Assessment of the Subsurface Hydrology of the UIC-NARL Main Camp, Near Barrow, Alaska, 1993-94

By Kathleen A. McCarthy and Gary L. Solin

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
hectare (ha)	2.471	acre
degree Celsius (°C)	°F = 1.8 x °C + 32	degree Fahrenheit (°F)

Mean sea level:

In this report, mean sea level refers to a tidal datum midway between the arithmetic means of the high-water heights and low-water heights for the Point Barrow tidal station. This is also called mean tide level. Mean sea level is 0.076 m above mean lower low water.

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Abstract

Imikpuk Lake serves as the drinking-water source for the Ukpeagvik Inupiat Corporation-National Arctic Research Laboratory (UIC-NARL, formerly known as the Naval Arctic Research Laboratory) near Barrow, Alaska. Previously acceptable hazardous-waste disposal practices and accidental releases of various fuels and solvents during the past several decades have resulted in contamination of soil and ground water in the vicinity of the lake. As part of an assessment of the risk that subsurface contamination poses to the quality of water in the lake, the subsurface hydrology of the UIC-NARL main camp was examined. The study area is located approximately 530 kilometers north of the Arctic Circle, on the northern coast of Alaska, and the short annual thaw season and the presence of shallow, areally continuous permafrost restrict hydrologic processes. A transient ground-water system is present within the active layer—the shallow subsurface layer that thaws each summer and refreezes each winter. Water-level and thaw-depth data collected during the summers of 1993 and 1994 show that the configurations of both the water table and the subsurface frost govern the ground-water flow system in the UIC-NARL main camp and indicate that recharge to and discharge from the system are small. Spatial irregularities in the vertical extent of the active layer result from variations in land-surface elevation, variations in soil type, and the presence of buildings and other structures that either act as a heat source or block heat transfer to and from the subsurface. Distinct features in the active-layer hydrologic system in the UIC-NARL main camp include a permafrost ridge, which generally acts as a flow-system divide between the Arctic Ocean and inland water bodies; a mound in the water table, which indicates increased impedance to ground-water flow toward Imikpuk Lake and acts as a flow-system divide between the lake and Middle Salt Lagoon; and a depression in the water table, which suggests a local breach in the permafrost ridge that allows some ground water to flow directly from the main camp to the Arctic Ocean. Similar thaw depths and water-table elevations were measured during the summers of 1993 and 1994, and little change occurred in the thickness of the ground-water zone between mid- and late-thaw-season measurements. These data suggest that the system is in a state of quasi-equilibrium and that ground-water discharge is small. The observed drop in the water table as the active layer develops over the summer is probably largely the result of evapotranspiration losses rather than system outflow.

INTRODUCTION

The main camp of the Ukpeagvik Inupiat Corporation-National Arctic Research Laboratory (UIC-NARL; formerly known as the Naval Arctic Research Laboratory), is located approximately 6 km northeast of Barrow and 10 km southwest of Point Barrow, Alaska (fig. 1). The camp covers approximately 30 ha and is bordered on the northeast by Imikpuk Lake (fig. 1). The lake serves as the source of potable water for the UIC-NARL facility, which includes a water-treatment and distillation facility that sells bottled water to the public.

During the past several decades, waste-disposal practices and accidental releases of various fuels and solvents have resulted in soil and ground-water contamination in the vicinity of the camp (Naval Energy and Environmental Support Activity, 1983; DOWL Engineers and Crowley Environmental Services, Inc., 1986; Science Applications International Corporation, 1987, 1989, 1990). Because of the proximity of the camp to Imikpuk Lake, sources of contamination within the camp are a potential risk to the water quality of the lake. Alternative sources of potable water in the Barrow area are either (1) frozen throughout most of the year, (2) insufficient in volume, (3) of poor quality, or (4) too costly to develop and distribute because of the arctic climate and tundra terrain (McCarthy, 1994). Therefore, preserving the quality of water in Imikpuk Lake is of particular concern.

Purpose and Scope

The objective of this report is to provide an assessment of the subsurface hydrology of the UIC-NARL main camp in order to enhance understanding of the potential impact of subsurface contamination on Imikpuk Lake. An overview of Imikpuk basin hydrology is addressed in an earlier report on the nearby airstrip site (McCarthy and others, 1994).

Previous Investigations

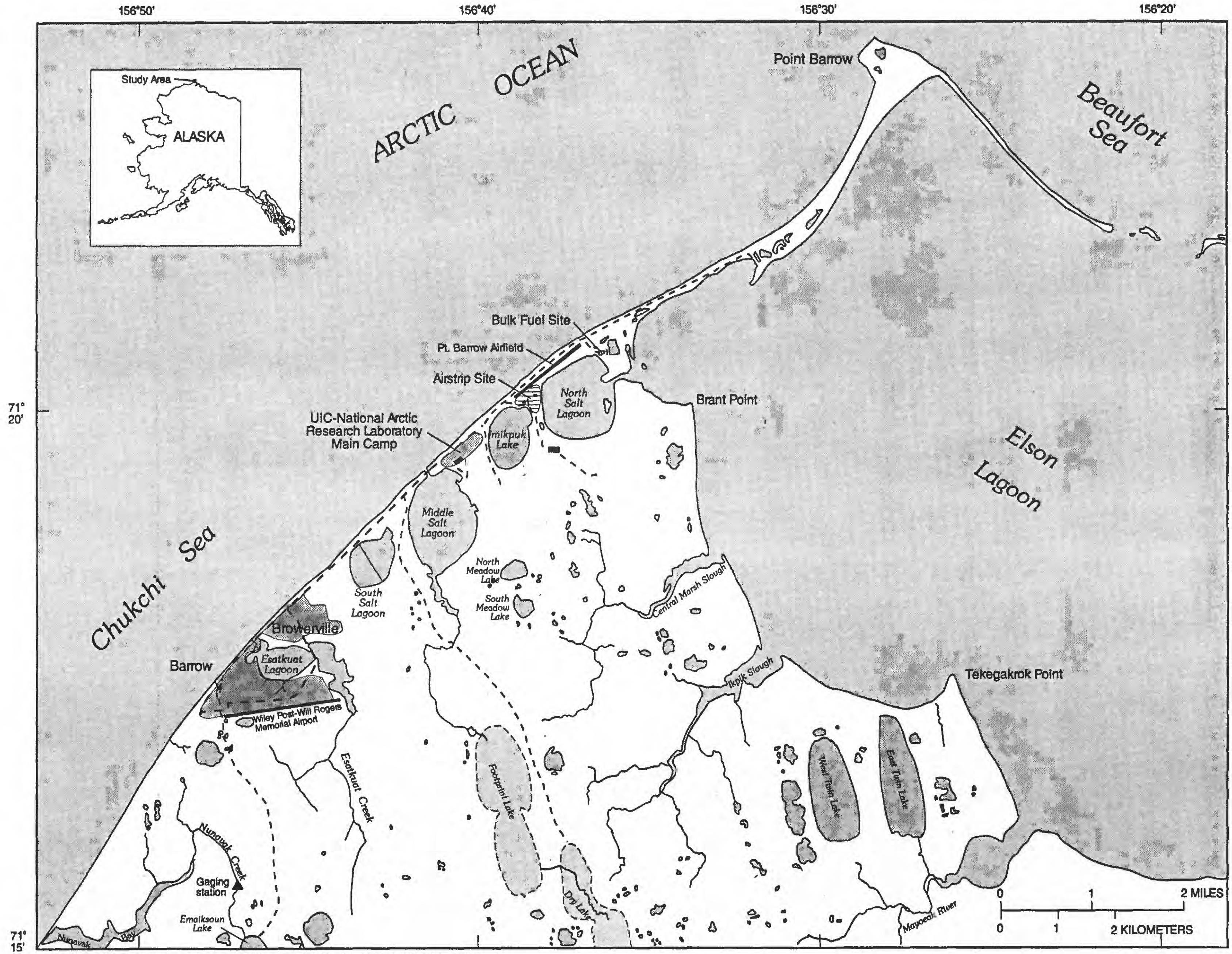
In the early 1980's, the U.S. Navy conducted an overall assessment of the UIC-NARL installation (Naval Energy and Environmental Support Activity, 1983). Areas of environmental concern identified in this initial assessment included the sites of the former dry-cleaning and power-house facilities, which are both located within the main camp (fig. 2). A number of investigations have since been conducted in an effort to characterize soil and ground-water contamination at these sites (Science Applications International Corporation, 1987, 1989, 1990; URS Consultants, Inc., and Shannon & Wilson, Inc., 1991a, 1991b, 1994).

SITE DESCRIPTION

The UIC-NARL main camp is located on the northernmost extremity of the Arctic Coastal Plain of Alaska (fig. 1), approximately 530 km north of the Arctic Circle. Freeze-thaw cycles and the presence of areally continuous permafrost, which extends from near the surface to depths of up to 300 m (Collins, 1961), govern hydrologic processes in the study area.

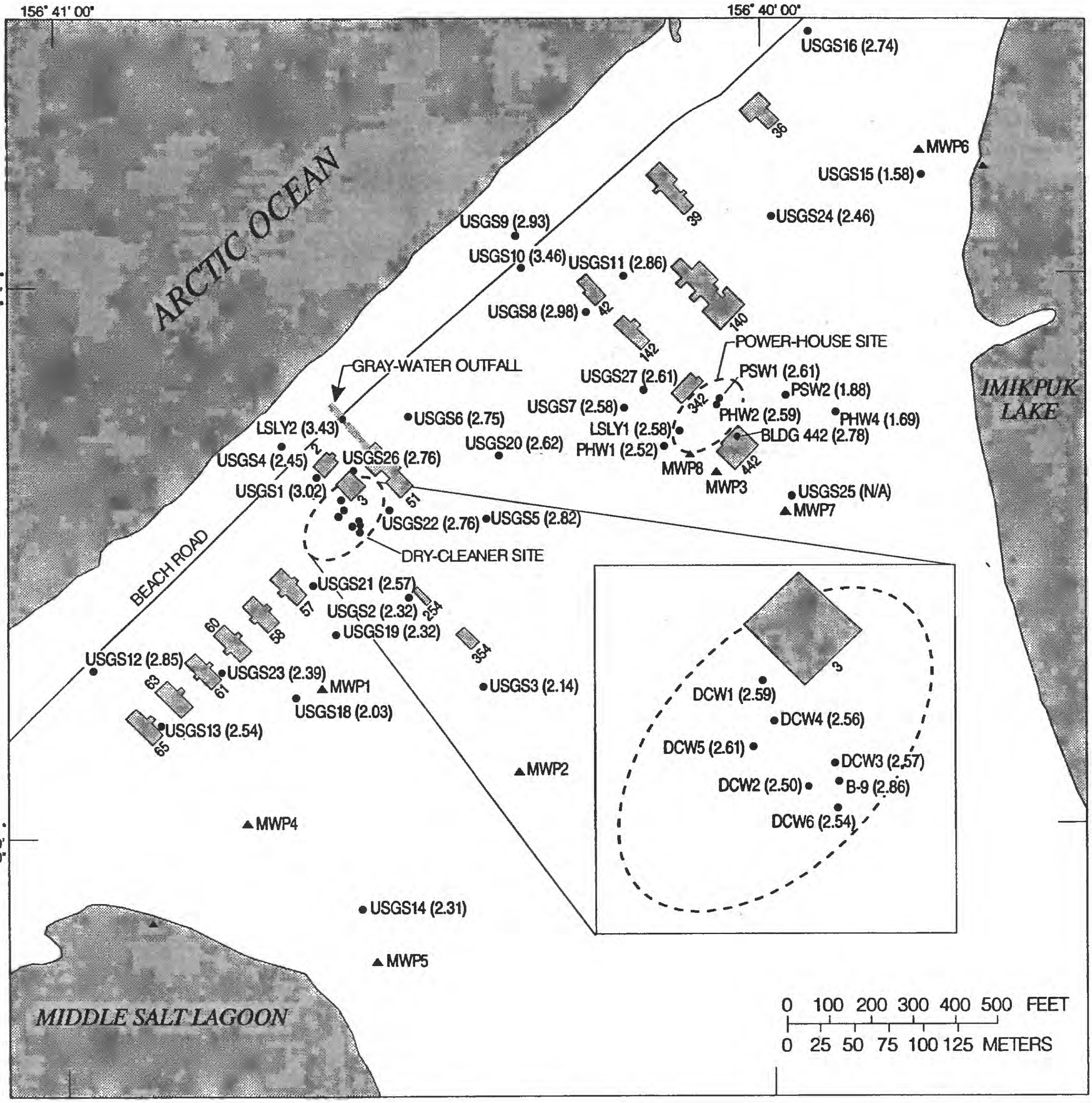
Development of the UIC-NARL facility began in 1944 (Reed, 1958). Most structures were built directly on the coarse sands and gravels of the Arctic Ocean beach, but as development continued inland toward the southeast, parts of the camp expanded onto beach-gravel fill placed over tundra soils. These finer grained tundra soils occur primarily near the shores of Imikpuk Lake and Middle Salt Lagoon and along the southeast border of the camp. There is little vegetation in the camp and land-surface features consist chiefly of buildings, gravel roadways, and areas of bare gravel.

The total topographic relief of the camp area is approximately 2 m. The road nearest the ocean (referred to as "the beach road") is built along a beach ridge that parallels the coastline of the Arctic Ocean. In some places, particularly in the main camp area, the beach ridge was built up during road construction to help prevent flooding of inland areas by tidal (storm) surges. The land surface slopes away from this road toward the ocean to the northwest and into the camp to the southeast (fig. 2).



Base from U.S.Geological Survey, Barrow (B-4), Alaska, 1:63,360, 1955

Figure 1. Location of study area near Barrow, Alaska.



EXPLANATION

• USGS14 (2.31)	Ground-water and (or) thaw-depth data-collection site (Land-surface elevation, in meters; "N/A" indicates no data available)
▲ MWP5	Surface-water data-collection site (Land-surface elevations are not applicable to surface-water sites)
354	Building

Figure 2. Data-collection sites, selected buildings, and land-surface elevations in the UIC-NARL main-camp area.

DATA COLLECTION

Data on ground water, thaw depth, surface water, and snowpack were collected throughout the Imikpuk Lake basin and surrounding areas during 1993 and 1994. This report focuses on the subsurface hydrology of the UIC-NARL main camp; surface-water and snowpack data are addressed in a previous report covering the nearby airstrip site (McCarthy and others, 1994).

Data-Collection Sites

Because of the considerable depth to which permafrost extends in the study area, only the suprapermafrost ground-water system, which thaws each summer and refreezes each winter, is relevant to local contaminant transport. Data collection was therefore limited to this shallow system, commonly referred to as the "active layer." The locations of all data-collections sites are shown in figure 2.

Existing wells.—Seven wells at the dry-cleaner site and five wells at the power-house site that remained from earlier investigations were used in this study (fig. 2). Wells labelled "PHW" and "DCW" were installed by Science Applications International Corporation (1989). Wells labelled "PSW" and well "B-9" were installed by URS Consultants, Inc., and Shannon & Wilson, Inc. (1991a,b, respectively).

Newly installed wells.—To expand the network of existing wells, 25 new wells were installed as part of the current study (fig. 2). These wells—labelled "USGS"—were constructed solely for short-term collection of water-level data. The holes were dug to the top of the subsurface frost using an 8-cm manual auger. Where caving soil was found, either PVC (polyvinyl chloride) casing or temporary drive points were installed to allow water-level measurements. The bottoms of the casings and drive points were installed as closely as possible to the frost surface, usually within 3 cm. The open interval of the wells—either hand-slotted casing or 0.25-mm slotted screen—extended from approximately 6 cm above the frost surface to 36 cm above the frost surface. Two additional holes—labelled "LSLY"—were excavated by UIC Construction, Inc. in August 1994, as part of an effort to locate a buried pipeline.

Additional subsurface flow-system data were collected at the airstrip site, along the northeast shore of Imikpuk Lake (McCarthy and others, 1994); at the bulk-fuel storage site, along the northeast shore of North Salt Lagoon; and in the undeveloped tundra area southeast of the camp, between Imikpuk Lake and Middle Salt Lagoon (fig. 1). These data provided further understanding of the subsurface flow system in the camp area and throughout the Imikpuk Lake basin.

Data-Collection Methods

Water-level measurements.—In wells with casings, after an initial depth to static ground-water level was measured, the well was pumped using a manual peristaltic pump, and the response of the water level was monitored to assure that the well was hydraulically connected to the surrounding ground-water system. In newly installed wells, measurements were made several times over a period of a week to assure that water levels had reached equilibrium. The water surface exposed during excavation at site LSLY1 was allowed to equilibrate overnight and then surveyed prior to backfilling of the hole. To assess changes in the subsurface flow system that occur as thawing progresses over the summer, water levels were measured twice during the summer of 1993—first in mid-July, and again in late August and early September.

Thaw-depth measurements.—The vertical extent of the ground-water zone at each well was determined by measuring the depth of thaw either by augering to the top of the frost with an 8-cm manual auger, or by driving a metal probe into the ground to the depth of refusal. The depth of refusal was assumed to be the surface of the frost. At several sites, thaw depth was measured using both methods and agreement between the methods was good (± 5 cm). The depths to frost were measured twice during the summer of 1993—first in mid July, and again in late August and early September.

Surveying

In July 1993, all data-collection sites were surveyed, including the water surfaces of Imikpuk Lake, Middle Salt Lagoon, the Arctic Ocean, and several small ponds. The elevation of the reference measuring point at each site was determined using trigonometric and differential field leveling. Elevations were referenced to a monument (Lounsbury and Associates, written commun., 1981) based on mean sea level for the Point Barrow tidal station. Sites were surveyed again during early September 1993 and August 1994 to determine whether measuring points had shifted vertically as a result of the freeze-thaw cycle. The largest change in the elevation of a measuring point over the course of the study was approximately 3 cm; no change was noted at most sites, however. The land-surface elevations at each well are shown in figure 2.

ANNUAL HYDROLOGIC CYCLE OF THE IMIKPUK LAKE AREA

The arctic climate and the presence of near-surface, areally continuous permafrost govern the hydrology of the Arctic Coastal Plain. The annual pattern of mean air temperature in the area (table 1) results in an annual hydrologic cycle that can be described in terms of four periods: winter, snowmelt, summer, and freeze-up. These periods are briefly outlined in the following sections. More comprehensive discussions of the distinct hydrologic processes that characterize these periods is provided by Brown and others (1968), Dingman and others (1980), Kane and Stein (1983), Sloan and van Everdingen (1988), Kane and Chacho (1990), and McCarthy and others (1994).

Table 1. Mean monthly and mean annual temperature at Barrow, Alaska, for the period 1949-87
[Data from Leslie (1989); values in degrees Celsius]

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
-25.4	-28.4	-26.3	-19.0	-7.3	0.9	3.9	3.3	-0.8	-9.7	-18.2	-24.3	-12.6

Winter.—The winter season in the study area typically begins during late September and continues through early to mid-June. Subfreezing temperatures prevail throughout this period (table 1) and, as a result, streamflow does not occur, freshwater lakes less than approximately 2 m in depth freeze to the bottom, and the subsurface is frozen from land surface to depths of up to 300 m (Collins, 1961).

Snowmelt Period.—The snowmelt period, which marks the transition from winter to summer in the Arctic, is the dominant hydrologic event of the year. In the Imikpuk basin, the brief thaw season generally begins during early to mid-June and most snowmelt occurs within approximately two weeks. Surface runoff is considerable during the snowmelt period, but recharge to the ground-water system is limited by incomplete thawing of the subsurface active layer.

Summer.—The brief summer in the Imikpuk Lake basin begins at the end of the snowmelt period (usually during mid- to late June) and typically extends through late August or early September. Thawing of the subsurface active layer, which begins during the snowmelt period, continues throughout the summer. However, the rate of thaw generally decreases considerably over the course of the season. Brown and others (1968) found that thaw penetration in a small basin near Imikpuk Lake usually reached 75 percent of its maximum by early July and that increases in thaw depth after mid-August were negligible. Thaw depths measured during the current study were generally consistent with these findings.

Freeze-Up Period.—The transition from summer to winter commonly begins during late August or September when temperatures drop below freezing and the ground surface cools and freezes. Precipitation during this period is considerable (table 2) and tends to saturate the soil. Freezing gradually progresses downward through the active layer and as soil moisture freezes, moisture from the warmer underlying soil migrates upward in response to thermodynamic instability at the freezing front. This vertical redistribution of soil moisture increases the moisture content in the vicinity of the freezing front and reduces the moisture content in underlying soil. Because this process progresses gradually, some remnant of the active layer persists at depth long after the surface freezes.

Table 2. Mean monthly precipitation data for Barrow, Alaska, adjusted for gage efficiency (McCarthy, 1994)

Month	Mean total precipitation (millimeters)[a]	Mean precipitation adjusted for gage efficiency		
		Rain (millimeters)[b]	Snow (water equivalent, millimeters)[c]	Total (millimeters)
January	5.1	0.0	15.2	15.2
February	4.6	0.0	13.7	13.7
March	3.8	0.0	11.4	11.4
April	5.1	0.0	15.2	15.2
May	4.1	0.0	12.2	12.2
June	9.1	5.0	13.7	18.7
July	22.1	24.3	0.0	24.3
August	24.6	27.1	0.0	27.1
September	16.3	8.9	24.4	33.3
October	13.0	0.0	38.9	38.9
November	6.9	0.0	20.6	20.6
December	4.3	0.0	13.0	13.0
ANNUAL TOTAL	119	65	178	244

[a] Mean total precipitation for the period 1949-87 (Leslie, 1989).

[b] Mean rainfall, adjusted by a factor of 1.1 for gage efficiency. Precipitation occurring from mid-June through mid-September was assumed to be rain (McCarthy, 1994).

[c] Mean water equivalent of snow, adjusted by a factor of 3 for gage efficiency. Precipitation occurring from mid-September through mid-June was assumed to be snow (McCarthy, 1994).

SHALLOW SUBSURFACE HYDROLOGY OF THE UIC-NARL MAIN CAMP

The areally continuous permafrost that underlies the active layer is a highly effective hydrologic confining layer and therefore defines the lower extent of the shallow ground-water system. Because the seasonal thaw generally extends less than 2 m deep in the study area, this confining layer is at shallow depth and its surface configuration can have a considerable influence on the magnitude and direction of ground-water flow. The flux of water through the shallow ground-water system is small relative to fluxes typical of temperate-zone systems because of the short duration of the thaw season and the limited thickness of the active layer. The shallow, vertically extensive confining layer also constrains the recharge area for the active-layer system to a local scale and therefore restricts inflow to the system.

Seasonal Subsurface Thaw

The depth of the seasonal subsurface thaw determines the vertical extent of the active-layer ground-water system. In addition to spatial variability in the maximum thaw penetration, differences in the rate at which thaw progresses cause changes in the system as the active layer develops throughout the summer. Factors that can affect the thaw in the UIC-NARL main camp include soil type; vegetation; the presence of buildings, other structures, lakes, and snow cover; and the chemical composition of ground water.

Soil type.—Most of the camp is underlain by coarse-grained mineral soils in which the depth of subsurface thaw ranged from approximately 1.0 to 1.5 m in both August 1993 and August 1994 (table 3). In contrast, the depth of thaw was considerably less at sites MWP2 and USGS25 (table 3), which are underlain by fine-grained, organic-rich soils characteristic of the undisturbed tundra in the area. These fine-grained soils generally have a much greater capacity to hold capillary water than coarse-grained soils. As a result, when the thaw season begins, these soils typically contain a much greater mass of ice per unit volume than coarser grained soils. The considerable energy that is consumed in the phase conversion from ice to water restricts thaw penetration in these soils. Once the ice is thawed, evaporation from these wetter soils consumes further energy and cools the surface, further inhibiting thaw penetration. In addition, organic material has a lower thermal conductivity than mineral material and the organic component of the fine-grained soils therefore tends to insulate underlying permafrost, resulting in shallower thaw penetration. Counteracting these effects is the fact that the thermal conductivity of soils increases with increasing moisture content. Once the ice is thawed, therefore, heat is transferred more efficiently in soils with a high moisture content. The data in table 3 indicate, however, that the effects of this latter mechanism are overshadowed by other factors governing thaw penetration in the study area.

Vegetation.—The presence of vegetation on the land surface helps to insulate underlying soil because of the low thermal conductivity of organic material. In the UIC-NARL camp area, sand and gravel soils are generally bare, and vegetation grows primarily on the tundra outside of the developed camp. Sites MWP2 and USGS25 are located in such areas of vegetation and the shallow thaw depths measured at these sites (table 3) can be attributed partially to the insulating effects of this vegetation.

Table 3. Depth of subsurface thaw
[Values in meters below land surface; --, no data available]

Site I.D.	1993		1994		Site I.D.	1993		1994	
	July	August	June	August		July	August	June	August
Bldg. 442	--	--	--	0.5	USGS7	0.9	1.2	0.4	1.2
DCW1	1.2	1.5	--	--	USGS8	0.9	1.2	--	1.2
DCW2	--	1.3	0.4	--	USGS9	0.9	1.0	--	--
DCW3	1.0	1.3	--	--	USGS10	1.2	1.3	--	--
DCW4	1.0		--	--	USGS11	1.2	1.4	0.6	1.3
DCW5	--	1.5	--	--	USGS12	1.0	1.3	--	--
DCW6	0.9	1.1			USGS13	0.8	1.1	0.4	--
LSLY2	--	--	--	>2.3	USGS14	1.0	1.3	0.5	--
MWP2	-	0.5	--	--	USGS15	0.5	1.0	--	--
PHW1	1.0	1.3	0.3	--	USGS16	1.1	1.3	--	--
PHW2	0.9	1.0	--	0.9	USGS18	--	0.9	0.5	--
PHW4	1.1	1.4	--	>1.2	USGS19	--	1.3	--	--
PSW1	--	1.4	--	--	USGS20	--	1.2	--	1.1
PSW2	1.1	1.3	--	--	USGS21	--	1.4	0.2	--
USGS1	1.1	1.2	0.5	1.2	USGS22	--	1.4	0.5	1.3
USGS2	0.9	1.0	--	--	USGS23	--	1.2	0.3	--
USGS3	1.1	1.3	0.5	--	USGS24	--	1.2	0.6	1.1
USGS4	1.0	--	0.5	--	USGS25	--	0.4	--	0.4
USGS5	1.3	1.5	--	--	USGS26	--	1.5	--	--
USGS6	1.2	1.2	--	--	USGS27	--	--	--	1.3

Surface features.—Beneath heated buildings that are not insulated from the land surface and beneath lakes that are more than approximately 2 m in depth, a zone of permanently thawed ground is commonly present. Such zones, referred to as "thaw bulbs" or "thermal taliks," may extend to considerable depths. For example, Brewer (1958) reported measurable warming of the permafrost at a depth of 15 m beneath a 12-by-30 m building in the Barrow area. Beneath Imikpuk Lake, which is approximately 3 m deep and 750 m in diameter, thermal data indicate that the depth to permafrost is more than 50 m (Brewer, 1958).

Unheated structures or heated buildings that are raised above the land surface on pilings reduce heat flux to the subsurface by blocking radiant energy from the sun and obstructing atmospheric convection of heat. This reduces the thaw penetration and can result in local mounds in the permafrost table. Such mounds reduce the area available for ground-water flow, which locally alters the magnitude of ground-water flux. In some cases, mounds in the permafrost can extend above the surrounding water table, creating barriers in the flow system and altering ground-water flow directions. Building 442 (fig. 2) is constructed above the land surface on pilings in order to isolate the underlying permafrost from the heated building interior. The shallow depth of thaw measured beneath the building (table 3) shows the effects of the reduced heat transfer in the building's shadow.

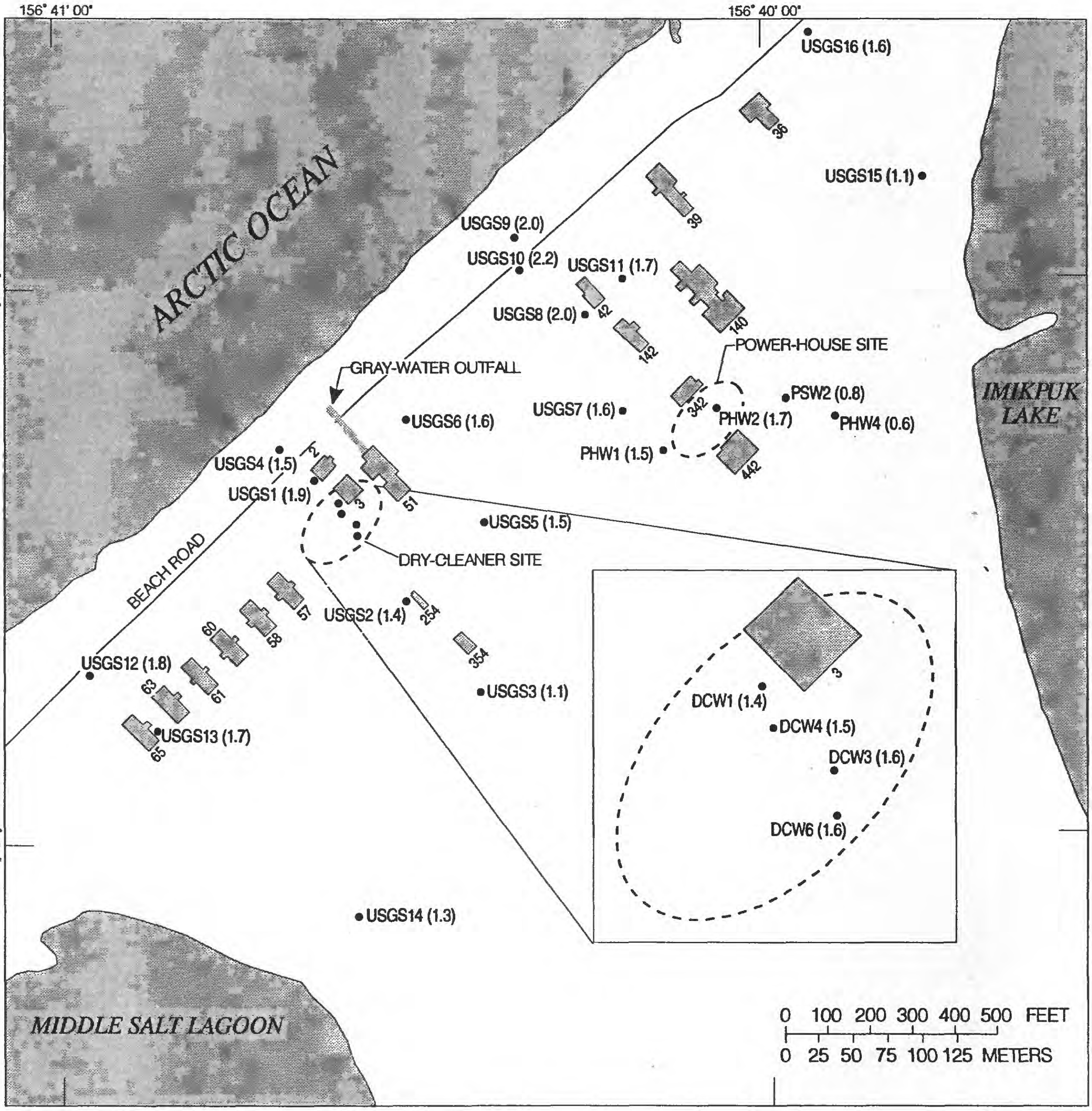
The effects of snow cover on the depth of thaw in underlying soil are analogous to those of unheated or well-insulated surface structures. Where the snow depth is considerable, due either to drifting or snow-removal and dumping activities, heat flux to and from the subsurface is blocked. In such locations, thawing of the active layer is delayed until the snow is melted, and the maximum thaw penetration is thus reduced. Conversely, the insulating effects of the snow cover are absent in locations that remain free of snow. Such locations include roadways and other areas from which snow is mechanically removed, and areas that are even slightly elevated relative to the surrounding terrain, which tend to remain snow free due to wind action.

Chemical composition of ground water.—The presence of solutes, such as salts, depress the freezing point of water. Saline ground water, which is common in the Barrow area, can therefore cause thawed zones in the permafrost, sometimes referred to as "chemical taliks." Where the salinity of the bulk ground water is insufficient to form chemical taliks, the concentration of solutes that occurs during freezing of the soil water can produce solute concentrations that are high enough to form taliks. The presence of liquid hydrocarbons in the subsurface can also affect subsurface freezing. Although the solubilities of most fuels and solvents are too low to depress the freezing point of water significantly, the presence of pure-phase hydrocarbons in soil pores in place of water—even at residual saturation—can cause chemical taliks.

Ground-Water Flow System

Local irregularities in the depth of thaw are ubiquitous in permafrost regions, especially in developed areas such as the UIC-NARL main camp. The effects of this considerable spatial variability are exaggerated by the limited vertical extent of the active layer, resulting in complex ground-water systems. Distinct flow regimes typically occur in these systems at scales ranging from meters to tens of meters rather than at more extensive, kilometer scales typical of temperate-zone systems. Within the UIC-NARL main camp, distinct features in the active-layer hydrologic system include a permafrost ridge beneath the beach road, a mound in the water table in the vicinity of the power-house site, and a depression in the water table beneath the dry-cleaner site.

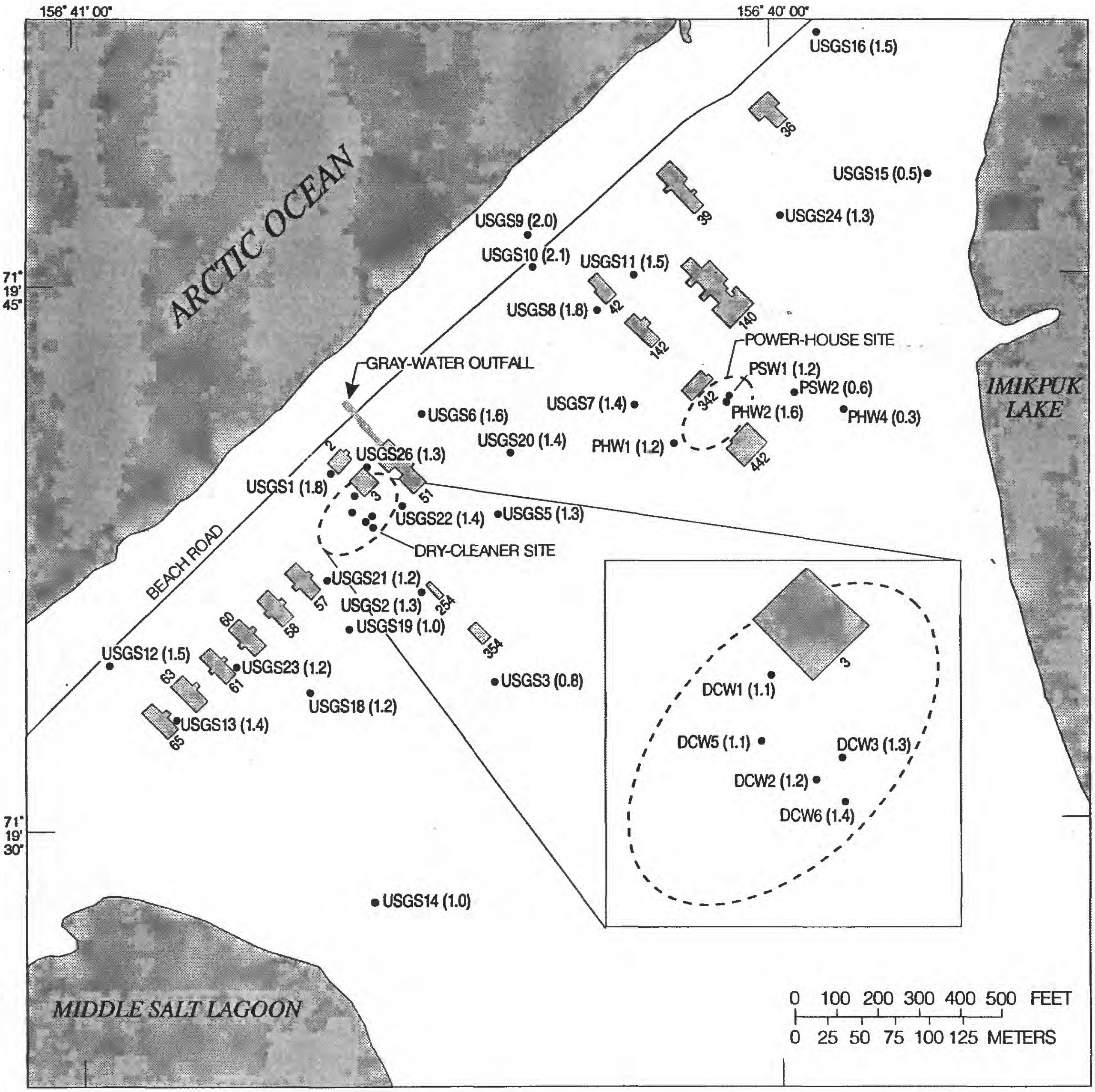
The elevation of the subsurface frost measured in the UIC-NARL main camp in both July and August 1993 (figs. 3 and 4) indicates that the land-surface ridge along the beach road is mimicked in the underlying frost surface. The configuration of the water table (figs. 5 and 6) indicates that this ridge in the permafrost acts as a barrier to lateral ground-water flow and that water northwest of the road flows toward the Arctic Ocean and water southeast of the road generally flows toward either Imikpuk Lake or Middle Salt Lagoon. The fact that the ground-water zone thins progressively toward the beach road from more inland areas (figs. 7 and 8) is further evidence that appreciable flow does not occur beneath the beach road.



EXPLANATION

• USGS1 (1.9) Subsurface-frost elevation, in meters

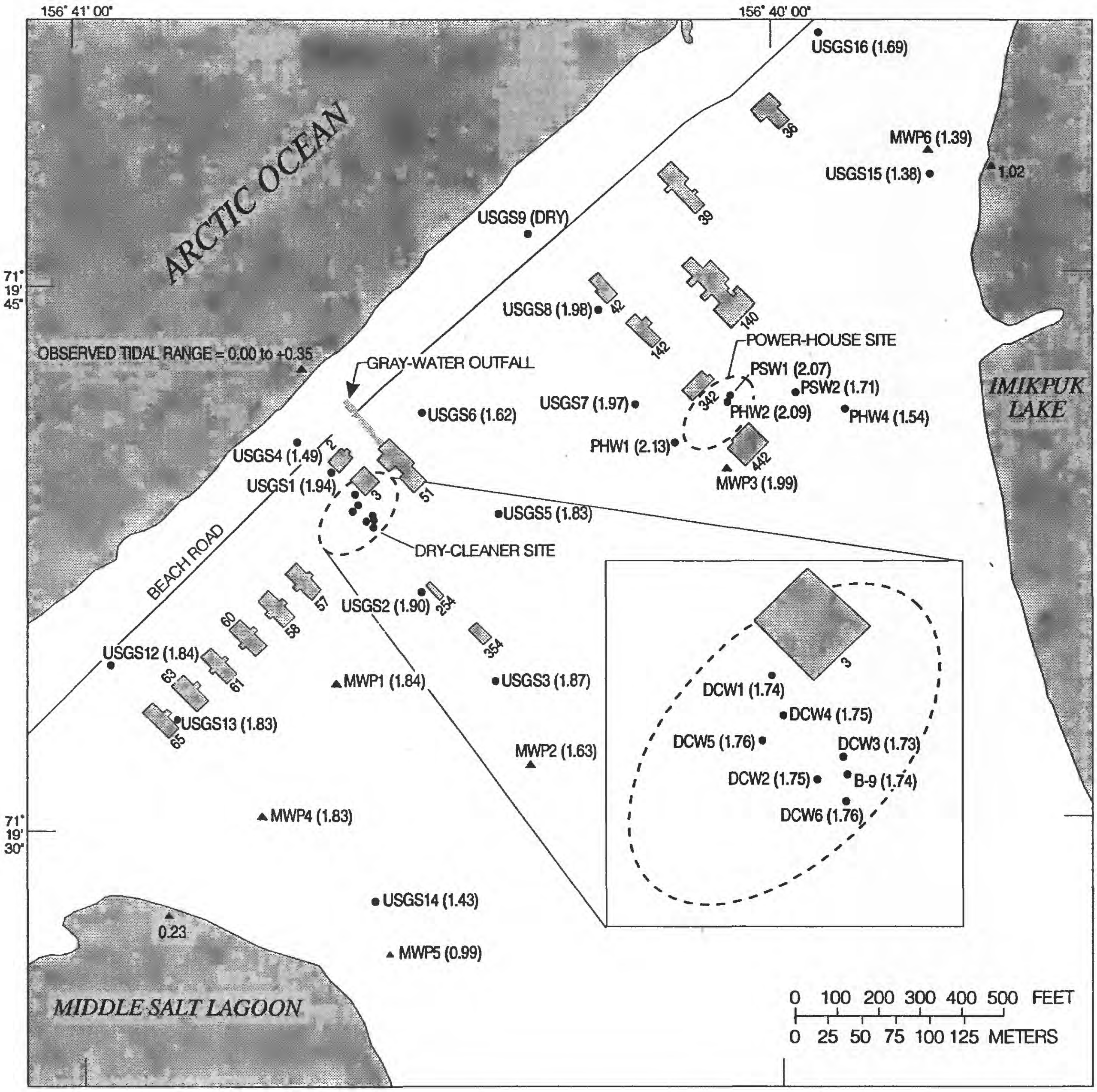
Figure 3. Subsurface-frost elevations in the UIC-NARL main-camp area measured in July 1993.



EXPLANATION

• USGS1 (1.8) Subsurface-frost elevation, in meters

Figure 4. Subsurface-frost elevations in the UIC-NARL main-camp area measured in August 1993.



EXPLANATION

● USGS1 (1.94) Water-table elevation, in meters

▲ MWP3 (1.99) Surface-water elevation, in meters

Figure 5. Water-table and surface-water elevations in the UIC-NARL main-camp area measured in July 1993.

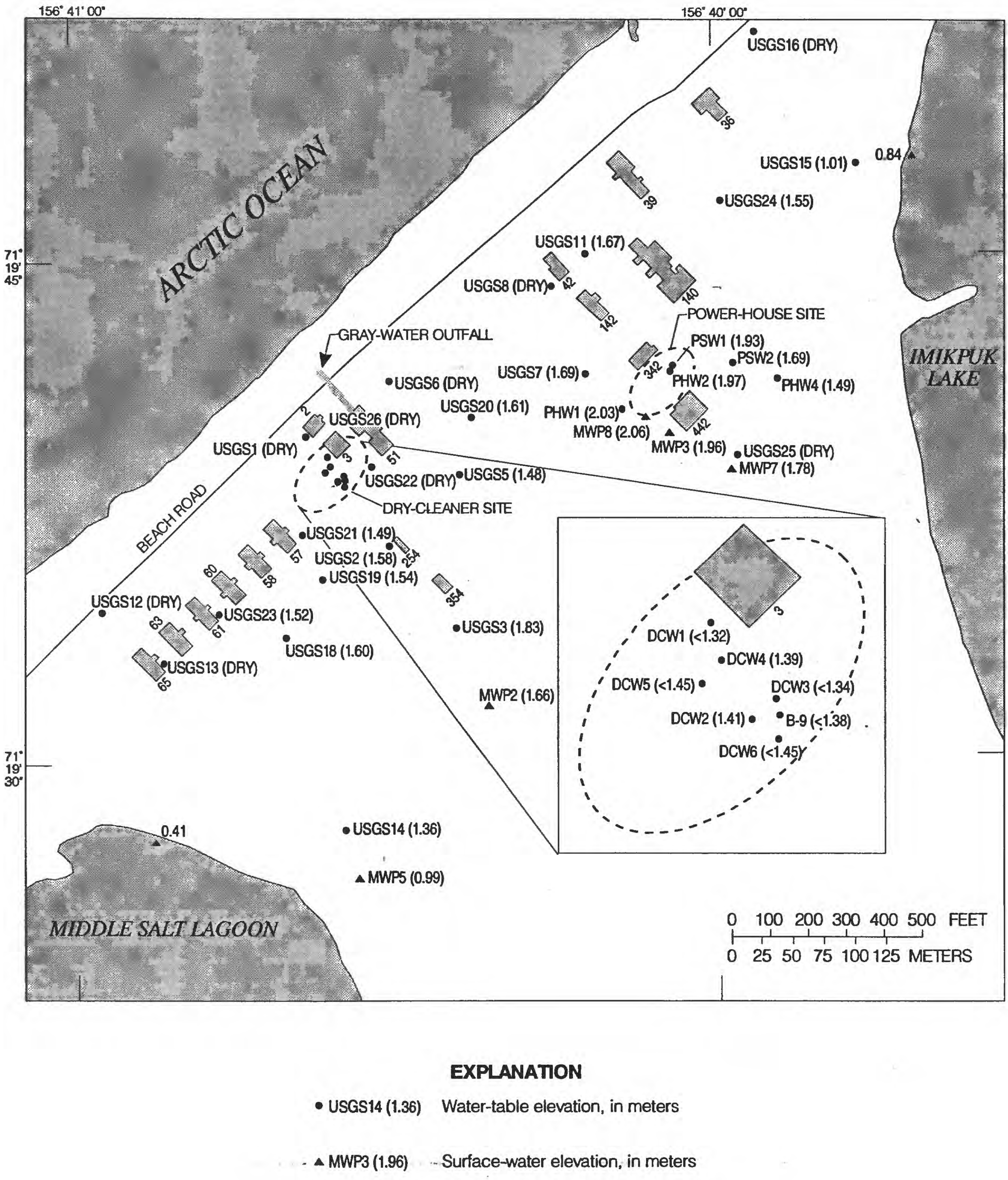
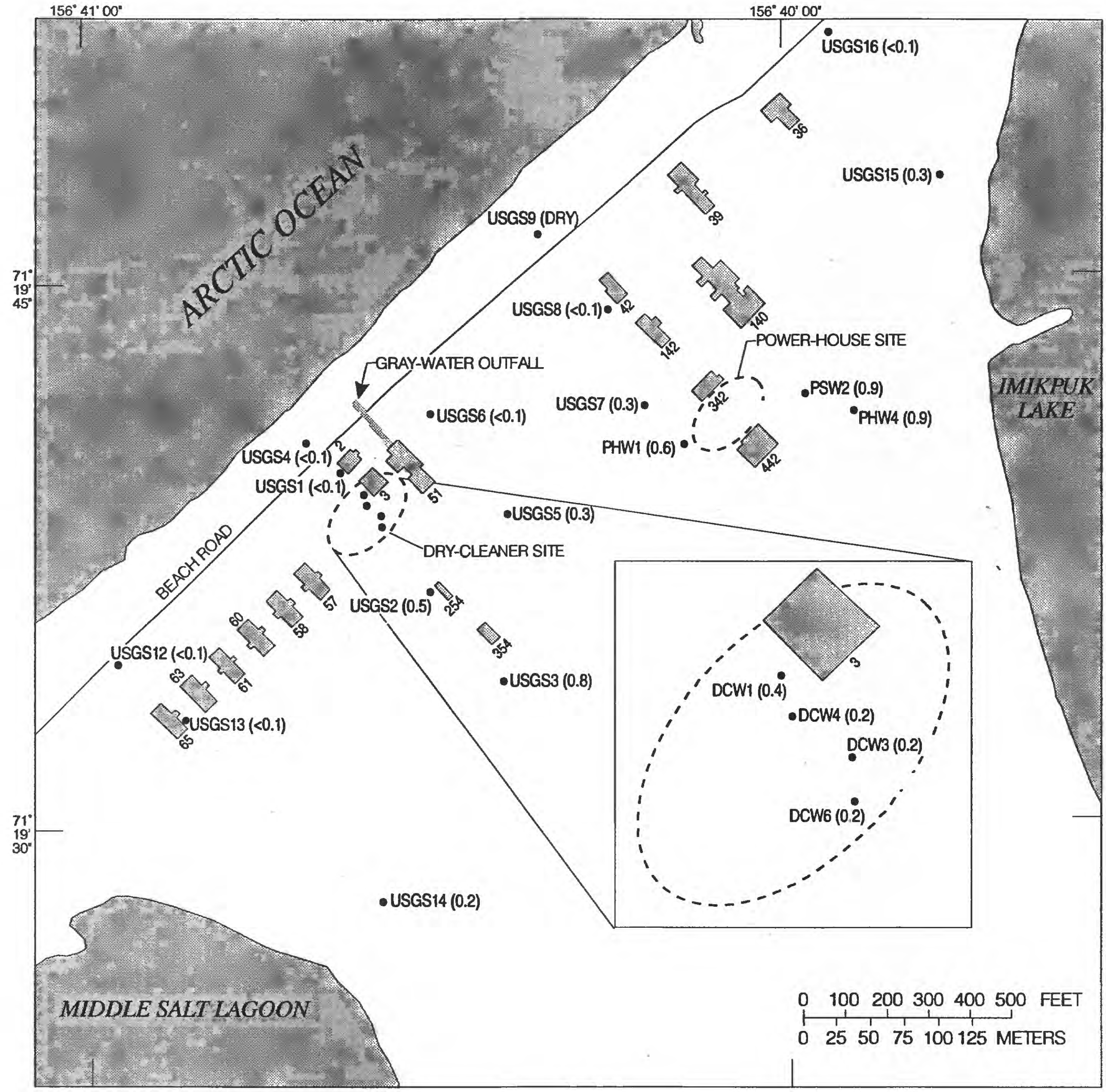


Figure 6. Water-table and surface-water elevations in the UIC-NARL main-camp area measured in August 1993.



EXPLANATION

• USGS14 (0.2) Thickness of the ground-water zone, in meters

Figure 7. Thickness of the ground-water zone in the UIC-NARL main-camp area measured in July 1993.

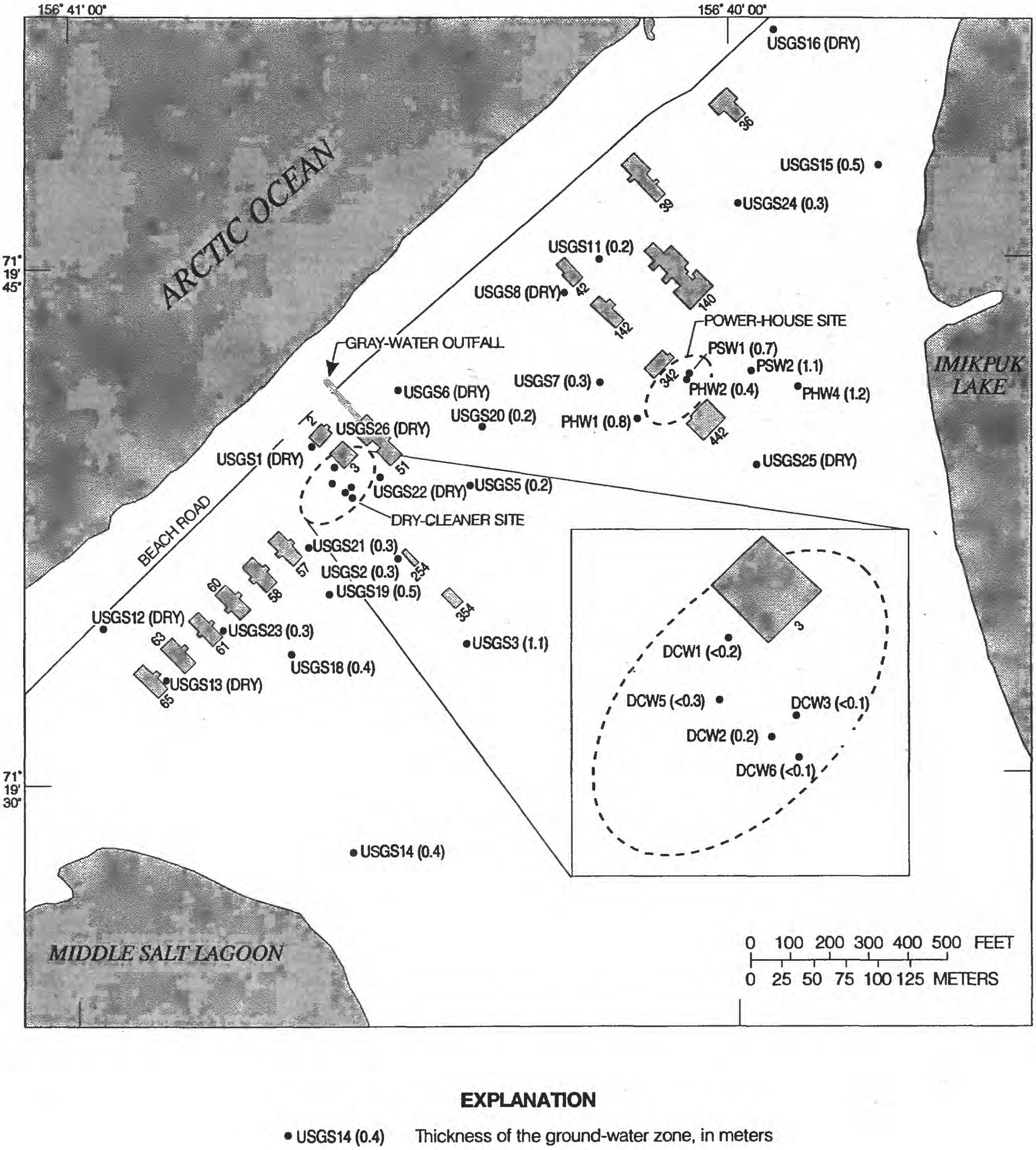
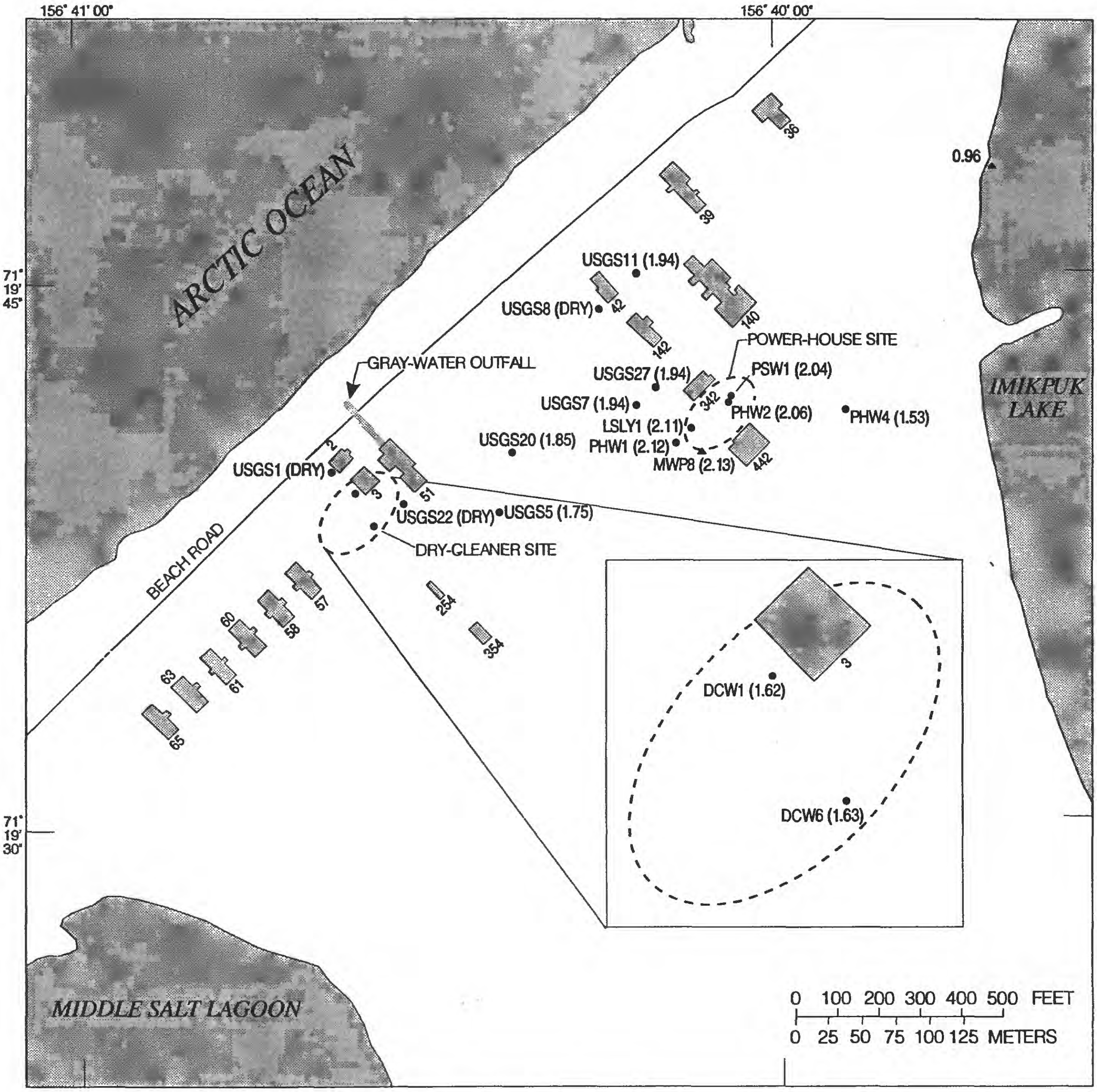


Figure 8. Thickness of the ground-water zone in the UIC-NARL main-camp area measured in August 1993.

The highest water-table and pond-surface elevations in the study area were consistently measured in the vicinity of the power-house site at wells LSLY1, MWP8, PHW1, PHW2, and PSW1 (figs. 5, 6, and 9). Lower water-table and pond-surface elevations were measured to the east, south, west, and north, indicating that the divide in the ground-water flow system, which separates the Imikpuk Lake drainage from the Middle Salt Lagoon drainage, occurs in this vicinity. This phenomenon may be at least partially due to snow-removal activities in the camp area. The entire power-house site is not generally plowed during the winter and, in addition, snow removed from other parts of the camp is often dumped in the vicinity of well PHW1. Melting of this additional snow acts as a source of focused recharge to the underlying active-layer system. The transition from permeable, coarse-grained soils in the interior of the camp to progressively finer grained, less permeable soils toward the lake edge may also partially explain the presence of the water-table mound. A relatively steep hydraulic gradient—manifested by high upgradient water levels—develops to compensate for the impedance to flow caused by increasingly low-permeability soils along the flow path toward the lake. The thickness of the ground-water zone also tends to increase toward the lake edge (figs. 7 and 8) and this increased cross-sectional flow area is further evidence that flow toward the lake is impeded by low-permeability material.

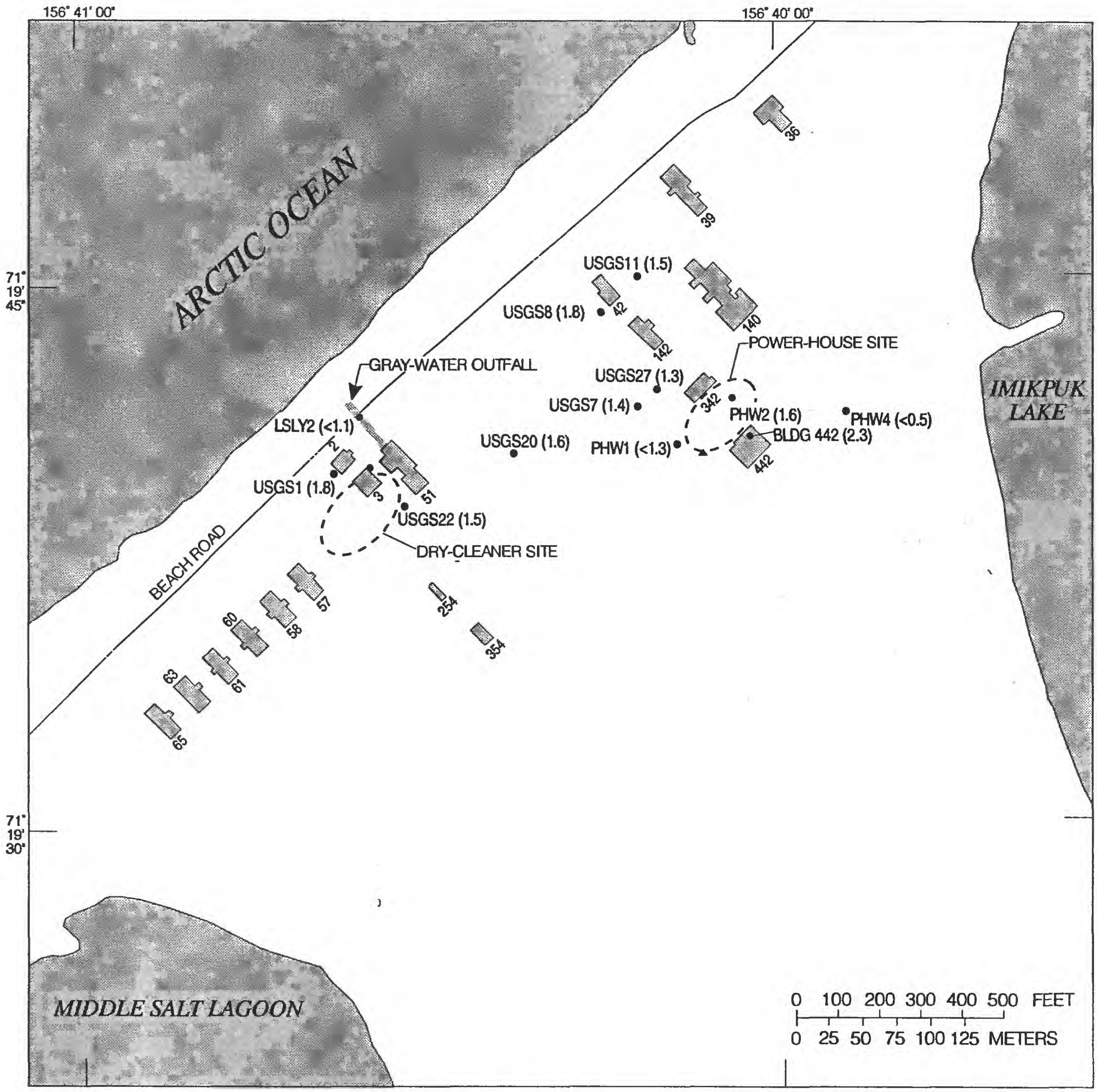
Persistent depressions in both the water table and the frost surface were measured beneath the dry-cleaner site (figs. 3-6 and 9). The water-table depression indicates that this is a local discharge area and that a local drain exists in the active-layer system. It is likely that in contrast to the rest of the camp, ground water in this local area flows toward the Arctic Ocean rather than toward Imikpuk Lake or Middle Salt Lagoon. The depression in the frost surface can be partially attributed to a similar depression in the overlying land surface, but it is likely that depressions in both the water table and frost surface result principally from operations of the UIC-NARL water-treatment facility, located adjacent to the dry-cleaner site in building 51. Because building 51 is heated year round and is not insulated from the ground surface, a substantial thaw bulb has probably developed in the permafrost beneath the building. In addition to the building, the subsurface gray-water outfall—which discharges water from building 51 toward the Arctic Ocean—may extend the thawed zone beneath the beach road. The temperature of the water discharging through this outfall was observed to be above ambient air temperature. Relatively warm water passing frequently through this outfall may inhibit freezing of surrounding material in the winter and promote thawing of this material in the summer, resulting in a localized pathway for ground-water flow beneath the beach road, toward the ocean. Thaw-depth measurements adjacent to the outfall at site LSLY2 support this hypothesis (table 3): although thaw depths measured in the gravelly soils throughout the NARL main camp, including the dry-cleaner site, ranged from approximately 1.0 to 1.5 m, no frost was reached prior to a depth of 2 m at site LSLY2. Because of this increased depth of thaw, the elevation of the frost surface in the vicinity of the outfall is significantly lower than at all other sites investigated (fig. 3, 4, and 10), which suggests that a breach exists in the permafrost ridge beneath the beach road, forming a drain for the local ground-water system.



EXPLANATION

• USGS11 (1.94)	Water-table elevation, in meters
▲ MWP8 (2.13)	Surface-water elevation, in meters

Figure 9. Water-table and surface-water elevations in the UIC-NARL main-camp area measured in August 1994.



EXPLANATION

• USGS1 (1.8) Subsurface-frost elevation, in meters

Figure 10. Subsurface-frost elevations in the UIC-NARL main-camp area measured in August 1994.

Ground-Water Recharge and Discharge

Ground-water recharge within the UIC-NARL main camp is restricted by a number of factors. Flow in the shallow active-layer system within the UIC-NARL main camp is characterized exclusively by local-scale flow lines, and the area that contributes recharge to the system is therefore of limited areal extent. The deeper, intermediate- or regional-scale flow lines associated with more extensive recharge areas cannot develop because of the near-surface permafrost. Recharge is further restricted by the prevailing climate and precipitation patterns (tables 1 and 2). The active layer remains partially frozen during much of the snowmelt period, which inhibits recharge to the ground-water system from the winter's accumulation of snowfall. Summer precipitation does not typically contribute substantial recharge to the active-layer system either, because total thaw-season evapotranspiration is approximately equal to total precipitation for the same period (Mather and Thornthwaite, 1958; Brown and others, 1968; Guymon, 1976; Dingman and others, 1980).

The limited vertical extent of the system and the consistency in thaw depths and water-table elevations observed during the 1993 and 1994 thaw seasons indicate that the active-layer system throughout the main camp is in a state of quasi-equilibrium. The hypothesis of quasi-equilibrium implies that annual discharge from the system is approximately equal to annual recharge to the system, and is therefore correspondingly small. It is probable that the drop in the water table observed between July and August 1993 (figs. 5 and 6) is primarily the result of evapotranspiration losses, which may exceed precipitation during part of the summer. In addition, a small part of the water-table drop may be attributed to the vertical redistribution of moisture that occurs during the freeze-up period. Upward moisture migration during soil freezing can result in a layer of high moisture content underlain by a layer of low moisture content. When the soil begins to thaw during the summer, the shallower, high-moisture content layer will thaw first. As long as the underlying soil is below freezing, water entering the pores from above will freeze and restrict further infiltration. Shallow water will thus remain perched atop the deeper, unsaturated frozen layer. As thawing progresses deeper into the subsurface and the underlying unsaturated soil thaws, the perched ground-water will infiltrate and the saturated zone will be displaced downward. A drop in the water table resulting from such downward displacement clearly does not indicate discharge from the system and is therefore consistent with the hypothesis that outflow from the system is small.

The thickness of the ground-water zone beneath the northwestern part of the camp—at wells USGS1, USGS6, USGS8, USGS12, USGS13, and USGS16—is a clear indication that discharge from this part of the system is negligible (table 4). Little or no ground water existed beneath this area, even in July 1993, and by August, this entire part of the system had gone dry. Beneath the southeast part of the camp—at wells USGS14, USGS3, PHW1, PHW4, PSW2, and USGS15—the thickness of the ground-water zone increased from July to August and the observed water-table drop may be attributed to downward displacement of the saturated zone rather than to discharge from the system. Because recharge from thaw-season precipitation is small, an increase over the season in the quantity of water stored in the system is further evidence that discharge is negligible. In contrast to the rest of the camp, the thickness of the ground-water zone in the vicinity of the dry-cleaner site—at wells DCW1, DCW3, DCW6, USGS2, and USGS5—decreased significantly from July to August 1993, suggesting that discharge was occurring from this part of the system. This is the area where the local water-table depression was observed and discharge from the area in the vicinity of these wells can be attributed to the hypothetical local drain in the ground-water system described earlier.

Table 4. Changes in the ground-water zone in the UIC-NARL main camp between July and August 1993
[Values in meters]

Site I.D.	Thickness of the ground-water zone		Decrease in elevation July to August r	
	July	August	Water table	Frost surface
DCW1	0.4	<0.2	>0.4	0.3
DCW3	0.2	<0.1	>0.4	0.3
DCW6	0.2	<0.1	>0.3	0.2
PHW1	0.6	0.8	0.10	0.3
PHW4	0.9	1.2	0.05	0.3
PSW2	0.9	1.1	0.02	0.2
USGS1	<0.1	Dry	--	0.1
USGS2	0.5	0.3	0.32	0.1
USGS3	0.8	1.1	0.04	0.2
USGS5	0.3	0.2	0.35	0.2
USGS6	<0.1	Dry	--	0.0
USGS7	0.3	0.3	0.28	0.3
USGS8	<0.1	Dry	--	0.3
USGS12	<0.1	Dry	--	0.3
USGS13	<0.1	Dry	--	0.3
USGS14	0.2	0.4	0.07	0.3
USGS15	0.3	0.5	0.37	0.5
USGS16	<0.1	Dry	--	0.2

SUMMARY

An investigation of the subsurface hydrology of the Ukpeagvik Inupiat Corporation-National Arctic Research Laboratory (UIC-NARL, formerly known as the Naval Arctic Research Laboratory) main camp was conducted to assess the potential impact of subsurface contamination on the quality of water in nearby Imikpuk Lake. Areas of soil and ground-water contamination exist in the vicinity of the lake, which serves as the drinking-water source for the UIC-NARL facility.

The study area is underlain by areally continuous permafrost. A shallow ground-water system, typically less than 1.5 m in thickness, develops each summer as the subsurface thaws and

refreezes each winter. To characterize this system, water-level and thaw-depth data were collected during the summers of 1993 and 1994. These data show that configurations of both the water table and the subsurface frost govern the shallow ground-water flow system and indicate that discharge from the system is small.

Spatial variations measured in the depth of seasonal thaw show that irregularities in the configuration of the subsurface frost result from differences in land-surface elevation, variations in soil type, and the presence of buildings and other structures that either act as a heat source or block heat transfer to and from the subsurface. These same factors therefore have a considerable influence on the ground-water flow system. Land-surface, water-table, and frost-surface elevation data show that a land-surface ridge in the camp is mimicked in the underlying permafrost. Because permafrost is relatively impermeable to water, this ridge restricts ground-water flow and generally acts as a flow-system divide. A mound observed in the water table in the vicinity of the power-house site suggests that flow toward Imikpuk Lake from the camp is restricted by progressively finer grained soils found along the flow path from the central part of the camp toward the lake. In contrast, a persistent depression in the water table and frost surface was observed in the vicinity of the UIC-NARL water-treatment facility. Water-table and thaw-depth data suggest the existence of a local drain in the ground-water system caused by thawing of the permafrost beneath the heated facility and around a subsurface gray-water outfall. Changes in the elevation and thickness of the ground-water zone between July and August 1993 suggest that discharge from the flow system is negligible, except within the area of influence of the hypothetical local drain.

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