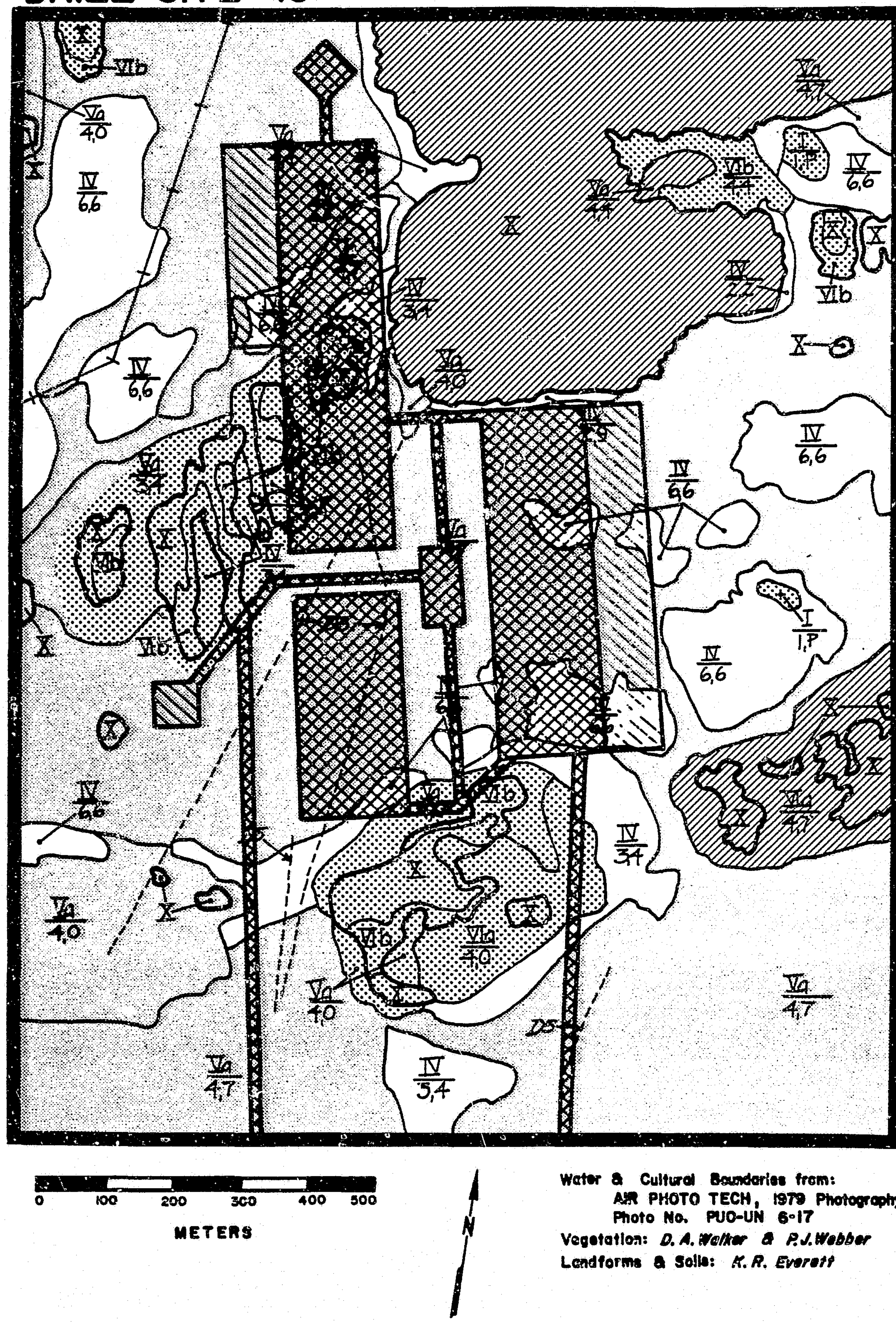
DRILL SITE 14



OVERALL HABITAT VALUE/SENSITIVITY

Fig. e L-51

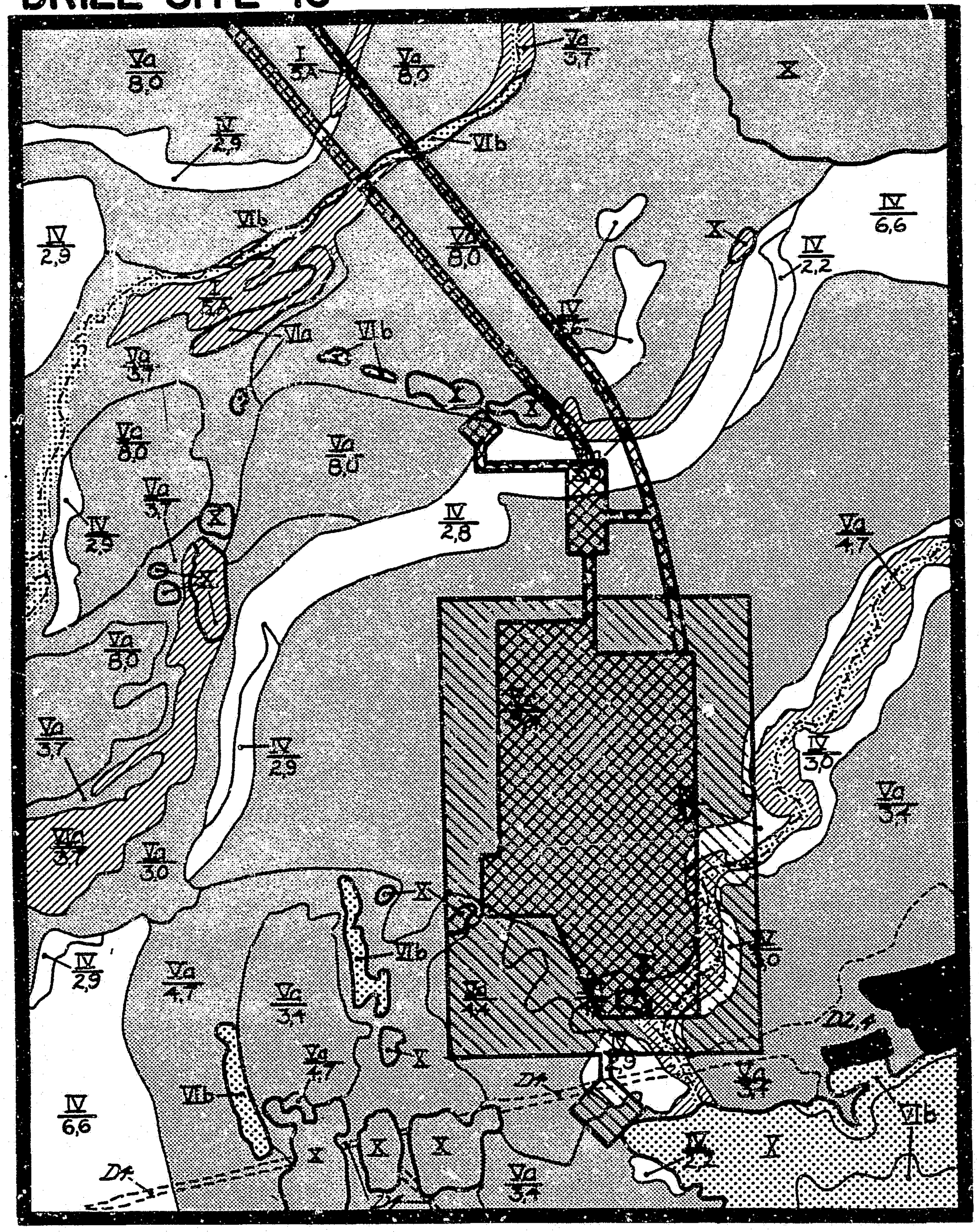
DRILL SITE 15



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-52

DRILL SITE 16



0 100 200 300 400 500

METERS

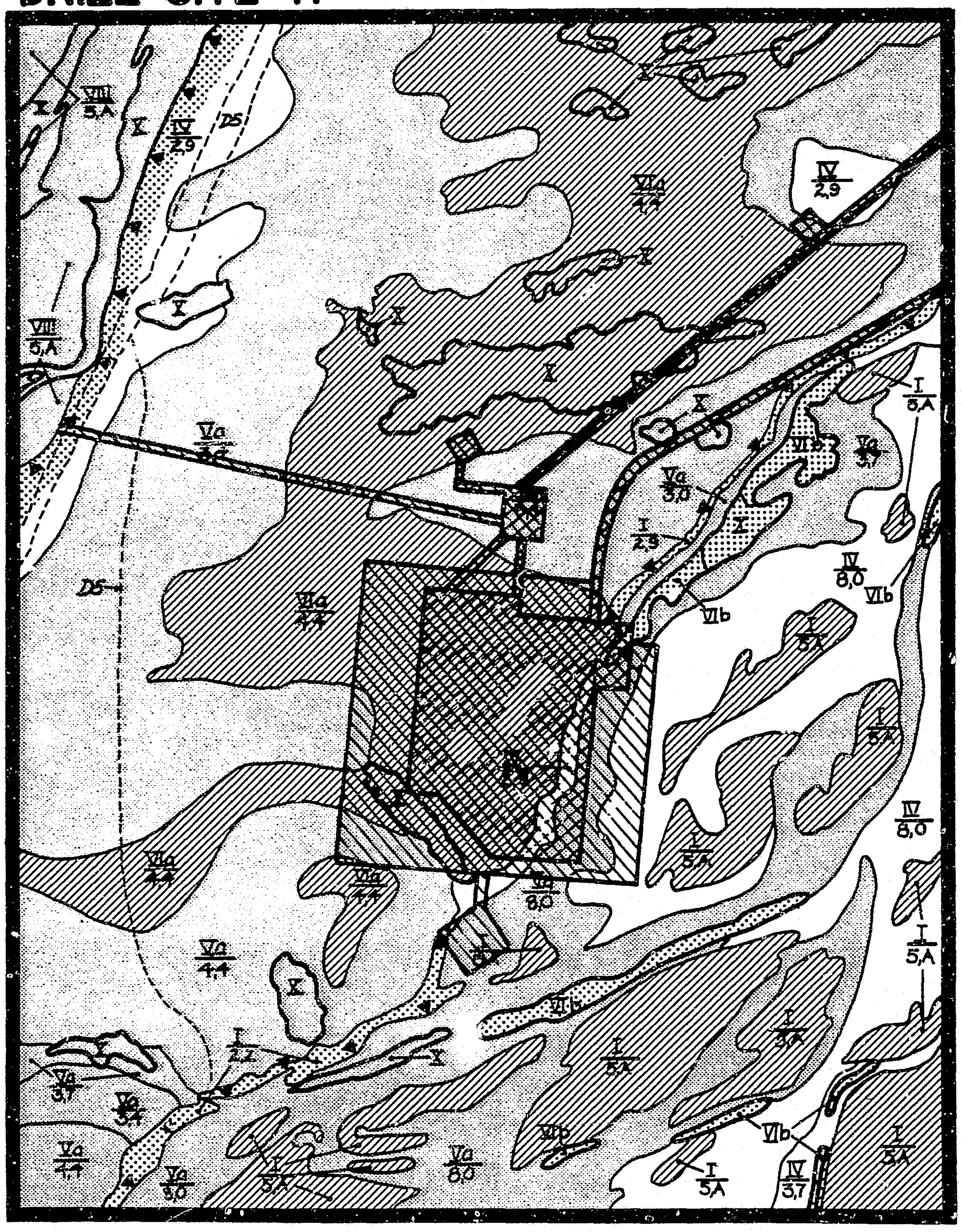
N

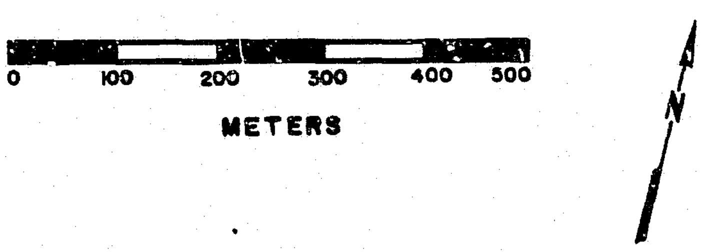
Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. FUC-UN 7-8
Vegetation: D. A. Walker & P.J. Webber
Landforms & Soils: K. R. Everett

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-53

DRILL SITE 17



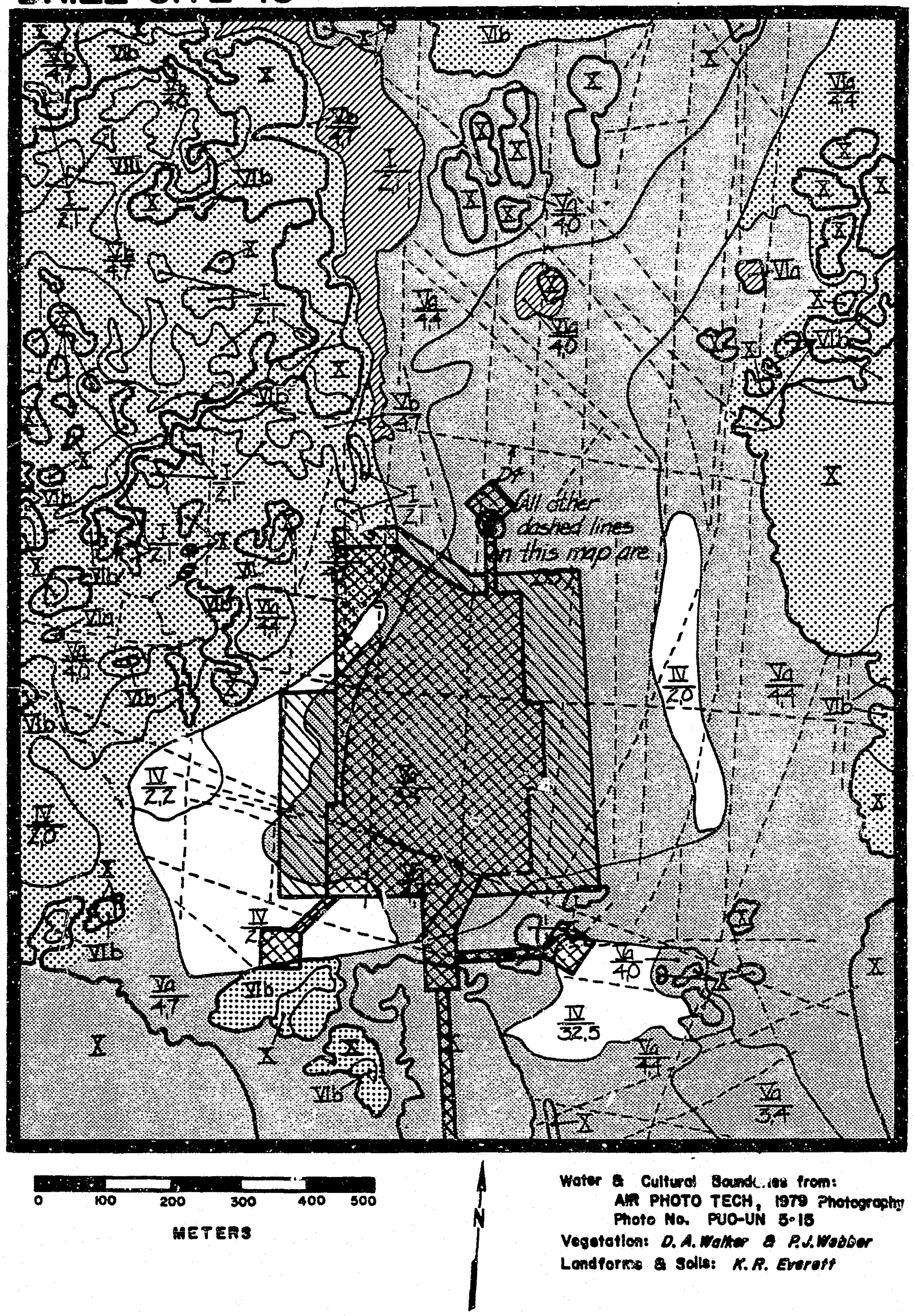


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 8-10
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-54

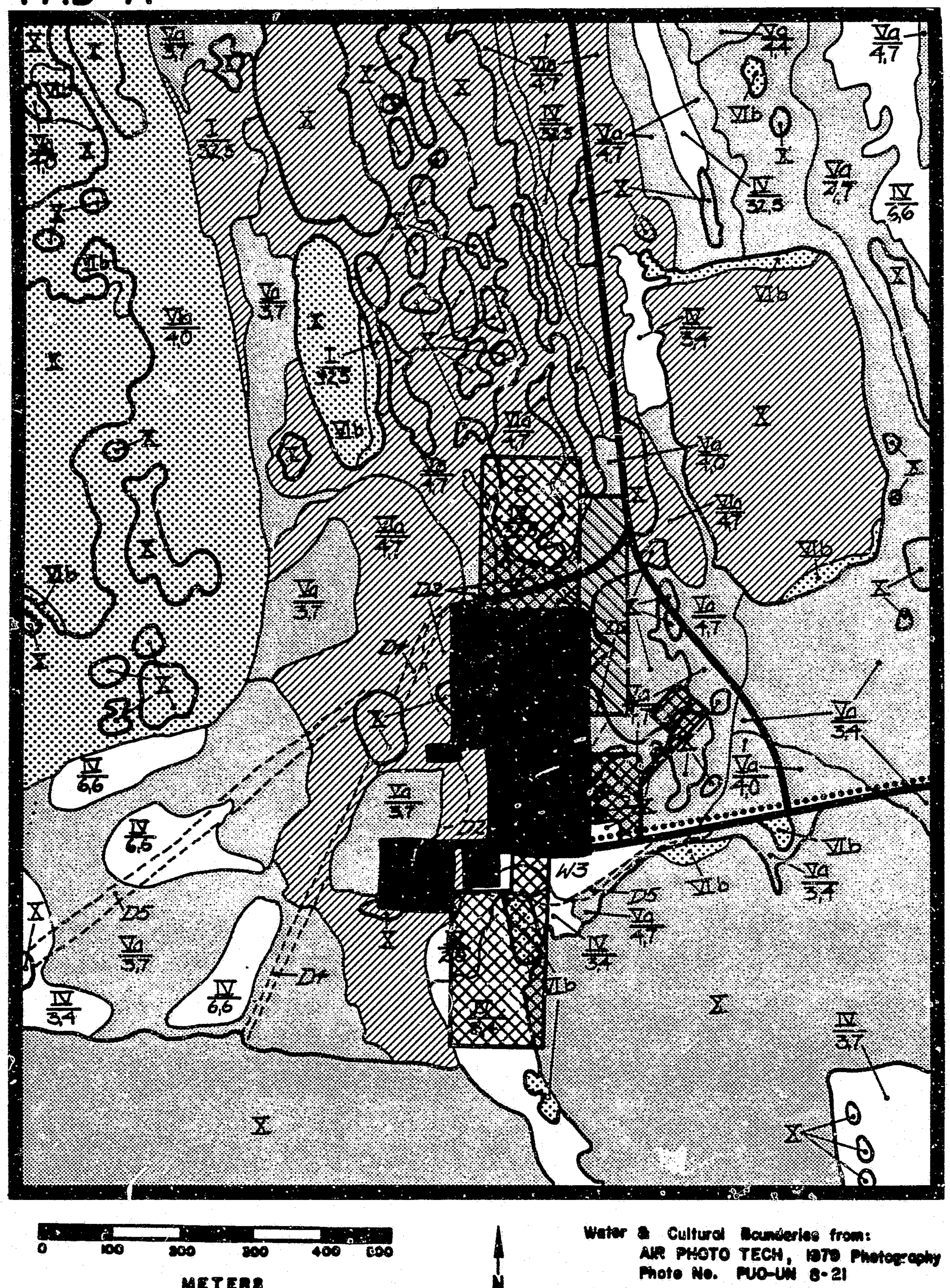
DRILL SITE 18



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-55

PAD A

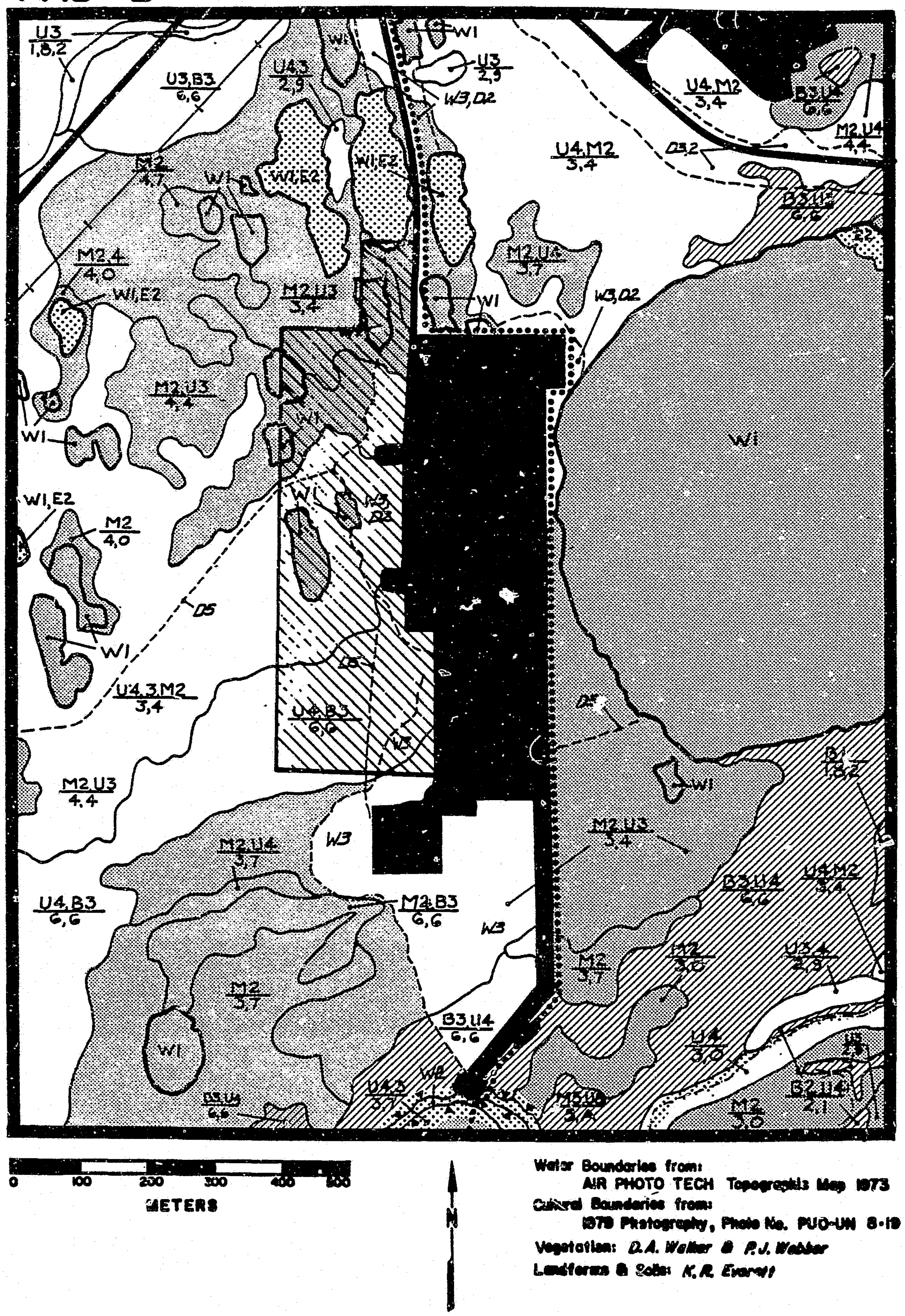


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 8-21
Vegetation: D. A. Walker & P. J. Webber
Landforms & Soils: K. R. Everett

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-56

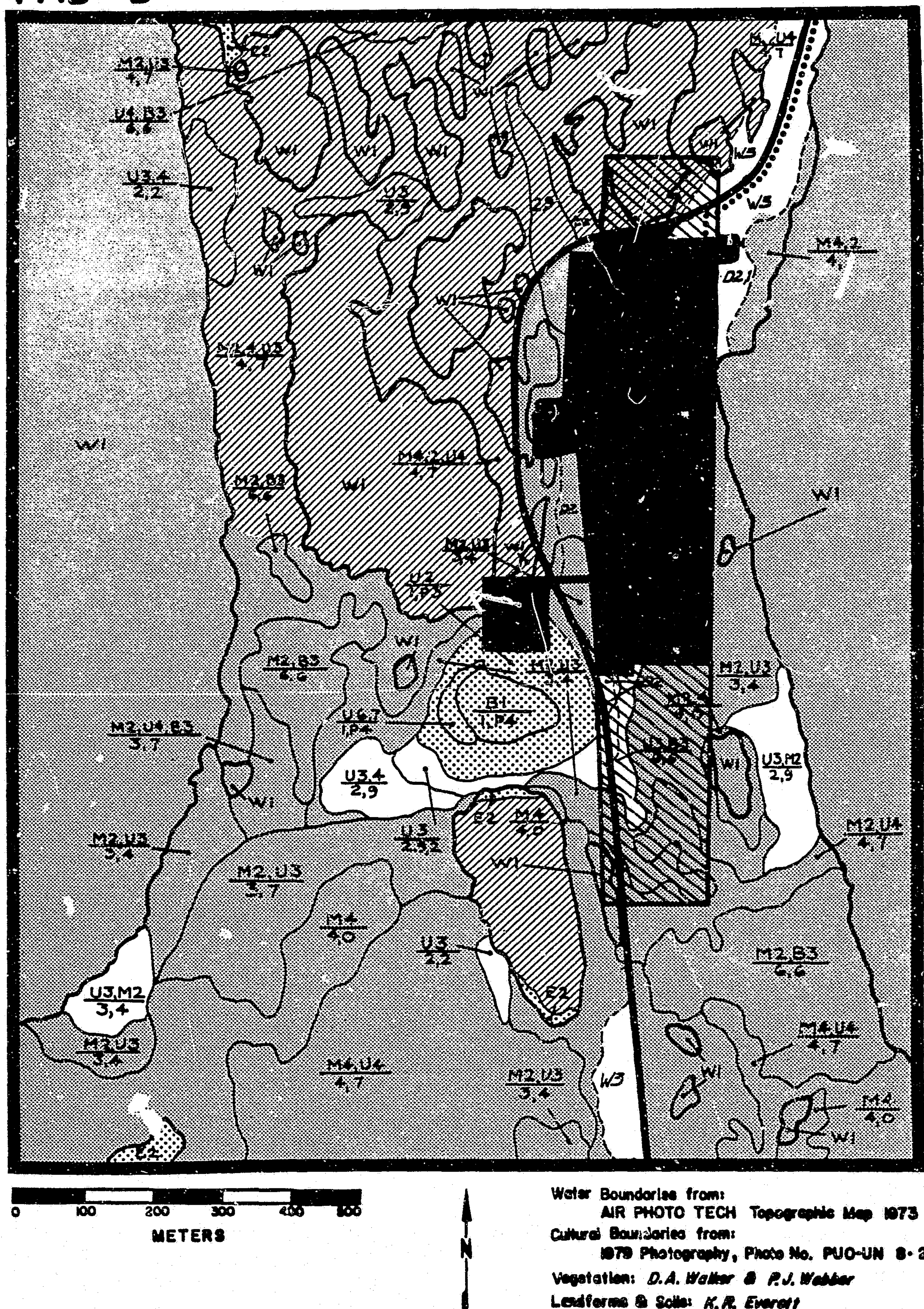
PAD B



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-57

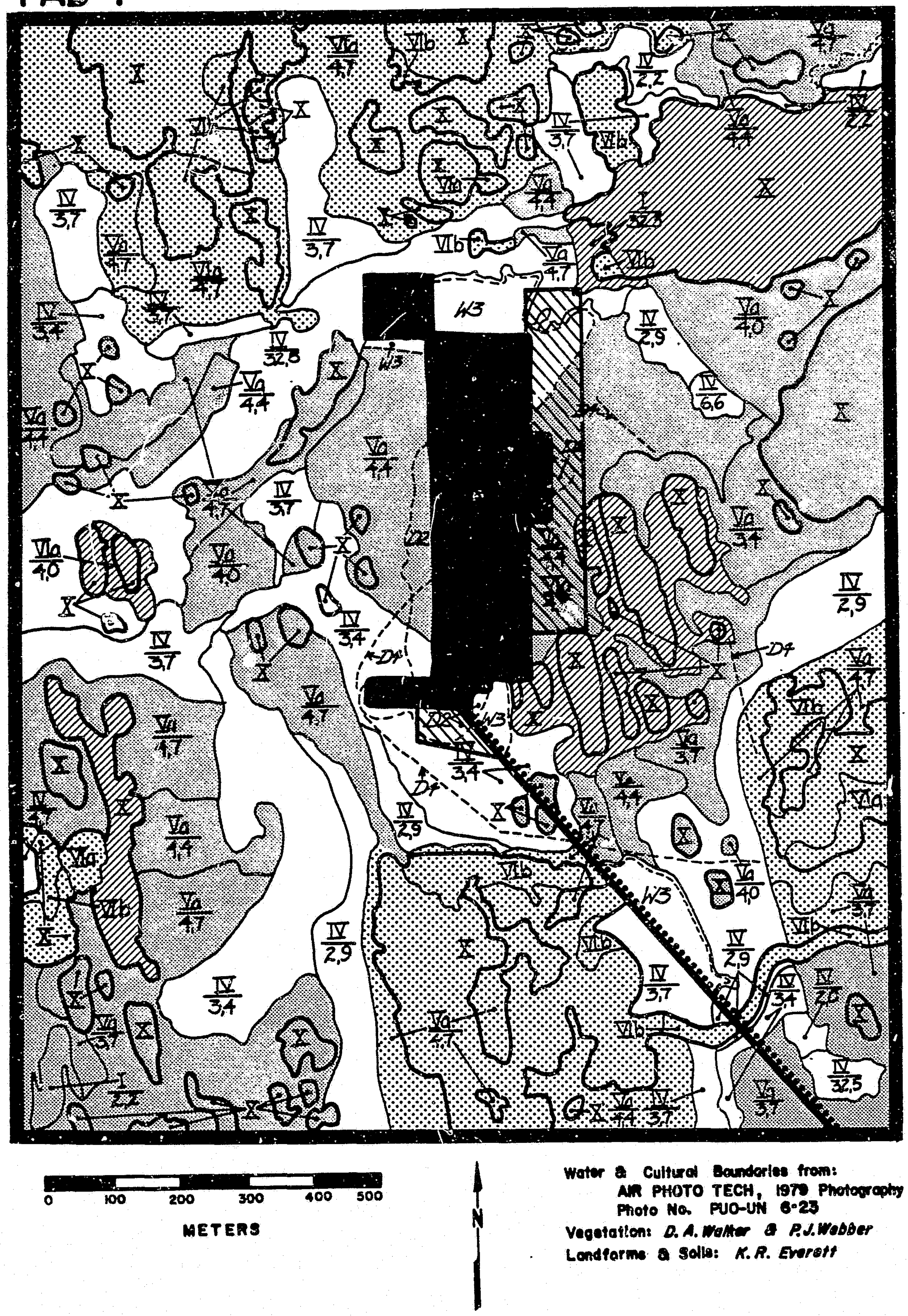
PAD D



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-58

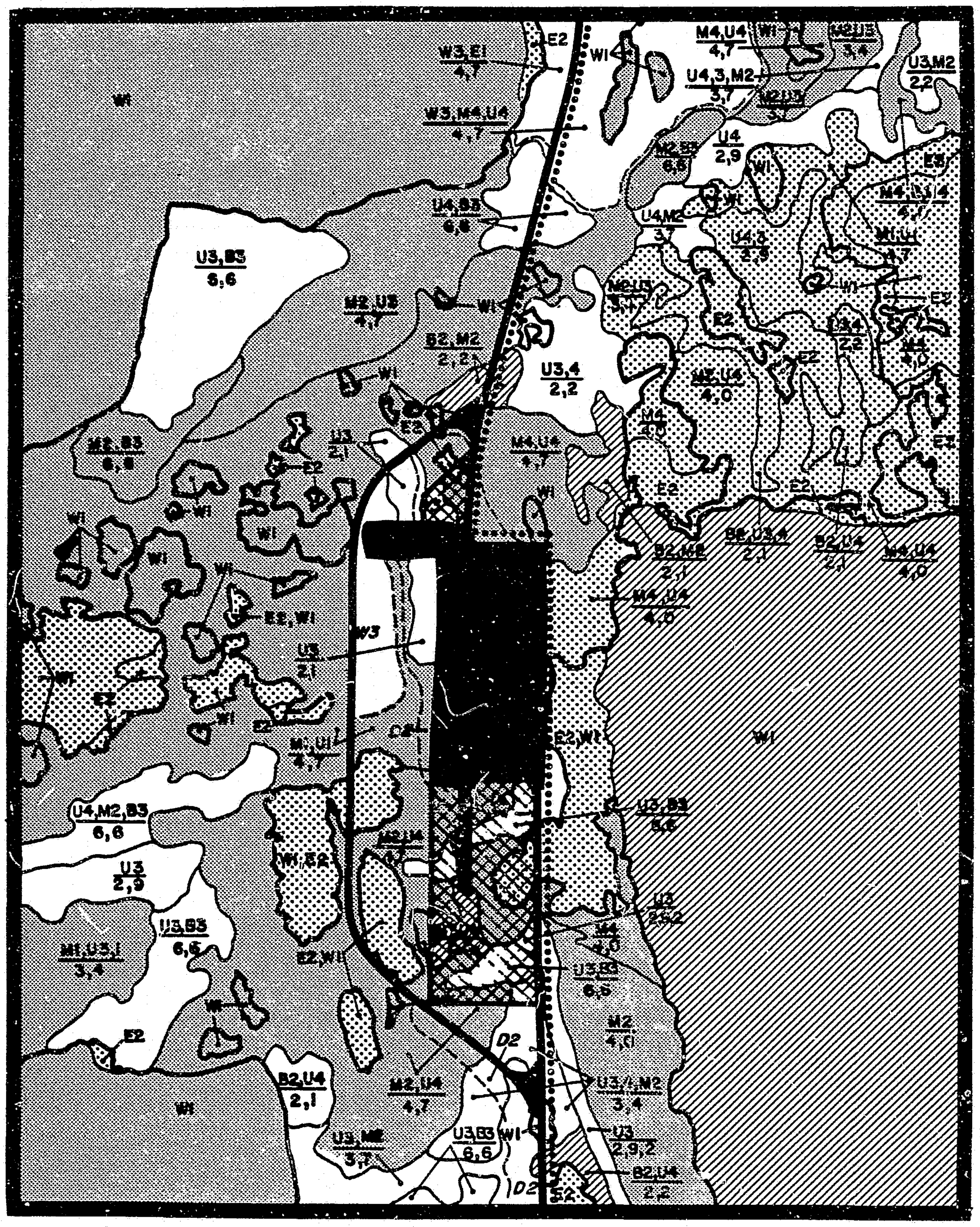
PAD F



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-59

PAD H



0 100 200 300 400 500
METERS

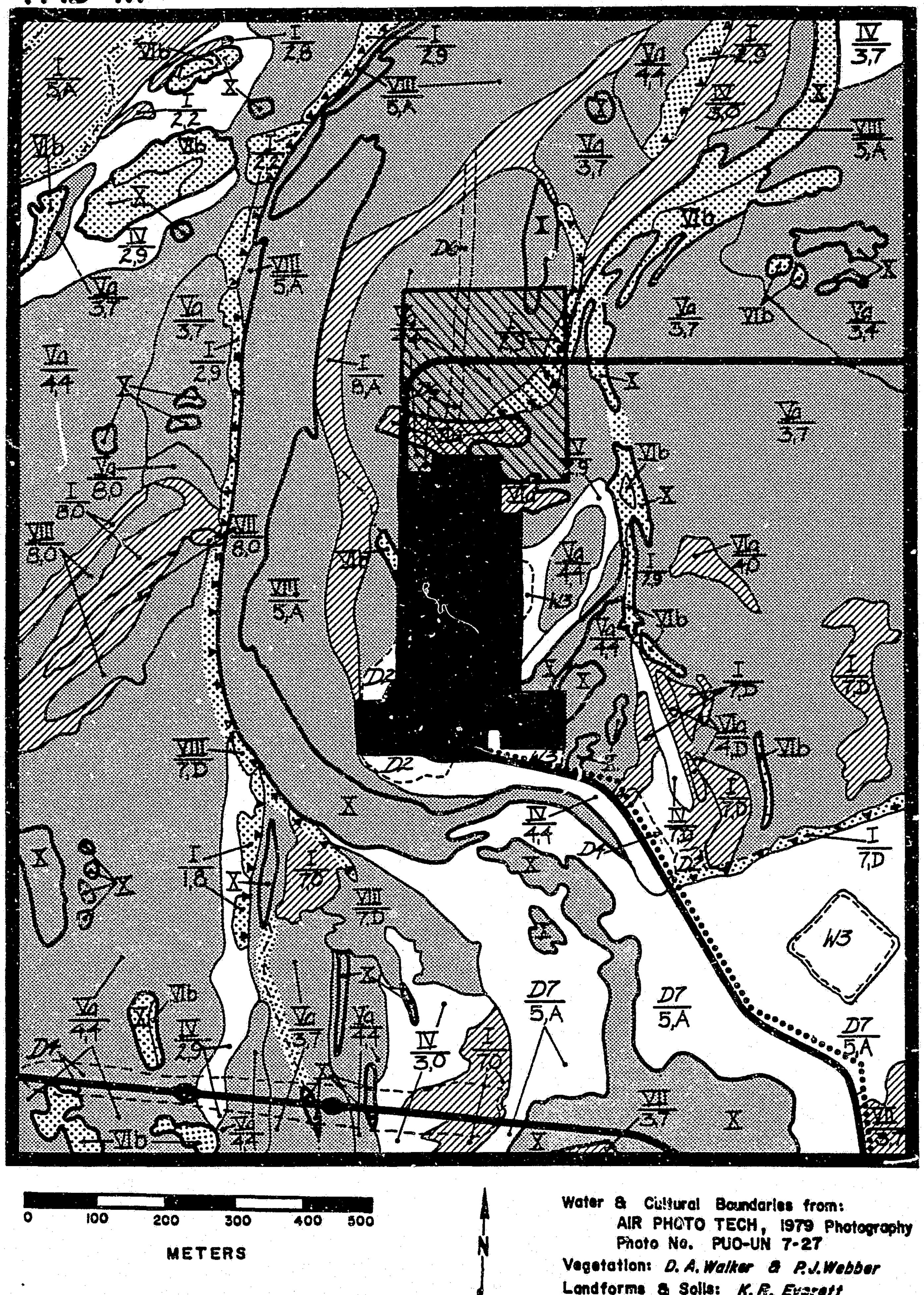
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UK 8-24
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-60

PAD M

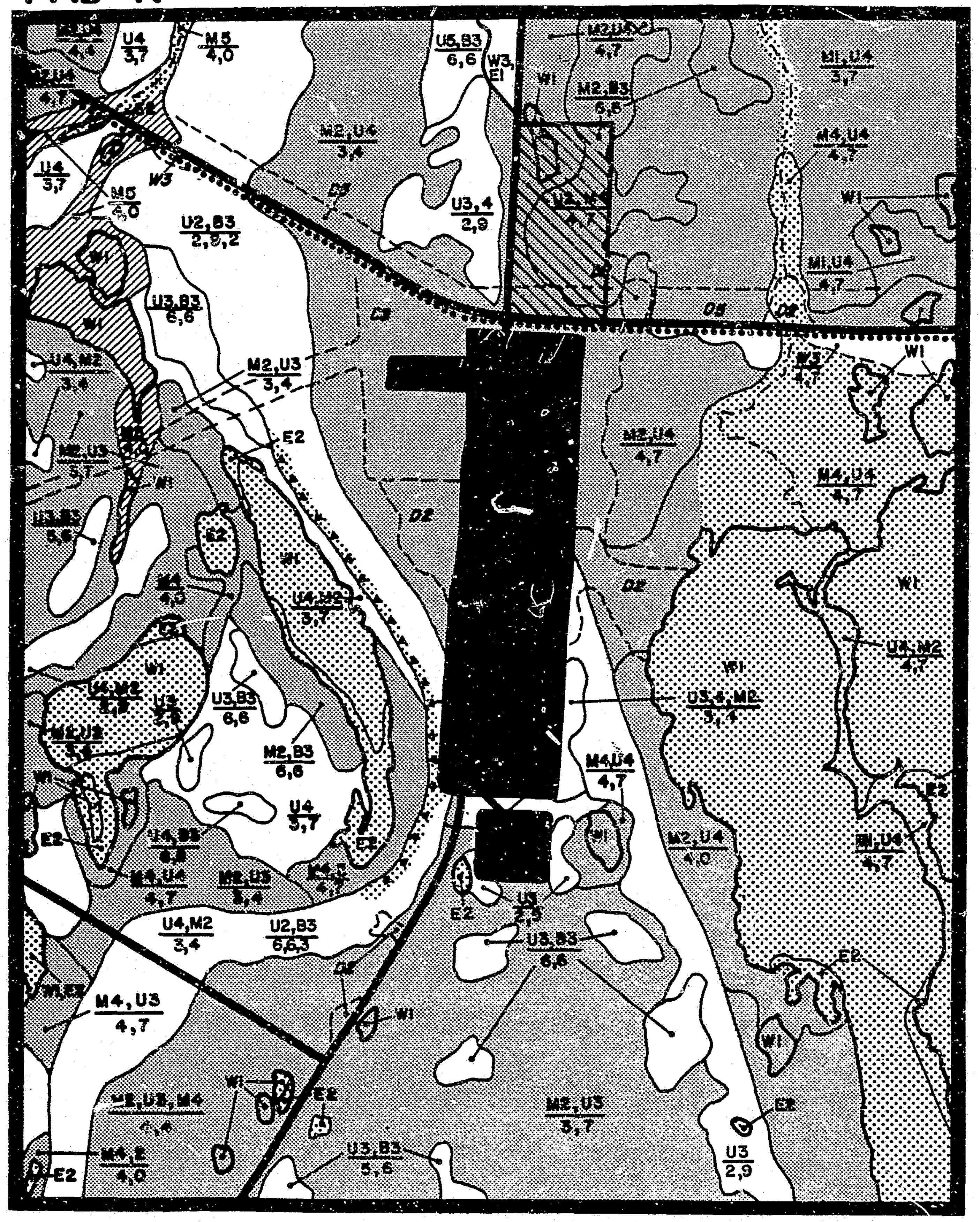


Water & Cultural Boundaries from:
AIR PHOTO TECH, 1979 Photography
Photo No. PUO-UN 7-27
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-61

PAD N



0 100 200 300 400 500
METERS

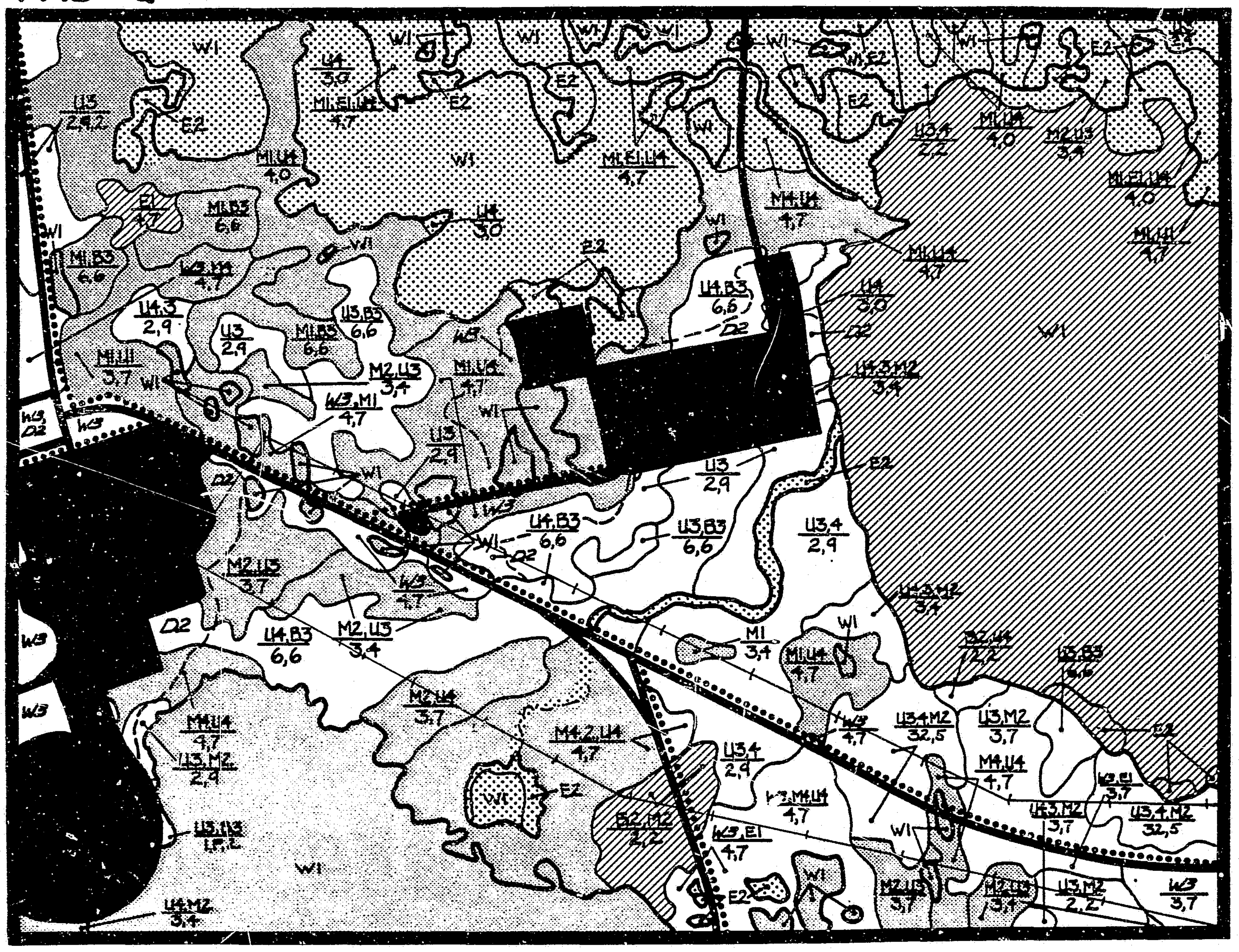
N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 8-28
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-62

PAD Q



0 100 200 300 400 500
METERS

N

Water Boundaries from:
AIR PHOTO TECH Topographic Map 1973
Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7·24
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-63

PAD R

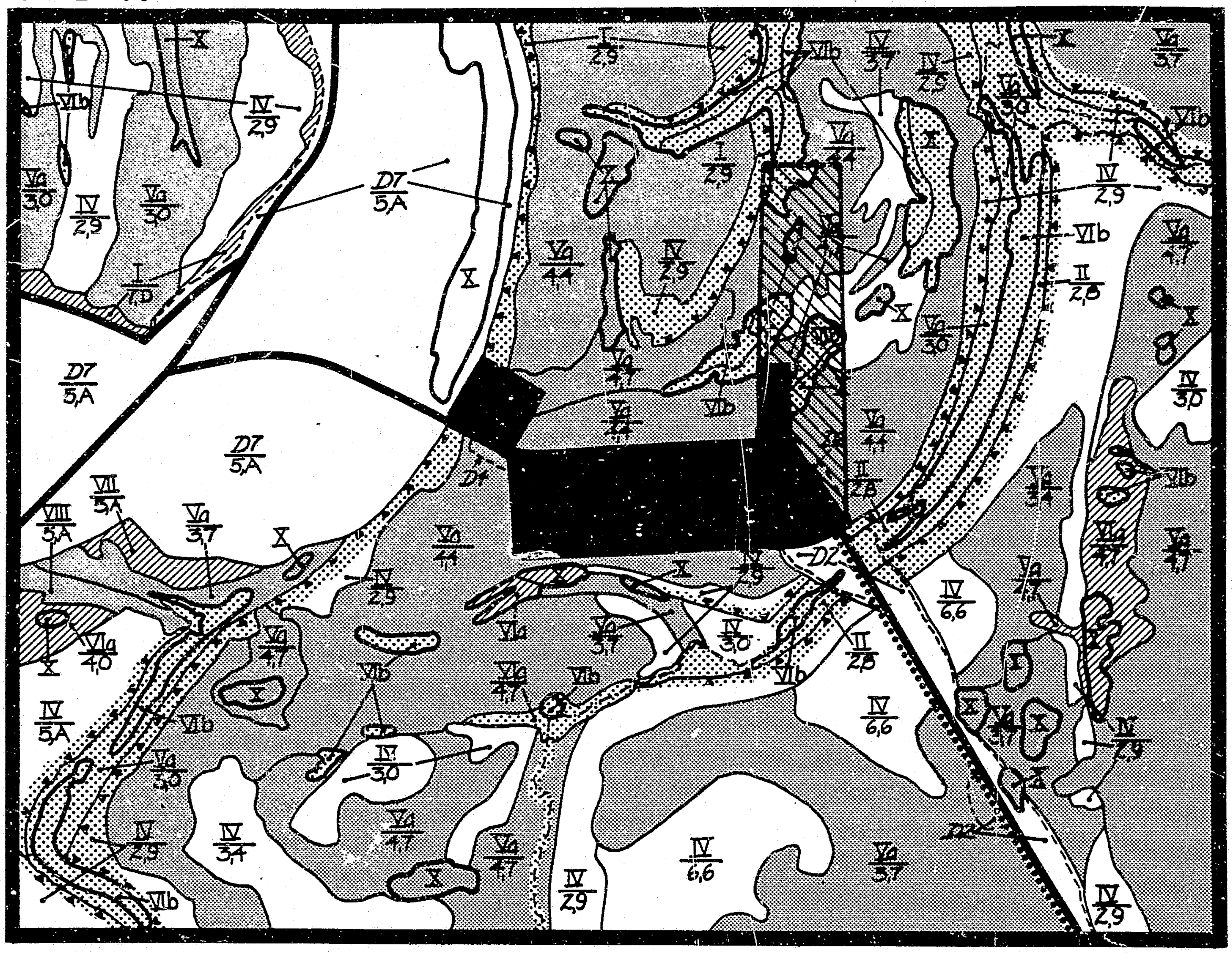


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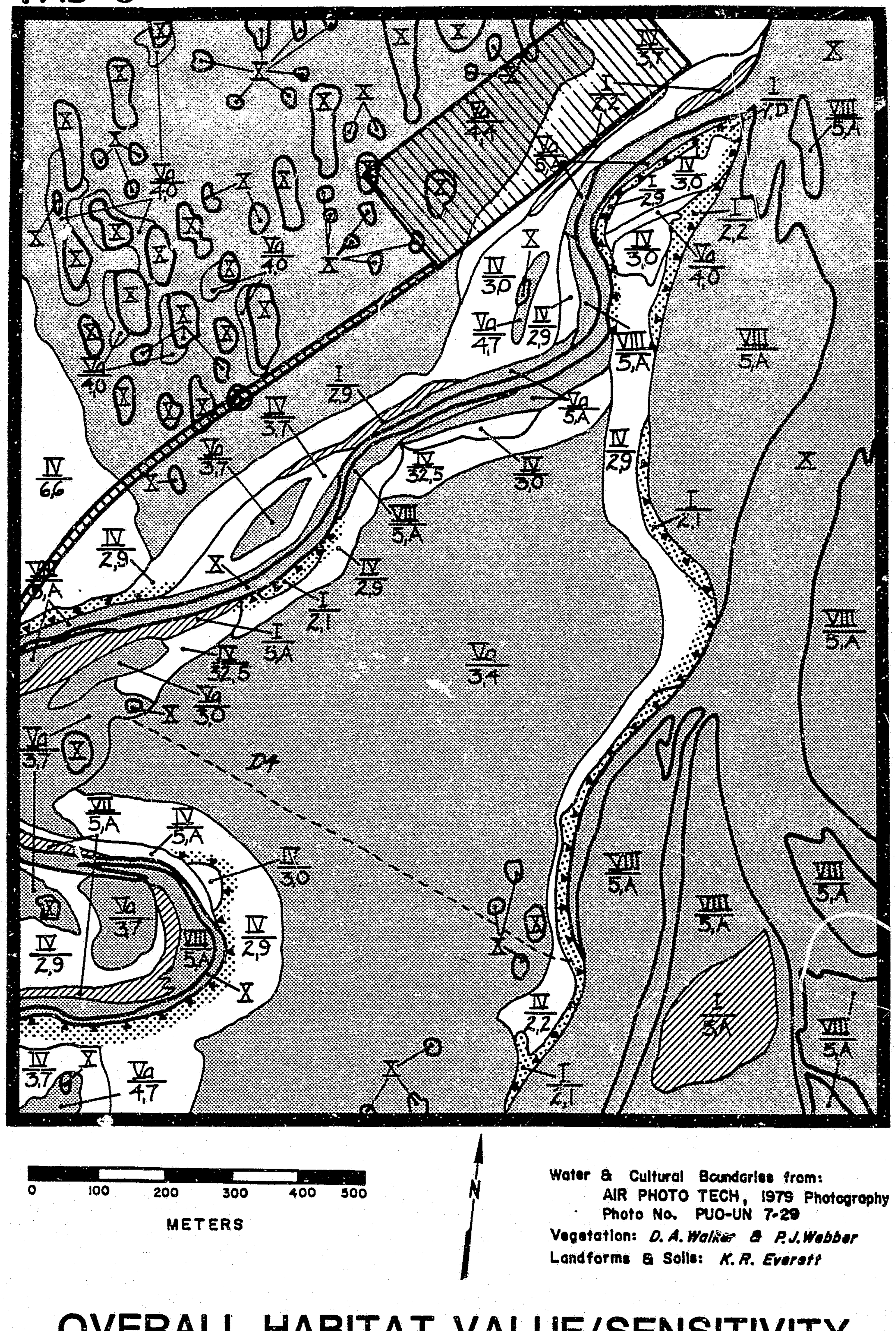
Photo No. PUO-UN 7-26
Vegetation: *D. A. Walker & P.J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-64

PAD S



OVERALL HABITAT VALUE/SENSITIVITY

Figure L–65

PAD X

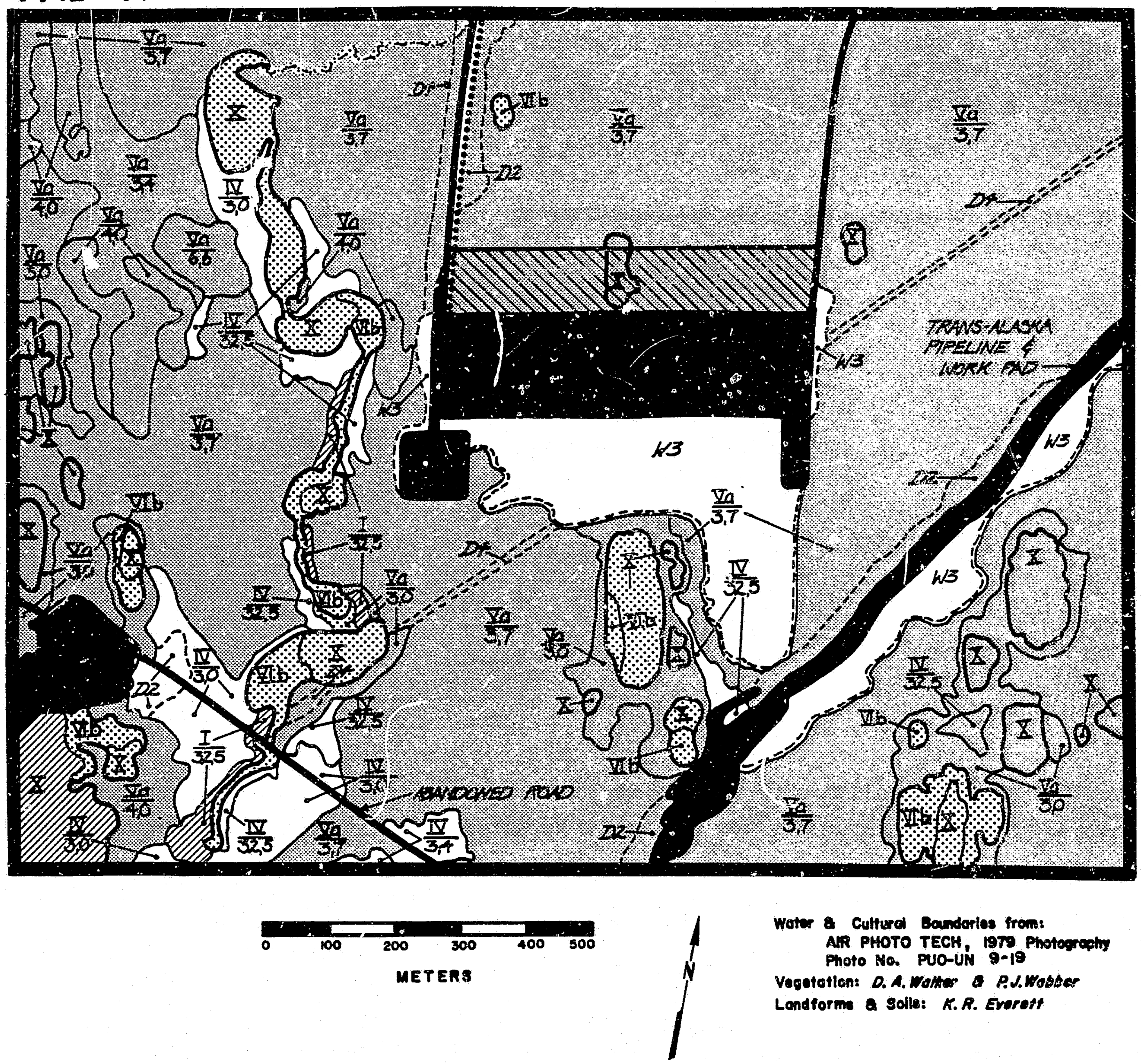


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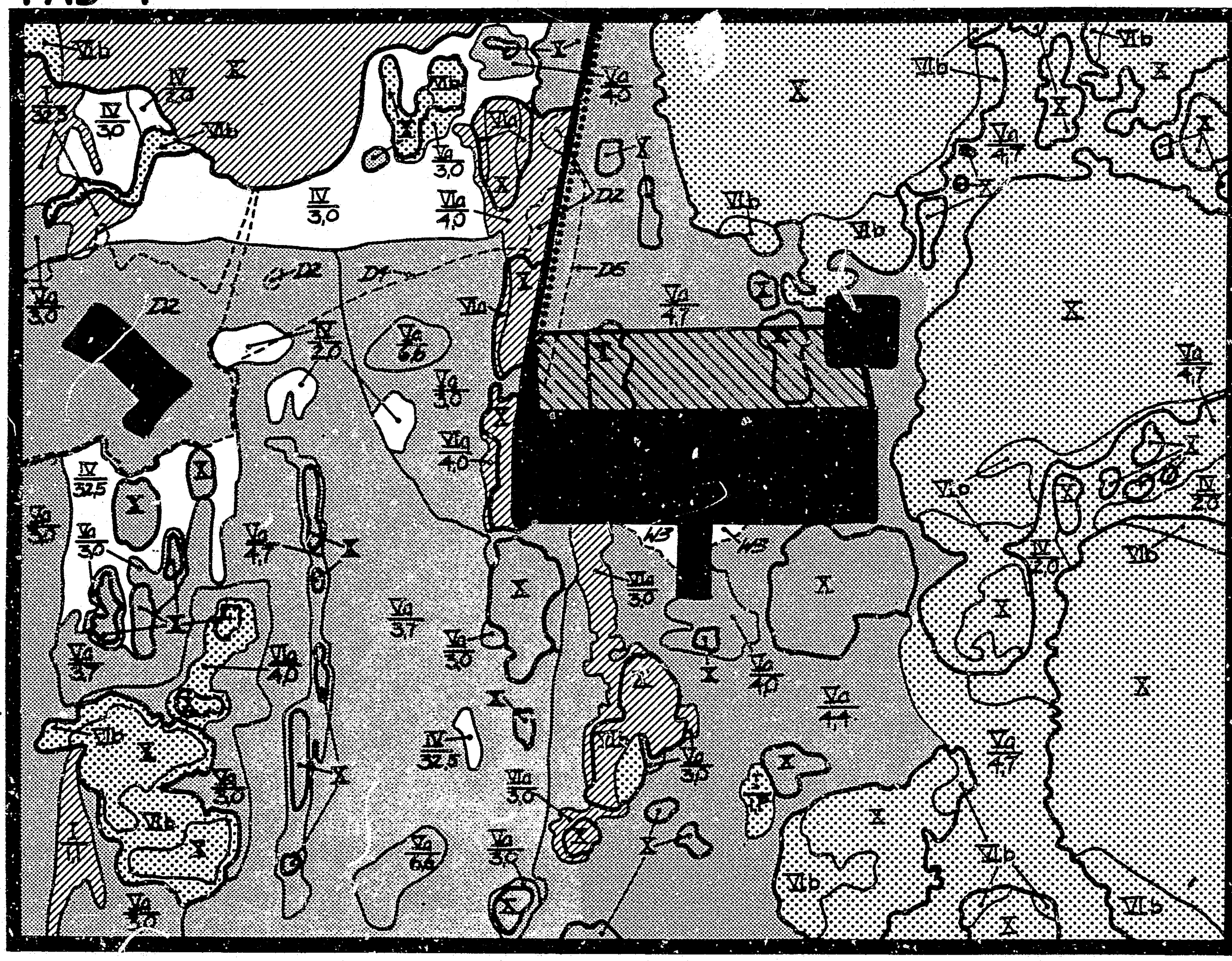
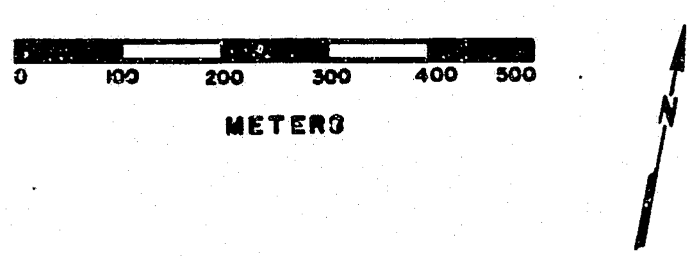
Photo No. PUO-UN 9-19
Vegetation: *D. A. Walker & P. J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-66

PAD Y





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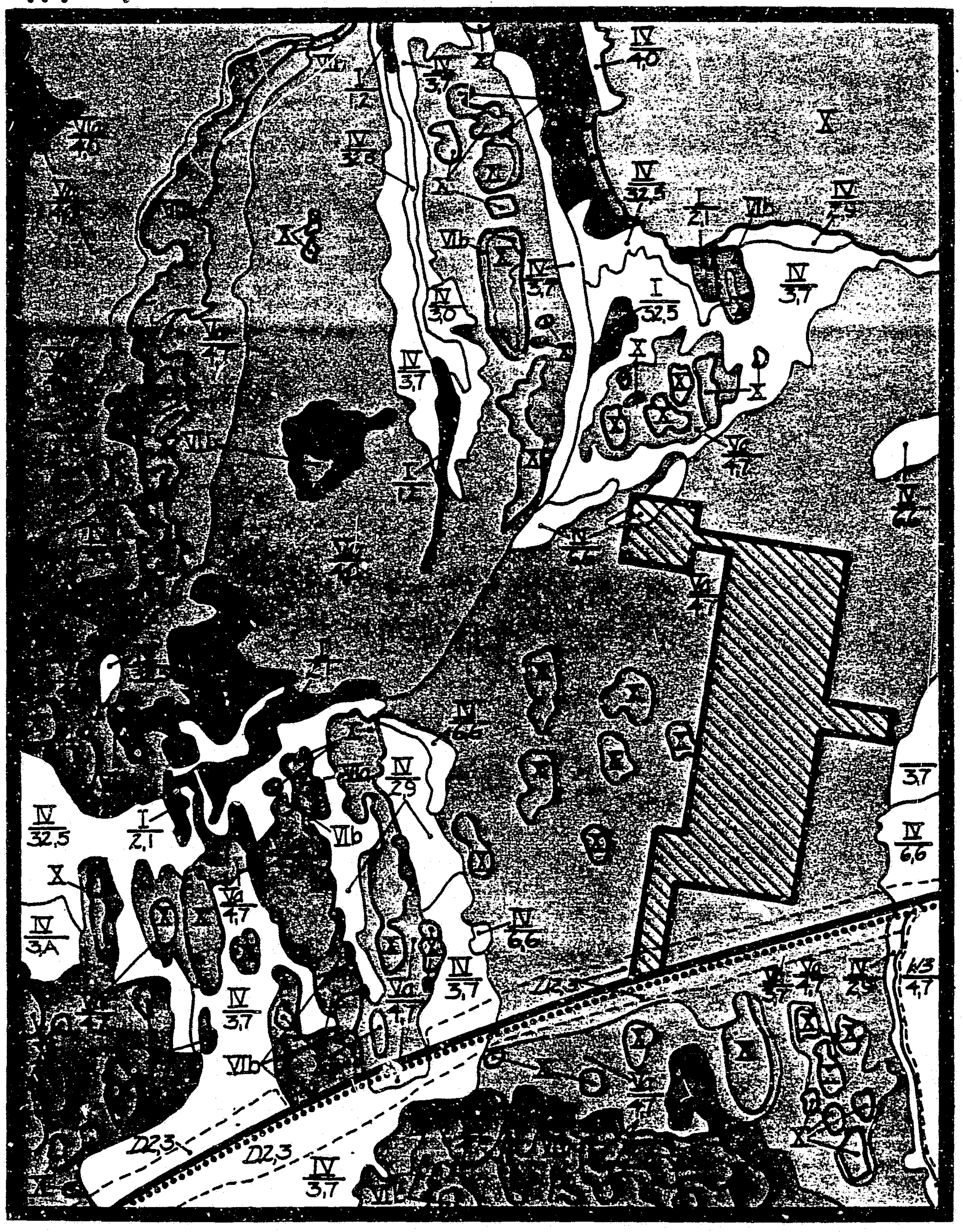
Vegetation: D. A. Walker & P. J. Webber
Landforms & Soils: K. R. Everett

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-67

WF I



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HIGH

HIGH MODERATE

LOW MODERATE

LOW

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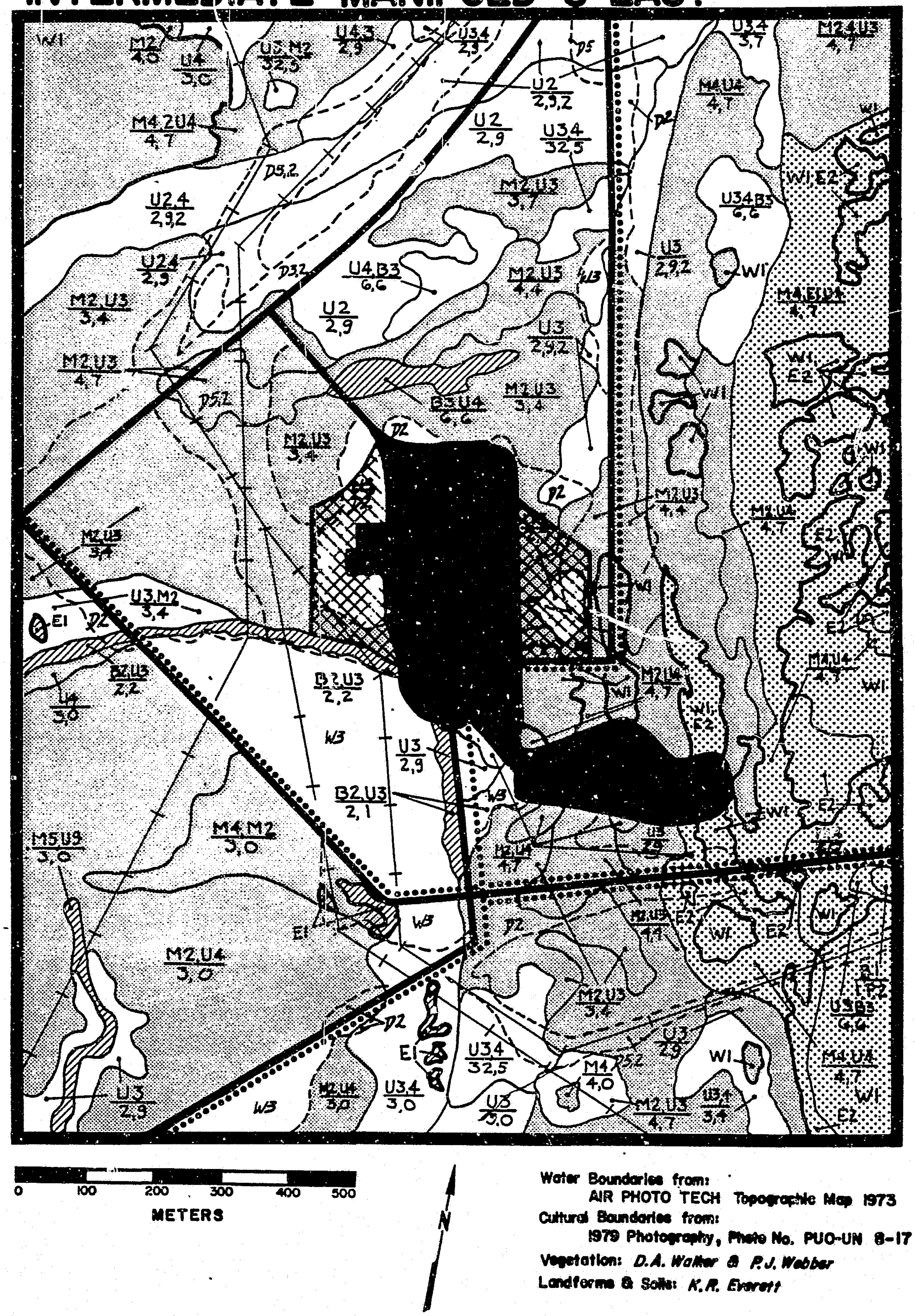
Photo No. PUO-UN 6-19
Vegetation: *D. A. Walker* & *P. J. Webber*
Landforms & Soils: *K. R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-68

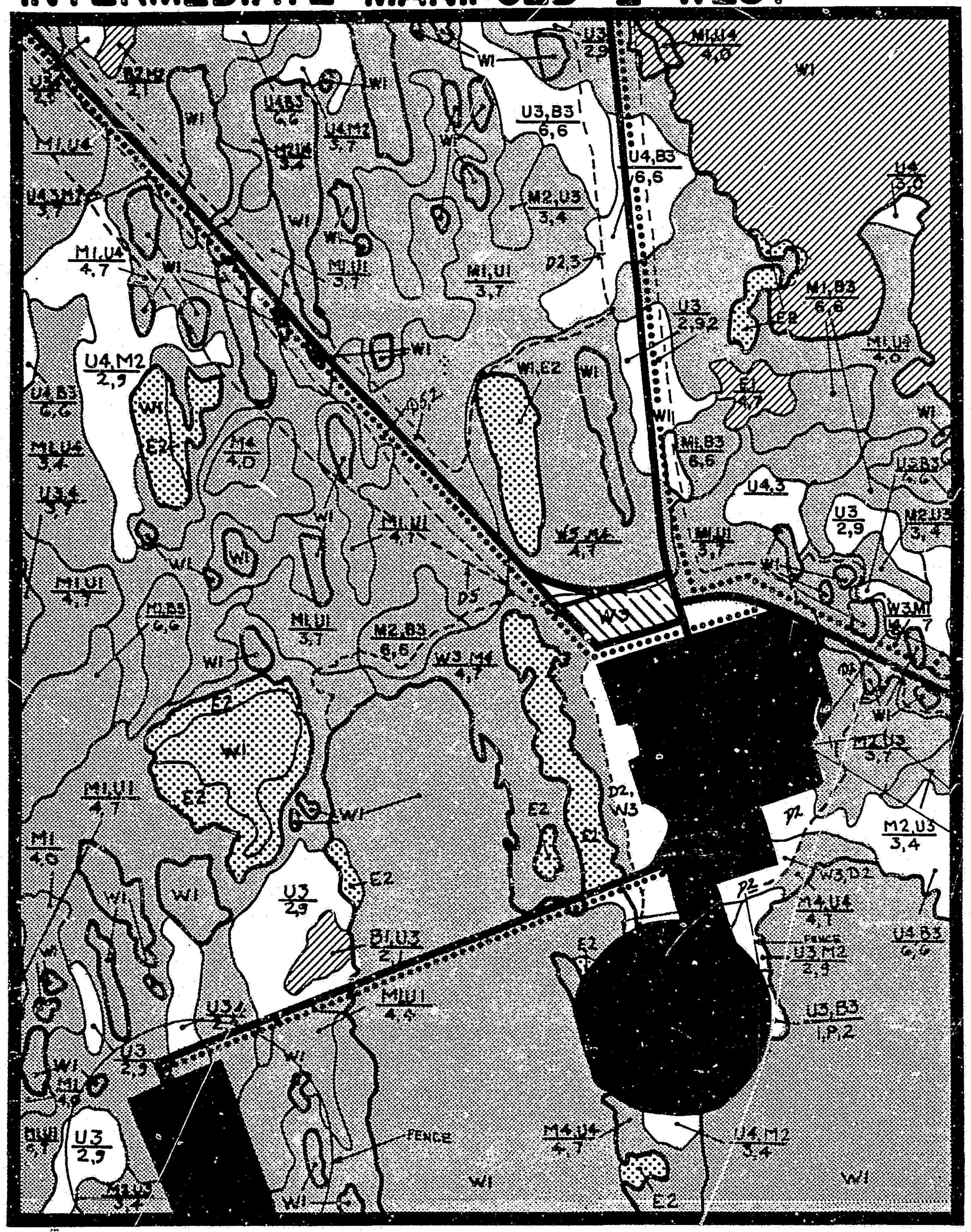
INTERMEDIATE MANIFOLD 3 EAST



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-69

INTERMEDIATE MANIFOLD 2 WEST



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METERS

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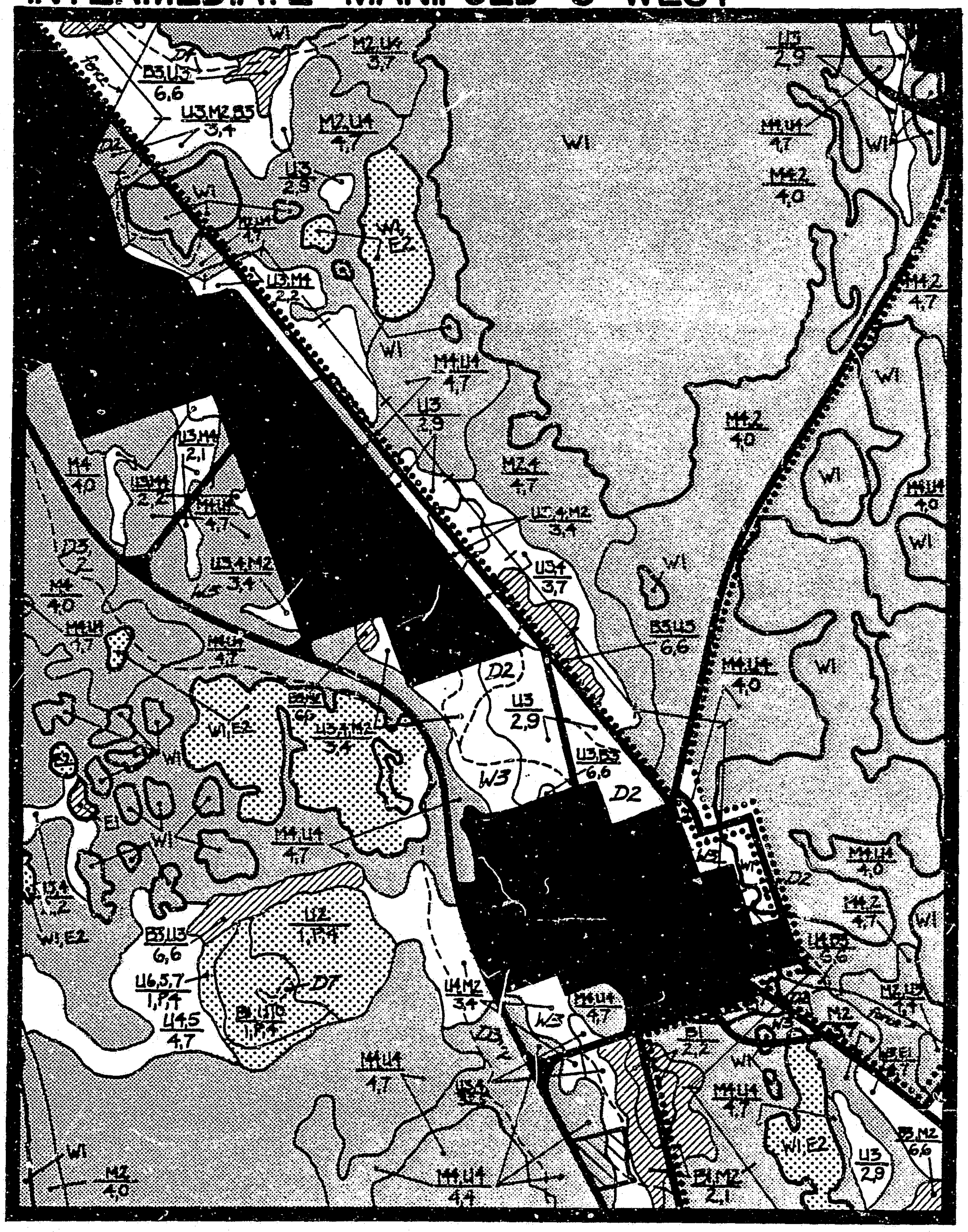
Cultural Boundaries from:
1977 Photography, Photo No. PUO-UN 8-25
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-70

INTERMEDIATE MANIFOLD 3 WEST



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METERS

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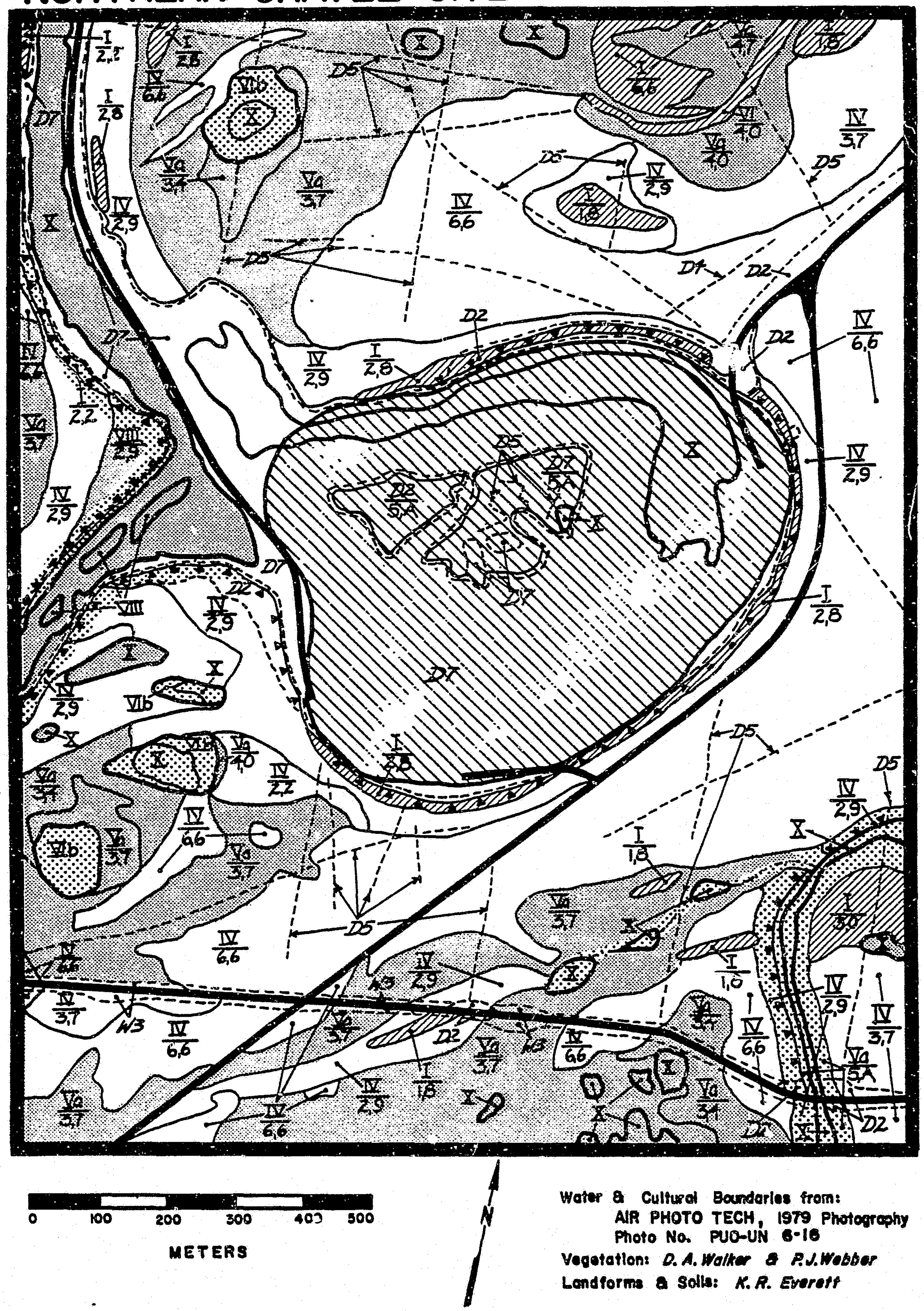
Cultural Boundaries from:
1979 Photography, Photo No. PUC-UN 7-20
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-71

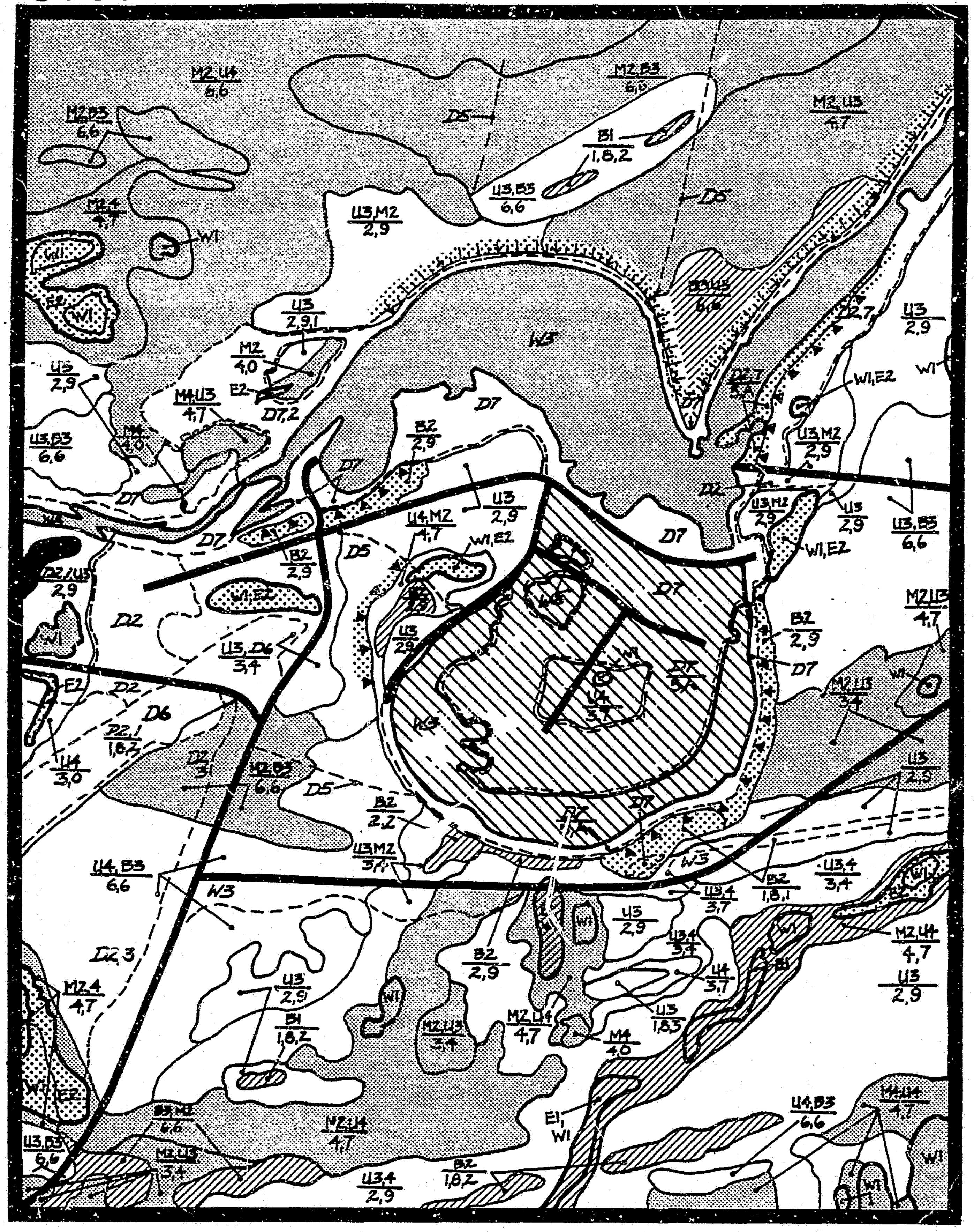
NORTHERN GRAVEL SITE



OVERALL HABITAT VALUE/SENSITIVITY

Figure L-72

SOUTHERN GRAVEL SITE



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METERS

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Cultural Boundaries from:
1979 Photography, Photo No. PUO-UN 7-17
Vegetation: *D.A. Walker & P.J. Webber*
Landforms & Soils: *K.R. Everett*

OVERALL HABITAT VALUE/SENSITIVITY

Figure L-73

REFERENCES

Alexandrova, V.D. 1970. The vegetation of the tundra zones in the USSR and data about its productivity. In: W.A. Fuller and P.G. Kevan, (Eds.) Productivity and conservation in northern circumpolar lands. Internat. Union Conserv. Natur., Morges, Switzerland, Pub. 16:93-114.

Bergman, R.D., R.L. Howard, K.F. Abraham, and M.W. Weller, 1977. Water birds and their wetland resources in relation to oil development at Storkersen Point, Alaska. U.S. Department of Interior Fish and Wildlife Service, Resource Publication 129. 38 pp.

Bliss, L.C. (ed.), 1977. Truelove Lowland, Devon Island, Canada: a high arctic ecosystem. Univ. Alberta Press, Edmonton; 714 pp.

Cameron, R., 1980. Personal communication with John Morsell, Dames & Moore.

Everett, K.R., 1975. Soil and landform associations at Prudhoe Bay, Alaska: a soils map of the Tundra Biome Area. In: J. Brown (ed.): Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report, No. 2; pp. 53-59.

Everett, K.R., P.J. Webber, D.A. Walker, R.J. Parkinson and J. Brown, 1978. A geoecological mapping scheme for Alaska coastal tundra. Third Internat. Conference on Permafrost, Edomonton, Alberta, 10-13 July, 1978; pp. 359-365.

Komarkova, V. and P.J. Webber, 1980. Two low arctic vegetation maps along the Meade River at Atkasook, Alaska. Arctic and Alpine Research 12:(in press).

U.S. Army Corps of Engineers, Alaska District, 1979. Alaska North Slope wetlands study, unpublished.

Walker, D.A., K.R. Everett, P.J. Webber, and J. Brown, in press. Geobotanical atlas of the Prudhoe Bay, Alaska region. CRREL Report.

Walker, D.A., 1980. Haul Road mapping program. In: Webber, P.J., Vegetation mapping and response to disturbance in Northern Alaska. Progress report to U.S. Army CRRELL Contract No. DAC A89-79-C 0006. (Unpubl. Manusc.).

Webber, P.J., 1974. Tundra primary productivity. In: J.D. Ives and R.G. Barry (Eds.), Arctic and alpine environments. London, Methuen, pp. 445-473.

Webber, P.J., 1979. Spatial and temporal variation of the vegetation and its productivity, Barrow, Alaska. In: L.L. Tieszen (Ed.), The ecology of primary producer organisms in Alaskan arctic tundra. Springer-Verlag, Inc., New York, pp. 37-112.

Webber, P.J. and Walker, D.A., 1975. Vegetation and landscape analysis at Prudhoe Bay, Alaska: A vegetation map of the Tundra Biome study area. In: J. Brown (ed.), Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska; Biological papers of the University of Alaska, Special Report No. 2; pp. 81-91.

White, R.G., B.R. Thomson, T. Skogland, S.J. Person, D.E. Russel, D.F. Holleman, and J.R. Luick, 1975. Ecology of caribou at Prudhoe Bay, Alaska. In: Brown, J. (Ed.), Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report No. 2, pp. 151-201.

APPENDIX M

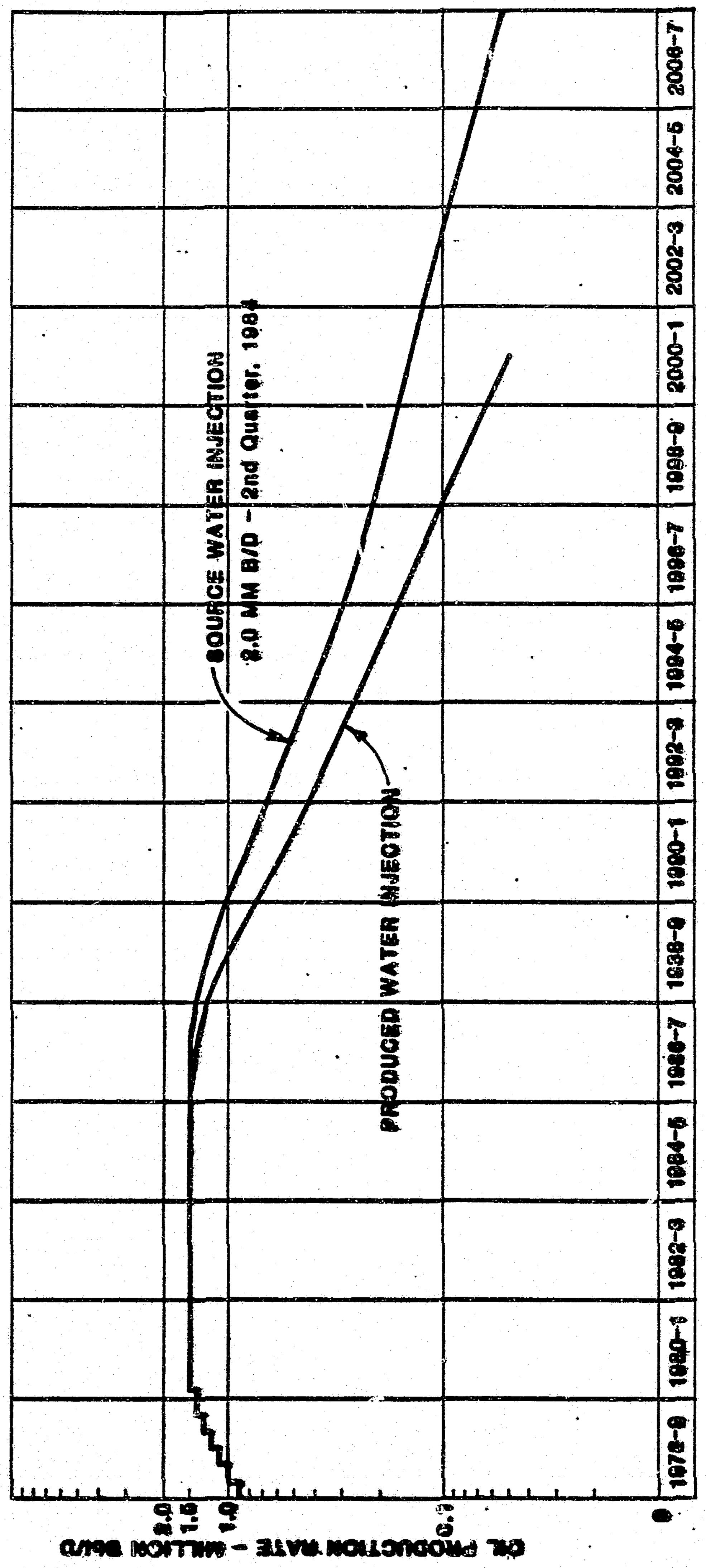
THE RELATIONSHIP OF INCREMENTAL OIL FROM THE PRUDHOE BAY FIELD TO THE U.S. ENERGY BALANCE

1.0 INTRODUCTION

Without the proposed 1984 waterflood start-up, the Prudhoe Bay field will begin to decline in early 1986. Given the existing OCS lease schedule, USGS resource estimates for Alaska, and 7 - 9 years lead-time, new Alaska supplies are unlikely to be found, developed, and supplied in large quantity to the Lower 48 before the early 1990's. Consequently, the timing of waterflood facilitates smooth transition to new Alaska supply sources.

Figure M-1 depicts an estimate of the decline of the Prudhoe Bay field with and without the planned 1984 start-up of water injection (Helton 1980). Table M-1 translates the decline curves into their annual production flows. From these estimates, the incremental Prudhoe production attributed to waterflood is calculated on an annual, daily, and cumulative basis. Almost 1.2 billion bbl would be captured by waterflood. The incremental production differences are highest (320,000 - 366,000 bbl/d) for the years 1988 - 1990, when prospects for significant supplies from new Alaska discoveries are low.

Petroleum development scenarios (Dames & Moore 1977, 1978, 1979a, b, c, d) for five of the six earliest scheduled Alaska OCS sales -- Beaufort (1979), second Gulf of Alaska (1980), Kodiak (1980), lower Cook Inlet (1981) and Norton Sound (1982) -- indicate that the time from lease sale to potential production ranges between 7 - 9 years. Large production levels may not occur for 10 - 12 years. Hence, significant new supplies of Alaska oil will not become available until after 1990.



PRUDHOE BAY FIELD PRODUCTION

PBU Waterflood Environmental Impact Statement

Figure M-1

TABLE M-1

EFFECT OF WATERFLOOD ON SADLEROCHIT PRODUCTION

	With Waterflood	Without Waterflood	Incremental Production	
Year	Million Barrels/Year	Million Barrels/Year	Million Barrels/Year	Thousand Barrels/Day
1986	547.5	529.6	17.9	49.0
87	547.5	462.3	85.2	233.4
88	524.8	401.0	1[illegible].8	339.2
89	441.7	308.0	133.7	366.3
90	353.4	236.5	116.9	320.3
91	282.7	181.6	101.1	277.0
92	226.1	141.1	85.0	232.9
93	181.0	160.9	70.1	192.1
94	144.7	87.2	57.5	157.5
95	113.5	68.5	45.0	123.3
96	91.7	53.9	37.8	103.6
97	79.1	42.3	36.8	100.8
98	68.2	33.3	34.9	95.6
99	58.8	26.2	32.6	89.3
2000	50.8	20.6	30.2	82.7
1	43.8	16.2	27.6	75.6
2	37.7	--	37.7	103.3
3	32.5	--	32.5	89.0
4	28.0	--	28.0	76.7
5	24.2	--	24.2	66.3
6	19.7	--	19.7	54.0
2007	17.0	--	17.0	46.6
		Cumulative Incremental Production	1195.2	

Based on Helton Engineering Co. estimates of decline, February, 1980.

2.0 WORLD OIL SUPPLY AND DEMAND

2.1 OPEC

The supply of oil is finite; however, oil shortages are more likely to depend on political considerations than on physical resource limitations in the near future. Political considerations within Middle East oil producing countries suggest that although proved reserves would allow higher production, OPEC oil during the 1980's probably will not be produced at maximum rates simply to meet demand.

Table M-2 reveals that OPEC's share of the non-communist world oil production was over 61 percent in 1978. Various economists project that oil will constitute nearly 48 percent of the non-communist world's 1990 energy consumption. To the extent that oil supplies are politically curtailed, alternate sources or new technologies will have to be substituted faster than projected, or consumers will have to institute more conservation measures, or do without.

The top half of Table M-3 shows a consensus non-communist world oil demand forecast. According to Thiel (1979), most estimates put western world oil demand near 66 million bbl/d by 1990--up from 52 million bbl/d in 1978. This represents a 2 percent annual growth rate in consumption. Thiel's consensus forecast shows considerably more upward risk (80 million bbl/d) than downward sensitivity (60 million bbl/d).

The bottom half of Table M-3 depicts Thiel's estimate of western world oil supplies to 1990. Thiel estimates OPEC's upper production limit in 1990 will be 40.7 million bbl/d, resulting in a supply to the western world from all sources of nearly 70 million bbl/d. The lower limit is under 60 million bbl/d if OPEC produces no more than 30 million bbl/d. Thiel, as well as other observers, predicts serious world oil price instability and supply disruption in the late 1980's if non-OPEC demand for OPEC oil approaches 40 million bbl/d. Some believe OPEC production will never exceed 35 million bbl/d.

TABLE M-2

NON-COMMUNIST WORLD OIL PRODUCTION: 1978

	(Million Bbl/D)		Percent
Total OECD[1]		14.2	28.6
of which, U.S.	10.3		
Total OPEC		30.3	61.1
of which, Saudi Arabia	8.5		
of which, Iran	5.2		
Total other countries		5.1	10.3
of which, Mexico	1.3		
Total non-communist		47.0	100.0

[1] Organization for Economic Cooperation and Development

Source: U.S. Energy Information Agency

TABLE M-3

NON-COMMUNIST WORLD OIL DEMAND
(Million Bbl/D)

	Actual 1978	Forecast 1980	1985	1990
Low	51.9	52	57	60
Probable	51.9	54	60	66
High	51.9	58	69	80

NON-COMMUNIST WORLD OIL SUPPLY
(Million Bbl/D)

		1978	1980	1985	1990
Non-OPEC LDC		5.1	6.8	9.3	11.2
OECD, Excl U.S.		3.9	5.5	6.3	7.5
U.S.		10.3	9.1	10.0	9.8
Subtotal, Production		19.3	21.4	25.6	28.5
Sino-Soviet Imports		1.8	1.0	0.5	--
Process Gain		0.5	.5	.6	.6
Free World Supply, Excl OPEC		21.6	22.9	26.7	29.1
OPEC Production:	Lower Limit	30.3	26.4 -	29.8 -	29.7 -
	Upper Limit		35.2	39.4	40.7
Total Supply:	Lower Limit	51.9	49.3 -	56.5 -	58.8 -
	Upper Limit		58.1	66.1	69.8

NOTE: Upper and lower limits of OPEC production are defined by conservative physical production limitations on the top side and estimated foreign exchange requirements on the bottom side.

Source: Michael F. Thiel (1979).

WORLD OIL PRODUCTION FORECASTS

Table M-4 shows several crude oil production forecasts. The range in these forecasts after 1985 is generally explained by various company and agency assumptions about OPEC production. Most industry analysts expect OPEC production to remain about 30 million bbl/d at least through 1985 (Anonymous 1979a). Thereafter, British Petroleum believes economic incentives to exporting countries will be reduced because incremental production would only increase the OPEC nations' financial assets held in foreign banks and would not benefit their domestic economic growth. Furthermore, if inflation continues, oil could earn more in the ground than as a financial asset in foreign banks.

The British Petroleum forecast is also pessimistic about the remaining world production capacity. It assumes significant new supplies in areas other than OPEC will not be brought into production and believes non-communist world production capacity will peak by 1985 at the latest.

The Energy Information Administration (EIA) forecast is the most optimistic. Its high case calls for OPEC production to be 39 million bbl/d by 1990. EIA's pessimistic case calls for OPEC production of 32 million bbl/d in 1990. Exxon's forecast, the second highest, was made before the current Middle East turmoil; it estimates OPEC production of 38 million bbl/d by 1990. Standard Oil of California forecasts a production peak by 1990 and plateau to the end of the century; its forecast calls for OPEC to produce 37 million bbl/d by 1990.

A CIA forecast (CIA 1979), not shown on Table M-4, contends that the potential oil shortage in the western world will be compounded by Soviet Bloc production capacity limitations. The Soviet production problem is regarded by analysts as a technological constraint. Russia's oil production industry is heavily dependent on U.S. oil field tools and technology. If the U.S. policy, announced in January 1980, limiting exports of American technology to Russia in retaliation for the Soviet invasion of Afganistan continues, Russia is not expected

TABLE M-4

NON-COMMUNIST WORLD CRUDE PRODUCTION FORECASTS[1]

(Million Bbl/D)

	Forecast Description	1980	1985	1990	1995	2000
British Petroleum	-OPEC At Max	--	64	62	--	52
	-OPEC No Inc.	--	55	52	--	43
Standard of Indiana	-Base Case	53.8	59.1	--	--	--
	-Pessimistic	52.5	55.1	--	--	--
Standard of California	-1990 Plateau	53.0	58	60.5	60	60
Shell	-Optimistic	--	--	66.5	--	70.3
	-Pessimistic	--	--	57	--	63.0
Exxon	-1978-Year-End	54	--	68	--	--
Energy Information Administration (EIA)	-Optimistic	--	59	76	85	--
	-Pessimistic	--	55	67	69	--
Michael F. Thiel	-Upper OPEC Political Limit	56.6	65.0	69.8	--	--
	-95% OPEC Limit	54.8	63.0	67.2	--	--
	-Lowest OPEC Production	47.8	55.4	58.8	--	--

[1]For consistency between forecasts NGL is excluded. NGL equals about an additional 5 percent.

SOURCES:

Anonymous (1979b,c).

Popcock (1979).

Thiel (1979).

to meet its 1980's production goals. The CIA predicts that the Sino-Soviets will change from a net exporter to the western world of 1.8 million bbl/d in 1978 to a net importer of 700,000 bbl/d by 1982. In view of the tenuous western world oil supply/demand balance extant in 1979 and forecasted to continue, a 2.5 million bbl/d shift in Sino-Soviet supply patterns could be disruptive not only to the supply balance and to the real price of oil, but also to political conditions (Anonymous 1979a).

3.0 UNITED STATES OIL SITUATION

DEMAND

Oil will remain the predominant fuel in the U.S. at least through 1990 although its share of total energy consumed will decline. The 1990's will be a transition period to alternate energy sources. Methods will be sought to produce new energy resources on a large scale and integrate their use into the existing distribution network in an economic and environmentally compatible way.

Shell, Exxon and Chevron forecast 1990 U.S. energy demand to range from 47.6 million bbl/d oil equivalent (O.E.) to 49.9 million bbl/d O.E. They further agree that crude oil will account for 20 - 21 million bbl/d of this total. The 1978 U.S. crude oil demand was 19.2 million bbl/d of a total of 38 million bbl/d O.E. for U.S. energy consumption.

Underlying the Shell, Exxon, and Chevron forecasts to 1990 are real GNP growth rates between 3.0 - 3.5 percent. The 1978 - 1990 U.S. oil consumption growth rate is forecast to range between 0.35 percent (to 20 million bbl/d) and 0.75 percent (to 21 million bbl/d). Total U.S. energy use growth is expected to fall within 2.0 - 2.25 percent between 1978 and 1990. Consequently, the ratio of total energy use to real GNP, shown on Figure M-2 to be declining since the early 1970's, is projected to continue its decline as the U.S. replaces inefficient energy technology and other conservation measures take hold.

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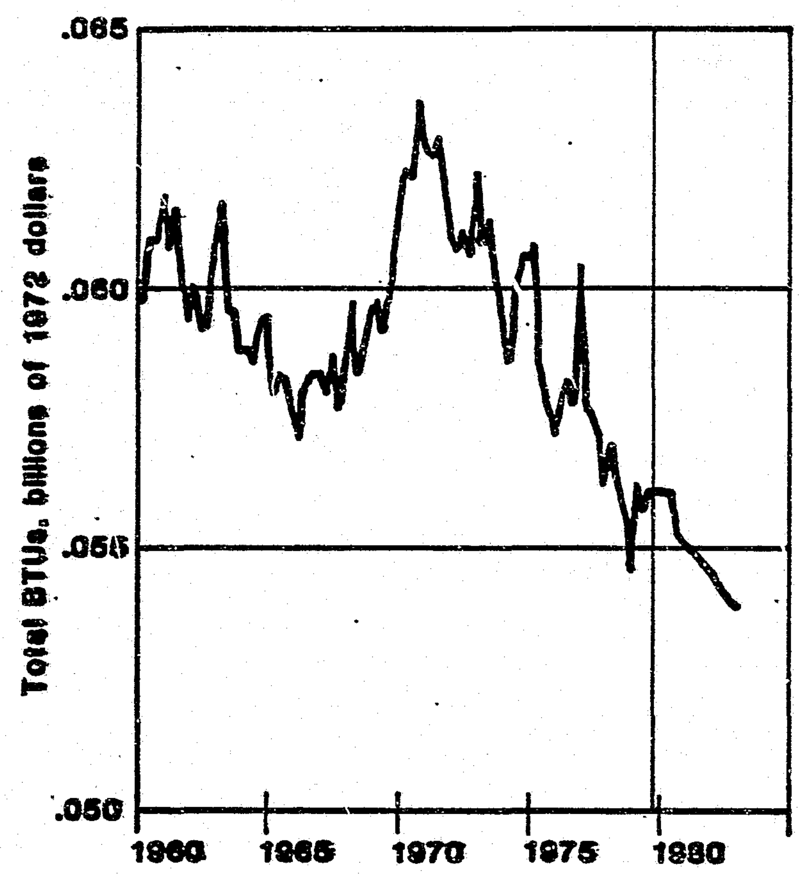


Source: Data Resources, Inc., Forecast November, 1979.

THE RATIO OF TOTAL ENERGY DEMAND TO REAL GNP

PBU Waterflood Environmental Impact Statement	Figure M-2

While absolute oil requirements are forecast to grow slightly to 1990, oil's relative share is expected to decline from 50 percent in 1978 to about 42 percent in 1990. The growth rate in oil use compared either to forecasted growth rate in GNP during this period, or historical U.S. oil consumption growth rates from 1960 - 1973 (4.4 percent annually), reflects a radical change in U.S. oil consuming patterns.

THE ALASKA LINK TO DOMESTIC OIL PRODUCTION

While U.S. oil consumption growth rates will drop significantly, the fact remains that domestically produced oil consumed in the 1990's must be developed during the 1980's to meet the projected demand. The U.S. is currently producing at a rate of approximately 3.75 billion bbl/yr. Proved reserves as of January 1, 1979, amounted to 27.8 billion bbl -- a sufficient inventory to last only 7.5 years, through mid-year 1986 at current production rates. Thus, to hold domestic production at current levels for another 7.5 years beyond mid-year 1986, additional reserves, at least equal to total current proved reserves, must be found and developed during this period.

Most forecasts of domestic oil production for the coming decade predict domestic production at about present levels. Production of crude and NGL in 1978 was 10.3 million bbl/d. A number of forecasts (Shell, ARCO, Chevron) peg a production range of 8.5 - 10 million bbl/d in 1990. Gulf estimates 8, 10 and 12 million bbl/d as the minimum, probable, and maximum domestic levels. Exxon estimates 1990 minimum domestic production at 7 million bbl/d, maximum at 9 million bbl/d, and probable at 7.5 million bbl/d.

Alaska represents the largest potential source of new crude oil supplies within the U.S. Table M-5 illustrates the range in industry estimates for additional discoveries onshore and offshore Alaska by 1990. Domestic oil production from Lower 48 and Cook Inlet proved reserves are declining. Neither Shell nor Chevron expect new discoveries to off-set this decline. While Shell and Chevron differ

TABLE M-5

DOMESTIC OIL PRODUCTION

(Million Bbl/D)

	Lower 48 and South Alaska	Arctic Alaska	Syncrude	Total
Shell				
1978 Actual	9.2	1.1	0	10.3
1980	7.9	1.6	0	9.5
1990	5.8	3.0	0.5	9.3
Chevron				
1978 Actual	9.2	1.1	0	10.3
1980	8.4	1.6	0	10.0
1990	7.0	1.8	0.5	9.3

Sources: Anonymous (1979d)
California Energy Commission (1979)

in their view of the relative shares of 1990 Lower 48 and Alaska production, they agree that they expect 1990 production to be 1 million bbl/d lower than 1978, including 500,000 bbl/d of syncrude.

By 1990, production from Prudhoe Bay will be declining, producing just over 1 million bbl/d (with waterflood) including new production from Kuparuk. Shell's forecast assumes that incremental production from new discoveries in arctic Alaska will nearly triple the Prudhoe Bay production rate by 1990. Chevron is more conservative and assumes production only sufficient to maintain the trans-Alaska pipeline near its maximum design rate. (Shell does not specify an assumption about transportation of crude from arctic Alaska in excess of pipeline capacity.) Delays in beginning exploration and development of potential offshore (Beaufort Sea) reserves reduce the likelihood of realizing these predictions and could result in production rates below pipeline capacity in the early 1990's.

IMPORTS

In view of the expected U.S. demand for oil in the 20 - 21 million bbl/d range and domestic production -- including production from yet undiscovered resources on the North Slope of Alaska -- in the 8.5 - 10 million bbl/d range, imports will have to amount to 10 - 12.5 million bbl/d by 1990.

The U.S., as well as much of the rest of the world, will remain dependent on oil from the politically unstable Middle East until sometime in the next century when alternative technologies and sources of energy are developed. Minor import supply disruptions will continue to have economic disruptions. To the extent that U.S. energy policies can stimulate domestic production above the 8.5 - 10 million bbl/d expected 1990 level or reduce expected 1990 demand for oil below the forecasted 20 - 21 million bbl/d, the U.S. will become less vulnerable to unpredictable disruptions.

REFERENCES

Anonymous, 1979a. CIA: global oil supply outlook poor. Oil and Gas Journal, September 3, 1979, p. 50-51.

Anonymous, 1979b. EIA optimistic on crude supply, outlook. Oil and Gas Journal, September 10, 1979, p. 102-103.

Anonymous, 1979c. Oil in the eighties; tight supply, soaring capital outlays. Oil and Gas Journal, November 12, 1979, p. 163-169.

Anonymous, 1979d. U.S. petroleum industry will face monumental task in next decade. Oil and Gas Journal, November 12, 1979, p. 170-184.

California Energy Commission, 1979. Fuel price and supply projections: 1980-2000. November, 1979.

CIA, 1979. The world oil market in the years ahead. August, 1979.

Dames & Moore, Peat Marwick & Mitchell, CCC/HOK, URSA, 1977. Beaufort Sea basin petroleum development scenarios for the federal outer continental shelf, interim report. Alaska OCS Socioeconomic Studies Program, Tech. Report No. 3. Bureau of Land Management, Alaska OCS Office.

Dames & Moore, 1978. Beaufort Sea petroleum development scenarios for the state-federal and federal outer continental shelf. Alaska OCS Socioeconomic Studies Program, Technical Report No. 6. Bureau of Land Management, Alaska OCS Office.

Dames & Moore, 1979a. Northern Gulf of Alaska petroleum development scenarios. Alaska OCS Socioeconomics Studies Program, Technical Report No. 29. Bureau of Land Management, Alaska OCS Office.

Dames & Moore, 1979b. Western Gulf of Alaska petroleum development scenarios. Alaska OCS Socioeconomic Studies Program, Technical Report No. 35. Bureau of Land Management, Alaska OCS Office.

Dames & Moore, 1979c. Lower Cook Inlet and Shelikof Strait petroleum development scenarios. Alaska OCS Socioeconomic Studies Program, Technical Report No. 43. Bureau of Land Management, Alaska OCS Office.

Dames & Moore, 1979d. Norton Basin OCS lease sale No. 57 petroleum development scenarios. Alaska OCS Socioeconomic Studies Program, Technical Report No. 49. Bureau of Land Management, Alaska OCS Office.

Helton Engineering and Geological Consultants, 1980. Prudhoe Bay waterflood project reservoir engineering. Report prepared for Dames & Moore.

Popock, C.C., 1979. Prospects for oil and gas: a look ahead to year 2000. World Oil, October, 1979, p. 107-111.

Thiel, M.F., 1979. World oil and OPEC: the razor's edge. World Oil, October, 1979, p. 123-133.

APPENDIX N

ENDANGERED SPECIES ACT COORDINATION

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
P.O. Box 1668
Juneau, Alaska 99802

April 14, 1980

Colonel Lee R. Nunn
District Engineer
Alaska District, Corps of Engineers
P.O. Box 7002
Anchorage, Alaska 99510

Dear Colonel Nunn:

This responds to your letter of January 17, 1980, in which you requested formal consultation under Section 7(c) of the Endangered Species Act regarding the proposal by the SOHIO Petroleum Company and the Atlantic Richfield Company to construct the Prudhoe Bay Unit Waterflood Project. You stated that the Waterflood Project consisting of multiple component parts, including a causeway extension, construction of intake facilities, and the ultimate operation of these facilities could have the potential to impact the bowhead whale.

Bowhead whales could occur in and adjacent to the project area during the period between late August-October, they migrate northward in the spring from Bering Sea wintering grounds. Most breeding and calving occur prior to early April while the animals are in the Bering Sea, although such reproductive activities have occasionally been reported during the spring and even in the summer. During April-June, the whales move northward through leads in the pack ice and then eastward towards Banks Island and the Amundsen Gulf area, dispersing throughout the Beaufort Sea and Amundsen Gulf north of the limit of heavy pack ice. The fall migration (late August-October) passes nearshore between the pack ice and the north coast of Alaska and Canada. Bowheads depart the Beaufort Sea during September and October, moving into the Chukchi and Bering Seas. In general, they occur in the proposed project area probably no sooner than August and probably no later than the end of October, depending upon ice conditions, although they may occur rarely in the project area during spring and summer.

Inasmuch as bowhead whales are not apt to occupy the area in the vicinity of the proposed project, and because the 12 foot water depth in which the waterflood intake will be placed effectively precludes their presence at anytime, it is our opinion that the proposed activity is not likely to jeopardize the endangered bowhead whale or its habitat. Further Section 7 consultation under the Endangered Species Act is not required in this case.

Other topics associated with the proposed activity will be addressed in our Fish and Wildlife Coordination Act review of the necessary Public Notices.

Sincerely,

Harry L. Rietze

Harry L. Rietze
Director, Alaska Region

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
1011 E. TUDOR RD.
ANCHORAGE, ALASKA 99503
(907) 276-3800

IN REPLY REFER TO: (SE)

[illegible] DEC 1979

Colonel Lee R. Nunn, District Engineer
Alaska District Corps of Engineers
P.O. Box 7002
Anchorage, Alaska 99510

Dear Colonel Nunn:

This responds to your 23 November, 1979, request for a list of threatened or endangered species which might be affected by the construction and operation of the Prudhoe Bay Unit Waterflood (PBUW) project.

Based on the best information currently available to us, no listed or proposed threatened or endangered species are present that would be affected by the proposed project. Therefore, preparation of a biological assessment as identified in Section 7(c) of the Endangered Species Act of 1973, as amended, is unnecessary and further consultation with the Fish and Wildlife Service concerning endangered species and the PBUW project is not presently required. Please note, however, that this determination regards only those threatened or endangered species for which the Fish and Wildlife Service has responsibility.

New information indicating the presence of currently listed threatened or endangered species administered by the Fish and Wildlife Service or the listing of new species which might be affected by the proposed project will require reinitiation of the consultation process.

We appreciate your concern for endangered wildlife. Please contact us if you have questions or if we can be of further assistance.

Sincerely,

Area Director

cc: [illegible]ES

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
P. O. BOX 1668 - JUNEAU, ALASKA 99801

December 13, 1979

Colonel Lee R. Nunn
District Engineer
Alaska District, Corps of Engineers
P.O. Box 7002
Anchorage, Alaska 99510

Dear Colonel Nunn:

We have received your request for information on endangered species which may be affected by the proposed Prudhoe Bay Unit Waterflood Project. According to information presented by the applicant at a November 15, 1979 meeting in the Federal Building in Anchorage, the diagram presented on the location map included with your request is no longer valid. Apparently the preferred plan now consists of a direct water intake system located at the end of a gravel causeway which will extend approximately 4,500 feet beyond the existing west dock.

The species of primary concern in the vicinity of the proposed project is the bowhead whale. Although gray whales are known to occur in the Beaufort Sea, it is unlikely they would be found in the area of concern. Bowhead whale studies have been ongoing in the Beaufort Sea for several years. The following information provides a brief overview of available knowledge of the bowhead whale:

Bowhead whales of the western Arctic ocean occur seasonally from the central Bering Sea northward throughout the Chukchi and eastern Siberian Seas and eastward throughout the U.S. Beaufort Sea to Banks Island and Amundsen Gulf, Northwest Territories, Canada. Bowheads are thought to winter in the northern and central Bering Sea, timing their northward migration with the breakup of the pack ice, generally in April. The migration proceeds through the Bering Strait and the Chukchi Sea to Point Barrow. From Point Barrow the whales travel northeasterly in the Beaufort Sea through leads to Banks Island, Canada and Amundsen Gulf.

In August and September, bowheads begin to leave the eastern Beaufort Sea on their fall migration back to the Bering Sea. The whales travel west through the southern Beaufort Sea to Point Barrow. During this migration, the whales are hunted by Alaskan Eskimos from the villages of Kaktovik, Nuiqsut, and Barrow. Suspected migration routes are shown in Figure 1.

Sightings made since 1974 indicate that bowheads occur in shallow coastal waters all the way out to the ice pack (beyond the 100 m contour), although their exact spatial distribution is not known. Nearshore areas in the western Beaufort Sea appear to be important to the bowhead since there have been numerous sightings in shallow water from Smith Bay to Point Barrow. (See Figure 2.)

The current population estimate of bowhead whales in the western Arctic is 2,264, with a range of 1,783 to 2,865. This estimate is the result of three years of counting conducted by NMFS biologists. Key biological parameters (e.g., recruitment, mortality, and age structure) controlling the population of bowhead whales are virtually unknown.

Bowheads begin reaching sexual maturity after attaining lengths exceeding 38 feet. Recent information obtained from harvested whales indicates that sexual maturity may not be reached in some whales until those animals have attained a length of 45-50 feet. The breeding period of the bowhead is not well known. Some researchers maintain that breeding occurs in early April before the whales reach Point Hope, whereas other researchers have reported witnessing copulatory behavior in May near Point Hope and near Barrow.

Gestation is estimated to last about 1 year, and the calving season corresponds with the time of breeding. Observations of cows with calves passing Point Hope and Point Barrow from mid-April to mid-June suggest that most bowheads are probably born in the spring, either before (February - March) or during (April - June) migration.

One researcher classified the bowhead as a bottom skimmer in terms of its feeding habits, although it is probable that it feeds throughout the water column. Although a comprehensive food habits study has not been conducted, available data indicate that pelagic arthropods (euphausiids, mysids, copepods, and amphipods) are the preferred food organisms, and that annelids, molluscs, and echinoderms are utilized to a lesser degree. Stomach contents of a whale taken by Point Hope Eskimos during a spring migration included the remains of polychaetes, molluscs, crustaceans, and echinoderms, whereas stomach contents of two whales taken at Point Barrow in the fall of 1977 contained (by volume) 90.3% euphausiids and 9.6% amphipods.

Researchers report whales moving past the NMFS ice camps in the spring at a rate of 1.0 - 4.0 knots depending on the direction of the current. During the spring migration, whales do not travel in close association with one another. Of 2,406 bowhead observations recorded during 1976-1978, 1,815 (75.4%) were singles, 470 (19.5%) were in pairs, 105 (4.4%) were in groups of three, and 16 (0.7%) were in groups of four. During the fall migration, bowheads may travel in larger groups.

Bowheads' reaction to noise appears varied. A bowhead will leave the area when an outboard motor approaches. However, reaction to airplanes flying overhead seems mixed, the whales reacting vigorously in some instances and showing little reaction in other instances. It appears that fright reaction to noise varies greatly, depending upon the source, environmental conditions, and activity of the animals.

Bowheads are known to occur near Prudhoe Bay. Since 1974, 53 fall sightings have been made totaling approximately 323 animals for the entire Beaufort Sea. These sightings are the result of aerial surveys conducted mostly west of 150° W longitude. Although fewer animals were observed east of 150° W longitude, the paucity of sightings is thought to be directly proportional to the effort expended (i.e., less extensive aerial surveys). Numerous sightings have been made in nearshore shallow waters between Point Barrow and Smith Bay during the past 5 years, suggesting that this is an area of importance to bowheads. The whales appeared to be involved in feeding activity at the time of these sightings. It is not possible at this time to determine whether the western portion of the Beaufort Sea is more critical to the bowhead than the eastern portion. Limited surveys east of 150° W longitude have not established heavily utilized areas in the eastern Beaufort Sea, although it is certainly possible that these areas exist.

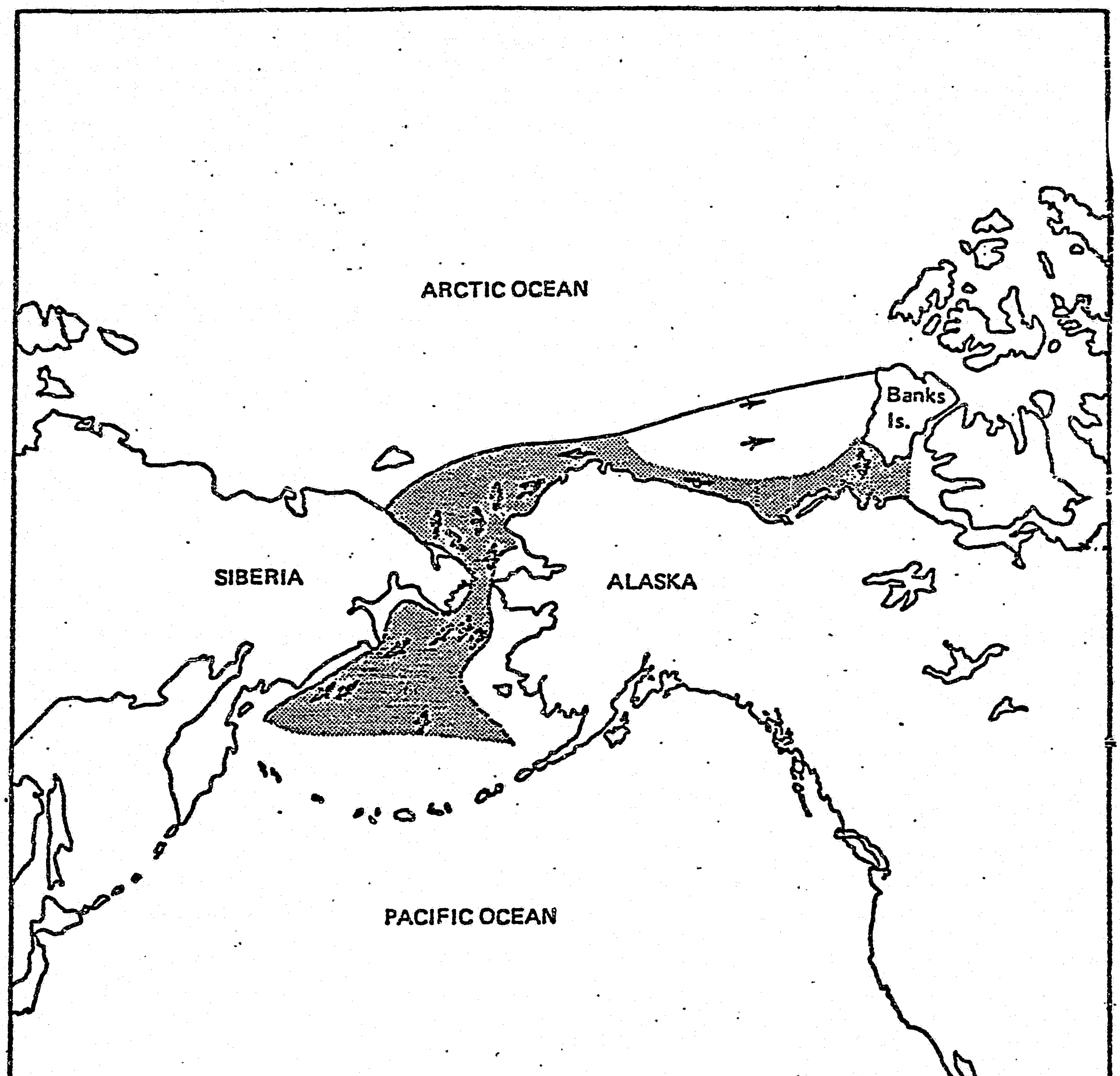
We appreciate the opportunity to comment on this project at this time. Please let me know if we can be of further assistance.

Sincerely,

Frederick W Thorstenson

for Harry L. Rietze
Director, Alaska Region

Attachments



SUSPECTED MIGRATION ROUTES

PROPOSED MIGRATION PATTERN OF THE BOWHEAD WHALE, BALAENA MYSTICETUS, IN THE BERING SEA AND THE ARCTIC OCEAN. NORTHERLY DIRECTED ARROWS DEPICT THE MARCH TO JUNE MIGRATION AND SOUTHERLY DIRECTED ARROWS DEPICT THE SEPTEMBER TO DECEMBER MIGRATION. SHADED AREAS ARE WHERE DATA ARE AVAILABLE FROM HISTORICAL ACCOUNTS OR FROM RECENT SIGHTINGS.

SOURCE: Braham, Krogman & Fiscus 1977

Figure 1

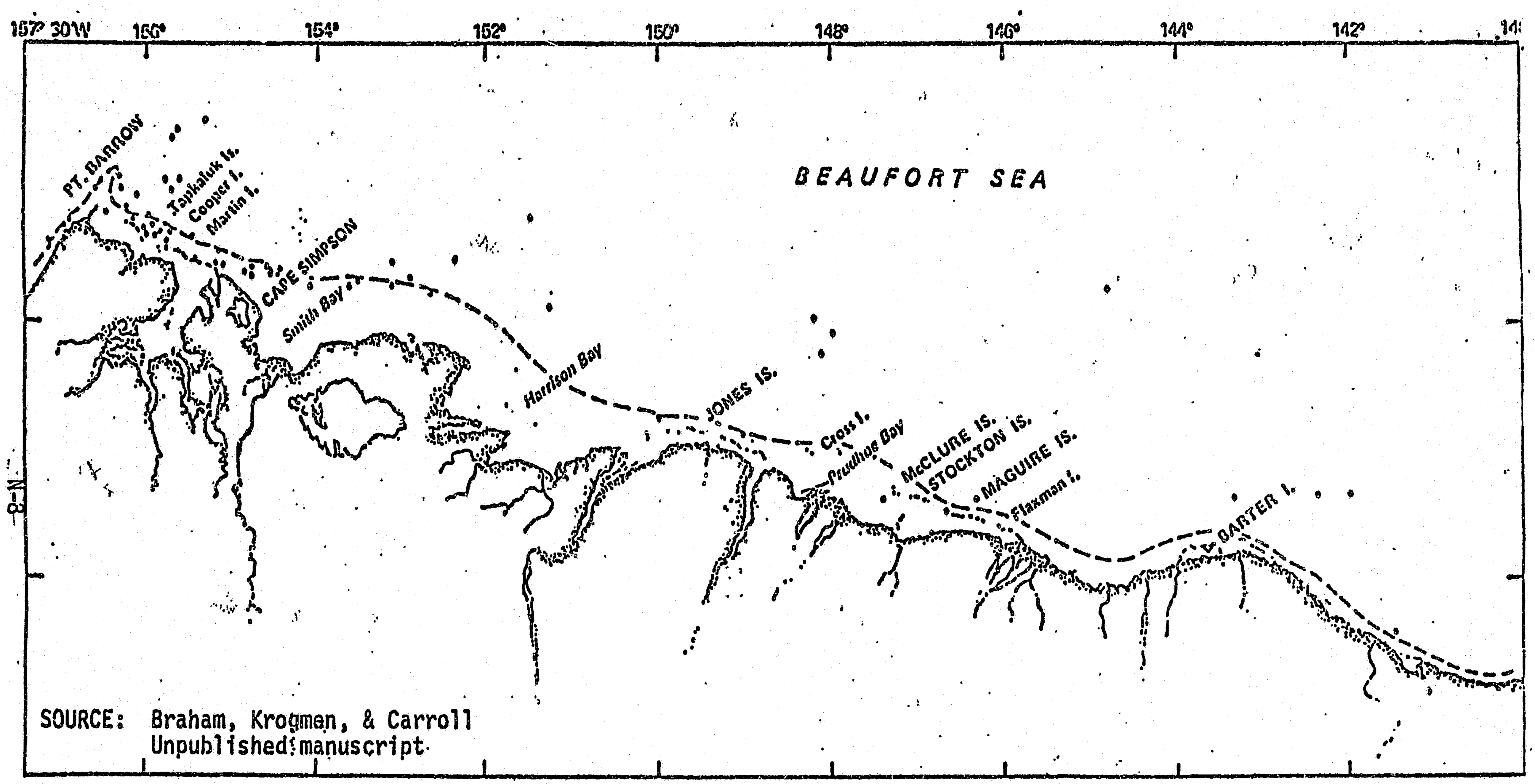


Figure 2 --Bowhead whale sightings (.) in the Beaufort Sea, August through November, 1974-1978, made during NMFS aerial surveys, and from contributing scientists. Only sightings with a verified position data were used. Most sightings occurred in the last half of September. The dashed line represents the 12 m contour.

PRELIMINARY DRAFT

Appendix O

Permit No.:
Application No.: AK-002984-0

AUTHORIZATION TO DISCHARGE UNDER THE

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

In compliance with the provisions of the Federal Water Pollution Control Act, as amended, (33 U.S.C. § 1251 et seq; the "Act"),

ARCO Oil and Gas Company (A division of Atlantic Richfield Company) and SOHIO Petroleum Company (A Division of SOHIO Natural Resources Company)

is authorized to discharge from a facility located at Prudhoe Bay, Alaska

to receiving waters named The Beaufort Sea

in accordance with discharge point(s), effluent limitations, monitoring requirements and other conditions set forth herein.

This permit shall become effective on

The permit and the authorization to discharge shall expire at midnight, five years from the effective date.

Signed this day of

Director, Enforcement Division

PRELIMINARY DRAFT

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

1. During the period beginning on the effective date of this permit and lasting through the expiration date the permittee is authorized to discharge filter backwash, strainer backwash, traveling screen spraywater and untreated seawater from outfall number 001.

a. Such discharges shall be limited and monitored by the permittee as follows:

EFFLUENT CHARACTERISTICS	DISCHARGE LIMITATIONS				MONITORING REQUIREMENTS	
	Monthly Average		Daily Maximum		Measurement Frequency	Sample Type
	Under Ice	Open Water	Under Ice	Open Water		
Flow	$17{,}100 m^3$/day (4.5 mgd)	$18{,}900 m^3$/day (5.0 mgd)	$18{,}900 m^3$/day (5.0 mgd)	$94{,}700 m^3$/day (25.0 mgd)	Continuous	Recording
Total Suspended Solids	1,880kg/day (4,130lbs/day)	10,300kg/day (22,700lbs/day)	2,090kg/day (4,590lbs/day)	69,400kg/day (153,000lbs/day)	Weekly	24Hr Composite
Volatile Suspended Solids	N/A	N/A	N/A	N/A	Weekly	24Hr Composite
Settleable Solids	5 ml/l	5 ml/l	20 ml/l	20 ml/l	Weekly	Grab-during backwash cycle
Chlorine Residual	N/A	N/A	0.1mg/l	0.1mg/l	Continuous	Recording
Ammonia (NH_3-N)	N/A	N/A	1.5 mg/l	1.5 mg/l	Monthly	24Hr Composite
pH	No less than 6.0 standard units and no greater than 9.0 standard units				Continuous	Recording
Temperature (°C)	No greater than 2.0°C above ambient conditions				Continuous	Recording

PRELIMINARY DRAFT

b. A single effluent sample shall be taken for analysis of the 65 priority pollutants designated pursuant to Section 307 (a)(1) of the Clean Water Act. This sample shall be taken during a backwash cycle at a time estimated to represent a maximum annual discharge during open water conditions.

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. Samples taken in compliance with the monitoring requirements above shall be downstream of all discharge processes.

e. In addition to the above effluent monitoring requirements the daily frequency of backwash cycles shall be recorded and reported on the monthly Discharge Monitoring Report.

f. All sanitary wastes shall be transported and disposed of at on shore treatment systems.

2. During the period beginning on the effective date and lasting through the expiration date, the permittee is authorized to discharge fish and other marine life sluiced with untreated seawater from travelling screens through outfall number 002.

a. A semi-annual monitoring program (representative of both under ice and open water conditions) shall be established in order to obtain an estimate of the mortality rate and abnormalties in behavior of various life stages of marine species returned through the outfall. The permittee shall submit details of a proposed monitoring program to the Environmental Protection Agency and the Alaska Department of Environmental Conservation within six months following permit issuance.

3. During the period beginning with the commencement of waterflood treatment plant operations and lasting through the expiration date of the permit, the permittee shall monitor the influent as specified below:

INFLUENT CHARACTERISTICS	MONITORING REQUIREMENTS	
	Measurement Frequency	Sample Type
Flow m^3/day(mgd)	Continuous	Recording
Total Suspended Solids (mg/1)	Weekly	24Hr Composite
Volatile Suspended Solids (mg/1)	Weekly	24Hr Composite
Temperature (^oC)	Continuous	Recording

Influent samples shall be taken at approximately the same time during the same day as effluent samples.

PRELIMINARY DRAFT

B. RECEIVING WATER MONITORING PROGRAM

1. Mixing Zone

An outfall diffuser system shall be utilized for the dispersal of the discharge into the Beaufort Sea. A mixing zone is provided below, the boundaries of which shall be monitored for determining compliance with the State of Alaska Water Quality Standards (18AAC 70.020).

a. The sides of the mixing zone shall be no more than 1,000 feet from the diffuser center line.

b. The ends of the mixing zone shall be no more than 1,000 feet from each end of the diffuser system.

2. Receiving Water Monitoring

The permittee shall implement the following receiving water and biological monitoring program. The emphasis of the program is on monitoring for subtle changes in water quality and sediment quality, sublethal responses of resident biota to waste water discharges, and to sample intensively at selected representative stations to provide a rigorous statistical basis for analysis of the data. The following program encompasses studies that are considered necessary to objectively evaluate existing environmental conditions and any chronic effects of proposed effluent discharges on water quality and biota.

This program shall be implemented no later than three (3) months following the effective date of this permit and will be reviewed semi-annually.

The permittee shall submit semi-annual and yearly progress reports on the studies to the Alaska Department of Environmental Conservation, Pouch O, Juneau, and the Environmental Protection Agency, Alaska Operations Office, and Director Enforcement Division. Semi-annual and annual reports shall be made available to other agencies upon request. The first semi-annual report shall be due on ____________ and semi-annually thereafter through ____________________. A final summary report, including all data and conclusions contained by that time, shall be submitted on ____________. This report shall include a synthesis of data and a discussion and interpretation of major findings and also principal investigator recommendations for further studies should any such studies be necessary.

a. Subtidal Benthos Monitoring Program

(1) Distribution, Abundance and Biomass Studies

The subtidal benthos infauna program shall consist of annual grab or diver sampling at each of the following stations: Station 5, 12, 33 and 48 of the Woodward Clyde grid and single additional stations at both the western boundary of the mixing zone and one adjacent to the diffuser. Eight replicate grabs per station shall be taken. Proposed methods for analysis of the data, including statistical treatments, shall be submitted to and approved by the Department of Environmental Conservation, Juneau, at least two (2) months prior to initiating the field program.

Temperature and salinity of the bottom water and percent organic (volatile solids) composition of sediments shall be monitored concurrently with this program.

A benthic epifauna sampling program shall also be initiated emphasizing the distribution and abundance of *Mysia relicta* and *Onisimus/Gammarus* at stations identical to the infauna program. Methods shall include the replicate drop-net sampling protocol employed under the OCSEAP program in Simpson Lagoon. Proposed sampling frequency and methods for analysis of the data, including statistical treatments, shall be submitted to and approved by the Department of Environmental Conservation, Juneau, at least two (2) months prior to initiating the field program.

(2) Biological Studies of Individual Species

Astarte borealis and *Ampharete vega* shall be individually monitored for purposes of detailing important biological events, including, but not limited to: a) seasonal and annual growth, b) reproductive biology (histological examination of reproductive stages) and c) mortality. Should population densities of these species be insufficient for monitoring purposes, *Liocyma fluctuosa* is recommended as an alternate species. Sampling intervals shall include at least the winter and summer seasons. Sampling data reduction and measuring methodology shall be consistent with techniques applied under the OCSEAP effort.

In addition to the study of selected biological events of individual species as described above, the permittee shall provide a measure of the overall biological condition of *Astarte borealis* and *Liocyma fluctuosa* using statistical methodologies consistent with published accounts on this index of health. These accounts generally specify the following ratios for calculating the index, either of which are acceptable in reporting results:

$$\frac{\text{Tissue dry weight (g)}}{\text{(shell length in mm)}} \times 100$$

(Reference: Stekoll, Clement and Shaw. 1978. Sublethal effects of chronic oil exposure on the intertidal clam *Macoma balthica*. University of Alaska. IMS)

or

$$\frac{\text{ash-free dry weight (g)}}{\text{(cm shell length)}^3} \times 1000$$

(Reference: Anderson, J.W. 1978. Condition index and free amino acid level of *Protothaca staminea* exposed to oil contaminated sediment. Battelle Northwest Laboratories, Sequim, Washington.)

Astarte and *Liocyma* shall be collected from the station along the western side boundary of the mixing zone (see a.1.). Establishment of suitable control site(s) away from this area to assess gradients in condition factor as a function of distance from the diffuser is a critical requirement of this study. Sampling frequency at all sites shall be at least semi-annually in conjunction with the elements in a.1. Temperature, salinity and percent organic composition of the sediment shall be monitored coincident with sampling.

b. Total Residual Chlorine and Ammonia

(1) Sediment concentrations of total resident chlorine and ammonia (NH_3-N) shall be monitored twice per year during summer and winter seasons at subtidal stations identified in a. above; and from a minimum of four (4) total sites located equidistant from one another around the perimeter of the mixing zone. A fifth sample shall be taken near the diffuser and inside the side boundaries of the defined mixing zone.

(2) Total residual chlorine and ammonia (NH_3-N) levels shall be monitored twice per year in the soft tissues of *Astarte borealis*, *Ampharete vega* and *Saduria entomon*. Sample sites shall include each of those stations listed in both a. and b. above. A sufficient number of

organisms shall be analyzed to provide a statistically defensible basis for comparing means.

(3) Total residual chlorine and ammonia concentrations shall be determined in bottom water samples collected at stations listed in a. and b(1) above concurrent with the taking of sediment and tissue samples.

c. Total Suspended and Volatile Solids Monitoring

Total suspended and volatile solids levels shall be determined at midwater depths at four (4) stations spaced equidistant from one another along the perimeter of the boundaries of the mixing zone. Sampling frequency shall be at least four times during the open water period and once during the winter period. Ambient concentrations shall be established from sites located sufficiently upcurrent or upwind of the defined mixing zone to be considered outside the zone of influence. Ambient samples shall be taken at the same time as samples from stations along the mixing zone perimeter.

3. Bioassay Monitoring

If appropriate methodology is developed which is mutually acceptable to EPA and ADEC in which to perform bioassay monitoring to determine acute toxicity levels of toxic pollutants from the expected effluent discharge, EPA may initiate a permit modification for review to establish a bioassay monitoring program to determine these levels.

C. MONITORING AND REPORTING

1. Representative Sampling

Samples and measurements taken as required shall be representative of the volume and nature of the monitored discharge. The permittee shall take samples and measurements to meet the monitoring requirements specified. Samples shall be taken in the effluent stream before its discharge to the receiving water, at the specific locations identified in Part A of this permit.

2. Reporting

Effluent and influent monitoring results shall be summarized each month on a Discharge Monitoring Report form (DMR: EPA No. 3320-1). These reports shall be submitted monthly and are to be postmarked by the fourteenth day of the following month. Signed copies of these, and all other reports herein, shall be submitted to the Director, Enforcement Division and the State agency at the following addresses:

1) United States Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

Attn: Water Compliance Section M/S 513

2) United States Environmental Protection Agency
Alaska Operations Office
701 C Street, Box 19
Anchorage, Alaska 99513

3) Alaska Department of Environmental Conservation
Northern Regional Office
Box 1601
Fairbanks, Alaska 99707

4) Alaska Department of Environmental Conservation
Pouch O
Juneau, Alaska 99811

3. Additional Monitoring by Permittee

If the permittee monitors any effluent parameter identified in this permit more frequently than required, the results of such monitoring shall be included in the DMR. Such increased frequency shall also be indicated.

4. Definitions

a. The "monthly average", other than for fecal coliform bacteria, is the arithmetic mean of samples collected during a calendar month. The monthly average for fecal coliform bacteria is the geometric mean of samples collected during a calendar month.

b. The "daily maximum" discharge means the maximum allowable discharge in any calendar day.

c. "Bypass" means the intentional diversion of wastes from any portion of a treatment facility.

d. "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.

e. "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, lack of preventive maintenance, or careless or improper operation.

f. mgd = million gallons per day

g. m^3/day = cubic meters per day

h. mg/l = milligrams per liter

i. ml/l = milliliters per liter

5. Test Procedures

Test procedures for the analysis of pollutants shall conform to 40 C.F.R. Part 136, which contains a list of approved methods.

6. Recording of Results

For each measurement or sample taken pursuant to the requirements of this permit, the permittee shall record the following information:

a. the exact place, date, and time of sampling and measurements;

b. the dates the analyses were performed;

c. the person(s) who performed the analyses, sampling or measurements;

d. the analytical techniques or methods used; and

e. the results of all required analyses.

7. Records Retention

All records and information resulting from the monitoring activities required by this permit including all records of analyses performed, calibration and maintenance of instrumentation, and recordings from continuous monitoring instrumentation shall be retained for a minimum of three (3) years, or longer if requested by the Director, Enforcement Division or the State water pollution control agency.

8. Noncompliance Reporting

a. Noncompliance notification will be made when any of the following situations occur:

(i) Bypassing of any treatment facilities (Part C.5., below).

(ii) Facility upset (Part D.6., below).

(iii) Failure of facility (Part D.7., below).

(iv) Other instances not covered by above.

b. Noncompliance notification shall consist of at least the following:

(i) A description of the discharge and cause of noncompliance;

(ii) the period of noncompliance to include exact dates and times and/or the anticipated time when the discharge will again be in compliance; and

(iii) steps being taken to reduce, eliminate and prevent recurrence of the noncomplying discharge.

c. Timing of report shall be consistent with the following:

(i) Permittee shall report telephonically within 24-hours from the time of becoming aware of any violation of a daily maximum. A written submission shall be provided within five (5) days of becoming aware of the noncompliance.

(ii) Permittee shall provide a written report of any violations of the monthly average. This report shall conform to a. and b. above and be submitted concurrently with the Discharge Monitoring Report as a separate report.

D. GENERAL REQUIREMENTS

1. Reopener Clause

If any applicable toxic effluent standard or prohibition (including any schedule of compliance specified in such effluent standard or prohibition) is established under section 307(a) of the Act for a toxic pollutant and that standard or prohibition is more stringent than any limitation upon such pollutant in the permit, the Director shall institute proceedings under these regulations to modify or revoke and reissue the permit to conform to the toxic effluent standard or prohibition.

2. Modification

The permit may be modified, terminated, or revoked during its term for cause as described in 40 C.F.R 122.31.

Any permittee who knows or has reason to believe that any activity has occurred or will occur which would constitute cause for modification or revocation and reissuance under 40 C.F.R. 122.31 must report its plans, or such information to the Director.

3. Right of Entry

The permittee shall allow the Director or an authorized representative, upon the presentation of credentials and such other documents as may be required by law,

a. to enter upon the permittee's premises where a point source is located or where any records must be kept under the terms and conditions of the permit;

b. to have access to and copy at reasonable times any records that must be kept under the terms and conditions of the permit;

c. to inspect at reasonable times any monitoring equipment or method required in the permit;

d. to inspect at reasonable times any collection, treatment, pollution management, or discharge facilities required under the permit; and

e. to sample at reasonable times any discharge of pollutants.

4. Operation and Maintenance

The permittee shall at all times maintain in good working order and operate as efficiently as possible all facilities and systems (and related appurtenances) for collection and treatment which are installed or used by the permittee for water pollution control and abatement to achieve compliance with the terms and conditions of the permit. Proper operation and maintenance includes but is not limited to effective performance based on designed facility removals, adequate funding, effective management, adequate operator staffing and training, and adequate laboratory and process controls including appropriate quality assurance procedures.

5. Bypass

a. Bypass is prohibited unless all of the following four (4) conditions are met:

(i) Bypass is unavoidable to prevent loss of life, personal injury or severe property damage;

(ii) there are no feasible alternatives to bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment down-time;

(iii) permittee makes notification in accordance with Part C.8.b. and c.; and

(iv) where the permittee knows in advance of the need for a bypass, prior notification shall be submitted for approval to the Director, if possible at least 10 days in advance. The bypass may be allowed under conditions determined to be necessary by the Director to minimize any adverse effects. The public shall be notified and given an opportunity to comment on bypass incidents of significant duration, to the extent feasible.

b. Prohibition of Bypass

The Director may prohibit bypass in consideration of the adverse effect of the proposed bypass or where the proposed bypass does not meet the conditions set forth in Part D.5.a., above.

6. Upsets

a. Effect of an Upset

An upset shall constitute an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limitations if the requirements of paragraph b. below are met.

b. Conditions Necessary for a Demonstration of Upset

The permittee who wishes to establish the affirmative defense of upset shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

(i) An upset occurred and that the permittee can identify the specific cause(s) of the upset;

(ii) the permitted facility was at the time being operated in a prudent and workman-like manner and in compliance with proper operation and maintenance procedures;

(iii) the permittee submitted information required in Part C.8.b. and c.

c. Burden of Proof

In any enforcement proceeding the permittee seeking to establish the occurrence of an upset shall have the burden of proof.

7. Failure of the Facility

The permittee, in order to maintain compliance with its permit, shall control production and all discharges upon reduction, loss, or failure of the treatment facility until the facility is restored or an alternative method of treatment is provided. This requirement applies in the situation where, among other things, the primary source of power of the treatment facility is reduced, lost, or fails.

The permittee shall report such instances in accordance with Part C.8.b. and c. above.

8. Adverse Impact

The permittee shall take all reasonable steps to minimize any adverse impact to waters of the United States resulting from noncompliance with the permit.

9. Removed Substances

Collected screenings, grit, sludges, and other solids removed in the course of treatment or control of wastewaters shall be disposed of in a manner such as to prevent entry of those wastes or runoff from such materials into navigable waters unless otherwise authorized in this permit.

10. Transferability of Permits

This permit may be transferred to another person by the permittee if:

a. The permittee notifies the Director of the proposed transfer;

b. a written agreement containing a specific date for transfer of permit responsibility and coverage between the current and new permittees (including acknowledgement that the existing permittee is liable for violations up to that date, and that the new permittee is liable for violations from that date on) is submitted to the Director; and

c. the Director within 30 days does not notify the current permittee and the new permittee of his or her intent to modify, revoke and reissue, or terminate the permit and to require that a new application be filed rather than agreeing to the transfer of the permit.

PRELIMINARY DRAFT

E. RESPONSIBILITIES

1. Availability of Reports

Except for data determined to be confidential under section 308 of the Act, all reports prepared in accordance with the terms of this permit shall be available for public inspection at the offices of the State water pollution control agency and the Director, Enforcement Division. As required by the Act, effluent data shall not be considered confidential. Knowingly making a false statement on any such report may result in the imposition of criminal penalties as provided for in section 309 of the Act.

2. Civil and Criminal Liability

Except as provided in permit conditions on "Bypass" (Part D.5.) and "Upset" (Part D.6.) and "Failure of Facility" (Part D. 7.), nothing in this permit shall be construed to relieve the permittee from civil or criminal penalties for noncompliance.

3. Oil and Hazardous Substance Liability

Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties to which the permittee is or may be subject under section 311 of the Act.

4. State Laws

Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties established pursuant to any applicable State law or regulation under authority preserved by section 510 of the Act.

5. Property Rights

The issuance of this permit does not convey any property rights in either real or personal property, or any exclusive privileges, nor does it authorize any injury to private property or any invasion of personal rights, nor any infringement of Federal, State or local laws or regulations.

6. Severability

The provisions of this permit are severable, and if any provision of this permit, or the application of any provision of this permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of this permit shall not be affected thereby.

APPENDIX P

PREVENTION OF SIGNIFICANT DETERIORATION (PSD) OF AIR QUALITY

The Federal Clean Air Act requires review and approval of the construction or modification of major sources of air pollution to assure that the air quality in areas attaining National Ambient Air Quality Standards is not deteriorated beyond allowable limits for all pollutants regulated by EPA as a result of increased emissions from such new or modified facilities. Before an application to construct a major stationary source can be approved, it must be demonstrated that the expected emissions of all applicable pollutants above the minimum level established by the Clean Air Act will not exceed the following:

1. Emission limits achievable by the application of best available control technology (BACT).

2. National Ambient Air Quality Standards (NAAQS).

3. In the case of particulate matter and sulfur dioxide, allowable air quality increments.

Prior to making a final determination on the application EPA is required to release for public review its preliminary determination of approvability. EPA has conducted a technical analysis of the application and has made a preliminary determination on the project. These two documents, together with the information submitted by the applicant are available for public inspection at the following locations:

EPA, Region 10
Regional Library, 11th Floor
1200 Sixth Avenue
Seattle, Washington 98101

EPA, Alaska Operations Office
701 C Street
Federal Building, Room E535
Anchorage, Alaska 99513

Alaska Department of Environmental Conservation
3220 Hospital Drive
Pouch O
Juneau, Alaska 99811

Fairbanks North Star Borough Regional Library
1215 Cowles
Fairbanks, Alaska 99701

Z-J Loussac Library
427 F Street
Anchorage, Alaska 99501

Interested persons are invited to submit for EPA's consideration written comments concerning the proposed project approval. To be most effective, comments should address air quality considerations and include support materials where available.

Comments should be submitted to the Regional Administrator, EPA, Region 10, 1200 Sixth Avenue, Seattle, Washington 98101, Attention: Mr. Michael Johnston, M/S 521; or presented at the public hearing. This public hearing will be held in conjunction with the Corps of Engineers' public hearing at Barrow, Alaska.